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AMC PAMPHLET **AMCP 706-360**

ENGINEERING DESIGN HANDBOOK

MILITARY VEHICLE ELECTRICAL SYSTEMS

HEADQUARTERS, U S ARMY MATERIEL COMMAND JUNE 1974

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY MATERIEL COMMAND
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ENGINEERING DESIGN HANDBOOK
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TABLE OF CONTENTS

Paragraph *Page*

PART ONE

VEHICLE ELECTRICAL SYSTEM ANALYSIS AND DESIGN

CHAPTER 1. INTRODUCTION

CHAPTER 2. ARMY MATERIEL DEVELOPMENT

SECTION I. PROGRAM DEVELOPMENT

SECTION II. PROGRAM MANAGEMENT

TABLE OF CONTENTS (Cont'd.)

Paragraph *Page*

CHAPTER 3. SYSTEM ANALYSIS

SECTION I. SYSTEM INTERPRETATIONS

SECTION II. ANALYTICAL FACTORS

3

SECTION III. LOAD AND POWER SUPPLY CHARACTERISTICS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Paragraph *Page*

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd)

CHAPTER 6. DOCUMENTATION

TABLE OF CONTENTS (Cont'd.)

Paragraph *Page*

PART TWO

VEHICLE ELECTRICAL SUBSYSTEMS AND COMPONENTS

CHAPTER 7. POWER GENERATION, STORAGE, AND CONVERSION

SECTION I. GENERATOR SYSTEMS

SECTION II. ENERGY STORAGE

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Paragraph *Page*

CHAPTER 10. MOTORS AND ACTUATORS

SECTION I. ELECTRIC MOTORS

SECTION II. ACTUATORS

CHAPTER 11. IGNITION SYSTEMS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Paragraph *Page*

TABLE OF CONTENTS (Cont'd.)

Paragraph *Page*

TABLE OF CONTENTS (Cont'd.)

Paragraph *Page*

CHAPTER 17. WEAPON SYSTEMS

SECTION I. VEHICLE WEAPONS

SECTION II. FIRE CONTROL SYSTEMS

SECTION III. AMMUNITION HANDLING AND WEAPON ARMING SYSTEMS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF ILLUSTRATIONS (Cont'd.)

LIST OF TABLES

LIST OF TABLES (Cont'd.)

LIST OF TABLES (Cont'd.)

LIST OF TABLES (Cont'd.)

LIST OF SYMBOLS AND ABBREVIATIONS

A = electric current amperes

A_a = achieved availability, dimensionless

AC = alternating current

A-hr = electric charge, ampere-hours

A_i = inherent availability, dimensionless

A_o = operational availability, dimensionless

AWG = American Wire Gage

a = angle of braid with wire axis, deg

Btu = energy, British thermal units

C = number of carriers

C_A = A-hr available per set of 6TN batteries at temperature and current drain under consideration

C_d = coefficient of derivative feedback

C_e = coefficient of error rate feedback

C_i = coefficient of integral feedback, dimensionless

C_m = remaining battery current or margin, percent; circular area of conductor, circular mil

C_R = required capacity of battery system, A-hr

c = capacitance, pF

cp = luminous intensity, candlepower

D = diameter of cable under shield, in.

DC = direct current

d = diameter of individual shielding wires, in.

dB = relative power, decibels

deg = degree

E = supply voltage, V; excitation force, lb; voltage drop, V

e = base of natural logarithms

F = number of failures in T; viscous friction

F = capacitance, farads

°F = temperature, degrees Fahrenheit

f = frequency, Hz

fpm = velocity, feet per minute

ft = length, feet

ft-c = unit of luminance, foot-candle

ft-L = unit of luminance, foot-lambert

ft-lb = torque, foot pounds

H = inductance, henrys

Hz = frequency, cycles per second (hertz)

hp = power, horsepower

hr = time, hours

I = load current, amperes

I_L discharge current from battery system, amperes

in. = length, inches

$in.^3$ = volume, cubic inches

J = energy, joules

J = moment of inertia of load

K = magnitude of amplification; constant; number of batteries in set; coverage, percent; dielectric constant, dimensionless; service factor, dimensionless

k = spring rate, lb per in.

kHz = frequency, kilocycles per second (kilohertz)

kV = electric potential, kilovolts

kW = electric power, kilowatts

L = conductor length, ft; inductance, henrys

lb = weight, pounds

$\bar{M}$ = mean active maintenance time, units of time

MCM = area, thousand circular mils

MDT = mean down time

MHz = frequency, megacycles per second (megahertz)

$\bar{M}_{ct}$ = mean corrective maintenance time, units of time

M_{pt} = time to perform preventive maintenance, units of time

$\bar{M}_{pt}$ = mean prevention maintenance time, units of time

$MTBF$ = mean time between failures, units of time

$MTBM$ = mean time between maintenance actions, units of time

$MTBP$ = mean time between preventive actions, units of time

m = number of groups in parallel; number of preventive maintenance actions; mass, lb-sec^2 per in.; length, meters

mA = electric current, milliamperes

mH = inductance, millihenrys

min = time, minutes

mL = unit of brightness, millilambert

mm = length, millimeters

mph = velocity, miles per hour

msec = time, milliseconds

mV = electric potential, millivolts

mW = electric power, milliwatts

N = number of wires per carrier

n = number of series elements within a group; number of failures

ohm = electrical resistance (not abbreviated)

P = power, W, hp; picks per inch of wire or cable length

pF = capacitance, picofarads

Q = unreliability, dimensionless

R = reliability, dimensionless; conductor resistance, ohm

R_s = system reliability, dimensionless

R_t = time to repair

r = constant failure rate reliability, dimensionless

rpm = rotation, revolutions per minute

S = speed, rpm

sec = time, seconds

T = discharge time, hr; total experience; time, cycles, miles; torque, lb-ft, lb-in.

t = operating time, units of time

T_ℓ = loss torque, lb-ft

U = utility (weighting factor), dimensionless

V = electric potential, volts

v = velocity of propagation, percent

W = electric power, watts

W = stored energy, W-sec; weight, lb

W-hr = energy, watt-hours

w_i = input axis rotation, rad/sec

w_p = output axis precession, rad/sec

x = response displacement, in.

$\ddot{x}$ = response acceleration, in. per sec^2

yr = time, years

Z = normal deviate; impedance, ohm; objective function

Z_o = characteristic impedance, ohm

% = percent

= number

ϵ = dielectric constant, F/m; signal error, rad

ζ = damping ratio, dimensionless

θ = servo signal angular displacement, rad

λ = failure rate, reciprocal time

λ_s = system failure rate, reciprocal time

μ = mean

μA = electric current, microamperes

μF = capacitance, microfarads

μH = inductance, microhenrys

μV = electric potential, microvolts

μW = electric power, microwatts

σ = standard deviation

ϕ = field flux, lines per in.^{2}

Ω = pulse repetition frequency

ω_M = maximum frequency

ω_i = angular speed, rad per sec

ω_n = undamped natural frequency, rad per sec

PREFACE

The Engineering Design Handbook Series of the Army Materiel Command is a coordinated series of handbooks containing basic information and fundamental data. The handbooks are authoritative reference books of practical information and quantitative facts helpful in the design and development materiel that will meet the tactical and technical needs of the Armed Forces.

The objectives of this Handbook are: (1) to collect diverse sources of information unique to combat and tactical vehicles in order to conserve time, materials, and money in the successful design of new equipment; (2) to provide guidance in capsule form for new personnel, Armed Forces contractors, or experienced design engineers in other fields who require information about vehicle electrical systems; (3) to supply current fundamental information; and (4) to place the reader in a position to use new information generated subsequent to the publication of this handbook. To meet these objectives, the handbook has been written to provide the necessary background regarding electrical equipment and systems so that more complete information and data available in the references can be utilized.

The text of this handbook was prepared by the Ordnance Engineering Division of FMC Corporation, San Jose, California, under subcontract to the Engineering Handbook Office of Duke University, prime contractor to the US Army Materiel Command for the Engineering Design Handbook Series. Mr. Philip MacBain, FMC Corp., served as Project Leader. Many helpful comments were supplied by Mr. Marquis Woody and Mr. George Kreiner of US Army Tank-Automotive Command, and other members of the Ad Hoc Working Group of which Mr. Woody and Mr. Kreiner were co-chairmen.

The Engineering Design Handbooks fall into two basic categories, those approved for release and sale, and those classified for security reasons. The Army Materiel Command policy is to release these Engineering Design Handbooks to other DOD activities and their contractors and other Government agencies in accordance with current Army Regulation 70-31, dated 9 September 1966. It will be noted that the majority of these Handbooks can be obtained from the National Technical Information Service (NTIS). Procedures for acquiring these Handbooks follow:

a. Activities within AMC, DOD agencies, and Government agencies other than DOD having need for the Handbooks should direct their request on an official form to:

Commander
Letterkenny Army Depot
ATTN: AMXLE-ATD
Chambersburg, PA 17201

b. Contractors and universities must forward their requests to:

National Technical Information Service
Department of Commerce
Springfield, VA 22151

(Requests for classified documents must be sent with appropriate "Need to Know" justification, to Letterkenny Army Depot.)

Comments and suggestions on this Handbook are welcome and should be addressed to:

Commander
US Army Materiel Command
ATTN: AMCRD-TV
Alexandria, VA 22333

(DA Forms 2028, Recommended Changes to Publications, which are available through normal publications supply channels, may be used for comments/suggestions.)

PART ONE
VEHICLE ELECTRICAL SYSTEM ANALYSIS AND DESIGN

CHAPTER 1
INTRODUCTION

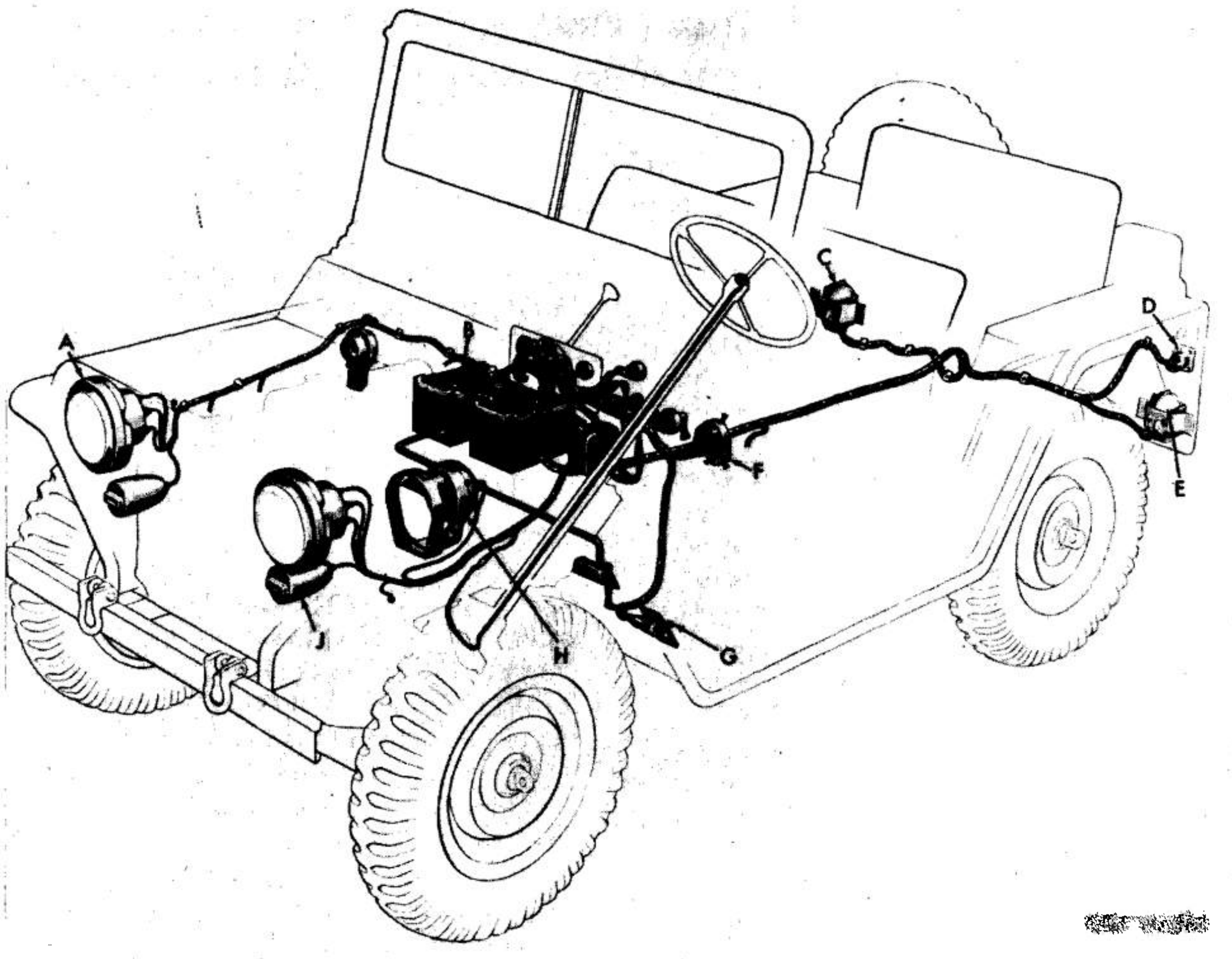
1-1 VEHICLE ELECTRICAL DESIGN

Electrical system design is a comprehensive task in the development of a military vehicle. The effort requires coordination among the electrical designer, project engineer, Government representatives, and all other design groups on a development program from the inception of a project until successful operation of the electrical system has been demonstrated. Normally, the electrical-system design will involve many mechanical and electromechanical design tasks in addition to circuit design problems that must be solved before the project is completed. In order to perform competently, the system designer will need a good working knowledge of the military environment and the various electrical components and subsystems commonly used on vehicles in the military inventory. The ability to plan ahead and recognize critical design paths requiring design effort early in the program, and to identify items subject to long purchasing lead times, and extensive testing or development requirements, is also important. Normally, the knowledge and skills required of a system designer will be acquired by the young designer or engineer as he works with senior engineers on various assignments over a period of years. Information presented in this Handbook is intended to aid in the development of new vehicle electrical system design personnel and provide a source of technical data and references for engineers and designers now active in this field of endeavor. TM 11-661, *Electrical Fundamentals (Direct Current)* and TM 11-681, *Electrical Fundamentals (Alternating Current)* are recommended as basic reference manuals.

1-2 PRINCIPAL ELEMENTS

The modern military vehicle may feature a simple electrical system as found on the M151 "Jeep" (Fig. 1-1) or a complex system of the type found on an M60A1 Tank (Fig. 1-2).

Through the years, the trend in the evolution of vehicles has been toward an increase in electrical system complexity and generating system capacity. The effect of this trend on the military is more pronounced because state-of-the-art electrical systems in military vehicles are called upon to implement a number of functions in addition to those found on most commercial vehicles. For example, systems for aiming and firing vehicle weapons are often electrically or electrohydraulically controlled and further complicated by stabilization and ballistic computer electronics. Infrared headlamps and periscopes, blackout driving and marker lights, xenon searchlights, and low light level image-intensifier systems are used to facilitate night operational capability. Coolant heating systems are used to maintain vehicle engines in a ready-to-start condition at temperatures below −25°F. Slave receptacles and cables are provided so that a vehicle with dead batteries can be started from another vehicle. Chemical, bacteriological, and radiological (CBR) air purifier systems are electrically powered. Waterproof, heavy duty wiring interconnection techniques are employed as standard practice. Military environmental stresses, reliability, durability, maintainability, standardization, and electromagnetic interference reduction must also be considered. These complex system requirements and equipment must be integrated with a basic vehicle electrical system so that the resultant combination will function harmoniously and dependably as the vehicle performs its mission in the military environment. Table 1-1 and Table 1-2 list the principal electrical equipment used on vehicles in the present inventory.



KEY	ITEM
A.	HEADLIGHT
B.	BATTERIES
C.	BLACKOUT AND SERVICE TAILLIGHT
D.	TRAILER RECEPTACLE
E.	BLACKOUT TAILLIGHT, SERVICE TAILLIGHT AND SERVICE STOPLIGHT
F.	LIGHT SWITCH
G.	DIMMER SWITCH
H.	BLACKOUT DRIVE LIGHT
J.	BLACKOUT SERVICE LIGHT
K.	INSTRUMENT CLUSTER
L.	HORN BUTTON
M.	HORN

Figure 1-1. M151 Electrical System

TABLE 1-1. TYPICAL COMBAT VEHICLE ELECTRICAL SYSTEM CHARACTERISTICS

FUNCTION	M114A1 COMMAND RECON	M551 ARMORED RECON	M107 GUN	M109 HOWITZER	M60A1 TANK	XM803 TANK
ENGINE TYPE	8 CYLINDER LIQUID COOLED GASOLINE	6 CYLINDER LIQUID COOLED DIESEL	8 CYLINDER LIQUID COOLED DIESEL	8 CYLINDER LIQUID COOLED DIESEL	12 CYLINDER AIR COOLED DIESEL	
ENGINE STARTER	1108259	1113940		1113847	1109472	
ENGINE IGNITION SYSTEM	SPARK IGNITION	COMPRESSION IGNITION	COMPRESSION IGNITION	COMPRESSION IGNITION	COMPRESSION IGNITION	
SPARK PLUGS	8	NONE	NONE	NONE	NONE	
DISTRIBUTOR	SHIELDED	NONE	NONE	NONE	NONE	
COIL	IN DISTRIBUTOR	NONE	NONE	NONE	NONE	
BATTERY TYPE	2HN-12V	6TN-12V	6TN-12V	6TN-12V	6TN-12V	
CONNECTION	TWO IN SERIES	TWO IN SERIES	FOUR IN SERIES PARALLEL	FOUR IN SERIES PARALLEL	SIX IN SERIES PARALLEL	
POLARITY	NEG GRD	NEG GRD	NEG GRD	NEG GRD	NEG GRD	
RATING AND CAPACITY	24 V 45 A-hr	24 V 100 A-hr	24 V 200 A-hr	24 V 200 A-hr	24 V 300 A-hr	
SLAVE START RECEPTACLE	1	1	1	1	2	
GENERATING SYSTEM	100 A DIODE RECTIFIED ALTERNATOR	300 A DC GENERATOR	300 A DC GENERATOR	100 A DIODE RECTIFIED ALTERNATOR	300 A DC GENERATOR	
ENGINE WATER TEMPERATURE	GAGE AND WARNING LAMP	GAGE	GAGE	GAGE AND WARNING LAMP	NONE	
ENGINE OIL PRESSURE	WARNING LAMP	WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	
ENGINE OIL TEMPERATURE	NONE	WARNING LAMP	WARNING LAMP	NONE	GAGE AND WARNING LAMP	
TRANSMISSION OIL PRESSURE	WARNING LAMP (DIFFERENTIAL)	WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	
TRANSMISSION OIL TEMP	WARNING LAMP (DIFFERENTIAL)	WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	
FUEL LEVEL INDICATOR	SIGHT GAGE TUBE	GAGE	GAGE	GAGE	GAGE	
BATTERY GENERATOR INDICATOR	GAGE	GAGE	GAGE AND WARNING LAMP	GAGE	GAGE	
SERVICE HEADLIGHTS	2	2	2	2	2	
INFRARED HEADLIGHTS	2	2	2	2	2	
BLACKOUT DRIVING LIGHTS	1	2	2	2	2	
BLACKOUT MARKER LIGHTS	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	
SERVICE TAIL & STOP LIGHT	1-LT REAR	1-LT REAR	1-LT REAR	1-LT REAR	1-LT REAR	
BLACKOUT STOP LIGHT	1-RT REAR	1-RT REAR	1-RT REAR	1-RT REAR	1-RT REAR	
SEARCHLIGHT	NONE	XENON KIT	NONE	NONE	XENON	
DOMELIGHT	3	4	1	1 HULL 3 TURRET	4	
PANEL LIGHTS	1	2	1	3	2	
TRAILER RECEPTACLE	1	NONE	1	1	NONE	
HORN	NONE	NONE	1	NONE	NONE	
BILGE PUMPS	1	3	NONE	1	NONE	
FUEL PUMP	MECHANICAL	MECHANICAL	MECHANICAL	TWO IN FUEL TANKS	TWO IN FUEL TANKS	
WINDSHIELD WIPERS	NONE	3-ELECTRIC	NONE	NONE	NONE	
HEATER	MULTIFUEL PERSONNEL	MULTIFUEL PERSONNEL	NONE	MULTIFUEL PERSONNEL	MULTIFUEL PERSONNEL	
BLOWER FANS	NONE	TURRET AND AIR CLEANER	GENERATOR	TURRET, RECTIFIER, FLOTATION AND AIR CLEANER	TURRET AND AIR CLEANER	
WEAPONS STATION CONTROL	MANUAL OR ELECTRO HYDRAULIC	MANUAL AND ELECTRIC	MANUAL AND ELECTRO HYDRAULIC	ELECTRO HYDRAULIC	ELECTRO HYDRAULIC	
COMMUNICATIONS	VHF-FM RADIO AND INTERCOM	VHF-FM RADIO AND INTERCOM	INTERCOM	INTERCOM	VHF-FM RADIO AND INTERCOM	
ACCESSORY OUTLET	1	1	2	1	1	

TABLE 1-2. TYPICAL TACTICAL VEHICLE ELECTRICAL SYSTEM CHARACTERISTICS

FUNCTION	M151 UTILITY TRUCK	M715 CARGO TRUCK	M48 TRUCK TRACTOR	M548 CARGO CARRIER	M113A1 PERSONNEL CARRIER	LVTP7 AMPHIBIOUS PERSONNEL CARRIER	M88 RECOVERY VEHICLE	M578 RECOVERY VEHICLE
ENGINE TYPE	4 CYLINDER LIQUID COOLED GASOLINE	6 CYLINDER LIQUID COOLED GASOLINE	6 CYLINDER LIQUID COOLED DIESEL	6 CYLINDER LIQUID COOLED DIESEL	6 CYLINDER LIQUID COOLED DIESEL	8 CYLINDER LIQUID COOLED DIESEL	12 CYLINDER AIR COOLED GASOLINE	8 CYLINDER LIQUID COOLED DIESEL
ENGINE STARTER	7017647	KAISER 944020	DELCO REMY 1996466	1113940	1113940	1113847	7018076	1113847
ENGINE IGNITION SYSTEM	SPARK IGNITION	SPARK IGNITION	COMPRESSION IGNITION	COMPRESSION IGNITION	COMPRESSION IGNITION	COMPRESSION IGNITION	MAGNETO SYSTEM	COMPRESSION IGNITION
SPARK PLUGS	4	6	NONE	NONE	NONE	NONE	24	NONE
DISTRIBUTOR	WATERPROOF AND SHIELDED	WATERPROOF AND SHIELDED	NONE	NONE	NONE	NONE	NONE	NONE
COIL	IN DISTRIBUTOR	IN DISTRIBUTOR	NONE	NONE	NONE	NONE	NONE	NONE
BATTERY TYPE	2HN-12V	2HN-12V	6TN-12V	6TN-12V	6TN-12V	6TN-12V	6TN-12V	6TN-12V
CONNECTION	TWO IN SERIES	TWO IN SERIES	TWO IN SERIES	TWO IN SERIES	TWO IN SERIES	FOUR IN SERIES-PARALLEL	FOUR IN SERIES-PARALLEL	FOUR IN SERIES-PARALLEL
POLARITY	NEG GRD	NEG GRD	NEG GRD	NEG GRD	NEG GRD	NEG GRD	NEG GRD	NEG GRD
RATING AND CAPACITY	24 V 45 A-hr	24 V 45 A-hr	24 V 100 A-hr	24 V 100 A-hr	24 V 100 A-hr	24 V 200 A-hr	24 V 200 A-hr	24 V 200 A-hr
SLAVE START RECEPTACLE	1	NONE	1	1	1	2	2	1
GENERATING SYSTEM	25 A DC GENERATOR 100 A KIT	60 A DIODE RECTIFIED ALTERNATOR	25 A DC GENERATOR	100 A DIODE RECTIFIED ALTERNATOR	100 A DIODE RECTIFIED ALTERNATOR	180 A DIODE RECTIFIED ALTERNATOR	300 A DC GENERATOR	300 A DC GENERATOR
ENGINE WATER TEMP	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE AND LOST COOLANT WARNING LAMP	NONE	GAGE
ENGINE OIL PRESSURE	GAGE	GAGE	GAGE	WARNING LAMP	WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	GAGE
ENGINE OIL TEMP	NONE	NONE	NONE	NONE	NONE	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP
TRANSMISSION OIL PRESSURE	NONE	NONE	NONE	NONE	NONE	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP
TRANSMISSION OIL TEMP	NONE	NONE	NONE	WARNING LAMP	WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP	GAGE AND WARNING LAMP
FUEL LEVEL INDICATOR	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE
BATTERY GENERATOR INDICATOR	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE AND WARNING LAMP	GAGE	GAGE AND WARNING LAMP
SERVICE HEADLIGHTS	2	2	2	2	2	2	2	2
INFRARED HEADLIGHTS	NONE	NONE	NONE	2	2	2	2	2
BLACKOUT DRIVING LIGHTS	1	1	1	1	1	NONE	2	2
BLACKOUT MARKER LIGHTS	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR	2 FRONT 2 REAR
SERVICE TAIL & STOP LIGHT	1-LT REAR	2	1-LT REAR	1-LT REAR	1-LT REAR	2	1-LT REAR	1-LT REAR
BLACKOUT STOP LIGHTS	1-RT REAR	1-RT REAR	1-RT REAR	1-RT REAR	1-RT REAR	1-RT REAR	1-RT REAR	1-RT REAR
SEARCHLIGHT	NONE	NONE	NONE	NONE	NONE	ONE SPOTLIGHT	TWO SPOTLIGHTS	TWO FLOODLIGHTS
DOMELIGHT	NONE	NONE	NONE	1	2	2	4	2
PANEL LIGHTS	2	2	2	2	2	3	3	E
CLEARANCE LIGHTS	NONE	NONE	NONE	NONE	NONE	NONE	NONE	FLASHING SIGNAL LAMP
TURN SIGNAL LIGHTS	NONE	2 FRONT 2 REAR	NONE	NONE	NONE	2 FRONT 2 REAR	NONE	NONE
BILGE PUMPS	NONE	NONE	NONE	2	2	2 ELECTRICAL 2 HYDRAULIC	1	NONE
FUEL PUMP	1	MECHANICAL	1	2	NONE	TWO IN FUEL TANK	1	1
WINDSHIELD WIPERS	TWO VACUUM	TWO VACUUM	TWO VACUUM	3-ARMS-ONE ELECTRIC MOTOR	NONE	NONE	NONE	NONE
HEATER	MULTIFUEL PERSONNEL	HOT WATER PERSONNEL	HOTWATER OR MULTIFUEL PERSONNEL	MULTIFUEL PERSONNEL AND COOLANT	MULTIFUEL PERSONNEL AND COOLANT	MULTIFUEL PERSONNEL AND COOLANT	MULTIFUEL PERSONNEL	NONE
BLOWER FANS	NONE	NONE	NONE	NONE	NONE	VENTILATOR	VENTILATOR	GENERATOR COOLING AIR CLEANER
WEAPONS STATION CONTROL	NONE	NONE	NONE	NONE	NONE	ELECTRO HYDRAULIC	NONE	MAGNETIC CLUTCH AND SLIP RING FOR BOOM CONTROL
COMMUNICATIONS	VHF-FM RADIO	VHF-FM RADIO	NONE	VHF-FM RADIO	VHF-FM RADIO AND INTERCOM	VHF-FM RADIO AND INTERCOM	VHF-FM RADIO AND INTERCOM	VHF-FM RADIO AND INTERCOM
ACCESSORY OUTLET	NONE	NONE	1	1	1	1	NONE	2
TRAILER RECEPTACLE	1	1	1	1	1	1	NONE	1
AUXILIARY POWER UNIT	NONE	NONE	NONE	NONE	NONE	NONE	1	NONE
HORN	1	1	1	1	1	1	POWER PLANT WARNING & STANDARD HORN	ENGINE & TRANSMISSION WARNING & STANDARD HORN

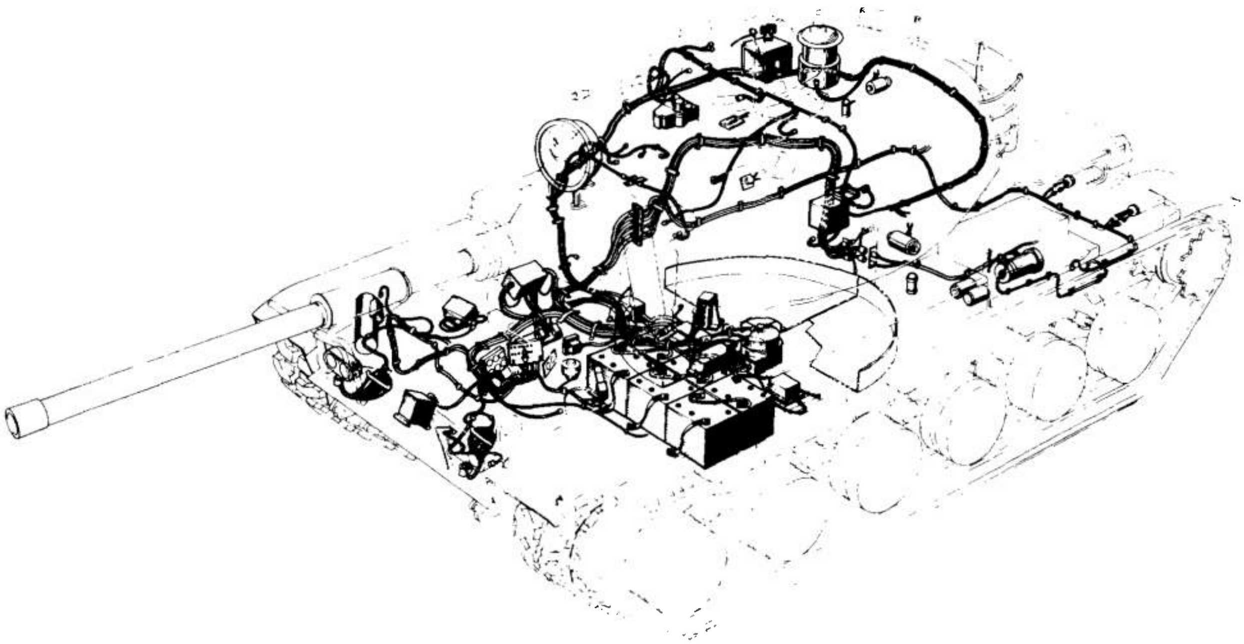


Figure 1-2. M60AI Tank Electrical System

1-3 GENERAL HANDBOOK SCOPE

Part One of this handbook, dealing with the analysis and design of vehicle electrical systems, is presented from an overall viewpoint illustrating how the electrical system dovetails with other vehicle systems and components. This overview of the entire electrical system design problem provides a reader with the insight necessary to optimize and document a vehicle electrical system intelligently.

The subject matter examined in Part One begins with an explanation of the research and development role of the Army Materiel Command (AMC) including objectives, policies, and philosophy. Then an introduction to system analysis and attendant design considerations is presented, defining systems and their relationship, describing analytical methods, and pointing out the many design factors that must be taken into account to design a trouble-free electrical system able to operate satisfactorily in the military environment. Next, component selection and application criteria, hardware procurement factors, and the necessity for prototype evaluation are examined; and finally, a description of minimum electrical system documentation requirements is presented.

Part Two of the handbook examines the nature of vehicle electrical subsystems and components in greater depth. Specific information regarding function and application of typical vehicle electrical equipment is presented. New developments having the potential for use in future military applications are described.

Electrical power generation, storage, conversion, and distribution are covered at the onset of Part Two, followed by a treatise on controls and actuators. Next, spark ignition systems are discussed, followed by separate chapters covering vehicle instrumentation, interior and exterior lighting, environmental controls, communications and electronics, and weapon systems. These chapters, which include the bulk of military vehicle electrical equipment in their scope, are supplemented by an explanation of electromagnetic interference and compatibility and a final chapter discussing various special purpose electrical equipment.

CHAPTER 2

ARMY MATERIEL DEVELOPMENT

SECTION I

PROGRAM DEVELOPMENT

2-1 INTRODUCTION

The acquisition of military materiel depends primarily on military need. It follows that an understanding of Department of the Army policies and procedures regarding development and description of materiel is important. This chapter, therefore, discusses program development objectives with regard to research, development, test, and evaluation of Army materiel. Military vehicles generally include the vehicle electrical system as part of the basic military vehicle concept. However, design and development of a vehicle electrical system, on occasion, has been undertaken independently to evaluate or incorporate new components, circuits, wiring, or termination concepts.

The U.S. Army Materiel Command (AMC), as a major field command of the Department of the Army[1]* (Fig. 2-1), is responsible for the integrated logistic management of Army materiel needs. Included in this responsibility as assigned materiel functions of the Department of the Army are: research and development, product improvement, production, maintenance, human factors engineering, test and evaluation, procurement and production, product assurance, integrated materiel inventory management, new equipment training, preparation or acquisition of technical publications, storage and distribution, transportation, maintenance, demilitarization, and disposal as related to the supply and maintenance systems, in addition to other assigned functions.

A specific statement cannot be applied regarding the life cycle of Army materiel because each project or program follows its own path from conception to production. However, this life cycle is governed by several factors such as the need for the materiel; the funds available for continued materiel development; and the complexity of problems introduced as a result of the materiel development.

2-2 SYSTEM ACQUISITION

Present policies for systems acquisition by the Department of the Army are thoroughly described in Army Regulation AR 1000-1[3]. The documents fostered by the new policy outlined in that regulation are related to former documents as shown in Table 2-1.

The first step in the development of a system must be the establishment of a Required Operational Capability (ROC). A ROC may originate anywhere in the Army – at one of the schools or centers, in one of the operational commands, in the Army Materiel Command (AMC), Training and Doctrine Command (TRADOC), Army Staff, Secretariat, or the idea might originate with industry. Generally speaking, a ROC will be produced when a technological opportunity appears, when potential enemies are developing equipment superior to ours, or when there is a general consensus that equipment in the hands of troops soon will be obsolescent.

*Superscript numbers refer to References listed at the end of each chapter.

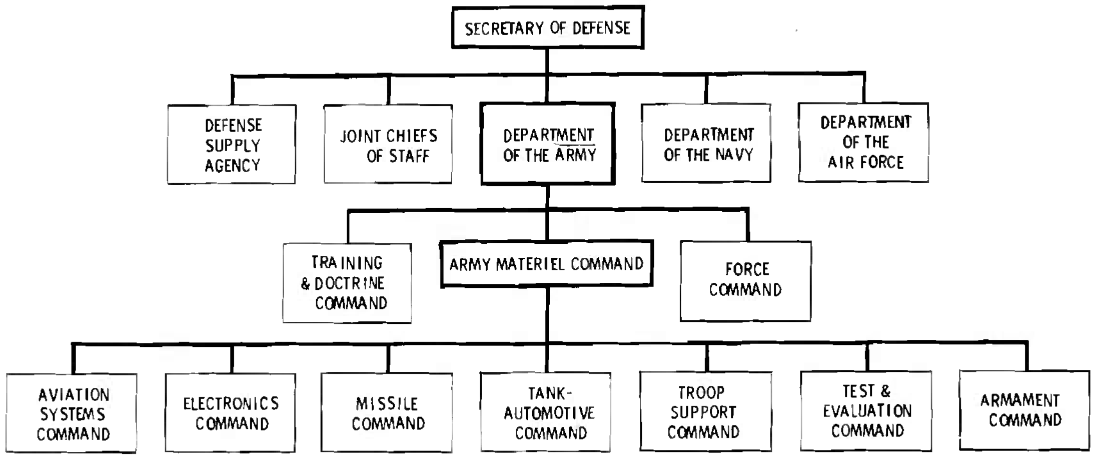


Figure 2-1. Army Materiel Command Organization[2]

The Required Operational Capability (ROC) will be a brief document which will describe in narrative form the minimum essential operational, technical, and cost information required for a HQDA decision to initiate development of a new material system. It is desirable that the size of the ROC be minimized. For most systems four pages seems to be a reasonable goal for a ROC.

The Development Plan (DP) is a single document which records program decisions, contains the user's requirement, provides appropriate analysis of technical options and the life cycle plans for development, production, training and support of materiel items.

The DP will be the controlling document for the materiel development effort and, as such, will be appropriately refined and updated throughout the development process and the ensuing life cycle when product improvement or changes to the materiel system occur.

The DP is appropriate for all materiel development efforts, both major and nonmajor. In the case of major systems, the Final Report of a Special Task Force is provided to the materiel developer for his use as it pertains to the DP. In the case of nonmajor systems, the materiel developer, in coordination with the combat developer, initiates the DP upon receipt of HQDA implementing instructions.

All testing will be divided into two broad categories: development testing (DT) and operational testing (OT). Development testing will be conducted by AMC and will include engineering testing and that part of service testing which assesses operability and maintainability of the system by the prospective user. Initial production testing will be considered as the final phase of development testing. Operational testing will be conducted beginning with early prototypes prior to the initiation of low rate production and continuing through production models. Operational testing will be conducted by user troops or individuals, preferably in units, to determine if the system is operationally suitable from a doctrinal, organizational, and tactical point of view and to collect performance and reliability, availability, and maintainability (RAM) data for the equipment when in the hands of troops.

2-3 ULTIMATE SYSTEM-DEVELOPMENT PHILOSOPHY

In the course of materiel development, it is not intended that engineering or operational system development of an item be limited to an assembly of off-the-shelf components. Nor is it intended, on the other hand, that such system development employ advanced tech-

TABLE 2-1. RELATIONSHIP OF FORMER DOCUMENTS TO DOCUMENTS FOSTERED BY PRESENT POLICY

FORMER	PRESENT POLICY
Operational Capability Objective (OCO)	Operational Capability Objective (OCO)
Initial Draft Proposed Materiel Need (IDPMN) Draft Proposed Materiel Need (DPMN) Proposed Materiel Need w/Technical Plan (PMN,TP) Materiel Need w/Technical Plan (MN,TP) Materiel Need (Product Improvement) (MN(PI)) Materiel Need (Abbreviated) (MN(A))	Required Operational Capability (ROC)
Advanced Development Plan (ADP) System Development Plan (SDP) Draft Proposed Materiel Need (Engineering Development) (DPMN(ED)) Proposed Materiel Need (Engineering Development) (PMN(ED)) Materiel Need (Engineering Development) (MN(ED)) Materiel Need (Product Improvement) (MN(PI)) Project Manager Master Plan (PMMP)	Development Plan (DP)
Concept Formulation Package (CFP) Trade-off Determination (TOD) Trade-off Analysis (TOA) Best Technical Approach (BTA) Cost and Operational Effectiveness Analysis (COEA)	Concept Formulation Package (CFP) Trade-off Determination (TOD) Trade-off Analysis (TOA) Best Technical Approach (BTA) Cost and Operational Effectiveness Analysis (COEA)
Materiel Need (Production) (MN(P))	Eliminated

nology which has not been demonstrated in experimental or laboratory form. Authorization to proceed with engineering or operational system development of an item, therefore, will be granted only when sufficient quantitative results have been obtained in laboratory or experimental devices to provide a reasonable level of confidence in final achievement of the predicted technological advancements.

SECTION II

PROGRAM MANAGEMENT

2-4 INTRODUCTION

The importance of total system management has become even more apparent as the complexity of military systems has increased. Groups of specialists emphasizing reliability, maintainability, survivability, durability, facilities, transportation, safety, human performance, and system testing have been required on military programs indicating substantial recognition that a system does not consist of equipment alone.

A system, as defined in MIL-STD-499, "is a composite of equipment, skills, and techniques capable of performing and/or supporting an operational role". All parts of a system must work together and have a unified purpose. In order to effect this coherence, an organization of creative technology is required which can lead to the successful design of a complex military system. This organized creative technology is called system engineering[4]

System Engineering Management (SEM) is the planning and control of a totally integrated engineering effort related to a system program. It includes the system engineering effort to define the system and the integrated planning and control of the program efforts of design engineering, system support engineering, production engineering, and test evaluation engineering.

Successful development, production, and deployment of major defense systems are dependent primarily on clearly defined responsibilities. Responsibilities of the contracting agency and of the design agency, therefore, are, covered briefly in the paragraphs that follow in order to acquaint one with respective considerations.

2-5 CONTRACTING AGENCY CONSIDERATIONS

The primary considerations of the contracting agency are to ensure:

1. Efficient engineering definition of a complete system which reflects Government objectives for the system.

2. Efficient planning and control of the technical program for the design, development, test, and evaluation of the system.

The contracting agency stipulates, in the request for proposal, the goals and minimum acceptable system functional requirements, technical performance, physical resources or other restraints, and figure(s) of merit. These are finally agreed to in the contract negotiation.

2-6 DESIGN AGENCY CONSIDERATIONS

The design agency is responsible for planning and executing a fully integrated system engineering management effort which encompasses the scope of responsibilities for total system definition and technical program planning and control as specified in the contract. This effort is tailored to the particular requirements. The various elements of the contract work breakdown and associated technical tasks are identified and controlled. Technical program tasks are planned and scheduled as finite increments of work whose completion is signified by accomplishment of specific final or interim technical objectives. The objectives usually are stated quantitatively and the target dates for their attainment are identified as milestones on contractual or supporting schedules.

The program definition effort analyzes functional requirements of the system; identifies critical areas; and defines design, development, or technical performance measurement tasks which will reduce the known risks and effect early identification of other risks as the work progresses.

The design agency is required to identify organizational elements responsible for the conduct of his system management. Responsibilities are assigned and lines of communications established for application and control of resources and the decision-making necessary to accomplish the system engineering management. The contracting agency is kept informed of changes made by the design agency during the contract effort.

The program and design reviews conducted by the design agency provide the means to monitor technical performance and ensure compliance with contractual obligations. The program review determines whether the planned technical program should be revised for maximum benefits as the program progresses, and seeks opportunities to redirect program effort to effect economies of budget and time. The design reviews are conducted on a periodic basis to assess the degree of completion of technical efforts related to major milestones before proceeding with further technical effort associated with a particular element of the system.

Army Regulations[5] establish policy, assign responsibilities, and prescribe procedures for the Department of Army to improve management of technical data and information necessary for research and development, test, evaluation, procurement, production, provisioning, cataloging, standardization, item entry control, quality assurance, maintenance, storage, distribution, operations, and disposal.

In general, specific requirements for data will be established as early as practicable during concept formulation or contract definition. Data requirements will be determined on the basis of the intended use of the data, with careful consideration of the immediately planned and probable future use of the system, materiel, or service to which the data relate. Only such data will be acquired from design agencies as are necessary to satisfy the intended use.

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CHAPTER 3

SYSTEM ANALYSIS

SECTION I SYSTEM INTERPRETATIONS

3-1 INTRODUCTION

System analysis involves the systematic determination of design requirements for the total vehicle electrical system and is most efficiently performed prior to the comprehensive design of elemental components or systems.

This systematic determination is facilitated if design personnel are familiar with the necessary electrical equipment, understand that the vehicle is a subsystem of the overall military system, and are cognizant of the electrical system as a subsystem of the vehicle, so that appropriate significance is attached to the requirements for trade-off study and optimization. Accordingly, this section discusses and clarifies the typical relationships encountered in the electrical system design process and describes functional vehicle electrical equipment.

3-2 SYSTEM

As stated in Chapter 2, the necessary composite of equipment, skills, and techniques capable of performing and/or supporting an operational role constitute a system. The military vehicle fits into the military operational system as an equipment element or subsystem and, therefore, all of the design factors illustrated in Fig. 3-1 must be given a measure of consideration during the vehicle development process.

3-3 SUBSYSTEM

A subsystem is an equipment group that performs one or more clearly defined functions of a system. A military vehicle is a subsystem in the military operational system, but further, the military vehicle itself is composed of a combination of major subsystems integrated coherently to satisfy the vehicle concept.

One typical division of a vehicle into subsystems is shown in Fig. 3-2. This type of division permits the allocation of functional design determinations to separate design groups, allowing orderly development to proceed without chaotic duplications or oversights.

As a rule, vehicle design agencies regard the vehicle as a system that consists of several subsystems; it is also generally true that personnel concerned with vehicle subsystems refer to them as systems—such as the hydraulic system or the electrical system.

With the preceding interpretations in mind, a vehicle electrical system is most properly perceived as an elemental building block in the military operational system, and it is then apparent that the pertinent interfaces require an appreciation of many design disciplines in addition to those purely electrical in nature.

3-4 SYSTEM ENGINEERING

All parts of a system must work together and have a common unified purpose, namely, to contribute to the production of a single set of highest outputs based on given inputs. This absolute necessity for coherence requires an organization of creative technology which leads to the successful design of a complex military system. This organized creative technology is called "system engineering". System engineering encompasses terms such as system

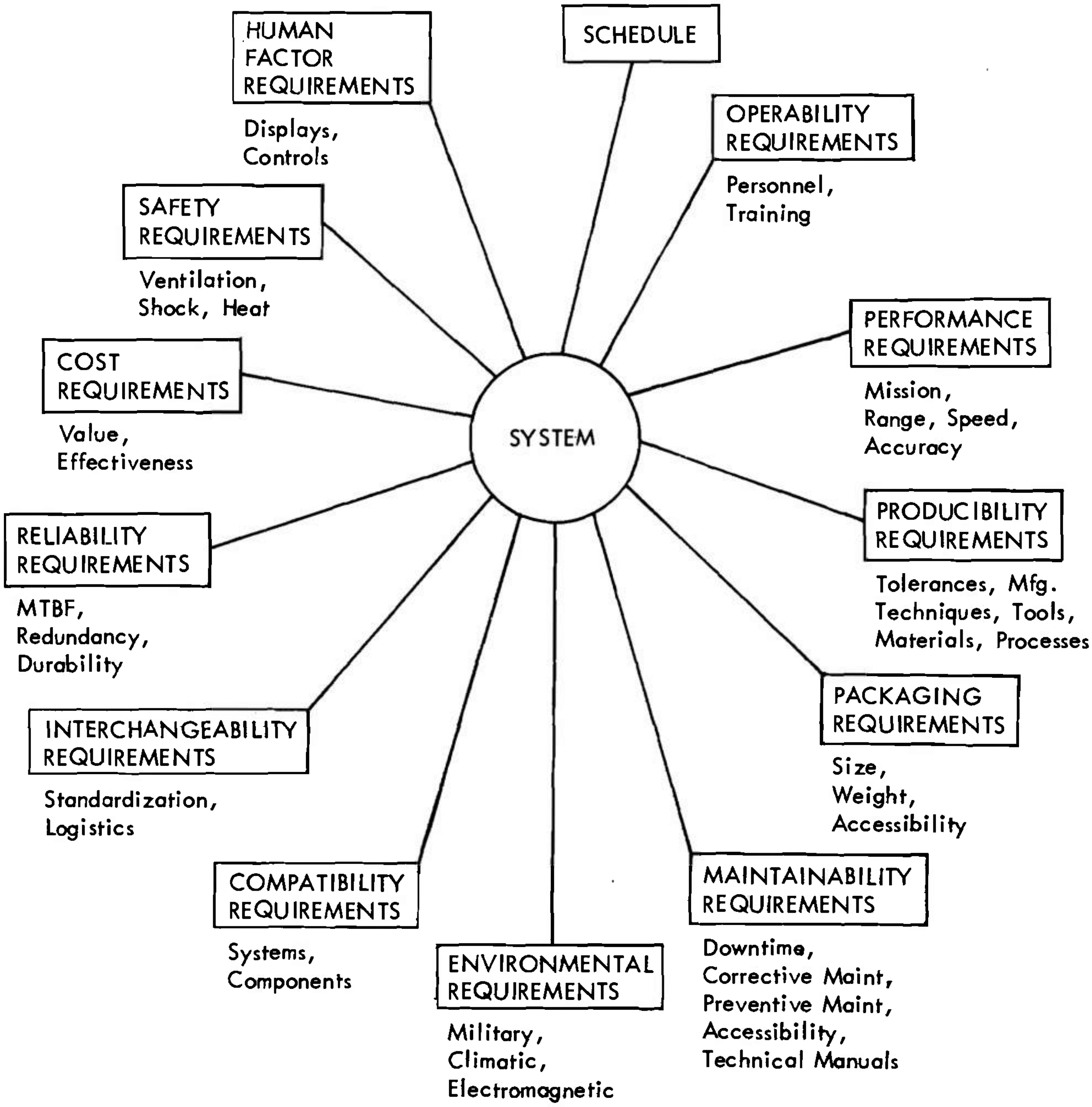


Figure 3-1. System Design Factors

approach, system analysis, system integration, functional analysis, system requirements analysis, reliability analysis, and maintenance or maintainability task analysis.

System engineering is concerned fundamentally with deriving a coherent total system design to achieve stated requirements. Although no two systems are ever alike in their developmental requirements, there is a uniform and identifiable process for logically arriving at system decisions regardless of system purpose, size, or complexity. As a rule this process requires the application of scientific and engineering knowledge to the planning, design, construction, and evaluation of man-made systems and components—including the overall consideration of the several possible methods for accomplishing a desired result and selection of the most appropriate method. Furthermore, it is axiomatic that the quality of performance and degree of acceptability that any vehicle electrical system design exhibits are proportional

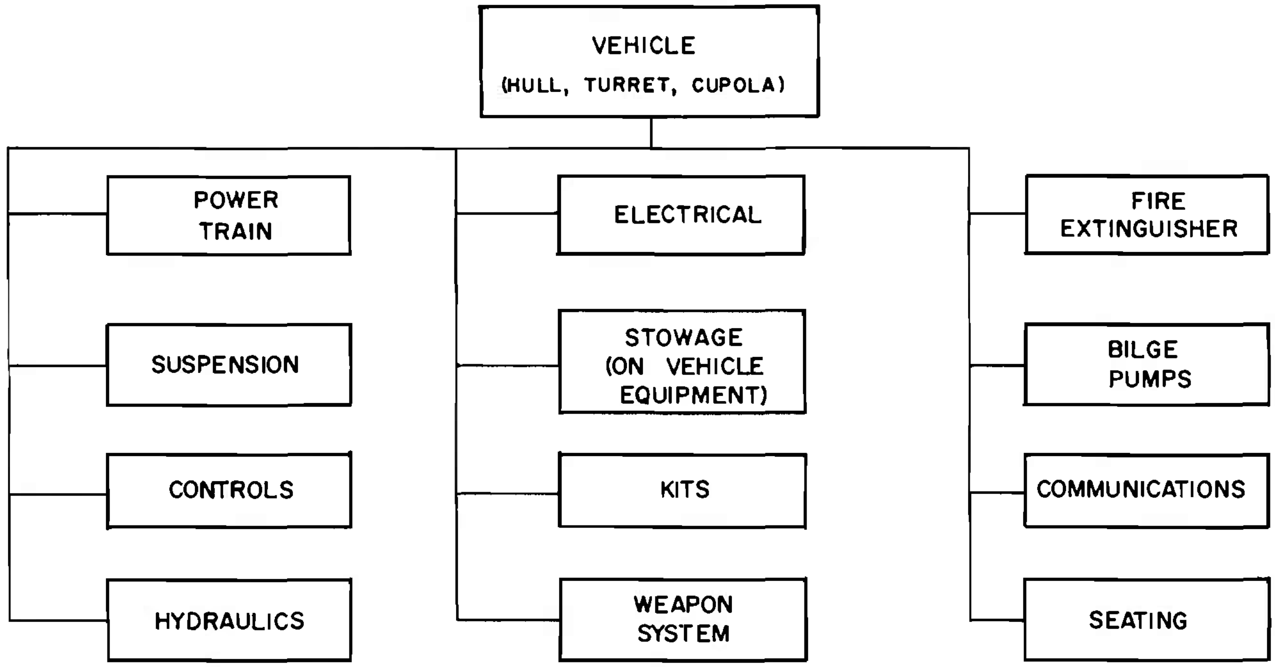


Figure 3-2. Vehicle Subsystems

to the amount of well directed system engineering effort expended by the design agency. The electrical system, in particular, services many other subsystems and has many man-machine control interfaces; therefore, the quality of the electrical system is extremely important in judging the acceptability of any vehicle as an end item of value. This consideration often is overlooked by mechanically oriented engineers.

The system engineering process is used to consider and evaluate logically each of the innumerable military, technical, and economic variables involved in total system design. Selecting the method of system operation and the system elements is a highly involved process since a change in one system variable usually will affect many other system variables, and rarely in a linear fashion. The generation of a balanced system design requires that each major design decision be based upon the proper consideration of system variables—such as facilities, equipment, environment, personnel, procedural data, training, testing, logistics, and intrasystem and intersystem interfaces. All considerations must be made within the effectiveness parameters of time, cost, and performance as defined or developed for the system. This logical consideration, evaluation, and selection process of a balanced design necessitates the closest coordination of selected skilled personnel who must work as a homogeneous system engineering design team.

3-5 SUBSYSTEM-TO-SYSTEM RELATIONSHIPS

The electrical system design engineer becomes extensively involved in subsystem-to-system relationships in pursuit of the following objectives:

1. Determination of the possible electrical requirements for the vehicle systems, including grounding and shielding needs

2. Analysis of the required functions to determine the best method of interfacing the individual functions into the complete vehicle

3. Development of a functional electrical system concept for the vehicle, stressing optimum end-item function

4. Design of the electrical equipment mountings and interconnections

5. Preparation of the lists of components required and the placing of timely orders for procurement of parts

6. Preparation of the required drawings and documentation

7. Coordination, as required, with other designers on the project to obtain the optimum vehicle design in all areas including maintainability, repairability, and producibility

8. Evaluation of the results of prototype-vehicle tests in order to correct deficiencies encountered during testing

9. Coordination with reliability analysts to insure that the reliability of the electrical system meets given requirements.

Because the vehicle is complex system composed of subsystems, and since many nonelectrical subsystems, are often partially powered or controlled electrically, a short in a minor subsystem could cause a vehicle to fail to accomplish its mission. Special attention is required to prevent or minimize the possibility of such occurrences. Analysis of possible failure modes followed by incorporation of appropriate protective measures is the most direct method for prevention.

3-6 BASIC ELECTRICAL SYSTEM FUNCTIONS

In order for an electrical system to perform properly, it must have adequate functional equipment and this equipment must be properly controlled and protected.

3-6.1 PRINCIPAL FUNCTIONAL EQUIPMENT ELEMENTS

The principal functional equipment elements of a vehicle electrical system are those which use or provide electrical energy to implement a vehicle function, and they may be grouped into the following general categories:

1. Actuators. Equipment which includes electric motors, servo valves, solenoids, or other devices used to produce mechanical movement.

2. Generators. Includes alternators, solar cells, and other devices used to produce electrical power from heat, light, or mechanical movement.

3. Lamps. The devices used to provide exterior and interior illumination, as required for nighttime operational capability, through the conversion of electrical power into visible light.

4. Instruments. Equipment capable of measuring physical conditions -- such as temperature, pressure, or liquid level – and producing, by various methods, a visual readout on a gage or indicator.

5. Energy Storage Devices. Battery or fuel cell equipment capable of storing considerable electrical energy for long periods of time.

6. Communications. Equipment, such as radio or intercom, capable of transmitting intelligence from one place to another.

7. Igniters. Devices used to produce spark ignition of engine fuels or explosive devices.

8. Sensors. Devices used to sense light level in night sights or sense position, roll rate, acceleration, etc., and provide feedback signals to servo-control systems, such as stability and weapon-pointing systems on tank-weapon stations, i.e., gyros, accelerometers, linear variable differential transducers, instruments, etc.

9. Power Converters. Devices used to modify the form of supplied power; i.e., amplifiers, inverters, converters, etc.

10. Weapon Systems. Power for weapon pointing, loading, and firing.

11. Servosystems, valves, LVDT, transducers, etc.

3-6.2 SECONDARY FUNCTIONAL EQUIPMENT ELEMENTS

The electrical inputs to or output from the principal functional equipment is dependent on satisfactory performance of the following secondary electrical system elements:

1. Power and Signal Distribution. Accomplished through interconnecting wiring or the electromagnetic transfer of energy.

2. Controls. Devices – such as switches relays, diodes, transistors – used to energize or control basic functions by connecting them to power or signal circuits.

3. Protectors. Devices – such as fuses, circuit breakers, reverse-current relays – used to protect wiring and components from electrical or thermal overload.

4. Regulators. Those devices designed to maintain voltage, current, etc., within prescribed limits.

5. Suppressors. Devices used to filter or suppress electromagnetic interference and/or voltage transients.

SECTION II

ANALYTICAL FACTORS

3-7 INTRODUCTION

A determination of vehicle system requirements in order to identify and analyze electrical system functions is the major electrical system design effort in the early stages of a vehicle development program. This effort must produce a comprehensive understanding of the vehicle, its mission, and requirements so that subsequent judgments can be made with the cognizance necessary to produce practical electrical system concepts.

3-8 SYSTEM FUNCTIONAL ANALYSIS

In the system engineering process, system functions are identified and the functions are then analyzed to determine the design requirements that will satisfy the functions and, ultimately, the combinations of personnel, equipment, and facilities that will satisfy the design requirements.

The purpose of functional analysis is to determine how each function can be performed in the system and to consider the feasible alternative combinations that will lead to successful completion of the mission. This step determines the design approach.

3-8.1 SYSTEM REQUIREMENTS AND CONSTRAINTS

System requirements are those things which the system must be able to do, and system constraints are the limits within which they must be accomplished. Requirements include the mission or purpose of the system as a whole, and the operational characteristics or performance requirements which detail the specific goals, objectives, and standards of the system mission. Constraints include the environmental, resource, cost, and time limits imposed on system design by the state-of-the-art, by nature, or by hardware availability. Analysis of system requirements must take into consideration the system constraints.

The purpose of analyzing system requirements and constraints is to identify the specific functions the system must perform, which in turn permits a determination of the kinds of human and instrumental capabilities required to satisfy the functional requirements.

A thorough understanding of requirements for a new vehicle electrical system will be achieved if the following approach, or an equivalent, is employed:

1. Study the vehicle specification, including the contractual requirements, and develop a set of questions to be answered in order to facilitate recognition of requirements applicable to the electrical system design. Seek answers to the following questions:

   a. What need must the vehicle concept fulfill or why is the vehicle necessary?

   b. What is the vehicle power source (prime mover)?

   c. What must the vehicle do or perform in the functional sense?

   d. How must the vehicle perform its functions and how are they powered?

   e. Who must control the vehicle functions and how are they controlled?

   f. Where must the functional parts be located?

   g. Must the functional parts be purchased, fabricated, or supplied by the Government?

   h. How must the parts be documented?

2. Consider general military vehicle electrical system requirements, as shown in Fig. 3-3,

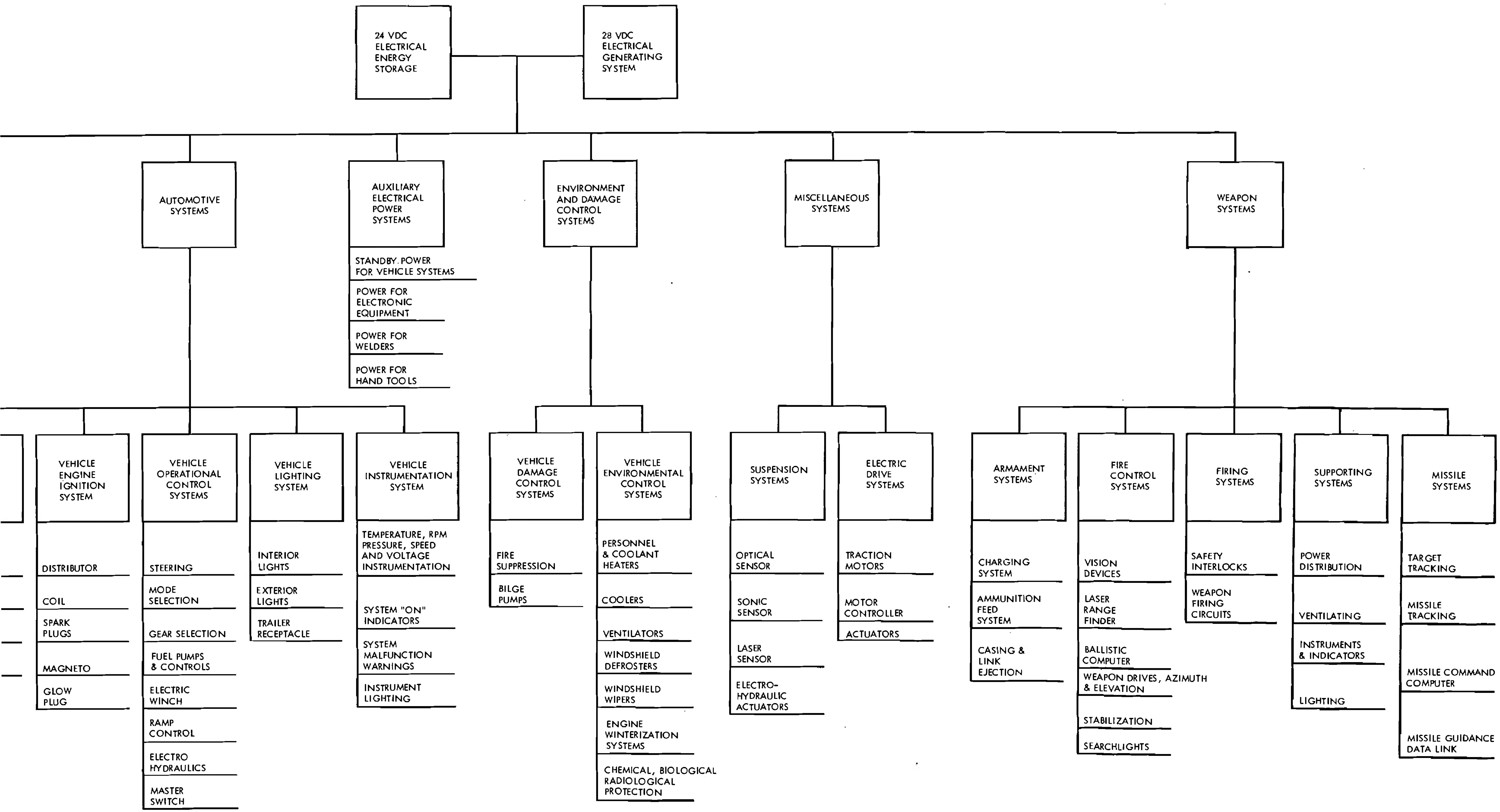
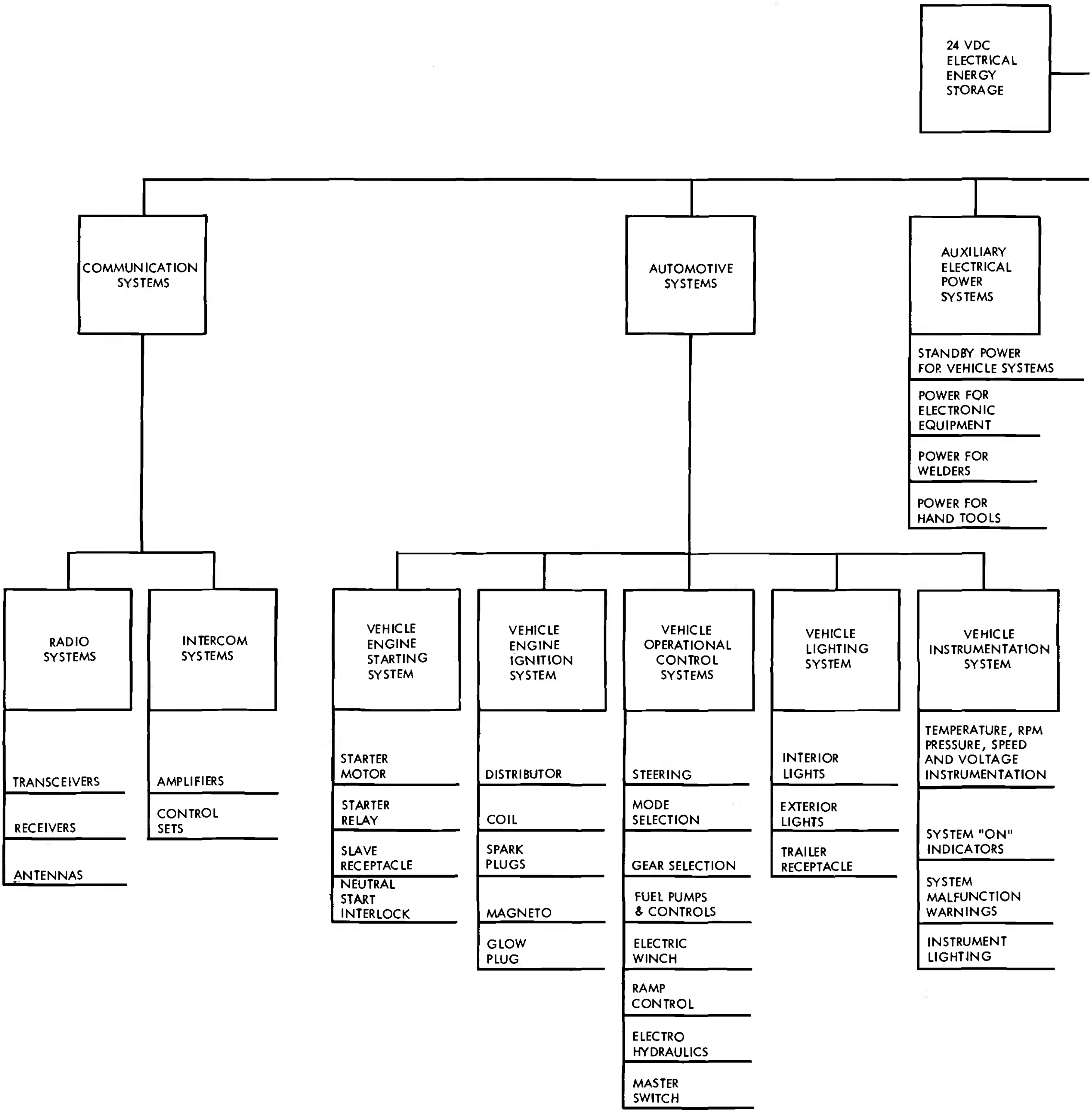


Figure 3-3. Typical Elements Required in Military Vehicle Electrical Systems



24 VDC ELECTRICAL ENERGY STORAGE
COMMUNICATION SYSTEMS
AUTOMOTIVE SYSTEMS
AUXILIARY ELECTRICAL POWER SYSTEMS
STANDBY POWER FOR VEHICLE SYSTEMS
POWER FOR ELECTRONIC EQUIPMENT
POWER FOR WELDERS
POWER FOR HAND TOOLS
RADIO SYSTEMS
TRANSCEIVERS
RECEIVERS
ANTENNAS
INTERCOM SYSTEMS
AMPLIFIERS
CONTROL SETS
VEHICLE ENGINE STARTING SYSTEM
STARTER MOTOR
STARTER RELAY
SLAVE RECEPTACLE
NEUTRAL START INTERLOCK
VEHICLE ENGINE IGNITION SYSTEM
DISTRIBUTOR
COIL
SPARK PLUGS
MAGNETO
GLOW PLUG
VEHICLE OPERATIONAL CONTROL SYSTEMS
STEERING
MODE SELECTION
GEAR SELECTION
FUEL PUMPS & CONTROLS
ELECTRIC WINCH
RAMP CONTROL
ELECTRO HYDRAULICS
MASTER SWITCH
VEHICLE LIGHTING SYSTEM
INTERIOR LIGHTS
EXTERIOR LIGHTS
TRAILER RECEPTACLE
VEHICLE INSTRUMENTATION SYSTEM
TEMPERATURE, RPM PRESSURE, SPEED AND VOLTAGE INSTRUMENTATION
SYSTEM "ON" INDICATORS
SYSTEM MALFUNCTION WARNINGS
INSTRUMENT LIGHTING

Figure 3-

to help determine whether obscure subsystem requirements, inherent in typical vehicle electrical systems but not necessarily listed in the vehicle specification or contract, are required.

3. Seek the guidance of experienced engineers, military personnel, and others who have been involved in the development and use of similar military vehicles.

4. Coordinate with the Government personnel who have technical responsibility for vehicle development.

5. Refer to technical manuals describing similar military vehicles to review their electrical system design and component usage.

6. Develop a clear statement of the functions to be assigned to operating personnel in order to define the human tasks and performance requirements of the system.

7. List all functions that can be established as definite or possible electrical system requirements.

An analytical study of this nature often leads to the realization that some of the requirements listed within the specification or contract are incompatible. If incompatibilities are found, immediate corrective action should be taken by negotiating specification or contract changes. Failure to resolve such problems when they arise can lead to serious misunderstandings between contractors and contracting agencies.

3-8.2 SYSTEM FUNCTION ALLOCATION

A system function is a broadly defined operation or activity which contributes to the system mission or goal. It usually constitutes the primary reason for including a particular subsystem, equipment, or crew position in the design of the system. Functions may include: detecting signals, measuring information, comparing measurements, processing information, and acting upon decisions to produce a desired condition or result. The identification, analysis, definition, and allocation of system functions represent the sequence which translates system requirements and constraints into an organized program for design implementation.

Functional allocation is the process of assigning the work to be performed by a system to personnel, equipment, and facilities so as to achieve a system that is maximally effective, taking into consideration the capabilities and limitations of men and machines. It involves determining which phases of the data-sensing, decision-making, control, and supporting segments of each function should be handled by human components and which by equipment components. Those functions that are allocated to equipment will then set the stage for end-item identification and initial hardware design. Those allocated to human components will establish a basis for examining the human performance involved, identifying and analyzing the specific tasks required, and forecasting the personnel and training that will be needed. This process of assigning functions to personnel and equipment, in order to establish design requirements for the system, is necessarily a joint effort of the various specialists on the project engineering team. Regardless of the specific procedures involved in allocating system functions, three major steps normally will be considered:

1. Examining each system function to determine the kinds of capabilities needed to meet system performance requirements

2. Exploring possible combinations of man-equipment capabilities through trade-off studies

3. Determining which design approach will maximize overall system effectiveness.

3-8.3 SYSTEM ENERGY SOURCES

In order to achieve early identification of those functions that should be implemented electrically, the electrical system designer may have to take the initiative in establishing which of the available energy sources should be used for performing the various functions. This necessity usually arises in the initial phase of development work on a new vehicle when most project personnel are working with the power train, suspension, and hull groups. The design problems in these areas demand early solution, while the electrical and other control problems seem remote and are easily postponed.

Most questions regarding the correct energy source for a given function are resolved by considering the power sources that are readily available on the basic vehicle. Manual, mechanical, and electrical power sources are available on most vehicles, hydraulic on some. Others might easily be made available, such as vacuum on a vehicle using a gasoline-burning engine or compressed air from a turbine-powered vehicle. Sometimes a power source analysis will indicate that it is advisable to choose mechanical implementation for a critical function in favor of an electrical method simply because the mechanical method is more understandable to the users and thereby enables them to make field repairs easily. As a general design goal, each function should be implemented with the simplest adequate system using the least number of components, and good balance in the use of available energy sources should be sought.

3-8.4 SYSTEM DESIGN REQUIREMENTS

System design requirements are the human or instrumented capabilities, or combinations of these, that may be used to accomplish the system functions. They identify the processes which convert available inputs into required outputs.

When major functions are restructured into lower level subfunctions, the kinds of subsystems, equipment, or man-equipment combinations that will satisfy the specific functional requirements are often apparent. In some cases, the availability of existing equipment will dictate the most realistic combination from a cost effectiveness standpoint.

If there is uncertainty as to how functions should be performed, it may be necessary or advisable to perform a subsystem optimization study as described in par. 3-9 and its subparagraphs. This would ordinarily be done in conjunction with project leaders and the responsible personnel of other groups.

Where the requirements essentially are defined by the similarity of the vehicle to other vehicles, by vehicle specifications that call out specific items that must be incorporated—such as existing weapon systems, or by the desire for commonality of spares with other vehicles—the designer may satisfy himself that the subsystem optimization study of par. 3-9 would not be productive. However, each capability must be analyzed in terms of interface requirements, and the probable effect of each alternative should be evaluated with respect to other aspects of system performance.

Whether electrical system design requirements are obvious or not, there must be a final agreement on these requirements among the electrical design engineer and designers in other subsystem groups on the project. As mentioned before, at the start of a program, it is easy to delay or postpone decisions on the electrical system in favor of seemingly more important subsystems in order to meet performance schedules.

On the other hand, the electrical design engineer cannot hope to develop an optimized system unless he establishes early in the program not only what the electrical system functional requirements are, but also how they will be controlled. Therefore, it is usually profitable for him to begin immediately by coordinating the ideas of all project design personnel in regard to vehicle control requirements.

This may be accomplished in part by preparing an outline of operations the driver and other vehicle personnel must perform to utilize the vehicle. The following example is an abbreviated outline of functions an operator at a typical driver's station might perform:

1. Turning the master switch and observing:

a. Battery-generator indicator showing battery voltage

b. Fuel gage reading fuel level

2. Pushing the engine control lever to the "run" position to energize the:

a. Fuel pumps

b. Transmission oil pressure gage

c. Engine oil pressure warning light

3. Depressing the starter switch. Engine will start if shift lever is in neutral

4. Once the engine starts, observing:

a. Engine oil pressure on an electrical gage

b. Engine coolant temperature (as it rises) on an electrical gage

c. System charging voltage on the battery-generator indicator

d. A differential oil pressure warning lamp that will not be lit if differential oil pressure is adequate

e. A mechanically driven tachometer reading engine rpm

5. Turning the light switch lever to "SER DRIVE" position to turn on the service headlamps which will:

a. Cause the service headlamps to light. These may be bright or dim depending on the position of the dimmer switch controlled by the driver's left foot

b. Cause left and right tail lamps to light (and also tail lamps of a connected trailer)

c. Cause the stop lamp to light if the brake is depressed (and also cause a connected trailer stop lamp to light)

6. Turning the light switch to "STOP LIGHT" position will light the stop lamp (and a connected trailer stop lamp) if the brake is depressed

7. Turning the light switch to "BO MARKER" position will . . .

8. Turning the light switch to "BO DRIVE" position will . . .

9. Turning the ventilation fan switch on will energize the personnel ventilation fan if:

a. The master switch is on

b. The engine is running so that the engine oil pressure switch is actuated. (This feature prevents inadvertently discharging the battery with this large electrical load when the generator system is not operating.)

10. Other functions, depending on the system under consideration.

By using information from this type of outline and from the list of possible electrical functions developed in the system requirements analysis (see par. 3-8.1), a functional equipment tabulation and preliminary functional schematic diagram may be developed.

The functional equipment tabulation serves to consolidate design and procurement data related to electrical components required to implement each primary function. Fig. 3-4 illustrates typical data requirements for an engine starting function.

A preliminary functional schematic diagram for the same engine starting function is illustrated in Fig. 3-5. In actual practice, the diagram for this function, and data shown thereon, may be nothing more than a freehand sketch that ultimately is used to facilitate the consolidation of all electrical functions into a preliminary vehicle electrical schematic diagram.

Working schematics of this sort are analogous to the design layout prepared by a mechanical designer in the course of mechani-

GROUP 06 – ELECTRICAL SYSTEM										
0601 – ENGINE STARTING FUNCTION										
ITEM NO.	COMPONENT	REFERENCE DESIGNATION	QUANTITY	VENDOR	COMMERCIAL PART NO.	MILITARY PART NO.	NOMINAL LOAD PER UNIT	MAX LOAD PER UNIT	MAX CURRENT RATING	COMMENTS
1	STARTER MOTOR & SOLENOID ASSY		1			10947131	APPROX. 300 A CRANKING AT NOR-MAL TEMP.	500 A (ARCTIC COND)		MAX LOAD RATED AT -25°F CRANKING WITHOUT HEATING AIDS. STARTER SOLENOID REQUIRES 50 – 60 A PULL-IN AND 7 – 8 A HOLDING CURRENT.
2	STARTER RELAY		1		DELCO REMY P/N 1484		0.5 A	0.5 A COIL CURRENT	CONTACTS 50 A INDUC-TIVE	
3	SLAVE RECEPTACLE		1			11588938			SEE COM-MENTS	245 A CONTINUOUS 500 A INTERMITTENT
4	NEUTRAL START INTERLOCK		1			11589014			10 A IND AT 30 VDC	
5	START BUTTON		1			8720190			10 A INDUC-TIVE	

Figure 3-4. Functional Equipment Tabulation

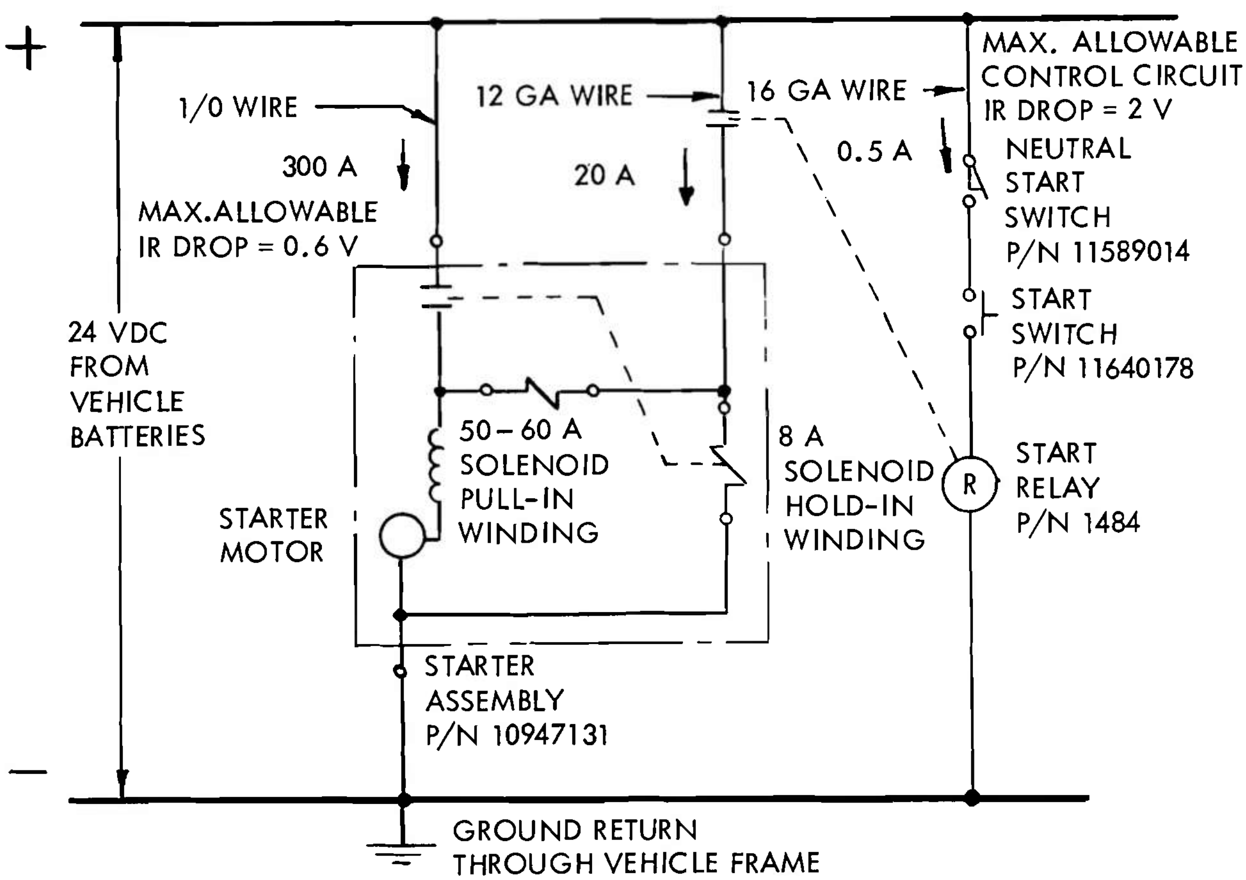


Figure 3-5. Engine Start Circuit Schematic

cal device development and are used extensively to discuss design concepts with managers and associates.

Every electrical circuit or function established as a definite requirement in the preceding functional analysis, par. 3-8, and allocation process will demand completion of the following steps in the design process:

1. Design or selection of the components required to perform each electrical function and early initiation of design effort on those items requiring long lead time for design, development, or procurement.

2. Design of mountings, assemblies, and enclosures required to install and interconnect the components.

3. Preparation of the drawings and other documentation required to describe the mountings and interconnection between components.

4. Initiation of the paper work for the procurement and fabrication of all other items required for the complete electrical system installation.

The system development process unfolds in a random manner as design problems are solved, and it is quite normal to have completed design and documentation of some functions while the search for suitable components is still going on with regard to other functions. However, sufficient control must be exercised over the development sequence to avoid allowing any function to go unresolved until the design quality or delivery schedule is jeopardized.

3-9 SUBSYSTEM OPTIMIZATION

In its broadest sense, "optimization" means "to make the best of". For a business man, this might mean selecting the investment alternative that would maximize profits. For a battlefield commander, optimization could mean tactical decisions aimed at minimizing casualties. For system engineering, optimization can be defined as "the process of identifying the relative operational and/or support effectiveness of alternative systems and technical program elements which have been defined by system engineering, relating cost and schedule implications, and selecting a preferred alternative or set of alternatives"[1]

To illustrate the application of optimization to a military vehicle, consider a vehicle system which has a hydraulic subsystem in addition to electrical and mechanical (drive train) subsystems. A requirement for a winch on this vehicle would involve an initial decision on the source of drive power for the winch–i.e., hydraulic power, electrical power, or a mechanical power take-off. An optimum selection among the alternatives available for a source of drive power must be predicated on considerations related to the vehicle system rather than to any individual subsystem–electrical, hydraulic, or mechanical. (The latter approach to decision making–i.e., the enhancement of performance of one subsystem at the possible expense of other subsystems, or of the entire system–is referred to as suboptimization[2], and is an obvious impediment to optimization in vehicle design or in any other endeavor.) In accordance with the definition given, an identification and evaluation of the operational/or support effectiveness of each of the three power sources must be made, in which each relevant characteristic is taken into consideration. These would include weight, cost, size, availability, stall torque capability, control characteristics, reliability, maintainability, and environmental suitability. The evaluation should also include consideration of factors related to installation of the unit in the vehicle, such as location, effect on other components (hydraulic pumps, electrical generators, batteries); and effect on operating characteristics and efficiencies of various subsystems (e.g., hydraulic pressure drops affecting other equipment, voltage transients of electromagnetic interference caused by the electric winch motor).

When the evaluation is completed and the power source for the winch has been selected, by methods described in the paragraphs that follow, the load requirements for the electrical subsystem may be modified as required and subsystem design may proceed. The same is true, of course, for the hydraulic and drive train subsystems.

The electrical system design engineer should be involved in the foregoing evaluation process for two reasons. First, his expertise is required to assure valid inputs relative to electrical equipment and effect on the electrical subsystem. Second, he will be directly affected by the decision.

3-9.1 DECISION MAKING

In the optimization process described, the significant element is the decision, i.e., the act of "selecting a preferred alternative". While there are no hard and fast rules on how decisions are, or should be made, an understanding of the elements involved in the decision-making process is useful in the attempt to arrive at reasonable and intelligent decisions. A model of the decision making process is shown in Fig. 3-6.

The first step in decision making is establishing an accurate and quantitative knowledge of the system, the system or subsystem variables (i.e., the alternatives and characteristics of the alternatives), and the interaction between the variables and other system or subsystem elements. It is here that the engineer's professional skill, training, and experience come into play, since the validity of the optimization process cannot exceed the accuracy of the data used. The elements implicit in the winch selection example given which comprise this first step are the various alternatives, the characteristics of the alternatives, and the effects of the alternatives on the various vehicle subsystems.

The second step is establishing an objective function, or decision rule, which can be expressed in terms of system variables. The objective function is a mathematical expression that describes the interrelationships among the system variables. For many engineering and economic decisions the mathematical relationships described in the objective function are based on deterministic values, such as costs, or on scientific or engineering laws or principles. The decision process in these cases is directed towards selection of values for the independent variables (within specified constraints) which optimize the value of the dependent variable (objective function).

In social or management decisions, including many system engineering decisions, an additional factor which must be considered is a value judgment of the utility (also known as relative worth or weighting) of the system independent variables, and each variable is weighted in accordance with the value judgments of its relative worth. These value judgments may be made by the system designer or may be specified requirements. In the latter case, the judgments are made by the

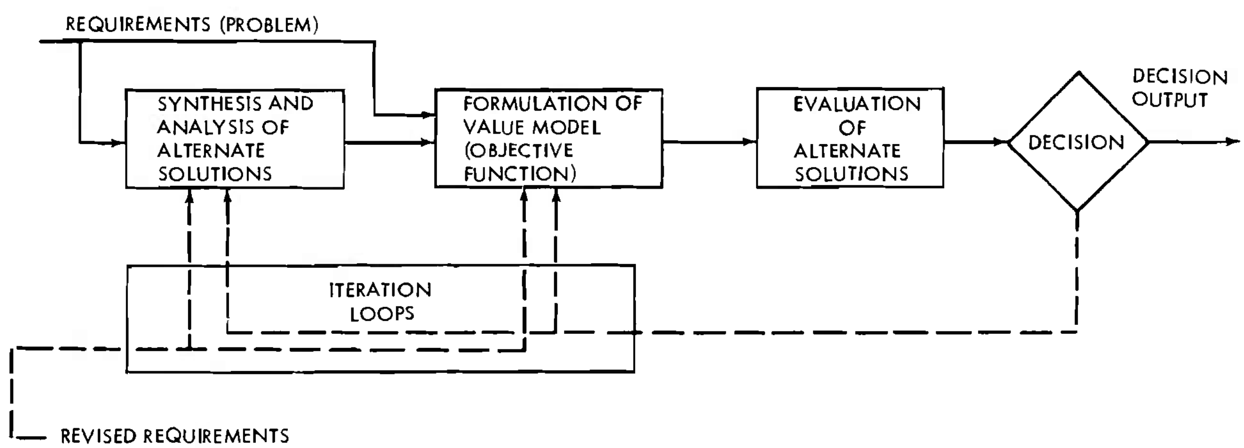


Figure 3-6. Model of Decision Process

customer or system user, but in either case the judgments must be made.

A further consideration is that the utility value judgments may vary for different operational conditions or situations. In this case, the probabilities of each of the possible operational conditions existing during system operation must be established. For practical design situations, these probabilities usually must be determined either from recorded statistical data (e.g., if climatic conditions or reliability are the variables being considered) or as a judgmental item (such as determining the probability of system use in guerrilla, conventional or nuclear warfare, combat or support situations). A detailed discussion of probability theory and statistics is beyond the scope of this handbook, but may be found by the interested reader in Refs. 3 and 4. Once probabilities have been determined, the utility value of each system variable becomes a sum of the utility value of that variable for each operating condition multiplied by the probability of occurrences of that operating condition.

To illustrate the foregoing, let us simplify our previous winch power source selection example. Consider, for each of the three candidate power sources, three characteristics of interest; namely, cost, weight, and an index of performance which covers all of the performance characteristics. Consider the use of utility values to weight of the characteristics of the alternative systems. Then we can write

$$Z_e = U_I I_e - U_w W_e - U_c C_e \tag{3-1}$$

where

Z_e = objective function evaluated for electric winch drive, dimensionless

I_e = index of performance of electric winch drive, dimensionless

W_e = weight of electric winch drive, lb

C_e = cost of electric winch drive, $

U_I = utility (weighting factor) of index of performance, dimensionless

U_w = utility (weighting factor) of weight, per lb

U_c = utility (weighting factor) of cost, per $

Similarly,

$$Z_h = U_I I_h - U_w W_h - U_c C_h \tag{3-2}$$

and

$$Z_m = U_I I_m - U_w W_m - U_c C_m \tag{3-3}$$

where the subscript h indicates hydraulic winch drive and the subscript m indicates mechanical winch drive.

Since the optimization goal in this case is to maximize the objective function, the weight and cost terms are negative. Thus a direct comparison of Z_e, Z_h, and Z_m would yield the optimum choice.

Constraints may be imposed on the system variables which override a winch selection by direct comparison of Z_e, Z_h, and Z_m. A necessary constraint would be a minimum performance index based on operational requirements. Suppose that it was further specified that the weight of the winch was constrained not to exceed 100 lb, i.e.,

$$W_e, W_h, W_m \leqslant 100 \text{ lb} \tag{3-4}$$

In that case, the winch drive alternative with the highest value objective function would have to be discarded if its weight exceeded 100 lb and a choice made among the remaining alternatives.

The third step is applying optimization techniques to the information established in step one, in order to determine the best, or preferred, alternative according to the decision rule which was established in step two. It is obvious from the simple example presented that the method shown would, in a more realistic example, rapidly result in a large, difficult-to-manage mathematical expression. In addition, while this method is applicable to the particular problem used as an example, it is not at all useful in many other types of optimization problems. For these reasons, many other techniques have been developed for various types of problems, degrees of complexity, and criticality of the decision to be made. From the standpoint of a military vehicle electrical system designer, the most significant of these are:

1. Trade-off studies

2. System effectiveness models

3. Mathematical models. (The previous example is a mathematical model.)

These are described in pars. 3-9.2, 3-9.3, and 3-9.4.

The fourth step is iteration, a process with two distinct aspects. First, the decision process itself may yield new or more accurate input data, or may precipitate revisions to the judgment values used in establishing the objective function. In this case, the decision process is reiterated before an output is given. Second, revisions to the input data and value judgments may occur at any time during the program (vehicle development), requiring a reiteration of the decision process.

3-9.2 TRADE-OFF STUDIES

In the design of vehicle electrical systems, the use of trade-off analysis techniques is of prime importance in selecting one from among several alternative design approaches and in the resolution of conflicting design objectives and constraints. Trade-off analysis, as an engineering decision process, must consider the impact of particular engineering decisions on the total system, including hardware, software, facilities, personnel, support equipment and services, as well as on the overall program effort.

Trade-off studies may consider revisions of system functions, performance, and design requirements which can result in revised configurations of the system or specific end items.

Criteria for trade-off studies must be expressed in terms of resources or variables. Examples of resources are funds, time, manpower and skills, or electromagnetic spectrum available. Examples of variables are weight, mission length, reliability, maintainability, safety, vulnerability, and survivability. Criteria for measurement of system effectiveness should be stated in quantitative terms where practical.

The criteria established for trade-off studies must be related to system requirements, with particular attention to "essential" characteristics and "desired" characteristics stated therein. Trade-off limitations are specified in relation to "essential" characteristics and performance requirements for operations, maintenance, test, production, and deployment elements.

System effectiveness models and mathematical models may be used to the extent they can contribute efficiently to the optimization of system definition decisions. However, the cost of trade-off studies, as with other system engineering techniques, should be considered relative to their potential payoff to the system and the project. Neither the rigor nor the depth of the procedures used should be greater than their worth to the project. For example, the cost of conducting a trade-off study between two alternative design approaches may be greater than the potential value differential of the alternatives. Conducting such a trade-off study would not be cost-effective, provided both alternatives fulfill the minimum performance requirements of the system. Similarly, the relationship between expenditure of engineering analysis time and level of confidence is usually nonlinear. In many instances, the potential value of increased confidence beyond a certain level would not warrant the added expenditure.

The trade-off studies are used primarily to optimize the preliminary design of the system. The optimum preliminary design of the system is that design which represents the best combination of equipments, facilities, personnel, technical/procedural data, procedures, and computer programs which have been selected separately to perform the operations, maintenance, test, production, and deployment functions. The criteria for selection of "best combination" are overall performance in terms of fulfillment of system requirements, life cycle costs, and elapsed time needed to meet deployment schedules. Trade-off decisions and rationale may be documented in a trade-off study report, if required, or may be part of the designer's working notes and calculations.

When formal trade-off study reports are required, the contents and format may be prepared, using Refs. 5 and 6 as a guide, modified as appropriate to suit the particular study. An abbreviated example of a trade-off study report for selection of a personnel heater for a military vehicle is shown in Fig. 3-7.

3-9.3 SYSTEM EFFECTIVENESS MODELS

A model, in the scientific sense, may be considered a representation of a real thing, either a physical object or an abstract concept. It may be the commonly envisioned miniature replica of the real object, such as a model airplane or railroad engine. However, it could also be a word or language description; a pictorial or diagrammatic representation; a direct analog; or a mathematical model. "System effectiveness is a measure of the degree to which a system achieves a set of specific mission requirements. It is a function of availability, dependability and capability."[1] Therefore, a system effectiveness model is a representation of the concept of system effectiveness expressed in terms of the three attributes of the system which we designate as availability, dependability, and capability.

Definitions of these terms evolve from the characteristics of a system (or subsystem) which contribute to system effectiveness. These characteristics may be grouped into three designated categories:

1. Availability. Characteristics affecting response to a mission call. A measure of the degree to which an item is in the operable and committable state at the start of the mission when the mission is called for at an unknown (random) point in time.

2. Dependability. Characteristics affecting endurance of item operation. A measure of the item operating condition at one or more points during the mission—including the effects of reliability, maintainability, and survivability—given the item condition(s) at the start of the mission. It may be stated as the probability that an item will enter or occupy one of its required operational modes during a specified mission and perform the functions associated with those operational modes.

3. Capability. Characteristics affecting terminal results of the mission. A measure of the ability of an item to achieve mission objectives, given the conditions during the mission.

The diagrammatic representation of this approach to system effectiveness is shown in Fig. 3-8[7]

To illustrate the application of the foregoing definitions to a quantitative evaluation of system effectiveness, consider the following simplified example.

1. Problem Statement. The system to be considered is that comprised of the XXX vehicle and its weapon subsystem. It is to operate in a limited warfare environment where rapid movement of supplies upon request is important. The mission of the system is that of transporting, upon random call, supplies from a central supply base to troop activities within a radius of 2 hr driving time. En route, proper functioning of the weapon subsystem enhances the chances of a successful delivery of the supplies in terms of defense against attack by enemy troops, etc.

XYZ CORP Military Ordnance Division	TITLE Comparison of personnel heaters for use on the M (xxx) vehicle	TRADE-OFF STUDY Report No. 27 Date: 12 July 71

1. Scope: This trade-off study report presents a comparative evaluation of three types of heaters available for heating the personnel compartment of the M (xxx) vehicle, and recommends use of one of the units.

2. Functional and Technical Design Data and Requirements:

a. Vehicle internal temperature to be maintained at ______°F minimum with outside temperature of – ______°F.

Heat required to maintain this temperature is ____ Btu per hr (Reference Heat Loss Calculations for M (xxx) Personnel Compartment dated 1 June 71).

b. Vehicle engine coolant temperature will be ______°F when operated in ______°F ambient.

(Reference model ________ Engine Specification dated __________).

c. Liquid fuel operated heater units, if used, must be suitable for operation on diesel fuel (MIL-____ - ____), kerosene (MIL-_____- ____) or _________ (Reference ___________).

d. Electrical components shall be operable on 24-28 VDC (MIL-STD-1275 dated _______ page ______ par. _______).

e. Heaters shall be capable of 30-min operation with vehicle engine off with temperature drop in passenger compartment not to exceed _____°F below requirement of par. 2a. (Reference M (xxx) Vehicle performance specification dated ____ page _____ par. ______).

3. Design Approaches and Significant Design Characteristics:

a. Three design approaches were selected for study:

(1) Multifuel heater
(2) Hot water heater
(3) Electric heater

b. Significant design characteristics of the three design approaches:

(1) Multifuel heater:

(a) Heat is available after a 1-min start up period.

APPROVAL ______________________ PAGE 1 of 3

Figure 3-7. Personnel Heater Trade-off Study

XYZ CORP Military Ordnance Division	TITLE Comparison of personnel heaters for use on the M (xxx) vehicle	TRADE-OFF STUDY Report No. 27 Date: 12 July 71

(b) Capable of using any fuel that the engine can operate on. (Special fuel not required)

(c) 30,000- and 60,000-Btu units available in the military approved components lists:

1. Maintainability established

2. Reliability established

3. Repair parts and replacement units available at military depots.

(d) Capable of operation without engine running.

(2) Hot Water Heater:

(a) Heat availability delayed due to engine warm up required to supply hot water to heater.

(b) 20,000 and smaller Btu units available in the military approved components list.

1. Could use several in one vehicle for increased Btu output.

2. Maintainability and reliability established.

3. Repair parts and replacement units available at military depots.

(c) Requires the vehicle main engine in operation to operate heater.

(3) Electric Heater

(a) Heat available rapidly. Engine must be running to avoid discharged batteries.

(b) Approximately 15 kW required for 60,000 Btu. Requires more power than is available in existing electrical system.

(c) Unknown if units exist in the military system, however, design of a unit from existing components is feasible.

PAGE 2 of 3

Figure 3-7. Personnel Heater Trade-off Study (Cont'd.)

XYZ CORP	TITLE	TRADE-OFF STUDY
Military Ordnance Division	Comparison of personnel heaters for use on the M (xxx) vehicle	Report No. 27 Date: 12 July 71

4. Comparison Matrix of Design Approaches:

Functional and Technical Design Requirements	Multifuel Heater	Hot Water Heater	Electric Heater
a. Availability in present inventory.	Yes, as a kit on some vehicles. Standard equipment in others.	Yes, but with vehicle gasoline burning engines.	Qualified NO. Investigation did not reveal any application.
b. Feasibility	Good — many similar vehicle applications proven successful.	Good — except this is diesel engine which requires long operating time at full load to reach max water temp.	Good — many commercial applications.
c. Reliability MTBF 1000 hr	Recommend service at 500 hr with life expectancy to be 1000 hr.	Unknown	Unknown
d. Compatibility	Yes, uses same fuel as vehicle engine.	Yes	Poor — vehicle electric power supply is limited.
e. Electrical power requirements	Low — fan load only.	Low — fan load only.	Very high — prohibitive.

5. Recommended Design Approach:

The multifuel heater is recommended for the following reasons:

a. Heat available in 1 min without running vehicle engine.

b. Requires no special fuel—uses vehicle supply.

c. Reliability and maintainability established.

d. Repair parts and replacement units available in the military supply system.

e. Electrical power requirements are low.

PAGE 3 of 3

Figure 3-7. Personnel Heater Trade-off Study (Cont'd.)

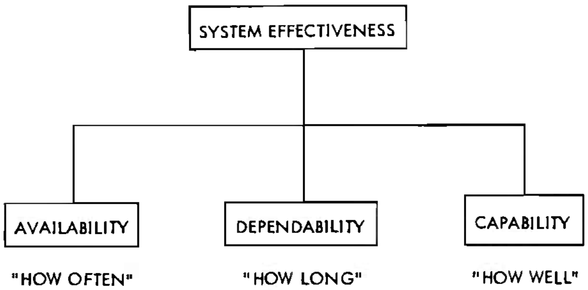


Figure 3-8. Definition of System Effectiveness[7]

Some major assumptions which are inherent in this example are:

a. A call for supplies is directed to a single vehicle that is located at the base. If this vehicle is not in operable condition (i.e., in process of maintenance) the mission will not be started. An operable vehicle is defined as one which is in condition to be driven with a standard supply load.

b. The driving time required to reach the combat area is 2 hr.

c. The weapon subsystem cannot be maintained or repaired during a mission.

d. A loaded vehicle which is lost en route to or does not reach the combat area either through mechanical breakdown or through enemy action has no delivery value.

2. Model Formulation:

a. For purposes of model formulation, the system condition is divided into three states, namely:

(1) State 1—Vehicle operable, weapon subsystem operable

(2) State 2—Vehicle operable, weapon subsystem nonoperable

(3) State 3—Vehicle nonoperable

b. The effectiveness model is defined as

$$E = ADC \qquad (3\text{-}5)$$

where E, A, D, and C are defined as follows:

E = system effectiveness

A = availability vector, a three-element row vector,

$$A = [a_1, a_2, a_3]$$

where a_i is the probability that the vehicle will be in State i at the time of call.

D = dependability matrix, a 3 X 3 square matrix (since there are 3 given operable states),

$$D = \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix}$$

where d_{ij} is the probability that, if the vehicle is in State i at the time of call, it will complete the mission in State j.

C = capability vector, a three-element column vector,

$$C = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix}$$

where c_i is the probability that, if the vehicle is in State i at the time of arrival at the combat area, the supplies can be successfully delivered. (For multicapability items, C would be a multicolumn matrix.)

3. Determination of Model Elements:

a. Past records indicate that the average time between maintenance activities (including preventive and failure-initiated maintenance) for this type vehicle is 250 hr and the average duration (including such variables as maintenance difficulty, parts availability, manpower, etc.) of a maintenance activity is 4 hr. Comparable data for the weapon subsystem show an average time between maintenance activities of 500 hr and an average duration of a maintenance activity of 5 hr.

b. From the preceding data the elements of A can be determined:

$a_1 = P$ (vehicle operable) X P (weapon subsystem operable)

$$= \left(\frac{250}{250+4}\right)\left(\frac{500}{500+5}\right) = 0.9745$$

$a_2 = P$ (vehicle operable) X P (weapon system not operable)

$$= \left(\frac{250}{250+4}\right)\left(\frac{5}{500+5}\right) = 0.0098$$

$a_3 = P$ (vehicle nonoperable)

$$= \frac{4}{250+4} = 0.157$$

where P (condition X) = probability that condition X exists.

c. Data available from past records indicate that the times between failures of the weapon system during a mission are exponentially distributed with a mean of 500 hr. Also the probability that a vehicle will not survive the 2-hr drive to its destination is 0.02 (includes probability of being destroyed by enemy action, mechanical failures, etc.). Then the elements of the D matrix may be calculated as follows:

(1) If the system begins in State 1:

$d_{11} = P$ (vehicle will survive trip) X P (weapon system will remain operable)

$$= (1-0.02)\exp\left(-\frac{2}{500}\right)$$

$$= 0.9761$$

$d_{12} = P$ (vehicle will survive trip) X P (weapon system will fail during trip)

$$= (1-0.02)\left[1-\exp\left(-\frac{2}{500}\right)\right]$$

$$= 0.0039$$

$d_{13} = P$ (vehicle will not survive the trip) = 0.0200

(2) If the system begins in State 2:

$d_{21} = 0$ because the weapon system cannot be repaired during the mission

$d_{22} = P$ (vehicle will survive the trip) = 0.9800

$d_{23} = P$ (vehicle will not survive the trip) = 0.0200

(3) If the system begins in State 3:

$d_{31} = d_{32} = 0$ because the mission will not start

$d_{33} = 1$, i.e., if the vehicle is nonoperable, it will remain nonoperable with reference to a particular mission.

d. Experience and technical judgment have determined the probability of successful delivery of supplies to be c_i if the system is in State i at the time of arrival in the combat area, where

$c_1 = 0.98$

$c_2 = 0.80$

$c_3 = 0.00$

4. Determination of Effectiveness.

The effectiveness of the subject system

$$E = ADC \tag{3-5}$$

$$= \begin{bmatrix} a_1 & a_2 & a_3 \end{bmatrix} \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix}$$

$$= c_1 \sum_{i=1}^{3} a_i d_{i1} + c_2 \sum_{i=1}^{3} a_i d_{i2} + c_3 \sum_{i=1}^{3} a_i d_{i3}$$

which becomes:

$$E = [0.9745 \quad 0.0098 \quad 0.0157] \begin{bmatrix} 0.9761 & 0.0039 & 0.0200 \\ 0 & 0.9800 & 0.0200 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.98 \\ 0.80 \\ 0 \end{bmatrix}$$

$$= (0.98)\ (0.9745)\ (0.9761) + (0.80) \left[(0.9745)\ (0.0039) + (0.0098)\ (0.9800)\right] + 0 = 0.943$$

which means that the system has a probability of 0.943 of successful delivery of supplies upon random request.

The effectiveness value attained provides a basis for deciding whether improvement is needed. The model provides the basis for evaluating the effectiveness of alternative systems considered.

3-9.4 MATHEMATICAL MODELS

A mathematical model is an equation, or a set of equations, that describes some characteristic of a system, subsystem, or component in sufficient detail to facilitate the analysis, evaluation, or optimization of the entity being modeled. The examples presented in pars. 3-9.2 and 3-9.3 illustrate the construction of models useful in analysis and evaluation of alternate available choices in order to assist the designer in the selection of the optimum subsystem or component. Once a subsystem or component is selected, mathematical modeling also may be used to optimize its design.

In order to be useful, a mathematical model must represent reasonably accurately that which is being modeled. On the other hand, rigorous mathematics can in many cases make the model so complex that the labor time and/or computer cost required for solution becomes unacceptable. A simple illustration is the commonplace mathematical model of the process of electrical current through a resistor, namely Ohm's Law,

$$E = IR \tag{3-6}$$

In using this model, we are consciously or unconsciously ignoring the effects of distributed inductances and capacitances inherent in the fabrication of the resistor. We, generally, are ignoring also the nonlinearities introduced by the resistor material thermal coefficients of resistivity and expansion. In many cases, the effects noted are insignificant and to include them in the model would complicate its use completely out of proportion to the increase in accuracy attained. However, the use of Ohm's Law in the form of Eq. 3-6 to calculate voltage drop in a power transmission line or signal attenuation in a radio frequency coaxial cable would constitute a simplification of the mathematics causing such gross inaccuracies as to make the model not acceptable as a representation of reality. In view of this practical necessity for compromising the conflicting requirements of accuracy (a meaningful model) and simplicity (a manageable model), a high degree of engineering judgment based on both technical skill and practical experience is required for successful mathematical modeling.

In general, more than one mathematical model will be required in the analysis, evaluation, and optimization of systems and subsystems. In addition to the value model and the system effectiveness model illustrated in pars. 3-9.2 and 3-9.3, mathematical models may be required to describe reliability [7,8], cost effectiveness[9], or technical function (as in circuit analysis and servo system transfer functions).

Once the mathematical models have been established, system or subsystem optimization is accomplished by solution and direct comparison as in the examples shown, or by any one of numerous analytical techniques. The most common of these are shown in Table 3-1. The choice of techniques used will depend in general on the form and nature of the model and the system it represents. Detailed descriptions of these techniques and their applications are abundant in the literature and are beyond the scope of this handbook. In particular, Refs. 10 through 13 are recommended for detailed treatment of these techniques.

It is frequently advantageous, and in many cases necessary, to use a computer to study or solve mathematical models. The computer used may be either of the analog type or the digital type, with the choice between the two types dependent on the exact nature of the problem. In general, an analog computer offers some advantage when studying actual physical devices, and the computer is used to represent an analog of a physical system whose components are to be realized in actual hardware. The study of the dynamic response of a servo system is a typical case in which an analog computer may be used. On the other hand, if the mathematics represent the description of physical relationships–e.g., vector resolution–that are automatically satisfied in nature, a digital computer may offer decided advantages. This will be particularly true if high-accuracy calculations must be carried out for a wide range of problem variables, especially if real-time simulation is unnecessary.

Regardless of which type of computer is employed, a number of factors must be considered in the process of preparing to study a mathematical model on a computer. Some of the more important of these factors are:

1. Information to be computed
2. Degree of sophistication necessary
3. Accuracy required
4. Solution time
5. Choice of parameter ranges.

Each of these five factors is discussed briefly in the paragraphs that follow.

3-9.4.1 INFORMATION TO BE COMPUTED

The first step a designer should take before plunging into the work of simulating a mathematical model on a computer is to define clearly the type of information being sought. A clear definition of what is to be computed will determine to a large extent the complexity of the computer study and the number of different computer setups that may be required. In addition, it may dictate particular

TABLE 3-1. PARTIAL LIST OF TECHNIQUES FOR OPTIMIZATION

I.	**Mathematical Techniques**
	Birth and death processes Calculus of finite differences Calculus of variations Gradient theory Numerical approximation methods Symbolic logic Theory of linear integrals Theory of maximum and minimum
II.	**Statistical Techniques**
	Bayesian analysis Decision theory Experimental design Information theory Method of steepest ascent Stochastic processes
III.	**Programming Techniques**
	Dynamic programming Linear programming Nonlinear programming
IV.	**Other Operations Research Techniques**
	Gaming theory Monte Carlo techniques Queuing theory Renewal theory Search theory Sensitivity testing Signal flow graphs Simulation Value theory

quantities that should be recorded or computed in order that the problem of analyzing the computer results and arriving at engineering design decisions based upon these results may be minimized.

3-9.4.2 DEGREE OF SOPHISTICATION NECESSARY

Obviously, there is no point in studying a mathematical model that is more complex than is required to yield the information being sought. The computer programming becomes more difficult as the problem complexity increases and, at the same time, in many cases the computer accuracy tends to deteriorate. Furthermore, with a digital computer, the solution time increases with problem complexity. Consequently, much is to be gained by employing the simplest model that still retains the essential characteristics of that particular aspect of the system under study. Generally speaking, it is preferable to gather one type of data using one model and another type using a different model, than to utilize a single model with the complexity necessary to yield both types of information. In making simplifications of this type one must, of course, determine that each model is adequate for the particular purpose for which it is used.

3-9.4.3 ACCURACY REQUIRED

The computer setup with which the mathematical model of a system is to be studied must provide an accuracy sufficient to permit engineering decisions to be made from the solutions obtained. Several different considerations are involved. The most exacting of these is concerned with the absolute accuracy of the results. In some situations, however, the absolute accuracy may be less than desired and yet the resulting solutions are entirely adequate for predicting the influence of particular system parameters on the overall performance. As a minimum, however, the computer must produce solutions that are reproducible to a precision greater than the variations that are to be attributed to parameter changes. For example, if the computer is capable of calculating a voltage regulator setting solution to within an error of ± 0.2 V it is ridiculous to use the same computer to evaluate the effect of temperature changes that cause only 0.05 V changes in the result.

A great deal of effort can be expended (particularly on an analog computer) in attempting to achieve accuracies higher than those of which the equipment is basically capable, and often higher than those needed for the engineering-design purposes at hand. Also, a great deal of time can be wasted in trying to appraise small computing errors when, in fact, some major error has been introduced in problem formulation or computer programming, or when the design data desired can be derived just as well from somewhat inaccurate solutions as they could from mathematically precise results. The important point to bear in mind is that one should not blindly accept the results obtained from a computer as being correct, nor should one become preoccupied in attempting to achieve a solution accuracy much higher than that required for the study being conducted.

3-9.4.4 SOLUTION TIME

The time required to obtain a solution on a computer may be greater than, equal to, or less than the time required for the event to take place in the actual physical system. If the entire physical system is simulated on the computer, then the choice of solution time, or time scale, is arbitrary. If the computer is capable of operating with a compressed time scale—i.e., if the computer produces a solution in less time than the event takes in the actual physical system (real time)—considerable overall time may be saved if the number of solutions to be examined is large. This situation occurs frequently when analog computers are used. Some analog computers are, in fact, designed to obtain solutions at the rate of 15 to 30 per sec. Such machines are particularly well adapted for making statistical studies. On the other hand, the solution of a high-order dynamic system on a digital computer may require much longer than real time. This situation may be inconvenient but is still acceptable for many studies.

The only case in which no choice in time scale exists is when it is desired to include some of the physical components from the actual system in the simulation. In this case, meaningful results can be obtained only if the solutions are run in real time. The programming of a digital computer to run in real time may be impossible, depending on the complexity of the problem and on the characteristics of the machine. In any event, such programming for a digital computer represents a more difficult task than exists if no fixed solution time is specified.

3-9.4.5 CHOICE OF PARAMETER RANGES

The fact that a computer is capable of producing a large number of solutions to a problem in a relatively short time tends to be a trap. There is little point in generating a much larger number of solutions than can be analyzed because this merely ties up computer time and increases the problems of adequately identifying solutions so that particular ones can be found readily. Nonetheless, the system designer is usually inclined to ask for more solutions than he really needs because he wishes to be sure he has covered all cases that might be of interest. A ready availability of the computer to the designer is helpful in reducing this tendency. The important point is for the designer to be realistic in regard to the number of solutions he requests. Although it may be easy for him to specify that he wishes to have solutions for 20 combinations of 20 different parameters, the running of the resulting 400 solutions and his evaluation of them (if he is to be at all critical) may require an exorbitant amount of effort. Frequently much of this effort can be saved if the designer spends just a little more time deciding what he really wants. It is more effective to survey a problem rather roughly in a first set of runs and then examine regions of real interest in a second, more detailed series than to try to do the whole job in one operation. The first method has the added advantage of permitting the designer to change the course of the study before too much effort is expended, in case a whole new approach is indicated by the first survey.

SECTION III LOAD AND POWER SUPPLY CHARACTERISTICS

3-10 INTRODUCTION

The unique characteristics of military vehicle electrical loads and power supply systems must be understood if design personnel intend to achieve system component and interface compatibility as a result of their system analysis efforts. These characteristics are introduced in this section. Details of specific component application and operation are presented in appropriate chapters in Part Two of this handbook.

3-11 VEHICLE POWER CHARACTERISTICS

The accepted voltage standard for the basic electrical systems in military vehicles is 24 VDC. Army Special Regulation SR 705-325-1 states that military vehicles must employ nominal 24 V direct current systems unless permission to deviate is granted by the General Staff of the United States Army. Standard electrical components have been developed to provide this system voltage, and these components are used repeatedly on military vehicles.

The 24-VDC value is established by the characteristics of 12 lead-acid battery cells in series. This 24-VDC value is the nominal system voltage when equipment is operated on battery power alone. However, when tested with a voltmeter, 12 unloaded, fully charged, lead-acid cells in series will actually measure about 25.2 V and a typical generator-system voltage setting employed to keep the batteries adequately charged is 28 VDC. Furthermore, this charging voltage may be adjusted. The regulator is set higher (up to 29 V) for cold climates, and lower (down to 27 V) for warm climates to provide optimum battery life. Standard generating systems on vehicles in the present inventory are available in 25, 60, 100, 180, 300 and 650 A capacities with voltage regulators adjustable from 26 to 30 VDC.

The regulated steady-state DC voltage in a typical vehicle electrical system oscillates above and below a nominal value. This oscillation is referred to as ripple.

Voltage transients are temporary system voltage deviations, above or below the steady state generator system ripple, which have been introduced by changes in the electrical load characteristics. Voltage transients may cause momentary malfunction or permanent destruction of solid state component elements of the circuit which makes up the load.

The voltage transient may take the form of either a surge or a spike. The voltage surge results during the finite period of time required for the generator regulator to adjust to a change in load conditions. During this transitory period, system operating voltage is out of regulation and control for a millisecond or more. Therefore damage to circuitry may occur since solid state elements are prone to failure when electric stresses exceed design limits for time durations in the microsecond region.

A voltage spike, as differentiated from a surge, is a high frequency oscillatory variation from the controlled steady-state level or surge level. It results from high frequency currents of complex wave form produced when loads (usually inductive) are switched. A spike generally lasts less than 50 μsec but may take up to 1 msec to taper off to the surge level or steady state level.

Fortunately, a half charged lead-acid battery, if its connections are reliable, is effective as a surge voltage suppressor for generator systems in ambient temperatures down to -65°F. This characteristic improves as both the electrolyte temperature and battery state of charge increase[14]

Therefore, all military vehicle electrical systems should make use of this desirable characteristic and employ the lead-acid battery as a power source voltage surge limiter by using vehicle circuitry that precludes accidentally disconnecting the battery from the power source terminals. However, this measure should be recognized as an imperfect solution to the problem because the reliability of a given battery connection cannot be guaranteed. Loads up to 50 A that must be reliably protected under all circumstances should employ a separate overvoltage suppressor[15].

MIL-STD-1275 prescribes allowable limits for transient and steady state voltages in electric power supply circuits of military vehicles. The purpose of the standard is to provide for compatibility between vehicular electric power supply and utilization equipment by confining electric power characteristics within definitive limits and restricting the requirements imposed on the electric power by the utilization equipment.

It is also worthy of note that battery voltages may drop to very low values during the momentary breakaway current surge typical of engine starter motors as they begin to rotate, and system voltage levels will drop below 24 V if loads in excess of the generator capacity are imposed.

Electrical disturbances that produce equipment malfunctions or undesirable responses as a result of the emanation of energy from varying electric or magnetic fields are defined as electromagnetic interference (EMI). Military vehicles must be relatively free of such interference.

In the past, the Navy, Air Force, and Army have used a number of general-purpose EMI specifications and standards for equipment and subsystems used with shipboard, submarine, aerospace, and ground systems. In general, these specifications were similar but many of the individual requirements and test methods were stated differently and had minor variations. Contractors had the problem of analyzing each of these differences to determine whether requirements were, in fact, the same or different. Since thousands of manufacturers did this every time a specification was changed, it became very costly and time consuming. MIL-STD-461 was subsequently developed in order to provide military interference control requirements in a coordinated document.

This standard covers the requirements and test limits for measurement and determination of the electromagnetic interference characteristics (emissions and susceptibility) of electronic, electrical, and electromechanical equipment. The requirements are applied to general or multiservice procurements and single service procurements, as specified in the individual equipment specification, or the contract or order. The requirements specified in the standard are established to:

1. Insure that interference control is considered and incorporated into the design of equipment.

2. Enable compatible operation of the equipment in a complex electromagnetic environment.

Army vehicles are normally designed with a single wire electrical system so that the battery is negatively grounded and the frame or hull of the vehicle serves as the negative conductor. Most of the standard vehicle generators, lamps, meters, motors, etc., are designed so that their outer case is the negative power terminal and mounting the unit to the vehicle completes the negative connection through the vehicle hull to the negative battery terminal.

Variations in this approach may be necessary where use of the hull may cause ground loops in sensitive circuits and a central ground point may have to be established for those circuits.

3-12 COMPONENT CHARACTERISTICS

Electrical components may be grouped into four distinct categories. These are:

1. Power consumers—such as lights, gages, and motors

The requirements of the vehicle establish the identity of these items.

2. Power controllers–such as switches, relays, and circuit breakers

3. Power sources–such as generator systems, batteries, and power conversion units

Batteries also are power consumers while they are being recharged.

4. Power distributors–to distribute power and signals among the other electrical components.

In general, commercial automotive components–such as lamps, motors, generators, instruments–are not directly applicable to military vehicles. They are usually 12-V devices, are not waterproof, shockproof, or otherwise protected against the severe military environment, and are not sufficiently shielded or suppressed to meet military electromagnetic interference specifications.

A brief explanation of the different power considerations for components in each category is given in the paragraphs that follow.

3-12.1 POWER CONSUMERS

Power consumers constitute the electrical system load and establish the need for the electrical system.

Although batteries are consumers during charging and generator systems use some of their own output power to supply current to the generator field, the system power requirements are primarily established by the motors, resistors, and inductors which make up the load.

The different power consumers have special characteristics, some of which have appreciable influence on the design of the rest of the electrical system.

3-12.1.1 INCANDESCENT LAMPS

Incandescent lamps require several times their normal operating current when they are initially switched on. This is because the lamp filament, an element with a resistivity that varies inversely with temperature, has a low resistance value when cold.

Due to the high operating temperature of tungsten filaments developed for illumination purposes (4300°F for a reasonably efficient lamp), the filament resistance calculated using the lamp operating voltage and wattage ratings is higher than the resistance of a cold filament by 15:1. Indicator lamps, tail lamps, etc., will ordinarily have much lower filament operating temperatures, but the hot-to-cold resistance ratio will still be 5:1 or greater.

Therefore, any switch or contact employed to turn on a lamp will experience a surge current that is much higher than the normal lamp operating current. Certain switch designs are sensitive to these surge currents, especially if the contacts bounce while mating; therefore, their normal current carrying capacity is derated for lamp loads. This characteristic is an important design consideration if lamps are powered with solid-state circuitry or if the switch capacity is marginal.

Another important incandescent lamp characteristic is that operating life is very sensitive to voltage. A 5 percent overvoltage will nearly halve the life of an efficient incandescent lamp and a 5 percent undervoltage will double the life (although light output also will drop considerably).

3-12.1.2 INDUCTORS

Inductors, such as solenoids and relay coils, tend to create high voltage transients when their magnetic fields collapse as the controlling switch contacts are opened. Flux lines in the collapsing field induce a high voltage across the inductor which can be damaging to switches and solid state equipment.

A typical method of reducing the voltage surge and the subsequent arcing across the switch contacts involves the insertion of a resistive-capacitive network (Fig. 3-9). When the contact points open, the energy stored in

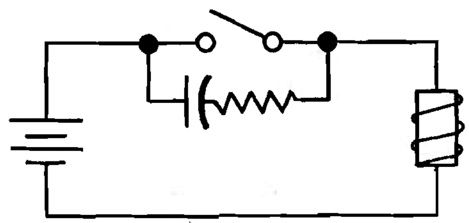


Figure 3-9. Resistive-capacitive Network in an Inductive Circuit

the coil dissipates through the network, preventing the sudden collapse of the magnetic field and reducing the induced voltage. In addition, the resistance helps dampen any oscillations that may occur. A capacitor should never be connected across the contacts without including a series resistance since the discharge of the capacitor upon contact closure can cause a heavy surge of current.

The use of a diode in parallel with an inductance is another popular arc suppression technique, however, diode suppressors are susceptible to reverse polarity damage unless properly protected (see par. 9-5).

Other available suppression techniques use resistors or varistors. All suppression methods will affect circuit characteristics, such as relay dropout time, and therefore their application must be carefully analyzed.

When transient suppressors are not employed, the energy from an inductor normally is dissipated through contact arcing. Each switching action and associated arcing will cause some contact deterioration, impose a high voltage transient on the powerline, and produce electromagnetic interference. The significance of these factors must be considered when applying inductive elements to a vehicle electrical system.

3-12.1.3 MOTORS

Direct current motors demand high starting currents and cause electromagnetic interference due to the switching action of the brushes on the commutator. Inrush currents are generally five or six times the normal operating current.

Stalling a DC motor armature produces a high current equal to the inrush current. This high current will, if allowed to persist, overheat and damage the motor. Circuit breakers are employed to preclude this possibility.

The most effective electromagnetic interference suppression techniques for DC motors employ feed-through capacitors built into the motor frame.

The inductive elements in electric motors also will produce voltage transients when the motor circuit is opened.

3-12.1.4 IGNITION SYSTEMS

Engine spark ignition systems distribute a high voltage to successive spark plugs. The switching action in the distributor and electromagnetic energy radiated when the spark bridges the plug gap produce severe radio interference. Military vehicle engine ignition systems are shielded completely to suppress the undesirable interference.

3-12.1.5 COMMUNICATION SYSTEMS

Communication systems are extremely sensitive to electromagnetic interference. Such interference overlays the intelligence signal and obliterates the information being transmitted. Interference can be introduced into sensitive systems by means of radiation or conduction.

Conducted interference enters the radio sets on the vehicle wiring supplying the radio set with power. As a consequence, the specifications for military vehicles using communication equipment establish an allowable limit for the amount of conducted electromagnetic interference. Measurement of this interference is accomplished by attaching instrumentation to the vehicle wiring to perform what is commonly called the "conducted interference tests".

Radiated interference is observed when the communication equipment receives the noise in its antenna system or other elements sensitive to radiated electromagnetic waves. Detection of this interference is accomplished by measuring the amount of interference received by antennas at specified locations. These measurements constitute the "radiated interference tests".

Armored vehicles are less likely to have radiated interference problems if they successfully pass conducted interference tests because vehicle armor provides a measure of electromagnetic shielding.

Military radios also use solid-state components extensively. As such, they are vulnerable to damage by transients. Although these radios have some protection against transients and reverse polarity built into their circuitry, experience has taught that this frequently is not adequate for all installations. This is especially true if the set was originally designed as a portable unit and later adapted to vehicles.

3-12.2 POWER CONTROLLERS

The most common electric power controllers are on-off devices such as switches, relays, and circuit breakers that apply either full voltage or no voltage to consumers. Other controllers limit current flow by applying only a fraction of the supply voltage to the consumers.

3-12.2.1 SWITCHES (MECHANICAL AND SOLID-STATE)

A switch is the most common load controller. An ideal switch uses no power since current flow is zero when the switch is open and resistance is zero when it is closed. Actually, the switch does have a very small resistance when closed, and this is one of several important considerations.

Switch ratings are established by life testing and as a rule define the number of times a switch can successfully transfer a specific type of load. The maximum capacity for a given switch will vary depending on the duty. Generally, a switch will be rated to handle a specified amperage at a specified voltage, and the maximum allowable amperage will depend on whether the load is resistive, motor, inductive, or lamp load. Often, ratings for all four types of loads are given. These ratings differ because switch operating life is reduced by motor, lamp, and inductive load stresses on the switch contacts.

Most switches are designed to operate for a number of cycles far greater than the requirements found in military vehicle electrical applications.

The arcing associated with most switching tends to clean the contacts of contaminants. However, if low currents and voltages are switched, this cleaning action may not be adequate. Therefore, a switch that has been designed to switch 10 A at 28 V may not work dependably at 50 mA and 0.5 V. Special contact materials or self-cleaning contacts are used in switches designed especially for these so called "dry circuits".

3-12.2.2 RELAYS AND CONTACTORS

Relays and contactors are remotely controlled electric switches. Contactors are essentially relays of high current-carrying capacity. The circuit of a simple relay or contactor is shown in Fig. 3-10. When the switch is closed, current flows through the coil of the electromagnet and the resulting magnetic field attracts the soft iron armature, overcoming the pull of the spring so that the armature is drawn up against the contact and allows current to flow through the load. When the switch is opened, the electromagnet is deenergized, which allows the spring to open the contact and arrest current flow.

Most relays are much more complex than indicated by this elementary sketch. They often have normally open contacts, which

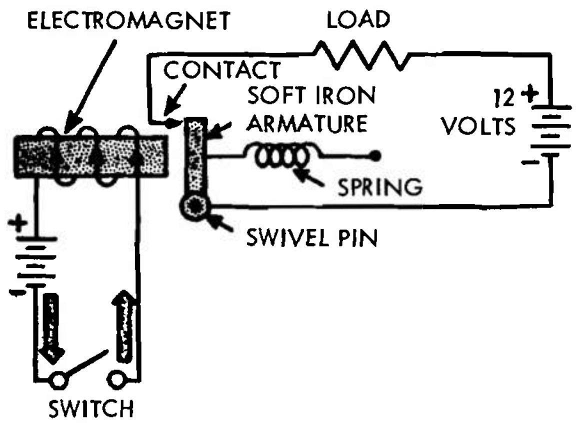


Figure 3-10. Simple Relay

close when the coil is energized and open again when the coil is de-energized, combined with normally closed contacts that operate in a reverse manner.

Many relays have been developed for special purposes. One type closes; mechanically latches in the closed position when one coil is energized; and requires a pulse of current through another coil to unlatch the contacts. Still other relays step to a succession of different contacts as the coil is pulsed with current. Some relays operate thermally and depend on the electrically induced dimensional change of different metals with temperature.

It is important to determine that a relay will be suitable for vehicle applications because many relays were designed originally for use in stationary structures. Their armatures and other parts are sensitive to damage and premature actuation due to shock and vibration when used in vehicle applications.

The current requirements of the coil of a relay are usually low and, therefore, produce insignificant power demands on the system. The coil is also an inductor and, unless suppressed, produces electromagnetic interference and transients as it is de-energized. Like switches, relays must be selected with contacts that adequately will carry the load, make and interrupt the load power, and survive for the required operating life. Dry circuit failures are more common with relays than switches because contact pressure is often much less and they are often used to control low power circuits.

3-12.2.3 FUSES AND CIRCUIT BREAKERS*

Fuses and circuit breakers are circuit-protecting devices. Their primary purpose is to disconnect individual circuits, components, or equipment from a power source when a potentially damaging fault occurs in the unit. This fault may be either a moderate overload or a short circuit which, because of the heating effect of an electric current, can create a fire hazard in the wiring system or damage equipment.

The operation of fuses and circuit breakers is based upon a time element principle; i.e., on a short circuit they operate practically instantaneously, but on overloads their operation has a definite time lag that varies inversely with the overload. The general shape of this characteristic is shown in Fig. 3-11.

All fuses are designed to carry rated load indefinitely and stated overloads for varying periods of time. They also have a maximum voltage rating. This is the maximum voltage at which a fuse can permanently interrupt the current in a circuit within a predetermined time.

The fuses commonly used in electronic equipment and circuits are known as normal lag, quick acting, and time delay. These descriptive names indicate the speed at which the fuses interrupt the current in a circuit.

A circuit breaker, like a fuse, can be used to protect either circuits or equipment. In addition, a circuit breaker can also be used as a switch. As a protective device, a circuit breaker should be able to carry rated current indefinitely and to trip with a definite time-delay characteristic when an overload occurs.

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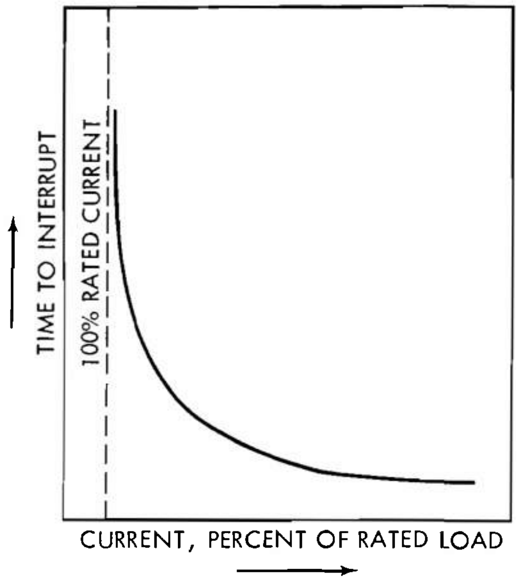

Figure 3-11. Basic Current-time Interruption Characteristics

As a switching device, it should be able to make and break rated current without excessive arcing at the contacts.

There are two basic types of circuit breakers – the magnetic type, which depends upon the electromagnetic effect of a current in a coil; and the thermal type, which depends upon the heating effect of current in a bi-metallic element.

3-12.2.4 SOLID-STATE SWITCHING

The use of semiconductors to perform switching functions in military vehicle electrical systems is increasing. Solid-state generator-regulators represent the most widely used military vehicle application of this technique. A semiconductor (transistor or silicon-controlled rectifier) is used to control the current in the generator field circuit in place of relay contacts or variable carbon pile resistance as used in the past.

Solid-state switching also is being used more frequently in the design of power supply units which convert 24 VDC vehicle power to different voltage levels (i.e., high voltage for the infrared vision devices) and to AC power of various frequencies.

Solid-state relays in which semiconductor devices perform the function of standard mechanical relay contacts are also gaining in usage because of their superior characteristics of no wear, fast response, no arcing, and insensitivity to shock and vibration.

The use of solid-state switching does burden the designer with the requirement for protecting semiconductors from transients, as mentioned previously, and the problem that the very fast switching of semiconductors may generate electromagnetic interference even though no arcing is produced. Thus, proper grounding and shielding methods must be incorporated to ensure that system interference reduction requirements are met.

3-12.2.5 SERVO CONTROLS

A servo control system is a combination of elements for the control of power. If the output of the system, or some function of the output, is fed back for comparison with the input, and the difference between these quantities is used in controlling the power, it is a closed loop servo system. The output could be the position of a gun barrel, a system generator voltage, or the attitude of a vehicle. The input is generally a low level position-indication or rate-of-change signal which must be amplified by the system to provide output power until the driven element reaches the desired position. Stability and response of the control system are the major design considerations. Interface compatibility with the vehicle electrical system is also important. Chapter 16 describes closed and open loop servo systems.

3-12.3 POWER SOURCES

Military vehicle electrical systems are regularly powered from any of the following four basic sources:

1. Power-storage elements that are normally lead-acid batteries.

2. Power-generating systems that are driven by the vehicle engine to provide direct current for normal vehicle operating loads.

3. Auxiliary power supplies that are direct current generator sets driven by gasoline or multifuel engines and are capable of providing 28 VDC power to a vehicle electrical system through the slave start receptacle.

4. Power converters that are used to change the voltage or frequency (see par. 7-9).

3-12.3.1 POWER-STORAGE ELEMENTS

The vehicle starter system requirements generally determine the power storage capacity required. These systems are generally sized to provide a vehicle start at temperatures down to −25°F without the use of starting aids. A battery system capable of meeting this requirement normally has enough reserve for minor additional requirements.

As previously stated, Army vehicles must use 24-V systems; therefore, the design requirement generally involves connecting two 12-V batteries in series, or several in series-parallel, to fulfull system requirements. Starter motors and battery-to-starter wiring are part of the starting system and must be optimized with the batteries to achieve optimum starting. Other important factors are the lowest temperature at which a start is required, viscosity of the engine lubricant, and required starter horsepower at this low temperature.

The horsepower a battery system provides is determined by its voltage-current product. If the batteries are not capable of providing adequate horsepower to drive the starter motor at the minimum required engine starting temperature, the system is underpowered.

The common vehicle storage batteries in use on vehicles in the present inventory are a 45 A-hr, 12-V unit and a 100 A-hr, 12-V unit. Two 2HN batteries in series will produce a 24-V, 45 A-hr power supply. Another two in parallel with these produce a 24-V, 90 A-hr power supply. Similarly the 6TN battery can be used in multiples to produce 24-V power supplies with A-hr capacities of 100, 200, 300, 400, etc.

Fig. 3-12 shows that, at −22°F, the maximum horsepower two 6TN batteries can provide after 2 min occurs when current demand is 340 A. The voltage at this demand for two 6TN batteries in series is 14.3 V.

Further examination reveals that if current demand ranges from 290 to 400 A these batteries will still provide close to that maximum horsepower. If the power required to crank the engine is known, battery horse power curve studies will facilitate the optimum battery configuration selection. Engine manufacturers are the best source for engine cranking information. Batteries also must provide standby power for coolant heater operation, communication systems, interior lighting, and weapon system silent watch requirements. The designer must, therefore, provide the vehicle with enough battery capacity to perform these services for a satisfactory length of time and still provide a vehicle start.

MS35000 defines the physical characteristics of the type 2HN and 6TN lead-acid vehicle batteries. These batteries have been designed for low temperature high starting current application. They are not intended to withstand repeated deep discharges. For this reason, it is important to design the electrical system to avoid features which inadvertently drain the batteries. This is particularly important in arctic operation because lead-acid batteries will not accept high charging currents when the electrolyte is cold and, therefore, are difficult to recharge.

The trend toward increased use of silicon diode rectified alternator systems and solid-state voltage regulators has somewhat relieved the batteries from operational stresses related to sulfation and overcharging. Charge-at-idle characteristics of alternator systems have reduced the frequency of deep discharge from the battery, while solid-state regulators have permitted more accurate voltage settings and thereby reduced the frequency or likelihood

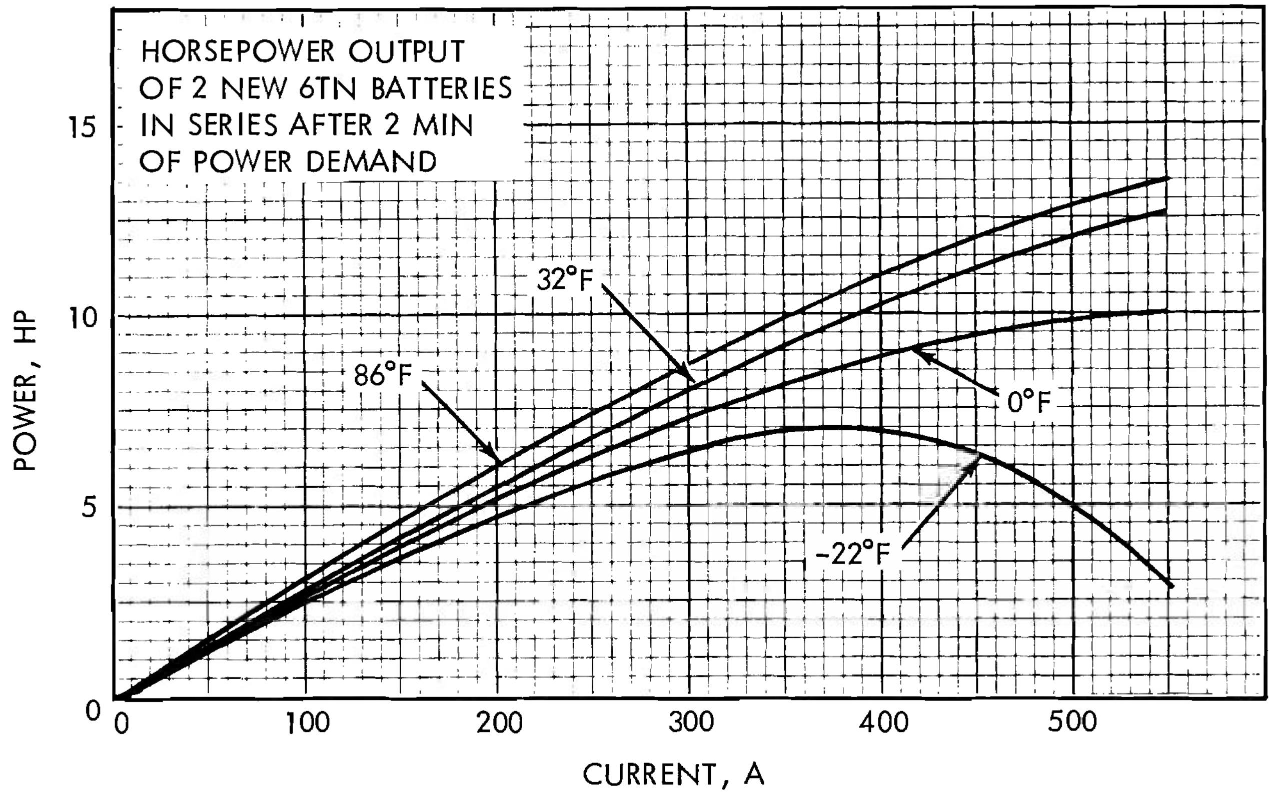

Figure 3-12. Horsepower Output of Two New 6TN Batteries in Series

of overcharging (Fig. 3-13). Charged batteries absorb a small current that maintains them at their charged level. Charging currents are sensitive to voltage setting and electrolyte temperature. Efforts in process to develop a charging-voltage regulator controlled by battery electrolyte temperature promise further overcharge protection to the battery. For two fully charged 100 A-hr batteries in series, the charging current will normally be less than 2 A at a a constant 28-V potential.

With normal use and maintenance the type 6TN battery is designed for a life of 4 yr. The average life of a battery in a military vehicle is 2 yr in the Continental USA, 1.5 yr in Europe, 1 yr in the Arctic, and 8 mo in the Far East. The most prevalent modes of field

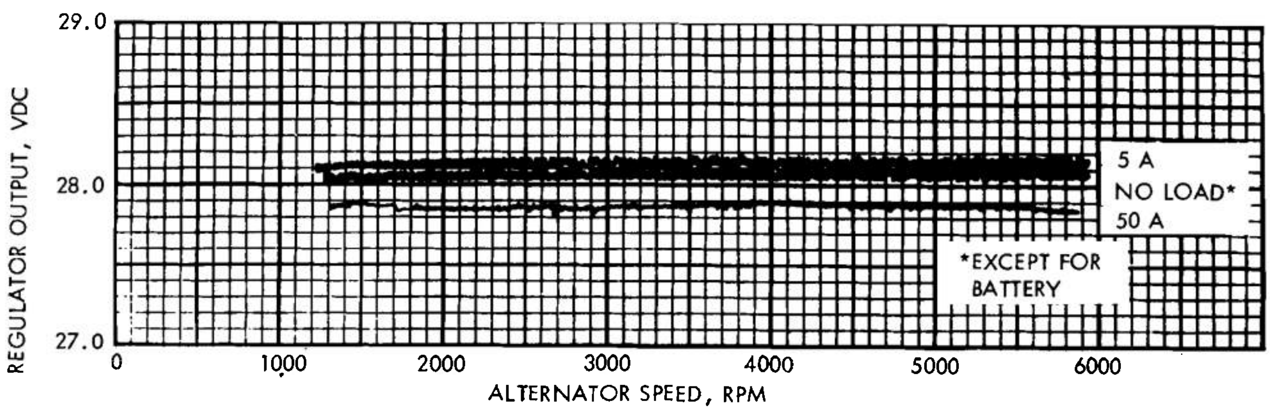

Figure 3-13. Generator System Voltage Characteristics With Solid-state Regulator

failure are sulfation from lack of proper charging or standing idle, deep cycling and positive plate grid corrosion from overcharging. A more detailed discussion of battery application and care is presented in Chapter 7.

Development of a 24-V military battery is in process. The 24-V battery will eliminate two battery connections, permit selection of batteries in units instead of sets of two as now required (two batteries at 12 V), and prevent the field use of an old and a new battery together, which results in excess stress on the new battery.

3-12.3.2 GENERATOR SYSTEMS

The required capacity for vehicle generator systems is determined by considering the consumer loads.

The battery system becomes a power consumer once the engine is started, and the generator system must provide power for all the other consumers and charge the batteries at a rate that is adequate to replace the energy that was used during engine cranking or while the vehicle engine was inoperative.

Generator capacity must be sufficient to provide the highest expected continuous load that the vehicle mission will demand. This analysis must consider both operation at normal engine speeds and operation at idle. There are two basic types of vehicle generators used in the present inventory. The 25-A and 300-A systems employ a DC generator and voltage regulator while the 60-, 100-, 180-, and 650-A systems use a diode-rectified alternator and voltage regulator. The 60-A alternator is a self-contained unit. The 650-A alternator is of brushless design.

The diode-rectified alternator offers many advantages over the DC generator, which accounts for its continued development. A diode-rectified alternator will provide greater output power per pound. It is definitely more reliable and has a longer life due to inherent characteristics of the design. The field windings rather than the output windings make up the rotor. Consequently, the brushes conduct low field currents rather than high output currents and they ride on smooth slip rings instead of a segmented commutator. Since the output windings are in the stationary member, they are not subjected to high centrifugal forces and they contain fewer electrical connections. The smooth slip rings reduce brush bounce and allow the machines to be operated at higher speeds. These characteristics permit greater output at idle speed. However, silicon diode rectifiers are shorted out and destroyed if the battery is connected to a diode-rectified alternator system with reverse polarity. Circuit breakers will not interrupt power quickly enough to protect the rectifiers and, therefore, other reverse polarity protection methods must be employed.

3-12.3.3 AUXILIARY POWER SYSTEMS

An auxiliary power system may be implemented by using an engine generator set that is either located on the vehicle or remotely from the vehicle. Most military vehicles have standard slave power receptacles that allow the vehicle to furnish power to and receive power from other vehicles or from auxiliary power systems. Standard slave cables are used to mate with these receptacles. These cables are carried on the vehicle or retained as part of organizational maintenance equipment.

Auxiliary power units are generally used to provide power for vehicle systems while the vehicle engine is inoperative. The need to run the large vehicle engine for power generation thereby is avoided. Auxiliary power units also may provide 100-VAC power for radios, tools, etc., through receptacles isolated from the vehicle electrical system.

The U.S. Army Materiel Command (AMC) is attempting to standardize and reduce the number of different power units in the supply system. Therefore, selection of an auxiliary power unit for future applications should be coordinated with the appropriate AMC command.

Some vehicles require auxiliary generator systems driven by the main vehicle engine for special purposes. The power output and input requirements for these systems vary widely and often are required to interface with systems, such as missiles, that are not vehicular in nature. Therefore, they are designed subject to the requirements of the interfacing systems.

3-12.4 POWER DISTRIBUTORS

Conductors consist of the various types of interconnecting wires and cables and the necessary terminals and connectors required to interconnect the electrical components of the system. Each type of conductor is discussed in detail in Chapter 8 along with the considerations to be made in their selection.

SECTION IV

TYPICAL LOAD REQUIREMENTS

3-13 INTRODUCTION

Vehicle electrical load requirements are determined in order to establish firm parameters for vehicle battery and generator selection. The size of these loads under various vehicle operating conditions must be investigated and provided for if the analysis is to be comprehensive and productive.

3-14 COMPLETE SYSTEM

Typically, vehicle electrical system power output requirements may range from 1 to 18 kW depending on the nature of the vehicle. However, a very evident trend toward higher power requirements for military vehicles has developed over the past 30 yr (Fig. 3-14). Specific capacities of generator systems and battery complements found on vehicles in the present inventory are illustrated in Tables 1-1 and 1-2.

The power demanded by each functional electrical component must be determined in order to establish the total load demand requirement for a new vehicle. An estimate of this total load demand is an important asset for use with feasibility and trade-off studies. Therefore, typical power demands for vehicle electrical equipment have been tabulated to facilitate the development of such estimates (Table 3-2). This information, coupled with power estimates for other unique equipment, may provide the only basis for procurement decisions regarding the generator system in those urgent programs where development time resources are low.

3-15 SUBSYSTEMS

The importance of analyzing subsystem and component power requirements to assure generator system adequacy is analogous to the importance of a building foundation where inadequate performance will result in a host of future problems. The analysis is facilitated if the vehicle electrical system is perceived as a composition of three basic subsystems in which power is consumed or supplied (Fig. 3-15).

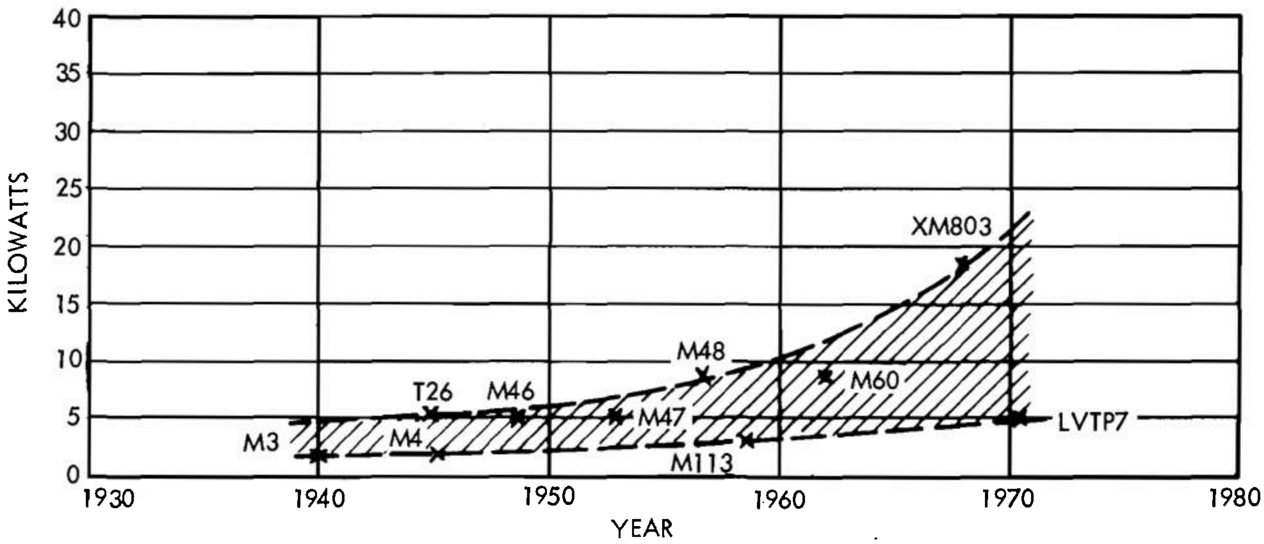

Figure 3-14. Increasing Vehicle Electrical Power Requirements

TABLE 3-2. TYPICAL ELECTRICAL POWER REQUIREMENTS FOR MILITARY VEHICLE COMPONENTS

APPLICATION	AMPERES AT 28 VDC	
	INTERMITTENT	CONTINUOUS
AUTOMOTIVE SYSTEMS		
Starter Motor (4.5 in. Frame)	150	
Starter Motor (5 in. Frame)	350	
Starter Motor (5.5 in. Frame)	700	
Starter Solenoid	60 pull in 8 hold	
Starter Relay	0.5	
Spark Ignition		1 to 4
Fuel Pump		1 to 2
Horn	3.5	
Infrared Headlight		3.93 HI-1.96 LOW
Service Headlight		3.93 HI-1.96 LOW
Blackout Driving Light		1.55
Blackout Marker Light		0.23
Service Tail Light		0.23
Service Stop Light	1.02	
Blackout Stop Light	0.23	
Dome Light		0.61
Panel Light		0.07
Indicator Light		0.07
Spotlight		5
Indicating Instrument		0.2
ENVIRONMENT & DAMAGE CONTROL		
Vent Fan		3 to 30
CBR Unit (3 man)		5
Coolant Heater	15 start	3.5 run
Personnel Heater	22 start	15 run
Heater Fuel Pump		1
Coolant Pump		2
Windshield Wiper		1 to 5
Bilge Pump (50 gpm)		20 max 6 Dry
Bilge Pump (125 gpm)		40 max 12 Dry
WEAPON SYSTEMS		
Weapon Pointing	200 to 500	
Firing	4 to 25	
COMMUNICATIONS		
Radio (AN/VRC 12 series)	11 transmit	1 receive
Intercom		1
ENERGY STORAGE		
Charging (100 A-hr battery)	120 at 1/4 Charge	2 at Full Charge

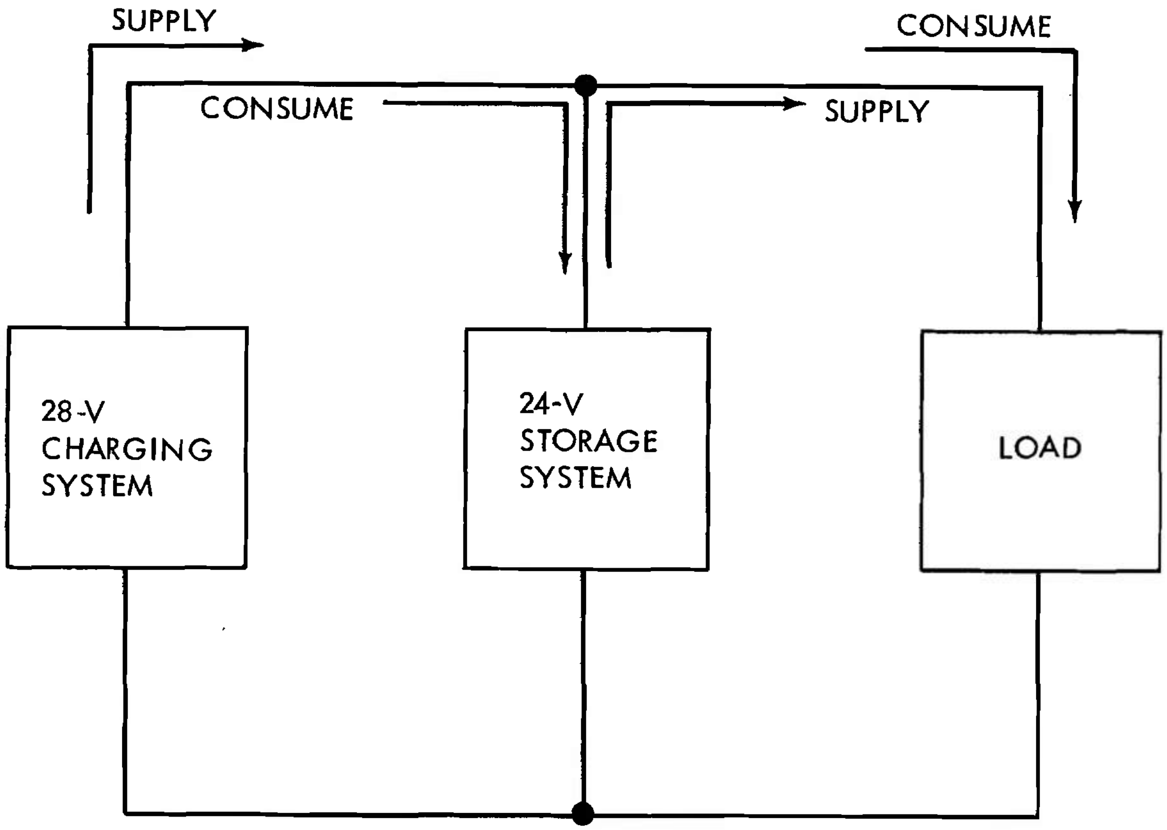

Figure 3-15. Vehicle Electrical System Power Distribution

The 28-V engine-driven charging system will supply both the storage system and the load when the engine is operating. Therefore, the size of the charging system must be based on demands from the storage system and the load, and it cannot be fully defined until these demands are established.

The 24-V storage system must supply power for standby loads and yet reserve enough power to provide adequate engine cranking. The required capacity of this system is dependent upon the size of these two demands.

The consumer load is determined by the mission and by the characteristics of the equipment chosen to implement the system design requirements (par. 3-8.4). Defining this load is the logical first step is performing a load and power supply analysis.

The consolidation of all electrical loads onto a preliminary layout of the vehicle electrical system in schematic diagram form will provide a starting point for determining load requirements. If this schematic is arranged so that a line representing the positive supply runs horizontally across the top of the diagram and a line representing the negative supply, or vehicle structure, runs horizontally along the bottom of the diagram then each function and its controlling elements can be placed in a separate circuit running vertically between the positive and negative supply lines much like the rungs in a ladder (Fig. 3-16). This ladder-type diagram is essentially an expansion of the load segment of Fig. 3-15. When the required functions have been placed in this format, it is very easy to consider each element from left to right and decide which functions are apt to be in operation during a given mission under specific environmental conditions and then establish a characteristic electrical load for the mission.

Maximum expected electrical load at normal engine operating speed and at engine idle should be determined. These requirements

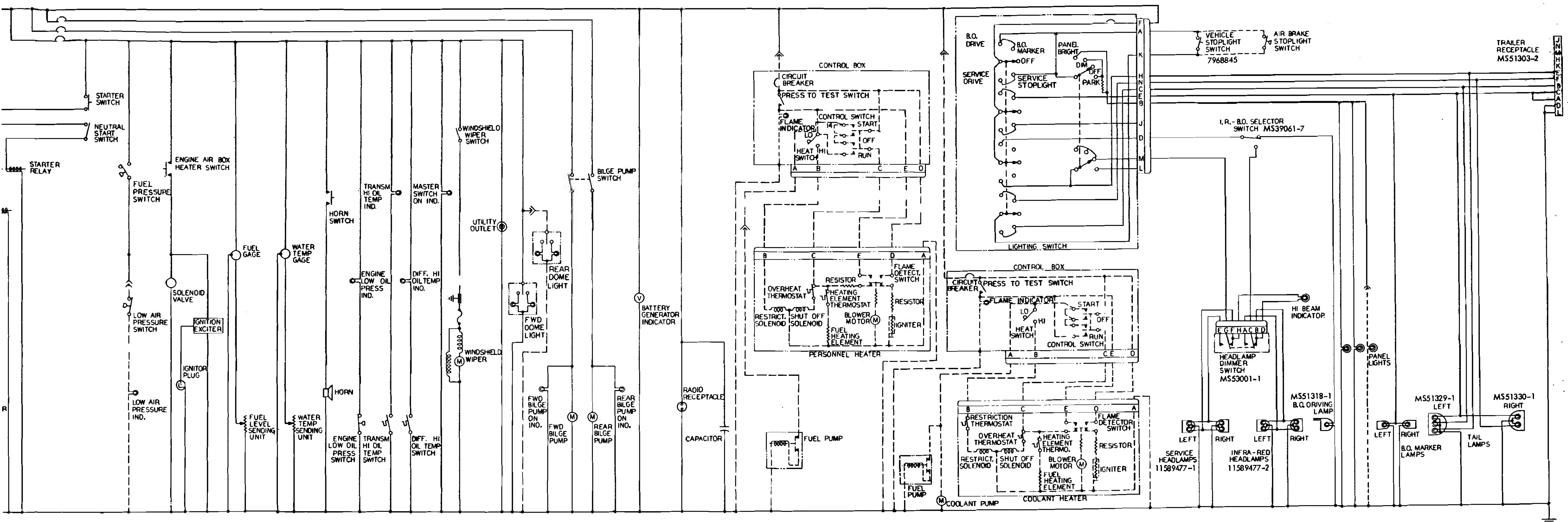

Figure 3-16. Vehicle Electrical Load Schematic

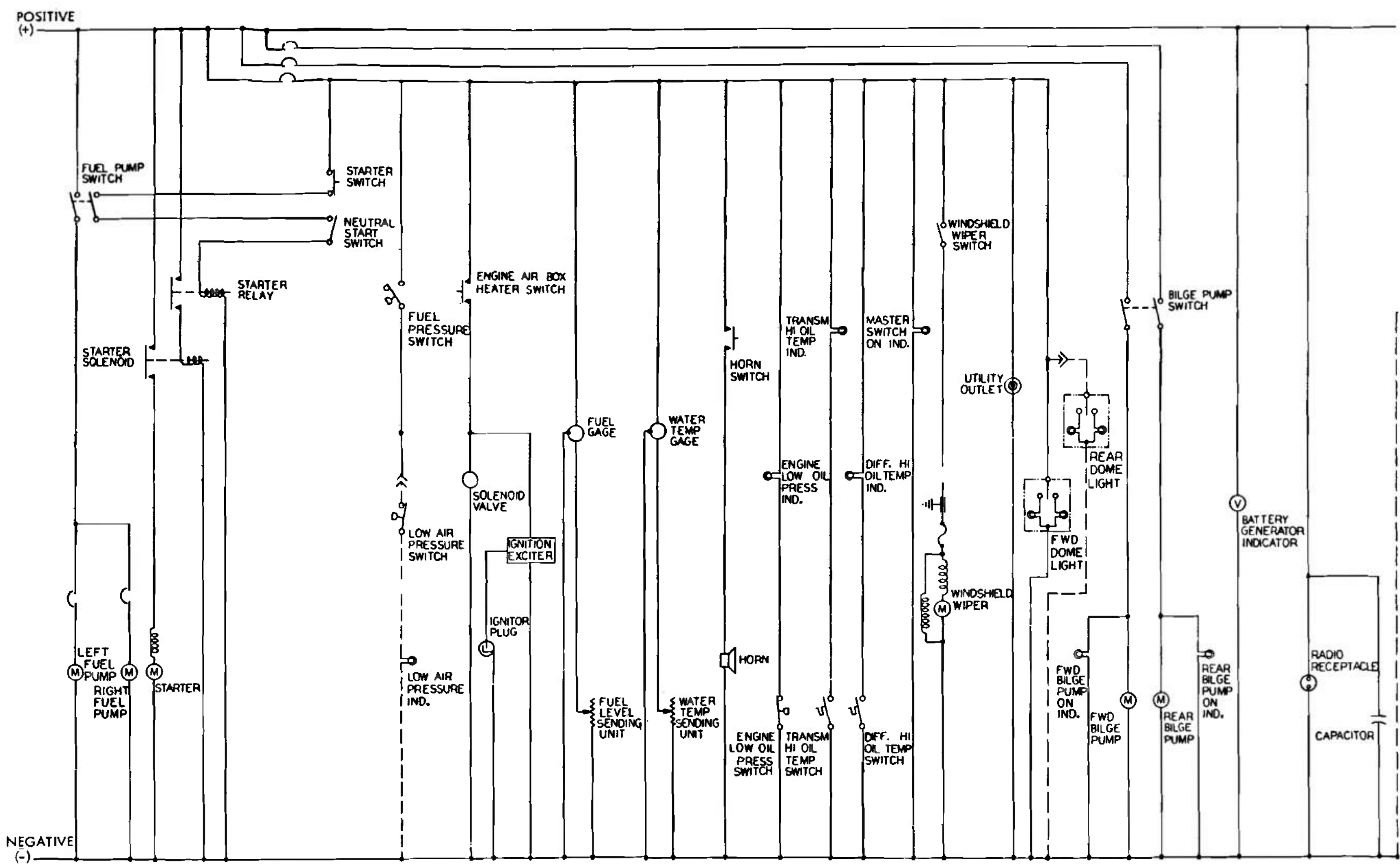

Figure 3-16. Vehicle Electrical Loa

will establish the generator capacity and influence the drive pulley ratio.

Normal load requirements based on the average operating conditions of the vehicle also should be defined. A comparison of normal loads with maximum loads provides a measure of extra generating capacity available for battery charging during operation.

Standby load requirements are based on the current demand from devices that must be operated by battery power while the engine is shut down. Definition of these loads in necessary in establishing battery capacity requirements.

Engine starting load current is considered separately from standby load. This is generally the most severe load requirement of a vehicle electrical system since most military vehicles must start at −25°F unaided. The maximum current and minimum voltage requirements for the starter motor at this low temperature must be obtained. Average cranking time to obtain an engine start in these arctic conditions also must be determined.

Preparation of a chart tabulating electrical loads expected under maximum, normal, standby, and intermittent operating conditions will facilitate further review and assessment (Table 3-3). The data obtained from a

TABLE 3-3. LOAD ANALYSIS CHART

	NOMINAL AMPERES/UNIT	QUANTITY USED	MAXIMUM LOAD, A		NORMAL LOAD, A	STANDBY LOAD, A	INTERMITTENT LOADS, A
			IDLE	2000 RPM			
Fuel Pump	1.75	2	3.5	3.5	3.5	–	–
Starter Motor	300 Normal 500 Arctic	1	–	–	–	–	500
Starter Solenoid	60 pull in 8 hold	1	–	–	–	–	60
Starter Relay	0.5	1	–	–	–	–	0.5
Low Air Indicator	0.07	1	–	–	–	–	0.07
Air Box Heater System	5	1	–	–	–	–	5
Fuel Gage	0.2	1	0.2	0.2	0.2	–	–
Water Temp. Gage	0.2	1	0.2	0.2	0.2	–	–
Horn	3.5	1	–	–	–	–	3.5
Low Oil Pressure Indicator	0.07	1	–	–	–	–	0.07
Hi Oil Pressure Indicator	0.07	2	–	–	–	–	0.14
Master Switch On Indicator	0.07	1	0.07	0.07	0.07	0.07	–
Windshield Wiper	5	1	5.0	5.0	–	–	–
Dome Light	0.61	2	–	1.22	–	–	–
Bilge Pump On Indicator	0.07	2	–	0.14	–	–	–
Bilge Pump	6 Dry 20 Pumping	2	–	40.0	–	–	–
Radio	11 Transmit 1 Receive	1	1.0	1.0	1.0	–	11
Personnel Heater	22 Start 15 Run	1	15.0	15.0	–	–	22
Coolant Heater	15 Start 3.5 Run	1	–	–	–	3.5	15
Personnel Heater Fuel Pump	1	1	1.0	1.0	–	–	–
Coolant Heater Fuel Pump	1	1	–	–	–	1	–
Coolant Pump	2	1	–	–	–	2	–
Service Headlamp	1.96 LO 3.93 HI	2	–	–	–	–	–
Infrared Headlamp	1.96 LO 3.93 HI	2	7.86	7.86	–	–	–
Hi Beam Indicator	0.07	1	0.07	0.07	–	–	–
Blackout Driving Lamp	1.55	1	–	–	–	–	–
Panel Light	0.07	3	0.21	0.21	–	–	–
Blackout Marker Lamp	0.23	4	0.92	0.92	–	–	–
Tail Lamp	0.23	1	–	–	–	–	–
Service Stop Lamp	1.02	1	–	–	–	–	1.02
Blackout Stop Lamp	0.23	1	–	–	–	–	0.23
Trailer Lamp Load	0.92	–	0.92	0.92	–	–	1.02
TOTALS	–	–	35.95	77.31	4.97	6.57	–

load analysis of this nature can be compared with performance curves for power generation and energy storage equipment described in Chapter 7. The use of these curves will facilitate selection of an adequate generator system and battery complement for the vehicle under development.

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CHAPTER 4

SYSTEM DESIGN CONSIDERATIONS

SECTION I DESIGN STAGES AND INTERFACES

4-1 INTRODUCTION

Vehicle programs involve varying types of design activity depending on the purpose of the program. The major types of design activity include new vehicle designs, modifications of existing vehicles, or revisions of existing designs. The interface requirements met by the electrical system designer vary with the types of activity as well as with the time frame within any one type. An understanding of these differing interface requirements will enable the designer to approach each task properly.

4-2 NEW DESIGN

In general, the opportunity to improve the design of vehicle electrical systems is rarely better than during the development of an entirely new vehicle. At such times, the deficiencies of inventoried vehicles may be analyzed objectively with an eye toward possible improvement in performance through the development of new components or better application of existing ones. Usually space reservations and locations for electrical equipment are easy to coordinate with other designers working to develop the remainder of the vehicle and, therefore, optimum component locations can be justified and established. The approach to new design work always should be conducted in response to the ultimate system development philosophy prescribed by the Army Materiel Command as outlined in par. 2-3.

4-3 DESIGN MODIFICATIONS

A basic vehicle that has been designed for a specific application, and that fulfills all of the requirements for that application, often is modified in order to fulfill adequately requirements for subsequently conceived applications. The design effort necessary to accomplish vehicle modifications usually follows the same guidelines as prescribed for new design. It is most important, however, that the electrical system of the basic vehicle be thoroughly understood prior to the addition or deletion of any electrical circuits or components which might change the characteristics of the original system. In the completed vehicle modification, all of the added components must be mechanically and electrically compatible with interfacing components of the original design. In addition, none of the original qualities or capabilities of the electrical system should be compromised without the understanding and approval of the contracting agency. Usually, the designer will not enjoy as much freedom from constraint in a design modification effort, because the fixed vehicle hardware configurations and logistic requirements will require consideration in his design concepts as additional constraining parameters.

4-4 DESIGN REVISIONS

Design revisions are generally initiated to improve a product, provide a cost savings, standardize applications, or correct records.

When a vehicle development program has progressed to the point where the release of detail and assembly drawings has initiated procurement and fabrication commitments, a rigid change control system is generally instituted to evaluate further revisions prior to their release.

The additional constraints imposed at this stage involve long range considerations of total costs for each change as compared with the apparent need. Cost considerations pertaining to obsolescence of materiel, rework expense, administrative costs, effect on the supply system, and the price of new tooling often will outweigh the apparent cost advantage of a proposed change when the length of the production run is limited.

Desirable product improvement or cost reduction changes generally are made without obsolescence of materials, and they are planned to take place at a point in the production schedule where previous material commitments have been depleted.

Mandatory product improvements, with obsolescence of material, are sometimes necessary to correct design errors resulting in unsafe or inoperable conditions.

Authority to incorporate all design revisions is granted through contracting agencies by approval of engineering change proposal documents submitted by vehicle design agencies. Operating procedures for this activity generally are specified in the program contract.

4-5 INTERCHANGEABILITY

When a part is revised or superseded by a new part, interchangeability is an important consideration from both physical and functional aspects. As a general rule, revised parts of a system, or superseding parts that are not physically or functionally interchangeable with their previous counterparts, must be assigned new part numbers to avoid confusion in service parts supply systems. In other words, all parts with the same part number within a system must be physically and functionally interchangeable.

Physical interchangeability does not imply that identically numbered parts have the same physical appearance. It does require that the interchangeable parts mount to interfacing parts in an identical manner and operate in the system without physical interference with other parts of the system.

Functional interchangeability requires that interchangeable parts function in the system without significant differences in system performance; but it does not demand that such parts perform their individual functions in exactly the same way.

Revisions to electrical parts can produce chaos in the supply system if interchangeability is overlooked. For example, a wiring harness revision that modifies electrical circuit connections might not appear physically different from its previous counterpart. If such a revision is made without a change in part number, the supply system would be stocked with two functionally different harnesses, bearing the same part number. During the resulting confusion, it would not be possible to sort out each type without expensive checkout of each harness.

Many military standard electrical components are described by performance specification, maximum envelope size, physical mounting features, and electrical connection requirements, so that a number of different vendors can qualify their parts to the standard without producing completely identical parts. The battery standard, MS 35000, is an example of this technique. Here the products of several vendors, all slightly different, are physically and functionally interchangeable because they conform to a standard specifying the parameters of interchangeability. Switches, relays, circuit breakers, instruments, and many other electrical components are defined similarly.

SECTION II SYSTEM ENVIRONMENT

4-6 INTRODUCTION

Satisfactory performance and easy maintenance of the electrical system throughout the life of a vehicle in all types of military environment are primary design goals. A working knowledge of the military environment will facilitate achievement of these goals. This environment may be classified in three types: the natural environment, the man-made environment, and the man-altered environment. The first, comprised of those natural conditions existing on the surface of the earth or in near proximity to it, consists basically of climate and terrain; i.e., weather and other atmospheric phenomena, landform, vegetation, hydrology, etc. The second type, the man-made environment, includes those conditions which are completely foreign to nature. Examples of activity in man-made environmental conditions are the combustion of fuel, producing air pollution; movement over the surface of the earth, producing shock and vibration; and the generation of electrical energy, producing electromagnetic interference. The third type, the man-altered environment, is concerned with natural conditions which have been changed by man's activities. Examples include the high temperatures experienced by a component in the center of an electronic assembly, and the mud produced by Army vehicles traveling over a wet, unsurfaced area[1].

4-7 GENERAL CLIMATIC ENVIRONMENT

Army regulations require that climatic considerations be included in all RDT&E of Army materiel, including storage and transit, in order to provide safe and effective materiel for areas of intended use. The Antarctic continent is excluded as an area of intended use[2].

MIL-STD-210 describes the probable extreme climatic conditions of the natural environment to which military equipment may be exposed worldwide, and is intended to establish uniform limits as parameters for normal design requirements. In addition, environments induced because of worldwide short term storage and transportation are presented to indicate the extreme conditions which any military item might be subjected to during shipment or while being stored. These limits are displayed in Table 4-1. Special operational requirements other than these limits may be established as appropriate by using services.

As a refinement of operational capability objectives, the mission narrative defines a battle field day and establishes the maximum duty cycle for a system under extreme environmental conditions. As applied to combat tanks, the battle day typically may be specified as 24 hr long; while for armored personnel carriers, the battle day may be specified as 3 days long. System specifications for these criteria vary.

4-7.1 CLIMATIC DIVISIONS

Eight climatic categories are differentiated on the basis of temperature and/or humidity extremes (see Fig. 4-1). Within each of the eight categories, a distinction is made between operational temperature and humidity conditions, and storage or transit temperature and humidity conditions[2]. Diurnal extremes, highest and lowest values in a 24-hr cycle, for temperature, relative humidity, and solar radiation are summarized in Table 4-2 for the stress producing extreme of each climatic category.

4-7.2 CLIMATIC STRESSES

The total stress imposed on vehicle electrical equipment by worldwide climatic extremes is caused by thermal, humidity, precipitation, pressure, wind, dust and moisture penetration, and abrasion-induced elements. Parameters for these conditions are displayed in Table 4-1.

TABLE 4-1. CLIMATIC EXTREMES FOR MILITARY EQUIPMENT

Extreme stress conditions		Environmental factors	OPERATION – Ground (outdoors) – World-wide				Arctic winter	Moist tropics				Hot desert	Shipboard (world-wide)				Short-term storage & transit land-sea-air (world-wide)			
Thermal	Hot	Duration, hr	10	5	4	5		10	5	4	5		10	5	4	5	10	5	4	5
		Air temperature, °F	90	↗	125	↘		75	↗	95	↘		90	↗	100	↘	90	↗	160	↘
		Radiation, W/ft²	0		105			0		90			0		90		0	0	0	0
		UV < 4000 Å, %	0	6	6	6		0	45	45	45	W	0	4.5	4.5	4.5	0	0	0	0
		IR > 7000 Å, %	0	50	50	50		0	51	51	51		0	51	51	51	0	0	0	0
		Wind speed, mph	7	7	7	7		4	4	4	4		6	6	6	6	0	0	0	0
	Cold	Duration, hr			72								24				Equilibrium		24	
		Air temperature, °F	Equilibrium		−65								−20				−40		−80	
		Sky temperature, °F	−40		−80		W						−45							
		Wind speed			5 mph								40 kt				0		0	
Humidity		Abs. humid, grains/ft³	13				21	W				W	W				W			
	High	Duration, hr	20		4		98 to 100													
		Relative humidity, %	93 to 97		100 w/cond		below	W					W				W			
		Air temperature, °F	80 to 85		75 to 80		freezing													
		Abs. humidity, grains/ft³	0.01				W	0.5					0.17				W			
	Low	Duration, hr	10	5	4	5											10	5	4	5
		Relative humidity, %	15	>	5	<						W					15	>	2	<
		Air temperature, °F	90		125												90		160 See note A	
Precipitation	Rain	Duration, hr:min	11:55	00:05	11:00	01:00														
		Amount, in.	12	2	11	7														
		Drop diam: mean, mm	2.25	4.00	2.25	3.20		W					W				P			
		std. dev., mm	0.77	1.68	0.77	1.10														
		Air & water temp, °F	70	70	70	70														
		Wind, mph			40															
	Snow	• Expectancy, days	1	3		150	W													
		Snow load, lb/ft	10	20		40														
Wind 10 ft above surface		• Expectancy, yr	2	5		25														
		Ordinary: steady, mph	40	50		65							85 (75 kt)							
		Gusts, mph	60	75		100	W	W				W	115 (100 kt)				P			
		Δ Exceptional: Steady mph	50	70		80														
		Gusts, mph	90	105		120														
Penetration and Abrasion	Blowing Snow	Flake diameter, mm	1 to 3																	
		Wind, mph	40				W						W				P			
		Air temperature, °F	0																	
	Blowing Sand	Grain diameter, mm	0.16 to 0.30																	
		Wind at 5 ft, mph	40									W	W				W			
		Air temperature, °F	100																	
	Blowing Dust	Grain diameter, mm	0.0001 to 0.01																	
		Density, grams/cm³	$6 \quad 10^{-2}$																	
		Wind at 5 ft, mph	40									W	W				W			
		Air temperature, °F	70																	
Pressure		Maximum	1,060 mb = 31.30 in Hg = 15.40 lb/in.²				W	W				W	W				W			
		Minimum	505 mb = 14.94 in. Hg = 7.35 lb/in.²				W	844 mb = 24.85 in. Hg = 12.20 lb/in.²				844 mb	887 mb = 26.18 in. Hg = 12.90 lb/in.²				375 mb = 11.1 in. Hg = 5.45 lb/in.²			

• Expectancies vary with type of equipment

TYPE	SNOW	WIND
Portable	1 day	2 yr
Temporary	3 days	5 yr
Semi-permanent	150 days	25 yr

W = Same as operation, ground, world-wide
P = Same as operation, ground, world-wide for packaging only
↘ = Change at uniform rate from preceding to following condition
Δ = Equipment for exceptional windy areas requires auxiliary kits to permit withstanding indicated winds.
= Additional low humidity storage. 30 days at 50° F and 0.5 relative humidity (simulating arctic storage).

4-7.3 MILITARY VEHICLE CONSIDERATIONS

The scope of military vehicle operations is worldwide; therefore, military vehicles and associated electrical equipment are required to be operational and to survive transit or storage in the worst extremes of temperature, humidity, precipitation, and wind as defined in Table 4-1. The basic design of a military vehicle electrical system must be predicated upon performance in these environmental extremes, and each new vehicle is generally subjected to arctic, tropic, and desert environmental testing before it is accepted into inventory.

4-8 OTHER ENVIRONMENTAL CONSIDERATIONS

Underestimating the severity of the military environment is a common error that can be avoided if design personnel are aware that vehicle electrical systems are affected by many other characteristics of the military environment in addition to arctic and tropical climatic extremes. The typical missions involving amphibious operations in fresh water

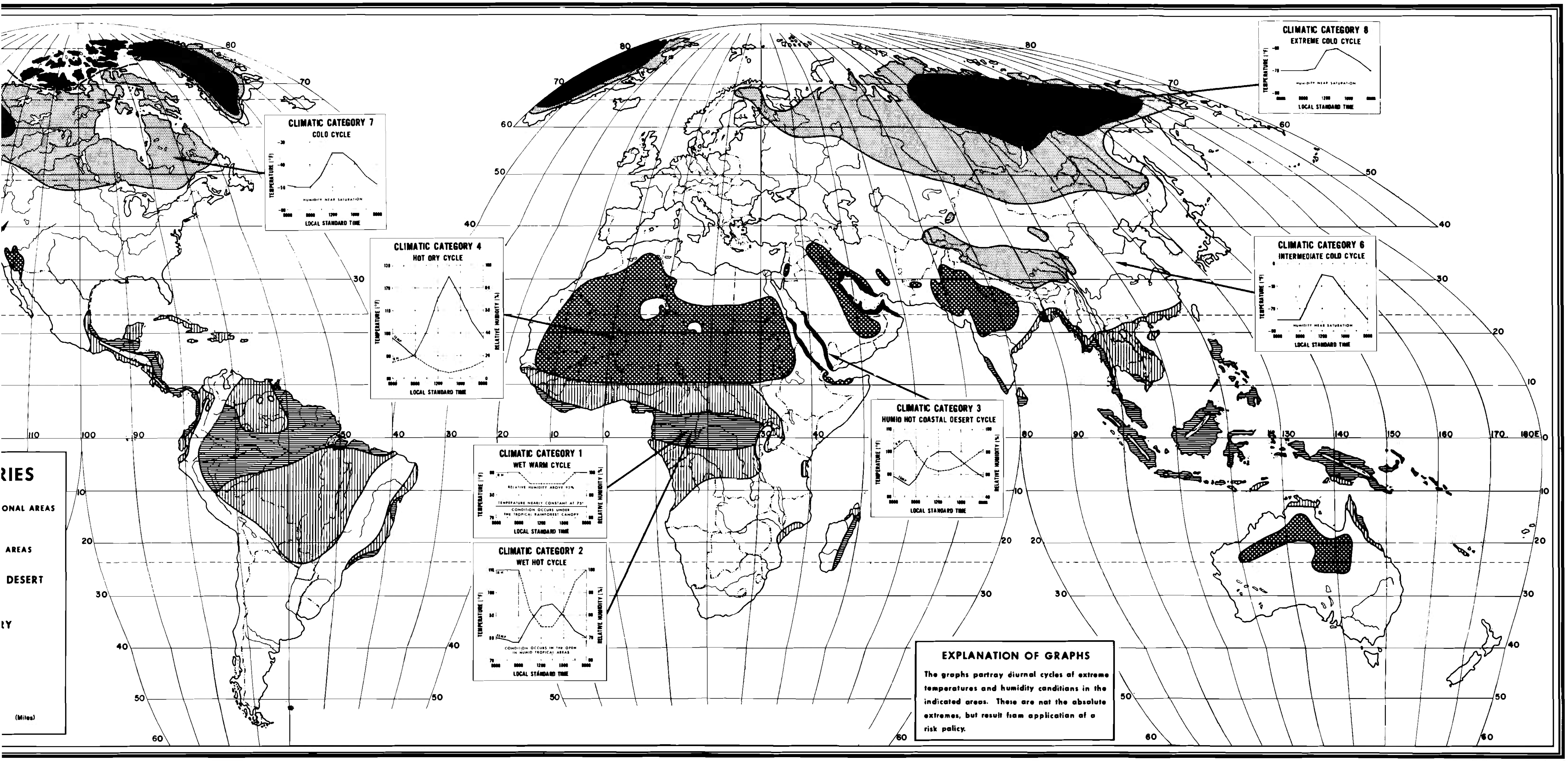


Figure 4-1. Worldwide Climate Categories[2]

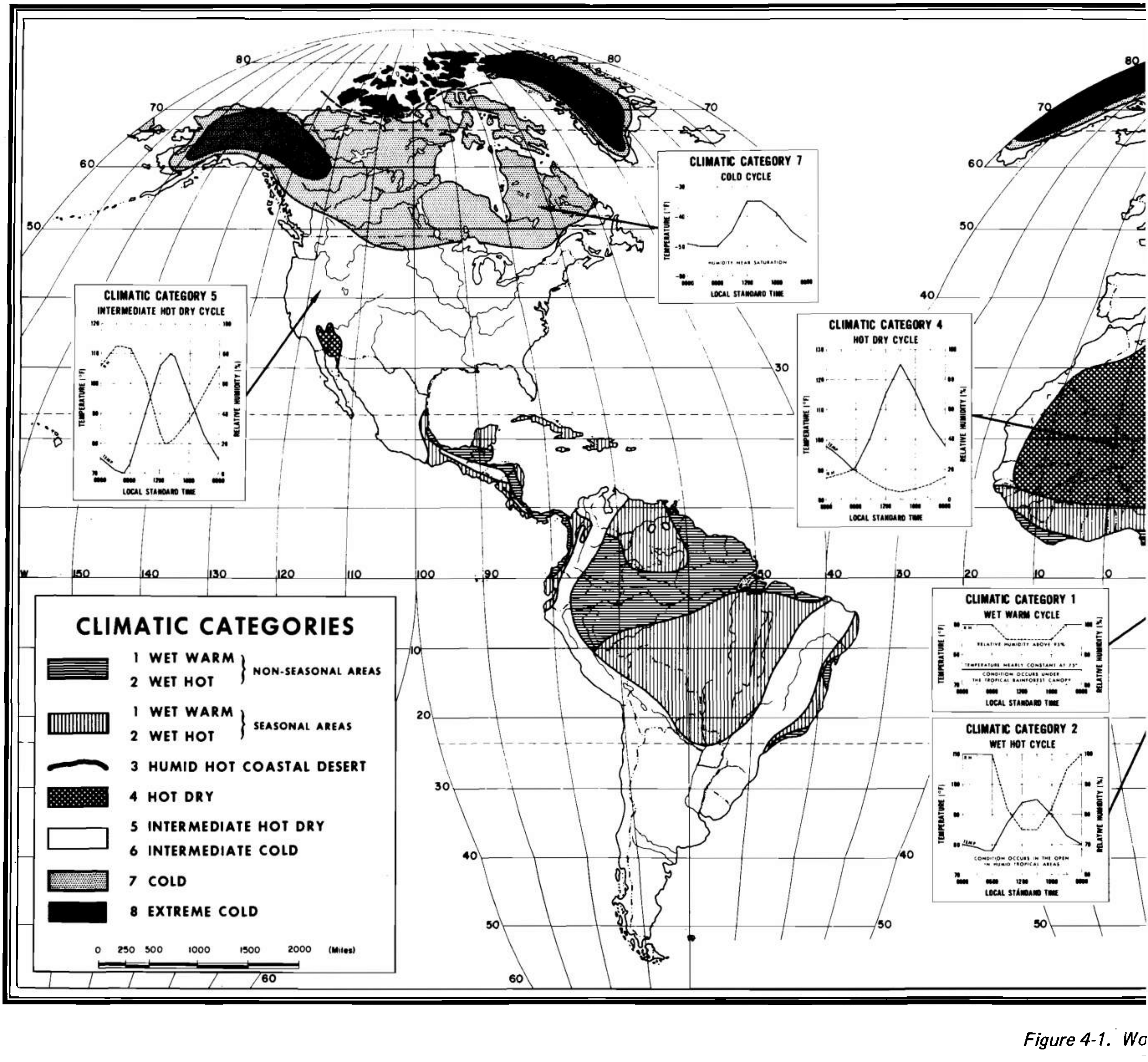

CLIMATIC CATEGORIES
1 WET WARM
2 WET HOT
NON-SEASONAL AREAS
1 WET WARM
2 WET HOT
SEASONAL AREAS
3 HUMID HOT COASTAL DESERT
4 HOT DRY
5 INTERMEDIATE HOT DRY
6 INTERMEDIATE COLD
7 COLD
8 EXTREME COLD
0 250 500 1000 1500 2000 (Miles)
CLIMATIC CATEGORY 7
COLD CYCLE
TEMPERATURE (°F)
HUMIDITY NEAR SATURATION
LOCAL STANDARD TIME
CLIMATIC CATEGORY 5
INTERMEDIATE HOT DRY CYCLE
TEMPERATURE (°F)
RELATIVE HUMIDITY (%)
LOCAL STANDARD TIME
CLIMATIC CATEGORY 4
HOT DRY CYCLE
TEMPERATURE (°F)
RELATIVE HUMIDITY (%)
LOCAL STANDARD TIME
CLIMATIC CATEGORY 1
WET WARM CYCLE
TEMPERATURE (°F)
RELATIVE HUMIDITY (%)
LOCAL STANDARD TIME
CLIMATIC CATEGORY 2
WET HOT CYCLE
TEMPERATURE (°F)
RELATIVE HUMIDITY (%)
LOCAL STANDARD TIME

Figure 4-1. Wo

TABLE 4-2. SUMMARY OF TEMPERATURE, SOLAR RADIATION, AND RELATIVE HUMIDITY DIURNAL EXTREMES

Climatic category	Operational Conditions			Storage and Transit Conditions	
	Ambient air temperature, °F	Solar radiation, Btu/ft^2-hr	Ambient relative humidity, %	Induced air temperature, °F	Induced relative humidity, %
1 Wet-warm	Nearly constant 75	Negligible	95 to 100	Nearly constant 80	95 to 100
2 Wet-hot	78 to 95	0 to 360	74 to 100	90 to 160	10 to 85
3 Humid-hot coastal desert	85 to 100	0 to 360	63 to 90	90 to 160	10 to 85
4 Hot-dry	90 to 125	0 to 360	5 to 20	90 to 160	2 to 50
5 Inter-mediate hot-dry	70 to 110	0 to 360	20 to 85	70 to 145	5 to 50
6 Inter-mediate cold	−5 to −25	Negligible	Tending toward saturation	−10 to −30	Tending toward saturation
7 Cold	−35 to −50	Negligible	Tending toward saturation	−35 to −50	Tending toward saturation
8 Extreme cold	−60 to −70	Negligible	Tending toward saturation	−60 to −70	Tending toward saturation

or sea water and off-the-road operations over all types of rugged terrain, produce severe shock, vibration, corrosion, and contamination stresses. Furthermore, user and operator abuse is ever present in the form of misuse, improper maintenance, and neglect. In addition, the electromagnetic environment must be considered so that interference-producing elements are avoided. Successful electrical equipment designs and applications are not possible without provisions for coping with these additional characteristics of the military environment.

4-8.1 TERRAIN

Vehicle operations over unimproved terrain encounter natural obstacles like trees, brush, hills, creeks, and rivers. Electrical equipment on the exterior of the vehicle must be protected against the water damage and physical damage inherent in such operations. In addition, most equipment in the electrical system must be unaffected by operation on side slopes or severe grades. Furthermore, contamination from dust or mud becomes extremely severe when vehicles are required to follow previously used paths over unimproved terrain. The electrical system, therefore, must be rugged enough to withstand the effects of steam cleaning or hosing down. The interior of a vehicle becomes almost as contaminated as the vehicle exterior in off-road operations and must be equally protected. The severe dust, mud, slope, and water conditions encountered in off-road operations with an M113 Armored Personnel Carrier are illustrated in Fig. 4-2.

4-8.2 EQUIPMENT

Arctic conditions affect most materials by making them brittle. Plastic and rubber materials particularly are susceptible to fracture in extreme cold. Electrical wire insulation and binding materials with poor low-temperature flexibility must be avoided.

Tropical conditions foster the development of fungi because of the constant warm, moist air in such environments. All electrical equipment must be fungus-resistant, and the use of any materials susceptible to fungus must be avoided.

Corrosion is accelerated by salt-laden air near the ocean. Electrical equipment must be designed with protection against corrosion through the use of noncorrosive materials or suitable protective coatings over susceptible materials and nonmetallic buffers between dissimilar metal joints except in the case of RF shields where the DC resistance of electrical bonds should be of the order of 0.0025 ohm.

Shock and vibration are extremely severe in the military environment, and electrical equipment must be isolated from such conditions with suitable mounting provisions. Incandescent bulbs, relays, and buzzers are particularly prone to failure from shock and vibration.

Resistance to water, temperature cycling, pressure variations, abrasion, and aging are additional qualifications placed on military electrical equipment. Suppression of electromagnetic interference is another.

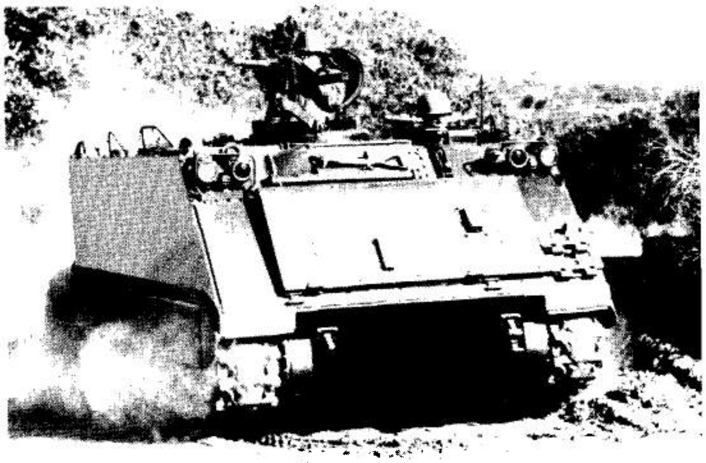
Properly documented drawings of components approved for use in military equipment will specify performance requirements, which include electrical and environmental tests. The designer will find a ready source of information regarding military environmental considerations if he examines the drawings describing such parts. This is particularly helpful when drawings for new components are being prepared.

When overriding environmental requirements are not spelled out in equipment specifications, electrical equipment should be designed to withstand the worst conditions for worldwide operations as listed in Table 4-1.

4-8.3 PERSONNEL

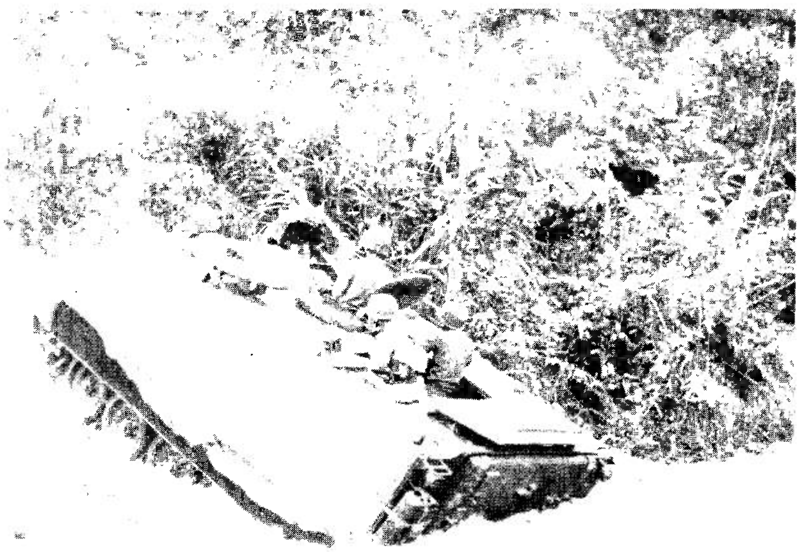
With the threat of possible chemical and radiological warfare, the military environment has become even more severe. These types of warfare require additional protection for combat personnel in the form of sealed and protected personnel compartments, the use of recirculated air, and provisions for the personal requirements of the crew during extended periods of time. Sealing personnel compartments and shielding them against nuclear radiation introduce requirements for providing effective vision outside the vehicle and providing remotely controlled weapons.

The need to keep warm is the most severe requirement for personnel engaged in arctic operations. Vehicle personnel heaters and arctic clothing provide the present answer to this need. Too often, vehicle control stations are not designed to allow for the bulky winter clothing that must be worn by operating personnel (see Fig. 4-3). Switches and controls must be selected and located so that an operator will not be hampered by his arctic wear during vehicle operation and maintenance.



(A) Dust

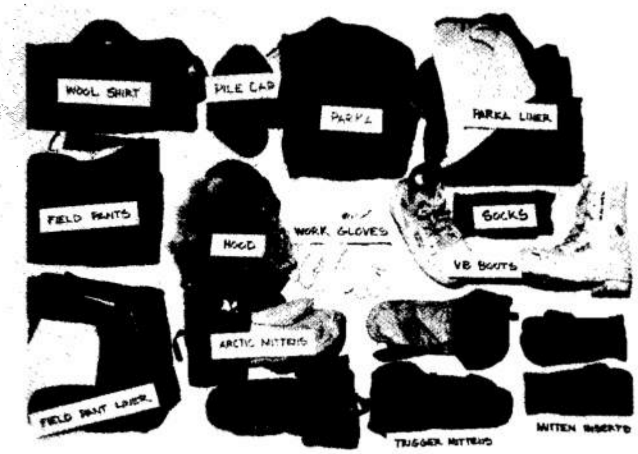
(B) Mud



(C) Slope and Water

Figure 4-2. Vehicle Off-road Operations

Outer shell and liner for proposed new lightweight arctic clothing, shown center and left. Underwear and gloves, right, are electrically heated. Intended for use in armored vehicles, the heated clothing plugs into the crew compartment power supply.



Full layout of Arctic clothing. Great bulk of the clothing must be considered in designing equipment the men must operate.

Typical winter uniform worn by Arctic Test Center personnel.

Figure 4-3. Arctic Clothing[43]

SECTION III CONSTRAINTS

4-9 INTRODUCTION

The constraints imposed on a system design effort include the environment in which performance will be required, personnel and materiel resources, availability of funds, time schedules, and state-of-the-art. These factors limit the extent of development that is possible on a given program and, therefore, are important design considerations.

4-10 SYSTEM AND COMPONENT COMPATIBILITY

The requirement for component compatibility in vehicle electrical systems is the result of logistic considerations relating to the field support of military vehicles. Widespread use of common parts in different vehicles is actually a materiel resource which reduces the number of repair parts required in the supply system and allows the use of parts from damaged or scrapped vehicles as an additional means for keeping vehicles operational when supply lines are broken. Furthermore, the availability of funds does not allow for redevelopment of all electrical components in each new vehicle program.

An example of a system compatibility requirement is the standardized use of a polarized dual-contact receptacle wired in parallel with vehicle batteries for auxiliary power connection. A two-conductor cable is employed to connect two vehicles together, so that a vehicle with good batteries can be used to start a vehicle with dead batteries. Therefore, standard requirements for vehicle auxiliary power connections, electrical polarity, and system voltage must be observed on all new development programs to retain this "slave" start capability.

Other characteristics of electrical components used on military vehicles have been established by the requirement for acceptable operation in the military environment. These environmental characteristics also include extra-strength waterproof connectors and receptacles designed to mate with standard heavy-duty interconnecting wiring assemblies. The components employed in this rugged interconnecting system are unique to military vehicle electrical systems and associated support equipment. All military vehicle electrical components, therefore, should be compatible with the features of this system (see Chapter 8).

Electrical components also must be compatible with typical vehicle electrical system power characteristics in order to avoid damage from power surges or transients. Electrical compatibility considerations are particularly important when devices contain solid-state elements.

4-11 PRACTICAL AND EFFECTIVE ARRANGEMENTS

The ideal arrangement for vehicle electrical equipment should be both practical and effective; however, this is not always attainable due to the constraining requirements of vehicle concepts which influence the location of major vehicle components. For example, weight distribution considerations may dictate that the vehicle batteries be located at a considerable distance from the engine starter motor. On the other hand, electrical considerations require that the batteries be located as close to the engine as possible to minimize voltage drop in the starter motor cable. In addition, the necessary size and weight of the starter motor cable increases in proportion to the distance between the starter motor and the batteries. Obviously, compromises must be made to achieve the most practical and effective arrangement within the constraints of this situation. The final compromise should be based on the best possible analysis of practicability and effectiveness. Similar analysis is required, for other reasons, for many components in the vehicle electrical system during the development program.

4-12 VALUE

Value, although a broad term, has been categorized so that it can be defined meaningfully. Four such categories are:

1. Use Value. Based on the properties and qualities of a product or material which accomplish a task or service.

2. Cost Value. Based on the cost of a product, almost always expressed in monetary terms.

3. Esteem Value. Based on the properties, features, or attractiveness involved in pride of ownership of the product.

4. Exchange Value. Based on the properties or qualities which make the product exchangeable for something else.

The total real value of a product probably embodies all of the preceding factors and more. For the vast majority of defense hardware, however, use value and cost value are virtually the only factors of significance. Fortunately, these two elements can be stated in fairly rigorous, precise terms. Use value can be stated in terms of operating requirements or functional characteristics; cost value, in terms of dollars. Since these values generally are precise and measurable, they can be dealt with on a relatively objective basis.

It is important to note that even though cost and use value can be stated precisely, value is always relative, not absolute. Thus, high value in the defense environment is a function of both use and cost values and the relation between them. For example, an item with only an average use value and a below-average cost may have higher value than one which is above average in use value, but is obtainable only at a very high cost. Analysis of such relationships is important in weapon system cost effectiveness studies, since the resultant decisions lead to selection of a specific system, definition of its performance requirements, and selection of specific contractors.

Once such a series of decisions is made, the use value of the system, in effect, is defined. Anything less than such established use value is unacceptable; anything more can be unnecessary and wasteful. To achieve high value, emphasis is placed on defining precise use value (neither higher nor lower than required) and obtaining this use value at minimum cost. In other words, a high value defense product is one which provides exactly the required use (or performance) at the lowest possible cost[3].

Ref. 48 provides information on value engineering.

SECTION IV HUMAN FACTORS ENGINEERING

4-13 INTRODUCTION

All electrical systems involve man in some way. A man may have to operate, maintain, or simply work adjacent to an electrical system. The interface between man and machine is often just as critical as the interface between machine components. The success of an electrical system design, therefore, depends in part on the quality of the man-machine interface.

It is this man-machine interface that Human Factors Engineering (HFE) seeks to optimize. HFE deals with both the man and the machine; it develops programs for personnel selection and training, and it helps designers incorporate HFE criteria into the equipment design. Through these efforts man and machine are brought together into a coordinated, efficient, and effective system.

This section presents the electrical system designer with HFE criteria so he can design his equipment to conform to the capabilities and limitations of man. It contains criteria for working environments, the sizes and weights of the equipment the man will work with, and design of controls, displays, and communication systems.

It is particularly important that the designer knows how to utilize the information in this section. The following steps should be useful[4]:

1. Determine the basic functions of the electrical system.

2. Determine which functions are to be performed by man and which by machine. This section and other HFE sources define the capabilities and limitations of man and can be used in the analytical process required to allocate the system functions.

3. Observe carefully the tasks man must do in order to perform his assigned function.

4. Utilize the applicable criteria in this and other sources to design the equipment, so that man can perform his tasks safely, efficiently, and effectively.

The information in this section is abbreviated. More detailed HFE design criteria and information on personnel selection and training can be found in other works such as Refs. 5, 6, and 7.

4-14 WORKING ENVIRONMENT

Many vehicle systems – such as the lighting, ventilation, and air conditioning systems – are designed specifically to control the environment. Other systems inadvertently may affect man's working environment if they generate noise, light, radiation, or heat.

The criteria presented in this section and the references that are noted will help the designer recognize electrical system elements that could adversely affect man's working environment. Once the designer has identified the tasks that the man in the system must perform, he can utilize these criteria to determine the environment that man requires in order to perform the necessary tasks. The equipment he designs should then create, or at least preserve, this requircd working environment.

Unsafe environmental conditions (which may cause actual injury or damage to personnel or equipment) are discussed in Section V of this chapter.

4-14.1 TEMPERATURE

Electrical equipment may generate enough heat to degrade man's performance in the system. The general effects of environmental temperature on man's performance are shown in Fig. 4-4. Unsafe surface temperature limits are given in Table 4-10.

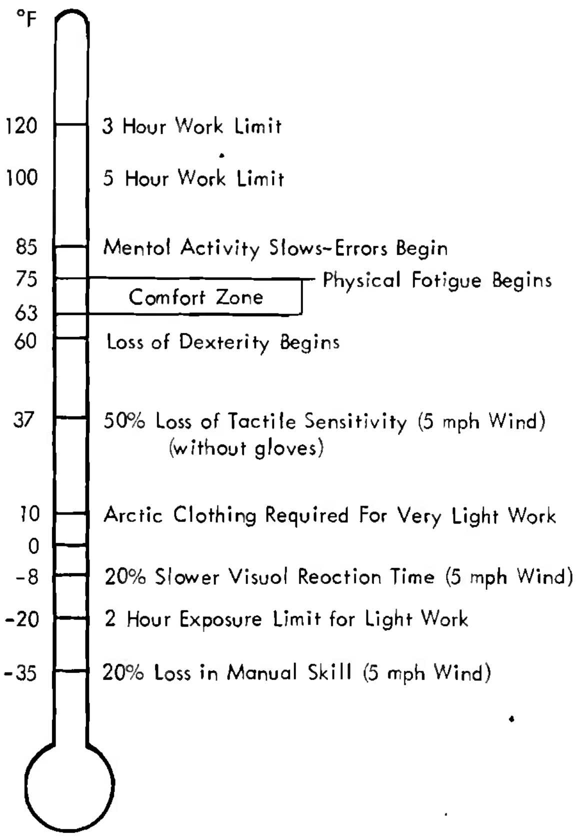


Figure 4-4. Effects of Temperature on Human Performance (Assume Proper Clothing Worn except as noted)

4-14.2 ILLUMINATION

Unsatisfactory illumination may impair the performance of operating or maintenance personnel. Some of the basic dangers of improper illumination and criteria for the reduction of these dangers are presented here.

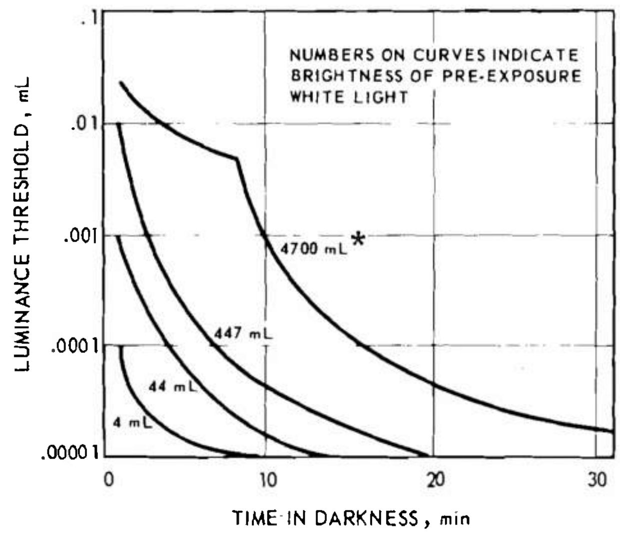
4-14.2.1 GLARE

Glare not only reduces visibility for objects in the field of view, but also causes visual discomfort and fatigue. Glare should be minimized by avoiding bright light sources within 60 degrees from center of the visual field.

4-14.2.2 DARK ADAPTATION AND FLASH BLINDNESS

Bright light can degrade the visual capabilities of man through a reduction in his dark adaptation and through flash blindness.

A man can see at very low light levels if his eyes are allowed to adjust to these low levels. Fig. 4-5 shows the brightness thresholds of man's vision versus the time he has spent adapting to a darkness after exposure to various light levels and colors. Low-brightness red light (wavelength of 620 millimicrons or above) maintains maximum dark adaptation and should be used whenever possible.



*mL = millilambert

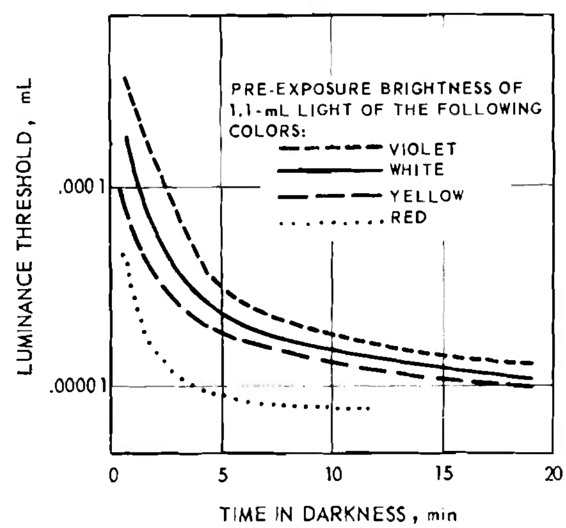


Figure 4-5. Dark Adaptation for Different Pre-exposure Conditions[8]

Weapons and electrical signalling devices may emit bright flashes. These flashes can temporarily blind man to objects of low-luminous intensity. The recovery times after exposure to 0.1-sec high-intensity flashes are shown in Fig. 4-6. Exposure of personnel to bright flashes of light should be eliminated whenever possible.

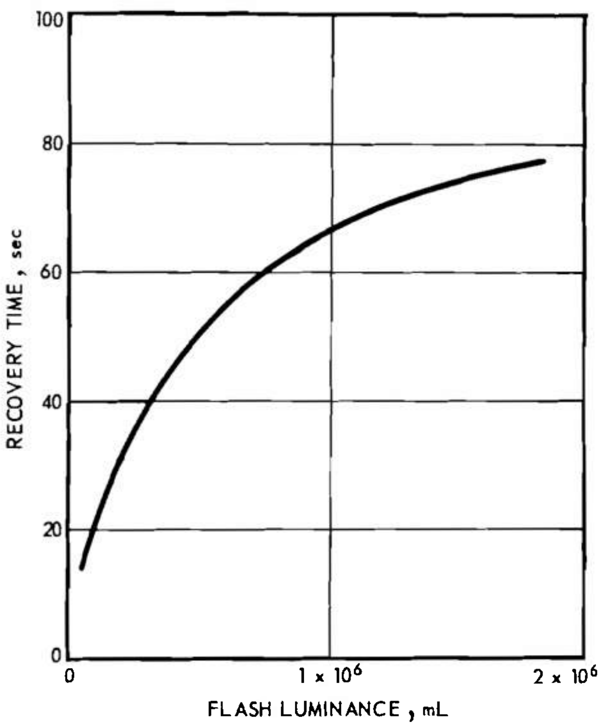


Figure 4-6. Recovery of the Eye After Exposure to Bright Flashes of Light[9]

4-14.2.3 FLICKER EPILEPSY

Experience has shown that a light flickering in the range of 10 to 30 Hz can produce an epileptic response under certain conditions, particularly if the viewer is fatigued[10,19]. Illuminating sources should avoid this critical frequency range.

4-14.3 NOISE

Electrical equipment may contribute to the acoustical noise environment of thc operation and maintenance personnel. Therefore, the effects of noise are considered here; acceptable noise limits are prescribed in par. 4-20.5.

4-14.3.1 EFFECTS OF NOISE

Noise can be both annoying and distracting, and can degrade nonauditory human performance. The tasks most likely to be affected by noise are vigilance tasks, complex mental tasks, communications, and tasks in which the operator is paced by the system[6]. Even at levels as low as 70 dB (A) (an A-weighted sound level of 70 dB as measured with a standard sound level meter), noise will degrade speech communications. Extremely high noise levels are hazardous to personnel and are capable of causing permanent hearing loss[17].

4-14.3.2 NOISE CONTROL

Because of the general undesirability of noise, every cffort should be madc to eliminate it from the system. There are generally three methods of controlling noise:

1. Control the source, either by moving the source or by reducing the noise output.

2. Reduce, by structural design, the noise that is transmitted.

3. Reduce the noise reaching the ear by the use of ear plugs or earmuffs.

The electrical system designer is normally able to control the noise output of electrical components only by prudent component sclection. His final electrical system design should bc such that maintenance and operating personncl never are exposed to hazardous noise levels, or noise levels that will not allow them to carry out necessary communication tasks.

4-14.4 VIBRATION

Electrical equipment applications should be designed to prevent the transmission of whole-body vibration at levels above those that permit safe operation and maintenance as shown in Fig. 4-7. Acceptable levels of vibration for safety, proficiency, and comfort may be defined as follows[7]:

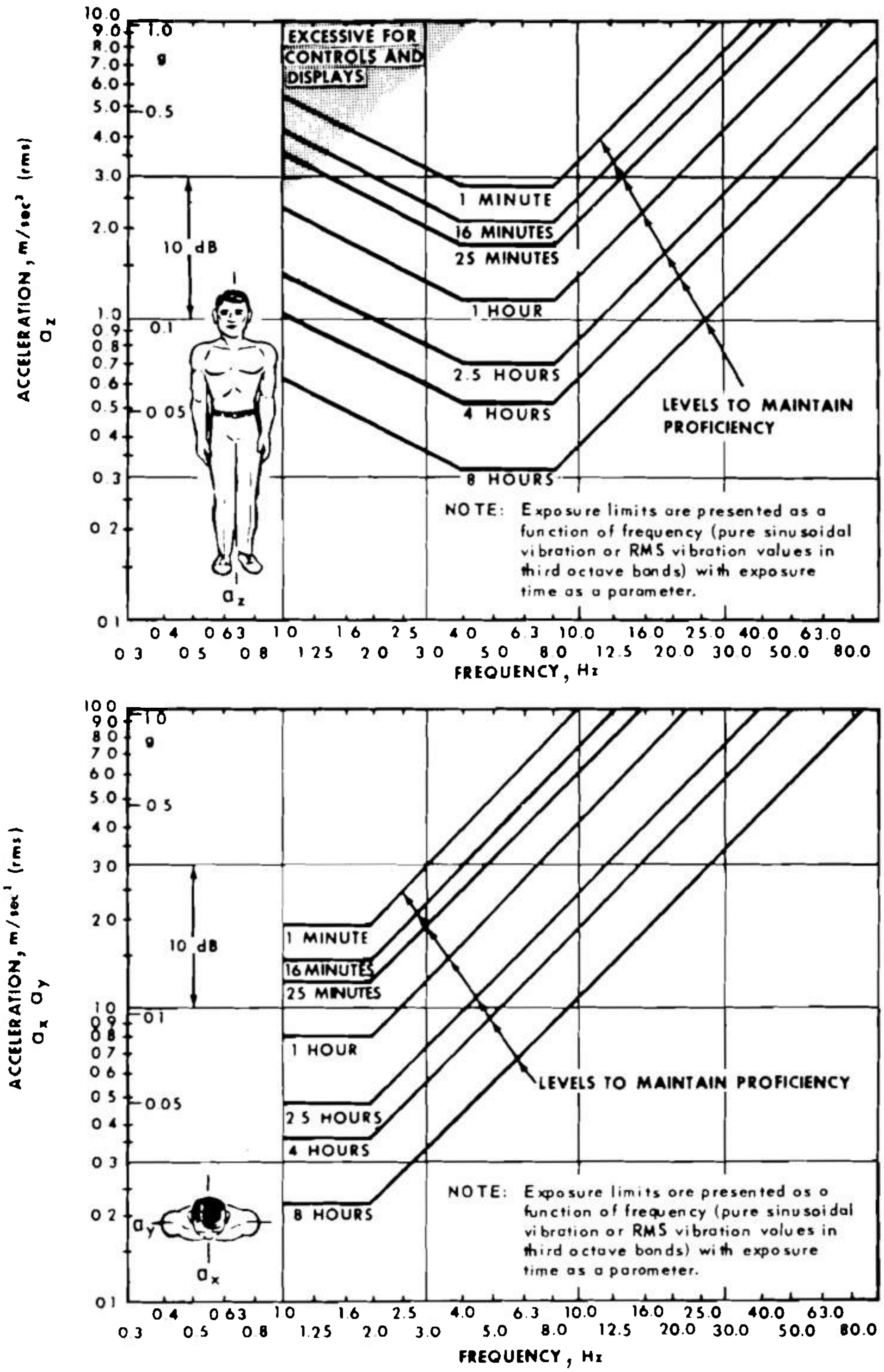


Figure 4-7. Vibration Exposure Criteria for Longitudinal (Upper Curve) and Transverse (Lower Curve) Directions With Respect to Body Axis[7]

1. Safety Limits. In order to protect human health, whole-body vibration should not exceed twice the acceleration values shown on Fig. 4-7 for the time and frequencies indicated.

2. Proficiency Levels. Where proficiency is required for operational or maintenance tasks, whole-body vibration should not exceed the acceleration values shown on Fig. 4-7 for time and frequencies indicated.

3. Comfort Level. Where comfort is to be maintained, the acceleration values should not exceed the value obtained when the proficiency level of Fig. 4-7 is divided by 3.15.

Where whole-body vibrations of the human operator or parts of his body are not a factor, equipment should be designed so that oscillations will not impair human performance with respect to control manipulations or the readability of numerals or letters. Such equipment should be designed to preclude vibrations in the shaded area of the upper curve of Fig. 4-7.

4-14.5 VENTILATION

Aside from the ventilation system interface normally encountered during the design of an electrical system (see Chapter 14), all other ventilation systems introduced to cool electrical equipment should be evaluated to establish that:

1. These systems do not produce unacceptable noise levels.

2. They do not produce air speeds (in excess of 65 fpm) that affect vehicle occupants adversely.

3. They do not produce significant temperature changes which degrade the working environment in the personnel compartment.

4-15 ANTHROPOMETRICS

Anthropometry is the study of human physical characteristics such as size, weight, or strength. These characteristics vary from person to person, and anthropometric measurements are usually expressed in terms of the ranges of sizes, weights, or strengths. The range is commonly expressed in terms of percentiles; a 5th percentile value means that 5 percent of the population measures less than the value and 95 percent measures greater, a 95th percentile value means 95 percent measures less than the value and 5 percent measures greater.

In designing an electrical system, a knowledge of the physical characteristics of the operator and maintenance personnel is essential. Early in the design concept, decisions must be made as to which functions should be allocated to man and which to machine. A knowledge of the limits of human arm strength, for example, can determine the need for a power-assist system. Once functions have been allocated and the design begins to take shape, the equipment must be designed to allow man to perform his tasks with adequate room and without undue physical stress. Anthropometric data will assist the designer in creating a satisfactory man-machine interface[7].

4-15.1 BODY DIMENSIONS

Any workspace must be designed to fit man and allow him to perform his tasks without undue restrictions in room and without undue stretching or reaching. The body dimensions of personnel using Army vehicle electrical equipment will be found in Refs. 5, 7, and 11. The latter reference is particularly helpful with arm reach limits. Use of the referenced body dimension data must take the following into consideration:

1. Nature, frequency, and difficulty of the related tasks

2. Position of the body during performance of these tasks

3. Mobility or flexibility requirements imposed by the tasks

4. Environment in which tasks will be performed

5. Clothing the personnel will be wearing.

In order to provide all operators with the required operating space, ideal workspaces are designed to accommodate both the large (95th percentile) and the small (5th percentile) man.

4-15.2 HUMAN STRENGTH

The strength required to perform a task should be less than the maximum strength of the weakest man. The maximum strength of the weakest man depends on several factors:

1. Body members used to exert the force

2. Body position when performing the task

3. Restrictions, such as clothing or cramped workspace

4. Environmental conditions, such as temperature and wetness

5. Frequency of operation.

Refs. 5 and 7 contain data on the maximum leg, hand, arm, and lifting strengths of a 5th percentile man. Additional data can be found in Ref. 11.

When the data in available reference sources do not match the task situation, then the designer should consult his human factors engineer and develop reliable data pertinent to the task in question. In order to develop data the task situation must be simulated as closely as possible, and a representative sample of the user population must be tested. The designer is then able to choose a strength value which an acceptable portion of the population can exert.

4-15.3 RANGE OF HUMAN MOTION

Electrical equipment design should allow operating and maintenance personnel to perform their tasks with adequate freedom of movement and yet not require movements that are beyond the normal range. The ranges, in angular degrees, for several types of voluntary movements can be found in Ref. 5. These ranges are somewhat high since they are based on measurements of lightly clothed personnel and do not account for the restrictions imposed by military clothing.

4-16 CONTROLS AND DISPLAYS

During the early phases of an electrical system design, it is important to consider the interface between men and machines in the system. In order to facilitate the man-machine relationship, controls and displays must be designed to interface with man as well as the machine. Due to the nature of his anthropometric, visual, auditory, and intellectual capabilities, man requires certain types of controls and displays to perform certain functions. Thus, HFE provides guidelines for designing controls and displays. Generally, the following items should be considered:

1. Control and display type

2. Control and display design

3. Control and display location.

4-16.1 CONTROL TYPES AND MOVEMENTS

The vehicle configuration will dictate the control function. Once the control function is determined, the electrical system designer can use HFE guidelines to select the type of control the operator will need to perform his function (see Table 4-3). Convention relates control movements to control function; a light switch for instance, is normally flipped up for "on". Deviations from these conventions may confuse the operator and cause delays and errors. Conventional control movements are listed in Table 4-4.

4-16.2 CONTROL DESIGN CRITERIA

Human factors engineering control design criteria are given in Fig. 4-8. Criteria for other

TABLE 4-3. RECOMMENDED MANUAL CONTROLS[5]

Control Function	Control Type
Small actuation force controls	
2 Discrete positions	Key lock
	Push button
	Toggle switch
	Legend switch
2 Discrete positions	Rotary selector switch
	Toggle switch
4 to 24 Discrete positions	Rotary selector switch
Continuous setting (linear and	Continuous rotary knob
less than 360 deg)	Joystick or lever
Continuous slewing and fine	Crank
adjustment	Continuous rotary knob
Large actuation force controls	
2 Discrete positions	Foot push button
	Hand push button
	Detent lever
3 to 24 Discrete positions	Detent lever
	Rotary selector switch
Continuous setting (linear and	Handwheel
less than 360 deg)	Joystick or lever
	Crank
	Two axis grip handle
Continuous setting (more	Crank
than 360 deg)	Handwheel
	Valve
	Two axis grip handle
Elevation setting	Crank
	Handwheel
	Joystick or lever
	Two axis grip handle

TABLE 4-4. CONVENTIONAL CONTROL MOVEMENTS[5]

Function	Direction of Movement
On	Up, right, forward, clockwise, pull (push-pull type switch)
Off	Down, left, rearward, counterclockwise, push
Right	Clockwise, right
Left	Counterclockwise, left
Raise	Up, back
Lower	Down, forward
Retract	Up, rearward, pull
Extend	Down, forward, push
Increase	Forward, up, right, clockwise
Decrease	Rearward, down, left, counterclockwise

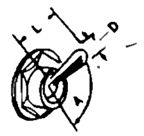
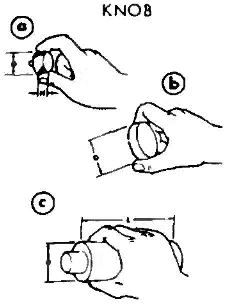
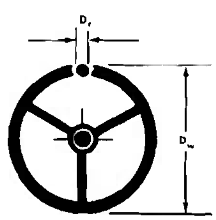
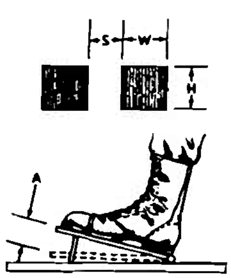
		MINIMUM	MAXIMUM	OPTIMUM
TOGGLE SWITCH 	DIMENSIONS			
	Tip Diameter (D)	0.125 in.	1.0 in.	--
	Lever Arm Length (L)			
	Bare Finger	0.5 in.	0.625 in.	--
	Gloved Finger	0.625 in.	0.625 in.	--
	RESISTANCE	10 oz	40 oz	--
	DISPLACEMENT (A)			
	Between Adjacent Position	30°	--	--
	Total	--	120°	--
	SEPARATION			
	One Finger-Random Order	0.75 in.	--	2.0 in.
	One Finger-Sequential Order	0.5 in.	--	1.0 in.
	Different Fingers-Random or Sequential Order	0.625 in.	--	0.75 in.
KNOB 	DIMENSIONS			
	a Fingertip Grasp			
	Height (H)	0.5 in.	1.0 in.	--
	Diameter (D)	0.375 in.	4.0 in.	--
	b Thumb and Finger Encircled			
	Diameter (D)	1.0 in.	3.0 in.	--
	c Palm Grasp			
	Length (L)	3.0 in.	--	--
	Diameter (D)	1.5 in.	3.0 in.	--
	RESISTANCE			
	1.0 in. Diameter or Smaller	--	--	4.5 in.-oz
	Larger than 1.0 in. Diameter	--	--	6.0 in.-oz
	SEPARATION			
	One Hand-Random Order	1 in.	2 in.	--
	Two Hands Simultaneously	3 in.	5 in.	--
LEVERS 	DIAMETER (D)			
	Finger Grasp	0.5 in.	3.0 in.	--
	Hand Grasp	1.5 in.	3.0 in.	--
	RESISTANCE			
	d-1 One Hand	2.0 lb	30.0 lb	--
	d-1 Two Hands	2.0 lb	60.0 lb	--
	d-2 One Hand	2.0 lb	20.0 lb	--
	d-2 Two Hands	2.0 lb	30.0 lb	--
	DISPLACEMENT (A)			
	Forward (d-1)	--	14 in.	--
	Lateral (d-2)	--	38 in.	--
	SEPARATION			
	One Hand-Random	2.0 in.	4.0 in.	--
	Two Hands-Simultaneously	3.0 in.	5.0 in.	--
STEERING WHEEL 	DIMENSIONS			
	Wheel Diameter (Dw)	2.0 in.	7.0 in.	--
	One Hand	4.25 in.	21.0 in.	--
	Two Hands	0.75 in.	2.0 in.	--
	Rim Diameter (Dr)			
	RESISTANCE			
	One Hand	5.0 lb	30.0 lb	--
	Two Hands	5.0 lb	50.0 lb	--
	DISPLACEMENT			
	One Hand	--	--	--
	Two Hands	--	120°	--
	SEPARATION-TWO HANDS SIMULTANEOUSLY	3 in.	5 in.	--
PEDALS 	DIMENSIONS			
	Height (H)	1.0 in.	--	--
	Width (W)	3.0 in.	--	--
	RESISTANCE			
	Foot Not Resting on Pedal	4.0 lb	20.0 lb	--
	Foot Resting on Pedal	10.0 lb	20.0 lb	--
	Ankle Flexation Only	--	10.0 lb	--
	Total Leg Movement	10.0 lb	180.0 lb	--
	DISPLACEMENT (A)			
	Normal Operation	0.5 in.	2.5 in.	--
	Heavy Boots	1.0 in.	2.5 in.	--
	Ankle Flexation	1.0 in.	2.5 in.	--
	Total Leg Movement	1.0 in.	7.0 in.	--
	SEPARATION (S)			
	One Foot-Random	4.0 in.	--	6.0 in.
	One Foot-Sequential	2.0 in.	--	4.0 in.
	Two Feet-Simultaneously	6.0 in.	--	8.0 in.

Figure 4-8. Control Design Criteria[5,7]

types of controls can be found in Refs. 5 and 7.

Handles are a special type of control through which man directly exerts mechanical force on equipment items. All handles should meet or exceed the minimum applicable dimensions shown in Fig. 4-9.

4-16.3 CONTROL LOCATION

Controls vital to the system performance or those requiring the greatest amount of use, speed, strength, or precision should be placed in optimum locations for the operator. When there is no definite sequence of operation, controls can most easily be found by the operator if they are grouped by function. When there is a definite sequence of operation, controls are easier to use if they are arranged from left to right or top to bottom by sequence.

4-16.3.1 SEATED OPERATION

The optimum and maximum locations of foot and hand controls for the seated operator are shown in Fig. 4-10[12]. Controls in the optimum area can be reached easily and operated quickly; this area should be reserved for primary and emergency controls. Controls in the maximum area are within the reach of 90% of the operator population; however, they are less easily reached and take longer to operate.

Fig. 4-10 assumes a 4-in. horizontal seat adjustment, a 10-deg seat back angle, a 5-deg seat cushion angle, and a 2-in. seat cushion deflection. The seat reference point is shown for an undeflected cushion and at the center of the seat adjustment.

4-16.3.2 STANDING OPERATION

The optimum and maximum locations of hand controls for the standing operator are shown in Fig. 4-11. Because of difficulties in retaining balance, foot controls should not be designed for use by a standing operator.

4-16.4 VISUAL DISPLAY

Selection of the proper type of visual display will depend on the information to be presented (see Table 4-5).

4-16.5 VISUAL DISPLAY DESIGN

Human factors engineering design criteria for the visual displays are given in Table 4-6. Additional design criteria can be found in Refs. 5, 7, 13, and 15. Even though the electrical system designer may not be required to design a particular display, these criteria can be used in the selection of off-the-shelf equipment.

4-16.6 VISUAL DISPLAY LOCATION

Visual displays should be located within the viewing areas indicated in Fig. 4-12. The optimum viewing area should be reserved for emergency displays or displays requiring close monitoring.

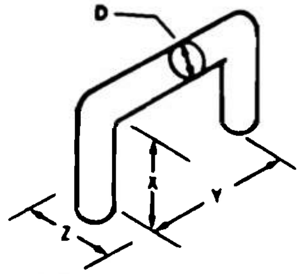
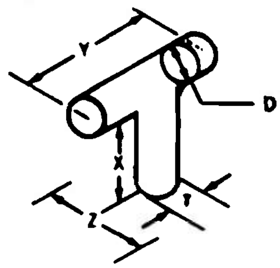
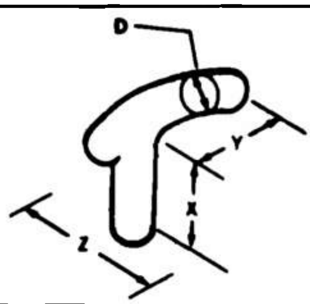
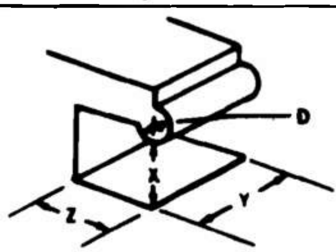
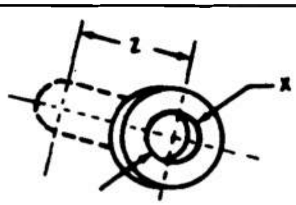
The viewing distance to displays located close to their associated controls is limited by reach distance and should not exceed 28 in. Otherwise, there is no maximum limit other than that imposed by space limitations, provided the display is properly designed. The minimum viewing distance to displays should be not less than 10 to 12 in. for short viewing periods, and preferably not less than 16 in.

Displays should be mounted perpendicular to the line of sight. Angular deviation from the line of sight up to 45 deg may be acceptable, provided accurate instrument reading is not essential and parallax is not too great.

4-16.7 AUDITORY WARNINGS

Auditory warnings, indicating a hazardous condition or conditions that require immediate corrective action, should meet the following three requirements[7]:

1. They should be used with a warning light. An auditory signal may be used without an accompanying warning light when there is

ILLUSTRATIONS	TYPE OF HANDLE	DIMENSIONS, IN.								
		(Bare Hond)			(Gloved Hand)			(Mittened Hand)		
		X	Y	Z	X	Y	Z	X	Y	Z
	Two-finger Bar	1.25	2.5	3.0	1.5	3.0	3.0	Not Applicable		
	Two-hand Bar	2.0	4.5	3.0	3.5	5.25	4.0	3.5	5.25	6.0
	One-hand Bar	2.0	8.5	3.0	3.5	10.5	4.0	3.5	11.0	6.0
	T-bar	1.5	4.0	3.0	2.0	4.5	4.0	Not Applicable		
	J-bar	2.0	4.0	3.0	2.0	4.5	4.0	3.0	5.0	6.0
	Two-finger Recess	1.25	2.5	2.0	1.5	3.0	2.0	Not Applicoble		
	One-hand Recess	2.0	4.25	3.5	3.5	5.25	4.0	3.5	5.25	5.0
	Finger-tip Recess	0.75		0.5	1.0		0.75	Not Applicable		
	One-finger Recess	1.25		2.0	1.5		2.0	Not Applicable		

Curvoture of Hondle or Edge:	Weight of Item	Diometer (Minimum)	
	Up to 15 lb	D – 1/4 in.	Gripping efficiency is best if finger con curl around hondle or edge to any angle of 120 degrees or better.
	15 to 20 lb	D – 1/2 in.	
	20 to 40 lb	D – 3/4 in.	
	Over 40 lb	D – 1 in.	
	T-bor Post:	T – 1/2 in.	

Figure 4-9. Minimum Handle Dimensions[5,7]

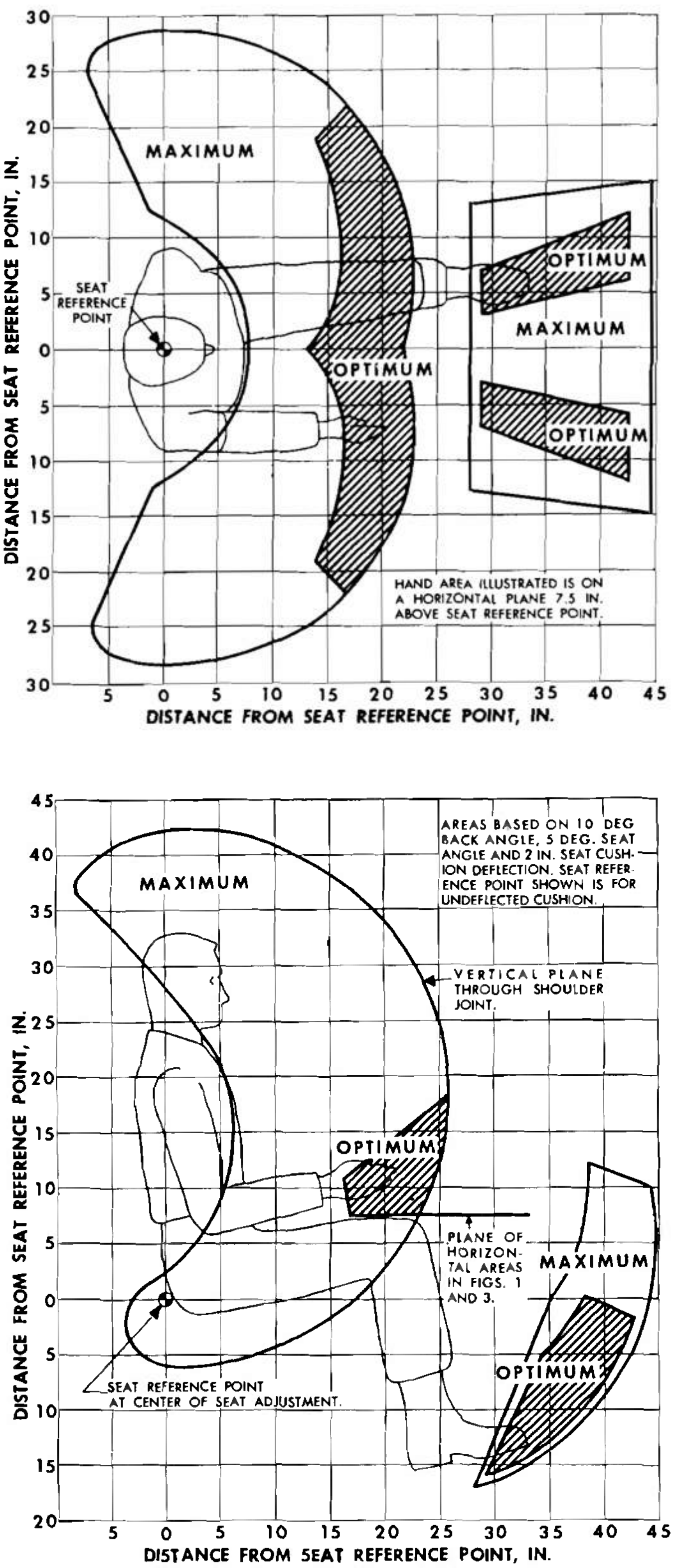


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Figure 4-10. Optimum and Maximum Foot and Hand Control Locations for Seated Operator[1 2]

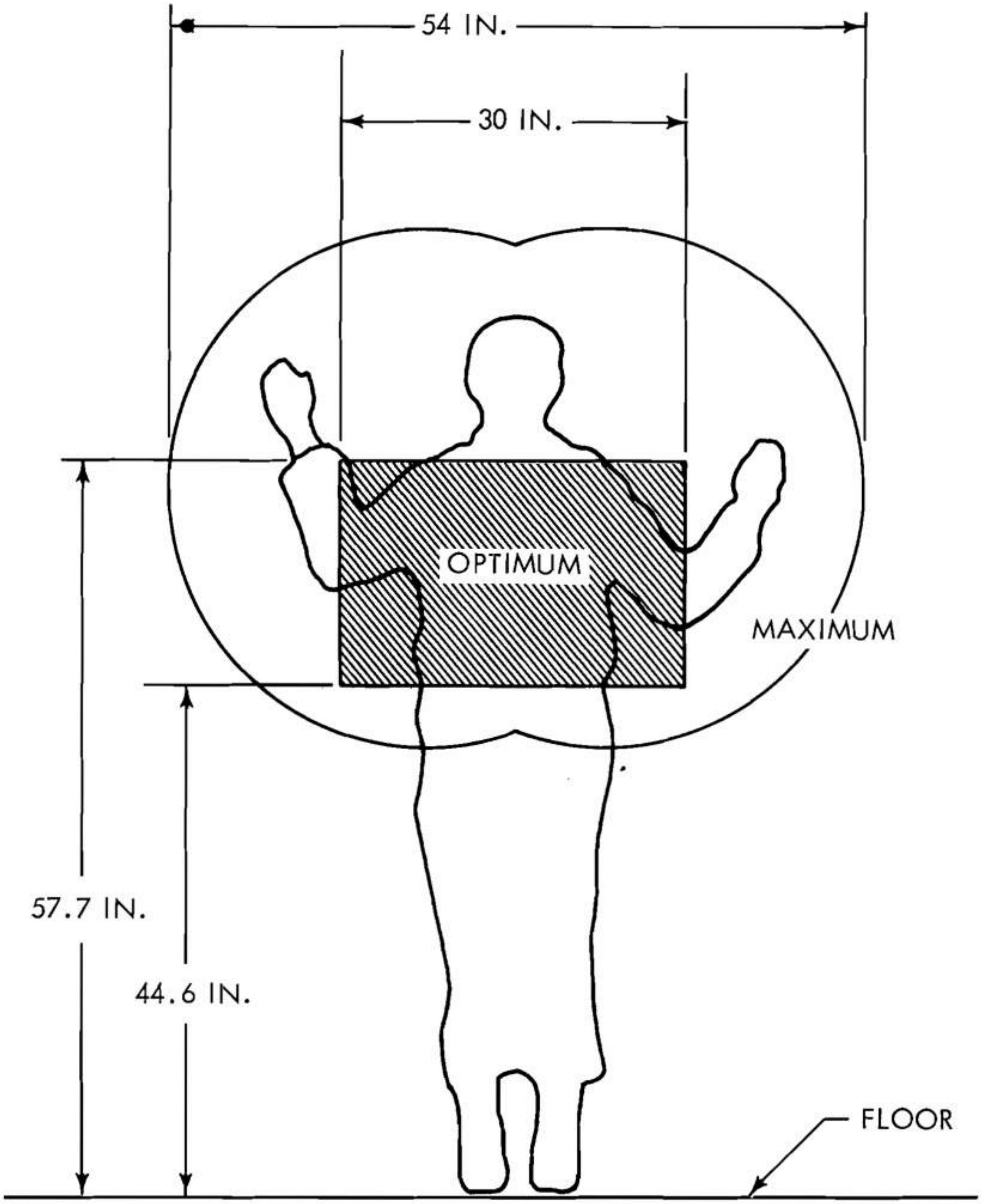


Figure 4-11. Optimum and Maximum Hand Control Locations for Standing Operator[13]

only one extreme emergency condition (e.g., vehicle on fire, "get out") but in such cases there should not be any other auditory signals in the vehicle.

2. Warnings should be easy to distinguish from background noises and easy to recognize. As a general rule, all warning signals should be louder than the ambient noise so they can be detected and identified immediately. In noisy locations, the warning signal should be about 20 dB above noise level. As a maximum, however, signals must be kept *well below* the human pain threshold, which is approximately 130 dB[7].

3. The frequency of the master warning signal should vary as indicated in Fig. 4-13. If

TABLE 4-5. GUIDES FOR VISUAL DISPLAY SELECTION[13,14]

To display	Use
Direction of movement or orientation in space Increasing or decreasing trends	Dials scales Gages meters
Exact quantity of slowly changing information	Digital counter
Movement of object Frequency or amplitude waves	Cathode ray tubes
Go, no-go status On-off	Mechanical flag
Go, no-go status On-off Warm-up status Warning or caution Identification	Indicator lights
Unchanging qualitative or quantitative information	Printed material

several warning signals are required, personnel can readily differentiate the following sounds:[5]

a. 160 ± 50 Hz tone interrupted at a rate of 1 to 10 Hz

b. 900 ± 50 Hz steady tone, plus 1600 ± 50 Hz interrupted at a rate of 0 to 1 Hz

c. 900 ± 50 Hz steady tone

d. 900 ± 50 Hz steady tone, plus 400 ± 50 Hz tone interrupted at a rate of 0 to 1 Hz

e. 400 ± 50 Hz tone interrupted at a rate of 1 to 10 Hz.

4-17 COMMUNICATION SYSTEMS

Voice communication is the most common method of requesting and providing information. In military vehicle systems, voice communication is transmitted in two ways:

1. Electrically, using radio or telephone

2. Directly, operator to operator.

4-17.1 SELECTION OF COMMUNICATION EQUIPMENT

The type of equipment needed to effectively transmit voice communications will depend largely on the ambient noise level. Table 4-7 indicates communication facilities required for various ambient noise levels. Noise limits, in terms of octave band sound pressure levels, for nonelectrically aided speech communication can be found in Ref. 17.

4-17.2 SPEECH SIGNAL TRANSMISSION

The nature of electrical transmission of speech signals will determine speech intelligibility. The following factors from Refs. 4 and 13 should be considered (further information can be found in Ref. 6):

1. Frequency. The part of the speech spectrum most essential to intelligibility is 150 to 6000 Hz. An acceptable frequency range for intelligibility is the band 200 to 4500 Hz.

2. Range. The dynamic range of a microphone should be great enough to admit variations in signal input of at least 30 dB and preferably 40 to 50 dB.

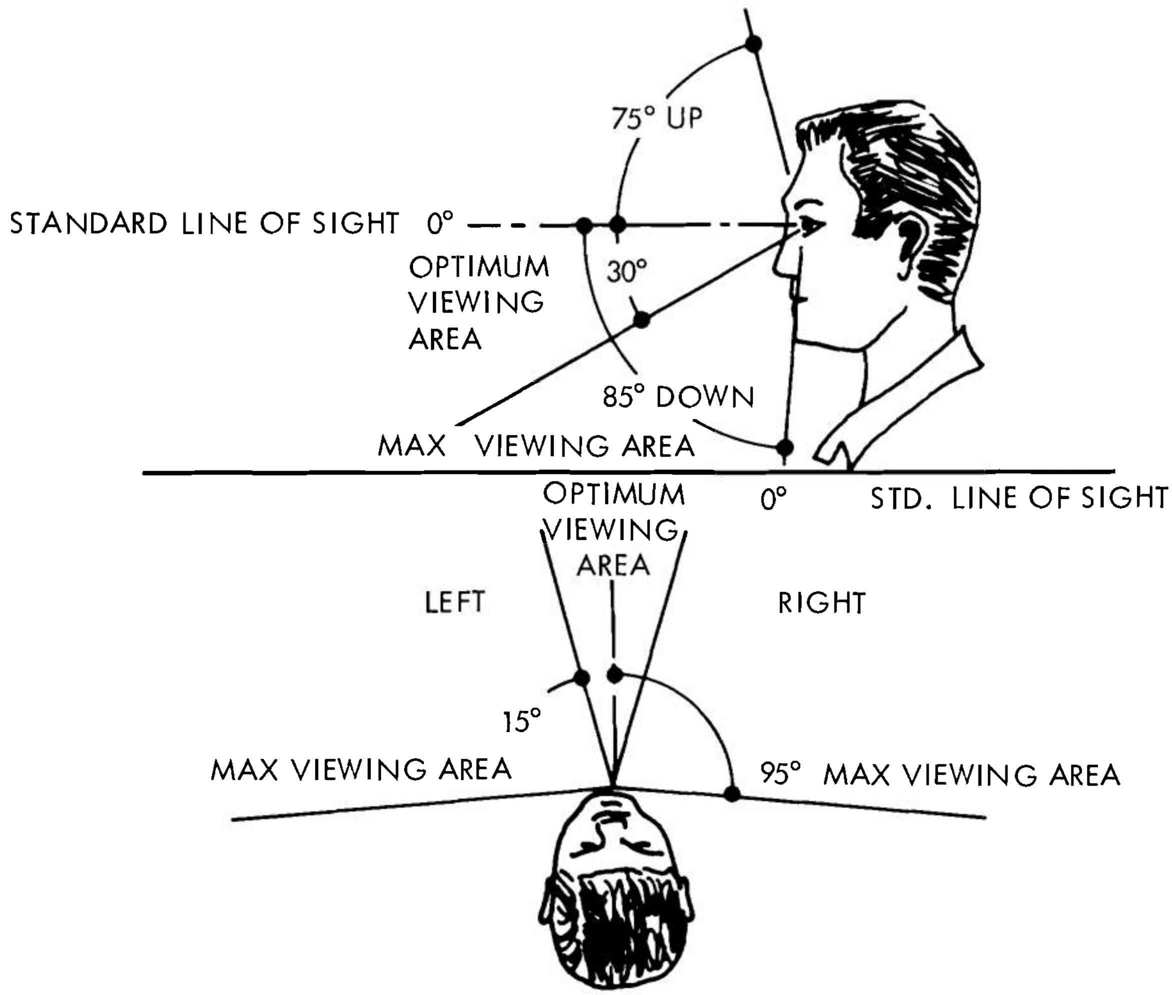
3. Frequency Response. As a minimum, a frequency response of ± 3 dB over the range of 300 Hz to 4500 Hz is satisfactory.

4. Speech to Noise Ratio. In high noise environment, noise-cancelling microphones should be used and should be capable of effecting an improvement of not less than 10 dB peak-speech to root-mean-square-noise ratio as compared with nonnoise-cancelling microphones of equivalent transmission characteristics. The signal at the ear should not exceed 105 dB.

5. Pre-emphasis and De-emphasis. If necessary, speech system input devices should

TABLE 4-6. VISUAL DISPLAY DESIGN RECOMMENDATIONS

Display	Recommended design characteristics
Digital counter	Snap-action change Maximum rate for consecutive reading - 2 displays per second Automatic as well as manual reset for sequencing counter Character dimensions: see "Printed Material" Brightness of display lighting o Dark adaptation necessary . . . . 0.02 to 0.1 ft-L* o Dark adaptation desirable . . . . 0.02 to 1.0 ft-L o Dark adaptation not necessary . . . . . 1.0 to 20.0 ft-L
Mechanical flag	Snap-action 50% brightness contrast with background, minimum Close to panel surface as possible Provisions for testing operation
Dials scales, gages, meters	Two types: o Moving pointer, fixed scale - preferred o Moving scale, fixed pointer - not desirable Scale design: o Precision and range meets viewer's information needs o Numerical increase: clockwise, left to right, or bottom to top (moving scale should move counterclockwise, right to left, or top to bottom) o Numerical progression by 1's, 5's, 10's, 100's is optimum o May be coded by color or pattern o Numerals on opposite side of graduation marks from pointer o Graduation mark dimensions (Ref. 5) o 50% brightness contrast between markings and background, minimum Pointer design: o Tip width same as smallest graduation mark o Tip never more than 1/16-in. from graduation mark and not covering numerals o Pointer located below, at center or to right of scale o 50% brightness contrast minimum Brightness of display lighting: see "Digital Counter"
Indicator lights	Provisions for testing operation Rapid and easy bulb change without tools Information normally relayed through presence of light, NOT absence of light Brightness: o Minimum . . . . 10% greater than surroundings o Maximum . . . 300% greater than surroundings Color Coding: o Green. . . . . . . go o White. . . . . . . neutral, indicates status o White Flashing. communication alert o Yellow . . . . . caution o Red . . . . no go o Red flashing . emergency
Cathode ray tube	Complex targets subtend less than 20 deg visual angle Viewing distance: 12 to 16 in. optimum Screen size: o 2- to 5-in. diameter . . . . infrequent calibration or tuning o 5- to 7-in. diameter . . . . adequate when plotting not required o 10- to 12-in. diameter . . . for plotting or multiple operators Surrounding illumination: o Do not degrade target visibility See Ref. 8 for more information
Printed material	Horizontal orientation Content: o Brief o Accurate o In terms familiar to operator All capital letters, except for extended copy Type style shall conform to Ref. 15 Color: o Ambient light above 1 ft-c† . . . . . Black on light o Ambient light below 1 ft-c . . . . . White on dark Character height (inches) minimum. o Minimum height increases linearly with view distance o 28-in. viewing distance: Low brightness (below 1 ft-L) / High brightness (above 1 ft-L) Critical Marking with variable position: 0.20-0.30 / 0.12-0.20 Critical Marking with fixed position: 0.15-0.30 / 0.10-0.20 Noncritical marking: 0.05-0.20 / 0.05-0.20 Character width: 3/5 height (except I, W, 1, and 4) Stroke width: 1/6 height (dark letters) 1/7 or 1/8 height (light letters) * ft-L = foot-lambert † ft-c = foot-candle



OPTIMUM*, deg		MAXIMUM: Eye Rotation Only, deg	MAXIMUM: Head and Eye Rotation, deg
Up	0	25	75
Down	30	35	85
Right	15	35	95
Left	15	35	95

*Display Area Defined by Angles Measured From Standard Line of Sight

Figure 4-12. Optimum and Maximum Visual Display Locations[13]

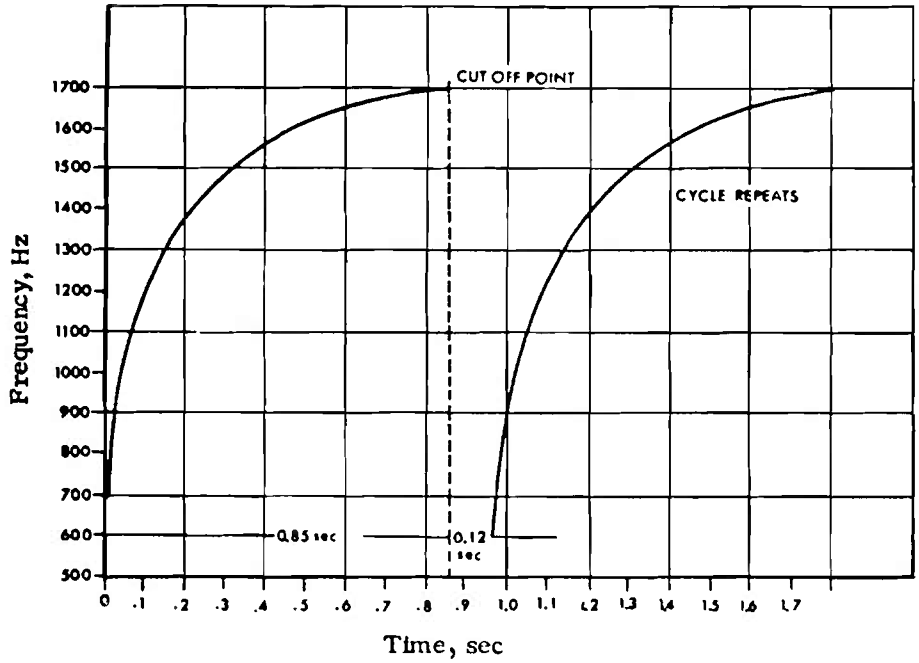


Figure 4-13. Recommended Frequency Characteristics for Auditory Master Warning Signals[5]

employ frequency pre-emphasis with a positive slope frequency characteristic of no greater than 9 dB per octave over the frequency range of 140 to 4,800 Hz. When transmission equipment employs pre-emphasis, and peak-clipping is not used, reception equipment should employ frequency de-emphasis of characteristics complementary to those of pre-emphasis only if it improves intelligibility; i.e., de-emphasis should be a negative-slope frequency response not greater than 9 dB per octave over the frequency range of 140 to 4,800 Hz.

6. Peak Clipping. Where speech signals are to be transmitted over channels showing less than 15 dB peak-speech to root-mean-square-noise ratios, peak-clipping of 12 to 20 dB may be employed at the system input and may be preceded by frequency pre-emphasis.

4-17.3 INTELLIGIBILITY MEASUREMENTS

Speech intelligibility through communication systems can be measured in two ways:

1. Direct Testing. Selected words are spoken into the system and a listener records what he hears. Comparison is then made between what is heard and what has been spoken.

2. Prediction. An articulation index is calculated from the intensities of the speech signal and the ambient noise.

A detailed description of these measurements is given in Ref. 6.

TABLE 4-7. VOICE COMMUNICATION CAPABILITIES IN VARIOUS LEVELS OF AMBIENT ACOUSTIC NOISE[16]

Communication facility	Noise Level Ranges, dB (A)				
	50-70	70-90	90-110	110-130	130
Face-to-face	Speakers may be separated by more than 3 ft	Some effort required for good communication to be maintained over 1 to 3 ft	Maximum satisfactory communication distance is 1 ft	Very difficult to impossible	Impossible
Conventional 1C squawk box	Satisfactory to difficult	Unsatisfactory	Impossible	Impossible	Impossible
Conventional 1C telephone	Satisfactory to slightly difficult	Difficult to unsatisfactory	Press-to-talk and acoustic booth needed	Special transducers needed	Impossible
Type microphone required	No special microphone needed for satisfactory communication	Any microphone satisfactory, including earphone used as microphone and bone contact	Any microphone. If earphone used as microphone, put under ear protector. If bone contact, under helmet	Good noise-cancelling microphones will reach 125 dB on short time	Noise-cancelling microphone in noise shield
Type earphone required	Any phone satisfactory	Any	Any, except bone conductors. Must be in helmet or adequate muff	Insert or over-ear earphones in good helmets or muffs good to 120 dB(A) on short time basis	Best insert or over-ear phones in best helmet or muff, good to 140 dB(A) on short term basis
Type loudspeaker required	Any	Good quality speaker needed for adequate intelligibility	Must be inside helmet or ear protector. If held up to ear, good up to 100 dB(A)	Inadequate	Inadequate
Special circuitry required	None	None	Use 6 dB/octave high frequency pre-emphasis	Pre-emphasis; speech clipping and noise-activated AGC for listener	Pre-emphasis; speech clipping and noise-activated AGC for listener

SECTION V SAFETY

4-19 INTRODUCTION

Safety is defined as "freedom from those hazard conditions which can cause injury or death to personnel, damage or loss to equipment or property"[18]. It is pointed out that safety involves preservation of equipment as well as of man.

The design and development of a safe system is implemented through a system safety engineering effort. System safety engineering involves "the application of scientific and engineering principles for timely identification of hazards and initiation of those actions necessary to prevent or control hazards within the system"[18].

Although a system safety engineering effort involves many design disciplines – such as reliability, maintainability, human factors, and quality control – responsibility for timely prevention and control of hazards lies largely with the designer. It is the purpose of this section, therefore, to supply the electrical system designer with guidelines for a safe design.

For clarity and convenience, these guidelines are divided into two categories:

1. Guidelines for personnel safety, to prevent death or injury to personnel.

2. Guidelines for equipment safety, to prevent damage or loss to equipment and property.

Additional safety design criteria can be found in Refs. 19 and 20.

4-20 PERSONNEL SAFETY

Consideration for man's working environment involves both personnel safety and human factors engineering. Generally, the dividing line is determined by the degradation intensity of the environment.

4-20.1 ELECTRICAL SHOCK

The principal electrical hazard to guard against is shock. Even a small shock is dangerous. Burns or nervous-system injuries are not the only possible effects; equipment damage and additional physical harm to personnel may also result from the involuntary reactions that accompany electrical shock.

The effect of electrical shock will depend on the resistance of the body, the current path through the body, the duration of the shock, the amount of current and voltage, the frequency of the current, and the physical condition of the individual. Shock current intensities and their effects are given in Table 4-8. Alternating current potentials exceeding 30 V root-mean-square or direct current potentials above 42 V present possible electrical shock hazards. Protective measures against shock hazards are summarized in Table 4-9.

All electrical equipment, regardless of voltages, should have a main power ON-OFF switch readily available and clearly marked. The design and construction of electrical equipment should also insure that all external parts, surfaces, and shields, exclusive of antenna and transmission line terminals, are at ground potential at all times during normal operation. Proper grounding and bonding techniques are covered in Chapter 18 where the intention of such techniques is to reduce electromagnetic interference. These techniques are generally more stringent from the design viewpoint than shock hazard grounding and will preclude shock hazard potentials. Individual efforts to reduce shock hazard and electromagnetic interference must be coordinated to prevent the inadvertent introduction of ground loops which could cause interference between electrical components on a single vehicle. Further details on protective measures can be found in Refs. 13, 21, 31, 44, 45, and 46.

TABLE 4-8. PROBABLE EFFECTS OF ELECTRICAL SHOCK[21]

Current values, mA		Effects
AC 60 Hz	DC	
0-1	0-4	Perception
1-4	4-15	Surprise
4-21	15-80	Reflex action
21-40	80-160	Muscular inhibition
40-100	160-300	Respiratory block
Over 100	Over 300	Usually fatal

4-20.2 FIRE, EXPLOSION, AND TOXIC FUME HAZARDS

The potential hazards from fire, explosion, or toxic fumes can be reduced if the vehicle electrical system design is prepared within the guidelines of safe practice described in the paragraphs that follow.

4-20.2.1 TOXIC MATERIALS

Avoid selecting materials that will liberate toxic gases or liquids under adverse operating conditions. For example, selenium rectifiers liberate a toxic gas when shorted. Data on toxic agents can be found in Ref. 23. However, since toxicology is a complex science sometimes involving life and death, the designer should consult a professional toxicologist for data pertaining to specific conditions.

4-20.2.2 WIRING

When selecting wiring for vehicular electrical systems, give consideration to high physical strength, high temperature resistance, high dielectric strength, and high abrasion resistance. Refer to Chapter 8 and to AMCP 706-125, Engineering Design Handbook, *Electrical Wire and Cable*[47] for wire selection and cable design. Specify frequent wiring supports to prevent chafing and to prevent the free end of a broken wire from contacting grounded metal surfaces. Use conduits for maximum protection of wiring in inaccessible or hazardous areas. The conduit should be large enough to permit growth in wire bundle size. Protection also can be achieved with heavy duty binding or jacket material over the wire bundle[19].

4-20.2.3 TERMINAL POINTS

Design all electrical terminal points to eliminate the possibility of a short circuit and the arcing which usually accompanies it. Protect terminal boards from being inadvertently short-circuited by operating personnel and from loose material becoming lodged in

TABLE 4-9. ELECTRICAL HAZARD PROTECTIVE MEASURES[21]

Voltage Range, V \ Type of Protection	None(1)	Guards and Barriers	Enclosures	Marking Voltage Warning	Interlocks		Discharge Devices		Step-Down Devices (voltage measurement)
					With bypass	No bypass(2)	Automatic	Ground rods	
0 – 30	x								
30+ – 70	x						x		
70+ – 500		x		x	x		x	x	
500+ – 1000			x	x	x	x	x	x	
1000+ up			x	x	x	x	x	x	x

(1) Although no specific requirements exist for servicing from 0 – 70, V designs should be reviewed for possible hazard in accordance with Table 4-8.

(2) Designs may use "No bypass" interlock applications below 500 V, but the intent is to imply complete enclosure.

terminal points. The most reliable person may unintentionally drop bits of safety wire, nuts, and other small items into inaccessible areas during maintenance. Provide adequate protection of electrical terminal points to prevent foreign objects from entering electrical junctions. To protect exposed electrical junctions, design connectors so that when they are disengaged, the socket inserts are energized "hot" and the pin inserts are de-energized[19].

4-20.2.4 COMBUSTIBLE MATERIALS

High-power electrical components may be potential ignition sources for combustible solids or flammable fluids when resistance heating occurs due to a malfunction. Insure that such electrical components are not fabricated from combustible material and that they are shielded or located away from combustibles. Provide overheat protection if equipment case temperatures, in a failure mode, can approach the autogenous ignition temperature of the surrounding materials. Insure that the materials used in the equipment cannot combine with elements of the operating environment to form toxic, corrosive, or combustible fumes[19].

4-20.2.5 EXPLOSION-PROOF APPARATUS

Insure that electrical apparatus located in an area likely to contain flammable fluids or vapors from any source is explosion proof. Explosion-proof apparatus is defined as: "Apparatus enclosed in a case which is capable of withstanding an explosion of a specified gas or vapor which may occur within it and of preventing the ignition of a specified gas or vapor surrounding the enclosure by sparks, flashes, or explosion of the gas or vapor within, and which operates at such an external temperature that a surrounding flammable atmosphere will not be ignited thereby"[20].

4-20.2.6 EXTINGUISHING AGENTS

Fire occurring in electrical equipment must be extinguished by a material that will not conduct electricity. Suitable extinguishing agents are carbon dioxide, dry powder, and monobromotrifluormethane. Unsuitable are foam, soda acid, and hand pump tanks with antifreeze solutions[24].

4-20.3 SHARP CORNERS AND EDGES

In accordance with Ref. 7, exposed equipment edges and corners should be rounded to prevent personnel injury (see Fig. 4-14).

4-20.4 SURFACE TEMPERATURE

Surfaces which personnel may inadvertently touch should be below 140°F; surfaces which personnel may handle should be below 120°F. Table 4-10 shows the effects on the skin of personnel coming in contact with surfaces at different temperatures.

4-20.5 NOISE

Exposure to high noise levels can permanently damage hearing acuity. Electrical

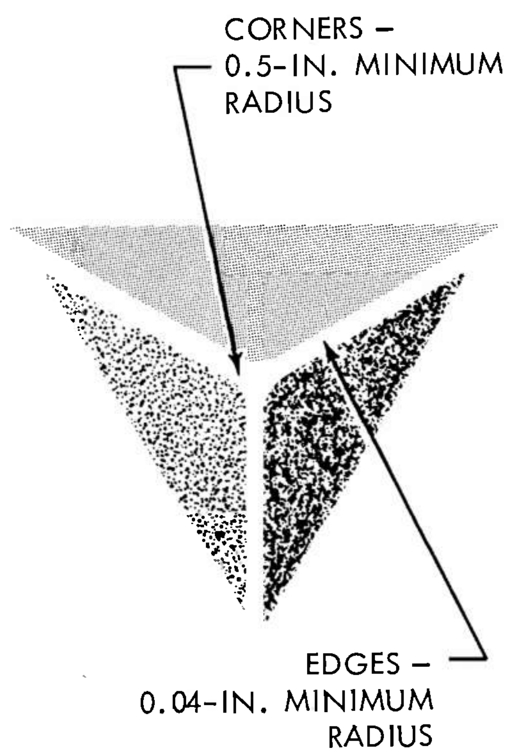


Figure 4-14. Minimum Rounding Dimensions for Sharp Corners

TABLE 4-10. SURFACE TEMPERATURE EFFECT ON HUMAN SKIN[13]

Temperature, °F	Sensation or Effect
212	2nd-degree burn on 15-sec contact
180	2nd-degree burn on 30-sec contact
160	2nd-degree burn on 60-sec contact
140	Pain; tissue damage (burns)
120	Pain; "burning heat"
91±4	Warm; "neutral" (physiological zero)
54	Cool
37	"Cool heat"
32	Pain
Below 32	Pain; tissue damage (freezing)

equipment should be designed so that personnel are not exposed to noise levels exceeding the limits for steady-state noise shown in Fig. 4-15. These noise levels are approximately equal to an A-weighted sound level of 85 dB when measured with a standard sound level meter[17].

Vehicle personnel wearing noise attenuating communication headsets should not be exposed to noise levels in excess of the limits prescribed in Fig. 4-16. Noise levels in this figure are approximately equal to an A-weighted sound level of 95 dB[17].

4-20.6 RADIATION

New trends in radar, communication, and display equipment are resulting in greater particulate and electromagnetic radiation hazards. For this reason, the electrical system designer should be aware of radiation hazards and the means for controlling these hazards.

Personnel limits for electromagnetic and ionizing radiation can be found in Table 4-11. Definitions and explanations can be found in Refs. 8, 29, and in the Glossary.

Measures for protection of personnel against radiation hazards include precautionary procedures and personal monitoring, shielding personnel from the source, and the use of signs, labels, and signals. Consult Refs. 8, 28, and 29 for details. Chapter 18 discusses the material aspects of radiation.

Protective devices, permissible dosages, and dosage rates change as new data accumulates; therefore, designers should contact the office of the U.S. Army Surgeon General for the latest available data.

4-21 EQUIPMENT SAFETY

Prevention of equipment damage or loss because of unsafe conditions involves application techniques, material selection, and environmental protective measures. Some of the more important factors are discussed in the paragraphs that follow.

4-21.1 CABLE AND WIRE ROUTING

Electrical wires and cables can be routed to decrease their susceptibility to damage through user abuse or adverse mechanical and environmental conditions. Some recommended design practices are:

1. Cables should be routed or protected in such a way that they will not be pinched by doors, lids, etc.; walked on, used for hand holds, or bent or twisted sharply or repeatedly.

2. If it is necessary to route cables and wires through holes in metal partitions, the conductors should be protected from cuts, damage, or wear. Grommets or equivalent devices are recommended.

TABLE 4-11. PERMISSIBLE RADIATION EXPOSURES[27, 29]

	Rem* per Calendar Quarter
Ionizing radiation	Whole body: head and trunk; active blood-forming organs; lens or gonads -- 1.25 Hands and forearms; feet and ankles ---18.75 Skin of whole body ---------------------------- 7.5
Electro-magnetic (nonionizing) radiation	Power density: 10 mW/cm² for periods of 0.1 hr or more Energy density: 1 mW-hr/cm² during any 0.1-hr period

*Rem = roentgen equivalent man, i.e., a dose unit of biological effect.

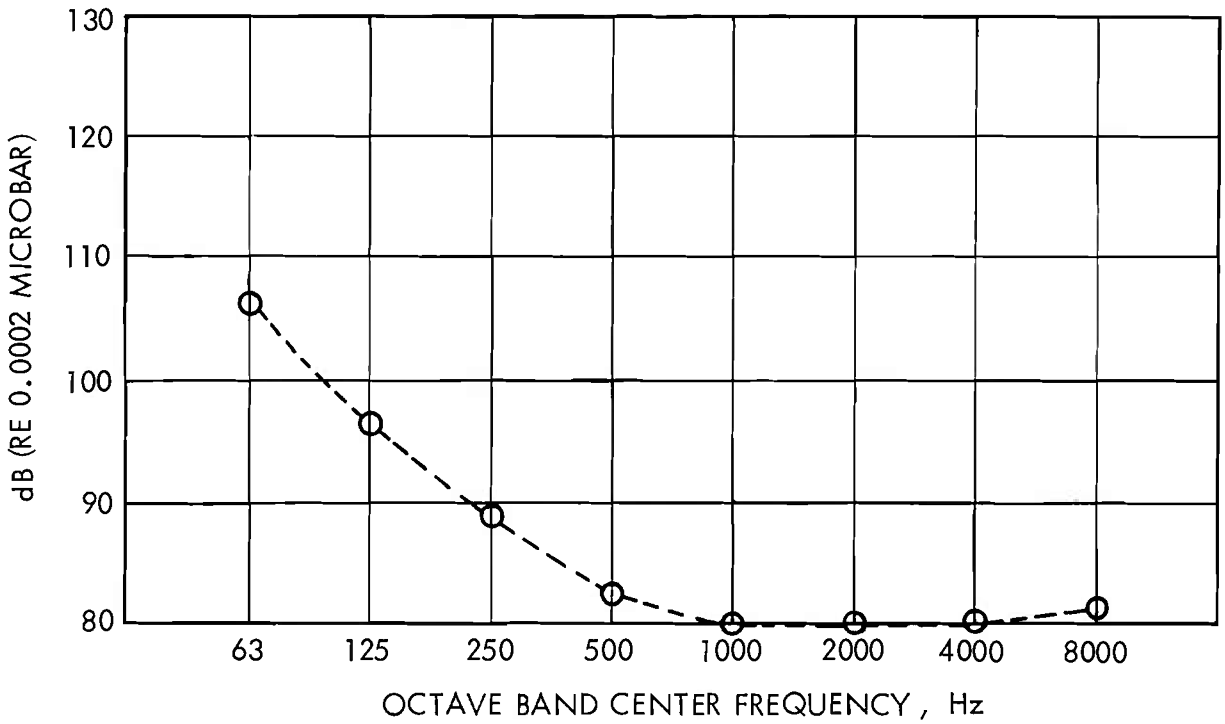


Figure 4-15. Maximum Allowable Steady-state Noise for Army Materiel Command Equipment[17]

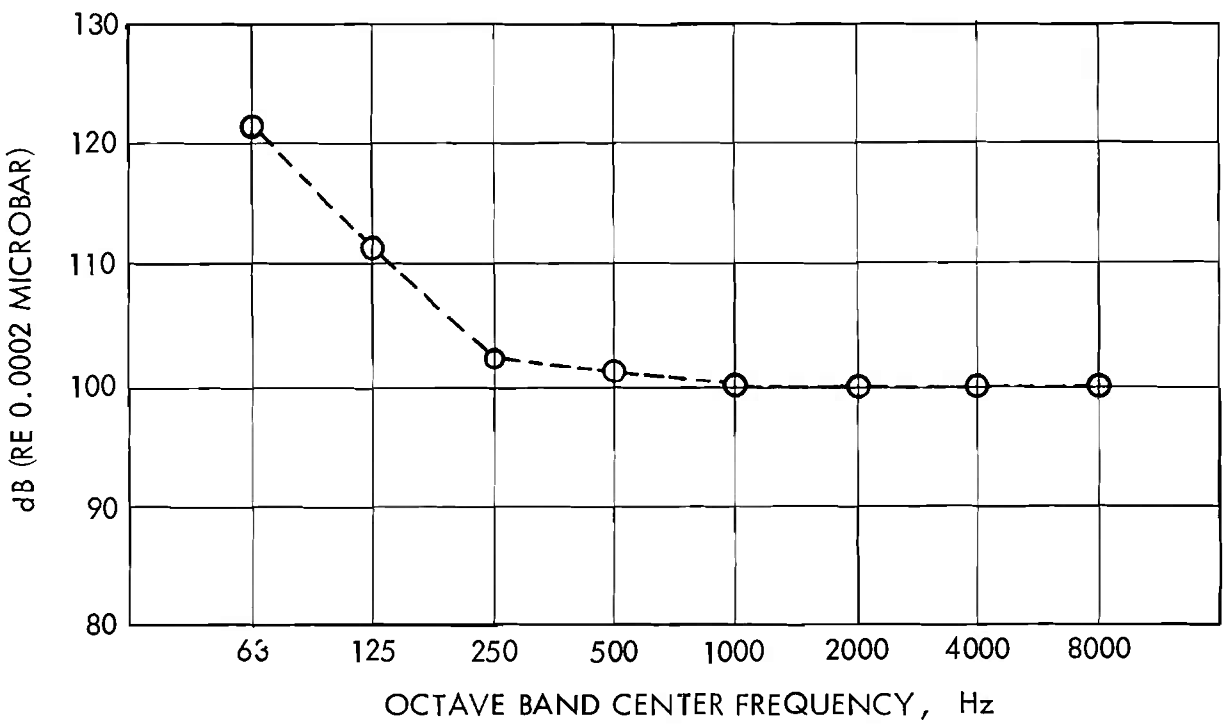


Figure 4-16. Maximum Allowable Steady-state Noise Environment for Vehicle Personnel Wearing Noise Attenuating Communication Headsets[17]

3. Cable routings should avoid close contact with high-temperature equipment so that cables will not be damaged by overheating.

4. Provide guards or other protection for easily damaged conductors such as waveguides, high-frequency cables, or insulated high-voltage cables.

5. Protect electrical wiring from contact with fluids such as grease, oil, fuel, hydraulic fluid, water, or cleaning solvents. These may damage or shorten the life of insulation.

6. Where cable connections are between stationary equipment and sliding chassis or hinged doors, provide service loops to allow wear-free cable movement.

7. Space all connectors and terminals far enough apart so work on one will not damage another.

8. Use alignment pins, keyway arrangements, or other means to make it impossible to cross-connect any connector and receptacle.

4-21.2 MATERIAL SELECTION

The materials selected for an electrical system design must be of the proper type and durability. Poorly selected material can cause the system to rapidly degenerate to a hazardous condition. Guidelines for material selection are given in Refs. 20 and 21. Basic considerations are:

1. Select materials that are consistent and uniform with regard to their chemical properties.

2. Select materials that are compatible with their operating environment and resistant to:

a. Corrosion

b. Fungi

c. Moisture

d. Sunlight

e. Ozone

f. Dust

g. Oil or grease

h. Radiation (α, β, γ, X)

i. Electromagnetic pulse (EMP).

3. Select materials that will not support combustion.

4. Select materials that are stable at expected operating temperatures.

5. Select coatings or finishes that do not degrade the material properties and are not subject to chipping, cracking, or scaling.

4-21.3 ENVIRONMENTAL SAFETY

Environmental safety requires that vehicle electrical systems be designed and constructed to withstand any probable combination of service conditions without creating mechanical or electrical hazards. Table 4-12 lists the environmental effects on specific electrical components.

4-21.3.1 CLIMATIC CONDITIONS

Equipment should be designed to meet the climatic extremes defined in Table 4-1 and in any additional equipment specifications.

4-21.3.2 VIBRATION AND ROAD SHOCK

Equipment should be designed and constructed so no fixed part will become loose and no movable part will shift its setting or position. Vibration and road shock environments within the cargo area of the M113 multipurpose tracked vehicle family are shown in Tables 4-13 and 4-14. Information on the road shock and vibration environments in other military vehicles is in Chapter 5 and in Ref. 33.

TABLE 4-12. ENVIRONMENTAL EFFECTS ON ELECTRICAL COMPONENTS[32]

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Blowers	Brinelling of bearings		Shorts; lubricant deterioration	Corrosion	Corrosion	Lubricant deterioration
Capacitors:						
ceramic	Increased lead breakage; piezoelectric effect; body and seal breakage	Lead breakage; piezoelectric effect; body and seal breakage	Changes in dielectric constant and capacitance; lowered insulation resistance with high temperature	—	Corrosion; shorts	Decreased capacitance; silver-ion migration
electrolytic	Increased lead breakage; seal damage; current surges	Lead breakage; seal damage; current surges	Increased electrolyte leakage; shortened life; increased current leakage; large change in capacitance; increased series resistance with low temperature	Decreased insulation resistance; increased dielectric breakdown; increase in shorts	Corrosion; shorts	Electrolyte deterioration; shortened life; increased chances for explosion; shorts
mica	Lead breakage	Lead breakage	Increased insulation resistance; silver ion migration; drift	Silver migration	Shorts	Change in capacitance
paper	Increase in opens and shorts; lead breakage	Opens; increased dielectric breakdown; shorts; lead breakage	Changes in capacitance; increased oil leakage; decreased insulation resistance; increased power factor	Decreased insulation resistance; increased power factor	Shorts	Decreased insulation resistance; increased dielectric breakdown; increase in shorts
tantalum	Opens; shorts; current surges; lead breakage	Opens; lead breakage	Electrolyte leakage; change in capacitance; insulation resistance; series resistance	Decreased insulation resistance; increased dielectric breakdown; increase in shorts	Corrosion	Electrolyte leakage; decreased insulation resistance; increase in shorts

TABLE 4-12. ENVIRONMENTAL EFFECTS ON ELECTRICAL COMPONENTS[32] (Cont'd)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Choppers	Increase in phase angle and dwell time	Contacts open; change in phase angle and dwell time	Decrease in phase angle; variation in dwell time		Corrosion	Change in phase angle
Circuit breakers	Premature activation	Premature close or open	Failure to function; premature function	Corrosion	Corrosion	Change in characteristics
Clutches, magnetic	Creep	Intermittent operation	Hot spots in coil	Falloff in torque	Binding	—
Coils	Loss of sensitivity; detuning; breaking of parts, leads, and connectors	Lead breakage; detuning; loss of sensitivity	Warping, melting; instability; change in dielectric properties	Electrolysis; corrosion	Corrosion; electrolysis	—
Connectors:						
standard	Separation of plugs and receptacles; insert cracks; opening of contacts	Opening of contacts	Flashover, dielectric damage	Shorts; fungus; corrosion of contacts; lowered insulation resistance	Corrosion	Deterioration of seals; corrosion of contacts
interstage	Insert cracks; opening of contacts	Opening of contacts	Flashover, dielectric damage	Shorts; fungus; corrosion of contacts; lowered insulation resistance	Corrosion	Deterioration of seals; corrosion of contacts
Crystals	Opens	Opens	Drift; microphonic	Drift	—	Drift
Crystal holders	Intermittent contact	Intermittent contact		Change of capacity	—	—
Diodes	Opens	Opens	Change in voltage breakdown; increased current leakage; increase in opens and shorts	Increased current leakage	Corrosion of lead and case	Increased current leakage

TABLE 4-12. ENVIRONMENTAL EFFECTS ON ELECTRICAL COMPONENTS[32] (Cont'd)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Gyros	Drift	Drift; leaks	Drift			Induced drift
Insulators	Cracking; elongation	Cracking	Epoxy cracking; ferrite separation (arcing); moisture condensation (insertion loss)	Moisture condensation (insertion loss); reduction in dielectric strength and insulation resistance	Reduction in dielectric strength and insulation resistance	—
Joints, solder	Cracking; opens	Cracking; opens	Loss of strength	Fungus	Corrosion	At room temperature, strength increased; at low temperature, strength decreased
Magnetrons	Arcing; "FM"-ing	Seal breakage		Arcing	Corrosion	Leaks; gassiness
Motors	Brinelling of bearings; loosening of hardware		Shorts; opens; deterioration of lubricants	Binding of bearings; shorting of windings; corrosion	Corrosion binding of bearings	Oxidation
Potentiometers	Increased noise; change in torque and linearity; wiper brush bounce; open circuit	Increased noise; change in torque linearity, and resistance; open circuit	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance with high temperature	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance	Decreased insulation resistance; increased corrosion; binding	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance
Relays	Contact chatter	Contact opening or closing	Open or shorts; decreased insulation resistance with high temperature	Decreased insulation resistance	Corrosion of pins	Oxidation of contacts causes open circuits; decreased insulation resistance

TABLE 4-12. ENVIRONMENTAL EFFECTS ON ELECTRICAL COMPONENTS[32] (Cont'd)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Resistors	Lead breakage; cracking	Cracking; opens	Increased resistance; opens; shorts	Increased resistance; shorts; opens	Change in resistance, lead corrosion	Change in resistance
Resolvers	Intermittent brush operation; brinelling of bearings; cracking of terminal board; loosening of hardware	Intermittent brush operation; cracking of terminal board; loosening of hardware	High breakaway voltage; shift in electrical axis; opens; shorts; deterioration of lubricants	Corrosion that causes expansion and blistering of potting compound; shorting of winding; pinion corrosion	Corrosion; binding	Oxidation; deterioration of lubricants
Servos	Brinelling of bearings; loosening of hardware; cracking of terminal board	Loosening of hardware; cracking of terminal board	Oil throw-out; breakdown of grease; high breakaway voltage	Corrosion that causes blistering of potting compound; shorting of winding; pinion corrosion	Corrosion that causes rotor binding; salt crystals in bearings and on motor	Deterioration of grease with age; oxidation of brushes and slip rings
Switches	Contact chatter	Contact opening	Oxidation of contacts	Pitted contacts; arcing	Oxidation and corrosion; pitted contacts	Oxidation of contacts
Synchros	Intermittent brush operation; cracking of terminal board; brinelling of bearings; loosening of hardware	Intermittent brush operation; cracking of terminal board; brinelling of bearings; loosening of hardware	High breakaway voltage	Corrosion that causes expansion and blistering of potting compound; shorting of winding; pinion corrosion	Corrosion	Oxidation
Thermistors	Lead breakage; case cracking; open circuit	Lead breakage; case cracking; open circuit	Increased shorts and opens	Change in resistance	Lead corrosion; change in resistance	Change in resistance

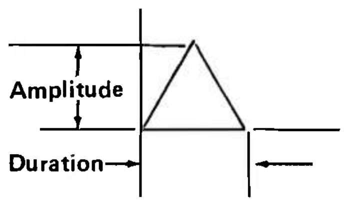
TABLE 4-12. ENVIRONMENTAL EFFECTS ON ELECTRICAL COMPONENTS[32] (Cont'd)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Transformers	Shorts; opens; modulation of output	Shorts; opens; modulation of output	Reduced dielectric; opens; shorts; hot spots; malformation	Corrosion; fungus; shorts; opens	Corrosion; shorts; opens	Deterioration of potting and dielectric
Transistors	Opens; functional disintegration	Opens; seal breakage	Increased leakage current; changes in gain; increases in opens and shorts	Increased leakage current; decreased current gain. If sealed, no effect	Increased leakage current; decreased current gain. If sealed, no effect	Seal leakage; changes in parameters
Tubes, electron	Opens; shorts; microphonics; loosening of elements; changes in characteristics	Opens; shorts; changes in characteristics	Shorts; temporary change in characteristics; formation of leakage paths; increased contact potential; shorting of heater life, gassiness; bulb puncture	Change in characteristics; leakage path; arcing	Shorts; corrosion; leakage path; arcing	Change in characteristics; leaks; gassiness
Vibrators	Intermittent	Intermittent	Lag	Case corrosion	Case corrosion	Decrease in frequency

TABLE 4-13. VIBRATION ENVIRONMENT IN THE CARGO AREA OF M113 VEHICLES[34]

Terrain	Vehicle speed, mph	Zero-to-peak Vibratory Acceleration, g's								
		Vertical			Transverse			Longitudinal		
		20-150 Hz	150-1200 Hz	1200-2400 Hz	20-150 Hz	150-1200 Hz	1200-2400 Hz	20-150 Hz	150-1200 Hz	1200-2400 Hz
Engine operation, (vehicle static)		0.2	0.2	0.1	0.1	0.4	0.3	0.1	0.1	0.3
Hard, smooth, paved track	10	2.0	0.7	0.2	1.2	0.9		0.8	1.1	
	20	3.7	0.7	0.3	2.1			1.1		
	30	2.7	0.7	0.3	1.8	0.2		1.1	0.2	
	40	2.0	2.2		1.7	2.2		1.5	2.0	
Washboard, spaced ramp	5									
	10	2.4	4.2		3.5	4.8		2.2	3.9	
	15	0.9	0.8		0.8	0.6		0.7	0.9	
Cross-country undulations	5									
	10	3.8	3.5		1.3	2.3		1.3	1.5	
	15									

TABLE 4-14. ROAD SHOCK ENVIRONMENT IN THE CARGO AREA OF M113 VEHICLES[34]



Shock Environment in Cargo Area

Terrain	Vehicle speed, mph	Vertical (Up)		Transverse		Longitudinal	
		Amplitude, g's	Duration, msec	Amplitude, g's	Duration, msec	Amplitude, g's	Duration, msec
Washboard,	5	3.5	30	2.0		2.5	
	10	10.5	100	6.5		9.0	
	15	8.5	200	4.0		7.0	
Cross country undulations	5	3.5	170	0.5	170	1.0	250
	10	4.0	110	2.5		3.0	
	15	4.5	250				

Note: The shock levels in the three directions do not occur simultaneously.

4-21.3.3 HAZARDOUS ENVIRONMENT

When equipment and associated wiring must be used in flammable or explosive atmospheres, design the electrical elements to be fire- and explosion-proof. The designer should also consult standards of the National Fire Protection Association (NFPA) dealing with the particular hazard (e.g., flammable liquids, gases, combustible solids, dusts, and explosives).

4-21.4 OVERLOAD PROTECTION

To protect equipment from damage by fire, explosion, or overheating; provide fuses, circuit breakers, or other protective devices for primary circuits. Make certain that test or checkout equipment is protected against possible current overloads or damage. Use fuses, circuit breakers, time-delays, and cutouts to open individual leads of a circuit whenever a fault occurs. Connect protective devices to the load side of the main power switch (unless neutral power sensing is essential for proper protection of the equipment). Protection of individual parts from failures of associated parts generally should not be provided.

Provide overload protection in each of the three ungrounded conductors of all three-phase motors in isolated or unattended locations, or in any mobile/portable equipment. Arrange overload protection so the highest rated device with the longest trip-time is closest to the power source, and the smallest rated device (commensurate with load) with the shortest trip-time is nearest the load[19].

4-21.4.1 FUSES

The uses of fuses in military vehicles is limited due to logistic problems they introduce (see Chapter 8). When fuses are required, install them in easily accessible locations. Use telltale or blown-fuse indicators where possible. Where fuses are used, provide at least one extra fuse for each type and rating used. Attach these fuses to the applicable units. Insure that panel-mounted fuse posts permit replacement of fuses without using tools.

4-21.4.2 CIRCUIT BREAKERS[2]

When circuit breakers are used, locate them so the restoring or switching device is readily accessible to the operator. It is desirable to provide a circuit breaker that gives a visual indication when the breaker is tripped. Select or design a breaker that will trip even if the switch lever is held in position. Provide overload or other protective devices that do not alter the normal performance of the source or load. Limit the use of protective devices in secondary circuits to a minimum.

SECTION VI RELIABILITY

4-22 INTRODUCTION

Reliability, or the capability of equipment to perform without failure for a given period, is a real consideration in every design and is, quite properly, an engineering function.

For many years reliability has been built intuitively into mechanical designs. If the equipment developed by this method failed, a redesign with a larger margin of safety was attempted. The intuitive method has given way to a statistical approach brought on by the advent of the electronic age and proven to be an absolute necessity in the space age. In the statistical approach, reliability is a statistically measurable product characteristic. Under this concept, reliability is defined as the probability that the equipment will perform, without failure, a specific function under given conditions for a given period of time. For an electrical motor, the time could be 10 yr; for a missile, 30 min. The statistical approach enables the engineer to measure reliabilities of increasingly more complex pieces of equipment. This complexity is very evident in modern electrical equipment designs.

The words "statistics" and "probability" are sometimes accepted with skepticism in the engineering field, since these terms are associated with variability, and engineering is regarded as an exact science. A close examination, however, will reveal that the natural world is not exact. No two things are exactly the same in size, weight, or shape, nor can these variables be measured exactly the same. The engineer using the old intuitive approach to design knows this variability exists. In mechanical design, he knows that increasing the strength of his design decreases the risk of failure due to stress. The same would apply to the electrical engineer designing a circuit. He may recognize intuitively that using a lower heat environment will result in a smaller risk of failure. The disadvantage of intuitive reasoning is that no quantity can be assigned to the probability of failure or success of an item. The modern statistical or probability approach to reliability allows the use of mathematical formulas to describe these probabilities. It also allows the mathematical description of the probability of failure when several items operate as a system. This probability description is not possible with the intuitive approach.

The mathematical formulas used for reliability calculations are exact formulas which define occurrence of events using various statistical distributions. From these distributions, the probability of occurrence or nonoccurrence of a failure is derived. The accuracy of the results obtained depend largely on the selection of the idealized model and on the dependability of the failure rate information used in the model. Use of the proper model and failure information gives the engineer a numerical assessment of the reliability of his design early in the design phase.

The extent to which the statistical approach to reliability has been accepted is reflected in the growing importance placed on it in current Government contracts. The requirements are much more stringent than the "supplier's best effort", common a few years ago. A typical contract not only will require a numerical assessment of reliability, but also will specify the mission required of the hardware. For example, a typical military vehicle contract will specify: "The vehicle shall be capable of operating for the required mission duration with a reliabilty of x percent and at a confidence level of y percent." Generally, the contract will further include a detailed description of the mission and will specify vehicle availability and maintainability requirements. The vehicle electrical equipment designer should realize the importance of his equipment meeting its own goals to fit in with the overall vehicle requirement. The typical military vehicle contract may require – in addition to requirements for reliability, maintainability, and availability – that the supplier establish a formal design assurance program to assure compliance with the requirements. The magnitude of this program will depend upon the individual contract.

Maintainability and availability (see Section VIII) have been mentioned in the previous discussion because of their interrelationships with reliability to determine a system effectiveness and its cost-effectiveness. The award of Government contracts is often determined by how effective and costly the system is when compared with similar systems. An example of a system cost-effectiveness plot is shown by the plot of three similar equipment systems in Fig. 4-17. Note that systems A and B have nearly equal costs, but different values for effectiveness. B is obviously a better buy than system A. System C, however, is superior to both A and B because it has both lower cost and higher effectiveness. System effectiveness, as shown in Fig. 4-17, is a probability described conceptually and mathematically in par. 3-9.3.

Vehicle effectiveness depends on the effectiveness of the subsystems within the vehicle. For this reason, the vehicle electrical equipment designer plays an important part in system effectiveness. The reliability of his design is a major factor in the overall determination of this effectiveness.

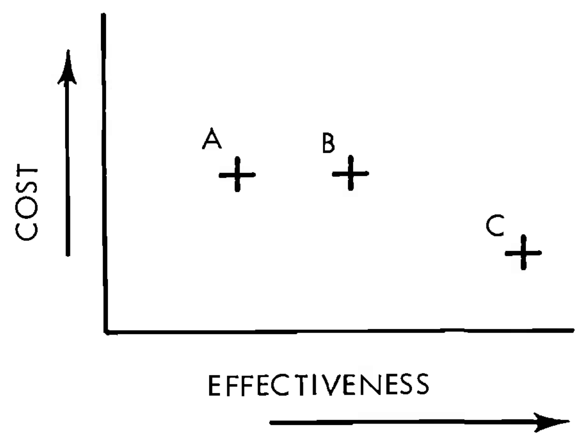


Figure 4-17. System Cost Effectiveness

Many useful documents have been prepared by the Government as guides in the field of reliability and in the structure of a contractor's reliability program. The scope of these documents further indicates the emphasis the Government is placing on the reliability of its purchased hardware. A listing of some of the more important documents follows in Table 4-15.

The previous discussion was presented to acquaint the vehicle electrical equipment designer with the concept of system reliability and to emphasize how his design fits into this concept. The electrical system designer, in order to produce a reliable system, must be able to do three things: first, he must predict electrical component reliabilities; second, he must determine the effect on system reliability of combining two or more of these components; and third, he must recognize alternate methods of system design in order to meet a given system reliability requirement. The paragraphs that follow indicate how these can be accomplished.

4-23 FAILURE RATE

In order to predict the reliability of electrical equipment, it is necessary to know the rate at which the equipment is expected to fail. The term "failure" is defined as any malfunction which would prevent the equipment from performing its given function. This can be expressed in failures per unit time (hours, million hours), distance traveled (miles, kilometers), or number of operations (cycles). For clarification, a brief explanation of "failure rate" follows.

The failure rate of an item is the rate at which failures occur at any instant over a time interval t_1 to t_2 This is sometimes referred to as the "hazard rate" or "instantaneous failure rate".

To demonstrate how failure rate is related to operating time, a diagram for the failure rate versus operating time of an ideal part is shown in Fig. 4-18. Although few parts in real life show these failure rate characteristics

TABLE 4-15. MILITARY RELIABILITY DOCUMENTS

MIL-STD-721	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety
MIL-STD-756	Reliability Prediction
MIL-STD-757	Reliability Evaluation and Demonstration
MIL-STD-785	Requirements for Reliability Program
MIL-STD-781	Reliability Tests, Exponential Distribution
MIL-STD-1304 (AS)	Reports, Reliability and Maintainability Engineering Data
WS-3250	Reliability, General Specification for
MIL-HDBK-217	Military Handbook, Reliability Stress and Failure Rate Data for Electronic Equipment
NAVSHIPS-93820	Handbook for Prediction of Shipboard and Shore Electronic Equipment Reliability
NAVSHIPS-94501	Bureau of Ships Reliability Design Handbook (Electronics)
MIL-R-22732	Military Specification, Reliability Requirements for Shipboard and Ground Electronic Equipment

exactly, this "bath tub curve" serves to demonstrate the three failure rate phases. First, there are the failures which occur early in the life of a part, causing the decreasing failure rate shown in the left of Fig. 4-18. These failures are caused by poor manufacturing and quality control techniques, and generally can be eliminated by vehicle "run-in" or component "burn-in". Second, there are the failures which are caused by component aging or wear-out, causing the increasing failure rate in the right of Fig. 4-18. These failures can be prevented if a part is replaced sometime before the mean wear-out life. Third, there are the failures which occur between the early failures and the wear-out failures, as shown in the center of Fig. 4-18. This phase is often called the useful life phase, where only failures of a random nature occur. These chance failures are caused by sudden stress accumulation beyond the design strength and are unpredictable in nature. However, their frequency of occurrence over a long period of time is relatively constant.

Obviously, it will require different mathematical models to describe the different failure rates shown in Fig. 4-18. In this section, only the mathematics associated with the constant or useful life phase will be discussed. The section on durability that follows presents other mathematical distributions that describe the failure characteristics for the early and wear-out phases.

Many electrical components have been shown to exhibit a constant failure rate over a measurable period of time. Also, a complex system of parts, even though it may contain parts subject to wear-out, will exhibit a constant failure rate. Because of this, a mathematical model which describes the constant failure rate situation is used. This model is known as the exponential distribution. The reliability, or probability of no failure, for the exponential distribution is expressed by the equation

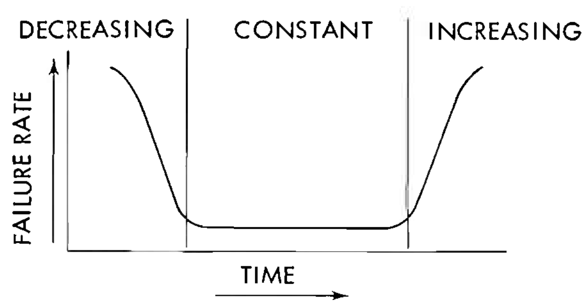


Figure 4-18. Failure Rate Characteristics

$$R = e^{-\lambda t} \tag{4-1}$$

where

R = reliability, or probability of unit operating without failure, dimensionless

λ = failure rate, reciprocal time

t = operating time, units of time

e = base of the natural log

It is important that λ and t be measured in the same units of time.

The mean time between failure ($MTBF$) of a component is defined as the total operating time divided by the total number of failures occurring in that time.

Therefore, for the exponential distribution:

$$MTBF = \frac{1}{\lambda} \tag{4-2}$$

Thus, to predict a component or system reliability and MTBF requires only the input of failure rates. These failure rates can be obtained from similar parts operating in a similar environment.

There are several sources where failure rate information can be obtained. This information is derived from controlled laboratory tests, other test data, and from field data. There is the FARADA (Failure Rate Data) program organized by the Department of Defense which lists failure rates from many sources for electrical, electronic, mechanical, and hydraulic components. There is the IDEP (Interservice Data Exchange Program) which gives failure rates from missile testing. MIL-HDBK-217 is a complete volume containing failure rates and stress-derating factors for electronic parts. Many manufacturers and some specialist suppliers have established data bank files that contain failure information on components. Despite some reluctance by the manufacturer to release this information, it is still a valuable source of failure information.

There are usually stress or environmental factors which need to be applied to failure rates obtained from these various sources. However, these factors usually are indicated in the source material. Also, the sources sometimes list grouped or "generic" failure rates for similar parts with confidence limits shown for the given failure rates.

Since the total amount of experience and the total number of failures often are given for individual components, a confidence limit on a particular failure rate can be calculated using formulas and statistical tables given in most reliability textbooks. Approximation formulas derived from these confidence limits are often more convenient to use. The following formulas, assuming an exponential distribution, give an upper confidence limit on the failure rate (the inverse will give the lower limit for the MTBF) for the indicated level of confidence.

1. 50% confidence

$$\lambda = (F + 0.669)/T \tag{4-3}$$

2. 60% confidence

$$\lambda = \left[(0.25 + \sqrt{4F + 3})^2 - 0.30\right]/(4T) \tag{4-4}$$

3. 95% confidence

$$\lambda = \left[(1.645 + \sqrt{4F + 3})^2 + 0.60\right]/(4T) \tag{4-5}$$

where T is the total experience (time, cycle, miles) and F is the number of failures observed in T.

4-24 PREDICTING RELIABILITY

The purpose of a reliability prediction is to make decisions early in the design phase, and to determine the probability of the proposed design meeting the established reliability goals or requirements.

Although the reliability goals or requirements for a complete system are specified in the contract, it is usually necessary to use a method of reliability apportionment to establish goals for the subsystems and components within the subsystem. This means basically assigning the expected proportion of total system failures to each of the subsystems and components to establish individual reliability goals. After predicting a subsystem reliability, if the reliability is less than apportioned, it will be necessary to improve the subsystem design to match its reliability goal, or else to effect a trade-off with subsystems that exceed their goal. An excellent guide to reliability apportionment may be found in Ref. 35.

The reliability prediction must be timely to be of use in system design. It must be made early so that time is available to consider design trade-offs or to add redundant features. The process of making predictions (compiling parts lists, constructing reliability block diagrams, and performing stress analysis) frequently discloses reliability problems that are not intuitively obvious.

Constructing a reliability block diagram is the first step in making a reliability prediction. A reliability block diagram portrays the mathematical relationship of the components in a system. It is sometimes called a mission-success diagram and is distinctly different from a functional-type block diagram or assembly diagrams. Fig. 4-19 shows an example of a simple series-type reliability block diagram.

In this system, all of the components must operate in order to have mission success. If the generator, pressure switch, or motor fails, the mission is a failure. In this situation, the reliability of the system R_s is found by the product rule:

$$R_s = R_1 R_2 R_3 \tag{4-6}$$

where R_1, R_2, and R_3 are the reliabilities of the generator, pressure switch, and motor, respectively.

Using Eq. 4-1, Eq. 4-6 can be rewritten as follows:

$$R_s = e^{-\lambda_1 t} e^{-\lambda_2 t} e^{-\lambda_3 t} \tag{4-7}$$

$$= e^{-(\lambda_1 + \lambda_2 + \lambda_3)t} \tag{4-8}$$

where λ_1, λ_2, and λ_3 are the failure rates of the generator, pressure switch, and motor, respectively.

Thus, for any system of constant failure-rate parts operating in series, the failure rate λ_s of the system may be found by summing all of the failure rates of the individual components. System reliability may then be expressed as:

$$R_s = e^{-\lambda_s t} \tag{4-9}$$

where

$$\lambda_s = \sum_{i=1}^{n} \lambda_i$$

Fig. 4-20(A) shows a similar system, except that there are now two generators included in the system. If one of the generators fails, the system will still operate. This is called an active or operational redundancy. A system generator failure will occur only when both generators fail; therefore, probabilistically, the generator unreliability is:

$$Q_{1,2} = Q_1 \cdot Q_2 \tag{4-10}$$

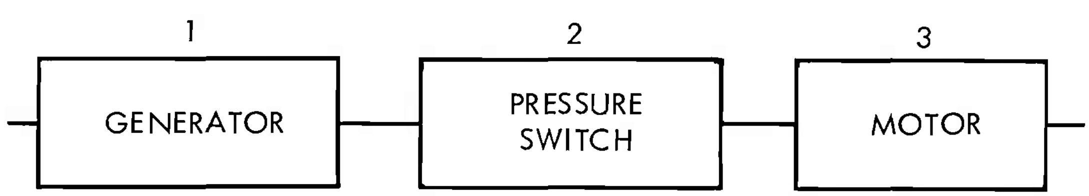


Figure 4-19. Series-type Reliability Block Diagram

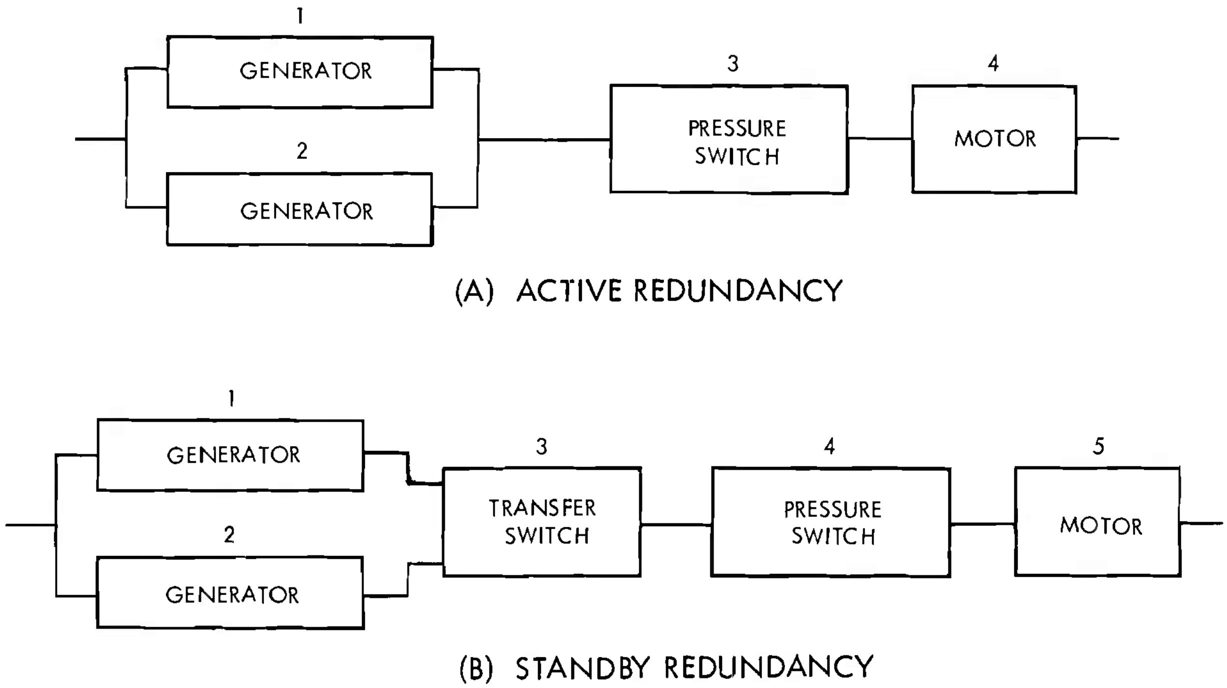


Figure 4-20. Block Diagram With Redundant Generator

where $Q_{1,2}$ is generator unreliability and Q_i is the unreliability of the generators. Since a component or system either will fail, or it will not fail, the sum of the probability of failure Q (unreliability) plus the probability of nonfailure (reliability) R is equal to unity, i.e.:

$$R + Q = 1 \qquad (4\text{-}11)$$

Therefore, the reliability of each generator is simply one minus the unreliability, and the generator system $R_{1,2}$ becomes

$$R_{1,2} = 1 - (1 - R_1)(1 - R_2) \qquad (4\text{-}12)$$

or

$$R_{1,2} = R_1 + R_2 - R_1 R_2 \qquad (4\text{-}13)$$

Again, assuming an exponential distribution and assuming that the generators have equal failure rates, Eq. 4-13 can be reduced to:

$$R_{1,2} = 2e^{-\lambda_1 t} - e^{-2\lambda_1 t} \qquad (4\text{-}14)$$

The entire systems reliability would be:

$$R_s = (2e^{-\lambda_1 t} - e^{-2\lambda_1 t})\, e^{-\lambda_3 t}\, e^{-\lambda_4 t} \qquad (4\text{-}15)$$

where λ_3 and λ_4 are the failure rates of the pressure switch and motor, respectively.

If the pressure switch, motor, and generators in Figs. 4-19 and 4-20(A) have a reliability of 0.980, 0.970, and 0.950, respectively, for a period of time t, then the system shown in Fig. 4-19 would have an overall reliability of 0.903. This is approximately one chance in ten of failure.

Adding the one redundant feature in Fig. 4-20(A) increases the reliability from 0.903 to 0.947 or approximately one chance in twenty of failure.

This simple example of an active redundant system is only one of many redundant arrangements that can be made to increase system reliability. Par. 4-25 presents further discussion on redundant arrangements.

The time t mentioned in the previous reliability discussion is not always the same for various components in a system. For example, a specification may say that a vehicle must operate for 5 hr over a specified course with 95% reliability. An apportionment and reliability prediction is accomplished on the electrical systems within the vehicle. In the process, however, it is found that many of the systems will not actually be operating for the full 5 hr. For this reason, it is necessary to derive from the mission a duty cycle for the subsystems and components in order to determine the actual operating hours. From this, a value of t is found for each of the components.

The electrical equipment designer can see from the previous discussion that predicting the reliability of a complex electrical system and performing design trade-offs are not easy tasks. MIL-HDBK-217 and some of the other listed Military Specifications provide valuable guides, but it is often advantageous and sometimes necessary to enlist the help of a reliability specialist. This person, trained in the reliability engineering field, can take much of the load off of the designer. This is particularly true in the early design phase when the designer has many other things to consider.

It should be emphasized that the reliability prediction of an electrical system is only a tool to be used by the designer and to provide an initial estimate of the reliability of the system. It is not a demonstration of reliability. Only the system itself, operating in its planned environment, can demonstrate that reliability.

4-25 REDUNDANCY

In par. 4-24, the subject of redundancy was introduced. In the paragraphs that follow, certain basic arrangements of active redundancy and of standby redundancy with switching devices will be discussed. A complex arrangement of components often can be broken down to these basic arrangements by use of a "decomposition method" described in Ref. 36.

Active redundancy was illustrated in Fig. 4-20(A). Fig. 4-21 shows a more complex arrangement of redundant components, called series-parallel. If the element reliabilities r are equal, then the reliability R of the system is:

$$R = \left[1 - (1-r)^m\right]^n \tag{4-16}$$

where n is the number of series groups of elements, m is the number of parallel elements within each group, and r is the reliability of a constant failure rate component, determined by Eq. 4-1.

Another arrangement that is often encountered in electrical-electronic circuit work is the parallel-series arrangement. This arrangement is shown in Fig. 4-22. The system reliability R for this arrangement, assuming the element reliabilities r are equal, is:

$$R = 1 - (1-r^n)^m \tag{4-17}$$

where n is the number of series elements within each group and m is the number of groups in parallel.

In the previous examples, the system was considered successful if at least one of the redundant elements was working. However, suppose two of three active redundant components must operate in order to prevent failure. This system reliability could be developed here probabalistically the same as the one out of two redundancy in par. 4-24, but this situation as well as other redundant arrangements are described fully in reliability textbooks[36, 37].

Table 4-16 shows the developed formulas for various redundant situations. This table is an excerpt from MIL-HDBK-217[42] and shows the formulas for both active (operational) redundancy and for standby redundancy for various situations. The table also lists approximation formulas which can be used to simplify calculations. Some discretion must be used when applying the approximation formulas, for certain magnitudes of λt can produce an appreciable error. The errors for certain calculations are shown in Table 4-17. In general, the error will not exceed 8% if λt does not exceed 0.05, and is much less for smaller

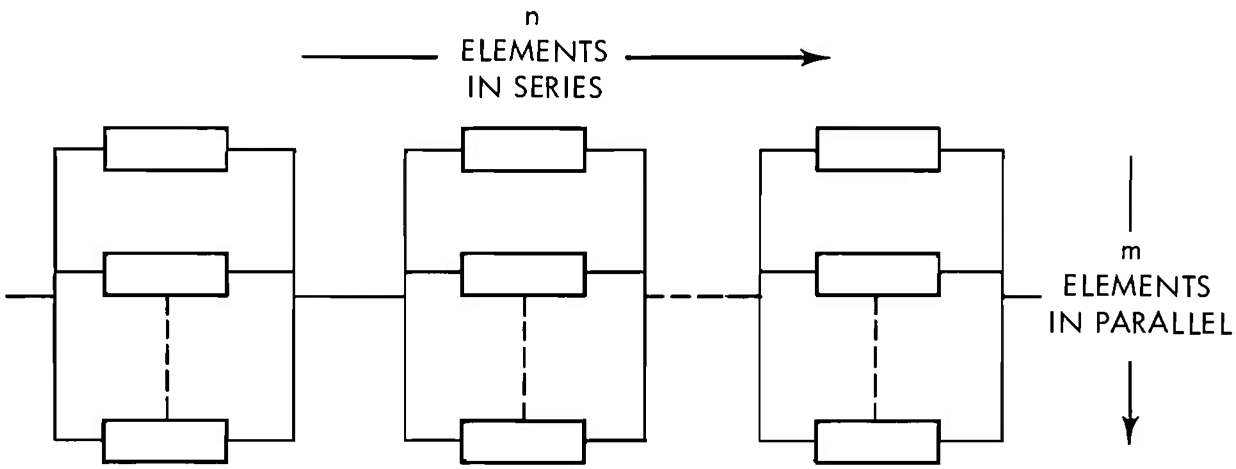


Figure 4-21. Series-parallel Redundancy

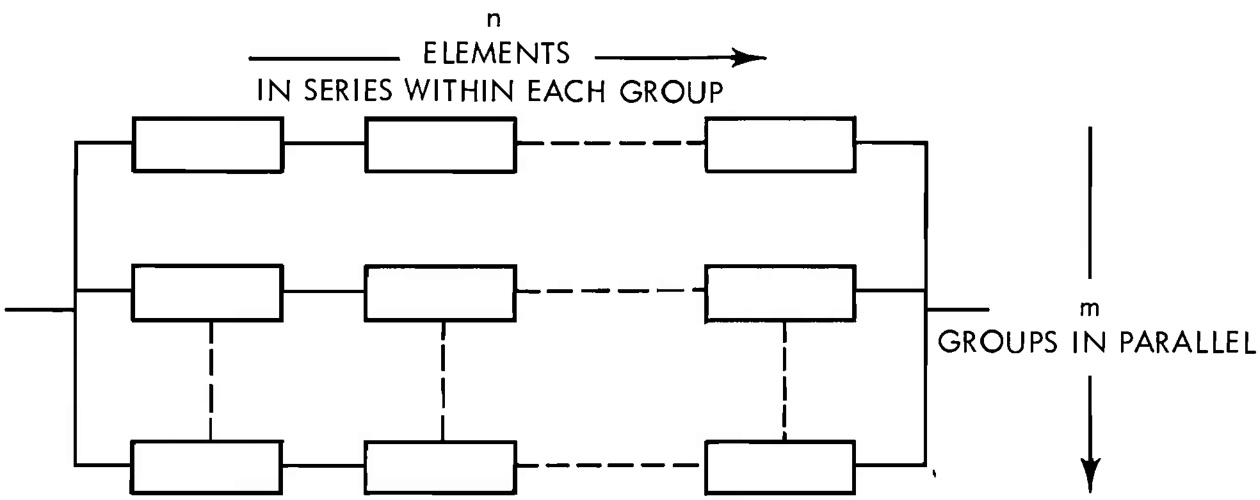


Figure 4-22. Parallel-series Redundancy

values of λt. Better values may be obtained by considering additional terms derived from the expansion of $e^{-\lambda t}$.

The standby redundant equations shown at the bottom of Table 4-16 are applicable when, for example, one of the generators shown in Fig. 4-20(B) remains in a standby condition and is switched in only when the other generator fails. This requires the addition of a transfer switch to the reliability block diagram. The equations shown in Table 4-16 are based on the assumption that this transfer device has a reliability of one. When it is other than one, which is usually the case, the last terms of the equations must be multiplied by the reliability R_{TD} of the transfer device. For example, in the situation where one out of two generators (Fig. 4-20(B)) must be operating for success, the equation for generator reliability would be[37]:

$$R_{1,2} = e^{-\lambda_1 t} + R_{TD}\lambda_1 t e^{-\lambda_1 t} \quad (4\text{-}18)$$

The entire system reliability with one generator on standby and with a transfer device in the circuit can now be calculated. The equa-

TABLE 4-16. REDUNDANCY EQUATION APPROXIMATIONS

Operational Redundancy Equation Approximations

Situation	Formula	Approximation
1 unit of 2 must be working for success	$2e^{-x} - e^{-2x}$	$1-x^2$ *or* e^{-x^2}
1 unit of 3 must be working for success	$3e^{-x} - 3e^{-2x} + e^{-3x}$	$1-x^3$ *or* e^{-x^3}
1 unit of 4 must be working for success	$4e^{-x} - 6e^{-2x} + 4e^{-3x} - e^{4x}$	$1-x^4$ *or* e^{-x^4}
1 unit of *n* must be working for success	$\sum_{a=1}^{n} (-1)^{a+1} \binom{n}{a} e^{-ax}$	$1-x^n$ *or* e^{-x^n}
2 units of 3 must be working for success	$3e^{-2x} - e^{-3x}$	$1-3x^2$ *or* e^{-3x^2}
3 units of 4 must be working for success	$4e^{-3x} - 3e^{-4x}$	$1-6x^2$ *or* e^{-6x^2}
n−1 units of *n* must be working for success	$ne^{-(n-1)x} - (n-1)e^{-nx}$	$1-\binom{n}{2}x^2$ *or* $e^{-\binom{n}{2}x^2}$
2 units of 4 must be working for success	$3e^{-4x} - 8e^{3x} + 6e^{-2x}$	$1-4x^3$ *or* e^{-4x^3}
3 units of 5 must be working for success	$6e^{-5x} - 15e^{-4x} + 10e^{-3x}$	$1-10x^3$ *or* e^{-10x^3}
n−2 units of *n* must be working for success	$\sum_{a=0}^{a} (-1)^a \binom{n}{a} e^{-nx} + \sum_{a=1}^{a} (-1) \binom{n}{a} e^{-(n-1)x} + \binom{n}{a} e^{-(n-a)x}$	$1-\binom{n}{3}x^3$ *or* $e^{-\binom{n}{3}x^3}$
m units of *n* must be working for success	$\left[\sum_{a=0}^{m} (-1)^d \binom{n}{a}\right] e^{-nx} + \left[\sum_{a=1}^{m} (-1)^d \binom{n}{a}\right] e^{-(n-1)x} + \ldots + \left[\sum_{a=m}^{m} \binom{n}{a}\right] e^{-(n-m)x}$	$1-\binom{n}{m-1}x^{n-m+1}$ *or* $\exp\left[-\binom{n}{m-1}x^{n-m+1}\right]$

Standby Redundancy Equation Approximations

Situation	Formula	Approximation
1 unit of 2 must be working for success	$e^{-x} + xe^{-x}$	$1-\frac{x^2}{2}$ *or* $e^{-\frac{x^2}{2}}$
1 unit of 3 must be working for success	$e^{-x} + xe^{-x} + \frac{1}{2}x^2 e^{-x}$	$1-\frac{x^3}{6}$ *or* $e^{-\frac{x^3}{2}}$
1 unit of *n* must be working for success	$e^{-x} + xe^{-x} + \frac{1}{2}x^2 e^{-x} + \ldots + \left(\frac{1}{n-1}\right)x^{n-1} e^{-x}$	$1-\frac{x^n}{n!}$ *or* $e^{-\frac{x^n}{n!}}$

Notes:

1. The errors associated with the use of some of these formulas are shown in Table 4-17.
2. e^{-x^2} is a more accurate approximation than $1-x$.
3. It should be noted that these approximations cannot be used indiscriminately.
4. Substitute λt for x in all equations.
5. The expression $\binom{n}{a}$ refers to the combinational formula (i. e., $\binom{n}{a} = \frac{n!}{a!\,(n-a)!}$

TABLE 4-17. COMPARISON OF TRUE AND APPROXIMATE REDUNDANCY EQUATIONS

Comparison of True and Approximated Values of $2e^{-\lambda t} - e^{-2\lambda t}$

λt	True value $2e^{-\lambda t} - e^{-2\lambda t}$	Approximate value $1 - (\lambda t)^2$	% Error in approx. of unreliability* $\left(\frac{T.V. - A.V.}{1 - T.V.}\right)100$
0.01	0.999901	0.9999	1.0
0.05	0.9976	0.9975	5.0
0.10	0.9909	0.99	10.0
0.20	0.967	0.96	20.0

Comparison of True and Approximation Values of $e^{-\lambda t} - \lambda t e^{-\lambda t}$

λt	True value $e^{-\lambda t} + \lambda t e^{-\lambda t}$	Approximate value $1 - \frac{(\lambda t)^2}{2}$	% Error in approx. of unreliability $\left(\frac{T.V. - A.V.}{1 - T.V.}\right)100$
0.01	0.9999503	0.99995	0.6
0.05	0.998791	0.99875	3.4
0.10	0.99532	0.995	6.8
0.20	0.9825	0.98	14
0.30	0.963	0.955	22

Comparison of True and Approximation Values of $3e^{-\lambda t} - 3e^{-2\lambda t} + e^{-3\lambda t}$

λt	True value $3e^{-\lambda t} - 3e^{-2\lambda t} + e^{-3\lambda t}$	Approximate value $1 - (\lambda t)^3$	% Error in approx. of unreliability $\left(\frac{T.V. - A.V.}{1 - T.V.}\right)100$
0.01	0.9999902	0.999999	2.0
0.05	0.999884	0.999875	7.8
0.10	0.99914	0.999	16
0.20	0.9940	0.992	33

Comparison of True and Approximation Values of $e^{-\lambda t} + \lambda t e^{-\lambda t} + \frac{(\lambda t)^2}{2} e^{\lambda t}$

λt	True value $e^{-\lambda t} + \lambda t e^{-\lambda t} + \frac{(\lambda t)^2}{2} e^{-\lambda t}$	Approximate value $1 - \frac{(\lambda t)^3}{6}$	% Error in approx. of unreliability $\left(\frac{T.V. - A.V.}{1 - T.V.}\right)100$
0.1	0.999999831	0.99999983	1
0.05	0.99997993	0.99997917	4
0.10	0.999845	0.999833	8
0.20	0.99885	0.99867	16

*T. V. = true value
A. V. = approximate value

tion for system reliability R_s becomes:

$$R_s = \left(e^{-\lambda_1 t} + R_{TD}\,\lambda_1 t e^{-\lambda_1 t}\right) e^{-\lambda_3 t} e^{-\lambda_4 t} \tag{4-19}$$

If the reliabilities of the pressure switch, motor, and generators are the same as before – 0.980, 0.970, and 0.950, respectively – and the transfer device has a reliability of 0.999 for one operation, then the system reliability is 0.949. There is a slight improvement in the reliability of this system, compared to the active redundant arrangement of Fig. 4-20(A), even with the addition of a transfer device.

Although redundancy is a powerful tool to improve reliability of a system, it should not be used indiscriminately. In some cases, redundancy may degrade reliability by introducing the possibility of short circuit. Since redundancy by nature must add weight and often is expensive, there are limits to the number of redundant elements that can be added and still improve reliability. Since redundancy introduces additional components, maintenance is increased. Formulas and curves to determine these optimum numbers may be found in Ref. 36.

SECTION VII DURABILITY

4-26 INTRODUCTION

In the previous section on reliability, the emphasis was on a constant failure rate situation, where all subsystems and components failed at a constant rate, and wear-out was not considered. On many electrical items, this is a reasonable assumption for the life cycle of a vehicle. However, wear-out or fatigue may occur in certain electrical items, usually those associated with mechanical wear. Then, it is of interest to consider a special case of reliability known as durability.

The dictionary defines durability as being of relatively long usefulness. In the field of reliability, durability is the length of time that a component operates before its replacement rate due to wear or fatigue becomes intolerable.

4-27 DESIGN LIFE

The tolerance limit for durability can be referred to as the design life. For example, the design life for a bearing is usually referred to as that point where 10% of the bearings are expected to fail. This is the B-10 life. For gears, it is sometimes designated as the B-20 life, or the point where 20% of the items are expected to fail. For other parts subject to wear or fatigue, it is the mean wear life of the part.

In the previous section, the mean time between failures (MTBF) was found by dividing the total operating time by the total number of failures. This was applicable for the exponential distribution of the form $e^{-\lambda t}$ with unpredictable random-type failure and with a constant failure rate. This is not true for components which wear out. The failure characteristics of these components cannot be described accurately by the exponential distribution. The distributions most often used to describe wear-out failure are the Normal, Weibull, or Gamma. The shape and scale of these distributions are time-dependent, i.e., the failure rates of the components described by the distribution are not constant with time t. The frequencies of failures are few at early operating times, but later increase rapidly such that many failures are clustered around the mean life, or mean of the distribution. In the case of a normal distribution, the mean life is the time when 50% of the components are expected to fail. In contrast, the MTBF for the exponential distribution always occurs where 63% of the original components have failed. The fundamental difference is that one represents failures due to wear-out, and the other represents random or chance failures.

Fig. 4-23 shows the density and the reliability functions for a normal distribution. The density function curve shows the mean life μ, standard deviation σ, and a general point t_i. The shaded area to the left of t_i represents the probability of failure of the component prior to time t_i, and the area under the density curve to the right of t_i represents the reliability. For a normal distribution, the area beneath the distribution curve between the values of μ and $\mu \pm \sigma$ on the abscissa is always 0.341. This means that approximately 68% of normally distributed events (failures) will occur in the time period between one standard deviation less than the mean time $(\mu - \sigma)$ and one standard deviation more than the mean time $(\mu + \sigma)$. The mean and the standard deviation completely define a normal distribution, and if these values are known, then the reliability of that component can be determined.

The calculation of reliability for a normal distribution is simplified by using what is called the normal deviate Z and any cumulative normal distribution table which can be found in most reliability and statistical textbooks and mathematical handbooks. The normal deviate Z expresses the abscissa value t_i in terms of the number of standard deviation distances between t_i and the mean, and the

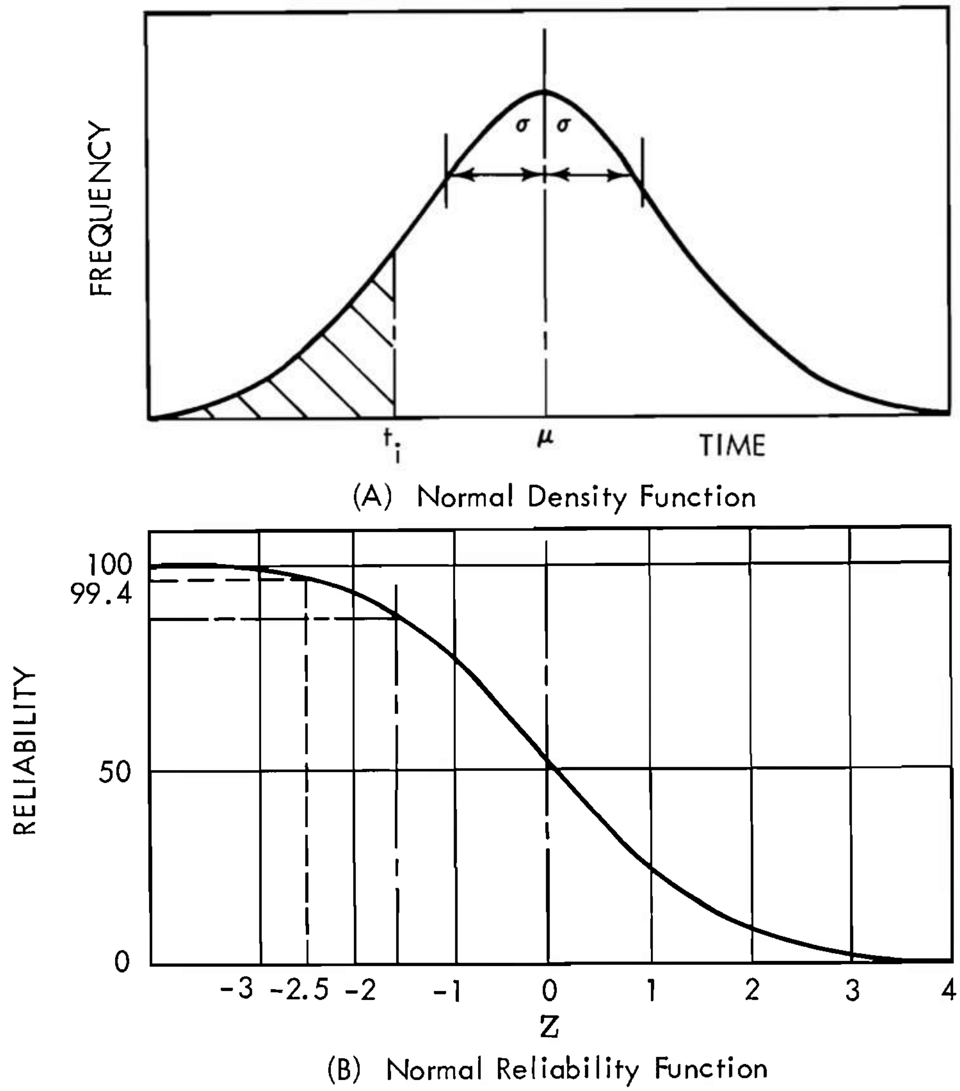


Figure 4-23. Density and Reliability Functions

direction from the mean μ to t_i, i.e.,

$$Z = \frac{t_i - \mu}{\sigma} \tag{4-20}$$

For example, suppose an electric motor has two brushes with a mean wear life of 2000 hr and a standard deviation of 400 hr. The probability of one brush surviving wear-out for at least 1000 hr can be determined by inserting $\mu = 2000$, $\sigma = 400$ and $t_i = 1000$ in Eq. 4-20, solving for Z and using a standard normal table. Z is found to be -2.5 or two and a half standard deviations to the left of the mean. From the standard normal table, the reliability of one brush is found to be 0.994. The reliability for two brushes would be $(0.994)^2$ or 0.988.

The curve at the bottom of Fig. 4-23 shows the reliability function of the normal distribution plotted against the Z values on the abscissa. The location of the values for the example given is shown in dashed lines.

4-28 DURABILITY FEATURES

Certain components in electrical design are susceptible to failure due to mechanical wear, fatigue, deterioration from heat, high voltage, and other environmental effects. For example, the brushes mentioned in the previous section are subject to wear. This wear is caused by a combination of various factors such as the voltage applied across the wear surface, the spring tension applied to the brush, the velocity between the wear surfaces, and the surface finishes involved. Brush wear, theoretically, can be reduced by increasing the hardness of the brush to increase its wear resistance, and this often is done if its electrical function is not affected. Also, the spring tension can be reduced to reduce wear, since wear increases nearly proportionally to the load. Too little spring tension, however, will cause arcing. Arcing increases the temperature, which again causes an increase in the wear rate. Thus, a proper balance is required in brush design to improve the wear reliability.

Electrical contact points are also subject to wear-out. The type of wear experienced here, however, is pitting caused by the breakdown of the surface material from electron transfer. The factors involved in this wear are the angle of contact of the contact surfaces, the type of contact material, the applied voltage, the load across the surfaces, and the shape of the surface. Each of these must be considered in contact point design.

Bearings in motors, generators, and alternators are another area where mechanical wear and fatigue occur. Bearings usually fail because of fatigue caused by contact stresses between the rolling surfaces. These stresses eventually induce pitting and spalling, which causes the bearings to become noisy followed by eventual failure, often catastrophic. Because of this, most bearing manufacturers list the B-10 design life for each of their bearings. Much work has been done in the field of reliability for bearings, including the derivation of formulas to determine the probability of survival or reliability of the bearings. For example, ball bearing reliability R can be determined by the following formula from Ref. 39.

$$R = \exp\left\{-\left[\frac{t}{6.84(B10)}\right]^{1.17}\right\} \qquad (4\text{-}21)$$

where t is operating time and $B10$ is bearing design life. The electric equipment designer can use this formula in a trade-off analysis to select the proper bearing for his design.

Spark plugs are another electrical component subject to wear. High voltage across the points, combined with high temperature and pressure, causes pitting and eroding. Plug life is lengthened by designing for the proper heat range, and considering the applied voltage and the cylinder pressure. Finally, springs used in relays, heavy duty switches, solenoids, and electrical starter engagements sometimes suffer from failure because of fatigue. This is caused by repeated loading, sometimes combined with high temperature and corrosive environment. The latter often can be prevented by proper protection.

The durability of all of these components can be improved. To do so requires selecting better materials, tightening manufacturing tolerances, changing the size or weight, and improving quality control for the component. In some cases, this may be difficult to accomplish. New materials or newly developed alloys can be prohibitively expensive. Also, the material may not be readily available. Tolerances may be hard to maintain in production. These are some of the penalties the designer must weigh against the gain in durability.

Since failures due to wear or fatigue are predictable in nature, it stands to reason that failures can be predicted in advance. This is already being done to some extent. The aircraft engine analyzer has been, for a number of years, detecting failing spark plugs and breaker points. It is possible to detect future bearing failures by the noise level emitted. It is also possible to develop gages to read dimensional changes, spring tensions, etc. In addition magnetic detection of chips in oil and visual inspections can be used to examine components at scheduled intervals to detect signs of component failure.

SECTION VIII MAINTAINABILITY

4-29 INTRODUCTION

Many of the pioneers in the field of reliability—those who determined its meaning, analyzed and reduced to order its complexities, and finally, translated reliability into the realities of design—are now applying their talents to solving the even more difficult problems of maintainability. The overall objective of maintainability—the reduction of maintenance by successfully meeting the user's need for fully minimized upkeep and repair requirements—can be attained only by incorporating the necessary design features into equipment specifications. By definition, maintenance is the action required to keep equipment in or restore it to a serviceable condition, whereas maintainability is a design characteristic that makes possible the accomplishment of operational objectives with minimal expenditure of support effort and resources.

Maintainability is a distinct concern of both engineering and management. The military services are placing much the same emphasis on maintainability as they formerly placed on reliability. This results from the increasing complexity of all types of equipment, and the attendant high cost of maintenance support. Our highly evolved research and development make maintainability fully possible in the systems and equipment yet to be developed. As systems and equipment become more and more complex, logically more emphasis will be placed on reducing the largest single element of system-life costs—namely, maintenance. Further, this reduction will most effectively be accomplished by the application of maintainability principles[22].

4-30 ARMY POLICY

Improving our state of combat readiness is one of the highest priority continuous missions of the Army. Maintainability is the most significant factor in the eventual solution of this problem, for it is the one design element that eliminates the need for excessive support requirements[22].

4-31 MAINTENANCE OBJECTIVES

The objectives of maintenance as specified in AR 750-5[25] are:

1. Assist in assuring the capability of Army units to carry on assigned missions.

2. Predict, prevent, detect, isolate, and correct incipient failures in a timely manner by preventive maintenance services and inspections.

3. Keep all types of equipment ready for their intended use.

4. Minimize requirements for replacement equipment.

5. Maximize the economical service life of all Army equipment.

6. Be responsive immediately to increased requirements of supported units.

7. Return unserviceable but economically repairable equipment to a serviceable condition with a minimum expenditure of manpower, money, and material.

8. Incorporate maintainability design concepts and techniques to achieve maintenance objectives.

4-32 MAINTENANCE CONCEPTS AND PRACTICES

Maintenance requirements and specifications will be developed in accordance with the concepts in AR 750-1[26] for each new item of equipment (to include commercially procured off-the-shelf items) and be made a part of the Required Operational Capability (ROC). See Chapter 2 for a discussion of the ROC concept. The maintenance specifications provided in the ROC for new equipment must provide the essential information required by the developing agency and all other agencies participating in the design, development, and maintenance support of the equipment. Maintenance requirements provide a basis for the maintenance support plan for Army materiel and are formulated with consideration of the user and the application of the several categories of maintenance. The maintenance support plan provides sufficient lead-time to accomplish necessary actions and changes in authorization documents. Maintenance is influenced by system tactical employment, feasibility, technical factors, peculiar skills, tools, test equipment facilities, and repair parts requirements. Maintenance through replacement of components or modules will be specified to the maximum feasible extent in the ROC documents.

4-33 MAINTENANCE CATEGORIES

Maintenance operations, as defined in the paragraphs that follow, are classified into four basic categories commensurate with the primary mission characteristics, degree of skill involved, and the economical distribution of personnel and materiel resources. These categories accomplish the following:

1. Relate maintenance operations to other military operations

2. Provide a basis for identifying organizations for maintenance operations in the Army

3. Facilitate the assignment of maintenance responsibilities to specific levels of command

4. Permit the orderly and efficient distribution of available maintenance resources.

4-33.1 ORGANIZATIONAL MAINTENACE

Organizational maintenance, the lowest level of maintenance, is the responsibility of the unit commander and requires that he maintain the operational readiness of equipment assigned under this control. This category of maintenance includes preventive maintenance services and those organizational level repairs authorized in appropriate technical publications. Organizational maintenance has been known as second echelon and also includes what was formerly known as user, or first echelon, maintenance. The use of the word echelon is no longer used in defining maintenance levels for the Army.

4-33.2 DIRECT SUPPORT MAINTENANCE

Direct support maintenance normally is assigned to and performed by designated maintenance activities in direct support of using organizations. The repair of end items or unserviceable assemblies is performed on a return-to-user basis.

4-33.3 GENERAL SUPPORT MAINTENANCE

General support maintenance normally is assigned to and performed by designated maintenance units or activities in support of individual Army Area supply operations. This category of maintenance constitutes the principal materiel overhaul means available to the Field Army Commander. General support maintenance units and activities repair or overhaul materiel in accordance with maintenance standards for each item, to obtain a ready-for-issue condition based upon the supported army area supply requirements. When required, general support maintenance units provide support on a return-to-user basis through the direct support units for equipment beyond the capacity of direct support units. Direct and general support maintenance have been known as third and fourth echelon, or field maintenance in the past. This collective grouping does not mean that maintenance at this level is conducted in an unimproved area. Direct and general support units usually use shop vans or some type of building. The designer should be aware that "field maintenance" is capable of rather sophisticated repair.

4-33.4 DEPOT MAINTENANCE

Depot maintenance normally is assigned to and performed by designated industrial-type activities under commercial contracts. This category of maintenance assists in satisfying total Department of the Army materiel requirements by overhauling or rebuilding unserviceable assets beyond the maintenance capability of general support maintenance units or activities. Depot maintenance may be performed overseas during wartime as necessary to support military operations. Fifth echelon maintenance was formerly used to define depot maintenance.

4-33.5 TECHNICAL MANUALS

The numbering system used to identify Technical Manuals (TM) utilizes the numerical values previously assigned to echelons. The last two digits of the TM numbers designate those maintenance levels for which the publication is intended. Table 4-18 provides a useful cross-reference between the TM numbers and the intended TM usage.

TABLE 4-18. NUMBERING SYSTEM FOR TECHNICAL MANUALS

TM Dash No.	Former Echelon 1 2 3 4 5	Use
–10	X	Operation instructions
–12	X X	Operation and organizational maintenance
–15	X X X X X	Operation and all maintenance, through depot
–20	X	Organizational maintenance
–30	X	Direct support maintenance
–40	X	General support maintenance
–50	X	Depot maintenance
–25	X X X X	All maintenance except operators
–34	X X	Direct and general support (Field maintenance)
–35	X X X	DS, GS, and depot maintenance

4-34 EQUIPMENT MAINTAINABILITY

For military systems, the competition is among nations, and national survival is maintained through deterrence of aggression, or through victory if deterrence of aggression is not possible. Mindful of these alternatives, the military and the defense industry have promoted maintainability as an important contributor to materiel readiness.

To achieve maintenance objectives, the principal factors affecting maintainability must be identified, measured, specified, controlled, and improved as follows:

1. Identification. The principal factors that limit equipment availability and contribute toward high cost of support must be identified.

2. Measurement. The principal factors must be expressed in quantitative terms.

3. Specification. Quantitative requirements must be placed in the procurement specifications along with suitable methods for demonstrating and evaluating conformance of the actual equipment to the requirements.

4. Control. Control of principal factors must be established, such control extending from product conception through development, production, and field use. Reasonably accurate prediction is necessary.

5. Improvement. The end objective is improvement in the quantitative variability of the principal factors and in levels of maintainability. Here again, an ability to predict is necessary.

There is great need for prediction methods that can evaluate a design in its early phases and predict the availability and support burden. AMCP 706-134[32] presents maintainability design concepts and techniques in detail. However, important electrical equipment maintainability considerations are presented in the remainder of this section. These considerations are generally directed to the man-machine interface, thus directly involving human factors engineering.

4-34.1 MEAN TIME BETWEEN MAINTENANCE ACTIONS (MTBM)

Establishing quantitative measures of maintainability is accomplished by determining the tasks which will restore a component, subassembly, assembly, or the end item to a serviceable condition.

The first stage of the analysis is to develop a maintenance flow diagram which will graphically portray the most logical sequence in which maintenance tasks will be accomplished. This diagram is then used to list the tasks for which Task and Skill Analysis forms are prepared.

Task and Skill Analysis (TASA) forms are used to record data for time-task relationships. Maintainability analysts review the design at all stages, from layout drawings through fabrication of the hardware, and complete the TASA's to show all subordinate tasks involved. The analyst draws on his knowledge of mechanical skills as well as any documented times that may be available. Actual timing may be used in the latter stages as hardware is fabricated.

The quantitative maintainability prediction is obtained by combining the time from the TASA with the reliability prediction (par. 4-24), and with separate predictions made for Mean Corrective Maintenance Time $\bar{M}_{ct}$ (sometimes referred to as Mean Time to Repair *MTTR*), and Mean Preventive Maintenance Time $\bar{M}_{pt}$. The diagram in Fig. 4-24 illustrates the typical flow of information culminating in a prediction.

Corrective Maintenance (CM) and Preventive Maintenance (PM) requirements are determined by the component design and the environment in which the component will operate. They are predicted by identifying tasks to be performed at each level of maintenance. To assist in the completion of valid predictions, maintenance flow diagrams are prepared for each anticipated maintenance requirement. The $\bar{M}_{ct}$ and $\bar{M}_{pt}$ are determined as follows:

$$\bar{M}_{ct} = \frac{\sum_{i=1}^{n} R_{t_i}}{n} \tag{4-22}$$

where

n = number of failures

R_{t_i} = time to repair each sample i

and

$$\bar{M}_{pt} = \frac{\sum_{i=1}^{m} M_{pt_i}}{m} \tag{4-23}$$

where

m = number of preventive maintenance actions

M_{pt_i} = time to perform preventive maintenance on each sample i.

These values are combined to determine the Mean Active Maintenance Time $\bar{M}$ by the equation:

$$\bar{M} = \frac{n\bar{M}_{ct} + m\,\bar{M}_{pt}}{n+m} \tag{4-24}$$

Substituting Eqs. 4-22 and 4-23 into Eq. 4-24 yields:

$$\bar{M} = \frac{\sum_{i=1}^{n} R_{t_i} + \sum_{i=1}^{m} M_{pt_i}}{n+m} \tag{4-25}$$

Mean Time Between Maintenance Actions *MTBM* is a combination of *MTBF*, derived from engineering estimates and documented failure rates, and the Mean Time Between Preventive Actions *MTBP*.

MTBM is determined as follows:

$$MTBM = \frac{(MTBF)(MTBP)}{MTBF + MTBP} \tag{4-26}$$

where

$MTBF = \frac{1}{\lambda}$ = mean time between failures

4-34.2 AVAILABILITY

Availability, as the primary reason for maintainability, is both a goal to be accomplished by design and a measurable character-

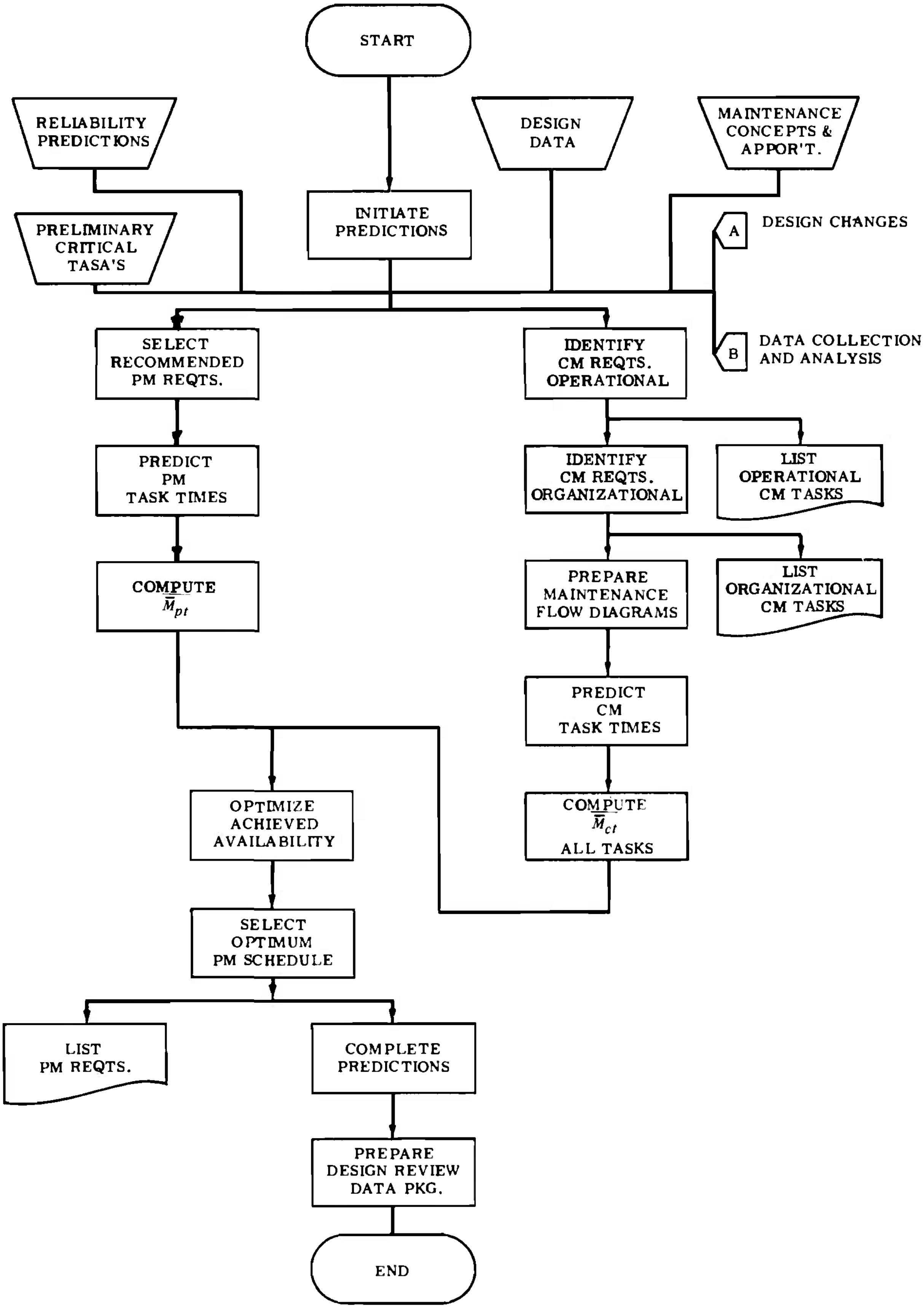


Figure 4-24. Maintainability Prediction

istic of a developed system. It is defined by three separate concepts[22]

1. Inherent availability A_i is the probability that, when used under stated conditions in an ideal environment without preventive action, a component will operate satisfactorily at any time. This ideal environment must include all of the following support items: tools, parts, skilled manpower, and technical publications. Inherent availability excludes all downtime except active, corrective maintenance. It is expressed by the formula:

$$A_i = \frac{MTBF}{MTBF + \overline{M}_{ct}} \tag{4-27}$$

2. Achieved availability A_a is the probability that, when used in an ideal environment, a component will operate satisfactorily at any time. This form of availability includes calculations for preventive maintenance time. It is expressed as:

$$A_a = \frac{MTBM}{MTBM + \overline{M}_{ct} + \overline{M}_{pt}} \tag{4-28}$$

3. Operational availability A_o is the probability that a component will operate satisfactorily at any time. This form of availability recognizes and includes all downtime, both for corrective or preventive maintenance and any other delays such as awaiting parts. It is expressed as:

$$A_o = \frac{MTBM}{MTBM + MDT} \tag{4-29}$$

where

MDT = mean down time ($\overline{M}_{ct}$ plus $\overline{M}_{pt}$ plus administrative, logistic, and other delay times)

These three types of availability have different uses by the procuring agency and the contractor who develops systems for that agency. While the first two, A_i and A_a, measure the work of the contractor, A_o is of utmost importance to the user and aids him in planning operations and in determining the number of systems required.

In applying these equations, one must exercise care to insure that the times are measured in the same units.

Designers must recognize that man is a subsystem of any equipment developed. This is true in any system regardless of its simplicity or sophistication. Man must either operate, or repair it. Failure to consider man as part of the machine negates many advances in the state of the art. This includes mental as well as physical considerations; while the designer may understand the equipment, there is no assurance that maintenance personnel will. Adequate instructions must, therefore, be provided for all maintenance tasks required. A maintenance evaluation conducted on the finished item will disclose the adequacy and effectiveness of the man-machine interface and of the technical publications supplied.

4-34.3 CABLES AND WIRES

System maintainability is improved if the following guidance is employed during the design and selection of wiring interconnection systems:

1. Friction-retainment connectors are the fastest and easiest to use; however, they should not be used in applications where they will be subjected to forces likely to separate them. Otherwise, they should be used for all connections that must be frequently disconnected.

2. Quick-disconnect devices, which are available in a variety of forms, provide the advantage of using friction-retainment connectors and also providing security against accidental separation. Therefore, they should be used on leads to items which require frequent disconnection or replacement, and which require replacement within critical readiness times.

3. Threaded connectors provide the most

secure connectors, particularly when locked into place with set screws, retainers, or safety wire. They do increase maintenance downtime, depending on the number of turns required and the accessibility to the connector locking features. These connectors should require no more than the minimum number of turns consistent with security. They should be operable by hand, and never require more than common hand tools, and they should be arranged to reduce the danger of accidentally loosening other connectors during maintenance operations.

4. Connectors must be accessible. The minimum distance between connectors, or between connectors and adjacent items are:

a. 0.75 in. if only bare fingers are required

b. 1.25 in. if bare hand or gloved fingers are to be used

c. 3.00 in. if a gloved or mittened hand must be used

d. As required for tool clearances.

5. Incorrect connections should be minimized by varying the lengths of leads so all connectors are not located at the same place, using polarized multicontact plugs wherever possible, and using legends or codes on leads near the connector. These features should be durable to remain legible through normal use.

6. Routing of cables and wires can assist in providing "ease-of-maintenance" if the following is considered:

a. Threaded cable clamps are kept to a minimum, with clip-on supports as intermediate fasteners.

b. Clamps are located far enough away from connectors so the clamp does not have to be removed to disconnect the lead.

c. Leads from removable components are not clamped or secured to intermediate structures before terminating at a connector.

d. Threaded fasteners used to mount clamps are of the same type throughout the run of a lead or harness. Do not mix slotted screws and cross-recess screws with each other, or with hexagonal head screws.

e. Harnesses are terminated at walls with a multilead connector on the wall. Do not run the harness through the wall.

f. Long complex harnesses are minimized by using shorter segments terminating in junction boxes. Use two or more branch harnesses to lead to the final destinations. These junction points then provide logical test locations.

7. The coding of connecting devices such as receptacles and plugs help differentiate between input and output lines connecting different items of equipment. Functional designations which identify equipment and mating plugs by name are most universally understood, whereas reference designations which employ coding systems are more difficult to understand.

8. The numbering of each circuit with attached permanent markings facilitates maintenance. The numbers used on the wires and connectors can be graphically shown on wiring diagrams and schematics. Color coded wires should be avoided due to fading of colors and oil staining. Faulty harnesses can be repaired at organizational maintenance level by cutting out the bad lead near each connector and splicing in a good wire of the same type and size. This added wire can then be taped to the harness and the faulty wire abandoned. Disassembly of the harness is not required.

4-34.4 ACCESS TO EQUIPMENT

Provide access to all points, items, units, and components which require testing, servicing, adjusting, removal, replacement, or repair. The type, size, shape, and location of access should be based on a thorough understanding of the following:

1. Operational location, setting, and environment of the unit

2. Frequency of using the access

3. Maintenance functions to be performed through the access

4. Time required to perform these functions

5. Types of tools and accessories required by these functions

6. Work clearances required for performance of these functions

7. Type of clothing the technician is likely to wear

8. Distance the technician must reach within the access

9. Visual requirements of the technician in performing the task

10. Packaging of items and elements, etc., behind the access

11. Mounting of items, units, and elements behind the access

12. Hazards involved in or related to use of the access

13. Size, shape, weight, and clearance requirements of logical combinations of human appendages, tools, units, etc., that must enter the access.

For ease of maintenance, the following access types are listed in order of preference (Fig. 4-25):

1. Uncovered or Exposed Equipment. When structural, environmental, operational, and safety conditions permit, equipment should be left exposed for maintenance, especially test and service points, maintenance displays and controls, and track-mounted "black boxes."

2. Semi-exposed Equipment. Equipment can be semi-exposed with:

a. Pullout rack or drawers

b. Full-length doors on cabinets or equipment racks

c. Quick-opening hoods or covers

d. Easily and quickly removable dust covers and cases.

3. Covered, Limited-access Openings. Covered accesses should be evaluated in terms of the types of covers and fasteners employed.

4. Stress Doors. Stress doors are usually required in high-performance equipment, but should be avoided wherever possible. When required, the accessibility of stress doors can be improved by selection of appropriate fasteners.

5. Riveted Panels and Doors. Riveted panels are never acceptable as access points. Overall layout and design of equipment should not require removal of permanently attached structures even for infrequent maintenance.

In general, one large access is preferable to two or more small ones, but visual and physical access may be provided separately when required.

4-34.4.1 SHAPE OF ACCESSES

Accesses should be whatever shape is necessary to permit easy passage of the required items, body appendages, implements, etc. (Fig. 4-26). The following should be considered:

1. Dimensions of the various items that must be replaced through the access

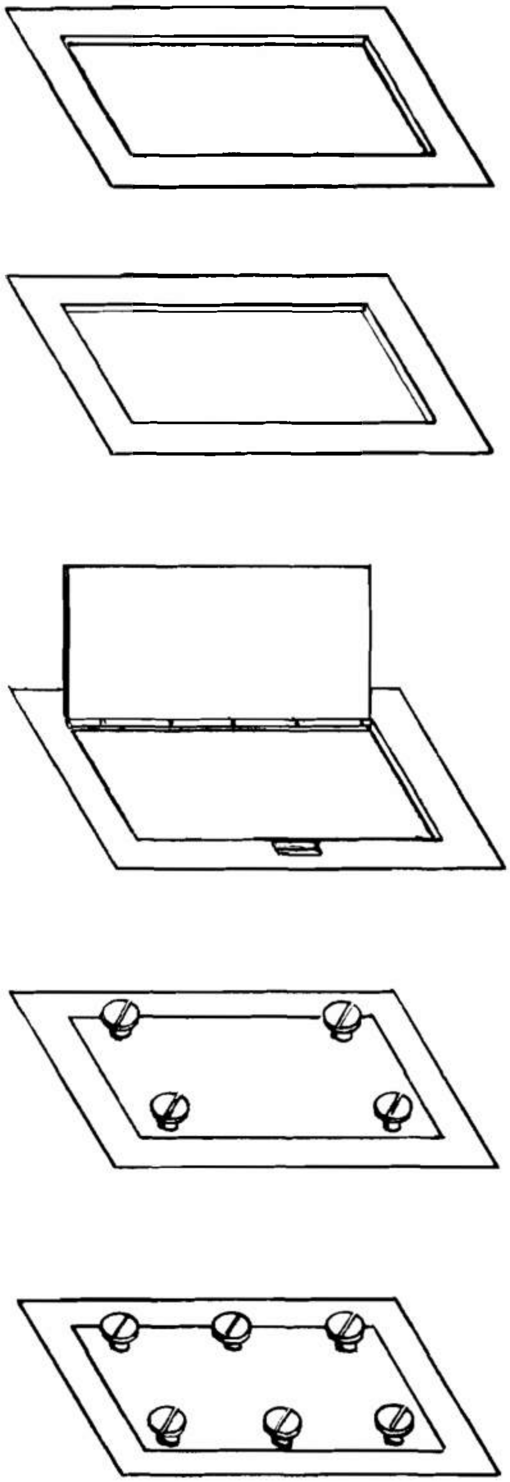


Figure 4-25. Covers and Accesses

2. Protuberances, attachments, handles, etc., on these items

3. Methods of grasping items during removal, and the required clearances

4. Requirements for work clearance within the compartment

5. The operator's need to see what he is doing inside the compartment.

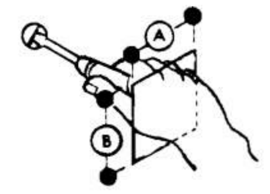
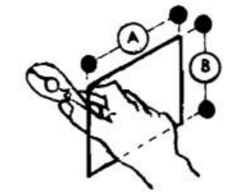
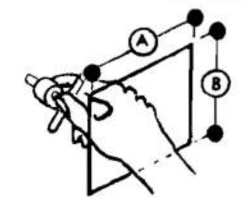
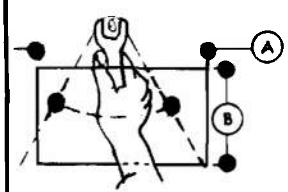
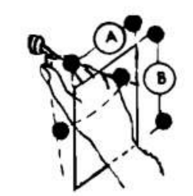
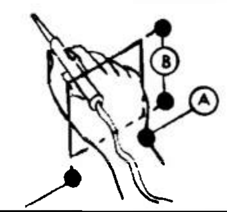
OPENING DIMENSIONS	DIMENSIONS, IN. A	B	TASK
	4.2	4.6	Using Common Screwdriver, With Freedom to Turn Hand Through 180 deg
	5.2	4.5	Using Pliers and Similar Tools
	5.3	6.1	Using T-handle Wrench, With Freedom to Turn Hand Through 180 deg
	10.6	8.0	Using Open-end Wrench, With Freedom to Turn Wrench Through 60 deg
	4.8	6.1	Using Allen-type Wrench, With Freedom to Turn Wrench Through 60 deg
	3.5	3.5	Using Test Probe, Etc.

Figure 4-26. Access Opening Dimensions

Accesses need not have regular geometric shapes; the designer should consider irregular shapes that will best satisfy both structural and accessibility requirements.

4-34.4.2 LOCATION OF ACCESSES

Accesses should be located as follows:

1. Only on equipment faces that will be accessible in normal installation.

2. For direct access and maximum convenience for job procedures

3. On the same face of the equipment as

the related displays, controls, test points, cables, etc.

4. Away from high voltages or dangerous moving parts, or with adequate insulation, shielding, etc., around such parts to prevent injury to personnel

5. So heavy items can be pulled out rather than lifted out

6. In keeping with work-space requirements

7. So the bottom edge of a limited access is no lower than 24 in. and the top edge no higher than 60 in. from the floor or work platform

8. To conform to heights of work stands and carts related to use of the access.

4-34.5 FASTENERS

Some of the important factors to consider when choosing fasteners for electrical equipment are described in the paragraphs that follow.

4-34.5.1 APPLICATION

Installation design factors that must be considered are:

1. Work space, tool clearance, and wrenching space needed around the fastener

2. Types of tools required to operate the fastener, depending on type of fastener, application, and location

3. Frequency of use

4. Time available for tasks involving operation of the fasteners.

Fasteners are available in a wide variety of types and sizes, and new types are always appearing. Before selecting fasteners, review the varieties available. Fasteners should be selected for durability, easy operation, speed, easy replacement, and other criteria in this section. Standardize fasteners wherever possible to reduce repair parts and minimize the damage from using the wrong tool or fastener. Minimize the number of types and sizes of fasteners within the system by:

1. Using only a few basic types and sizes which are readily distinguishable from each other

2. Using the same type and size of fastener consistently for a given application (e.g., all mounting bolts should be the same for a given type of item)

3. Making certain that screws, bolts, and nuts with different threads also have clearly different physical sizes, so they will not be interchanged.

Minimize the types and sizes of tools required for fastener operation by avoiding fasteners that require special tools. In designing, consider how stripped, worn, or damaged fasteners can be replaced. Avoid fasteners (studs) which are an integral part of the housing. Fastener mounting holes or other tolerances should be large enough to allow "starting" fasteners without perfect alignment.

Attach hinges, catches, latches, locks, and other quick-disconnect devices with small bolts or screws, not with rivets. Mount nuts and bolts, particularly those which are operated frequently or which are not very accessible, so they can be operated with one hand or one tool, as follows:

1. Provide recesses to hold either the nut or the bolt.

2. Attach either the nut or the bolt semipermanently.

3. Use double nuts on terminal boards and similar applications.

4. Use nut plates, gang-channeling, or floating nuts.

Use a few large fasteners rather than many small ones (unless system requirements dictate otherwise). Fasteners should be located so they:

1. Can be operated without removing other parts or units first.

2. Can be operated with minimum interference from other structures

3. Do not interfere with each other or with other components during release

4. Are not hazards to personnel, wires, or hoses

5. Have adequate hand or tool clearance for easy operation. Consider that it may take two hands or power tools to manipulate, break away, or remove stuck fasteners.

4-34.5.2 TYPES OF FASTENERS (listed in order of preference).

1. Quick connect-disconnect devices are fast and easy to use, do not require tools, may be operated with one hand, and are very good for securing plug-in components, small components, and covers. However, their holding power is low, and they cannot be used where a smooth surface is required. The following factors should be considered in selecting quick connect-disconnect fasteners:

a. Use these fasteners wherever possible when components must be dismantled or removed frequently

b. These fasteners must fasten and release easily, without requiring tools.

c. They should fasten or unfasten with a single motion of the hand.

d. It should be obvious when they are not correctly engaged.

e. When there are many of these fasteners, prevent misconnections by giving the female section a color or shape code, location, shape, or size so it will be attached only to the correct male section.

2. Latches and catches are very fast and easy to use, do not require tools, and have good holding power; especially good for large units, panels, covers, and cases. They cannot be used where a smooth surface is required. Use long-latch catches to minimize inadvertent releasing of the latch. Spring load catches so they lock on contact, rather than requiring positive locking. If the latch has a handle, locate the release on or near the handle so it can be operated with one hand.

3. Captive fasteners are slower and more difficult to use, depending upon type, usually require common hand tools; but they stay in place, saving time that would otherwise be wasted handling and looking for bolts and screws, and they can be operated with one hand. The following factors should be considered in the selection of captive fasteners:

a. Use captive fasteners when "lost" screws, bolts, or nuts might cause a malfunction or excessive maintenance time.

b. Use fasteners that can be operated by hand or with a common hand tool.

c. Use fasteners that can be replaced easily if they are damaged.

d. Captive fasteners of the quarter-turn type should be self-locking and spring-loaded.

4. Round, square, or flathead screws take longer to use and are more subject to loss, stripping, and misapplication. Squarehead screws generally are preferable to round or flat ones; they provide better tool contact, have sturdier slots, and can be removed with wrenches. Screw heads should have deep slots that will resist damage. Use screws only when personnel can use screwdrivers in a "straight-in" fashion; do not require personnel to use offset screwdrivers. If personnel must drive screws blindly, provide a guide in the assembly to help keep the screwdriver positioned properly.

5. Bolts and nuts are usually slow and difficult to use. Personnel must have access to both ends of the bolt, use both hands, and often use two tools. Also, starting nuts requires precise movements. There are many loose parts to handle and misplace (nuts, washers, etc.). Consider the following factors regarding bolts and nuts:

a. Keep bolts as short as possible, so they will not snag personnel or equipment.

b. Avoid left-hand threads unless system requirements demand them; then identify both bolts and nuts clearly by marking, shape, or color.

c. Use wing nuts (preferably) or knurled nuts for low-torque applications, because they do not require tools.

6. Combination-head bolts and screws are preferable to other screws or bolts, because they can be operated with either a wrench or a screwdriver, whichever is more convenient, and there is less danger of damaged slots and stuck fasteners. In general, slotted hexagonal heads are preferable to slotted knurled heads.

7. Internal-wrenching screws and bolts allow higher torque, better tool grip, and less wrenching space; but they require special tools, are easily damaged, and are difficult to remove if damaged. They also become filled with ice and frozen mud. The following factors should be considered in selecting internal-wrenching fasteners:

a. Minimize the number of different sizes to minimize the number of special tools; preferably, use only one size.

b. Select fasteners with deep slots to reduce the danger of damaged fasteners.

c. Design so there will be a way to remove damaged internal-wrenching fasteners.

8. Rivets are permanent fasteners which are very hard and time-consuming to remove. They should not be used on any part which may require removal.

9. Cotter keys and pins should fit snugly, but they should not have to be driven in or out. Cotter keys should have large heads for easy removal.

10. Use safety wire only where self-locking fasteners or cotter pins cannot withstand the expected vibration or stress. Use safety wire where it is easy to remove and replace.

11. Use retainer rings that hold with a positive snap action when possible, and avoid rings that become difficult to remove and replace when they are worn.

12. Retainer chains:

a. Use to:

(1) Keep hatches or doors from opening too far and springing their hinges.

(2) Change doors or covers into useful shelves for the technician.

(3) Prevent small covers, plates, or caps from being misplaced.

(4) Secure small, special tools where they will be used.

(5) Secure objects that might otherwise fall and cause personnel injury.

b. Selection for use in design should consider:

(1) Use link, sash, or woven-mesh chains. Avoid chains that may break easily.

(2) Attach chains with screws or bolts; attach them strongly and positively, but so they can be disconnected easily when required.

(3) Provide eyelets at both ends of the chain for attaching to the fasteners.

(4) Chains should not be longer than their function requires.

(5) Chains to filler caps should be attached externally rather than internally to facilitate replacement and prevent broken parts from damaging equipment.

4-34.6 TEST AND TROUBLESHOOTING

In order to make testing and servicing as simple as possible, and facilitate system fault diagnosis, the following recommendations should be considered by the designer:

1. Distinctively different connectors or fittings should be provided for each type of test or service equipment to minimize the likelihood of error or misuse.

2. Requirements for separate adapters and other accessories should be avoided. Where practical, these should be built into the equipment or service equipment, so they need not be separately handled. If adapters are the only alternative, use standard adapters.

3. Test points should be combined into clusters for multipronged connectors, particularly where similar clusters occur frequently. These clusters should be located for maximum accessibility and convenient use.

4. Templates or overlays should be provided to expedite different test procedures when they use the same set of test points.

5. The maximum use of codes, guidelines, symbols, and labels should be made to facilitate following logical test routines among test points (see par. 8-5).

6. Test points should be arranged on a panel or other surface according to the following criteria, listed in order of priority:

a. The type of test equipment used at each point

b. The type of connector used and the clearances it requires

c. The function to which each point is related

d. The test routines in which each point will be used

e. The order in which each will be used.

7. In order for the operator to best utilize the test and service points on electrical equipment, all test and service points should be provided, designed, and located as follows:

a. According to the frequency of use and time requirements for use

b. To provide a minimum of disassembly or removal of other equipment or items

c. On surfaces or behind accesses which may be easily reached or readily operated when the equipment is fully assembled and installed.

d. To be clearly distinguishable from each other (where necessary use color coding and labeling)

e. So test points and their associated labels and controls face the technician

f. So adequate clearance is provided between connectors, probes, controls, etc., for easy grasping and manipulation. Use 0.75-in. clearance when only finger control is required. Use 3-in. clearance when the gloved hand must be used.

g. So they offer positive identification, by calibration, labeling, or other features of the direction, degree, and effect of the adjustment

h. With guards and shields to protect personnel and test and service equipment, particularly if the equipment must be serviced while operating

i. At a central panel or location, or at a series of functionally autonomous panels and locations

j. To avoid locating a single test or service point in an isolated position; such points are most likely to be overlooked or neglected

k. To bring hard-to-reach test and service points to an accessible area and located to permit use by 5/95 percentile man standing on the ground or in the normal position required to operate the equipment under test.

l. To overcome accessibility deficiencies resulting from critical lead lengths and similar constraints

m. With windows to internal items requiring frequent visual inspections

n. Connection to test points should be made without tools wherever possible, i.e., use thumbscrews, wing nuts, etc.

o. With tool guides and other design features to facilitate operation of test or service points which require blind operation

p. Within easy reaching or seeing distance of related or corresponding controls, displays, fittings, switches, etc.

q. Away from dangerous electrical, mechanical, or other hazards. A hand's width separation (4.5 in.) should be provided from the nearest hazard, along with guards and shields as necessary to prevent injury.

r. So they are not concealed or obstructed by the hull, turret, brackets, or other units to eliminate the need to disassemble, remove, or support other units, wires, etc., to test, service, or troubleshoot.

s. To permit one man operation if possible.

8. Where adjustment controls are associated with test and service points, they should be designed and positioned so:

a. They are located on a single panel or face of the equipment, or on a minimum number of functionally independent panels.

b. They are capable of being quickly returned to the original settings to minimize realignment time if they are moved inadvertently.

c. Adjustments are independent of each other whenever possible.

d. Those that require sequential adjustment are located in the proper sequence and marked as necessary to designate the order of adjustment.

e. Adjustment procedures are clear and straightforward, and do not require conversion or transformation of related test values.

f. Knobs are used in preference to screwdriver adjustments; the latter are generally unsatisfactory from the standpoint of easy manipulation and the requirement for tools.

g. Adjustability is avoided whenever the part values will not change during the life of the equipment, or an out-of-tolerance will not affect the system in any manner.

9. The following types of adjustment should be avoided except where their use will considerably simplify the design or use of the equipment:

a. Extremely sensitive adjustments

b. "System adjustments", e.g., a component or system should be designed so components can be replaced without harmonizing or recalibrating the whole system.

c. Harmonizing or "mop-up" adjustments, e.g., those that require A or B to be readjusted after A, B, and C have been adjusted in sequence.

4-34.6.1 TEST EQUIPMENT

Technicians will avoid using testing devices, unless they can recognize the device as being useful, reliable, and operable. Therefore, test equipment must be designed for usability, regardless of the engineering sophistication of the device. To design for usability, the vehicle electrical system designer should understand that:

1. Technicians are trained to use complex devices, but they occasionally forget what they learn.

2. Technicians avoid using devices they do not understand or find difficult to operate.

3. Supervisors hesitate to let technicians use expensive, complex equipment when the operation of the equipment is not simple or self-evident.

4. When test equipment is overly complex and difficult to operate, the technician:

a. Must spend considerable time and effort learning to operate it

b. Tends to make errors in usage

c. Can learn to operate only a small number of devices well

d. Finds that habits developed with one device interfere with his learning to use or operate another device

e. May damage test equipment through improper use.

5. Military testers which are drab, unattractive, and apparently rugged, actually get rougher treatment than those which look fragile or have eye appeal. Therefore, select testers that look no tougher than they are to compensate for the rough treatment they are likely to receive.

6. Rectangular or square shapes are recommended for easy storage. If possible, they should be dimensioned to fit relay racks for transportation in shop vans in the field.

7. The weight and dimensions or portable test equipment should not exceed those listed in Table 4-19.

TABLE 4-19. TEST EQUIPMENT WEIGHTS

	Operability Hand-held		Portability One Man	Two Men
Dimensions	Optimum	Maximum	Maximum	Maximum
Weight, lb	3	5	25	90
Height, in.	2	4	18	19
Length, in.	8	10	18	––
Width, in.	4	5	10	––

4-34.6.2 TROUBLESHOOTING PROCEDURES

Always provide systematic troubleshooting procedures for the technician to follow. Lack of good procedures frequently leads to inefficient and even dangerous practices on the part of repairmen. Systematic troubleshooting should proceed through the following phases:

1. Routine check of the equipment or system to identify or verify malfunction symptoms

2. Analysis of symptom patterns to narrow the area of malfunction

3. Special check to isolate the malfunction to a replaceable or repairable unit.

4-35 AUTOMATIC DIAGNOSTIC EQUIPMENT REQUIREMENTS

A family of diagnostic test equipment is now in development. Electrical and other interface requirements may be obtained from the USATACOM Diagnostic Equipment Group. The general requirements for diagnostic equipment require that, on new vehicles, built-in test points and adapters shall be included to enable rapid hookup of Test, Measurement, and Diagnostic Equipment (TMDE) of the 1970-80 time frame (i.e., test plugs, test points, jacks, taps, tees, etc.). Built-in transducers shall also be included where economically feasible. Emphasis shall be placed on access to test points required for system/subsystem/component diagnosis for all levels of maintenance. Test points for items requiring frequent servicing, testing, or checking will be readily accessible without the removal of armor or other vehicle disassembly.

SECTION IX STANDARDIZATION

4-36 INTRODUCTION

An engineering standardization effort is based on the accumulation of past engineering and manufacturing knowledge. It attempts to make known and to encourage the implementation of those ideas, methods, and materials which have previously resulted in successful developments.

In the absence of engineering standards, each new designer is faced with the problems of rediscovering suitable designs and practices. A standardization effort, as it relates to military programs, may be defined as the use, wherever feasible, of items and procedures which are already in successful use in the military system and for which there is existing Government documentation.

Government documentation includes various Government standards, drawings, or specifications, such as:

1. Military Standards (MS)

2. Air Force–Navy Aeronautical Standards (AN)

3. Ordnance, NavShips, BuOrd Drawings

4. Military Specifications

5. Federal Specifications

Standards are documents created primarily to serve the needs of designers and to control variety. They may cover materials, items, features of items, engineering practices, processes, codes, symbols, type designations, definitions, nomenclature, test inspection, packaging, and preservation methods and materials; define and classify defects; and standardize the marking of material and parts and components of equipment, etc. Standards represent the best solution for recurring design, engineering, and logistic problems with respect to the items and services needed by the military services.

4-37 OBJECTIVES OF STANDARDIZATION

The standardization mission of the Department of Defense (DOD) is to develop, establish, and maintain a comprehensive and integrated system of technical documentation in support of design, development, engineering, procurement, manufacturing, maintenance, and supply management. This documentation contributes to the improvement of efficiency and effectiveness of logistical support and operational readiness of the military services, and conserves money, manpower, time, production facilities, and natural resources.

Application of the products resulting from the standardization program should provide the military with the materiel needed and with the degree of reliability and performance required without over-extending the economy.

The Defense Standardization Program (DSP) seeks to achieve these objectives through:

1. Management and engineering actions required to establish and effectively implement standardization agreements and decisions

2. Establishing and maintaining uniform and technically adequate records of the engineering definition of equipment and supplies

3. Promoting the re-use of engineering definition records in support of procurement, maintenance, supply, and, as appropriate, future design; and promoting the re-use of engineering criteria and of previously developed or acquired materiel represented by these records

4. Prescribing for specifications, standards,

drawings, and other standardization-associated documentation the format and procedure for effective coordination, quality of documentation, and collating and disseminating this information.

A Defense Standardization Manual (M 200B) disseminates the required policies, procedures, and instructions[30].

A standardization process of selection and application of preferred materials and parts seeks to eliminate: unproven (untested) items, sole-source items (where possible), the unnecessary use of moving or adjustable parts, nonstandard (special) items, and the use, at any time, of designs which require laboratory settings.

4-38 BENEFITS OF STANDARDIZATION

Manufacturers of equipment and systems for the military continually are confronted with unavailability of parts and components which will meet the ever-increasing demands of the military for reliability, maintainability, transportability, and performance. As a result, a great volume of engineering talent and money is being expended in research and development on production of weapons and systems.

The independent solution, by each contractor, of these research and development problems results in a tremendous increase in the number of items that enter the military supply systems, and a tremendous load of duplicate effort in development, testing, etc. Resources, both in supply and production, are wasted unless designers, engineers, and supply managers have specifications, standards, drawings, and related documents which contain the answers to these repetitive problems.

The use of standardized formats, practices, materials, and parts reduces the required design effort, eliminates unwarranted duplications, and produces simplified designs.

Simplicity of design further increases the inherent reliability of a system; therefore, the benefits expected to be derived from a standardization effort are:

1. Decreased cost, weight, and number of required components

2. Increased utilization of standard tooling

3. Increased probability that the design will perform its intended function.

4-39 INTERNATIONAL STANDARDS

The leading international body is the International Organization for Standardization (ISO) founded in 1946. Its primary purpose is to promote the development of industrial, commercial, engineering, and safety standards to facilitate the international exchange of goods. Fifty-one nations, including the United States, are members of this international body and constitute the General Assembly. Each member nation sends a representative to the General Assembly, which meets every third year. The participating representatives normally are from national standards organizations in their respective countries. They do not represent officially their countries' governments.

Subordinate to the General Assembly is a council, consisting of the General Assembly president and 14 elected representatives from member nations; a general secretariat that coordinates the continuing activities of the ISO; technical committees that meet to develop and propose new standards; and nine administrative committees for such matters as plans, finance, and organization.

Recommendations of the ISO represent the worldwide work of many technical experts. These recommendations reduce or eliminate the conflicts between national standards. Consequently, there is an improvement in international trade.

Universal military standardization is not an attainable objective, since opposed factions direct their efforts to the development of material which is intended to be uniquely superior, and purposely noninterchangeable with enemy materiel.

On a polarized basis, various military alliance groups engage in a continuing effort to standardize to the fullest feasible extent. Important outputs of such groups include:

1. STANAGS (Standardization Agreements). These are documents which establish standards for the North Atlantic Treaty Organization (NATO), and are obtainable through application procedures as established by the Central United States Cosmic Registry, The Pentagon, Washington, DC 20310.

2. AGARD (Advisory Group for Aeronautical Research and Development). This NATO development group has published a number of handbooks which disclose the material standards of the following countries: Canada, France, Germany, Italy, Netherlands, United Kingdom, and the United States. AGARD documents are distributed from centers in the following countries: Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Italy, Luxemberg, Netherlands, Norway, Portugal, Turkey, United Kingdom, and the United States.

The United States distribution center is the National Aeronautics and Space Administration.

4-40 STANDARD COMPONENTS

MIL-STD-143 sets forth the criteria and order of precedence for the selection of specifications and standards to be used by design activities in the design and construction of military materiel for the DOD. MIL-STD-454 provides a technical baseline for the design and construction of electronic equipment for the DOD. Contractors engaged in work for the Government are obligated to use standard or proven production techniques, methods, and processes. Furthermore, the contractor is required to make maximum use of standard military components that are readily available through Government channels, or readily and competitively obtainable through two or more commercial sources. Each contractor's efforts should result in the production of an end item such that the Government will not be required to pay costs for technical assistance fees, patent royalties, or the use of proprietary equipment, techniques, methods, or processes.

The term "Standard Military Component" means an item listed in the Federal Standards, Military Standards, Ordnance Engineering Standards, or Government Design Agency Standard Military Component Directories.

The inventory of automotive electrical equipment employed on military vehicles has evolved in general from commercial automotive designs. These designs have been modified for 24-V operation and upgraded to withstand the rigors of the military environment. The equipment features waterproof electrical connections, heavy duty construction, and resistance to shock, vibration, corrosion, fungus, and climatic extremes. An interconnecting system employing MIL-C-13486 cable and waterproof connectors is used with standard components.

4-41 STANDARD TOOLS AND REPAIR PARTS

An electrical connector tool kit is one of many maintenance aids available from military vehicle repair facilities. This kit is supplied to armed services personnel for field maintenance of electrical systems. The kit, Federal Stock Number (FSN) 5180-876-9336, is made up of a metal case, FSN 5140-772-9655, and these tools:

Crimping tool	FSN 5120-251-3990
Remover	FSN 5120-797-8495
Remover	FSN 5120-797-8494
Remover	FSN 5120-391-1710
Wire stripper	FSN 5110-268-4224

Repair components kept in the kit depend upon the type of equipment to be serviced, and are listed in the parts manuals for the

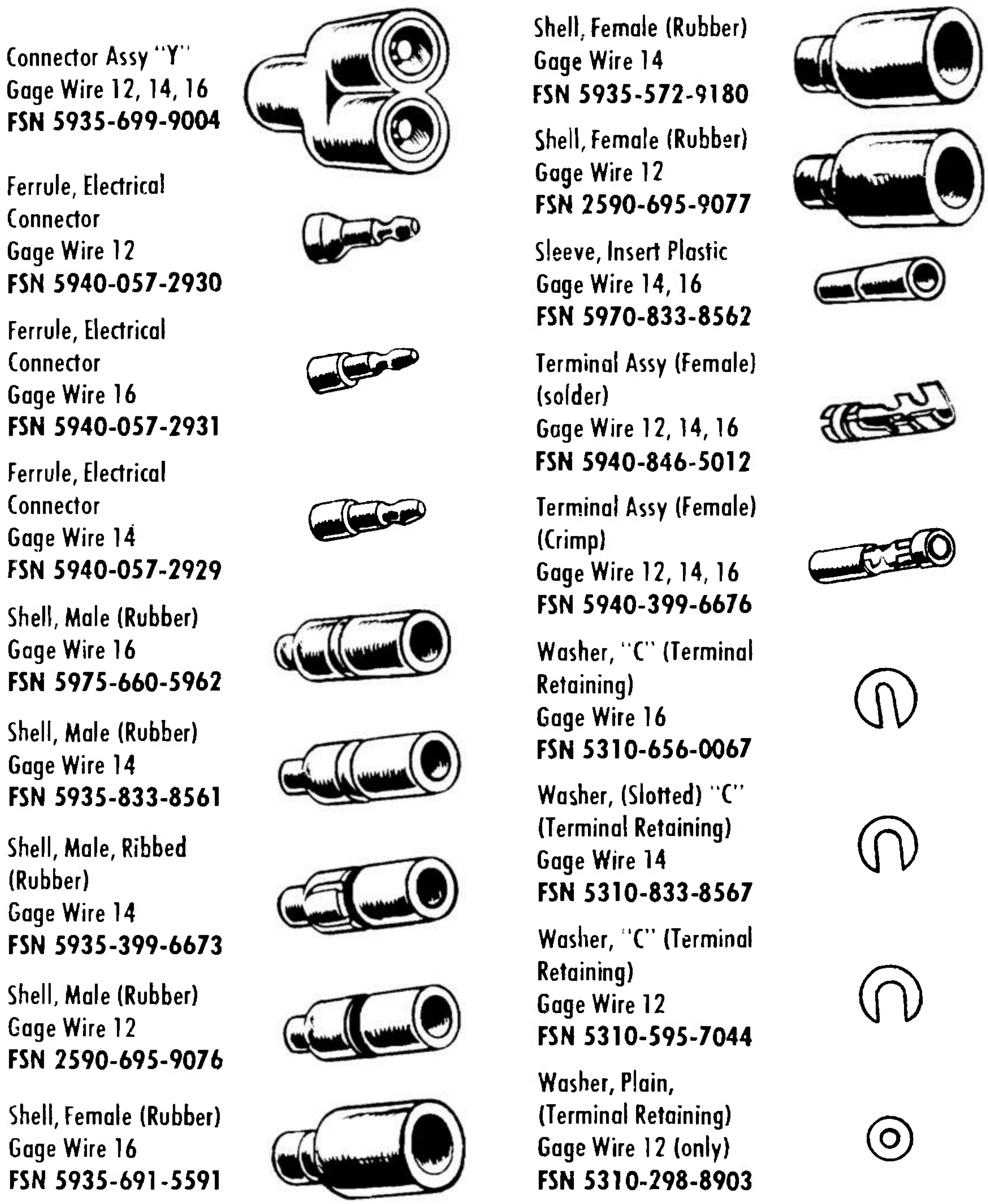


Figure 4-27. Replacement Parts for Friction Retainment Connectors[41]

different end items. A replacement parts kit for the threaded retainment connectors in widespread use on military vehicles can be obtained as FSN 5935-570-1380. Friction retainment connector parts are available separately (Fig. 4-27).

4-42 STANDARD TEST EQUIPMENT

Standard electrical test equipment is included in the various tool kits supplied for field maintenance work. The kits are identified as:

1. Number One Common Tool Kit
2. Number One Supplemental Tool Kit
3. Number Two Common Tool Kit
4. Number Two Supplemental Tool Kit.

Electrical test equipment available to field maintenance personnel from these kits is listed in Table 4-20. Valuable information regarding the theory and use of electronic test equipment is provided in TM 11-664[38].

TABLE 4-20. STANDARD ELECTRICAL TEST EQUIPMENT[41]

Test Equipment	Federal Stock Number
Generator and voltage regulator test set	FSN 4910-092-9136
Battery electrolyte solution tester	FSN 6630-171-5126
Spark plug tester	FSN 4910-261-5868
Tach-dwell tester set	FSN 4910-788-8549
Ignition timing light	FSN 4910-937-5724
Multimeter	FSN 6625-543-1438 or 6625-975-4482

SECTION X CRITICAL MATERIALS

4-43 INTRODUCTION

The Business and Defense Services Administration (BDSA) of the U. S. Department of Commerce is responsible for the administration of the Defense Materials System, which is generally referred to as DMS.

DMS is a series of Government regulations, orders, and procedures issued under the authority of the Defense Production Act. It is designed to accomplish two main purposes: first, it directs the flow of materials and products to the production, construction, and research and development requirements of the nation's defense programs. By definition in the Defense Production Act, "defense programs" include the military, atomic energy, space, and directly related programs. DMS helps to maintain these defense programs on schedule by providing a priority for the purchase of materials by defense contractors, subcontractors, and their suppliers. Second, DMS facilitates the prompt mobilization of industrial resources in a limited or general war[40].

4-44 CONTROLLED MATERIALS

There are four controlled materials: steel, copper, aluminum, and nickel alloys. These materials are divided into eight categories as follows:

1. Carbon steel (including wrought iron)

2. Alloy steel (except stainless steel)

3. Stainless steel

4. Copper and copper-base alloy brass mill products

5. Copper wire mill products

6. Copper and copper-base alloy foundry products

7. Aluminum

8. Nickel alloys.

Each of these eight categories is further broken down into the various forms and shapes of the four basic materials; e.g., sheet, strip, rods, bars, wire.

4-45 PRIORITIES AND CONTROLS

DMS provides priorities and allocations of the controlled materials for defense and related programs. There are two sources for priorities: from a Government agency, or from the customer. It is mandatory that all contracts or purchase orders for defense programs be identified by a priority. This applies equally to the Government agency that places the order or lets the contract, the defense contractor who places an order with a supplier or a subcontractor, and the supplier or subcontractor.

There are two types of priorities: a rated order, or an authorized controlled material (ACM) order. ACM orders are used to obtain controlled materials, i.e., steel, copper, aluminum, and nickel alloys. Rated orders are used to get other materials and products. A rated order must contain these four elements:

1. The priority rating, which consists of the prefix DO or DX, followed by the appropriate program identification such as A-1, E-1, etc.

2. Either of the following certifications:

"Certified for national defense use under DMS Reg. 1" or "Certified under BDSA Reg. 2". Either of these certifications is acceptable on a rated order.

3. The signature of an authorized official of the firm placing the rated order.

4. The delivery date or dates required.

The purchaser or Government agency must also furnish the supplier with a statement reading substantially as follows:

"You are required to follow the provisions of DMS Reg. 1 and all other applicable regulations and orders of BDSA in obtaining controlled materials and other products and materials needed to fill this order."

4-45.1 PRIORITY RATINGS

There are two types of priority ratings: DO ratings and DX ratings. A complete priority rating consists of one of these rating symbols plus the appropriate program identification, for example: DO-A-1 or DX-A-2. The program identification does *not* affect the preferential status of the rating. All DO ratings have equal preferential value. A DO-A-1 has the same status as a DO-C-2. DO-rated orders take precedence over unrated orders. All DX ratings have equal preferential value, but DX-rated orders take precedence over DO-rated orders and unrated orders. A DX rating is really a super-priority and is used to a very limited extent, primarily for specially designated defense programs of critical or emergency nature.

4-45.2 AUTHORIZED CONTROLLED MATERIAL ORDER

All defense contractors, either prime consumers or self-authorizing consumers, must place an order to obtain the controlled materials needed to fill a rated contract or order.

An ACM order means any purchase order for any controlled material (as opposed to a product that contains controlled material) which is placed pursuant to an allotment of controlled material or pursuant to self-authorization.

All ACM orders must contain four elements, in addition to the basic data on the purchase order, as follows:

1. Required delivery date

2. Statement on applicability of BDSA regulations and orders

3. Allotment number and certification

4. Authorized signature of a responsible official.

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CHAPTER 5

COMPONENT SELECTION AND APPLICATION

5-1 INTRODUCTION

Many functionally acceptable electrical devices may be totally unacceptable in a proposed vehicle application because of production availability, repair parts inventory, life cycle, storage life, documentation, and environmental inadequacies. The vehicle electrical equipment designer, in selecting a component for a particular application, must evaluate such factors if the component is expected to be suitable.

Electrical component selections generally are based on electrical performance ratings and electromagnetic interference and compatibility characteristics. Equally important, however, are component environmental considerations which include vibration, shock, corrosion, waterproofing, temperature, humidity, atmospheric pressure, micro-organisms, and flammability. Furthermore, availability factors, procurement criteria, and test and evaluation requirements for a proposed component demand a measure of consideration.

Although the fundamental criterion for component selection is performance of the required function, the designer must consider the other factors. One of the most important guidelines is that of selecting a well-tested component, proven in service. An excellent selection of proven electrical components can be made from those covered by Military Specifications. Such standard parts should be the first choice of a designer dealing with military vehicles. These components in general have satisfied specified requirements through acceptance testing.

If a standard component, covered by a military document or specification, will not perform a required function, it may still be possible to use another standard component by employing a slightly different design. This is encouraged. Furthermore, it should be emphasized that the Government discourages the use of nonstandard parts because of the problems involved with logistics, maintenance, documentation, and cost when new parts are added to the existing inventory. If it is absolutely necessary to select a nonstandard part, then the component parts groups of TACOM, ECOM, and ARMCOM should first be consulted for approval. In addition, all nonstandard parts must meet certain test and evaluation objectives, which are described in par. 5-6.

Aside from using standard parts wherever possible, the designer should employ circuit configurations to favor mission completion should one of the components fail; i.e., provide for redundant or parallel operation.

Component trade-off evaluations conducted during the selection and application phase should also consider human factors, safety, maintainability, and reliability.

An important requirement during component application design is to locate components where they will not become convenient steps or handholds, and to provide protective guards against operator and user abuse.

5-2 ELECTRICAL CONSIDERATIONS

There are several basic electrical considerations to review during component selection. These include the electrical rating of components, electromagnetic interference suppression, and electromagnetic compatibility of circuits and components. The effect of nuclear radiation on electrical system design may also be a problem for future vehicle electrical system designers to resolve.

5-2.1 ELECTRICAL RATINGS

Electrical equipment is designed to work within certain electrical parameters which, if exceeded, will result in equipment damage or malfunction. Electrical components, therefore, must be applied only within these parameters. Wire and cable ratings for maximum working voltage and maximum insulation temperature are typical examples of the parameters involved. For an electrical motor, the important rating may be the minimum horsepower, or the amperage drawn at a rated voltage. For a relay, it may be the minimum pull-in voltage. For other components, it may be the power in watts.

Electrical equipment failures often have occurred when components are required to withstand stresses in excess of their rated capacity. Most component ratings have been established as a result of actual life testing and, therefore, define the manufacturer's faith in the life of his product under specific loading. When an electrical equipment designer uses an electrical component in an application that exceeds prescribed ratings, the part may fail at any time and reliability of the system is reduced accordingly. In fact, the conservative approach requires that components selected for electrical functions be rated considerably higher than the actual electrical stresses expected so that reliability is increased.

5-2.2 ELECTROMAGNETIC INTERFERENCE AND COMPATIBILITY

During component selection and application, it is important to evaluate and incorporate the electromagnetic interference (EMI) and electromagnetic compatibility (EMC) requirements. If these features are not considered and incorporated during the component selection and application phase of development, the first vehicle tested for EMI and EMC will fail, resulting in expensive followup changes to the troublemaking components.

5-2.3 NUCLEAR RADIATION

Designing a vehicle electrical system to withstand nuclear radiation is a specialized task requiring knowledge of the different forms of nuclear radiation and their effect upon the different components of the electrical circuit. Because the nature of radiation design is so specialized, only a general insight to the problem will be presented here.

In a nuclear blast, a tremendous amount of energy is released. For example, a 1-megaton explosion releases about a billion kilowatts of energy in a fraction of a second. To produce this energy, two separate reactions occur at the time of detonation. One is a fusion reaction or the uniting of the nuclei of a light chemical element to form nuclei of a heavier element, and the other is a fission reaction or splitting of the atoms of a heavier radioactive element. The fission reaction is used to trigger the fusion reaction.

The explosion caused by nuclear reaction releases electromagnetic radiation which can seriously damage a vehicle electrical system. It is estimated[1] that the electromagnetic pulse (EMP) caused from a nuclear blast can attain field strengths as great as 10,000 volts per meter, inducing severe electrical overloads. However, defense against these overloads can be provided, unless the explosion occurs so close that it either melts or permanently degrades the circuitry or the vehicle carrying it.

Electrical systems and devices can be protected by hardening measures, i.e., by placing thin layers of relatively dense material between the explosion and the system. A vehicle, carrying a weapon system with its protective metal, already has some measure of protection. A thin layer of material, corresponding in density to 1 foot of air at sea level, will absorb as much as 90% of the soft X-ray energy and an additional amount of radiation at larger wavelengths. The density of the shielding determines the degree of protection. Thus, a very dense material such as uranium provides the best protection.

The previous discussion provides only a general insight to radiation protection design. The designer who requires additional information should refer to AMCP 706-335 through-338[2].

5-3 ENVIRONMENTAL CONSIDERATIONS

The effect of environment on design is of immediate concern, particularly for the electrical equipment designer. An adverse environment can cause catastrophic failure of an electrical system in contrast to other systems which may be more tolerant of these environmental effects. Each of the environmental considerations that follow presents different problems to the electrical designer.

5-3.1 VIBRATION

Vibration can cause two types of failures in electrical systems. These are electrical malfunctions such as contact chatter and spurious signals or structural failures of leads, standoffs, brackets, etc. The occurrence of these failures can be minimized by proper selection of components and a careful design of assembly and support methods. A primary concern should be the selection of components that are not inherently sensitive to vibration. Refer to par. 5-3.2 for a discussion of shock and to Refs. 3 and 4 for guidance.

There are many sources of vibration in a military vehicle. External excitations result from road roughness and cross-country undulations that exercise the suspension. Internal sources include the engine, drive train, blowers, pumps, etc. Probably the most significant disturbance in a tracked vehicle is caused by the track blocks impacting the drive sprocket teeth and the roadwheels. This periodic shock is at the track-laying frequency, which is a function of vehicle speed and track pitch.

A necessary first step for the designer is to determine or estimate the vibration environment that all these sources impose upon the electrical system. All operating modes must be considered. A composite picture of the resulting environment might appear as shown in Fig. 5-1, where vibration acceleration in g's is plotted against frequency.

Ideally, actual test data would be available for the vehicle in question or one of similar characteristics. For example, typical test data for an armored personnel carrier is summarized in Table 5-1.

Electrical system structural failures are caused by excessive vibration of the functional elements and their supports. Relative motion occurs between connected parts, causing flexing and internal stresses. If these stresses are high enough and occur enough times, fatigue damage accumulates to the point of failure. It is the designer's responsibility to ensure that this does not happen.

All physical systems may be simulated as a series of masses interconnected with springs and dampers. The simplest such system consists of a single mass connected to a base through a spring as shown in Fig. 5-2. This system prefers to vibrate at a certain frequency, called its natural frequency, and will do so if displaced from its rest position, released and allowed to vibrate freely. If a disturbance such as a vibratory motion of the base contains periodic movements whose frequency of occurrence coincides with the natural frequency of the spring-mass combination, the motion of the mass will greatly exceed the motion of the base and resonance is said to occur. This relative motion between the mass and the base must be accommodated

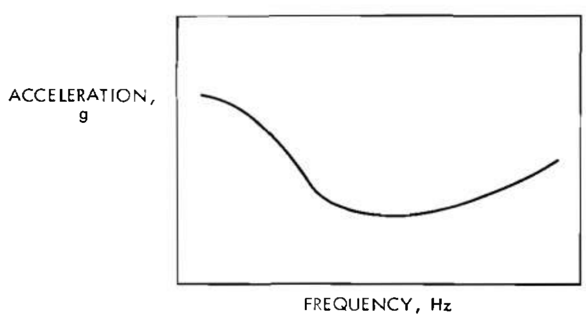


Figure 5-1. Vibration Environment

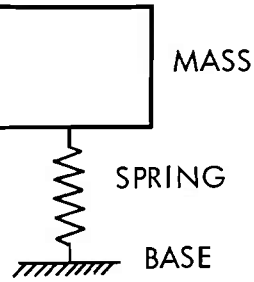


Figure 5-2. Spring-Mass System

by the spring, causing stress fluctuations in it. These stress fluctuations cause fatigue.

Therefore, resonance is to be avoided if possible. In theory this may be done by changing the disturbing frequency or the natural frequency. Changing the disturbing frequency is very unlikely because the electrical designer seldom has any control over the environmental disturbances that cause the base of his system to vibrate. These vibrations emanate from sources both within and outside the vehicle as noted previously.

The natural frequency of vibration f of the spring-mass system of Fig. 5-2 is:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}, \text{ Hz} \tag{5-1}$$

where

k = spring rate, lb per in.

m = mass, lb-sec^2 per in.

This equation shows that the natural frequency is increased by making the spring stiffer and/or making the mass smaller. It is generally advisable to increase the natural frequency as much as practicable because a stiff spring supporting a small mass is able to tolerate high accelerations with a low stress, and excitation disturbances usually have less energy at higher frequencies so resonance can be tolerated.

The most effective method for protecting electronic components is to embed them in solid-epoxy modules. However, if this method cannot be employed for items such as large capacitors and resistors, they should be supported by strap clamps in addition to the soldered leads. Wiring can be stiffened by harnessing (rather than running single strands) and by employing sufficient supports. Heavy components such as transformers and relays should be mounted rigidly, preferably near the corners of metal cabinets or junction boxes.

If this "hardening" still leaves some electrical components subject to damage, damping features must be introduced to absorb some of the disturbing energy before it arrives at the component base. This is accomplished by inserting vibration isolators between the vehicle frame and the electrical package as shown schematically in Fig. 5-3.

Note that each isolator consists of both a damper and a spring. The damper absorbs vibration energy by converting it to heat. The spring is relatively soft so the natural frequency of the overall assembly will be low. The energy transmitted through the isolator at resonance will be reduced by the damping effect, but it is still sufficient to warrant designing so that the natural frequency is not excited by the major disturbing frequencies. When the disturbing frequency is more than $\sqrt{2}$ times the natural frequency, the magnitude of vibration transmitted to the electrical system is less than that of the disturbance. As the disturbing frequency increases, the transmitted vibration decreases rapidly.

TABLE 5-1. VIBRATION TEST DATA[19]

Vibration Environment in Cargo Area of Tracked Military Vehicle

Frequency, Hz	20-150	150-640	640-1200	1200-2400
Acceleration, g	3.8	4.8	1.5	0.3

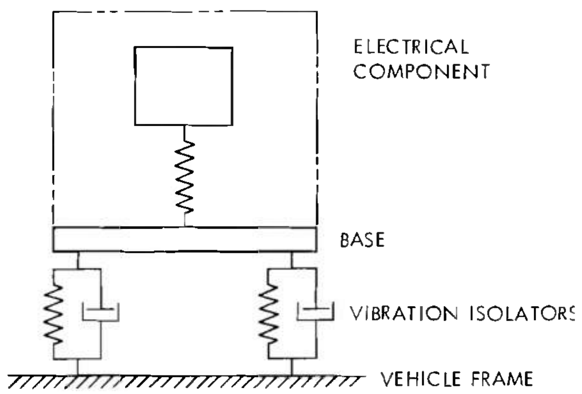


Figure 5-3. Isolated Electrical Package

Isolators are designated by a static load rating and the natural frequency resulting from a combination of the isolator and its rated load. Therefore, selection involves establishing the weight of the package to be isolated and a frequency at which resonance can be tolerated. Of course, resonance with the isolators will not be nearly as severe as resonance at the same frequency without them, because of their energy absorption.

These vibration isolators allow increase motions of the electrical packages, so "bounce space" must be provided.

In summary:

1. Make electrical components and their supporting structures as stiff and light as practicable to make resonance frequencies high.

2. Incorporate isolation mounts if necessary to reduce energy input at resonance.

3. Select components with inherent vibration insensitivity.

5-3.2 SHOCK

Shock environments may produce electrical system failures that can be classified in two categories. These are failures resulting from damage to component parts or to the supporting structure, and failures resulting from electrical malfunctions caused by motion of component parts.

Component or supporting structure failures that occur in the shock environment are seldom fatigue failures. Structural damage can occur in the shock environment with relatively few applications of the shock pulse if the response induces stresses above the yield point of the material.

Electrical system failures may occur as a result of electrical malfunctions such as a change in circuit inductance caused by shock motion momentarily opening an electrical contact.

System failures resulting from component responses to shock environments may be reduced by adequate design of component supports and, where possible, by selection of components that are not inherently sensitive to shock.

The origin of shocks in military vehicles may be traced to both external and internal sources. The most common external source is terrain irregularity but more severe shocks are often produced by rail shipment, air drop, ballistic impact, or high-explosive blast. Internal sources are transient disturbances in the drive train, weapon firing, etc.

Proper design of equipment for shock survival requires a description of the shock environment imposed upon the electrical system by the external and internal sources. Each shock environment is described by its magnitude, pulse shape, and duration.

Fig. 5-4 shows typical idealized shock environments for tracked and wheeled vehicles operating on a rough road surface[5,6,7]

Although the shock levels experienced on a particular vehicle may vary from those shown, this information provides some insight into the shocks that can be expected on military vehicles during normal operation. The magnitude of the shocks transmitted is controlled to a large extent by driver tolerance. Therefore, occasional shocks may greatly exceed the values shown; for this reason the designer must provide for the maximum shock condi-

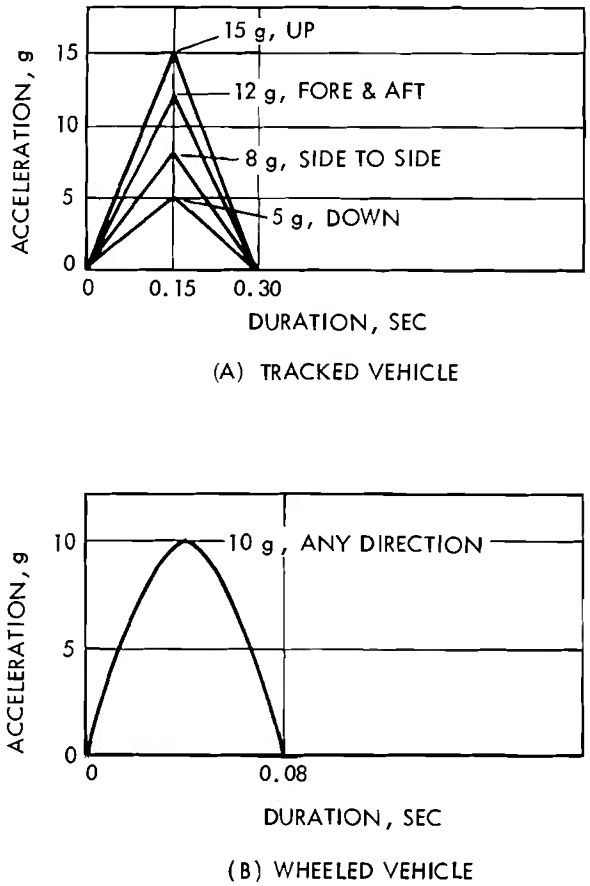


Figure 5-4. Typical Shock Environments on Tracked and Wheeled Vehicles[5,6,7]

tion as specified in Military Standards such as MIL-S-901[8]. Similar plots of shock environments showing magnitude, duration and pulse shape for rail shipment, air drop, ballistic impact, high-explosive blast, weapon firing, etc. should be available to the designer. Ideally, actual test data would be available for the vehicle in question or for one of similar characteristics.

Determination of the response of the electrical components to the various shock environments requires an understanding of the basic characteristics of transient responses to pulse functions. Generally the design problem can be approached with sufficient accuracy by considering a component and its supporting structure to be a linear, undamped, single degree-of-freedom system. For this type of system the differential equation of motion may be expressed in the general form:

$$m\ddot{x} + kx = E(t) \qquad (5\text{-}2)$$

where

m = mass of the supported component, lb-sec^2 per in.

k = spring rate of the supporting structure, lb per in.

x = response displacement, in.

$\ddot{x}$ = response acceleration, in. per sec^2

E = excitation force, lb

t = time, sec

The excitation function $E(t)$ mathematically represents the shock pulse, describing the magnitude, shape and duration of the shock.

The nature frequency f of the responding system is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}\ , \ Hz \qquad (5\text{-}3)$$

Responses to many pulse shapes have been determined by solving the differential equation of motion; these response functions are readily available in the literature[4]. Study of these functions reveals certain characteristics which are common to all types of excitation pulses. For a given boundary acceleration shock pulse, the amplitude of the acceleration response increases with an *increase* in the natural frequency of the responding system, and the amplitude of the displacement response increases with a *decrease* in the natural frequency of the responding system.

The acceleration response of a given electrical component can be attenuated by reducing the spring rate of the component mounts, thereby reducing the natural frequency of the system. Where electrical components are mounted in a rigid cabinet, the cabinet must be provided with relatively flexible mounts. However, introducing this flexibility to attenuate the shock acceleration response will increase the *displacement* response of the component, so adequate clearance space must be provided. The designer is cautioned that reducing the natural frequency of the electrical components and their mounts may cause increased acceleration response in the vibration environment where mount rigidity is an important design consideration. The designer, therefore, must determine an acceptable compromise between component response in the shock and vibration environments, and design the mounting stiffness accordingly.

For each mount considered, the designer must calculate the displacement and acceleration responses of the equipment for the input shock pulse. The designer can then determine if the mount and the location in the vehicle will allow for this displacement and if the mount and equipment will tolerate the resulting dynamic load. Finally, the designer must determine if the mount selected is compatible with the requirements of the vibration environment as discussed in the previous paragraph.

Quite often the design of the equipment mounts represents a compromise for equipment survival in the shock and vibration environments, and the electrical components must be able to withstand some portion of the applied shock pulse. For this reason, the designer must use all means possible in the design of the equipment to provide inherent protection against malfunction due to shock. In certain types of electrical component design, tolerance to shock can be increased by using small masses and stiff springs.

Another technique is to employ mechanisms that allow a great deal of motion before malfunction occurs. An example of a simple pushbutton is shown in Fig. 5-5. This example can be used to illustrate three desirable design features. First, the magnitude of the inertia force that would close the circuit because of shock in the upward direction is directly proportional to the mass of the moving parts. Thus, the designer should make the pushbutton (*D*) and the contact plate (*C*) as light as possible. Second, the spring (*E*) should be made as stiff as practicable and positioned so it is partially compressed in its normally opened position to resist movement from shock. This must be consistent with ease of operation. The same principles illustrated here can be applied in many other design situations.

Other methods can be used in component design to prevent system malfunctions due to shock. For example, a useful method to prevent the opening of contacts under shock is to employ two contacts in parallel. A normally closed contact arrangement is shown in Fig. 5-6.

Here, any inertial force tending to open contacts *a* will increase the contact pressure at *b*; and likewise any force acting to open contacts *b* will increase the pressure at *a*, assuring that the circuit remains closed even under severe shock loads.

5-3.3 CORROSION

Corrosion of electrical components is caused by galvanic cells operating at the surface of a metal, between dissimilar metals in electrical contact, or between areas of unequal electrolyte concentration. In each case, it results from the electrodeposition of material due to the flow of current from a higher to a lower potential.

Corrosion takes more than one form. Uniform corrosion is a result of incomplete

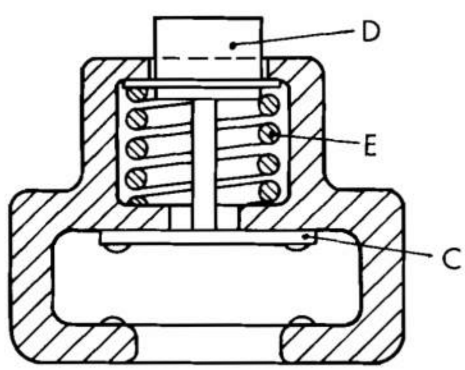


Figure 5-5. Pushbutton

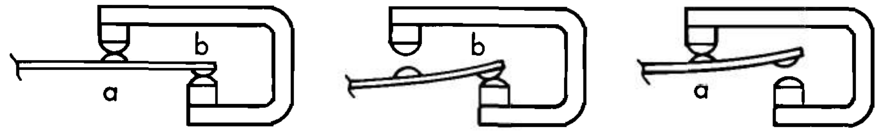


Figure 5-6. Contacts Arranged in Parallel

homogeneity in the metal at the microscopic level. Minute discontinuities result in the forming of anodes and cathodes in adjacent areas, creating a galvanic cell. The action of these cells cause surface damage that makes the surface appear uniformly corroded. Exposure of parts to moist conditions, particularly a salt fog environment, accelerates this effect.

Another form of corrosion is pocket corrosion, where electrolyte or corrosive agents collect in traps or pockets of a structure. This results in a difference in solution potential, again causing a damaging current to flow.

Still another form of corrosion is joint corrosion. This is caused by having two dissimilar metals in contact, and the presence of an electrolyte to cause corrosion at the points of contact. Corrosion is intensified by welding, brazing, or force-fitting stresses.

To provide the corrosion protection required, intermetallic couples should be restricted to those shown in Table 5-2. This table shows metals and alloys by groups, which have common electromotive forces (emf) within 0.05 V when coupled with a saturated calomel electrode in sea water at ordinary room temperatures. All members of a group are considered as completely compatible, one with the other. Compatible couples between groups in this table are based on a potential difference of 0.25 V maximum. To simplify any arithmetic involved, the table shows, in addition to emf against a calomel electrode, a derived "anodic index" with Group 1 (gold, etc.) as 0 and Group 18 (magnesium, etc.) as 175. Subtraction of a lower group anodic index from a higher group anodic index gives the emf difference in hundredths of a volt. See MIL-F-14072[9] for a more detailed discussion.

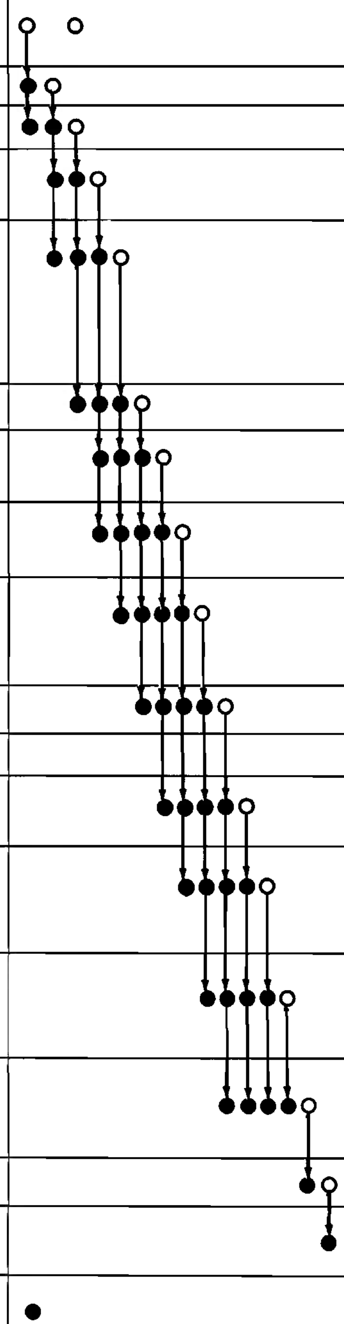
Nonstandard parts may or may not have the necessary degree of corrosion resistance. In any case, nonstandard parts must be tested to assure their resistance to a corrosive environment.

5-3.4 WATERPROOFING AND DUSTPROOFING

Military vehicles are expected to operate in many climatic conditions including marine, tropical, and desert environments. Portions of the vehicle electrical system—such as bilge pumps, trailer receptacles, and associated wiring—must operate when completely immersed in water. (All external electrical components on deep-fording vehicles experience immersion.) Other components may be exposed directly to a muddy or dusty environment. The presence of moisture, mud, and dust is an ever-present problem to most vehicle electrical systems. It is, therefore, the duty of the electrical designer to provide the necessary degree of environmental protection for electrical equipment and connectors commensurate with the requirements for reliable operation.

The enclosures required to protect electrical equipment from the environment must be designed to accommodate the worst extremes expected at the specific equipment location. This design requirement is a variable because many equipment locations receive a measure of protection from the vehicle structure, while others do not. Furthermore, some components, such as those in an engine ignition system, must be completely watertight and dustproof to achieve consistent and reliable operation, while other components may require ventilation to achieve the same result. MIL-STD-108[10] guides the designer in the analysis of electrical equipment enclosure

TABLE 5-2. COMPATIBLE COUPLES

Group No.	Metallurgical Category	EMF, V	Anodic Index, mV	Compatible Couples
1	Gold, solid and plated; gold-platinum alloys; wrought platinum	+0.15	0	
2	Rhodium plated on silver-plated copper	+0.05	100	
3	Silver, solid or plated; high silver alloys	0	150	
4	Nickel, solid or plated; Monel metal, high nickel-copper alloys	-0.15	300	
5	Copper, solid or plated; low brasses or bronzes; silver solder; German silver; high copper-nickel alloys; nickel-chromium alloys; Austenitic stainless steels	-0.20	350	
6	Commercial yellow brasses and bronzes	-0.25	400	
7	High brasses and bronzes; naval brass; Muntz metal	-0.30	450	
8	18% chromium type corrosion-resistant steels	-0.35	500	
9	Chromium, plated; tin, plated; 12% chromium type corrosion-resistant steels	-0.45	600	
10	Tin-plate; Terne-plate; tin-lead solders	-0.50	650	
11	Lead, solid or plated; high lead alloys	-0.55	700	
12	Aluminum, wrought alloys of the Duralumin type	-0.60	750	
13	Iron, wrought, gray, or malleable; plain carbon and low alloy steels armco iron	-0.70	850	
14	Aluminum, wrought alloys other than Duralumin type; aluminum, cast alloys of the silicon type	-0.75	900	
15	Aluminum, cast alloys other than silicon type; cadmium, plated and chromated	-0.80	950	
16	Hot-dip-zinc plate; galvanized steel	-1.05	1200	
17	Zinc, wrought; zinc-base die-casting alloys; zinc, plated	-1.10	1250	
18	Magnesium and magnesium-base alloys, cast or wrought	-1.60	1750	

Note: ○ Indicates the most cathodic member of the series, ● An anodic member, and the arrows the anodic direction.

requirements and selection of appropriate test requirements.

5-3.5 TEMPERATURE

The effect of temperature extremes on electrical equipment can be very detrimental. Temperatures experienced by military vehicles may range from a low of -65° F to a high of 125°F with an average daily change in temperature of 35 deg F[11]. For example, self-discharge of storage batteries increases with temperature.

In addition, certain electrical components such as capacitors and slug-tuned inductors particularly are affected by changes in physical dimensions as a result of changing temperatures. Also, extremely low temperatures may result in brittleness of metal and loss of flexibility in elastomers.

Preventive measures to combat the effect of temperature variations on electrical parts include the use of heat-resistant terminal boards, effective seals, special wire insulation, high-temperature solders, and temperature-stable potting compounds. In addition, the location of electrical components should be selected with temperature as a consideration. For example, storage batteries should be located away from heat sources in the vehicle.

Operating temperature has a definite effect on the performance of an electrical component, particularly electronic parts. As operating temperature increases, so does the failure rate of the component. This rate increases even more rapidly as the ratio of the operating temperature to the rated voltage, wattage, etc., approaches one. The subject is described in detail for many electronic parts in MIL-HDBK-217[12]. Designers may select a component suitable for the prevailing environmental conditions and in effect prolong the life of the design, by using the temperature-stress derating guidelines presented in Ref. 12.

5-3.6 HUMIDITY

Humidity is one of the main causes of electrical component and equipment failure. High humidity produces lower arc-over levels as well as physical distortion and rapid disintegration of many organic compounds. It is a direct cause of corrosion on metals because galvanic cells are formed only in the presence of moisture.

The problem of moisture control often will require some design trade-off. For example, electrical equipment operating in extreme temperatures found in the tropics requires adequate ventilation. Ventilation exposes the components to the atmosphere and introduces the undesirable effects of condensation.

When equipment is to be used under conditions of high humidity, chassis design should always include provisions for drain channels and drip holes.

All hygroscopic materials, which are sensitive to moisture and deteriorate rapidly under humid conditions, should be avoided in design. Absorption of moisture results in changing physical size, strength, and mechanical properties of a material, as well as destroying its functional ability. For example, absorption of moisture can seriously degrade the electrical properties of insulation materials.

5-3.7 ATMOSPHERIC PRESSURE

Military vehicle electrical systems must be capable of operating at an extreme altitude of 18,000 ft above sea level[11]. At this altitude, the atmospheric pressure is approximately one-half that at sea level. This pressure reduction can have a distinct effect on vehicle electrical systems. For example, air and insulation materials have lower insulation strength at reduced pressure. Unless the designer considers this factor, low atmospheric pressure can result in failures of electrical equipment due to changes in insulation effectiveness. Low barometric pressure also reduces the life of electrical contacts because arcing is intensified by the low pressure.

Because electrical equipment may fail as a result of low barometric pressure, endurance tests of electromechanical components are often conducted in a low-pressure environment. These low-pressure tests are intended to determine changes in dielectric constants of materials; the effect of reduced mechanical loading on vibrating elements, such as crystals; and the decreased ability of the less dense air to transfer heat away from heat-producing components. In addition, low-pressure testing sometimes is used to test the ability of seals in components to withstand rupture due to pressure differentials.

5-3.8 MICRO-ORGANISMS

The electrical equipment designer should be more concerned than other designers with micro-organisms because electrical and electronic assemblies use more of the nonmetallic materials which are most susceptible to fungal attack. Military vehicles must be capable of operating in warm humid climates, and the existence of nonmetallic materials as nutrients provides an ideal environment for fungi growth.

The best way to prevent fungi is to use fungi-resistant materials during design. In general, metals, glass, ceramics, and minerals are fungi-resistant; while organic materials such as fur, silk, leather, or cotton are fungi-nutrient. Lists of these materials are given in MIL-E-11991[13] and MIL-STD-454[14]. Table 5-3 also gives examples of such materials.

The electrical designer should avoid the use of fungi-nutrient material. When this is not possible, he should specify materials that have been coated or impregnated with a fungicide. To ensure fungus-free new equipment, the designer should specify equipment tests to be conducted in accordance with MIL-E-5272[15]

TABLE 5-3. MICRO-ORGANISM MATERIAL LISTS

Fungi-resistant Materials
Acrylonitrile — vinyl chloride copolymer
Asbestos
Ceramics
Chlorinated polyether
Fluorocarbons
Glass
Metals
Mica
Plastics (using glass, mica, etc., as fillers)
Rubber
Silicone

Fungi-nutrient Materials
Cardboard
Cellulose nitrate
Cellulose (regenerated)
Cotton
Cork
Felt
Leather
Linen
Paper
Plastics (using paper, cotton, linen, etc., as fillers)
Silk

5-3.9 FLAMMABILITY

Fire obviously represents a serious and potentially catastrophic hazard, particularly in a military situation. Flammability is something that should be avoided at all cost in military vehicle design. The electrical designer should be most concerned with this hazard because vehicle electrical systems use much nonmetallic material.

A flammable material is one capable of being easily ignited and, once ignited, burns with extreme rapidity. A material is fire-resistant when: it self-extinguishes after application of a flame; an applied flame does not cause violent burning or an explosive-type fire; or the spread of surface-burning on large parts is deterred.

The electrical system designer should specify self-extinguishing materials whenever possible in the vehicle electrical system. If not, then the materials should be treated with, or enclosed by, a fire-retardant material. The selection of components covered by Military Specifications may or may not satisfy flammability design considerations. Although parts covered by Military Specifications must meet certain minimum requirements, flammability is not always one of them. However, the designer can assess this by referring to the particular specifications covering the component.

5-4 AVAILABILITY CONSIDERATIONS

Availability of material or component parts or production is another consideration equal in importance to electrical and environmental considerations. The designer should consider whether the use of a certain material or component might lead to a future shortage. Such shortages often occur with specialized or proprietary materials such as potting compounds or rare metallic alloys.

Another type of shortage may occur if demand exceeds supply. A small supplier may not be able to meet the demand because of lack of equipment or plant limitations. Even a large supplier may not be able to meet the demand if it were to increase rapidly. These are factors that the electrical equipment designer should consider when selecting the material or components for his design. Further discussion of factors which affect availability are given in the procurement considerations that follow.

5-5 PROCUREMENT CONSIDERATIONS

Procurement of material and components for a design is concerned with future production of parts or material, how much leadtime is required between the initial purchase of parts and vehicle production, and the selection of suppliers to meet the overall demand and to assure a continuous and timely delivery. The paragraphs that follow discuss these considerations.

5-5.1 LEADTIME

Parts are introduced into the system by the assembly or installation drawings. Often, the drawing completion date does not occur early enough to allow procurement of parts in time to meet a fabrication commitment. For this reason, the designer should initiate advance procurement orders for critical parts so all will be available at the scheduled fabrication date.

Although it is often difficult to know exactly how much leadtime is required for a particular electrical component, Table 5-4 shows the amount of estimated leadtime for typical electrical components[16]. Since procurement leadtimes are subject to change, the designer should use Table 5-4 only as a guideline and should consult with his purchasing agent as to the current situation.

5-5.2 SOURCES

Many suppliers of material and components have established by their past performance that they can produce quality products and meet a timely delivery schedule. These suppliers are well known to quality assurance personnel and purchasing agents. The electrical system designer can avoid many of the problems associated with procurement if he specifies products produced by these reputable manufacturers. Although the purchasing agents and quality assurance personnel are most concerned with this aspect of design development, it is the system designer who does the component selection and, therefore, must evaluate the source.

It is often desirable for the vehicle electrical equipment designer to specify alternate or multiple sources of supply for a particular component. This not only assures a continuous supply of parts for increased future demands, but also maintains a high quality level through supplier competition.

5-6 TEST AND EVALUATION

Testing of components and electrical systems should be of primary concern to the electrical equipment designer. This is particularly true where the designer must use nonstandard parts in his electrical system. It is of utmost importance to test the proposed component for intended application requirements. Appropriate test methods may be found in MIL-STD-202[17] and MIL-STD-810[18]

5-6.1 PROTOTYPE TESTING

Newly developed components procured for a prototype vehicle should be tested as soon as they are received. Also, endurance and

TABLE 5-4. ELECTRICAL COMPONENT LEADTIME

Component	Estimated Leadtime, weeks
Aluminum wire and cable	2-6
Batteries	4-6
Chart recorders	4-10
Chemicals	1-4
Copper wire and cable	2-8
Electric meters	2-10
Electric motors: fhp	4-10
Electric motors: 1-30 hp	4-12
Electric motors: over 30 hp	6-14
Electronic test equipment	4-10
Instrument motors	4-8
Insulators	4-8
Magnet wire	2-6
Measuring instruments and gages	2-10
Molded rubber and plastic parts	4-10
Pressure gages	4-10
Printed circuits	4-8
Relays and solenoids	2-8
Resistors, capacitors, etc.	4-8
Semiconductor devices	4-8
Switches	4-8
Temperature controls	4-10
Thermometers	4-10
Transformers	4-8

acceptance testing for all new developments in the component field should be performed as early as possible. This is essential to avoid costly delays in fabrication. A faulty component calls for some degree of redesign which is always time-consuming and often causes late delivery. Therefore, it is imperative to find faults before rather than during final assembly of the first production vehicle.

The electrical system designer should become involved with the prototype vehicle acceptance testing to thoroughly evaluate the performance of the electrical system and its interface with other systems. Also, every effort should be made to find problems and correct them during development testing before production begins.

5-6.2 DEFICIENCY CORRECTION

The system designer should recognize that the development engineering team is more familiar with design requirements than production engineering personnel. Development personnel are, therefore, best equipped to solve potential production problems before they occur. The designer must not procrastinate in solving development problems. Often his task can be made simpler by seeking opinions and assistance of trained specialists such as maintainability, reliability, or human factors engineers; procurement agents; mechanics; and test drivers.

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CHAPTER 6

DOCUMENTATION

6-1 INTRODUCTION

Vehicle electrical system design documentation is an important factor affecting the development and quantity production of any vehicle. For example, the release of incomplete documents encourages suppliers and manufacturers to make suppositions regarding design intent for the documented items. These well-intentioned suppositions are not always correct and often result in the delivery of inadequate material. Furthermore, the release of inaccurate documents can, and generally does, result in "no-fit" or hazardous conditions requiring expensive revisions with obsolescence of materiel and tooling. An overabundance of problems arising from such shortcomings can produce chaos at the initiation of production for a new vehicle. A smooth transition from research and development (R&D) to production, which is desired by the Government and contractor alike, is facilitated by an engineering effort that produces accurate documents fulfilling the minimum requirements described in the paragraphs that follow. Electrical drawings are also valuable as maintenance aids if they are properly organized and contain sufficient information. Complete and accurate documentation is also necessary to establish a base for reprocurement and resupply actions required for proper maintenance of vehicles where other than the original supplier may receive contracts for the part.

6-2 TYPICAL ELECTRICAL SYSTEM DOCUMENTATION

Components of an electrical system are documented and introduced through callouts appearing on assembly and installation drawings. The various diagrams used for electrical interpretations are, by their nature, reference information, and, accordingly, cannot be used to introduce parts into the supply system. However, assembly and installation drawings often include complete diagrams. Such treatment usually is limited to situations where the diagrams are comparatively simple. Complicated diagrams should be prepared as separate drawings, referenced on installation or assembly drawings. All diagrams, assembly, and installation drawings should be prepared using standard techniques in accordance with MIL-STD-100[1], except where otherwise specified in the development contract. A typical vehicle electrical system drawing structure, charted in Fig. 6-1, illustrates the typical drawing support requirements deemed necessary at installation, assembly, and subassembly levels. Drawing types are described in subsequent paragraphs.

6-2.1 SYSTEM INSTALLATION DRAWING

A vehicle electrical system installation drawing is required to convey general configuration requirements and the complete information necessary to install units, assemblies, subassemblies, and their interconnecting cable or harness assemblies to the supporting structure. The method used to prepare an installation drawing depends on the complexity and nature of the system. A simple plan view may be adequate. In other situations, a three-view orthographic drawing or an isometric drawing may be required to delineate clearly the items of the installation and the interconnecting cable assemblies. Generally, the method selected should require the fewest drawings possible.

MIL-STD-100 requires that an installation drawing include the following, as applicable:

1. Interface mounting and mating information, such as locations and specifications for attaching hardware

2. Interfacing pipe and cable attachments required for the installation and cofunction-

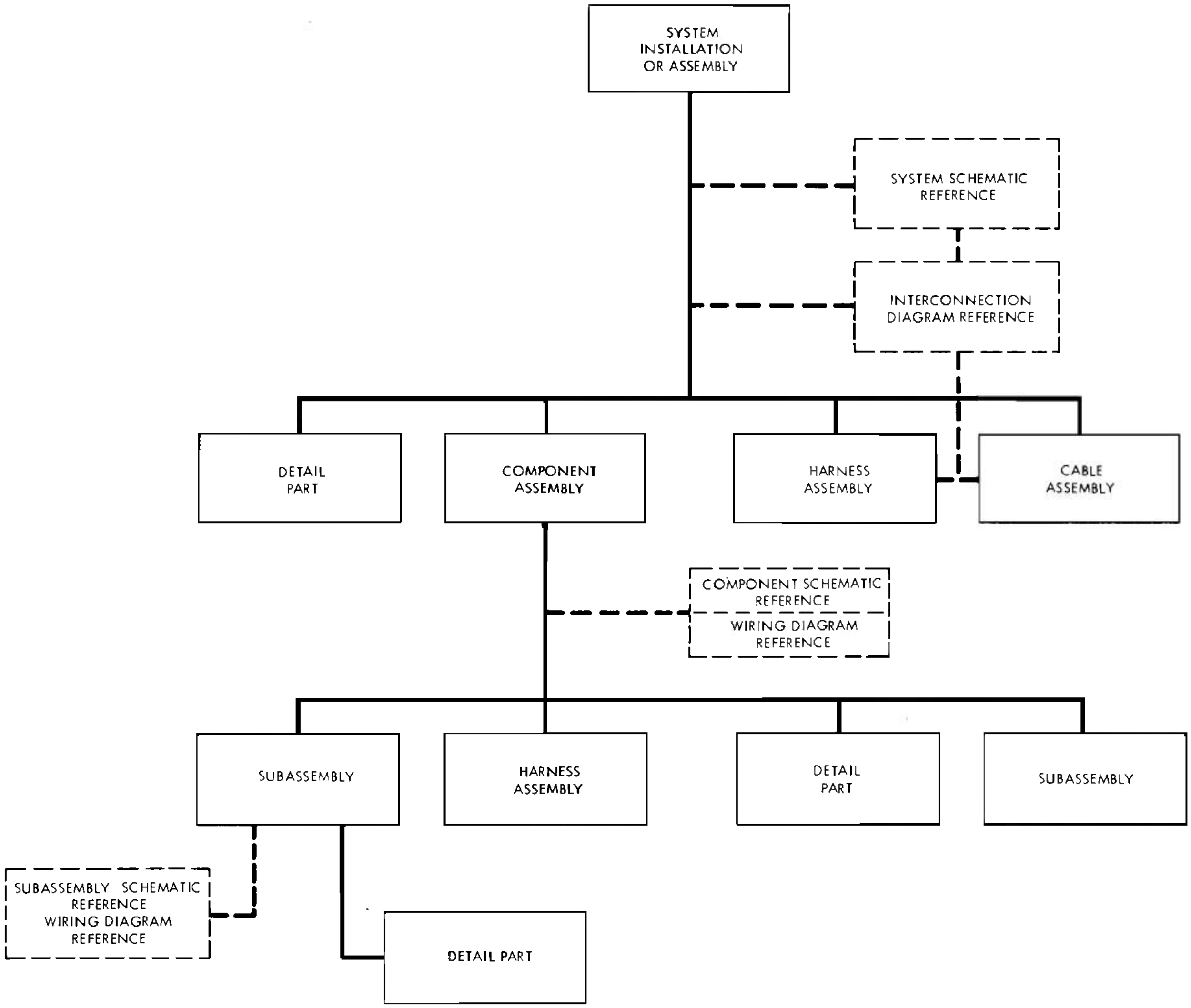


Figure 6-1. Electrical Drawings—Structure Chart

ing of the item to be installed with related items

3. Information necessary for preparation of equipment mountings, including mounting plate details, drilling plans, and shock mounting and buffer details

4. Location, size, and arrangement of ducts

5. Location, type, and dimensions of cable entrances, terminal tubes, and electrical connectors

6. Interconnecting and cabling data

7. Reference notes to applicable lists and assembly drawings

8. Overall and principal dimensions in sufficient detail to establish the limits of space in all directions required for installation, operation, and servicing; the amount of clearance required to permit the opening of doors or the removal of plug-in units; and clearance for travel or rotation of any moving parts, including the centers of rotation, angles of elevation, and depression.

6-2.2 SINGLE LINE DIAGRAM

A diagrammatic drawing delineates features and relationships between items of an assembly or system by means of symbols and lines[1]. A single line or block diagram is a line drawing, using single lines to connect block outlines which designate units or functional groups. It is used for general arrangement studies, functional explanations, illustrating flow, etc. This type of drawing generally is prepared when the characteristics of a given system, group, or item must be clarified and conveyed to others through the use of a simplified illustration. A single line diagram for a loudspeaker system is illustrated in Fig. 6-2.

6-2.3 SCHEMATIC DIAGRAM

A schematic is a diagram which shows, by means of graphic symbols and reference designations, the electrical connections and functions of a specific circuit arrangement without regard for the actual physical size, shape, or location of the components (Fig. 6-3). The schematic diagram facilitates tracing the circuit and its functions because the diagram is so organized that each function and its relationship to its controlling or protecting elements are readily perceived.

Schematic diagrams supplied as reference drawings in a complete documentation package are a natural outgrowth of the system analysis process. Such documents can be prepared, with very little additional effort, from the schematic layout developed during the electrical system load analysis (Fig. 3-15). Schematic diagrams should be arranged to read functionally from left to right and top to bottom. The overall result is a circuit layout that follows the signal or transmission path from input to output, or in order of functional sequence.

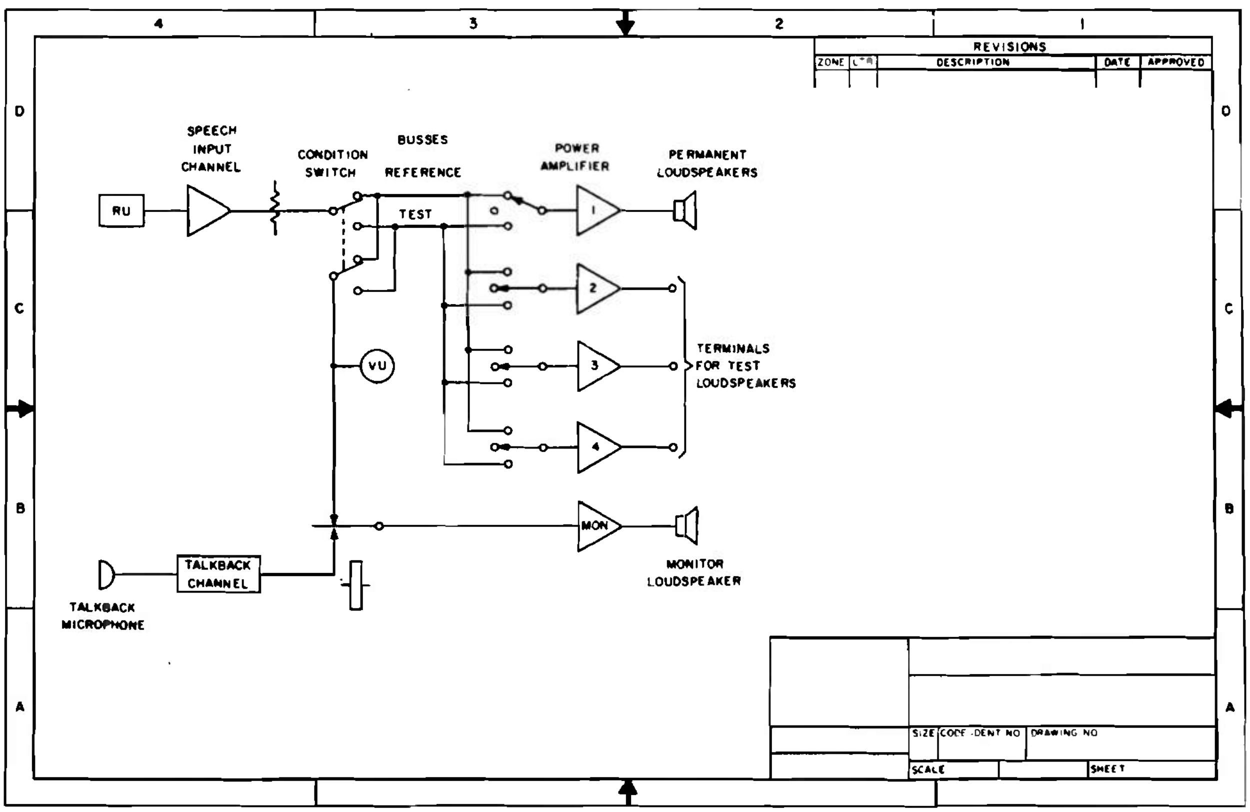


Figure 6-2. Single Line Diagram of Loudspeaker System

The schematic diagram is usually drawn in the horizontal format. The positive circuits are represented by an upper horizontal line on the drawing, and the lowest or bottom line represents the negative circuits. In systems employing the vehicle structure as the negative supply circuit, the lower negative line is often omitted, and each functional circuit is shown terminating in a standard ground symbol.

The schematic diagram in a direct current system may be arranged so the line representing the positive supply wire runs down the left side of the diagram, while the line representing the negative supply runs down the right side of the diagram. Then the lines and symbols representing each functional circuit run horizontally on the diagram between the positive and negative lines.

The sequence of operation is an optional document providing descriptive information for engineering personnel and for inclusion in Technical Manuals describing operation and maintenance. This document is closely associated with the electrical schematic and describes the step-by-step operation of the electrical system. The sequence begins with the closing of the master switch and proceeds through complete energization of the system by describing the function of each successive circuit and the associated switches and interlocks controlling it.

6-2.4 WIRING DIAGRAM

A wiring or interconnection diagram shows the electrical connections of an installation or of its component parts or devices. It may cover internal or external connections, or both, and contains such detail as needed to make or trace the connections that are involved. A wiring diagram (Fig. 6-4) usually shows the general physical arrangement of the major component parts or devices in a system and generally is employed in conjunction with a functional schematic diagram.

The wiring diagram is also a natural product of the development process. A wiring layout generally is produced during the hardware design stage, and usually such layouts are presented as a plan view of the vehicle with every electrical component located thereon. The designer then draws in the point-to-point wiring using circuitry on the schematic diagram as a basis for the wiring connections between components. The resulting layout is consolidated further by grouping interconnecting wires along common pathways and introducing connectors at required breakpoints, so the final layout depicts all electrical components and interconnecting cable assemblies or wiring harnesses in diagrammatic form. A wiring diagram suitable for use as a reference document in the vehicle data package is prepared easily from such a wiring layout.

6-2.5 WIRING HARNESS AND CABLE ASSEMBLY DRAWINGS

A wiring harness drawing shows the path of a group of wires laced together in a specified configuration, so formed to simplify installation (Fig. 6-5). The drawing should show all dimensions necessary to define the harness form and termination points. The drawing should also include a wire data tabulation of wire numbers or color codes, circuit reference designations, lengths, material specifications, and other data as necessary. Included in note form should be instructions, or references thereto, for the preparation and installation of the harness, associated schematic diagram, and the wiring diagram[1].

A cable assembly drawing depicts power, signal, radio frequency, or audio frequency cables normally used between equipments, units, inter-racks, etc. Cable terminations are normally plugs, sockets, connectors, etc.

A cable assembly drawing should include the following information as applicable: overall dimensions, including or excluding terminations; tolerances; preparation of ends of cable; wiring or schematic diagrams identifying color code of wires and termination terminals; identification bands or marking; special cable end-preparation instructions; ap-

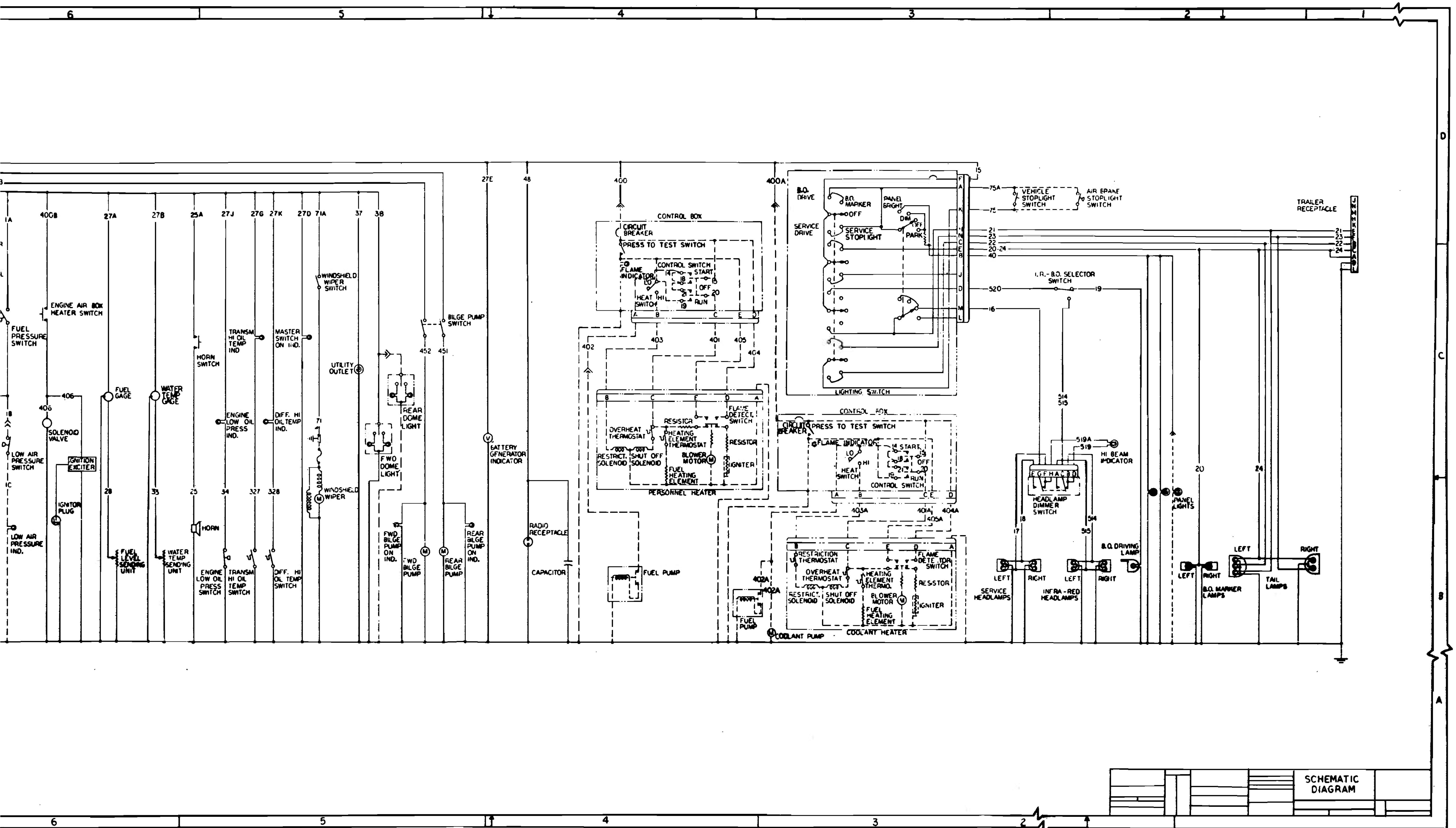
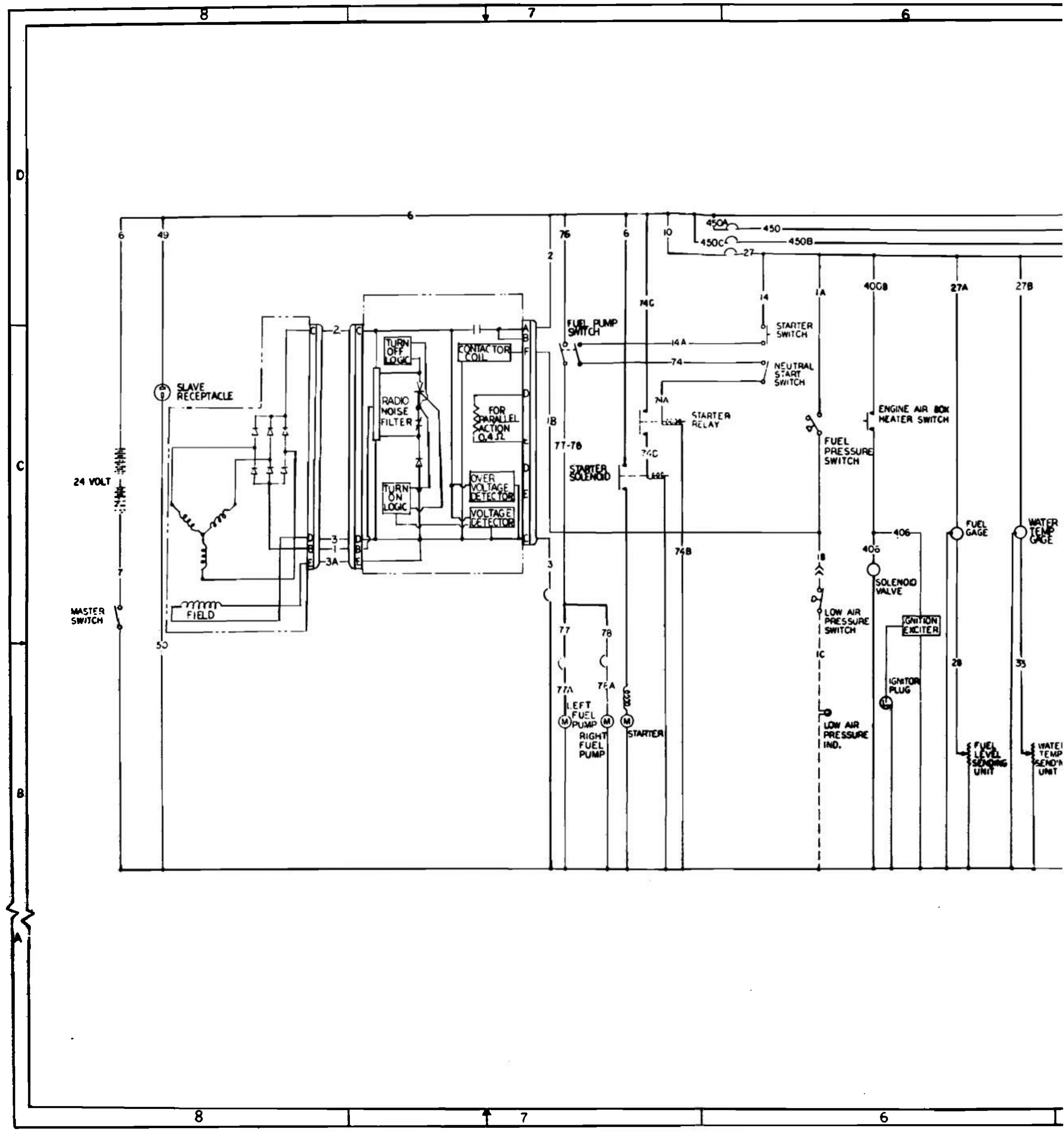


Figure 6-3. Typical Schematic Diagram, Complete Vehicle Electrical System



SLAVE RECEPTACLE
24 VOLT
MASTER SWITCH
FIELD
RADIO NOISE FILTER
TURN OFF LOGIC
TURN ON LOGIC
CONTACTOR COIL
FOR PARALLEL ACTION 0.4 Ω
OVER VOLTAGE DETECTOR
VOLTAGE DETECTOR
FUEL PUMP SWITCH
STARTER SOLENOID
STARTER RELAY
STARTER SWITCH
NEUTRAL START SWITCH
LEFT FUEL PUMP
RIGHT FUEL PUMP
STARTER
FUEL PRESSURE SWITCH
LOW AIR PRESSURE SWITCH
LOW AIR PRESSURE IND.
ENGINE AIR BOX HEATER SWITCH
SOLENOID VALVE
IGNITION EXCITER
IGNITOR PLUG
FUEL GAGE
FUEL LEVEL SENDING UNIT
WATER TEMP GAGE

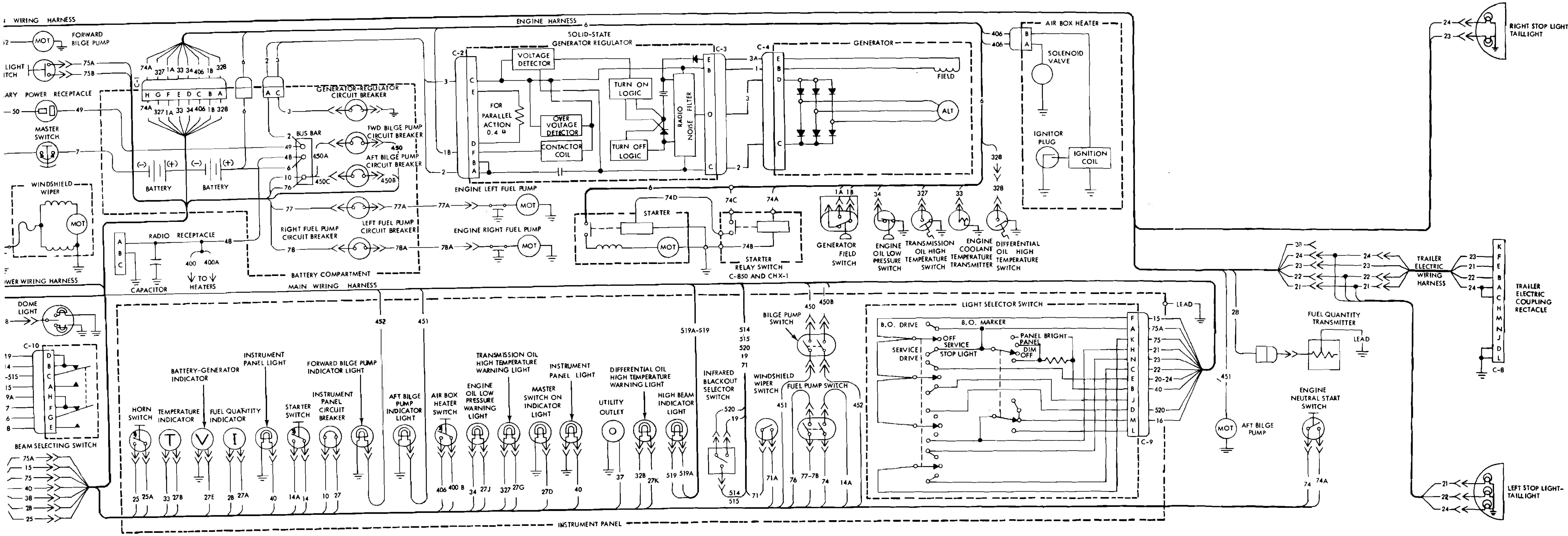


Figure 6-4. Typical Wiring Diagram, Complete Vehicle Electrical System

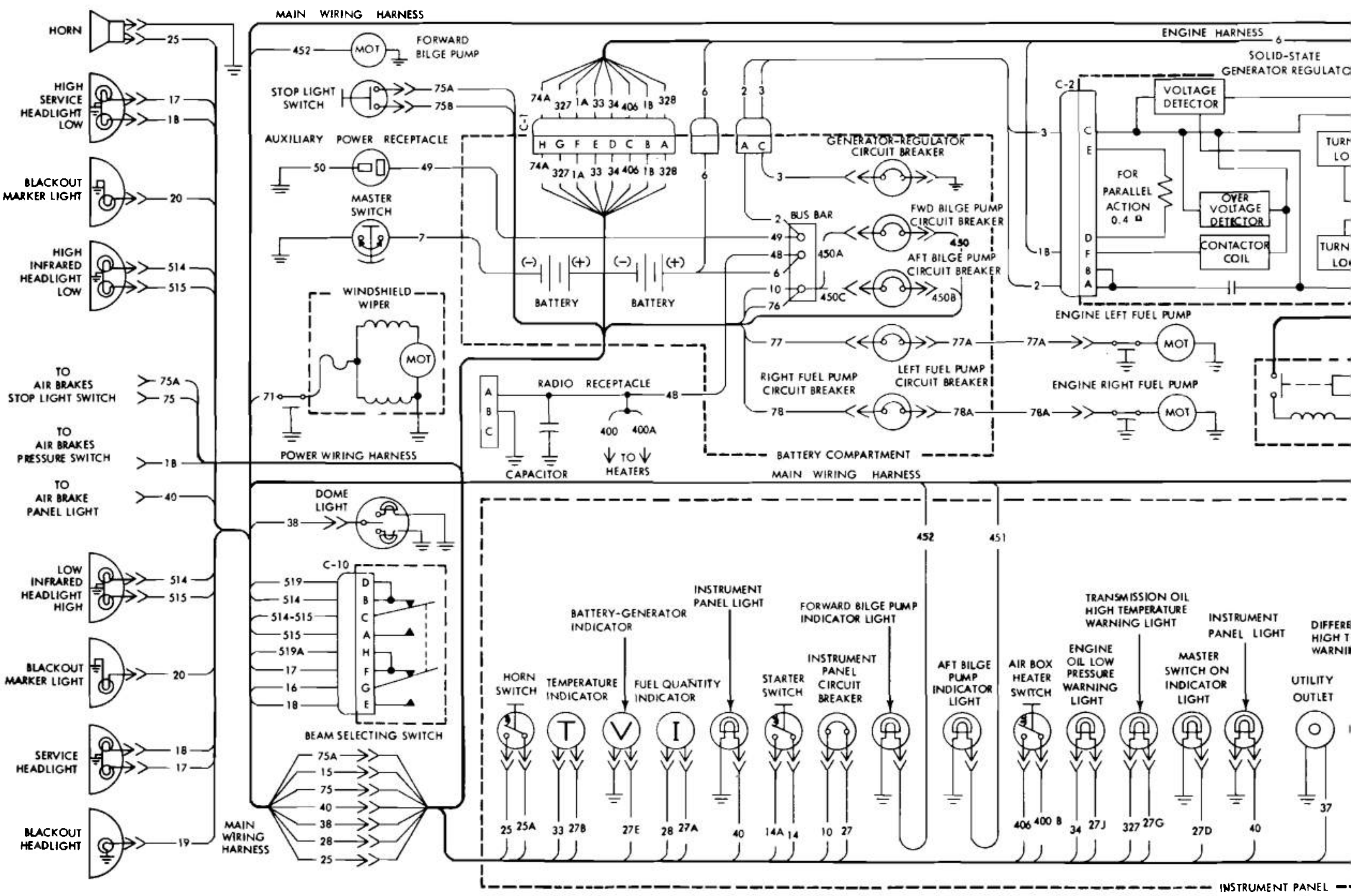


Figure 6-4. Typical Wiring D

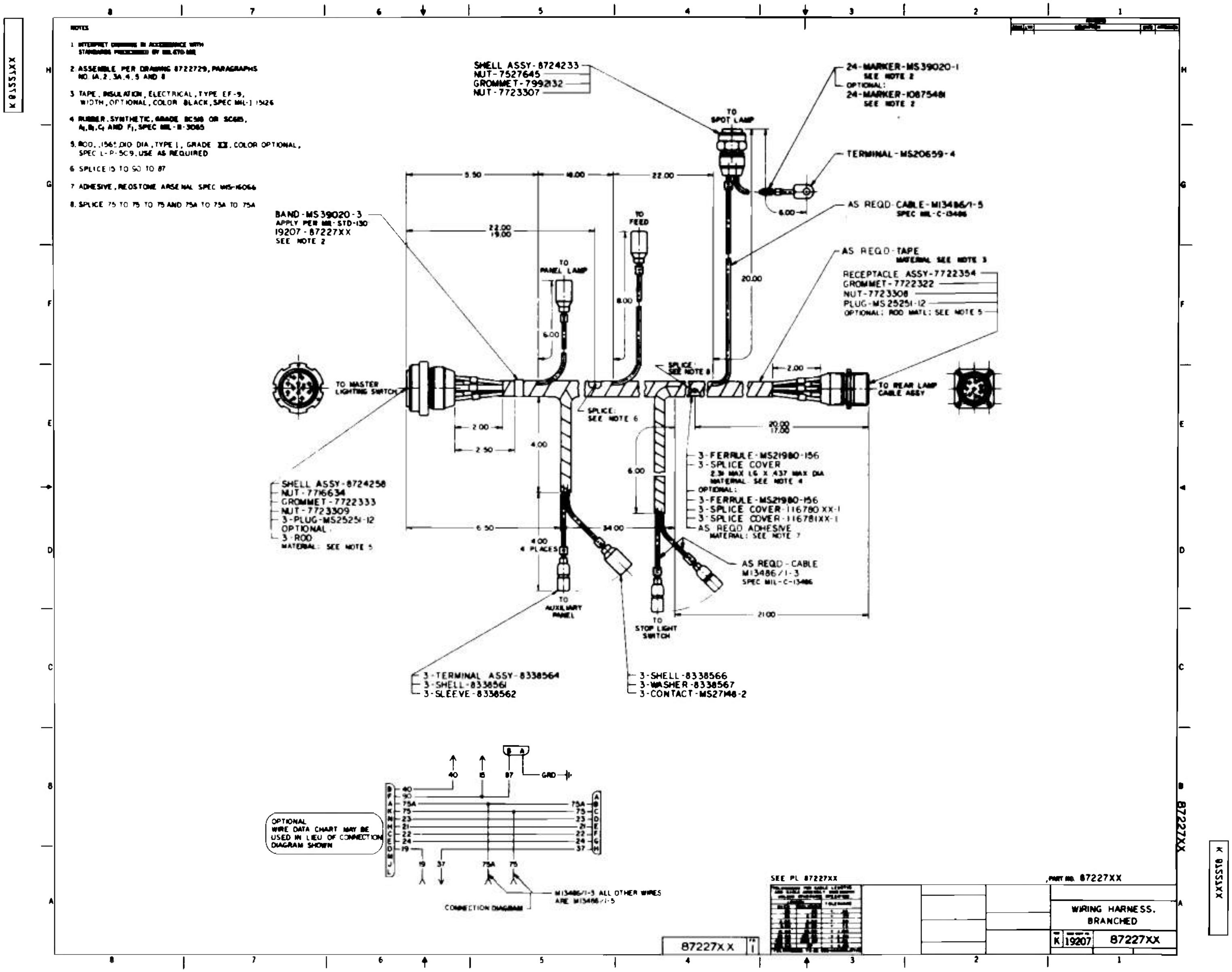


Figure 6-5. Wiring Harness Drawing

plicable tests; finish, if any; and special assembly instructions[1].

6-2.6 ELECTRICAL COMPONENT ASSEMBLY DRAWINGS

An assembly drawing depicts the assembled relationship of two or more parts, a combination of parts and subordinate assemblies, or a group of assemblies required to form an assembly of higher order. It should contain sufficient views to show the relationship between each subordinate assembly and part comprising the assembly depicted. Subordinate assemblies and parts should be called out in the field of the drawing, either by their identifying (part) numbers or by find (item) numbers cross-referenced to the identifying numbers in a table or parts list. When information regarding the assembled relationship and identification of parts is shown on assembly drawings of subordinate assemblies, it should not be repeated on the assembly drawing of higher order. Only the identifying number of each subordinate assembly, its configuration, and location should be shown. Assembly drawings should contain references to pertinent associated lists, installation drawings, wiring and schematic diagrams, etc. The division of an item into subordinate assemblies should be in accordance with practical assembly and disassembly procedures[1]. Electrical performance requirements and a schematic diagram of the electrical circuit are required to document thoroughly an electrical device (Fig. 6-6).

6-3 DRAWING STANDARDS

A uniform system of control for engineering drawings through standardization of drawing practices is established by basic standardization documents, such as MIL-STD-100[1] and MIL-D-1000[2].

The preparation of documentation for submittal to requiring activities of the Department of Defense (DOD) is governed by one of 10 possible Intended Use Categories from MIL-D-1000 and may be produced in one of three possible forms. Both category and form generally are specified in the development contract.

6-3.1 INTENDED USE CATEGORIES

1. Category A–Design Evaluation

2. Category B–Interface Control

3. Category C–Service Test

4. Category D–Logistic Support

5. Category E–Procurement (Identical Items)

6. Category F–Procurement (Interchangeable Items)

7. Category G–Installation

8. Category H–Maintenance

9. Category I–Government Manufacture

10. Category J–Interchangeability Control.

6-3.2 FORMS OF DRAWINGS

1. Form 1–Drawings to Military Standards (MIL-STD-100)

2. Form 2–Drawings to Industry Standards (Partial Military Controls)

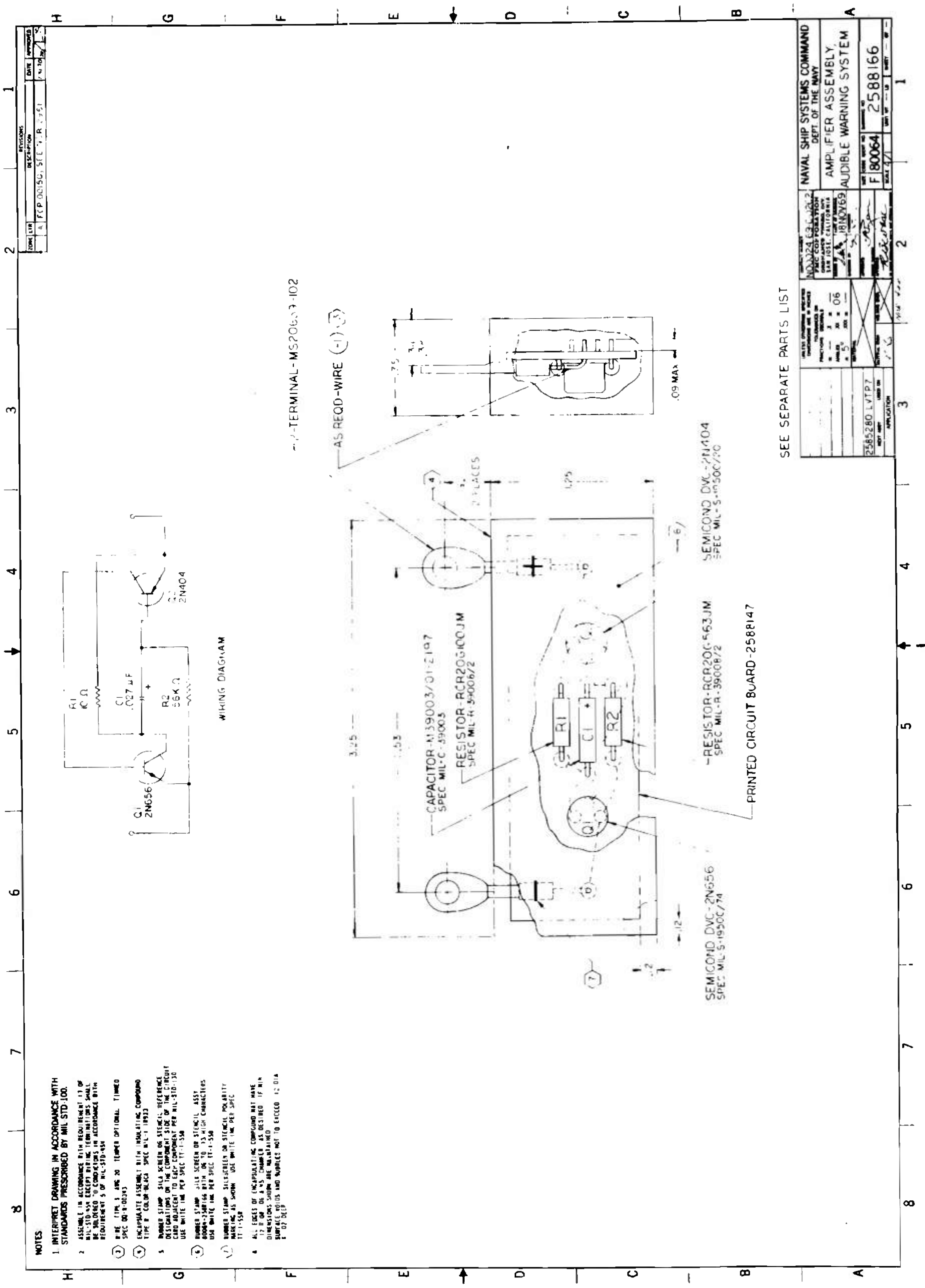
3. Form 3–Drawings to Industry Standards (Minimum Military Controls).

6-3.3 GUIDANCE DOCUMENTS

Other basic standards used as guidance in the preparation of electrical drawings are:

1. * ANSI Y32.2, *Graphic Symbols for Electrical and Electronic Diagrams*. This stand-

*American National Standards Institute (ANSI) (formerly USAS and ASA)



(Dimensions in Inches per MIL-STD-100)
Figure 6-6. Electrical Component Assembly Drawing

ard provides a list of graphic symbols for use on electrical and electronic diagrams.

2. * ANSI Y32.16, *Reference Designations for Electrical and Electronic Parts and Equipment*. This standard covers the formation and application of reference designations for electrical and electronic parts and equipment. The reference designations of this standard are intended for uniquely identifying and locating discrete items on diagrams and in a set, and for correlating items in a set, graphic symbols on diagrams, and items in part lists, circuit descriptions, and instructions.

3. * ANSI Y14.15, *Electrical and Electronic Diagrams*. This standard contains definitions and general information applicable to most of the commonly used electrical and electronic diagrams. It also includes detailed recommendations on preferred practices for use in the preparation of electrical and electronic diagrams. The recommended practices covered by this standard are ground rules designed to eliminate divergent electrical and electronic diagram drafting techniques. The illustrations included in this standard represent good drafting practices.

4. MIL-STD-806, *Graphic Symbols for Logic Diagrams*. This standard prescribes the graphic symbols for logic diagrams in which connections between symbols are shown with lines. Definitions of logic functions, the graphic representations of the functions, and examples of their application are given.

5. MIL-STD-275, *Printed Wiring for Electronic Equipment*. This standard establishes design principles governing the fabrication of rigid, single, or double-sided printed wiring boards, and the mounting of parts (including integrated circuits) and assemblies used in electronic equipment. The requirements do not apply to parts – such as resistors, inductors, capacitors, or transmission lines – fabricated using these techniques.

*American National Standards Institute (ANSI) (formerly USAS and ASA)

6. MIL-STD-12, *Abbreviations for Use on Drawings, Specifications, Standards and in Technical Documents*. This standard provides a list of abbreviations authorized for use on drawings, specifications, standards, and other technical documents.

7. H6-1, *Federal Item Identification Guide for Supply Cataloging*. This guide contains all names approved and published by the directorate of cataloging for use in preparing item identification.

8. MIL-STD-681, *Identification Coding and Application of Hook Up and Lead Wire*. This standard establishes identification coding systems for insulated hookup and lead wire used in electrical and electronic equipment.

6-4 DESIGN CONTROL

Two basic techniques are used to maintain design control over an item. Each of these techniques has advantages and disadvantages with the selection made on a case-by-case basis.

The form, fit and function type of control, sometimes referred to as performance specification and outline drawing, is particularly adaptable to commercial or modified commercial hardware – bilge pumps and batteries are good examples. Commercial applications for these items are numerous. Engineering data and production capability exist. Slight modifications in packaging or designs may be all that is required to adapt an individual producer's design to military requirements. In this type of control, the Government is not interested in the internal design provided the component performs its function. This design flexibility permits updating of components with advances in the state of the art. The one major pitfall in this method of control is the possibility that all requirements may not be included in the specification. In a highly competitive situation, new methods may be applied for lowering production costs, which will result in lowering the performance of some unspecified parameter. Another pitfall is that changes to a component which appear harmless for one vehicle may result in new problems in other vehicle system applications.

The military design method of control is particularly adaptable to those components whose requirements are unique to military vehicles and whose development costs cannot be amortized through application in the commercial market. Winches for use in vehicle recovery operations, or the 650-A generator for combat tanks, are good examples that fall in this category. The Government designs or contracts for the design of these types of items so as to meet military requirements, and detailed drawings are developed to describe them. The Government then contracts for production to the detailed drawings and assumes responsibility for the design as well as for updating the drawings to current production processes and techniques. The major drawback with this method is that the design itself is fixed and may become outdated.

These design control techniques result in the generation of three basic types of drawings which are used in the subsequent procurement process, namely:

1. Completely detailed part drawings that result from the mono-detail system, wherein each item is detailed individually. This system is employed with the military design method of control.

2. Envelope drawings that are prepared for any item, including existing privately developed items, where it is desirable to have all features other than those shown on the drawing left to the ingenuity of the producer to meet the specified performance data and design requirements. An integral repair parts list shall be included when applicable.

3. Source control drawings that are used when the Government has determined a particular component meets the vehicle system requirement, but definitive data are not available to establish a specification for competitive procurement. Further, it may not be cost effective to develop a specification because small quantities are involved or the prospects are poor for developing competitive suppliers. A source control drawing generally lists a sole source. However, if component equivalency can be determined by comparative testing, additional or multisources are added to source control drawings.

6-5 MILITARY SPECIFICATION SYSTEM

The Military Specification system is an excellent source for technical information on component parts and their performance characteristics in the military environment. Every vehicle design agency should be equipped with a complete file of these specifications to facilitate the use of standard parts in the greatest number of applications.

Specifications are prepared for items (and processes relative to the manufacture of items) which vary in complexity from paper clips to missile weapon systems. They establish requirements in terms of complete design details or in terms of performance but, in most instances, in terms of both design and performance. Specifications may cover a single item such as a camera, or thousands of items such as bolts, where each single style may include several materials, several finishes, and hundreds of sizes.

Federal Specifications are developed for materials, products, or services, used, or potentially for use, by two or more Federal agencies, at least one of which is an agency other than the DOD. This policy does not preclude the issuance of Military Specifications when conditions or requirements warrant such action.

Military Specifications cover items or services which are intrinsically military in character, commercial items modified to meet special requirements of the military, or commercial items with no present or known potential use by Federal agencies other than military. Military Specifications are issued as either coordinated or limited coordination documents. Coordinated Military Specifications are issued to cover items or services required by more than one military department. Limited coordination documents cover items or services of interest to a single activity or department. As a practical matter, a limited coordination document, prepared and issued by one activity or department, is often the first formal document to describe an item or service which is later used by other activities. It is the responsibility of the activity preparing a limited coordination document to inform potentially interested activities of the availability of the document by listing it in the *DOD Index of Specifications and Standards.* Activities are responsible for using all limited coordination documents wherever they are applicable. Further, an activity or department shall not issue limited coordination documents which duplicate or overlap those available[3].

Since most specifications are based on performance requirements, the possible variations in design and quality and the nature of the requirements and tests for certain classes of products are such that it is impractical to procure products solely on acceptance tests without unduly delaying delivery. To determine availability of products of requisite quality in such cases, qualification of specific products is required prior to the opening of bids or the award of negotiated contracts. Testing of a product for compliance with the requirements of a specification in advance of, and independent of, any specific procurement action is known as qualification testing. The entire process by which products are obtained from manufacturers, examined, and tested, and then identified on a list of qualified products is known as qualification. To establish a *Qualified Products List (QPL)*, a specification which requires qualification and sets forth the qualification examination and tests must exist. The preparing activity for a specification is responsible for qualification as specified in a specification. Qualification shall be specified only through the medium of a specification. The fact that a product has been examined and tested and placed upon a QPL signifies only that at the time of examination and test the manufacturer could make a product that met specification requirements. Inclusion on a QPL does not in any way relieve the supplier of his contractual obligation to deliver items meeting all specification requirements. Nor does the inclusion of a product on a QPL guarantee acceptability under a contract, because the products must conform to specification requirements. Qualification does not constitute waiver of the requirement for either in-process or other inspection or for the maintenance of quality control measures satisfactory to the Government[3]

6-6 SPECIFICATION WRITING

Generally, Military Specifications establish the acceptance criteria for the quality of purchased components for military equipment; therefore, the specifications must be written with producibility in mind. Quality requirements must be clear and practical so that, in time of need, quantity production of acceptable parts can be achieved by several sources.

As a rule, component specifications are not current with the state of the art because considerable time is required to gain acceptance for new items. Therefore, when a contractor is faced with circumstances wherein he must establish unique requirements for components, new specifications must be developed and the following factors should be considered:

1. Each specification should clearly and accurately describe the technical requirements of the specified item.

2. Specifications must also define the necessary tests required to verify that production components do indeed meet specified requirements.

3. New specifications should be prepared only for parts that have a distinct possibility of eventually being covered by a Military Specification.

4. Specifications may provide complete details of construction, or they may be

limited to outline dimensions for interchangeability purposes combined with performance requirement data.

5. New specifications should be prepared in the same form as existing Military Specifications. Such preparation will facilitate the future conversion of nonstandard part specifications to Military Specifications. MIL-STD-490[4] describes the specification writing process and format requirements.

REFERENCES

1. MIL-STD-100, *Engineering Drawing Practices*, October 1967.

2. MIL-D-1000, *Drawings, Engineering and Associated Lists,* March 1965.

3. M200B, *Defense Standardization Manual, Standardization Policies, Procedures, and Instructions*, April 1966.

4. MIL-STD-490, *Specification Practices*, February 1969.

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PART TWO
VEHICLE ELECTRICAL SUBSYSTEMS AND COMPONENTS

CHAPTER 7

POWER GENERATION, STORAGE, AND CONVERSION

SECTION I GENERATOR SYSTEMS

7-1 INTRODUCTION

The electrical generators used in military vehicles are electromechanical devices that serve to convert mechanical energy supplied by the vehicle engine to electrical energy as necessary to supply current for electrical system functions and to maintain the vehicle batteries in a fully charged condition.

In order to avoid damage to the batteries and other components, it is mandatory that the voltage supplied by the generator be regulated and set at a prescribed value. Allowable limits are established in MIL-STD-1275 (Fig. 7-1). Under normal environmental conditions, the system voltage is regulated at a nominal 28 V. This is the level required to provide charging of the 24-V batteries with minimum gassing at full charge. The regulated voltage set point may be adjusted to other values between 26 and 30 V in order to maintain the minimum gassing voltage on the battery when operating in tropic or arctic climatic extremes. Voltage surges above and below the 26- to 30-V range will occur as the generator-regulator system experiences sudden load changes. However, allowable steady-state voltage ripple is limited to 4-V peak to peak by MIL-STD-1275 (Fig. 7-1 and Fig. 7-2).

In addition to supplying the proper voltage, which is essentially controlled by the regulator, the generator must have sufficient capacity to supply the current required under maximum load conditions. This condition must be established by determining the maximum sustained load current required by the electrical system under representative operating conditions, including current supplied to the battery for charging purposes. Obviously, if sufficient generator capacity is not available to support the load, the battery must deliver the remainder. Such a condition is undesirable, if prolonged, because it results in battery discharge and a low system voltage.

In order for the generator to provide rated output, it must be operated at sufficient speed. Since military vehicles spend a large portion of their time at engine idle, it is important to note that during such periods the generator may be required to supply full rated current on a large portion thereof. It follows that the requirement for establishing the speed at which full rated output must be delivered is the controlling factor for optimizing the size of the generator. As a general rule, engines have a speed ratio between 4 and 5 to 1 from idle to maximum speed; i.e., typical engine idles at 650 rpm and has a maximum speed of 3,000 rpm. Typical generator speeds can be 2 to 4 times engine rpm. Top speed is limited by bearings, winding integrity, rotor growth, etc. Fig. 7-3 shows typical performance curves for common generating systems. It is apparent that if the proper drive speed is not selected, there will be low generator output at engine idle. This is more severe with DC generators than with diode-rectified alternators. At the other extreme, an undersized generator will experience overspeed when the engine is at maximum rpm if it is driven at sufficient speed to produce rated output at engine idle.

Other factors to consider regarding the minimum speed for rated output are the drive system characteristics and the engine horsepower available. The generator is essentially a constant horsepower device and this factor,

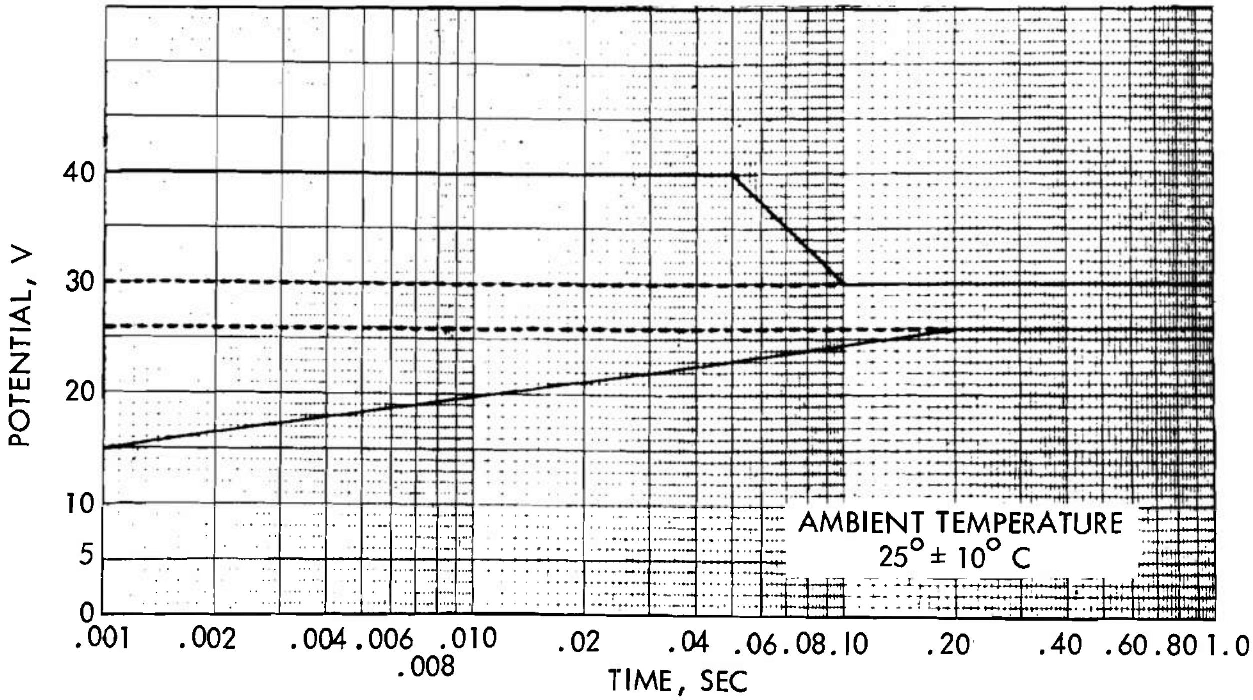


Figure 7-1. Charging System Voltage Limits[1]

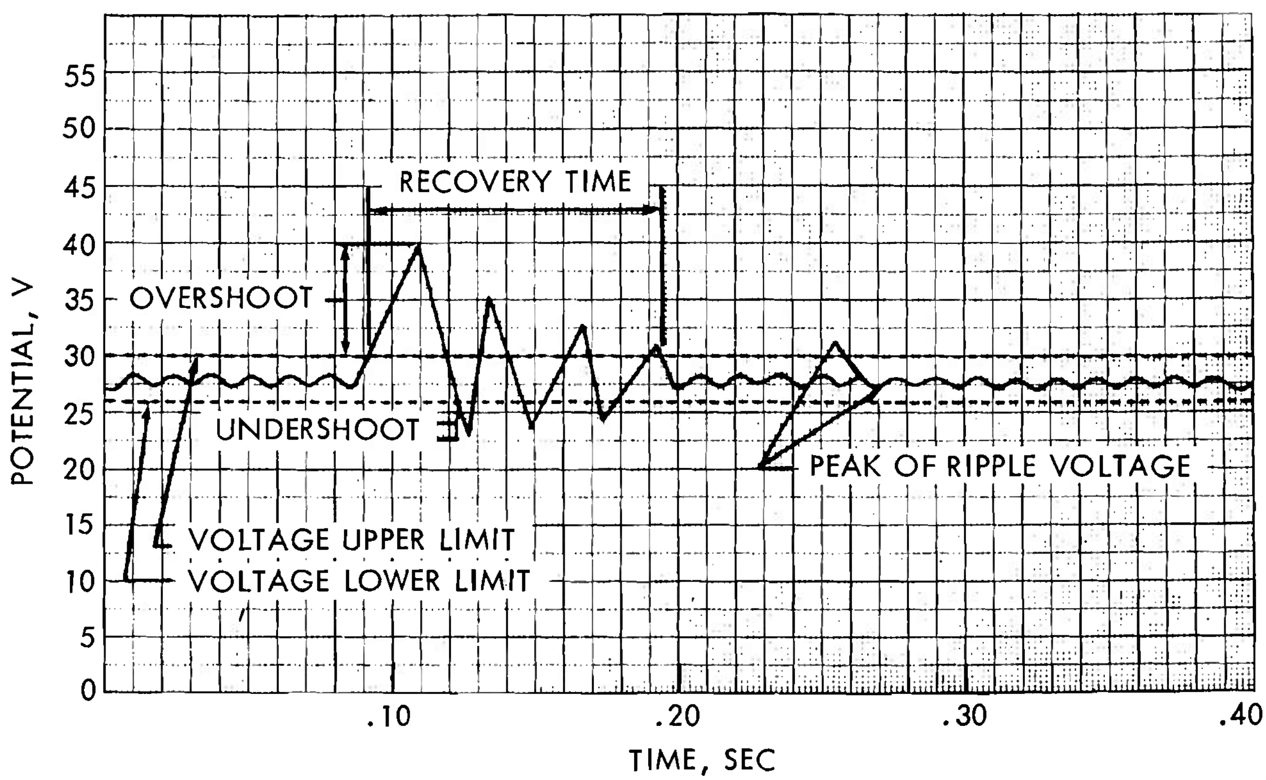


Figure 7-2. Typical Voltage Ripple and Transients[1]

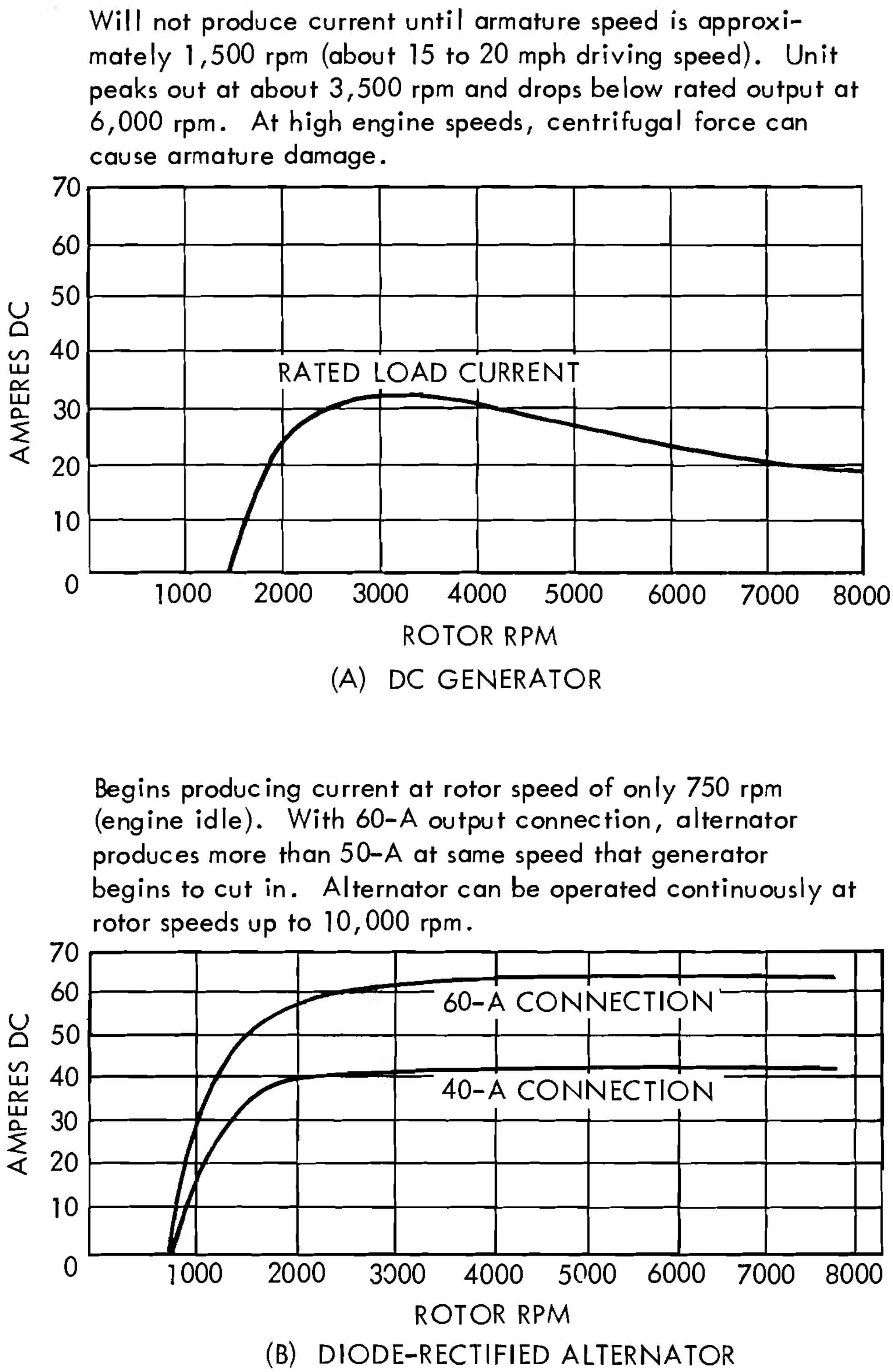


Figure 7-3. Typical Generator and Alternator Performance Curves[2]

along with a typical torque requirement, is illustrated in Fig. 7-4. As the minimum full output speed is reduced, the torque requirements approach a level taxing the drive system to its extreme.

Electrically, a charging system consists of a generator and regulator. The regulator may be a relay type, carbon pile, or solid-state device. The particular functions of the regulator include voltage, current, and reverse current

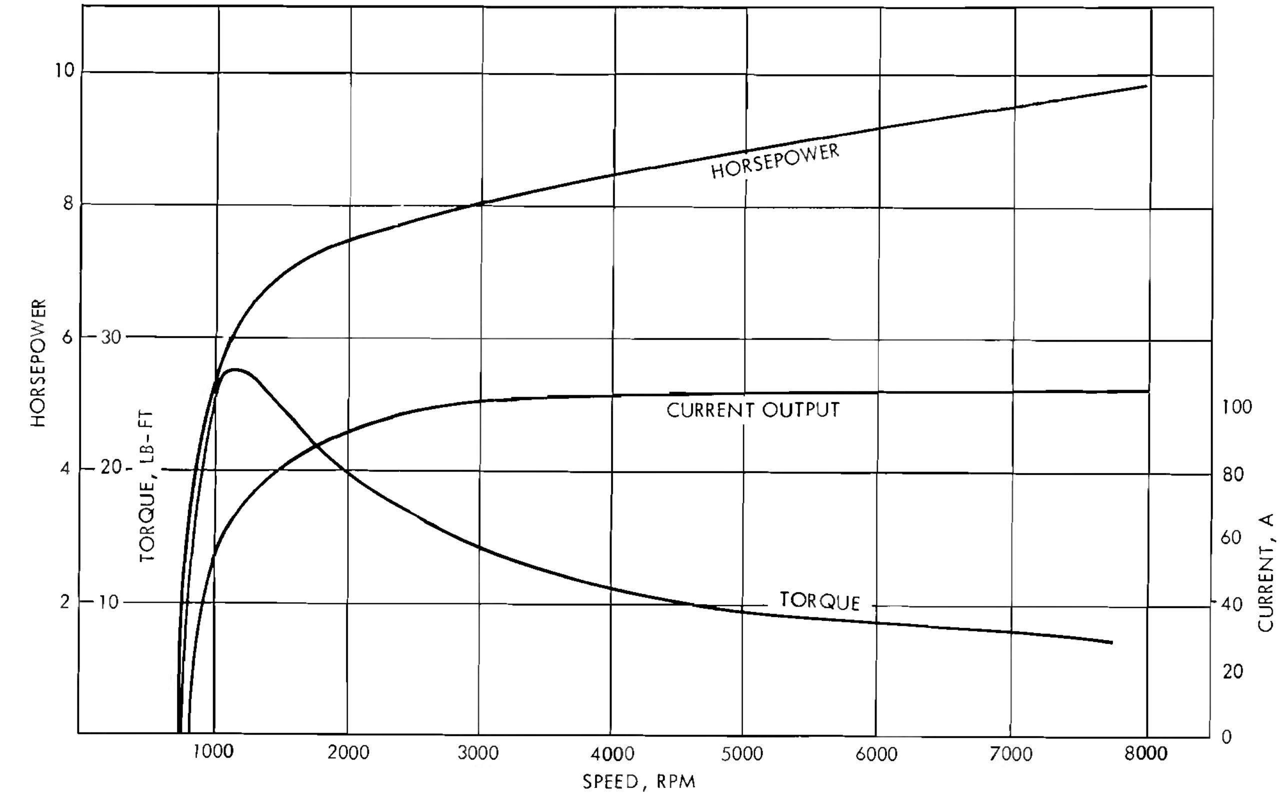


Figure 7-4. Torque-horsepower Characteristics[3]

control. Typical military vehicle charging systems are available in capacities from 25 to 650 A, and they employ a variety of generator types as indicated in Table 7-1. Components of these systems recommended for future applications are listed in Table 7-2 along with size, weight, and part number data.

7-2 GENERATOR TYPES

There are two basic generator types described in the following subparagraphs. These are the conventional DC generator and the diode-rectified alternator. Construction features, advantages, and disadvantages are examined as they relate to the DC generator and the wound pole, Lundell, inductor Lundell, inductor, and brushless rotating rectifier types of alternator. Generator cooling features, trends, and installation factors also are reviewed.

7-2.1 DC GENERATOR

Historically, the conventional synchronous generator with wound rotor-commutator construction evolved as the most common means for generating direct current and, until the increase in alternator popularity about 10 yr ago, this type of machine was used exclusively on automobiles and many military vehicles requiring a totally enclosed generator. Fig. 7-5 illustrates a typical DC generator in cross section so that construction features are visible.

The output waveform of a DC generator is a reasonably constant DC voltage with low ripple and superimposed high frequency, low energy, brush and commutation noise. Typical efficiencies for this type of machine can range from 65% to 80%. Efficiency is affected by brush drag, copper, rotor, and fan windage losses.

The generator has three main functional sections: the field, armature, and commutator. A field is generated between the pole pieces and, as the armature rotates through this field, an alternating voltage is induced in

TABLE 7-1. TANK-AUTOMOTIVE CHARGING SYSTEMS

Charging System, A	Voltage Range, V	Speed Range, rpm	Generator Type	Regulator Type
25	26-30	1,310- 8,000	Direct current generator	Separate electromechanical
60	27-31	700-10,000	Diode-rectified rotating field alternator	Integral solid-state
100	27-30	1,850- 8,000	Diode-rectified rotating field alternator	Separate solid-state
180	27-29	800- 8,000	Diode-rectified inductor alternator	Integral solid-state
300	26-30	2,500- 8,000	Direct current generator	Separate solid-state
650	26-30	4,000-12,680	Diode-rectified rotating field alternator	Separate solid-state

TABLE 7-2. CHARGING SYSTEM COMPONENTS

Charging System, A	Generator					Regulator		
	Cooling	Dia, in.	Length, in.	Weight, lb	Ord. part no.	Size, in.	Weight, lb	Ord. part no.
25	Air	6	11.85	44	10950808	Approx 6.5X3X9	3.5	11631857
60	Air	6.62	11.56	34	10929868	–	–	Integral with generator
100	Air	6.62	11.94	38	10947517	Approx 8X6X5	7	10947439
180	Air	8.00	12.18	72	Navships 80064-2586556	–	–	Integral with generator
300	Air	8.00	15.14	95	10889713		16	10945299
650	Oil	9.00	11.54	55	None	Approx 2.75X4.5 X6.8	3	None

the windings. The commutator and brushes serve mechanically to rectify this alternating current and cause direct current to appear at the output terminals.

As illustrated previously in Fig. 7-3(A), rated current is reached at a relatively high speed, reaches a maximum, and decreases with increasing speed. The decrease at high speed is attributable to armature reactive characteristics and commutation inefficiency. Advantages and disadvantages are:

1. Advantages:

a. Has experienced considerable evolution and exists in many configurations and capacities

b. Does not require rectification

c. Low ripple content

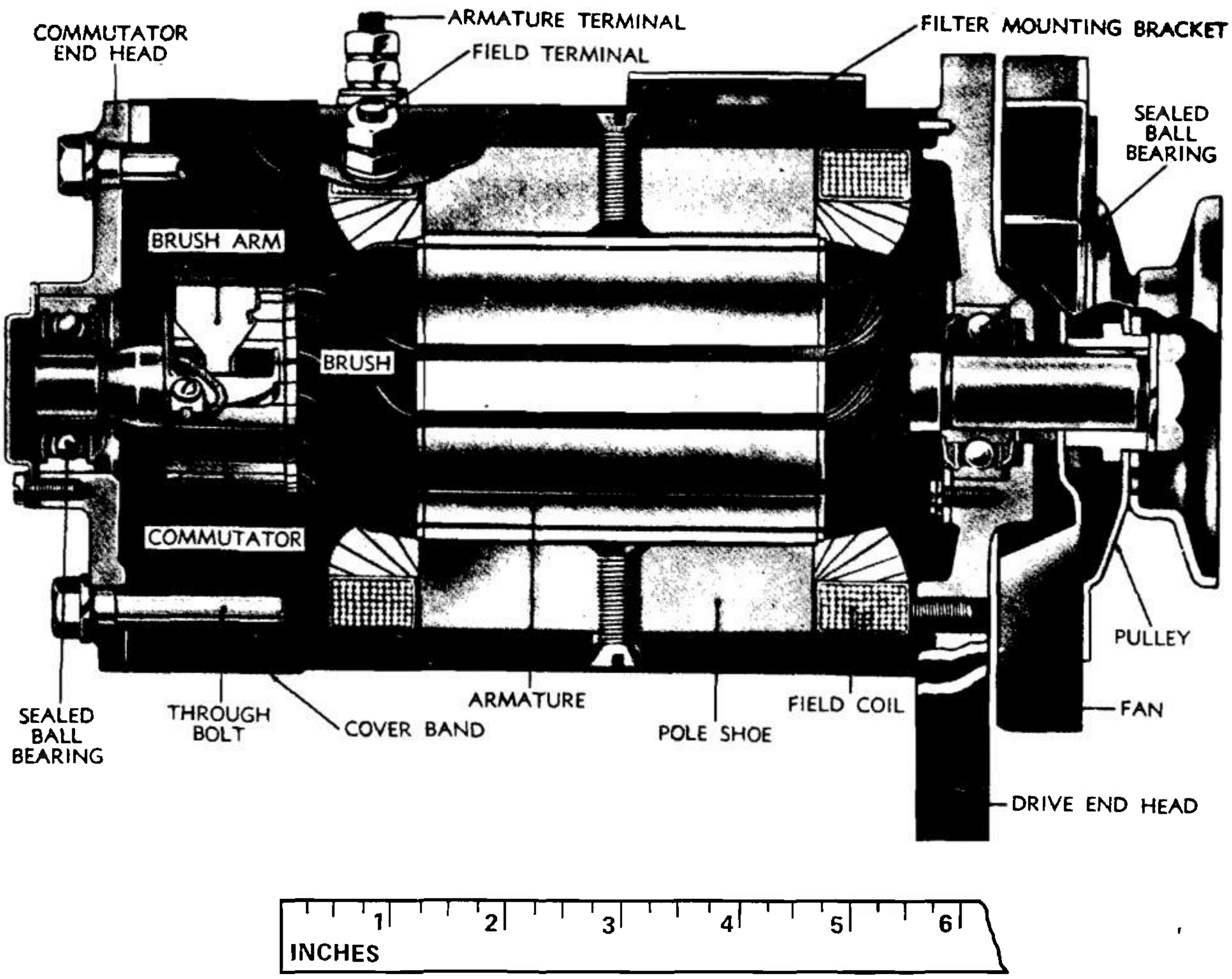


Figure 7-5. Typical DC Generator Assembly[4]

2. Disadvantages:

a. Complicated and expensive armature

b. Brush and commutator wear requires maintenance action

c. Low maximum speed limit

d. Lower efficiency due to brush drag and windage

e. Generated current transmitted through brushes.

7-2.2 DIODE-RECTIFIED ALTERNATOR

The diode-rectified alternator systems are represented by a variety of rotating machinery configurations. They will produce alternating current that is rectified to form direct current. The rectifying unit is generally a semiconductor element that may be integral with the generator or exist as a remote unit.

Included in the list of alternator design types are listed below.

1. Wound pole
2. Lundell
3. Inductor Lundell homopolar
4. Inductor homopolar
5. Rotating rectifier, brushless.

The basic variations are the means of exciting and constructing the field.

7-2.2.1 WOUND POLE

Fig. 7-6 illustrates the configuration of a typical wound pole alternator with rotating field. Alternate polarity occurs on successive poles. Pole excitation current is obtained through slip rings. Advantages and disadvantages are:

1. Advantages:

a. Wide speed range

b. Output current windings are stationary

c. Slip rings carry low field excitation current

2. Disadvantages:

a. Brushes and slip rings wear, are affected by contamination, produce contaminating carbon dust, may cause voltage modulation, and are not reliable for high-temperature, high-altitude, or high-speed applications.

b. Brush arc is an explosion hazard. Fuel or oil cannot be safely used as a coolant.

c. Rotor winding is hard to cool and is relatively unreliable in high-speed or rough-drive applications that cause stress on rotor windings and insulation.

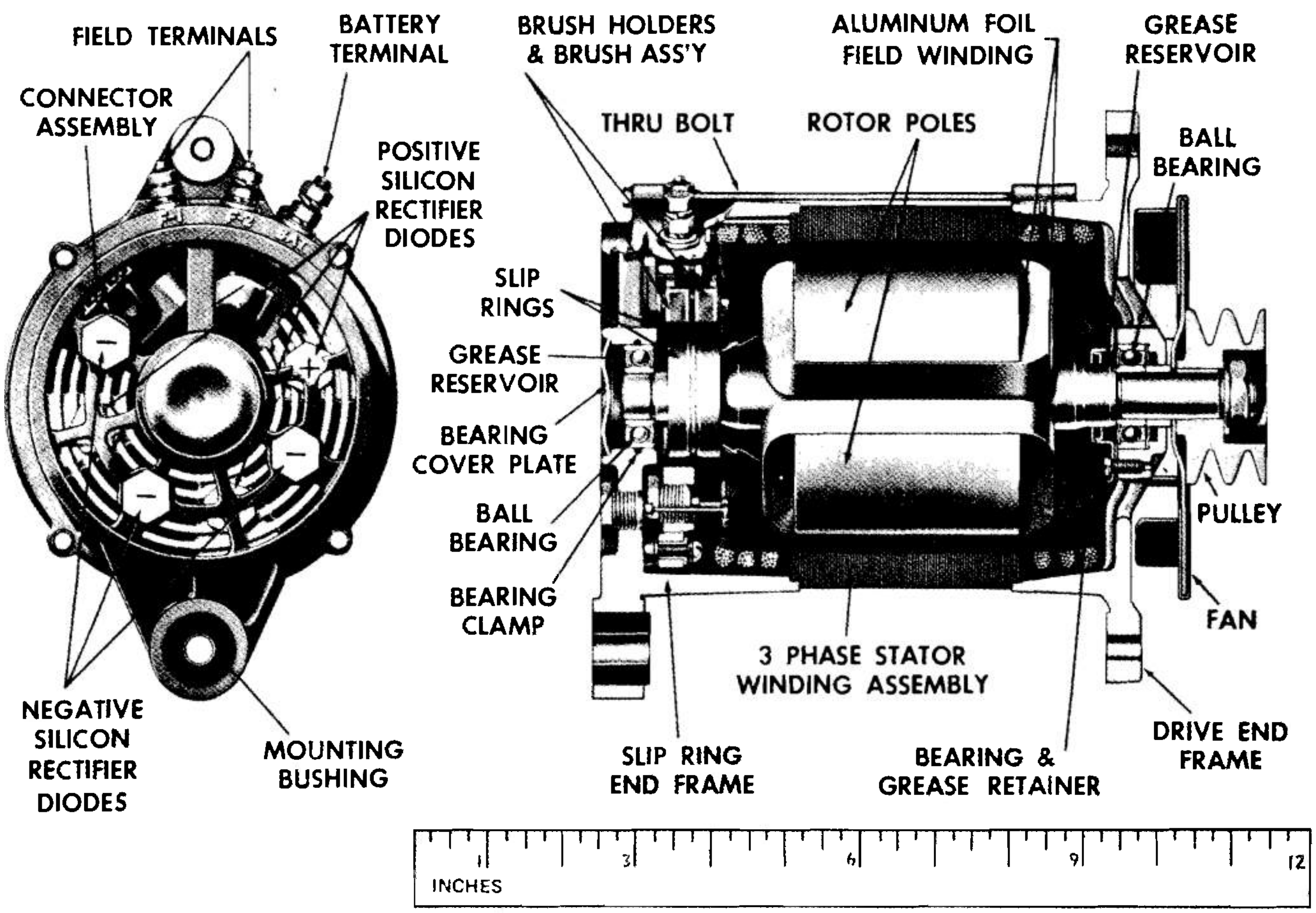


Figure 7-6. Alternator, Wound Pole Rotor Type[5]

d. Has an extensive history of development, but is best suited for low-speed applications in a limited range of environments.

7-2.2.2 LUNDELL ALTERNATOR

The Lundell rotor, as shown in Fig. 7-7, develops a field by placing the excitation windings around the axis of the rotor shaft, resulting in each end of the shaft assuming a polarity. Coupled to each end are interspaced fingers forming opposite that which provide an alternating field when rotated. Field excitation is achieved through slip-ring conduction. Advantages and disadvantages are:

1. Advantages:

    a. Simple rotor winding construction

    b. Stationary output current windings

2. Disadvantages:

    a. Windage losses

    b. Slip rings and brushes.

7-2.2.3 INDUCTOR LUNDELL

This generator type differs from the previously described Lundell type in that the rotor contains no windings. Excitation is induced into the rotor poles by stationary field coils located at the ends of the rotor. This results in the elimination of slip rings and rotating windings. Further advantages can be obtained by casting a nonmagnetic material around the pole fingers, thus producing a smooth rotor with low windage losses and high speed capability.

An inherent design requirement of this stationary field arrangement is the inclusion of an auxiliary air gap in the magnetic circuit. This requires greater field current for excitation. Fig. 7-8 illustrates construction features. Advantages and disadvantages are:

1. Advantages:

    a. No slip ring wear or contamination problems, and the unit is inherently explosion proof

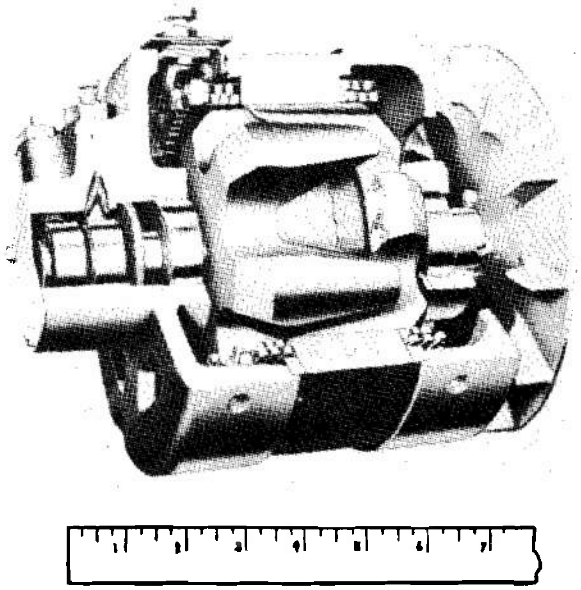


Figure 7-7. Lundell Alternator[6]

    b. Rotor can be solid and permanently balanced

    c. All windings are stationary and readily accessible for cooling

    d. Low rotor mass reduces bearing loads and permits rapid acceleration

    e. The bearing center-to-center distance is minimized by elimination of slip rings, and this in conjunction with a large shaft diameter permits high-speed operation.

    f. The field windings are simple, bobbin-wound coils permitting short mean turn length

2. Disadvantage: Extra air gaps in magnetic circuit require increased excitation power.

7-2.2.4 INDUCTOR ALTERNATOR

An inductor alternator employs a fixed-nonrotating field coil that induces excitation into the central portion of the rotor as if it

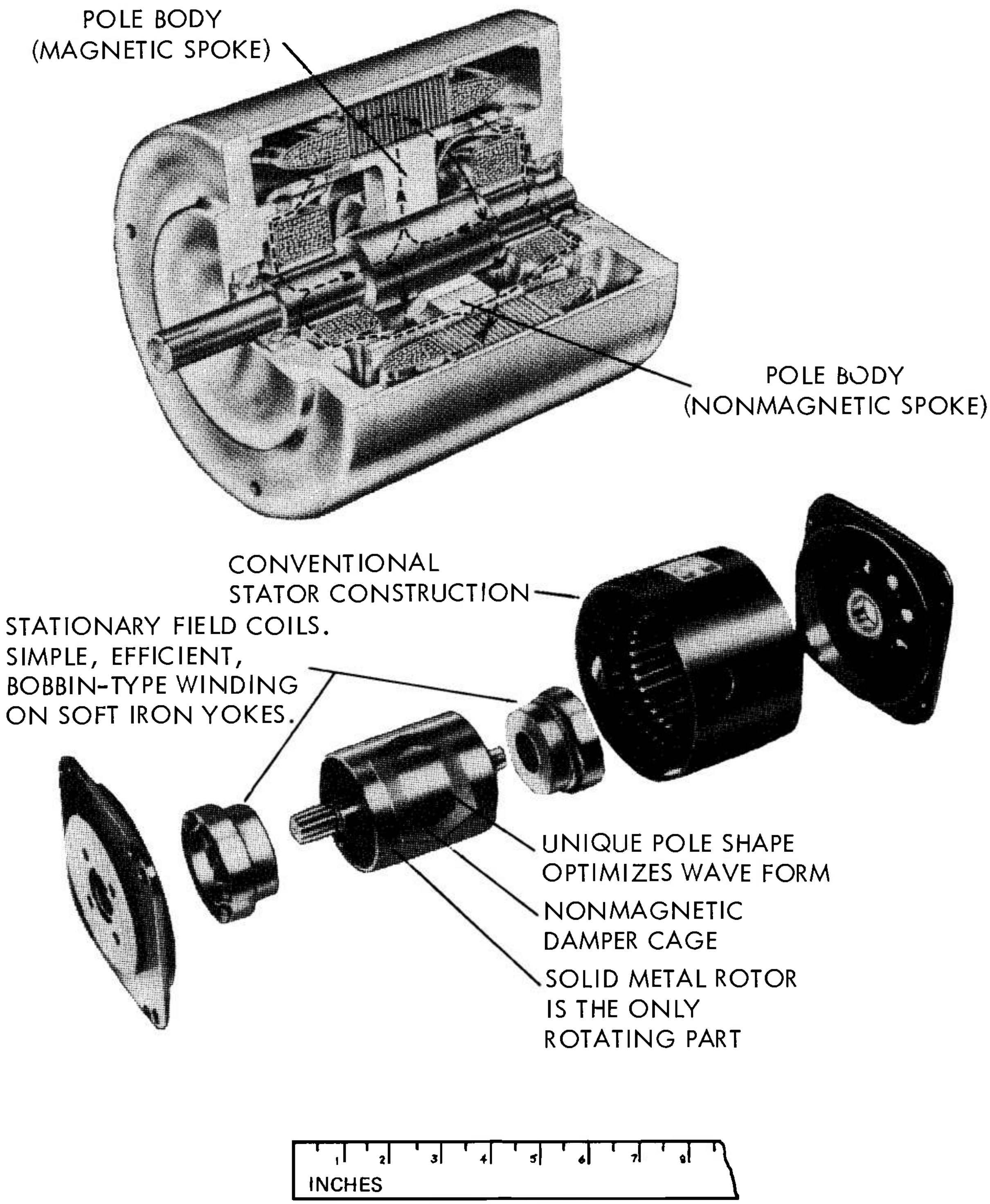


Figure 7-8. Inductor Lundell[7]

were a solenoid. Each end of the rotor assumes a polarity. Affixed to each end is a multilobed segment which, as it rotates, varies the reluctance in the magnetic circuit. As a result, the fixed stator poles experience a variation in magnetic strength or coupling and produce a resulting output voltage in the stator coils. In contrast to other types of generators, the iron does not experience a flux reversal. Consequently, there is only a

50% utilization of the iron in the stator. Fig. 7-9 illustrates typical construction of the inductor alternator. Advantages and disadvantages are:

1. Advantages:

a. Easier winding construction for field and stator coils

b. Simplified cooling

c. Brushless

d. Integral solid rotor without windings permits high-speed operation

2. Disadvantages:

a. Has less than 50% utilization of iron, resulting in an inherently heavier unit

b. Increased total air gap in magnetic circuit requires more excitation.

7-2.2.5 BRUSHLESS-ROTATING RECTIFIER

Another means for eliminating brushes and slip rings is found in the rotating rectifier type of alternator. The machine consists of five main functional elements. These include a stator-mounted exciter field, the exciter armature, a main rotating field, the main output stator windings, and the output rectifier assembly.

The exciter field induces alternating current in the rotating armature and the output is rectified and directly coupled to the rotating main field which excites the stator–mounted output windings. With this arrangement, a small amount of exciter field excitation can be amplified in the exciter stage to supply a high level of main field current. A diagram of elements is shown in Fig. 7-10 along with a cross section through the 650-A alternator that features this construction. Advantages and disadvantages are:

1. Advantages:

a. Brushless

b. Low exciter field current permits a low-level regulator.

2. Disadvantages:

a. Wound rotor limits top speed.

b. Multiple windings contribute to complexity and cost.

c. Large number of heat-producing rotating elements increases cooling requirements.

d. Large magnetic circuit limits response.

7-2.2.6 GENERATOR COOLING

The common methods used for cooling generators employ heat transfer by air flow or oil circulation. Each has its particular application based on characteristic advantages and disadvantages. In tank-automotive applications, air cooling is the most common method. The usual configuration consists of an integral fan that forces air through the alternator to cool the rotor, stator, and integral rectifier. The major advantage of air cooling is that the generator and cooling are self contained, drawing air from the environment. However, fan power requirements can become excessive at high speeds because fan designs usually are structured to provide sufficient cooling at the lowest speed corresponding to rated output. It follows that fan power at high speeds appears as a severe degradation in generator efficiency. Another factor is that, unless it is filtered, cooling air can deliver abrasive particles, water, etc., to the generator interior. Furthermore, rotor and stator design must permit unrestricted passage of air through the generator. This can be accomplished by designing passages through the rotor and stator.

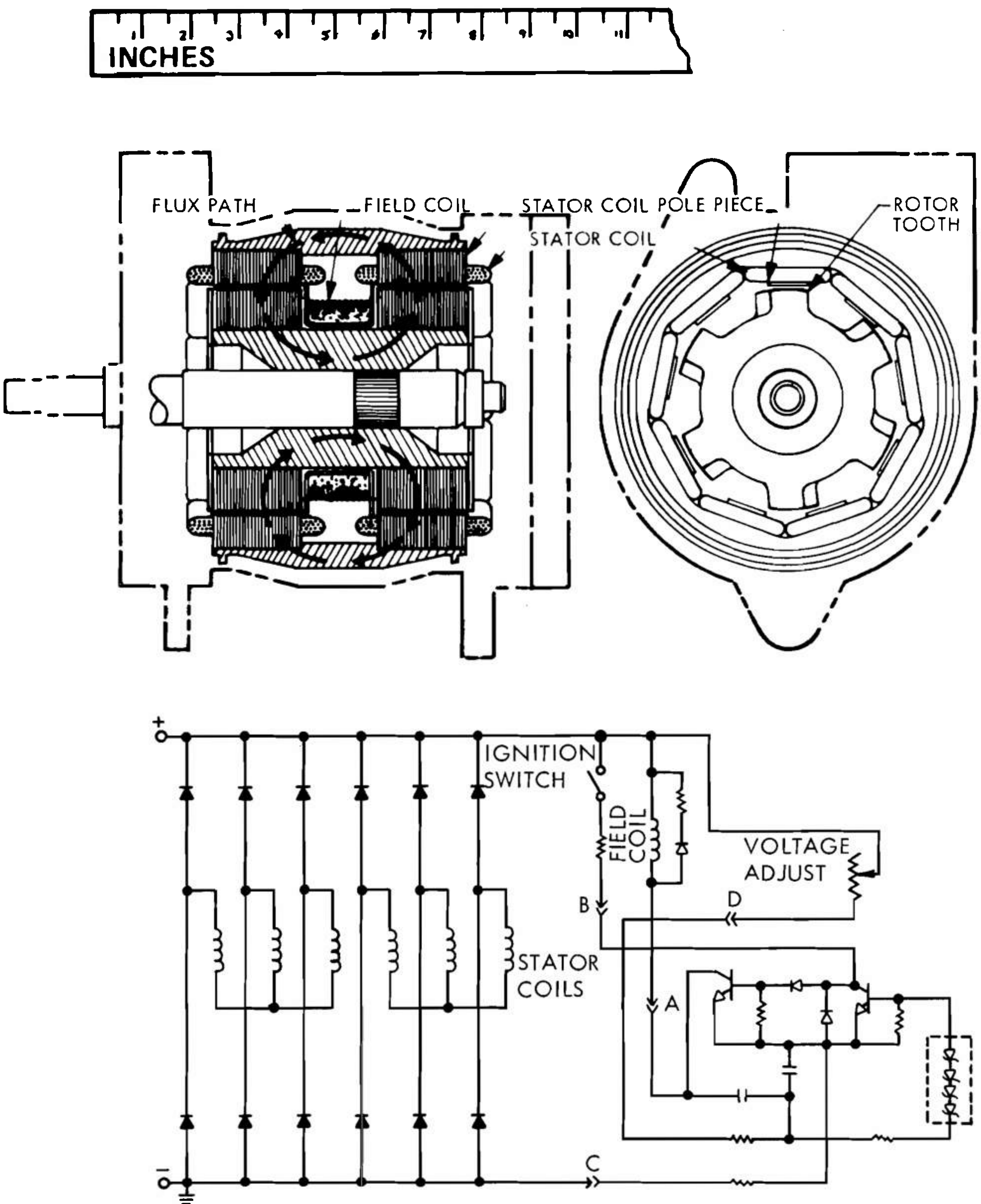


Figure 7-9. Inductor Alternator

However, discontinuities in the surface of the rotor contribute to windage losses, further affecting unit efficiency.

Oil cooling features a transfer of alternator heat into the circulating oil flow, followed by cooling of the hot oil in a heat exchanger. The

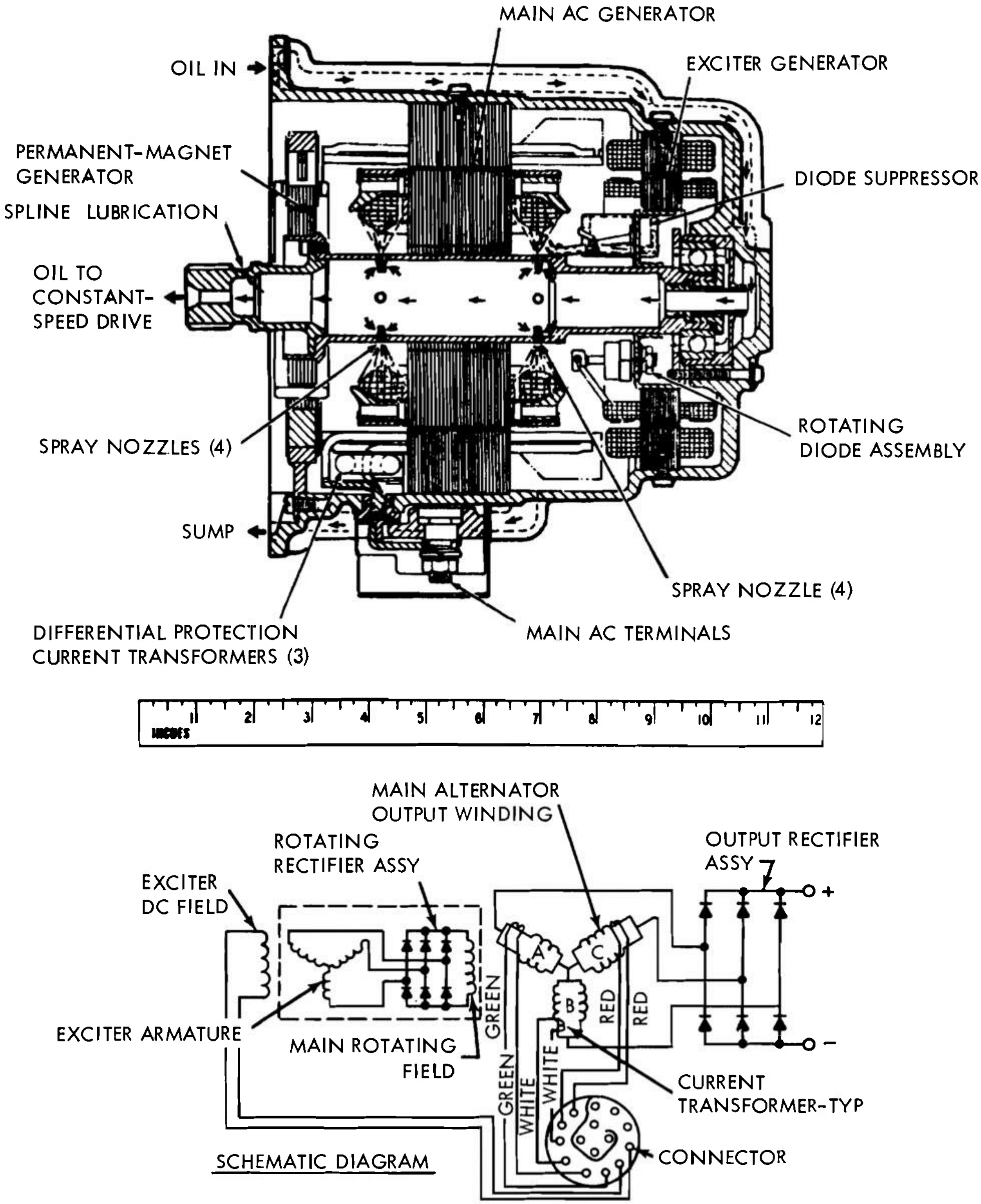


Figure 7-10. Brushless Alternator With Rotating Rectifier[8]

oil supply can be a part of the driving power system or a separate self-contained system.

Some oil-cooled system advantages are that the generator can be completely sealed, preventing entrance of foreign matter, water, etc.; cooling oil can be used for bearing lubrication; the rotor can be solid, reducing windage losses; and generator efficiency can be higher since the effective losses incurred in oil circulation are constant with generator speed.

Several disadvantages encountered with oil cooling include the consideration that complex manifolding, porting, seals, and passages increase costs; and that auxiliary heat exchangers and pumps increase cost, weight, and complexity.

7-2.2.7 TRENDS AND DEVELOPMENTS

Charging systems have evolved considerably since diode-rectified alternators began to replace the traditional DC generator in vehicle electrical systems. Initially the diode-rectified alternator was more attractive than the conventional generator because it promised charge-at-idle capability and higher output from a smaller machine. In addition, the continuous slip rings used to energize the rotating field in the alternator were inherently more reliable than the brushes and commutator in a conventional generator.

The first diode-rectified alternator systems employed separate selenium rectifiers and carbon pile voltage regulators with each of the three units having a preferred location. Alternators were mounted on the engine, rectifiers in the engine cooling air stream, and carbon pile regulators were shock mounted in a horizontal position in protected locations. Each of these units was joined with multiconductor interconnecting harnesses routed through bulkheads and other interfaces.

Selenium rectifiers were chosen for rectifier applications in the first diode-rectified systems because they were most suitable and available. They are relatively immune to voltage transients. However, the maximum voltage rating of a single junction is a fixed value below the generated 28 VDC. Therefore, several junctions must be connected in series for rectifier applications. In addition, the junction is distributed over a large area, because junction size is proportional to current capacity. These characteristics preclude integrating the regulator with the alternator.

Copper oxide rectifiers are not used in diode-rectified systems because their maximum voltage rating is very low, requiring a complex arrangement of junctions to produce a suitable rectifier assembly.

On the other hand, the silicon rectifier proved to be a semiconductor development of practical value for diode-rectified generator systems. The junction is small and efficient, can be incorporated as an integral part of the generator, and the junction can have a voltage rating capable of withstanding any possible transient occurring in the system. These characteristics stimulated development of the alternator with integral rectifier that in turn eliminated the need for an interconnecting harness between rectifier and alternator, and thereby improved reliability.

The efficiency of a silicon rectifier determines the cooling requirements. Heat losses within the rectifier are caused by the voltage drop across the junction resistance. Several other factors are characteristic of these semiconductors. Overload capabilities are related to the junction construction and the rate at which the generated heat can be dissipated. Resistance to voltage transients relates to the response of the device to line conducted voltage peaks that might originate from devices such as solenoids, relays, starter motor. In addition, the rectifier must have a sufficient voltage rating to withstand any possible transient without being destroyed. Some rectifier types have an inherent immunity to transients while others are sensitive. Switching characteristics become important at the higher AC frequencies, particularly in applications using solid rotor alternators which may have switching frequencies in excess of 1 kHz. Leakage is a rectifier characteristic which refers to the current which flows in the reverse direction. A rectifier with large leakage can cause discharge of the battery if not disconnected when the alternator has no output. Reverse polarity protection should be provided to avoid destruction of the diodes in the event batteries are accidentally installed in reverse. Application of reverse-polarity essentially applies full battery current through the diode junctions. This current, being limited only by the resistance of the wiring and the generator output windings, destroys the diodes.

Recently, the development of solid-state (transistorized) voltage regulators has led to the development of diode-rectified alternator systems with integral rectifier and regulator. These machines effectively have eliminated all of the multiple connections involved in the complex interconnecting wiring harnesses required to connect components in the early systems.

Emphasis is now being placed on improving reliability and maintainability in order to reduce life cycle costs of military equipment. This will result in further evolution of the vehicle charging system. Concepts employing brushless solid rotor construction in combination with integral rectification and regulation may achieve these desirable goals.

All new charging systems developed for military vehicles, however, must produce output power characteristics within the limits prescribed by MIL-STD-1275 and must meet electromagnetic-interference levels of MIL-STD-461.

MIL-STD-1275, which specifies transient characteristics for 28 VDC systems for military vehicles, is intended to assure compatibility between the power supply and utilization equipment. In the design of generator-regulator systems, response to step load changes, voltage ripple level, and the tolerances placed on the supply voltage are of particular concern.

MIL-STD-461 covers the requirements and test limits for the measurement and determination of electromagnetic interference characteristics of electromechanical equipment. The requirements specified in this standard are established to ensure that interference control is considered and incorporated into the design of equipment and to enable compatible operation of the equipment in a complex electromagnetic environment. Generator regulator switching transients must be suppressed to conform with this standard.

7-2.2.8 GENERATOR INSTALLATION FACTORS*

Vehicle generator installations require that a thorough drive train design analysis be made to ensure proper and reliable machine operation. In the analysis, the following aspects of the installation must be considered:

1. Generator horsepower, torque, and speed characteristics
2. Power source characteristics
3. Type of generator duty
4. Externally transmitted vibration/shock
5. Environmental temperature
6. Environmental atmosphere
7. Regulator type
8. Engine acceleration/deceleration rates
9. Generator rotating element inertia.

Knowledge of these parameters influences the selection of an applicable drive system and helps to define the precautions required. A cold generator has a low internal resistance and therefore can produce an output as much as 30% higher than a warm machine. This produces a corresponding input torque increase. It follows that cold generator operating characteristics establish the maximum torque parameter in drive system considerations.

Most tank-automotive systems incorporate a V-belt or multiple V-belt drive system for

**Machine Design*, December 18, 1969, Copyright 1969, The Penton Publishing Co., by permission[2 3] generators producing 180 A and less (Fig. 7-11). Higher capacity units are generally gear driven from the engine.

As a rule, belt driven systems should be designed so that the belt will operate at maximum permissible speed. Table 7-3 lists belt speed recommendations for various belt types.

Belts made to SAE standards especially for automotive applications are available in two constructions—wrapped and raw-edge. In high-capacity (narrow) belts, both types use a single layer of load-carrying cords for flexibility. The two smaller cross sections—0.380 and 0.500 in.—are high-capacity types; these are the most widely used.

A guide to belt torque capacity is shown in Fig. 7-12. A typical generator, limited to a maximum speed of 8000 rpm, would require a pulley with pitch diameter of 3.9 in. when driven by a drive pulley of 10 in. pitch diameter. The torque capability of a V-belt driving this generator would be limited to 8.5 lb–ft for a 0.375-in. belt, and 11.5 lb–ft for a 0.5-in. belt. Torques exceeding the capacity of a single belt require a multiple belt installation. This introduces belt matching, pulley alignment, and pulley design problems.

7-2.2.8.1 CHOICE OF V-BELT SIZE

The correct choice of a V-belt section is based on design horsepower, and speed of the smaller sheave. Manufacturers provide charts as a guide to proper selection.

If the calculated belt length is not a standard length, the center distance should be modified until a standard length is obtained. After calculating a center distance from a standard pitch length, allowances must be made for adjusting the center distance to permit proper installation and belt tensioning.

In determining drive centers a good rule of thumb is to keep the center distance between 1 and 1.5 times the diameter of the larger sheave. At any rate, center distance should be such that a standard-length belt can be used.

Horsepower ratings given in USASI standards for V-belts are for average-length belts having a 180 deg arc of contact. A correction factor must be applied to allow for other than this value.

For each standard belt cross section, rated horsepower is tabulated on the basis of the small-sheave pitch diameter and its speed in rpm. To this value must be added the "add-

TABLE 7-3. V-BELT CHARACTERISTICS[10]

Type of Belt	Maximum Power, hp	Maximum Speed, fpm	Belt Speed for Max Power, fpm	Max Speed Ratio	Shock Absorption
Constant-speed					
Light Duty	7.5	5,000	3500	8	Poor
Standard	350*	6,000	4500	7	Good
Super	500*	6,000	5000	7	Very good
Cogged	500*	8,000	5000	8	Very good
Steel, glass cable	500*	8,000	5000	7	Poor
Narrow	500*	10,000	7500	7	Very good
Wide angle	50	10,000-	....	10+	Fair
Variable-speed					
Conventional	300	6,000	....	..	Good
Wide-range	75	6,000	....	..	Good

*Stock items. Drives available to 1500 hp.

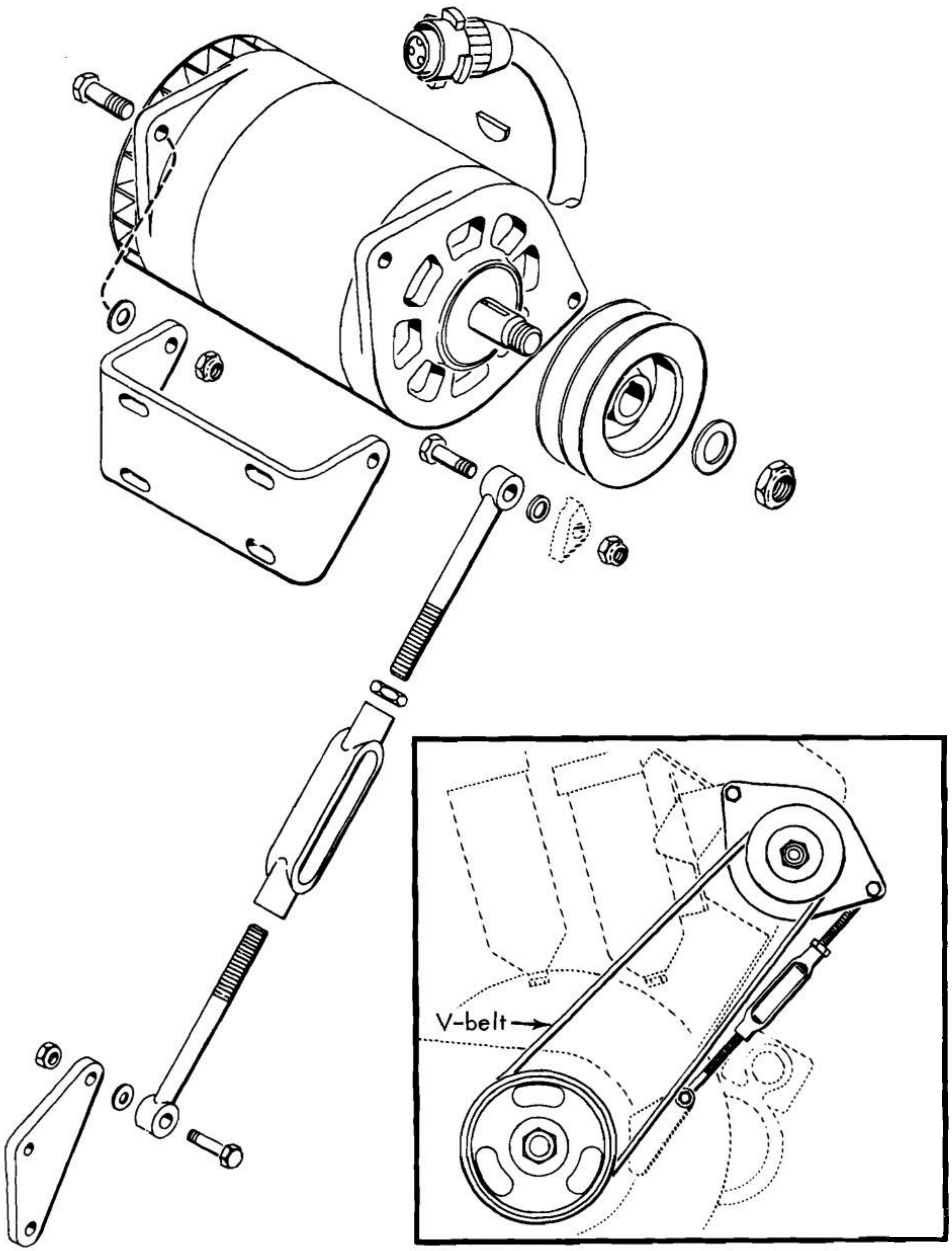


Figure 7-11. 100-A Generator Drive System[9]

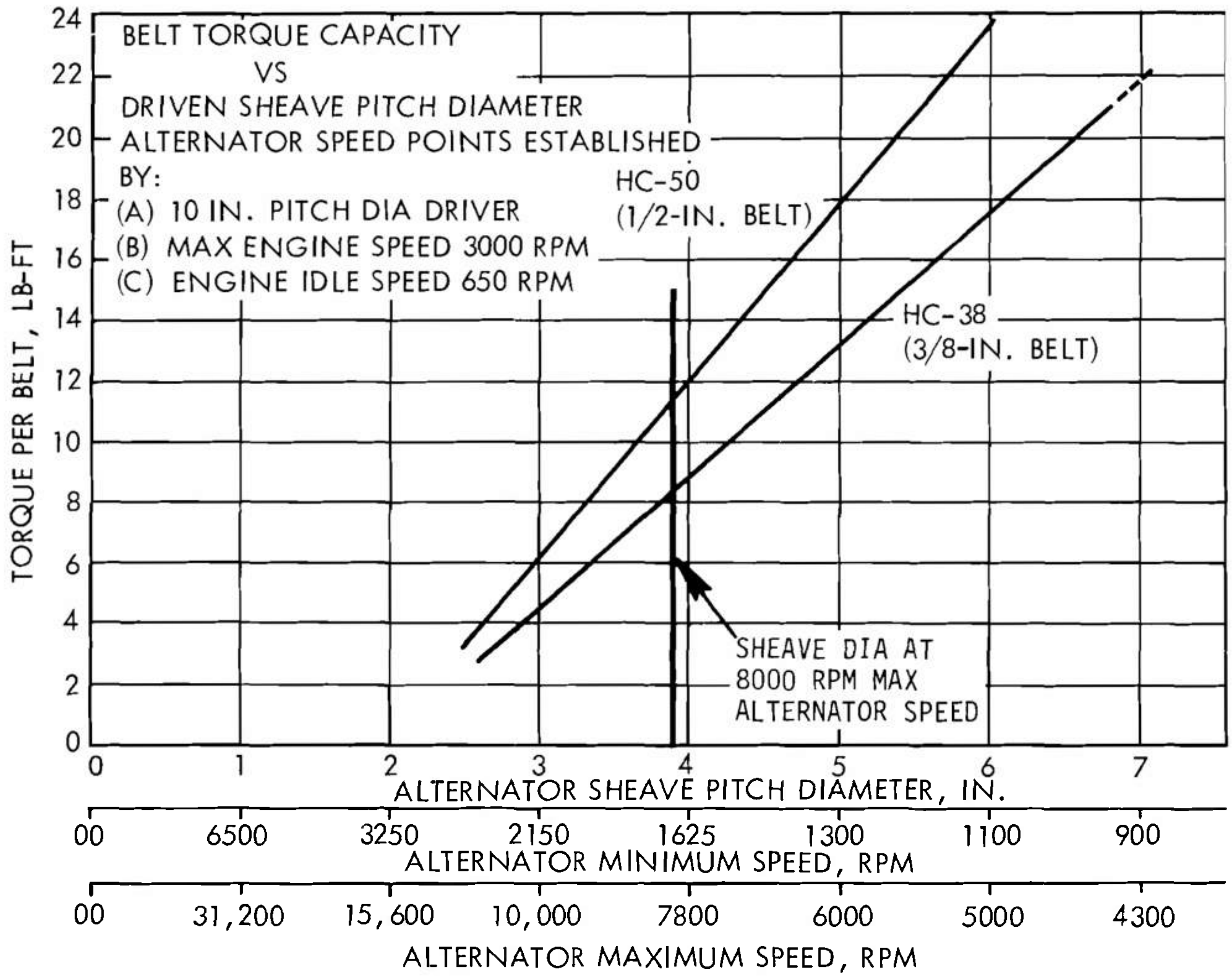


Figure 7-12. Belt Torque Capacity Guidelines[3]

on" horsepower, based on the speed ratio of the drive. This total allowable power per belt is then multiplied by the arc-of-contact and length correction factors to give the net allowable horsepower per belt.

To obtain the number of belts, the design power is divided by the net allowable power per belt.

Multiple belts of a V-drive should have the same length to provide a smooth-running set. Manufacturers code all standard V-belts with a number. Code number 50 indicates nominal length, numbers above 50 indicate belts longer than nominal, and numbers below 50 indicate belts shorter than nominal. Each number above or below 50 represents 1/32- or 1/10-in. increments, depending upon the manufacturer. Multiple V-belts are standardized under USASI B55. Matching tolerances listed in this standard may be defined as the maximum permissible length difference between the longest and shortest belt in a set. The amount of tolerance depends on the length of the belt.

7-2.2.8.2 SHEAVE SIZE

Normally, the drive sheave should be as large as possible. At any rate, smaller-sheave diameters should not be below the minimum diameter recommended for the belt section. The ratio of sheave pitch diameters selected must correspond to the ratio of driver and driven speeds desired. In choosing a sheave, care should be taken that belt speed and sheave rim speed are not excessive.

Most sheaves are made of cast iron, which is economical, stable and long lived. For light duty, sheaves may be of formed steel, cast iron, or diecast aluminum. Formed-steel sheaves are used primarily in automotive applications. For special applications they may be made of steel or aluminum alloy.

Cast-iron sheaves are generally limited to 6500-fpm rim speeds. For speeds up to 10,000 fpm, aluminum, steel, and ductile iron are used.

Sheaves are made with either regular or deep grooves. A deep-groove sheave is generally used when the V-belt enters the sheave at an angle—as, e.g., in a quarter-turn drive—on vertical shaft drives, or whenever belt vibration may be a problem.

7-2.2.8.3 BELT TENSION

Although a V-belt will not generally stretch to any great extent, provisions must be made for adjustment and to take up the slack caused by belt stretch and belt and sheave wear, as well as to allow for installation of the belt without damage.

A number of methods have been suggested for determining the proper amount of tension. Basically, a V-belt is properly tensioned if, during operation, it is just at the point of slipping. In practice, a V-belt can operate satisfactorily over a comparatively wide range of tensions but, for maximum performance, the designer should specify the amount of tension for a particular drive.

Total tension for a V-belt drive depends on the power transmitted, not on the number of belts used to transmit the power. Usually narrow belts operate at a higher tension per belt than conventional belts because fewer narrow belts are necessary to transmit a given load. That is especially true when they transmit the load over smaller sheaves. Because operating tension is almost impossible to measure, drive tension is established by setting static tension.

If there are no provisions for belt takeup, an idler is used. Idlers always cause additional flexing of the belt and shorten drive life. For best results, they should be placed on the slack side of the drive, on the inside of the belt, and should be as large as possible. An idler can be placed in any of three other positions, in the following order of preference: outside on slack side, inside on tight side, outside on tight side. The last position is extremely hard on V-belts and should be used only when absolutely necessary. Actually, any tight-side idler will require heavier idler bearings and should be avoided if possible.

As a general rule, idlers should be placed as far as possible from the next sheave which the belt will enter. If vibration is a problem, the idler should be placed where it will dampen the vibration, most effectively, usually at one-third of the belt span.

Diameter of an inside idler should be at least as large as the small sheave. Any outside idler should have a diameter at least one-third larger than the smaller sheave. Belt length should be the minimum length that will fit on the drive without the idler.

Although idlers are widely used to tension a V-belt, it should be remembered that any idler will cause additional flexing and shorten belt life. But proper attention to the factors given here will keep injurious effects to a minimum and assure that a satisfactory belt life is attained.

7-2.2.8.4 BELT LOADING

Alternator rotor inertia will produce an additional torque proportional to engine acceleration capability. A reciprocating engine produces torque peaks at the rate of cylinder firing which are in turn transmitted to the alternator by the drive system. The rotor inertia will influence the response to these pulses, resulting in pulse loading of the drive.

The type of loading on the alternator will vary with the installation. Intermittent, frequent, high current demands producing torque pulses can be expected from the operation of equipment such as weapon station drives. A particular type of voltage regulator can excite the alternator in such a manner as to produce a varying frequency torque demand. Such excitation can contribute to fatigue failures of mounting and drive components, and amplify drive train oscillations.

7-2.2.8.5 ENVIRONMENTAL FACTORS

Environmental factors include temperature, water, oil, vibration, etc. Although a drive system must be located in a convenient place, it should not be situated in a "hot spot" where circulation is poor and exhaust system radiation levels are high or in a "wet spot" where it is subject to water splash.

The generator mounting bracket has the important function of providing a stable base for the generator. Sufficient stiffness must be present to prevent excursions of the generator which would result in belt oscillations, belt slip, and roll-over. The bracket must not flex under vibration or load so as to decrease belt tension or cause pulley misalignment.

A gear or direct coupled generator, when driven by a reciprocating engine, experiences a step torque input at each cylinder firing. The rotor inertia, as a result, transmits an impulse load to its drive system. This commonly is alleviated by adding a damped torsional member, in the form of a quill shaft, coaxial with the armature shaft.

7-3 GENERATOR VOLTAGE REGULATORS

The evolutionary process has also changed the design of generator voltage regulators. Until recently, the electromechanical relay and carbon pile types dominated the scene. However, with the development of the transistor, new regulator circuits were designed and solid-state regulators are now in widespread use as indicated by Table 7-1.

7-3.1 ELECTROMECHANICAL GENERATOR REGULATOR

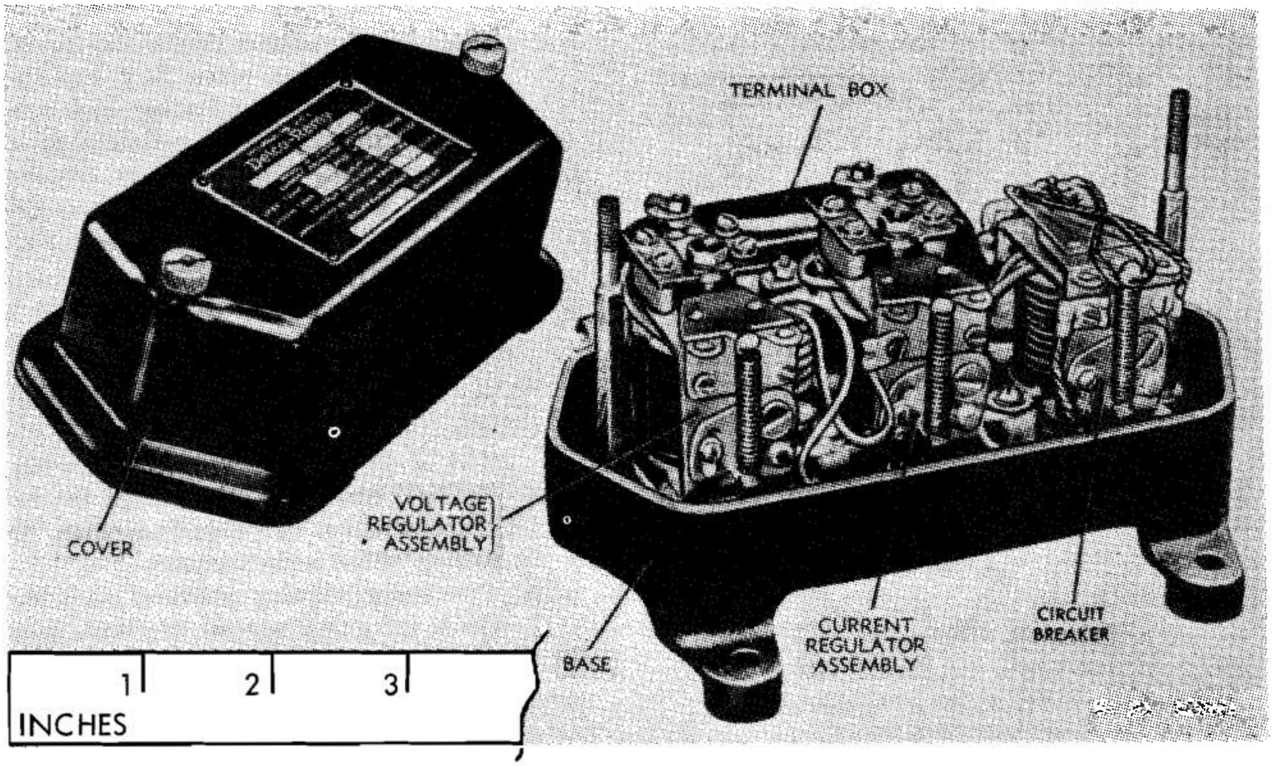
An illustration of an electromechanical generator regulator featuring three control relays is shown in Fig. 7-13.

This regulator was initially developed to operate in conjunction with the conventional DC type generator. The unit contains three regulating components—the voltage control relay, current control relay, and reverse current relay.

The voltage control relay senses the generator output voltage that is applied to the coil. A set of normally closed contacts is in series with the field excitation circuit. Across the normally closed contacts is a resistance which is inserted in the field circuit when the contacts are open. The contacts are maintained closed by a spring connected to the relay armature and when sufficient voltage is applied to the coil, the spring force is overcome and the contacts open. This immediately reduces the field excitation, resulting in a lower generator output, and the contacts again close. This switching or vibrating of the contacts occurs at several hundred hertz in order to maintain the correct field excitation. Adjustments to the voltage regulation set point are effected by changing the tension of the spring either by screw adjustment or spring anchor bending.

The current control relay performs similarly to the voltage control relay so that when a preset output current level is exceeded, series resistance is added in the field circuit. The fundamental difference is that this relay has a heavy current winding that controls the contactor as a function of generator output current.

The reverse current or circuit breaker relay provides continuity between the generator and the battery when the generator voltage is sufficient to ensure current flow to the battery. A winding on the relay senses generator voltage and closes the contacts when the voltage is at a proper level. A current winding



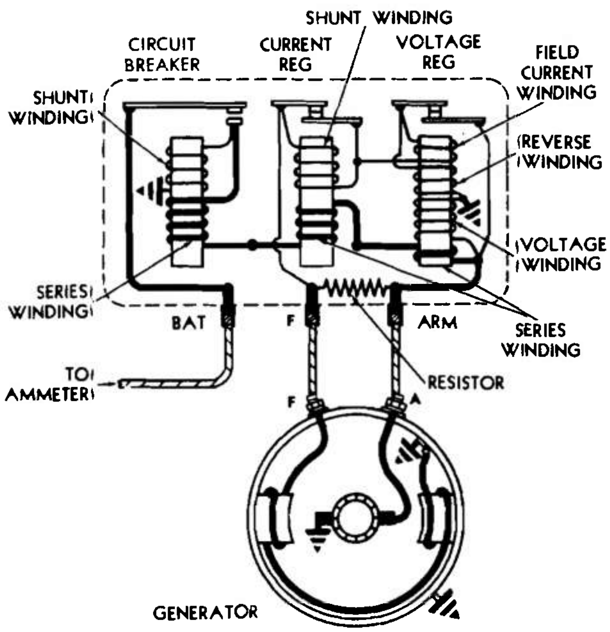


Figure 7-13. Three Unit Electromechanical Generator Regulator[4]

wound over the voltage winding aids in holding the contacts. However, should the generator voltage become too low, battery current flows in the reverse direction in the coil causing a field to oppose any created by the voltage winding, and the contacts open. This feature prevents motoring of the generator and discharge of the battery. These regulators are no longer in production but may be found on vehicles built before 1968.

7-3.2 CARBON PILE REGULATOR

The carbon pile regulator is a linear type of electromechanical device that employs a variation in contact resistance with respect to force between a series of carbon plates in order to regulate the field current of a generator (Fig. 7-14).

The carbon plates are in the form of discs and are maintained in close contact by a spring load. The force of the spring establishes the minimum resistance of the pile. To effect a variation in the carbon pile resistance, the spring force is opposed by the pulling action of a solenoid sensitive to the generator output voltage level.

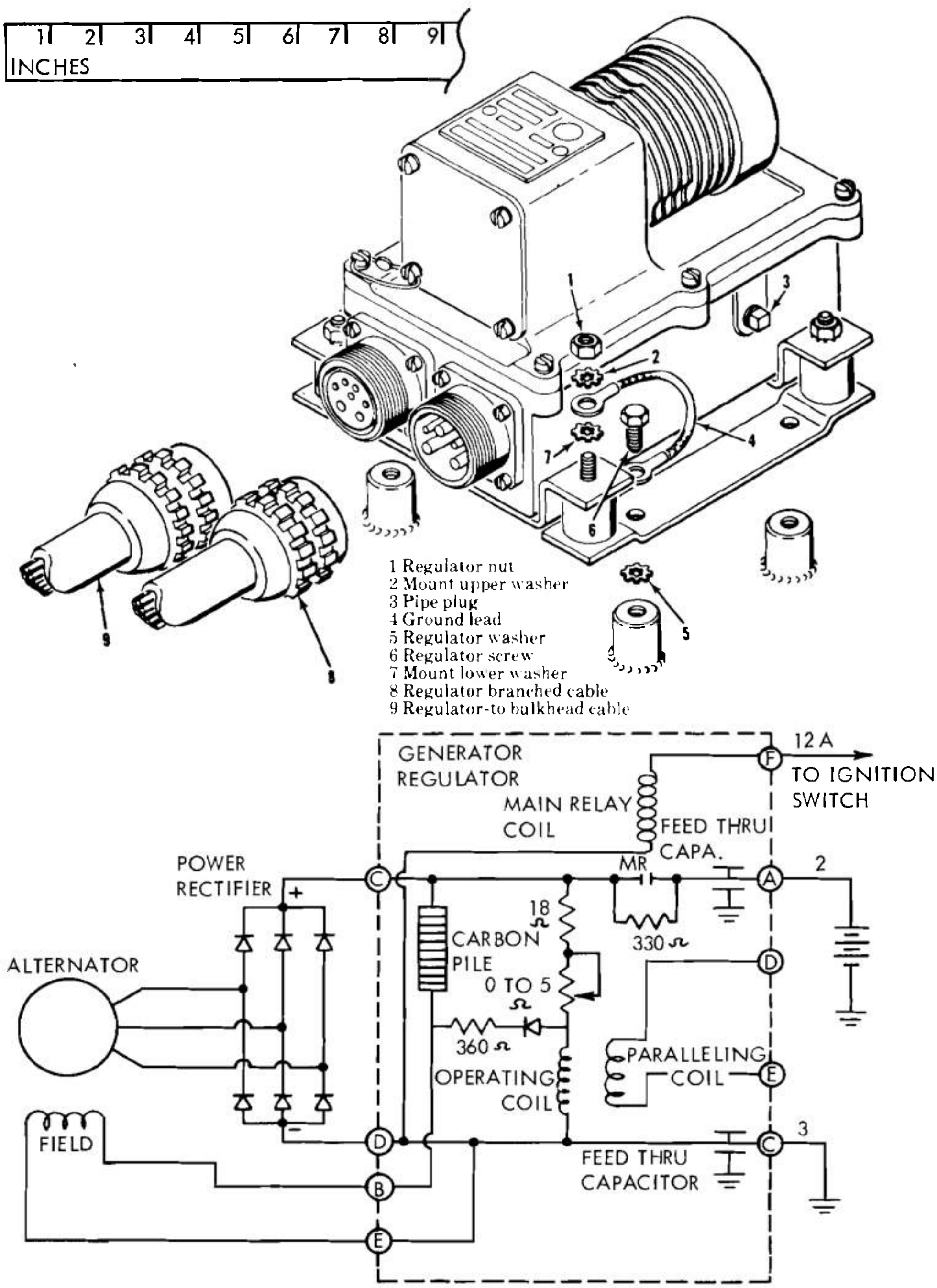


Figure 7-14. Carbon Pile Generator Regulator[9]

The solenoid contains two windings—a voltage control winding and a current control winding. Both windings serve to control field excitation with resulting voltage regulation and current protection.

Voltage adjustment is accomplished by modifying the excitation of the voltage control winding with a potentiometer.

In a vehicle system, provisions must be made for shock and vibration isolation of the unit. The regulator is a separate element and may be mounted remotely from the generator. However, precaution must be taken in mounting orientation. The axis of the carbon pile must be kept horizontal in order to maintain proper regulation characteristics.

One of the limitations of the carbon pile regulator is that it has a minimum field current requirement. In essence, there always must be current flowing through the carbon pile because the discs cannot be completely separated to interrupt the field or sparking and destruction of the carbon elements will result. These regulators are being superseded by solid-state regulators.

7-3.3 SOLID-STATE REGULATOR

Although solid-state regulators may be designed as linear or switching devices, the switching type is predominant. Switching regulators are inherently more efficient and require minimum cooling. Generally, the regulation attained with this type of regulator has proven adequate for vehicle supply and battery charging purposes. However, the ripple content is relatively high depending on the type of generator and the type of switching control.

The two basic types of switching control are the voltage switching type and the oscillator type. The voltage switching type has a variable switching frequency that is dependent on the generator inductance and the magnetic circuit. Voltage control depends on adequately sensing generator voltage output in excess of the regulation point, and switching off the field until the voltage returns to the set point. One of the problems encountered in this scheme is overshoot which is dictated by the time constant of the unit. The rectification ripple is modulated by the switching ripple and varies with the load.

On the other hand, the oscillator-type regulator has an internal frequency shaping circuit that results in the switching frequency being independent of generator characteristics. In a typical oscillator regulator circuit the switching frequency is load sensitive so that frequency will increase with load. This serves to keep the switching frequency above the natural frequency of the device. In operation, the oscillator initiates turn-on of the field whereas turn-off is established when the output voltage exceeds the set point.

The major problem encountered with regulators in alternator-rectifier systems producing high output ripple content is determination of the proper voltage setting for battery charging. A voltmeter commonly used for measuring generator output is average voltage sensing. The battery, in comparison, will charge to peak voltage. Therefore, in systems with high ripple content the battery can be overcharged although the average voltage is apparently correct. The common correction for this is to lower the average voltage. The necessary correction will vary with the amount of output ripple. Ripple induced by field switching varies from 0.05 V to 0.3 V in DC generator systems and from 0.2 V to 1.0 V in alternator rectifier systems.

The voltage regulating characteristics of two independently manufactured solid-state regulators used in the 100-A system on M113 vehicles are shown in Figs. 7-15 and 7-16. Characteristics of a third manufacturer's product are shown in Fig. 3-13.

The proper battery charging voltage required to avoid excessive gassing varies as a function of battery electrolyte temperature. In order for a regulator to compensate for battery electrolyte temperature variations, it must be designed to sense the electrolyte

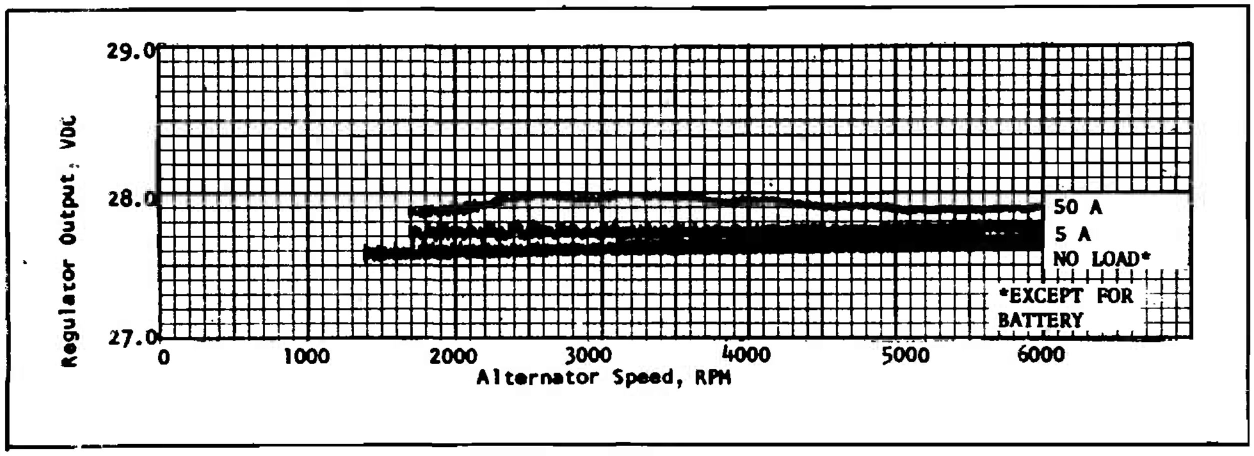


Figure 7-15. Solid-state Voltage Regulator Characteristics, Manufacturer "A"[11]

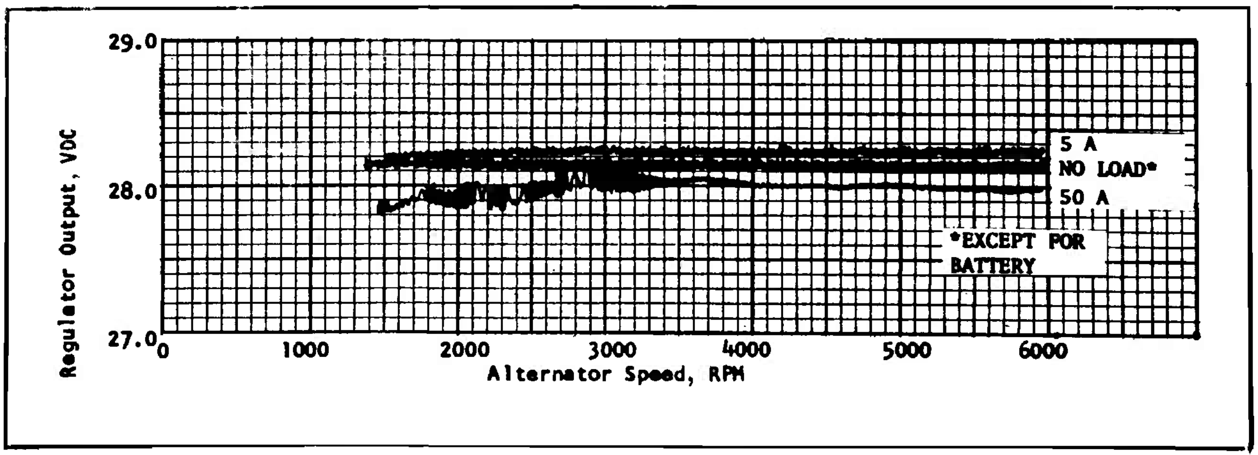


Figure 7-16. Solid-state Voltage Regulator Characteristics, Manufacturer "B"[11]

temperature with a probe and adjust regulated voltage accordingly. Regulators of this type are not in the inventory as yet. A compromise is to place the regulator near the battery where it will experience a similar atmosphere. This is not always a very practical arrangement, either from a wiring or mounting standpoint. With the trend toward integral generator-rectifier-regulator it becomes impossible.

SECTION II ENERGY STORAGE

7-4 INTRODUCTION

Because electrical energy is essential for the complete operation of all systems on a military vehicle, the electrical designer should be cognizant of the equipment presently used or being considered for electrical energy storage.

The energy storage devices presented in this section can be divided into three separate classes. One is the rechargeable storage battery, which is currently used for most heavy duty applications. Another is the nonrechargeable or primary battery. This is commonly referred to as the "dry-cell". Still another is the fuel cell, which has potential energy stored in a fuel and oxidizer.

Each of the three classes of energy storage devices produce electrical energy by the same principle, i.e., they produce electrical energy from a chemical reaction. They differ only in the type and physical makeup of the chemicals used and in the method in which the chemicals are combined or packaged.

The paragraphs that follow will describe the three classes of devices, the types most commonly used in tank-automotive vehicles, performance data, battery installations, and future trends.

7-4.1 BATTERY PERFORMANCE

Although other energy sources have been and are still being considered, the lead-acid storage battery is used almost exclusively as the basic electrical energy storage source on tank-automotive vehicles. This battery provides the electrical power required to operate the engine starter motors and power other vehicle systems such as communications, lighting, and heating when the engine is not operating. The success of the lead-acid battery can be attributed to economic as well as performance factors.

Other energy sources are used to a lesser extent. For example, the nickel-cadmium battery is used to power weapon stations and other auxiliary systems. In addition, primary batteries are used to power auxiliary communications, sensors, and lighting systems.

To design a vehicle electrical energy storage system, the electrical designer must first establish the required system capacity and extremes of environment in order to select a battery complement that will provide both economical and reliable performance under expected environmental conditions. He must conduct a thorough analysis of parameters such as the cranking requirements of the engine, the demands of accessory systems when the engine is shut down, and the battery performance characteristics at both hot and cold temperatures. Each of these parameters is an important concern for the designer if he is to choose the proper battery or combination of batteries to power his electrical system.

Current military batteries are rated by ampere-hour capacity. For example, a 100 A-hr battery will theoretically supply 1 A for 100 hr at 80°F. This rating, however, always is listed in the Military Specifications at a 20-hr rate. This means that the 100 A-hr rated battery will supply 5 A for 20 hr.

Table 7-4 shows a tabulation of lead-acid storage batteries that are described by MIL-B-11188[1,2]. The batteries marked with an asterisk are used for tank-automotive applications. The AN and SAE type designations also are given where available. Class defines whether the battery is a free electrolyte (FE) or electrolyte-retaining (ER). The ER battery contains separators and plates which absorb and retain within the cell at least 80% of the electrolyte. The last two columns show the voltage and the rated capacity in amperehours at the 20-hr rate.

TABLE 7-4. MILITARY STANDARD BATTERIES

Military Standard No.	AN Type Designation	SAE Type Designation	Class	Voltage, V	Rated capacity, at 20-hr Rate, A-hr
*MS35000	BB-249/U	2HN	FE	12	45
*MS35000	BB-248/U	6TN	FE	12	100
MS35001	BB-57	7H	FE	6	200
MS35001	BB-221/U	2H	FE	6	120
MS35001	BB-55	4H	FE	6	150
MS35001	BB-223/U	8T	FE	12	200
MS35001	BB-282/U	9T	FE	6	335
MS90901	BB-49		FE	6	90
MS90903	BB-53		FE	12	45
MS90904	BB-54A		ER	2	28
MS91310	BB-46		FE	12	90
MS91311	BB-50		FE	12	55
MS91314	BB-207/U		ER	6	21
MS91315	BB-210/U		ER	2	20
MS91318	BB-236/U		ER	2	2.3
MS91319	BB-237/U		ER	2	3.9
MS91320	BB-238/U		ER	2	6.5
MS91321	BB-239/U		ER	2	9.5
MS91322	BB-240/U		ER	2	15
MS91323	BB-241/U		ER	2	23
MS91324	BB-242/U		ER	2	35
MS91325	BB-243/U		ER	2	58
MS91326	BB-246/U		ER	6	23
MS91327	BB-247/U		ER	6	20

*Used in all military tactical and combat vehicles; they are NATO standards. Other batteries are for Signal Corps use in electronic equipment, Engineer Corps off-the-road equipment, or remaining WWII equipment.

Each of the batteries listed in Table 7-4 must be capable of passing certain performance tests required by MIL-B-11188[12]. Some of these tests are:

1. Discharge capacity at 80°F
2. Charge capacity at 80°F
3. Low temperature capacity at -40°F
4. Life-cycle capacity tests (charge-discharges)
5. Storage life performance.

In addition to the batteries shown in Table 7-4, there are others available under other Military Specifications. One of these is a 4HN, 24-V, 21 A-hr, lead-acid battery described by MS75047 and MIL-B-55166[13]. Others of importance are the 2HNC, 12-V, 35 A-hr and the 6TNC, 12 V, 70 A-hr, nickel-cadmium batteries of MIL-B-23272[14].

In current tank-automotive applications, heavy duty batteries never are used alone. They are arranged in a series or series-parallel arrangement of two or more batteries. The 2HN and 6TN batteries described by MS35000 (see Table 7-4) are the two most commonly used as principal vehicle batteries. These 12-V batteries are arranged to provide 24 V to the vehicle electrical system. For example, the M715 and M725 Trucks use two 2HN batteries connected in series to provide

24-V 45 A-hr service. The M113A1 Armored Personnel Carrier (APC) uses two 6TN batteries in series to provide 100 A-hr. The selection of these batteries was determined by the electrical designer only after careful consideration of the cranking requirements of the engines, the expected demand of accessory systems, and the other parameters mentioned at the beginning of this section.

Often, the designer will find that he needs more electrical power than that provided by two standard batteries in series (Fig. 7-17(A)). He can obtain this additional power by placing additional batteries in parallel. The parallel arrangement increases the ampere-hour capacity of the system by increasing the effective plate area. Thus, four 100 A-hr batteries connected in series-parallel arrangement as shown in Fig. 7-17(B) will provide 200 A-hr service at 24 V. Similarly, the six battery series-parallel arrangement of Fig. 7-17(C) will provide 300 A-hr service.

Both the M108 and M109 Self-propelled Howitzers use an arrangement of four 6TN batteries, while the M60 Tank uses six 6TN batteries. The electrical load requirements for these vehicles demand the added capacity.

Low temperature not only has an effect on the battery itself but also upon the load applied to the battery. This is particularly true during vehicle starting, and varies widely with the type of vehicular power. For example, a gasoline engine normally is easier to start in cold weather than an equivalent cubic-inch displacement diesel engine. This is because gasoline is more volatile at lower temperatures and the gasoline engine uses a spark for ignition, while the diesel depends primarily upon temperature rise due to high compression in the cylinder to ignite the injected fuel. Even with "glow plugs" or preheated chambers to aid starting, the diesel requires a higher starting torque and a much higher cranking speed to start. Table 7-5 shows a comparison of starting characteristics of typical 4- and 6-cylinder, 4-cycle gasoline and diesel engines with the same 200 in.^{3} displacement[15].

The data in Table 7-5 indicate a significant difference in the starting requirements of gasoline and diesel engines. It also indicates that the number of cylinders has little effect on the gasoline engine, while it has a major effect on the diesel engine. In general, for the diesel, fewer cylinders for the same displacement increase the average cranking speed required for starting. The relative horsepower tabulation in Table 7-5 is significant in that it points out the large difference in the size of battery and starting motor that is required to crank the various engines.

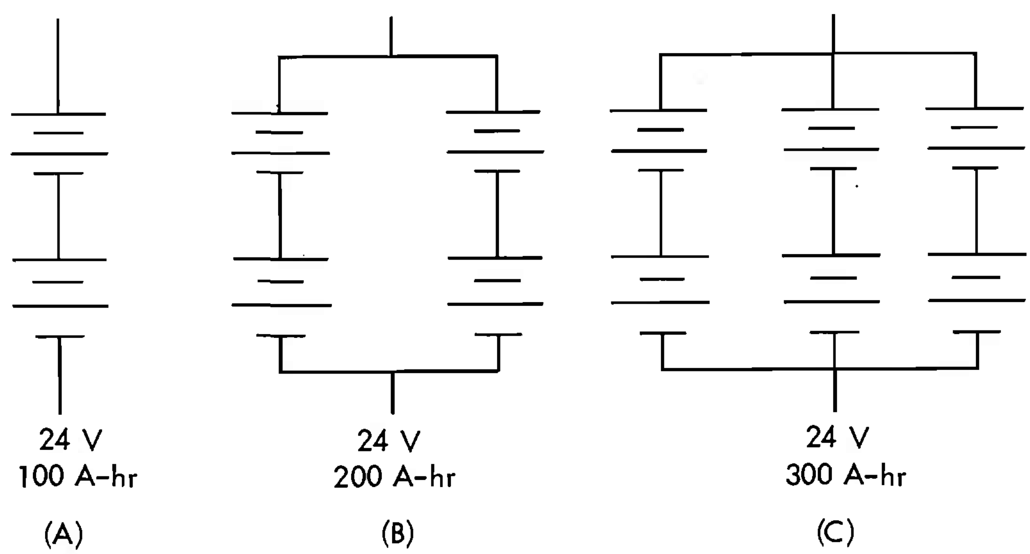


Figure 7-17. Series and Series-parallel Arrangements, 12V 100 A-hr Batteries

TABLE 7-5. COMPARATIVE STARTING CHARACTERISTICS

	Engine Type			
	Gasoline		Diesel	
Characteristic	4 cyl.	6 cyl.	4 cyl.	6 cyl.
Minimum cranking rpm	20	20	100	60
Maximum cranking rpm	60	60	150	100
Relative cranking horsepower	Base	1	4	3

Table 7-6 shows a tabulation of battery arrangements and engine starting motor horsepowers for several vehicles now in the Army's inventory. This represents a broad spectrum of Army vehicles used in tank-automotive applications.

As stated previously, the temperature to which a battery is subjected affects its power output. Fig. 7-18 presents a series of curves which shows the discharge characteristics of two fully charged (1.280 specific gravity, corrected to 80°F) 6TN batteries connected in series. Voltage versus discharge time in minutes is presented at 50-, 100-, 300-, and 500-A discharge rates, and at four different ambient temperature readings: 86°F, 32°F, 0°F, and -22°F.

The information on Fig. 7-18 is used to plot another family of curves that show how initial voltage varies with the load imposed on the batteries and with the temperature (Fig. 7-19).

The major demand on a vehicle storage battery occurs during starting. To obtain optimum starting performance, it is necessary to match the engine starter system to the battery system. The problems in doing this can be depicted most clearly with horsepower-current curves portrayed after both 1 and 2 min of power demand (Fig. 7-20).

Figs. 7-18, 7-19, and 7-20 illustrate that, although a reasonable amount of initial power exists at all temperatures down to -22°F, after 1 min at -22°F, a 500-A demand will cause the horsepower output to decline drastically. A study of these curves for new 6TN, 100 A-hr batteries—coupled with knowledge of a given engine starter system will allow designers to decide how well a vehicle equipped with these batteries will meet cold weather starting specifications.

Another series of curves that illustrate the effect of temperature on the A-hr capacity of the 6TN battery at various discharge rates is shown in Fig. 7-21. Notice that the standard battery capacity is 100-hr at 80°F, at a 5-A discharge rate (20 hr). However, at 0°F the capacity at the same 5-A rate is only 56% of the rated capacity at 80°F. An increase in discharge rate has a similar effect. Calculating

TABLE 7-6. TANK-AUTOMOTIVE VEHICLE ELECTRICAL COMPONENTS

	Battery				Starting-Motor	
	Type	Quant	Arr	V	Part No.	Approximate horsepower
Truck, Utility, M151	2HN	2	Series	24	7017647	2.25
Truck, Cargo, M715	2HN	2	Series	24	Kaiser 944020	2.25
Tank, M60A1	6TN	6	Ser-par	24	1109972	11
APC, M113A1	6TN	2	Series	24	1113940	9.5
Armored Reconaissance Vehicle, M551	6TN	2	Series	24	1113940	9.5
Howitzer, Self-propelled, M109	6TN	4	Ser-par	24	1113847	9.5

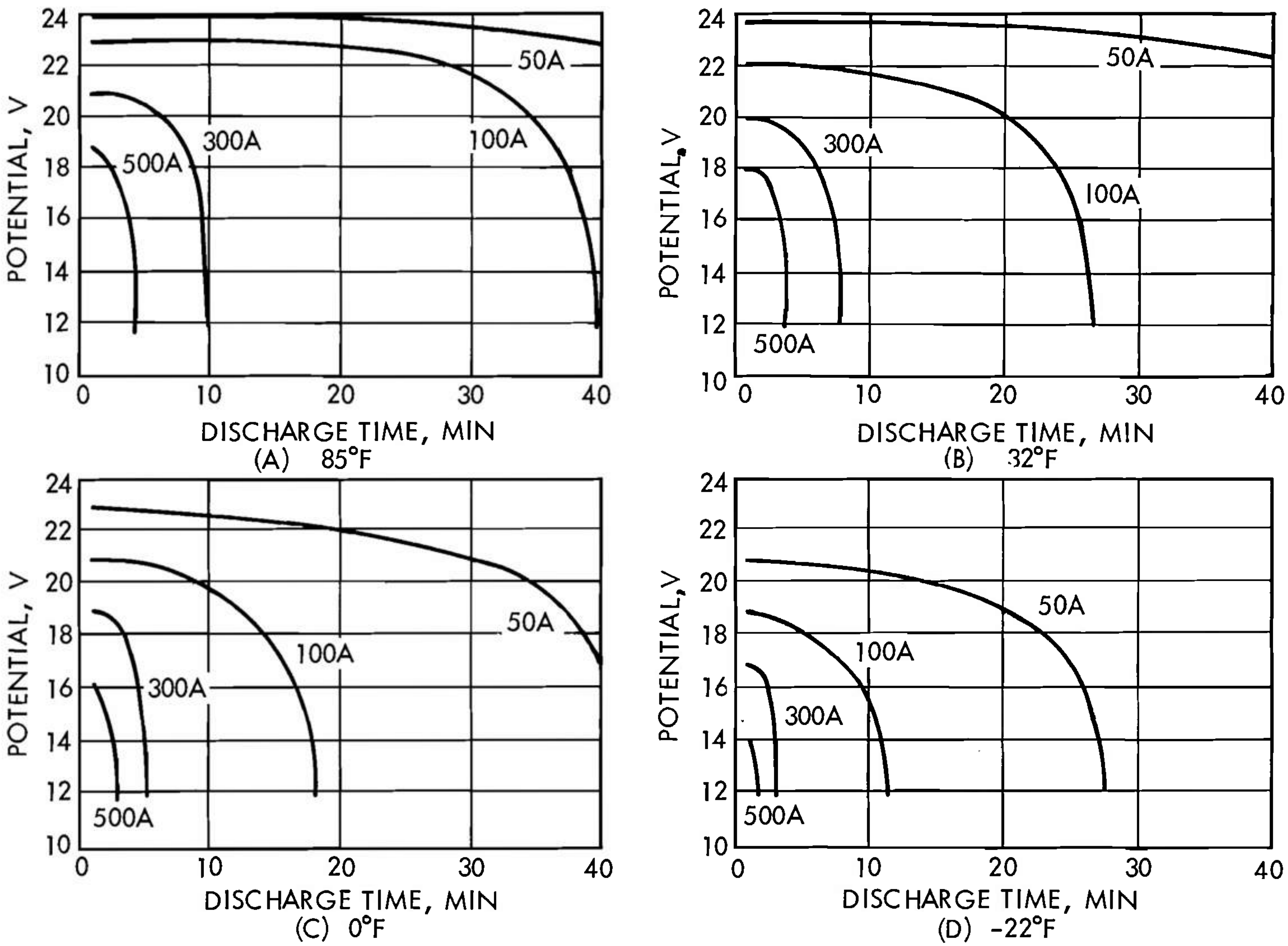


Figure 7-18. Discharge Characteristics, Two 6TN Batteries in Series[16]

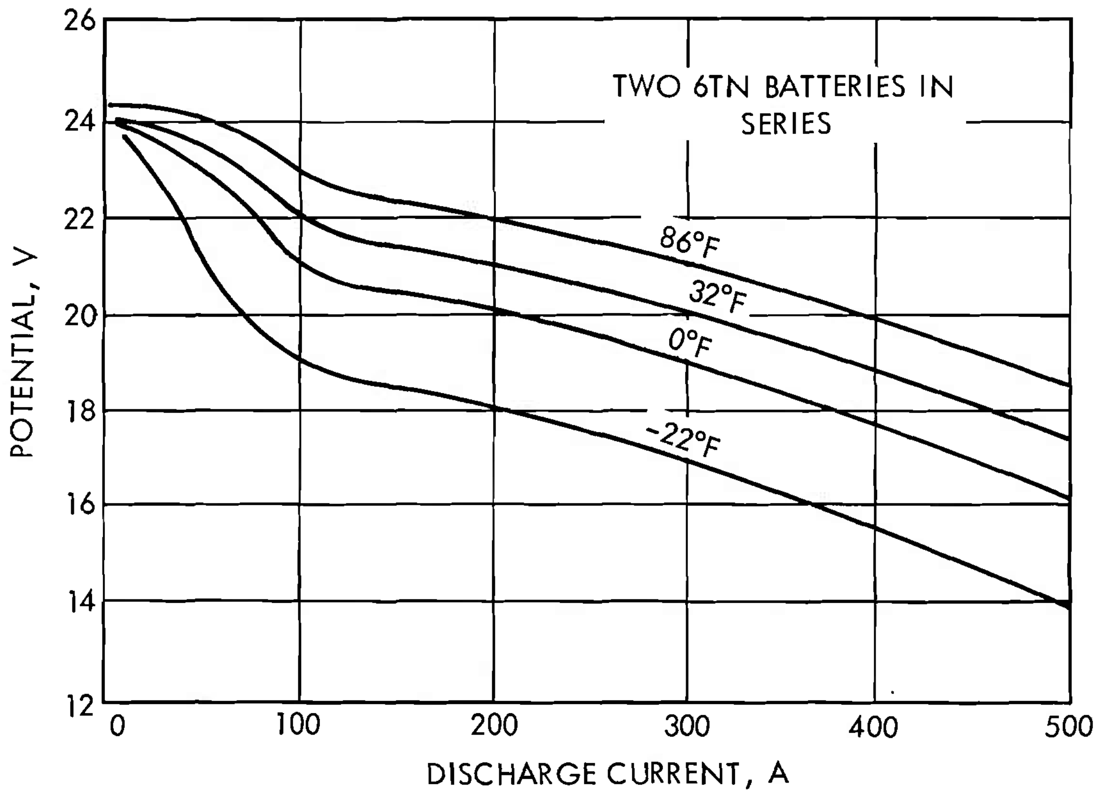


Figure 7-19. Initial Battery Voltage vs Discharge Current at Various Temperatures[16]

the reserve battery power in a vehicle system after several hours of coolant heater or silent watch operation is simplified using these curves as illustrated in the example that follows.

Ordinarily, battery capacity requirements are calculated using the formula:

$$C_R = I_L T, \text{ A-hr} \tag{7-1}$$

where

C_R = required capacity of the battery system, A-hr

I_L = discharge current from the battery system, A

T = discharge time, hr

Given a vehicle requirement to provide sufficient battery power for a 2-hr silent watch followed by an engine restart, it is first necessary to establish the silent watch load, the cranking motor current, the cranking period, and the battery electrolyte temperature. For the purposes of this illustrative example, assume that the silent watch load is 30 A, the cranking motor current is 300 A, the cranking period is 12 sec, and the electrolyte temperature is 0°F.

Then the actual battery system capacity required as a result of the vehicle silent watch load is described as:

$$C_{R1} = I_{L1} T_1 \tag{7-2}$$

$$C_{R1} = 30 \text{ A} \times 2 \text{ hr} = 60 \text{ A-hr}$$

The necessary battery system capacity required to supply the 300-A, 12 sec cranking power is calculated with the following result:

$$C_{R2} = I_{L2} T_2 \tag{7-3}$$

$$C_{R2} = 300 \text{ A} \times \frac{12 \text{ sec}}{3600 \text{ sec/hr}} = 1 \text{ A-hr}$$

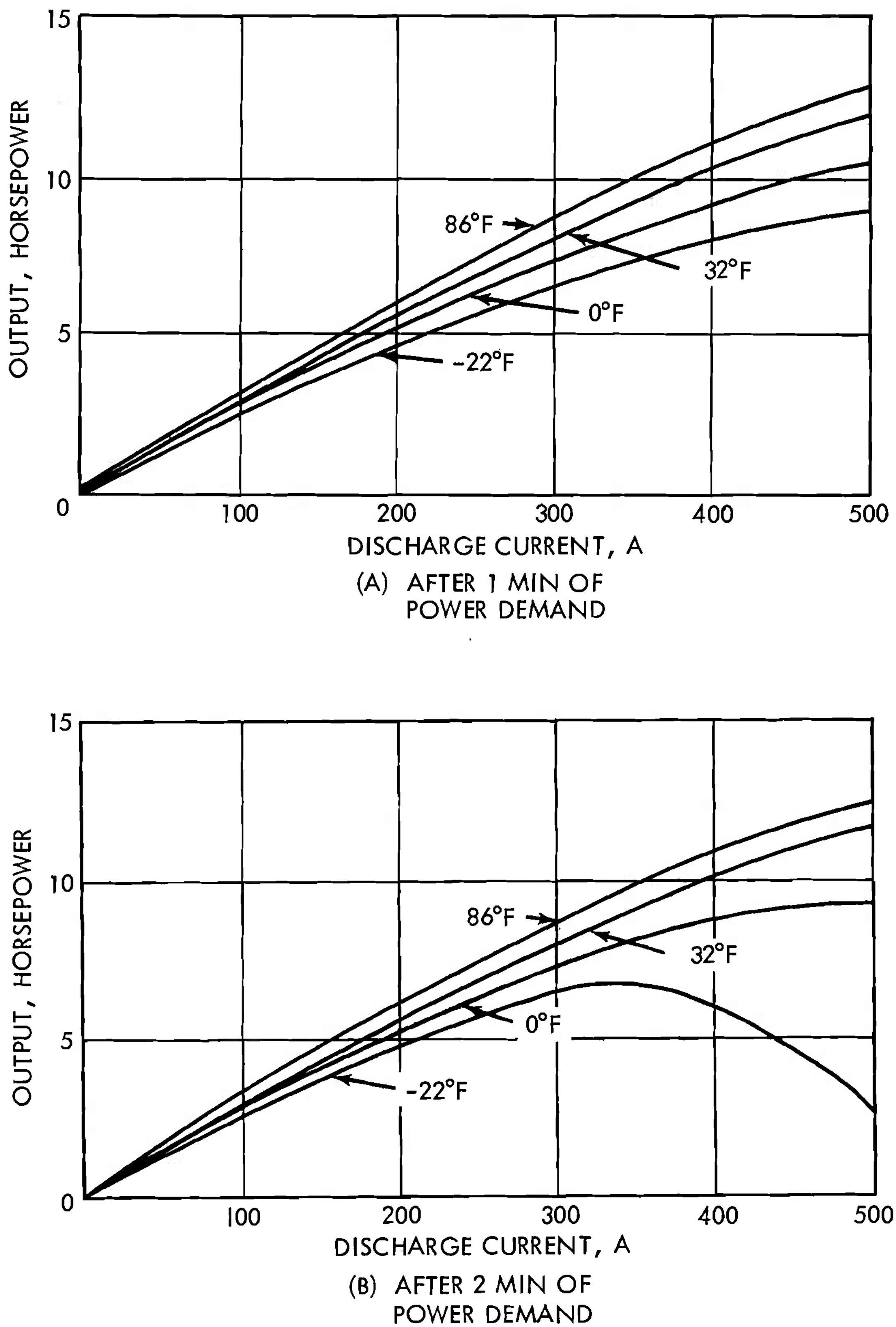


Figure 7-20. Horsepower Output vs Amperes—Two 6TN Batteries in Series[16]

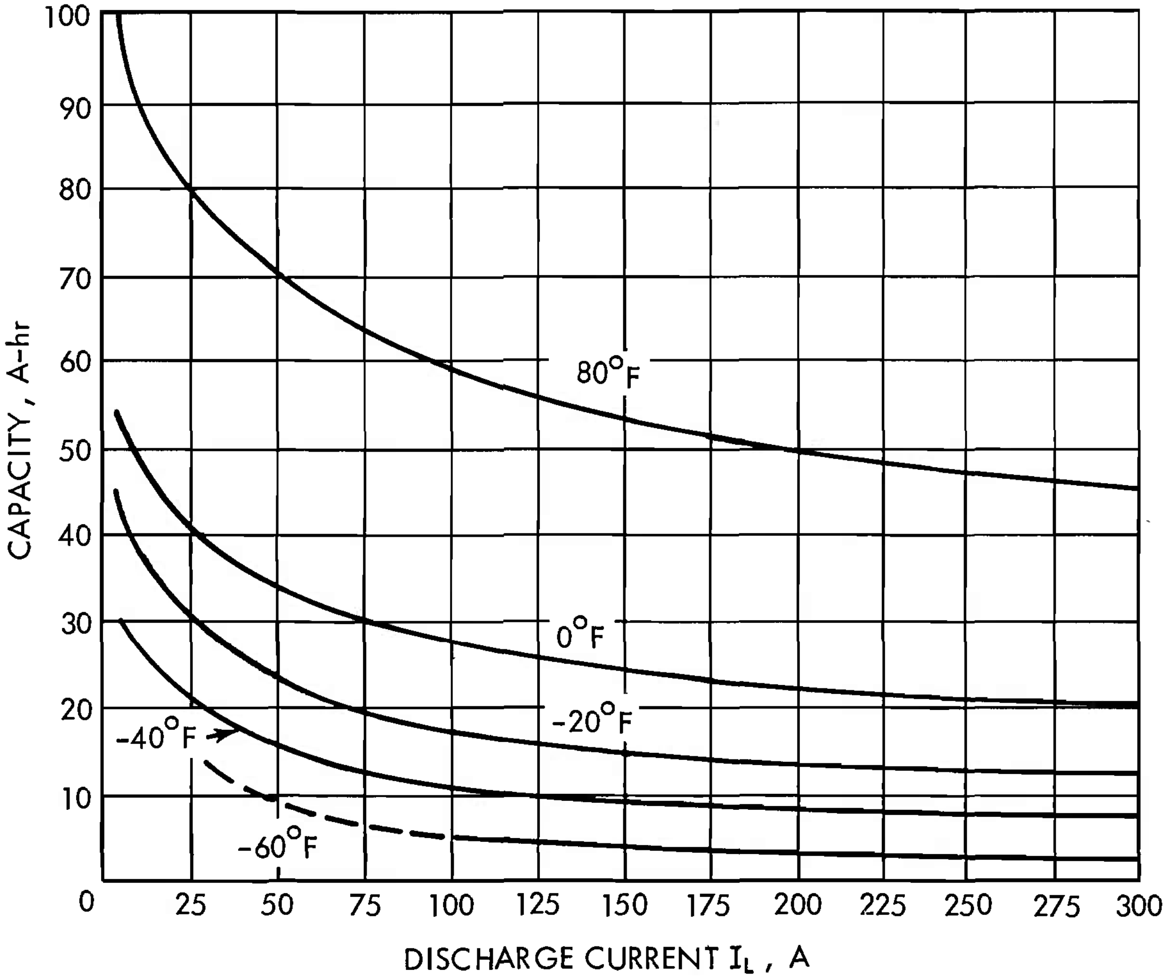


Figure 7-21. Battery Capacity vs Discharge Current at Various Temperatures—6TN Battery[16]

The percentage of total capacity remaining in the vehicle storage battery system after a period of discharge at the aforementioned rates and temperature may be established using the following formula:

$$C_m = 100\left[1-\left(\frac{C_{R1}}{KC_{A1}}+\frac{C_{R2}}{KC_{A2}}+\ldots+\frac{C_{RN}}{KC_{AN}}\right)\right] \quad (7\text{-}4)$$

where

C_m = remaining battery capacity or margin, %

K = number of battery sets in parallel (a set is two 6TN batteries connected in series)

C_A = A-hr available per set of 6TN batteries at the temperature and current drain under consideration

This capacity may be read directly from Fig. 7-21 by establishing the intersection between the current ration I_L/K in a single ser of 6TN batteries and the appropriate temperature curve. If two sets of 6TN batteries are considered for silent watch loads, then

$$\frac{I_{L1}}{K} = \frac{30\,A}{2\text{ sets}} = 15\text{ A/set} \quad (7\text{-}5)$$

Therefore, from Fig. 7-21 on the 0°F curve

$$C_{A1} = 46\text{ A-hr/set} \quad (7\text{-}6)$$

For engine restart loads

$$\frac{I_{L2}}{K} = \frac{300\ A}{2\ \text{sets}} = 150\ \text{A/set} \qquad (7\text{-}7)$$

Therefore, from Fig. 7-20 on the 0°F curve

$$C_{A\,2} = 26\ \text{A-hr/set} \qquad (7\text{-}8)$$

Then solving Eq. 7-4 yields

$$C_m = 100\left[1-\left(\frac{60\ A\text{-}hr}{2\ sets \times 46\ A\text{-}hr/set}+\frac{1\ A\text{-}hr}{2\ sets \times 26\ A\text{-}hr/set}\right)\right]$$

$$C_m = 100\ \left(1-0.672\right) = 32.8\%$$

which indicates that two sets of new 6TN batteries in parallel (four 6TN batteries) will be less than 70% discharged after the 2-hr silent watch mission followed by an engine restart. However, the average battery in the field only has eight-tenths of the capacity of a new battery, therefore, the actual expected capacity margin C_m is:

$$C_m = 100\ (0.08 - 0.672) = 12.8\%$$

The relationship between the state-of-charge of a battery and the initial terminal voltage, particularly when combined with low temperature, is significant. This is illustrated in Fig. 7-22 where the arrangement of two 6TN batteries in series is shown at the same ambient temperatures shown in Figs. 7-18, 7-19, and 7-20. Fig. 7-22 shows the batteries at four different states-of-charge: 100%, 75%, 50%, and 25%, and plots initial terminal voltage versus output amperes. The combined effects of the three parameters, state-of-charge, load, and temperature, can reduce the terminal voltage to less than 50% under conditions of low charge, low temperature, and heavy load.

All vehicles used in tank-automotive applications have a constant potential charging system, i.e., the voltage regulator of a given vehicle is adjusted to control the voltage in a narrow band. This is normally around 28 V and seldom will it be allowed to exceed 29 V. The reason for restricitng the voltage is to avoid excess gassing, the primary cause of plate grid corrosion in the battery cells, and to prevent damage to other vehicle electrical components. As indicated in Chapter 3, excess voltage can reduce drastically the life of incandescent lamps and can have adverse effect on other electrical and electronic components.

The electrolyte temperature has a definite effect on the constant voltage charging rate. Fig. 7-23 shows measurements taken on two fully charged 6TN batteries in series and portrays temperature versus charging voltage at four separate amperage readings[16]: 0.1, 0.2, 0.5, and 1.0 A. The dotted line superimposed on the figure is plotted from the charging voltage at different temperatures that will begin to produce excess gassing of a cell.

Since the data indicate that fully charged batteries require less charging voltage at higher electrolyte temperatures, it follows that something other than the constant potential charging is desirable. At the present time, military vehicle electrical systems pay some heed to the characteristics shown in Fig. 7-23 by providing a voltage adjustment for different climatic conditions. This adjustment is built into the regulator and is set for "arctic", "normal", and "tropical" conditions as necessary. More sophisticated methods to temperature compensate voltage regulators are under development and are discussed in par 7-4.3.

Two other important curves are shown in Fig. 7-24. These illustrate the charge characteristics for two 6TN batteries in series in 1/4-charged condition when charged at temperatures of 32° and 80°F. Note the temperature rise and amperes drawn as a function of time when a constant potential of 28.5 V is applied to the 1/4-charged batteries.

The effect of extremely low temperature on battery charging is illustrated in Fig. 7-25, where a constant potential charge of 35 V is applied at −28°F. At very low temperatures, it is difficult to effect battery charging even at increased voltages where, in an hour's time, there is only a 7% increase in battery capacity.

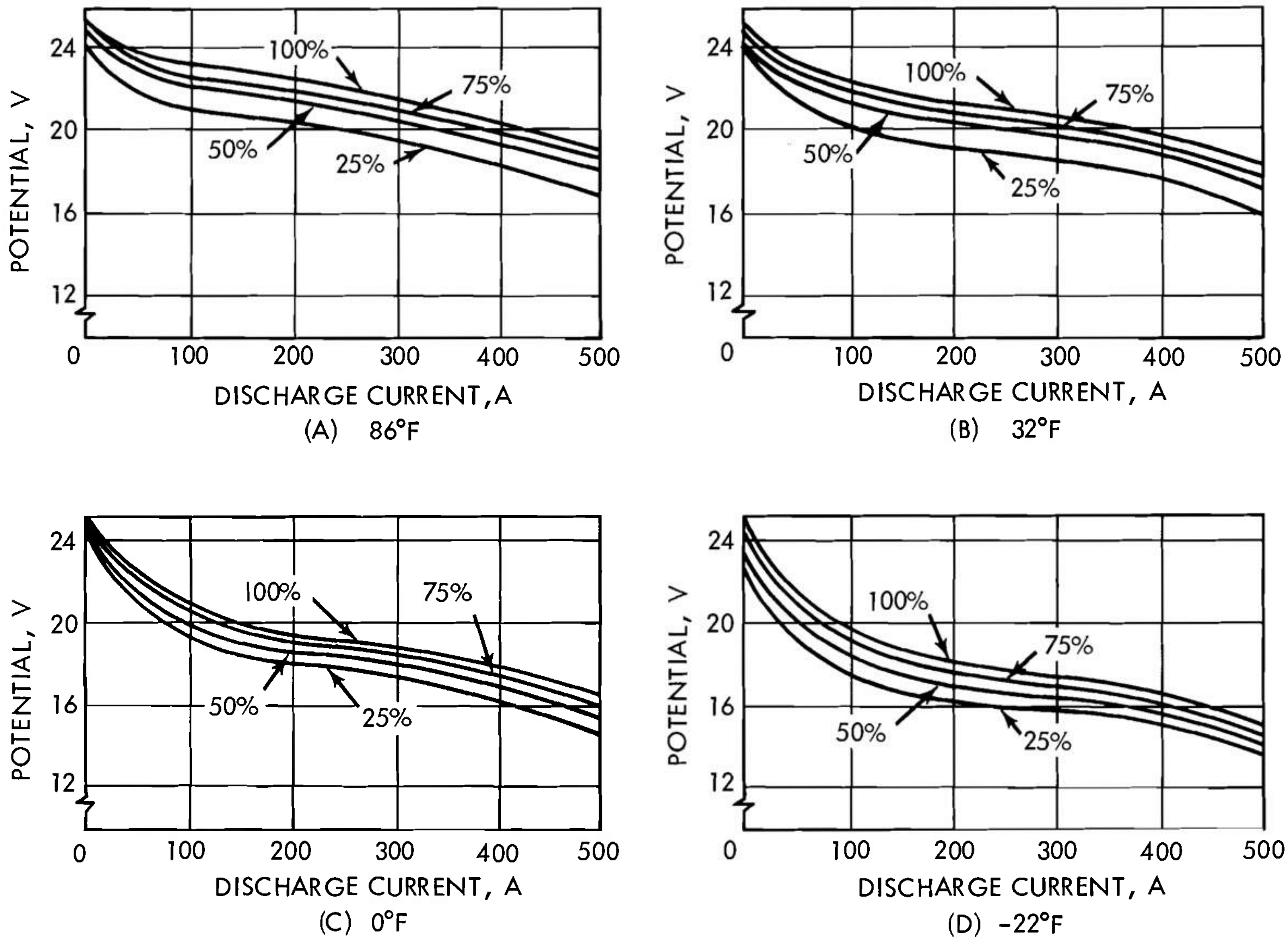


Figure 7-22. Discharge Characteristics of Two 6TN Batteries in Series—Various States of Charge[16]

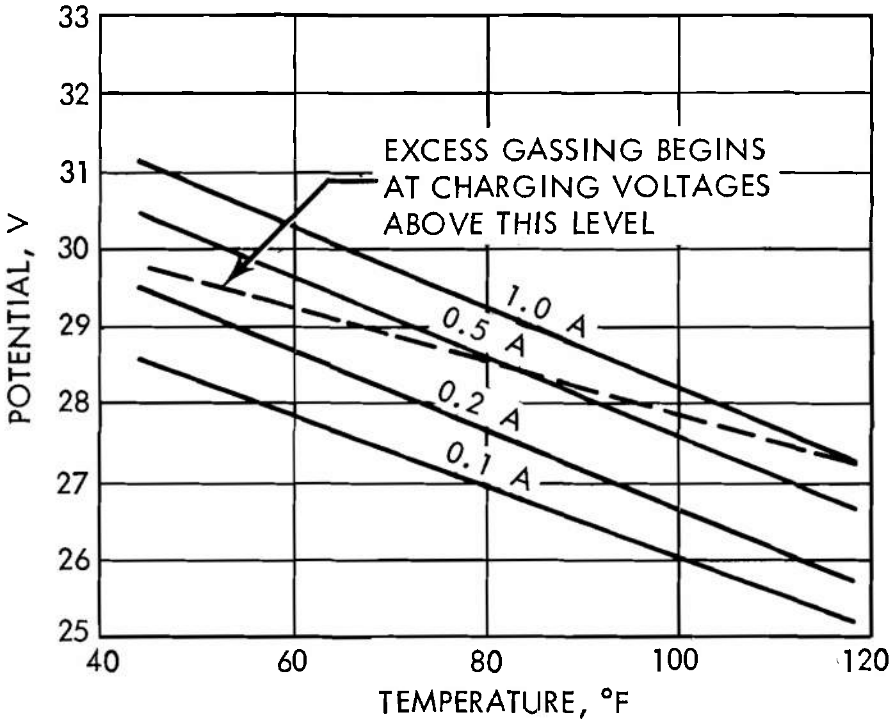


Figure 7-23. Charging Voltage vs Temperature—Two 6TN Batteries in Series[17]

As electrolyte temperature rises as a result of the charging current, the current increases and a regenerative situation occurs. Without current limiting, a runaway condition could exist with the high charging potential. Also, a vehicle using this charging potential would need circuitry that isolated the high voltage from sensitive components.

All of the data presented so far have been on the 6TN batteries. Figs. 7-26 and 7-27 give performance information on two 2HN batteries connected in series[7]. Fig. 7-26 gives discharge characteristics of these batteries, while Fig. 7-27 shows charge characteristics.

7-4.2 BATTERY INSTALLATION

The design of a battery installation will vary with the type of vehicle. There are, however, certain design features that can be applied to all vehicles used in a tank-automotive application.

For example, the battery should be mounted always in a location that is clean and protected from accumulations of mud, dust, and excess moisture. Protection from the elements is not only beneficial to the operation of the battery itself but can be the means to prevent unforeseen accidents. For example, if salt water comes in contact with the positive plates of a damaged lead-acid battery, it will produce chlorine gas. Proper design will avoid the possibility of such an occurrence. Also, provisions for periodic cleaning of the battery installation always should be made.

The battery should be mounted to facilitate maintenance and provide ready access to the batteries without the need for removing other components. All access plates should be hinged and employ quick-release fasteners when feasible. Allow for adequate clearance to allow maintenance personnel wearing arctic clothing to gain access for removal and replacement. Allow enough overhead room to provide for easy, accurate testing and servicing of the batteries.

Battery boxes should be designed to protect the vehicle and crew from gases produced during battery charging. These gases are oxygen and hydrogen, which constitute a highly

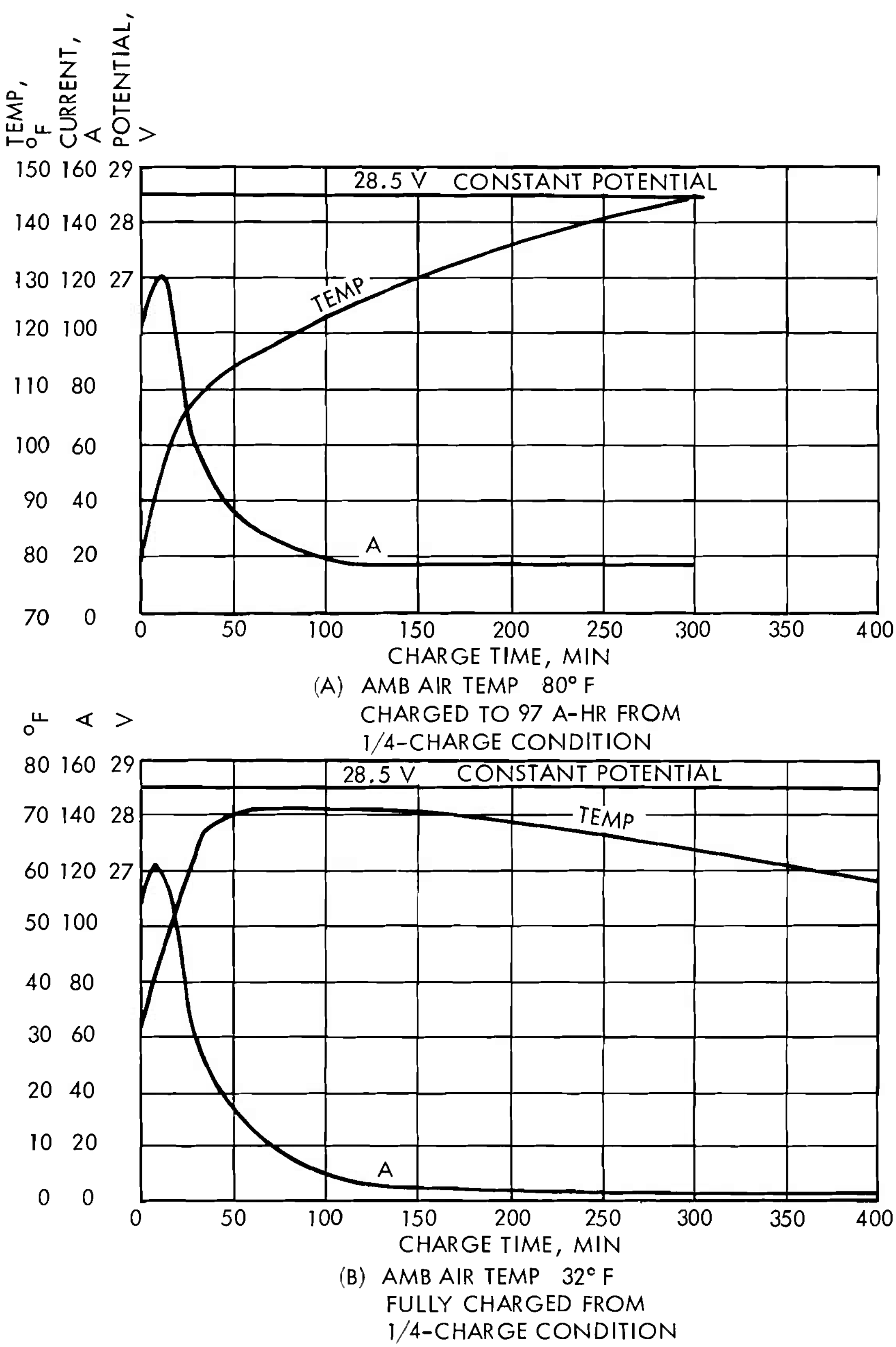


Figure 7-24. Constant Potential Charging Characteristics—Two 6TN Batteries in Series—No Current Control[18]

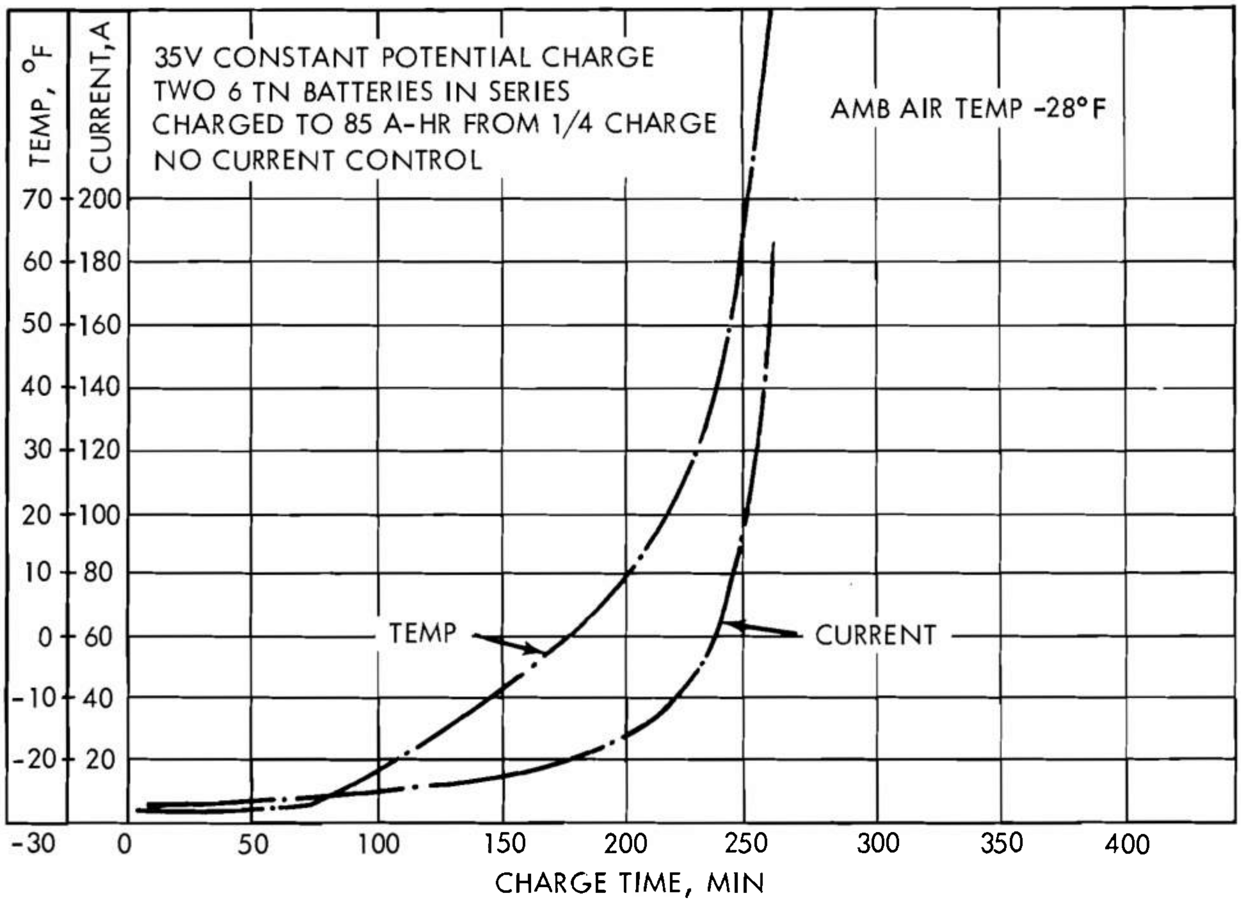


Figure 7-25. Low Temperature Charge Characteristics [18]

explosive mixture. Thus, adequate ventilation must be provided to allow all gas to escape. This ventilation is also necessary to limit temperature rise in hot climates.

The temperature range of the storage battery should be controlled to prevent extreme cold or heat. Ideally, this is a range of from 35° to 110°F. As shown in Fig. 7-25, a lead-acid battery is difficult to charge in an extremely cold environment. Conversely, an extremely hot environment, 110°F or more, can lead to overcharging and buckling of the battery plates. High temperature tends to shorten the life of the separators, which are installed between the positive and negative plates. Also, high temperature increases internal losses in a battery because the materials used in all batteries contain a certain amount of impurities. These impurities cause slight chemical action within the cell, even when the battery is not being used, and the action is accelerated at higher temperatures. For example, an unused, fully-charged battery allowed to soak at 100°F will lose most of its charge in 2 to 3 months[20].

To combat the effect of low temperature on batteries, the designer may have to winterize the battery box. Military vehicles which are to be used in cold climates must have some provision for warming the batteries. This has been accomplished using the circulation of warm engine coolant, electric heating blankets, or through hot air circulation.

For example, the M113 Armored Personnel Carrier has a winterization kit that supplies engine coolant to warm the batteries in cold climates. In this configuration, the battery box has insulated walls and top and contains a hollow floor plate through which engine coolant flows. The coolant is first heated by

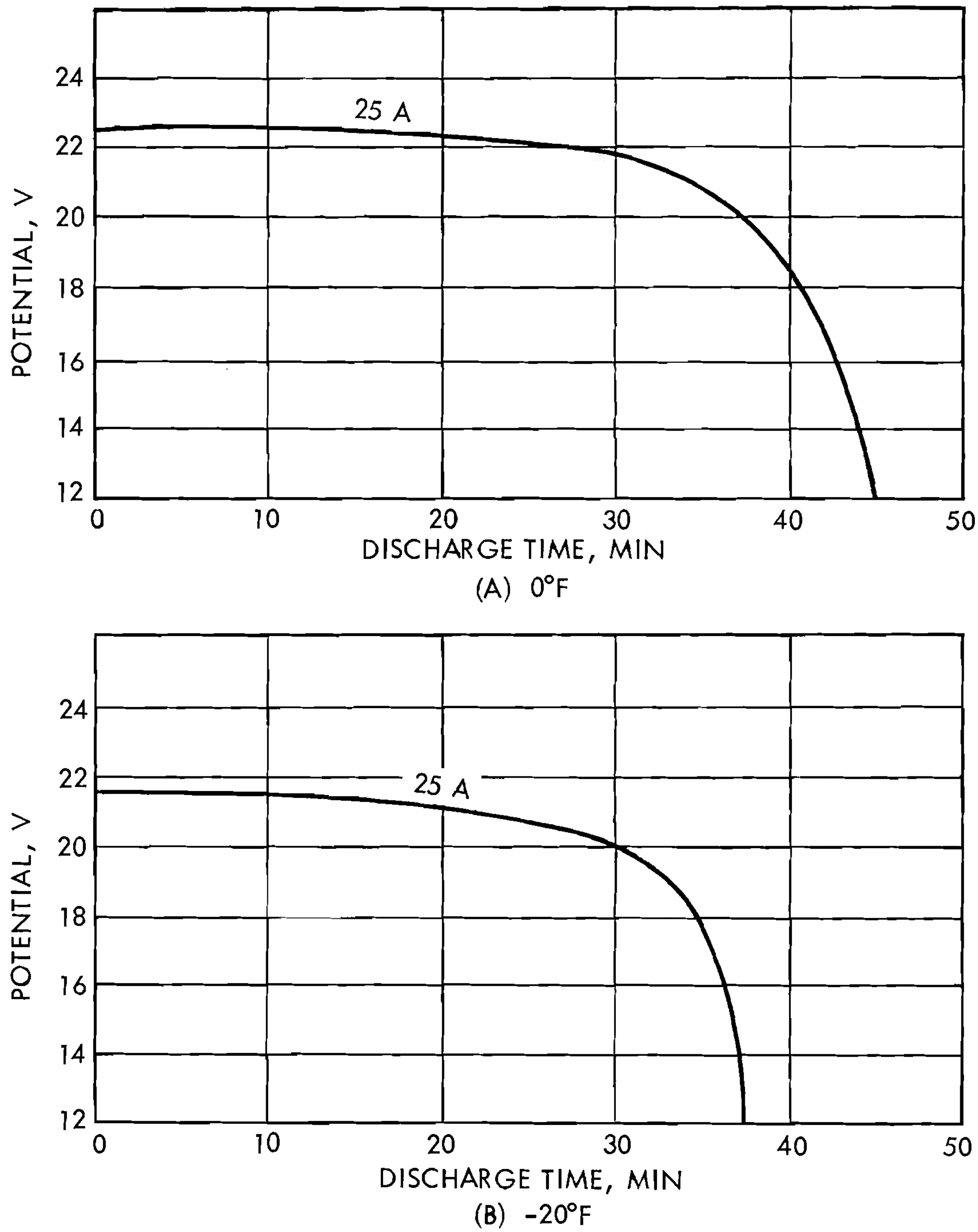
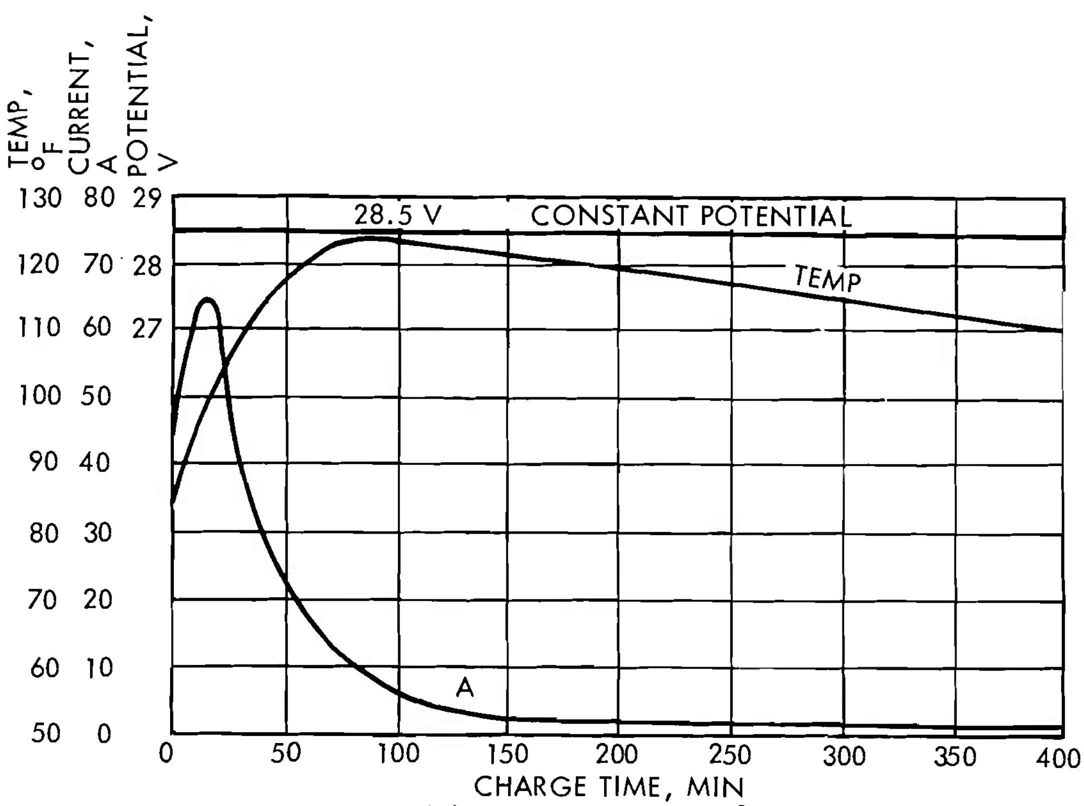


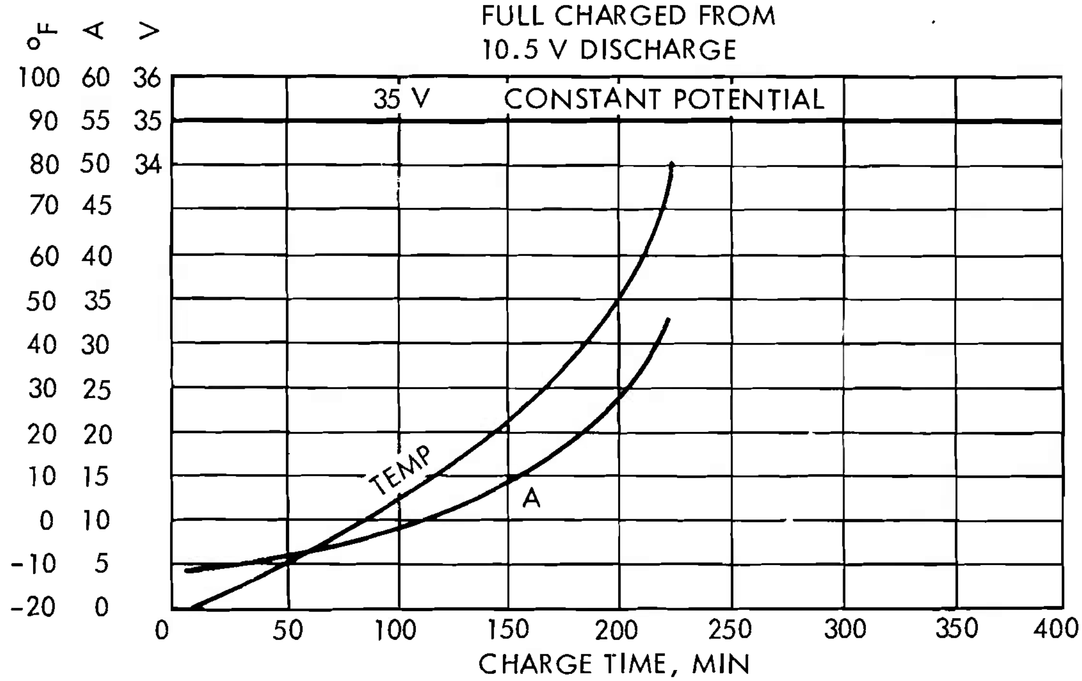
Figure 7-26. Discharge Characteristics—Two 2HN Batteries in Series[16]

the engine coolant heater. It has been shown through tests[21] that this arrangement will allow this particular vehicle—which has a 6-cylinder, diesel engine and two 6TN batteries in series—to be immediately started following a 12.5-hr temperature soak at −65°F. This start was made after the batteries had provided power to the engine coolant heating system for 12.5 hr and without the assistance of a manifold heater. In contrast, a vehicle with no battery heating provisions could not be started after a cold soak of 9 hr at −10°F.

The use of electric heating blankets and hot air circulation to heat batteries presents certain disadvantages. One is that they require



(A) AMB AIR TEMP 85 °F
FULL CHARGED FROM
10.5 V DISCHARGE



(B) AMB AIR TEMP -20°F
FULL CHARGED FROM
50% DISCHARGED

Figure 7-27. Constant Potential Charging Characteristics—Two 2HN Batteries in Series—No Current Control[18] more power drain from the vehicle batteries. Also, the temperature range in hot air systems is more difficult to control. Electric heating blankets, when used, should be acid and fire resistant for obvious safety reasons.

Shock and vibration can cause serious damage to a vehicle storage battery. Vibrations in a resonant frequency range of 3 Hz to 300 Hz should be damped out with the battery installed. For this reason, battery boxes should be mounted on adequate resilient mounts.

Since battery boxes and hold-downs are susceptible to severe electrolytic corrosion, materials should be made resistant to such corrosion. Acid-resistant paints or other means of corrosion protection should be specified. Also, drain holes should be provided in the battery boxes to drain off excess moisture and spillage.

Battery hold-downs should be designed to distribute forces over the wall and/or solid partition area of the battery case. Flexible leads should always be used between battery assemblies and junction blocks to minimize stresses on the terminals. Adequate clearance should be allowed around uninsulated parts to minimize risk of accidental shorts and excessive self-discharge.

Many of the problems associated with battery installation can be eliminated by adapting military standard parts. This includes not only the battery itself but battery terminal adapters and battery tie-down components. This will ensure standardization for easier maintenance, better material quality, and proven reliability. However, since several battery manufacturers are on the battery Qualified Products List (QPL) lists, the designer must consider the variations in battery configuration and effects that such variations have on the tie-down-hardware. In the field, it is not uncommon to find that replacement batteries in a vehicle have been produced by a manufacturer other than the original equipment supplier. Obviously, if the tie-down hardware will not adapt to both configurations, the user has a problem.

7-4.3 FUTURE TRENDS

There are several new developments that may be applied to batteries and battery systems in tank-automotive applications. Among these are new materials for use in battery construction, new charge control systems with electrolyte temperature probes, maintenance-free batteries, water-activated batteries, improved case materials, and other innovations such as a visual level sensor.

7-4.3.1 NEW CHARGE CONTROLS

The present life of a battery used in a military vehicle is only about half of its design life. This has been attributed to a stringent duty cycle where the prevalent modes of failure are sulfation from lack of proper charging or from standing idle, excessive deep discharged-charge cycling, and plate grid corrosion from overcharging. Work is going on at the present time to increase battery reliability by improving the overall charging system of military vehicles and by standardizing the loads on the batteries. For example, the phase-out of all but three starter sizes for use on Army vehicles, the conversion to solid-state voltage regulator systems, and the incorporation of circuit changes that prevent operation without the batteries connected to the generator, are recognized as potential electrical system improvements that should help extend the life of present and future battery systems. In addition to load standardization and circuit improvements, the typical generator output capacity must be sized to handle maximum operating loads to prevent deep battery discharges.

Battery electrolyte temperature sensing systems also are being developed for future use. These will control the amount of charge to a battery by sensing the temperature of the electrolyte. A typical system will consist of temperature probes, contained in the battery cells, which sense the temperature of the electrolyte and a regulator system which will vary the charging rate with the electrolyte temperature to provide the optimum charge. This system has the potential to eliminate excess gassing, and thus reduce plate corrosion to a minimum.

7-4.3.2 MAINTENANCE-FREE BATTERY

Another development that could be applied to military vehicles is the maintenance-free battery now used for commercial application. This battery is a completely sealed unit that requires no maintenance. The major difference between this battery and conventional design is the absence of antimony in the lead grids.

Since lead alone is not rigid enough to hold its form in use, antimony is usually added to stiffen conventional battery plates. As a result of the added antimony, the conventional battery uses an excessive amount of water during the charge and discharge cycles. In the maintenance-free battery, the designers replaced the antimony with a calcium additive to strengthen the plates. This design effort resulted in a battery with very little water loss over its lifetime. Another advantage of the sealed battery is that the battery posts do not become corroded as a result of acid leakage. However, batteries filled and sealed at the factory would become a charging problem in the military system due to "wet" storage. Because of shipping delay and distances involved, and long term storage requirements, a battery is seldom used within the first year after its production.

7-4.3.3 WATER-ACTIVATED BATTERY

Another recent commercial development that holds much promise for military applications is the water-activated battery. This design ends the need to mix sulfuric acid for activating the battery. If adaptable for military applications, this battery would eliminate the need for separate inventories of acid and batteries, and would permit indefinite shelf storage. In addition, these batteries could be used as on-vehicle replacements. The battery remains inert until needed and is immediately activated by the addition of ordinary tap water. The design feature of the water-activated battery responsible for its apparent advantages is the acid storage system which confines the sulfuric acid until the battery is activated. Other benefits are realized with the water-charged battery. One is that the temperature inside of the battery rises during activation approximately 70 deg F to 80 deg F due to the reaction of the water and acid. This results in instant power, even in sub-zero weather. Another is that the battery is relatively safe in case of accidental rupture during storage, since the acid is immobilized.

7-4.3.4 CASE MATERIALS

Another change in tank-automotive batteries that can be expected in the future involves battery case materials. The recent trend in battery case design, particularly in commercial applications, has been away from the heavy, wall-molded rubber cases and toward thin-walled plastic cases. These plastic cases, now in use or being considered for future use, are made from polypropylene, Fiberglas-reinforced polyethylene and similar new materials. These materials offer advantages in impact and shock resistance, they are lightweight, offer cold weather stability, and provide better terminal sealing.

7-5 LEAD-ACID STORAGE BATTERIES

As mentioned previously, the lead-acid battery using lead-antimony grids is the most commonly used. Although the output of a lead-acid battery is affected more by extreme temperature changes than some other types of batteries at normal temperatures, it has a watt-hour output per pound of active material that is higher than many other types of batteries. This, in addition to production cost and availability of materials, is the reason for its widespread acceptance.

The principle of operation of a lead-acid battery is well known and will not be discussed.

As mentioned previously, the primary modes of failure of a lead-acid battery are by plate corrosion due to overcharging and hardened plate sulfation due to insufficient charging or standing idle when discharged. When a battery is overcharged frequently, particularly at high temperatures, the lead dioxide buildup in the positive plates will cause the plates to buckle because of the expansive action of the building up of the lead dioxide. This expansion under these conditions is more rapid than the grid can withstand and still retain its shape. The grid may become distorted enough to puncture the separators, causing a short circuit. Excess charging also causes rapid shedding of the active material due to abrasion from the bubbles caused by rapid gassing.

Similarly, continual undercharging of a storage battery will cause the negative plates to harden because the lead sulfate is not being converted into active material. Extensive undercharging will eventually lead to permanent loss of this material and a corresponding loss in battery capacity.

Thus, the key to an efficient lead-acid battery is to avoid overcharging and yet provide for adequate recharge. Much of the current battery system design effort is intended to achieve this delicate balance.

The state-of-charge of a lead-acid battery is determined by the specific gravity of the electrolyte. The specific gravity is the ratio of the weight of the sulfuric acid solution to the weight of the same volume of pure water. A lead-acid military battery is considered to be fully charged when it has a specific gravity of 1.280 at 80°F and to be completely discharged near 1.130.

The specific gravity is measured by a graduated hydrometer, which floats in the solution at a depth varying with the gravity. This hydrometer is mounted inside the glass barrel of a syringe used to withdraw the electrolyte solution from the battery. The graduated mark that appears at the surface of the solution indicates the specific gravity.

The specific gravity varies not only with the state-of-charge, but changes slightly with the temperature. This is because the electrolyte expands as the temperature rises, resulting in a lower specific gravity reading. Conversely, as the temperature lowers, the specific gravity rises. Gravity readings taken at temperatures other than 80°F must be corrected. Correction is made by subtracting 0.001 from the reading for each 2.5 deg below 80°F, and adding 0.001 for each 2.5 deg above 80°F (Fig. 7-28). For example, if the reading were specific gravity 1.240 and the temperature 60°F, then the corrected specific gravity would be 1.240 −0.008 or 1.232.

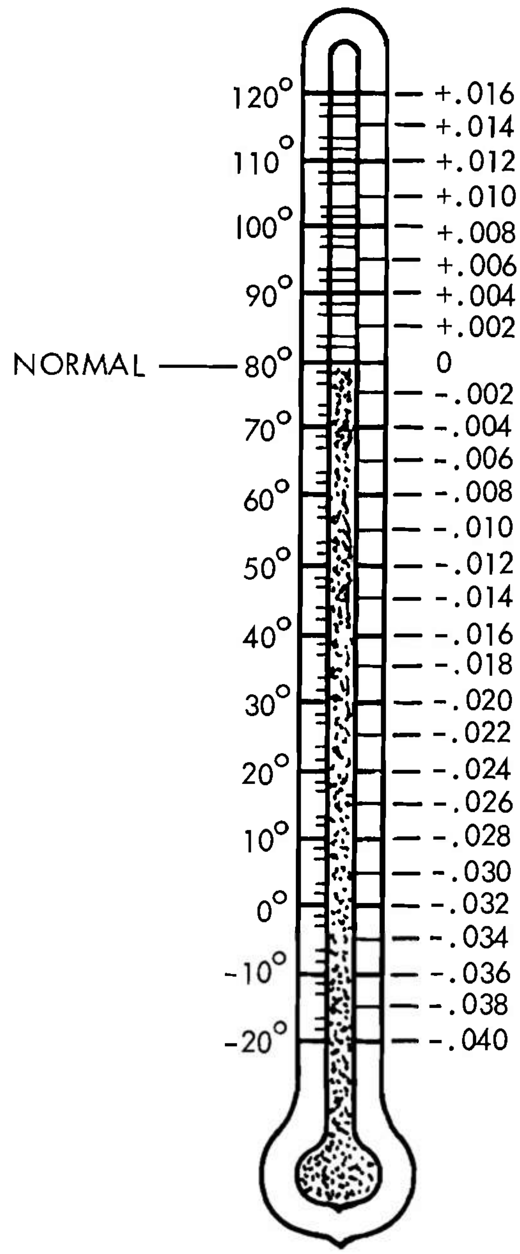


Figure 7-28. Hydrometer Temperature Correction Chart

7-6 NICKEL-CADMIUM STORAGE BATTERIES

The nickel-cadmium, alkaline battery has been receiving serious consideration and extensive testing for tank-automotive applications. This battery employs nickel and cadmium compounds as the active material and potassium hydroxide as electrolyte. There are actually two basic types of nickel-cadmium batteries. These are distinguished by the method used to construct the plates. One is called a pocket plate and the other a sintered plate design. In addition, the nickel-cadmium battery is produced with both vented cells and completely sealed cells.

The vented sintered-plate, nickel-cadmium battery is the one most often used in military applications because it offers high discharge rates at wider temperature ranges. For this reason, the discussion of the nickel-cadmium battery will be largely confined to the sintered plate version. The basic difference between the pocket and sintered plate is that in the pocket type the active material of the plates is encased within perforated steel pockets, while the sintered type has the active material contained in a sintered structure surrounding the grid. Although the sintered method is more expensive per ampere-hour than the pocket plate type, superior performance at high rates and reduced capacity loss at low temperatures qualify it as the logical choice for military applications.

The low internal resistance of the sintered plate battery makes it ideal for service requiring long battery life and high current drains over a wide temperature range.

The sintered plate construction of the positive and negative electrode allows plates to be constructed as thin as 0.020 in. This allows more plates to be installed in a given sized cell with less space between plates. The internal resistance of the sintered plate cell is thus about one-half that of a pocket plate type.

The sintered plate consists of three components. One is the metal grid which acts as the current collector. This grid is constructed either of pure nickel, a woven screen of nickel plated steel, expanded metal, or perforated sheet. The second component is a fine nickel powder that is sintered on the grid and has a porosity of about 80%. The third component is the active material that is impregnated into the pores of the sintered powder. A nickel salt is used for the active material in the positive plate, and a cadmium salt for the negative.

Once the plates are constructed, they are formed into cell elements similar to the lead-acid battery. The plates are isolated from one another with nylon-cellophane type separators and placed into a container usually of high-impact plastic.

The positive plate of the nickel-cadmium battery is made up of $Ni(OH)_3$ and $Ni(OH)_2$ whereas the negative consists of Cd and $Cd(OH)_2$. During discharge, the trivalent nickel hydroxide $Ni(OH)_3$ is converted to the divalent hydroxide $Ni(OH)_2$ at the positive plate with the reverse process occurring during charging. The negative plate consists of metallic cadmium when fully charged. This is converted to the hydroxide during discharge and back to metallic cadmium during charging.

The specific gravity of the potassium hydroxide electrolyte does not change during charge or discharge. This is because the electrolyte does not enter into the chemical reaction between the positive and negative electrodes, as does sulfuric acid in the lead-acid battery. For this reason, specific gravity readings of the nickel-cadmium electrolyte are not an indication of the state-of-charge. The open circuit voltage of a charged nickel-cadmium cell is about 1.30 V, and the average and final discharge voltages at normal rates of discharge are about 1.20 and 1.10 V, respectively.

The fact that the electrolyte serves virtually as a conductor offers several advantages. One is that very little gassing occurs on charging, except when overcharged, and none on discharge. Therefore, little water is lost. Another is that the rate of self-discharge is very low. Thus, the battery may be left standing on open circuit for periods up to a year and still retain as much as 70% of its original charge[19]. Still another advantage of the nickel-cadmium battery is that it will accept a charge at a temperature as low as −40°F, by virtue of self-heating. At temperatures below −40°F, however, the electrolyte forms a slush which does slow down chemical reactions.

As with the lead-acid battery, excess charging voltage, particularly at high temperatures, should be avoided. Voltages greater than 28.5 V applied to a 24-V nickel-cadmium battery can raise the electrolyte temperature to the boiling point, resulting in water loss and a strong alkaline solution. This increases the internal resistance of the cell, causing higher internal heating of the battery, and eventually results in thermal runaway.

The constant voltage charging that is used on tank-automotive vehicles is not recommended by nickel-cadmium battery manufacturers unless the voltage can be finely controlled. They recommend, rather, a constant current charging system. The reason is that constant voltage charging tends to cause capacity fading with repeated shallow discharge cycles. This fading is an actual loss of output current capacity due to the cell voltages becoming unbalanced. The battery can be rejuvenated with a deep discharge cycle followed by a recharge of the battery. Capacity fading is an undesirable characteristic of the nickel-cadmium battery and the vehicle electrical designer should recognize it as such.

A discharge performance comparison between the nickel-cadmium battery and the lead-acid battery is shown in Fig. 7-29. This figure, obtained from Ref. 22, shows discharge characteristics of fully charged 34 A-hr, 24 V, lead-acid and nickel-cadmium batteries discharged at the 1 hr rate of 30 A. This figure illustrates an important characteristic of the nickel-cadmium battery, i.e., its

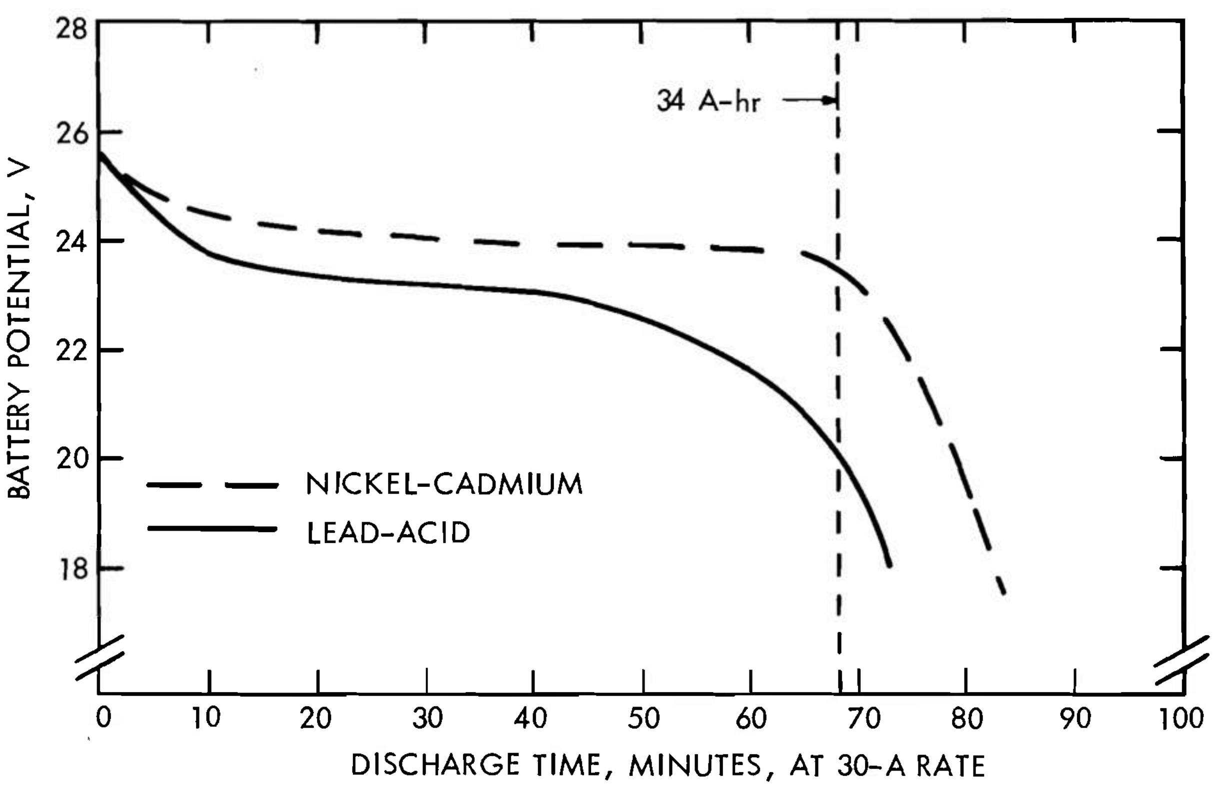


Figure 7-29. Comparison Between Nickel-cadmium and Lead-acid Battery Discharge Characteristics[22]

ability to maintain a nearly constant voltage until approximately 90% of the capacity is delivered. This feature, combined with its recharge capability at low temperatures, makes the nickel-cadmium battery a prime candidate for heavy duty applications.

Table 7-7 has been prepared to show a comparison between certain characteristics of military standard nickel-cadmium and lead-acid batteries. These are the 6TN lead-acid described by MS35000-4 and MIL-B-11188, and the 6TNC nickel-cadmium described by MIL-B-23272/1.

The last two characteristics in Table 7-7 point out possibly the most desirable and least desirable features of the nickel-cadmium battery—i.e., cranking ability at low temperature, a most desirable feature, and the undesirable initial acquisition cost. The latter indicates an initial cost of approximately 35 times that of the lead-acid battery. Whether this added cost can be justified by longer life and better performance is up to the electrical designer to evaluate in his particular application. In addition, the manufacture of nickel-cadmium batteries requires critical materials during war time.

7-7 OTHER STORAGE BATTERIES AND FUEL CELLS

Although the lead-acid and the nickel-cadmium storage batteries have received the most attention, several other battery types deserve a brief description. These are: nickel-iron, nickel-zinc, silver-zinc, and silver-cadmium.

TABLE 7-7. 6TN VS 6TNC CHARACTERISTICS

	6TN	6TNC
Battery weight, lb	70	70
Number of cells	6	10
Voltage	12	12
A-hr capacity, (5-A rate)	100	70
Cranking ability at -40°F, minimum time, min, at 300-A rate	1.25	5.5
Initial acquisition cost current Govt catalog	\$25	\$1000

7-7.1 NICKEL-IRON

This is a battery of rugged construction, used for many years for heavy cycling service to provide reliable, long life service in applications such as electric industrial trucks and railway cars. The battery may have limited use in certain tank-automotive applications. Charging problems occur due to high over-voltage and performance is poor at low temperatures.

7-7.2 NICKEL-ZINC

This battery has received attention only in recent years. It is still in the development stage. Problems to be overcome are low nickel plate capacity, separator deterioration, and poor zinc cycle life. With added improvements it could become competitive with silver-zinc types in many applications.

7-7.3 SILVER-ZINC

This battery is the best high-rate performer in existence. It has been designed to provide from 40 to 55 W-hr/lb in service and has high-rate discharge with good voltage. Its greatest disadvantages are that it is expensive, and it does not have an exceptionally long cycle life. These shortcomings are expected to be improved in the near future.

7-7.4 SILVER-CADMIUM

This battery has similar construction to the silver-zinc, but has lower cell voltage and more moderate discharge rate. It is similar in cost to the silver-zinc, but better in cycle service due to its cadmium electrode. This battery, as well as the silver-zinc, is presently used for space satellite applications and possibly could have future use in tank-automotive applications.

7-7.5 BATTERIES IN DEVELOPMENT

Some other battery systems in the development stage offer extremely high-energy outputs and efficiency. These are the sodium-sulfur and lithium-chlorine types. They do, however, present many development problems and are not expected to be of practical use in the immediate future.

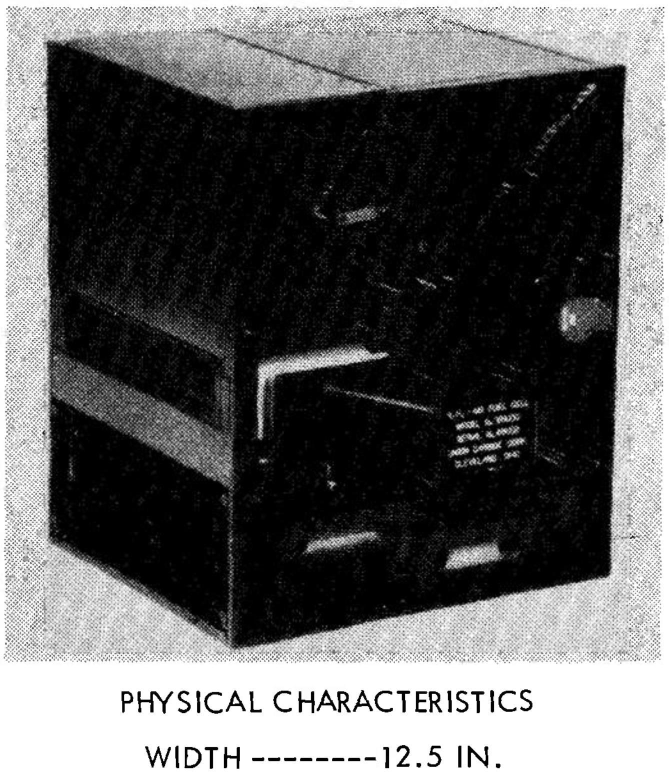
7-7.6 FUEL CELLS

As mentioned in the introduction, another type of energy-producing device is the chemical fuel cell. Fuel cells have received much attention in recent years and currently are being used in space applications. At least one version has received extensive testing by the U.S. Army in actual field tactical situations in Southeast Asia.

Fuel cells are similar to conventional batteries in that they produce electrical energy. The major difference is that batteries consume (or oxidize) their electrodes when delivering current, while the fuel cells consume (or oxidize) an external fuel such as hydrogen, kerosene, or alcohol. The electrodes act only as catalysts and remain unchanged.

The major advantage of fuel cells over the storage battery is the high efficiency with which they convert fuel into electrical energy. The output from a fuel cell can be in the range of 1,000 W-hr/lb of fuel[23], with efficiencies in excess of 40%.

Fuel cells can use either gaseous or liquid fuel, and either pressurized oxygen or air as an oxidizing agent. For example, the fuel cell used in the military testing program[24] mentioned previously uses liquid hydrazine monohydrate ($N_2H_4 \cdot H_2O$) for fuel, ambient air for the oxidant, and potassium hydrozide as the electrolyte. This fuel cell system provides a source of portable power that delivers 0.3 kW at 28 VDC (Fig. 7-30).



PHYSICAL CHARACTERISTICS

WIDTH --------12.5 IN.
LENGTH -----14.75 IN.
HEIGHT -------18.0 IN.
WEIGHT ------ 73.1 LB

Figure 7-30. 0.3 kW Hydrazine-air Fuel-cell Power Source[25]

A more complete description of the hydrazine-air fuel cell system is given in Ref. 25, but basically, this system consists of five major subsystems:

1. Fuel cell stack
2. Electrolyte subsystem
3. Fuel subsystem
4. Chemical-air subsystem
5. The electronic control module.

These subsystems were designed as a modular concept and assembled into a compact unit.

A simplified schematic of this fuel cell system is shown in Fig. 7-31*. The fuel cell stack is the heart of the system. The electrochemical action takes place within this unit. The stack contains a series of reactive units or bi-cells, which are connected in series to produce the desired voltage output. Each bi-cell, depicted schematically in the top right of Fig. 7-31, consists of two cathodes, connected electrically in parallel, and an anode as shown. Incoming electrolyte containing the fuel passes into the stack where the reaction

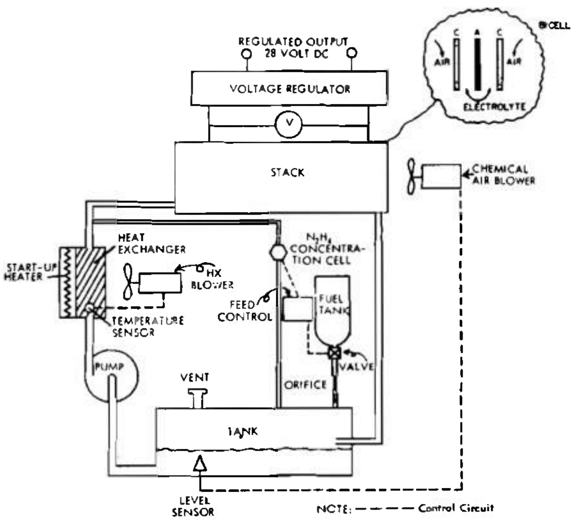


Figure 7-31. Schematic of Hydrazine-air Fuel cell System[25]

***Proceedings Twenty-Third Annual Power Sources Conference*, 1969, 20-21-22 May, Copyright 1969, PSC Publications Committee, reprinted by permission[25].

occurs. Outflow from the stack containing the by-products N_2 and H_2O of the electrochemical reaction flows back into the reservoir.

Electrolyte is circulated from the reservoir by the centrifugal pump through a primary loop consisting of a liquid-to-air heat exchanger, transistor heat sink, and the fuel cell stack. A secondary loop feeds a hydrazine concentration-sensing cell. The electronic control module, acting on signals received from the sensing cell, controls the amount of hydrazine added to the electrolyte by opening and closing a solenoid valve. The concentration of hydrazine is maintained at approximately 0.5% by volume.

The electronic control module also maintains system operating temperature by varying the speed of the heat exchanger fan, controls the voltage for auxiliary equipment and system output power, and provides circuit protection. In addition, the module controls the fuel cell starting circuit during system warmup. Starting power is supplied from a secondary battery until the fuel cell voltage rises and the system is brought up to operating temperatures. Initial heating is provided by the start-up heater.

Fuel cells, such as the one described, may someday be used in tank-automotive applications. They provide a source of silent and highly efficient power and could be used in a situation where a long, silent watch capability has to be designed into a vehicle. The acceptance of the fuel cell depends, to a large extent, on whether future units can be produced less expensively than the present ones.

7-8 PRIMARY CELLS

A primary battery also converts chemical energy into electrical energy. However, it is not practical to reverse the reaction because electrode material is dissolved in the electrolyte. In other words, the battery discharges, then is either thrown away or has its active material replaced.

Military primary batteries are of the "dry" cell type. This is a cell that has its electrolyte in the form of a paste or jelly. The electrolyte is confined in an acid-resistant case to avoid corrosive damage, and to permit ease of handling. A battery may consist of a single cell or a group of cells connected in series or series-parallel to provide the desired voltage and amperage.

MIL-B-18[26] describes the majority of dry cells and batteries used in military applications. This covers the common zinc-carbon LeClanche dry cells and the mercury cells.

The LeClanche dry cell is the most common battery used and the annual commercial production of these is in the billions. This battery offers an economical and reliable source of power with a storage life of up to one year at 70°F. A cross-sectional view of a LeClanche type battery is shown in Fig. 7-32. This is a common 1.5-V battery used in most flashlights. All dry cells have four major components—the anode, cathode, electrolyte, and a depolarizing agent. The cell shown in Fig. 7-32 is the common cylindrical shape, but other carbon-zinc cells are constructed in slab shape to form square and rectangular shaped batteries. Regardless of the shape, they all contain the four major components.

The electrical capacity of a dry cell is generally not given in the Military Specifications because the electrical output generally depends on how the battery is used. The output of a LeClanche type battery varies widely with temperature and the duty cycle of the battery. For example, a battery used on intermittent or low amperage continuous duty will last longer and provide more ampere-hours. The amperage output of similar size cells varies with the grade and the manufacturer. Amperage is usually higher in larger cells than in the small ones due to the larger quantity of active materials.

Mercury cells, also described in MIL-B-18[26], and commonly referred to as "RM" cells have an anode of high-purity zinc, a cathode of mercuric oxide which also acts as a depolarizer, and an electrolyte of either potassium or sodium hydroxide. Unlike the common carbon-zinc cells, the mercury cell container is a steel can that does not enter into the electrochemical reaction. The mercury cell provides a longer service life, several times the capacity, and can be stored longer than the standard dry cell. It is also more expensive.

MIL-STD-688[27] has been prepared to aid the electrical designer in selecting the proper dry cell for a given application. This document lists the preferred types of dry cells for military applications. This Standard covers both a single and multicell battery of 1.3 to 6 V and Type B multicell battery of 22.5 to 135 V. The designer is referred to this Standard and to MIL-B-18[26] to select a primary battery of a given size and voltage to fit his application.

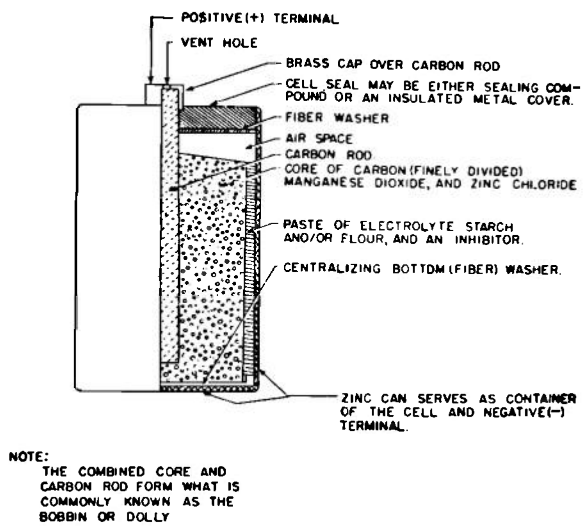


Figure 7-32. Cross-sectional View of a Dry Cell Showing Parts[28]

SECTION III

POWER CONVERTERS

7-9 INTRODUCTION

Power conversion is required whenever a unique voltage level or characteristic is mandatory for the proper operation of electrical equipment on or in conjunction with a vehicle. Examples of such equipment are infrared or low light level viewing devices, radios and other communication equipment, and portable tools.

As a general rule, the equipment specified for use with military vehicles includes the necessary power conversion components as part of the equipment design. However, if it is necessary to use unique equipment originally designed for applications other than in military vehicles, the interface between the vehicle electrical system and the equipment must be examined.

If the interface examination proves that such equipment is not compatible with the power characteristics of a typical vehicle electrical system, it will be necessary to establish performance specifications and design or procure the appropriate power conversion equipment. In general, power conversion equipment falls into two basic categories:

1. DC to AC inverters

2. DC to DC converters.

Unfortunately, most Military Specifications in the system have been written to describe aircraft or shipboard power conversion devices and there is very little that can be found to apply directly to military vehicle equipment. Furthermore, conversion equipment to modify 28 VDC input power is not common in the commercial realm. Although this section will introduce the designer to power conversion devices and their characteristics, the topic is extremely specialized and thorough coverage is beyond the scope of this handbook. Power converter characteristics are given in Table 7-8, and the reader is referred to Refs. 29, 30, and 31 for further design guidance.

7-10 DC TO AC INVERTERS

There are two practical methods for producing alternating current from a typical vehicle electrical system. Early applications used the rotary converter, whereas the most recent applications employ transistorized static inverter concepts.

7-10.1 ROTARY INVERTERS

The rotary inverter has the longest history of development and use. The rotary inverter is basically a DC motor driving an AC generator. In actual implementation, the motor and generator field structures may be combined to produce a machine with a single moving element. The resulting machine is simple, rugged, and easily maintained. The output voltage is directly proportional to the input voltage with an essentially constant output frequency. However, these machines are inefficient at low powers, and the requirements for transformation and ripple removal exact a high weight penalty[31].

The inverter shown in the diagram of Fig. 7-33 has two armatures and two fields func-

TABLE 7-8. CHARACTERISTICS OF POWER CONVERTERS

Characteristic	Rotary	Transistor	SCR*
Power range, W	5 - 2,000	0 - 1,000	100 - 10,000
Efficiency, %	25 - 75	75 - 90	90 - 95
Power output, W/lb	12	30	50
Expected life without maintenance	2000 hr	Extremely long	Extremely long

*SCR = silicon controlled rectifier.

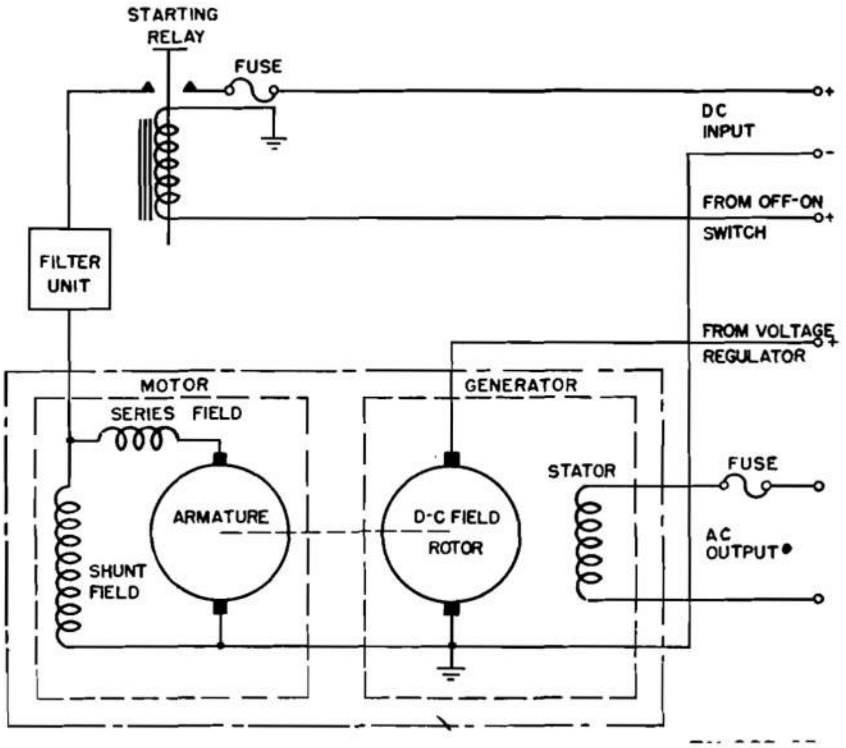


Figure 7-33. Rotary Inverter Schematic[29]

tioning separately as a motor and a generator. The reason for this arrangement is that the inverter is unstable if the same armature and field are used for both AC and DC. Maximum possible stability is one of the requirements in military applications, and this machine is used widely with communications equipment. As an additional assurance of stable operation, the field of the motor section is compounded, consisting of both a series and shunt winding. This provides better speed regulation under varying load and a reasonably constant frequency in the AC output[29].

When the operating switch is closed, current flows through the relay coil and a magnetic field is created which attracts the relay plunger, and so closes the relay contacts in the input line. The contacts remain closed as long as there is current through the relay coil. The input line to the relay contacts is fused; this prevents excessive current drain which may be caused by an abnormal condition in the inverter. The filter unit in the input to the inverter reduces the electrical noise generated at the brushes and commutator of the motor armature.

Application of exciter voltage to the field causcs the field to generate a voltage in the stator winding. The generated voltage is made available by means of terminals connected directly to the stator. The DC field rotor is ganged mechanically to the motor armatures and rotates with the speed of the motor. The exciter voltage is applied to the rotating field through brushes and a commutator. To insure an unvarying field voltage, the exciter voltage is regulated before application to the field. The current through the DC field winding creates a magnetic field that is rotating at the speed of the motor. The rapidly moving lines of force cut the stationary winding and a voltage is induced in the stator. The output from the stator is an AC voltage of the value, phase, and frequency determined by the design and power rating of the particular inverter unit. The output winding is fused to prevent damage to the inverter from excessive current drains by the operating equipment.

If the inverter has a single armature winding, connection to an inductive load tends to weaken the inverter field. This causes the machine to speed up, changing the frequency;

the output voltage is not changed greatly. This instability in the speed of an inverter with a single armature winding is inherent in the machine unless the inverter field is excited by a special exciter circuit directly connected to the inverter output. Any tendency toward increase of speed is corrected by a corresponding increase in exciter voltage, causing a stonger field. Other methods of speed control include the use of a centrifugal overspeed device that automatically opens the line connections if the inverter speed increases beyond a predetermined operating point. The use of dual windings on the armature helps to correct for excessive speed (Fig. 7-33).

7-10.2 STATIC INVERTERS*

Compared to the rotary inverter, static inverters have the advantages of no moving parts, small size, light weight, shock and vibration resistance, long life, and high efficiency[32].

The static inverter uses an electronic switch to interrupt incoming DC power in the power conversion process. This interrupted direct current is applied to a transformer primary that produces an alternating current in the transformer secondary. The switching is usually accomplished with a transistor for low power applications and a silicon controlled rectifier (SCR) for high power. The boundary between high and low power is approximately 1 kW. When the power to be handled is below an approximate value of 100 W, a very simple transistor inverter configuration is available (Fig. 7-34). This configuration employs a saturable core transformer, and the transistor switches are driven with feed back derived from the output transformer. A very desirable feature of this inverter is the inherent self-limiting output characteristic.

This transistorized power inverter consists essentially of a saturable reactor with the requisite number of windings and the power transistors. Operation depends on a switching action accomplished by the power transistors when triggered by signals from a feedback winding of the reactor.

The transistors function in a manner similar to the contacts of a vibrator in that when one is open the other is closed. In practice, these transistors differ from true switches or switch contacts in the following respects: they have intermediate conductance levels between full "on" and full "off", which accounts for some rather high dissipation levels during switching, and they require a reverse power to hold them off at high temperatures.

The transistors operate in a push-pull oscillatory circuit with the transformer or reactor windings arranged to provide positive feedback from the collector of each transistor to its emitter. The operation of the circuit shown in Fig. 7-34 can be described as follows. Assume that transistor *A* starts to conduct and develops a voltage across the primary winding. The polarity is arranged so that the voltage induced in the feedback winding will drive the emitter more positive. This increases the emitter drive, which further increases the collector current. If the circuit components are appropriately selected, the collector will rapidly bottom; and a voltage approximately equal to the supply voltage will appear across the associated half of the transformer primary winding. Since the windings are out of phase, the opposite collector is driven negative to twice the supply voltage.

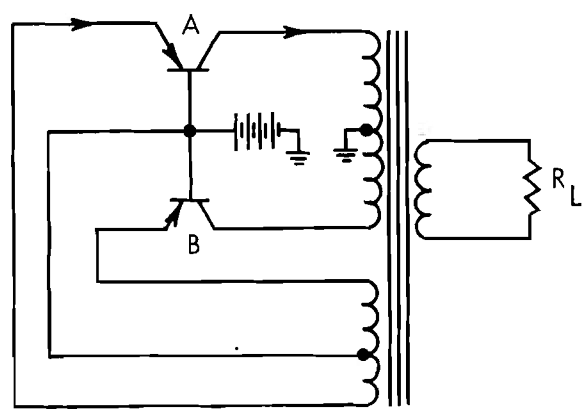


Figure 7-34. Basic DC to AC Inverter Circuit[32]

**Electronic Components Handbook,* Volume 2, Henney and Walsh, Copyright 1958, McGraw-Hill Book Company, by permission[32].

In this condition, transistor *A* must supply sufficient collector current to equal the reflected load current, reflected emitter current, and the transformer exciting current. As long as the core is unsaturated, the exciting current requirements will be very low, and, provided the transistor can supply the reflected load and emitter currents, the collectors will remain bottomed. With this voltage across the primary winding, the magnetic flux increases. Eventually, the core will become saturated causing the exciting current requirement to rise sharply. At some point the transistor becomes incapable of supplying this extra current and the voltage across the primary starts to decrease. This decrease results in decreased emitter drive, which further reduces the collector current. Thus, transistor *A* shuts off, turning transistor *B* on at the same time. The next half cycle is identical, except that transistor *B* conducts. During this half cycle, the core flux is driven to saturation of the opposite polarity.

The significant interval in the overall cycle of operation is that in which the actual switching occurs. During this interval the transistor enters and leaves a region of high dissipation. It is important to maintain low-transistor dissipation, which means that the collector of the conducting transistor must remain bottomed as nearly as possible for the full half cycle[32].

The control circuitry employed with the higher power static inverters must include protective circuits to guard against damage due to overloads and transient conditions. These circuits can become quite complex.

7-11 DC-DC CONVERTERS

A DC to DC converter is employed to convert low voltage from the vehicle electrical system to a higher DC voltage as required by the electronic circuits to be powered. The operation of a typical static converter is essentially identical to the operation of a static inverter with the exception that the AC output from the transformer is rectified (Fig. 7-35).

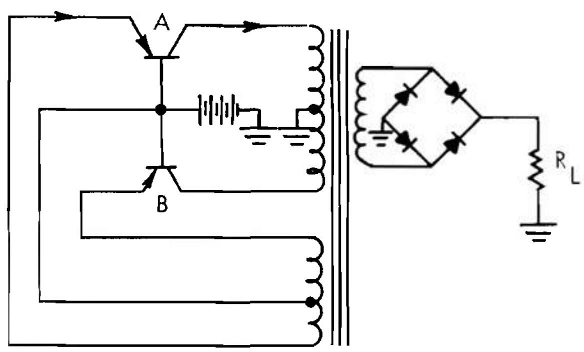


Figure 7-35. Basic DC to DC Converter Circuit[32]

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CHAPTER 8

POWER DISTRIBUTION*

SECTION I GENERAL CONSIDERATIONS

8-1 INTRODUCTION

Electrical power and control signals must be delivered to electrical devices reliably and safely so that the electrical system functions are not impaired or converted to hazards. This goal is accomplished through careful circuit design, prudent component selection, and practical equipment location.

The list of common equipment used to fulfill power distribution requirements in military vehicles includes single-conductor cable, multiconductor cable, bus bars, slip rings, terminal blocks, terminals, connectors, fuses, switches, relays, and circuit breakers. In order to facilitate the successful application of such equipment, guidelines for the design of main power distribution circuits, conductor selection and routing practices, wiring and cable assembly requirements, human factors, environmental considerations, circuit protection requirements, and circuit identification techniques are discussed in this section. Included are the general power distribution considerations necessary for effecting good performance, economy, and safety in a vehicle electrical system design. However, switches and relays are fundamentally controls and therefore are presented in Chapter 9.

8-2 DISTRIBUTION CIRCUITS

Ordinarily, the voltage impressed upon vehicle electrical equipment must not be significantly lower than the voltage of the power supply system. It follows that the voltage drop in the power distribution circuits under maximum load must be held to a minimum by selection of appropriately sized conductors for use as power distribution wiring. As a general rule, wiring voltage drops greater than 5% at the load under maximum load conditions are considered excessive[1]. However, the tolerance to voltage variation is unique for each load. Therefore, individual examination of load voltage requirements is necessary, e.g., starter motor circuits should not have more than 0.2 V drop for each 100 A of conducted current.

Aside from the voltage drop consideration, there are several other factors of importance regarding power distribution circuit design. For instance, various methods have been employed to connect the battery, generator, and load circuits in military vehicles. Each of these methods has advantages and disadvantages and as yet the perfect solution has not been found. A review of typical power distribution circuits which follows is necessary to understand the true nature of the problem.

8-2.1 MASTER SWITCH CIRCUITS

In contrast to commercial vehicles, most military vehicles are equipped with a master switch to disconnect the batteries from the load. Attempts to optimize vehicle master switch applications introduce several factors worthy of consideration. The primary question is whether to locate the master switch in the positive or negative battery bus. Normally, a switch in the negative bus can effectively remove the ground from the battery. This is a good safety feature because it is impossible for maintenance personnel to short out the distribution system when the master

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Electronic Components Handbook, Volume 3, Henney and Walsh, Copyright 1958, McGraw-Hill Book Company, by permission[13].

Electronic Wire and Cable, Wire Cable Division International Telephone and Telegraph Corporation, Clinton, Mass., by permission[12].

Military-Specification Connector Manual, MS-LK170, Elco Corporation, Willow Grove, Pa., by permission[25].

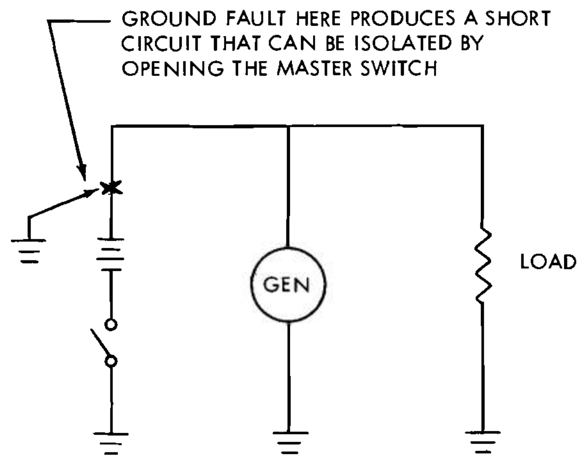


Figure 8-1. Master Switch in Negative Bus

switch is open except by directly connecting the positive and negative battery terminals (Fig. 8-1). Conversely, a switch in the positive bus is not as safe because even though the switch is opened, the positive battery terminal or battery side of the master switch may be accidentally shorted to the vehicle hull by maintenance personnel working with metal tools (Fig. 8-2).

Unfortunately, master switch locations cannot always be justified on the basis of such obvious advantages or disadvantages. For example, the master switch location must be within the driver's reach from a human factors point of view, and often the batteries are located at the other end of the vehicle. In these circumstances, a master switch located in the negative bus of the typical ground return system requires that both the positive

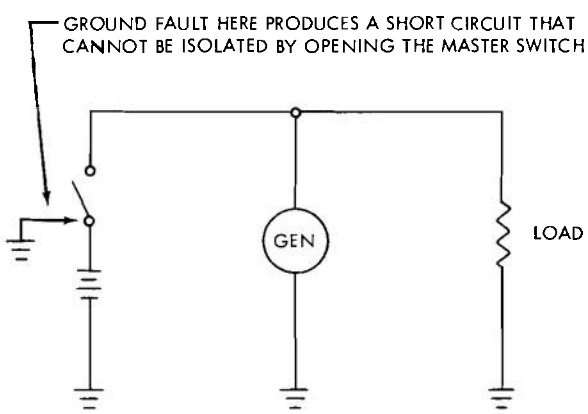


Figure 8-2. Master Switch in Positive Bus

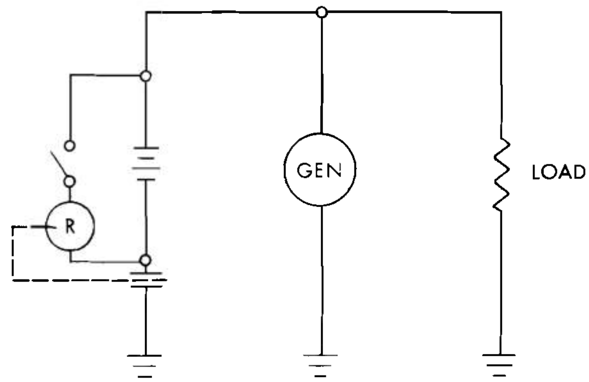


Figure 8-3. Master Relay With Contactor in Negative Bus

and negative cables run the entire length of the vehicle. Whereas, if the master switch is located in the positive bus, the negative cable can be grounded to the vehicle hull adjacent to the battery. Then only the positive cable need run the length of the vehicle. These factors must be weighted in order to evaluate their importance, e.g., locating the master switch in the positive bus may be more advantageous when the cranking current and allowable voltage drop of the engine starter circuit are considered. Certainly the best compromise must be sought, and it is therefore often necessary to use a power relay *R* (Fig. 8-3), located near the battery, which is controlled by a toggle switch at the driver's station. These features serve to reduce starter circuit voltage drop, reduce cable requirements, and retain most of the desirable safety advantage gained by interrupting the negative bus. However, the negative wire of the control circuit, although of much smaller size than the main bus, must still run the length of the vehicle.

8-2.2 BATTERY-GENERATOR-LOAD CIRCUITS

The master switch circuits examined in par. 8-2.1 have one undesirable feature in common. In each of these circuits the batteries can be disconnected after the engine is running and, in that situation, the generator will sustain the electrical load. Although it is important in a tactical vehicle to retain this capability in case batteries are damaged in combat, it is equally important to avoid

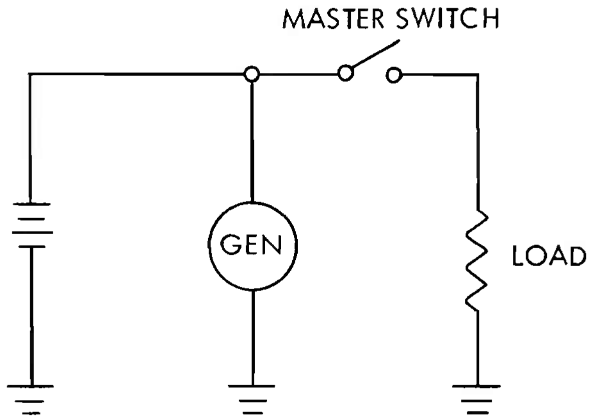


Figure 8-4. Master Switch Disconnecting Load

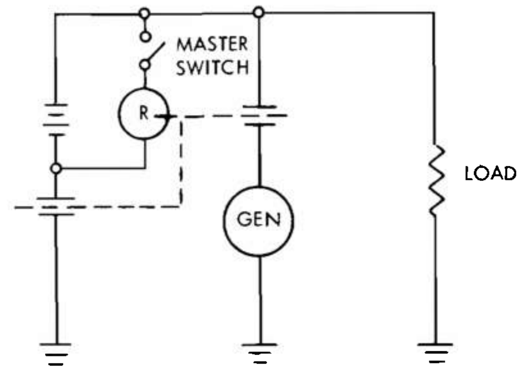


Figure 8-5. Master Relay Disconnecting Load

circuit designs that allow the vehicle to be operated inadvertently with the batteries disconnected from the generator. Otherwise, voltage surges reach unacceptable levels. For example, generator voltage regulators control the generator voltage by adjusting the generator field current. If the generator output voltage rises above a preset level, the regulator reduces the field current to produce a reduction in generator output voltage. Conversely, when the generator output voltage falls, the regulator increases field current in order to raise the generator output voltage. These field current adjustments require a finite period of time to occur and during this transitory period the system voltage is out of control. When substantial changes in load take place, severe voltage surges are produced unless the battery, which acts as a surge limiter, is connected in parallel with the generating system. The high level of unlimited voltage surges is sufficient to damage the electrical system components[2]. Therefore, the power distribution circuit design should preclude the possibility of inadvertently disconnecting the batteries from the generating system while the generator remains connected to the load[3]. Since the negative side of the typical generator is case grounded, the necessary circuit design usually takes form as shown in Figs. 8-4 or 8-5.

8-2.3 SLAVE RECEPTACLE CIRCUITS

Another important aspect of power distribution circuit design involves circuit placement of the slave starting receptacle. This polarized dual contact receptacle is wired in parallel with the vehicle batteries and is found on most military vehicles. As previously described, it allows the connection of two vehicle electrical systems in parallel so that a vehicle with good batteries may be used to start a vehicle with dead batteries. The receptacle may be located in the circuit on the battery side of the master switch (Fig. 8-6(A)) or on the load side (Fig. 8-6(B)). In the event the master switch is located between the batteries and slave receptacle as shown in Fig. 8-6(B), the dead vehicle batteries can be isolated from the starter load by opening the master switch during slave start operations. As a result, the demand from the auxiliary power source is lower than it would be if the dead batteries also were connected. This lower demand requirement can be an advantage since it allows the user more latitude when the need for an auxiliary power source for slave starting purposes arises.

8-2.4 REVERSE POLARITY PROTECTION

One of the most damaging military vehicle electrical system user abuse problems is associated with improper use of the slave start feature. Presumably this abuse occurs when a proper slave cable cannot be found and the operator resorts to an expedient method wherein he plugs individual wires into the slave receptacle and connects the other ends to a power source. This expedient circumvents the normal polarizing features of the slave cabling system and often results in the application of reverse polarity to the vehicle

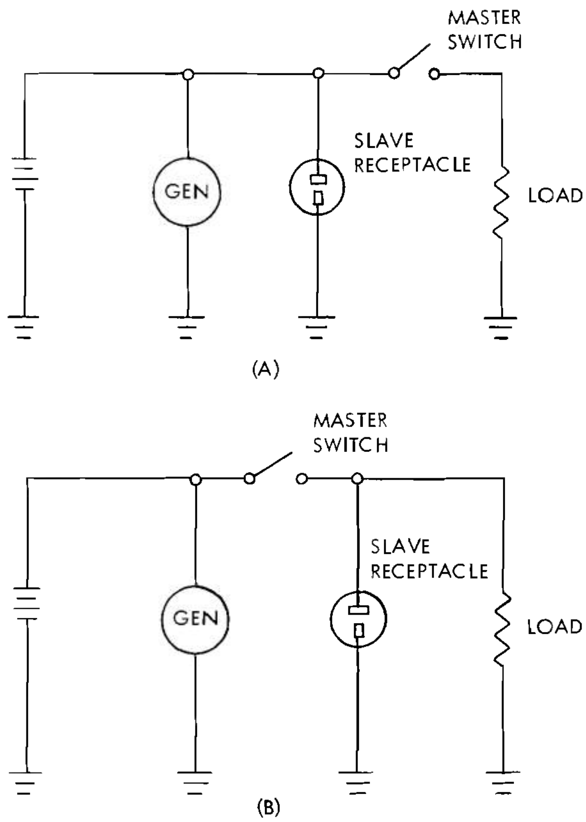


Figure 8-6. Slave Receptacle Locations

electrical system. As a result of reverse polarity, the diodes in a diode-rectified generator system are destroyed and the charging system becomes inoperable. This same maintenance error may occur when vehicle batteries are replaced. Therefore, it is desirable to provide reverse polarity protection in power distribution circuit design.

The power distribution circuit shown in Fig. 8-7 combines reverse polarity protection with many of the desirable features presented in par. 8-2.1. Master relay K1 is controlled by master switch S1.Master relay contacts K1-C and K1-D connect the generator output to the positive bus, whereas contacts K1-A and K1-B connect the negative side of slave receptacle J1 and battery B1 to ground. Diode CR1 in series with master relay coil K1 prevents operation of the master relay if polarity of thc battery or slave input is reversed.

Other desirable features of this circuit arrangement are:

1. The master switch is truly a master control over the electrical system since it will deactivate the entire electrical system when opened.

2. Failure of the generator or destruction of the batteries in a combat situation will not incapacitate the vehicle electrical system, assuming both power sources are not damaged simultaneously and the master relay remains energized.

3. The circuit design assures that during normal operation the batteries always will be

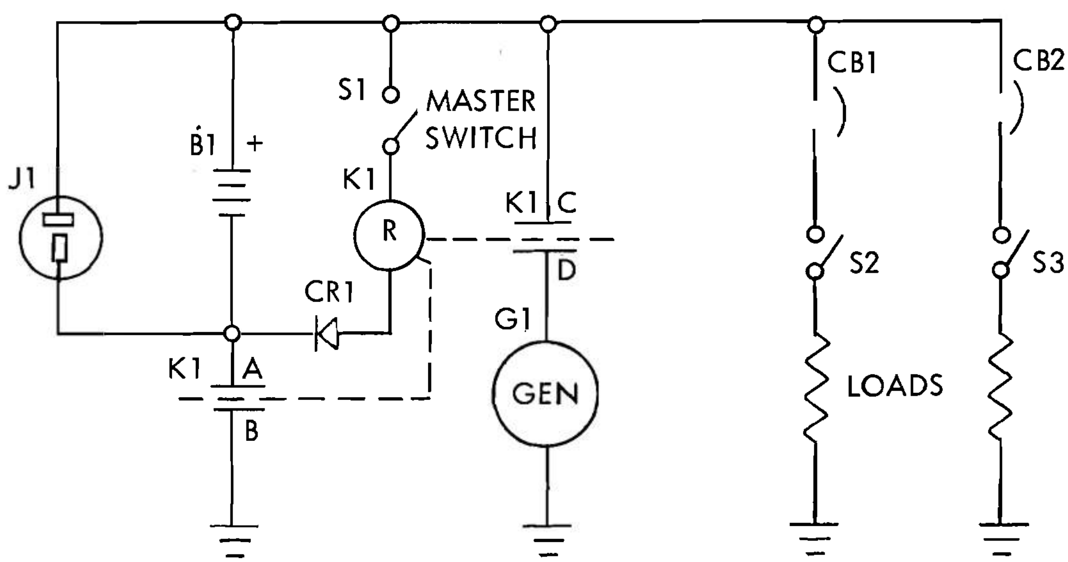


Figure 8-7. Power Distribution With Reverse Polarity Protection

in parallel with the generator to act as a surge limiter.

4. The extra safety for maintenance personnel afforded by removing the ground from the battery is achieved by merely opening the master switch.

This circuit arrangement is not perfect because it can be fooled. If the vehicle batteries are too weak to crank the engine, they may still have enough power to pull in the master relay. Then if the operator leaves the master switch on and slaves the vehicle with reverse polarity, the vehicle generating system could be damaged. On the other hand, it is a good compromise as power distribution circuits must be, and the one obvious weakness may be recognized and avoided by placing a sign near the slave receptacle stating: "Warning - Open master switch before applying auxiliary power".

8-3 ENVIRONMENT AND HUMAN FACTORS

The severity of the military environment must be taken into account during the design of an electrical power distribution system for a military vehicle. Standard interconnecting wire and cables described in this chapter have been designed to perform successfully in worldwide environmental extremes. Equipment enclosures should be designed in accordance with applicable requirements of MIL-STD-108[4]. The full scope of the military environment and its effects are described in pars. 4-7 and 4-8.

Human and safety factors relating to both personnel and equipment are particularly important in the design of power distribution wiring and enclosures. These aspects of the design problem are presented in pars. 4-20 and 4-21.

8-4 WIRE AND CABLE ROUTING

Main power distribution wiring should be kept as short as possible and routed separately from component feeder lines so that feeder line shorts cannot destroy main power circuits. This sort of protection against possible damage or abuse is one important feature to strive for when selecting a wiring route. Many other factors of significant importance are described in pars. 4-21.1 and 4-34.3.

8-5 CIRCUIT IDENTIFICATION

Wires in an electrical system should be identified by a number, color, or code to facilitate tracing circuits during assembly, troubleshooting, or rewiring operations. This identification should appear on wiring schematics and diagrams and whenever practical on the individual wire. The assigned identification for a continuous electrical connection should be retained on a schematic diagram until the circuit characteristic is altered by a switching point or active component[5]. Fig. 8-8 illustrates this practice. An extension of this system involves the use of suffix letters on wiring diagrams and wiring assemblies to identify the segments of wires between terminals, connector contacts, etc., as shown in Fig. 8-9. The use of suffix letters is advantageous in those instances where it is necessary to identify several individual wires of a common circuit that are bound in the same harness.

Tank-automotive electrical circuits have been identified over the years with unique numbers for specific circuits based on the premise that maintenance personnel would become familiar with wire numbers for these circuits and this familiarity would facilitate their ability to service a variety of vehicles. These standard wire numbers are listed on

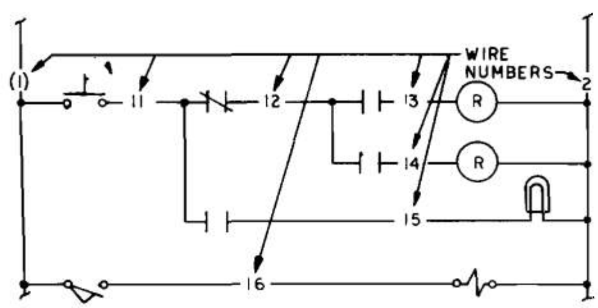


Figure 8-8. Wire Identifications

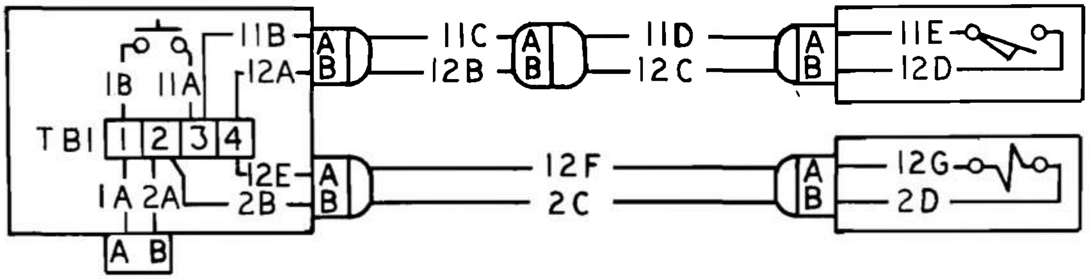


Figure 8-9. Segmented Wire Identification

Drawing 19207-7070301. Furthermore, common standard automotive electrical components in the supply system such as headlight, taillight, and stoplight switch assemblies are marked with these standard wire numbers. Therefore, these numbers should be used to the maximum extent practical for the identification of circuits in future military vehicle electrical systems.

MIL-STD-646 describes another method of identifying wires connecting vehicle electrical components based on the use of wire end markings which identify the component and the terminal to which the wire end is connected. However, the method, which was developed originally for tactical vehicles only, is not widely used because it requires that each wire be marked with a different identification at each of its ends. This practice complicates rather than improves system producibility and maintainability in complex (high density) interconnecting wiring systems for combat vehicles. Furthermore, the system is not compatible with the wire numbers marked on many standard ordnance components in the inventory or with the presentation of the electrical system in schematic diagram form.

Complex wiring systems developed in recent years have employed reference designations for electrical and electronic parts as prescribed in ANSI Y32.16[28] with application guidelines formulated by the respective Vehicle Engineering Agencies. Designers of systems now in development are considering the use of wire coding methods as specified in MIL-W-5088[29].

MIL-STD-681 describes an acceptable identification coding system intended only for identifying hookup wire within the confines of electrical or electronic equipment enclosures.

In conjunction with all of these identification systems, there are several practical methods used to apply wire identification characters on wiring assemblies. Four of the commonly employed methods are:

1. Lettering may be hot stamped per MIL-M-81531, with 0.050 in. minimum height type, directly on the wire or cable insulation using white letters on dark backgrounds or black letters on light backgrounds.

2. Lettering may be hot stamped per MIL-M-81531, with 0.050 in. minimum height type, on MIL-I-23053/2 heat shrinkable sleeving, length and diameter as required, assembled over the wire insulation.

3. Lettering may be indented or embossed with 0.093 in. minimum height type on band, marker blank, MS39020, style and length as required, in accordance with MIL-STD-130.

4. Lettering may be indented with 0.093 in. minimum height type on band, marker, Drawing 19207-10875481, in accordance with MIL-STD-130.

Of these, the metal marker bands with indented or embossed characters, Items 3 and 4, are the most durable and they remain legible even if painted over.

SECTION II CONDUCTORS

8-6 INTRODUCTION

Metal conductors are the arteries that transmit electrical power in military vehicle electrical systems. Accordingly, the design factors regarding conductor sizing, insulating, and shielding requirements are presented in this section as guidance material. Brief descriptions of the hookup and interconnecting wire cable commonly used in military vehicles also are included.

The basic factors to consider when selecting a conductor for the distribution of electricity in a military vehicle are:

1. Electricity must be delivered to the consumer without an excessive voltage drop or signal loss.

2. The power losses must not heat the conductor to a temperature that would damage the insulation, cause a fire, or present a personnel hazard.

3. The conductor must have sufficient mechanical strength, insulation dielectric quality, and flexibility to withstand the military environment.

A conductor may satisfy one of these conditions and not the others; therefore, all three must be evaluated in the design process.

8-7 SIZING CONDUCTORS

Since conductors must be sized appropriately in order to carry the required current with a minimum voltage drop, the following formula for sizing copper conductors as a function or voltage drop is presented[6]:

$$C_m = \frac{K \times I \times L \ (\times 2 \text{ for two-wire circuit}),}{E}$$

circular mil (8-1)

where

C_m = circular area of conductor (one circular mil is the area of a circle 0.001 in. in dia), circular mil

K = 10.75 (multiplied by a constant for the mil-foot-resistance of copper)

I = load current, A

L = conductor length, ft

E = acceptable conductor voltage drop, V

Assume that a bilge pump feeder circuit carrying 20 A is 2 ft long with ground return through the vehicle hull and that the maximum allowable voltage drop is 3% with a system voltage of 28 V. The conductor size is calculated using Eq. 8-1 as follows:

$$C_m = \frac{(10.75)\,(20)\,(12)}{(0.03)\,(28)}$$

$$C_m = 3{,}057 \text{ circular mils}$$

Referring to Table 8-6, it is seen that #14 AWG stranded wire has a slightly larger circular mil area than that required by calculation; therefore, it is the obvious choice for this application.

When Eq. 8-1 is used to calculate bus bar requirements, it is convenient to use Table 8-1 for solid wire selection or convert the resulting circular mil area to square mils or square inches to facilitate the selection of appropriate bar stock. These conversions are easily made as follows:

$$\text{square mils} = \text{circular mils} \times 0.7854 \qquad (8\text{-}2)$$

$$\text{square inches} = \text{circular mils} \times 7854 \times 10^{-10} \qquad (8\text{-}3)$$

8-8 INSULATED CONDUCTORS

Insulated conductors are assigned voltage ratings and operating temperature ranges

TABLE 8-1. AMERICAN WIRE GAGE FOR SOLID ANNEALED COPPER WIRE[8]

AWG	Diameter, in.	Area, circ. mil	lb per 1000 ft	DC Ohms per 1000 ft at 77°F 100% Conductivity
4/0	0.460	212,000	641	0.04998
3/0	0.410	168,000	508	0.06303
2/0	0.365	133,000	403	0.07947
1/0	0.325	106,000	319	0.1002
1	0.289	83,700	253	0.1264
2	0.258	66,400	201	0.1594
3	0.229	52,600	159	0.2009
4	0.204	41,700	126	0.2534
5	0.182	33,100	100	0.3195
6	0.162	26,300	79.5	0.4029
7	0.144	20,800	63.0	0.5080
8	0.128	16,500	50.0	0.6406
9	0.114	13,100	39.6	0.8078
10	0.102	10,400	31.4	1.019
11	0.091	8,230	24.9	1.284
12	0.081	6,530	19.8	1.620
13	0.072	5,180	15.7	2.042
14	0.064	4,110	12.4	2.576
15	0.057	3,260	9.86	3.248
16	0.051	2,580	7.82	4.095
17	0.045	2,050	6.20	5.164
18	0.040	1,620	4.92	6.512
19	0.036	1,290	3.90	8.210
20	0.032	1,020	3.09	10.35
21	0.0285	810	2.45	13.06
22	0.0253	642	1.94	16.46
23	0.0226	509	1.54	20.76
24	0.0201	404	1.22	26.18
25	0.0179	320	0.970	33.01
26	0.0159	254	0.769	41.62
27	0.0142	202	0.610	52.48
28	0.0126	160	0.484	66.18
29	0.0113	127	0.384	83.46
30	0.0100	101	0.304	105.2
31	0.0089	79.7	0.241	132.7
32	0.0080	63.2	0.191	167.3
33	0.0071	50.1	0.152	211.0
34	0.0063	39.8	0.120	266.1
35	0.0056	31.5	0.0954	335.5
36	0.0050	25.0	0.0757	423.0
37	0.0045	19.8	0.0600	533.5
38	0.0040	15.7	0.0476	672.7
39	0.0035	12.5	0.0377	848.2
40	0.0031	9.9	0.0299	1,070

based on the characteristics of the insulation material. When applying a conductor in an electrical system, the insulation voltage rating must be high enough to withstand the momentary transient voltages expected in the system (par. 7-1) without experiencing dielectric breakdown. In addition, the insulation must be capable of withstanding the physical and climatic environment that the system will experience. These are the first two factors of importance in the selection process.

Insulation temperature ratings also are directly related to the operating stresses imposed on individual conductors. For example, electrical energy is partially converted to heat energy when an electric current flows through a conductor. The amount of power P converted in this process is

$$P = I^2 R, \text{ W} \tag{8-4}$$

where

I = current, A

R = conductor resistance, ohm

This heat energy raises the temperature of the conductor and insulation above that of the ambient temperature of the environment. It follows that the maximum allowable temperature of the conductor is limited by the heat resisting characteristic of the insulation. The actual operating temperature of the wire, which is ambient temperature plus the temperature rise due to current flow, should not exceed the temperature rating of the insulation.

One useful "rule of thumb" allows that insulation life is halved for every 18 deg F temperature rise and doubled for every 18 deg F temperature reduction beyond the rated operating temperature. Therefore, derated operation prolongs insulation life significantly.

Derating must be applied where conductors are bundled into compact harnesses. Hot spots close to the wires also must be considered and avoided or isolated with protective insulation[13].

Table 8-2 may be used as a guide for selecting appropriate hookup wire by comparing the current carrying capacity of variously insulated single conductors in free air at

TABLE 8-2. CURRENT-CARRYING CAPACITY OF SINGLE-CONDUCTOR HOOKUP WIRE[13]

Wire size AWG #	Temperature rating of insulation		
	140°F	176°F	392°F
	Ambient temperature		
	77°F	77°F	77°F
	Current-carrying capacity		
	A	A	A
12	16	26	72.5
14	10	16	54.0
16	6	10	40.5
18	4	6	35.0
20	2.5	4.0	26.0
22	1.6	2.5	18.5
24	1.0	1.6	14.0
26	0.6	1.0	10.5
28	0.4	0.6	7.9
30	0.2	0.4	6.0

room temperature. Table 8-3 presents current ratings for single, isolated cable (single-conductor similar to MIL-C-13486) in still air. The ratings given in this table are based on calculations involving 60-Hz alternating current and ambient air temperature, of 104°F, round standard strand conductors; all dielectric and induced AC losses, insulation and jacket thickness, and a load factor between 30% and 100%. The load factor is the percentage of time that the cable is operated at the maximum current ratings given in Tables 8-2 and 8-3. Correction factors for loaded cables in close proximity in air, exposed or enclosed, are given in Table 8-4 and those for ambient temperature in Table 8-5. In addition to the temperature rise, the current that is passed through a given length of conductor is limited also by the permissible voltage drop that may be produced in the conductor (par. 8-7)[13].

It may be seen in Table 8-3 that the #14 AWG conductor selected for the bilge pump feed circuit on the basis of a 3 percent voltage drop (par. 8-7) will stabilize at a 140°F conductor temperature when carrying 20 A in ambient temperature of 104°F. These factors can be evaluated with respect to the maximum temperature ratings of the insulation on the wire to be used. Assuming that this insulation has a maximum allowable continuous operating temperature of 158°F, that the ambient temperatures in any body of water that the vehicle might negotiate will hold ambient air temperatures to 104°F or lower, and that the cable in question is routed

TABLE 8-3. CURRENT-CARRYING CAPACITY OF RUBBER-INSULATED, SINGLE-CONDUCTOR CABLE IN AIR AT 104°F[13]

Size AWG or MCM* #	140°F copper temp		167°F copper temp		185°F copper temp
	0-5000 V	5001-8000 V	0-5000 V	5001-8000 V	0-8000 V
	Current per conductor				
	A	A	A	A	A
16	8	–	10	–	–
14	20	–	26	–	–
12	26	–	33	–	–
10	35	–	44	–	–
8	47	54	61	70	78
6	64	72	83	93	104
4	86	94	110	121	135
2	117	126	150	163	182
1	135	145	172	187	208
0	158	166	202	214	239
00	183	190	235	245	273
000	212	220	273	284	317
0000	245	255	315	329	367
250*	275	280	352	362	403
300*	306	312	393	403	449
350*	346	345	443	445	496
400*	375	377	481	486	542
450*	399	402	516	519	579
500*	425	430	546	554	618

* MCM is the conductor size designation in 1000 circular mils.

TABLE 8-4. CORRECTION FACTORS FOR VARIOUS AMBIENT TEMPERATURES[13]

Air ambient temperature, °F	Temperature of copper conductor		
	140°F	167°F	185°F
	Correction factors		
50	1.58	1.36	1.29
68	1.41	1.25	1.21
86	1.22	1.13	1.12
104	1.00	1.00	1.00
122	0.71	0.85	0.88

TABLE 8-5. CORRECTION FACTORS FOR CABLES IN CLOSE PROXIMITY IN AIR*[13]

Number of cables vertically	Number of cables horizontally					
	1	2	3	4	5	6
1	1.00	0.93	0.87	0.84	0.83	0.82
2	0.89	0.83	0.79	0.76	0.75	0.74
3	0.80	0.76	0.72	0.70	0.69	0.68
4	0.77	0.72	0.68	0.67	0.66	0.65
5	0.75	0.70	0.66	0.65	0.64	0.63
6	0.74	0.69	0.64	0.63	0.62	0.61

*These correction factors apply only when the spacing between cable surfaces is not greater than cable diameter or not less than one-quarter cable diameter.

by itself, the choice of #14 AWG wire is justifiable. Electrically adequate power distribution wiring assemblies may be designed with a minimum number of calculations using these techniques for conductor selection.

The mechanical strength and flexibility of conductors used in military vehicles are also important selection considerations. One form of electrical connector in common use is a friction retainment device that must be pulled apart to effect a disconnect. The wire is usually the handle in these operations. Wire pigtails on component assemblies are also convenient handles. For these reasons, it is standard practice to avoid the use of a wire smaller than #16 AWG in such applications.

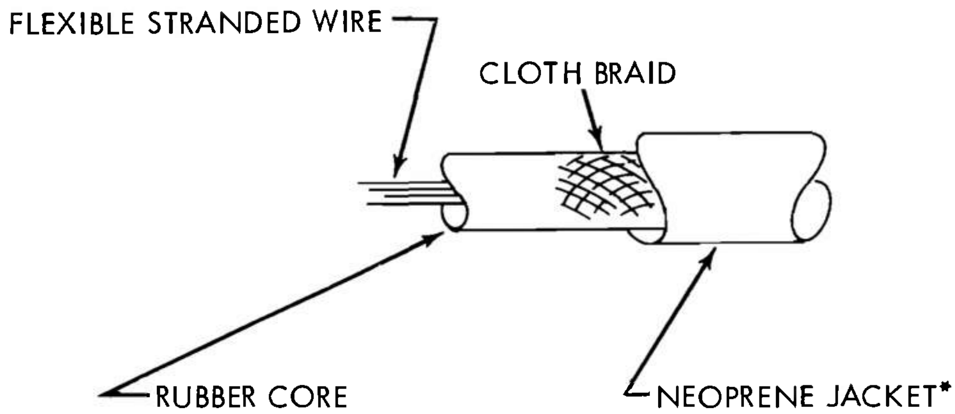
Multiconductor interconnecting cables or hookup wire for use in junction boxes and electronic assemblies in military vehicles should not be specified in conductor sizes smaller than #20 AWG except in special circumstances. Smaller wire sizes are very fragile and prone to failure when subjected to shock and vibration or handling in the military environment.

All interconnection cable and hookup wire recommended for vehicle applications is designed with stranded conductors fabricated from a large number of fine wire strands. This construction serves to increase flexibility and flex life. Typical wires and cable recommended for use in military vehicles are described in the paragraphs that follow. The interested reader is referred to Chapter 3 of AMCP 706-125[7] for a more detailed discussion of hookup and interconnection wire design factors.

8-8.1 INTERCONNECTING WIRE AND CABLE

The external connections between various units of vehicle electrical equipment are accomplished with rugged flexible interconnecting wire harnesses or cables using multipin connections to facilitate quick connection or disconnection of the individual units. Ruggedness is necessary because interconnection wiring is subject to severe physical abuse. Most wire and cable used to interconnect electrical components installed in military vehicles have been selected from MIL-C-13486, *Cable, Special-Purpose, Electrical, Low-Tension, Heavy-Duty, Single-Conductor and Multiconductor*[9], which is standardized for use in tank-automotive applications and is compatible with watertight connectors used extensively in vehicle electrical systems. The specification covers shielded, unshielded, single, and multiconductor heavy-duty, insulated electrical cable for use in low tension circuits that may be subjected to severe environmental conditions. High density cable assemblies found in turret applications use cable with thin wall insulation per MIL-W-81044 or equivalent.

The single-conductor cable is constructed as illustrated in Fig. 8-10 and is subjected to severe qualification tests. For example, in order to qualify, the cable must withstand a 180 deg bend around a mandrel not more than 10 times the cable diameter while at a temperature of −65°F. In addition, the cable must withstand 120 hr in an oven at 250°F while draped over a mandrel not more than 5 times the cable diameter with a weight attached to each end of the sample. Dielectric tests are also severe since they require that cables of various sizes withstand alternating current stresses ranging from 5,000 to 10,000 V at 60 Hz for 1 min. Other important tests that the cable must pass include oil absorp-



DESIGN FEATURES
1. GOOD FLAME RETARD PROPERTIES
2. EXCELLENT FLEXIBILITY
3. EXCELLENT WEATHERABILITY
4. -65° TO +250° F TEMPERATURE RANGE

*OPTIONAL CONSTRUCTION EMPLOYING SOLID CHLOROSULFONATED POLYETHYLENE INSULATION IS ALSO APPROVED.

Figure 8-10. Single Conductor, Unshielded Wire Cable Construction Per MIL-C-13486

tion, liquid immersion, flammability, fungus resistance, and ozone resistance[9]. Additional single conductor cable construction details are given in Table 8-6. Cables designated as preferred are in common use and are compatible with standard ordnance connectors. Furthermore, the different AWG sizes are easily differentiated in actual service since each conductor size has a unique outside diameter. Maximum continuous operating temperatures for this cable should be limited to 158°F to prolong insulation life.

The neoprene outer jacket on single and multiconductor cable per MIL-C-13486 is relatively impervious to the normal military environment but the insulation on individual conductors within the multiconductor cable jacket has not been designed to survive when exposed to such environments. This characteristic is typical of most available multiconductor cable types. Therefore, multiconductor cable should be used in applications where the outer jacket is continuous between connector or junction-box packing glands, so that stripping of the outer jacket occurs only within watertight connector housings or protected junction boxes.

MIL-C-3432 describes light-duty, medium-duty, and heavy-duty, semiflexible, flexible, and extra-flexible, single-conductor wires and multiconductor cables, shielded and unshielded, for use in circuits of 300 and 600 V root mean square (rms). MIL-C-3432 also covers heavy-duty, multiconductor, unshielded cables containing ground wires. The latter cables are limited to two, three, and four conductors, all of the conductors being of the same size, ranging from #500 MCM to #8 AWG, inclusive.

The cables covered by MIL-C-3432 are intended for use by the Armed Services in electrical and electronic applications. The cables may be used to transmit power, synch pulses, data transmission voltages, video-, audio-, or control-power. A tough and flexible

TABLE 8-6. STRANDED CONDUCTORS, UNSHIELDED WIRE CABLE PER MIL-C-13486[9]

Conductor size	Minimum area, circular, mils	Number of strands, minimum	Maximum diameter of stranded conductor, mil	Part No.	Cable Outside Diameter, in.	Former Part No.
20	985	10	41.0	M13486/1-1	.115 ± .010	None
18	1,575	16	52.0	M13486/1-2	.130 ± .010	None
16	2,360	19	61.0	*M13486/1-3	.135 ± .010	7722204
16	2,360	19	61.0	M13486/1-4	.160 ± .010	8690176
14	3,753	19	76.0	*M13486/1-5	.160 ± .010	7720853
14	3,753	19	76.0	M13486/1-6	.235 ± .010	7056679
12	5,966	19	96.0	*M13486/1-7	.235 ± .010	7056678
10	10,338	105	132.0	M13486/1-8	.300 ± .010	None
8	16,180	133	176.0	*M13486/1-9	.360 ± .010	7056677
6	25,725	133	218.0	*M13486/1-10	.422 ± .010	7056676
4	40,905	133	272.0	*M13486/1-11	.485 ± .010	8690175
2	65,495	663	345.0	*M13486/1-12	.610 ± .010	7056675
1	80,170	812	384.0	None	–	–
0	101,235	1,033	432.0	*M13486/1-14	.672 ± .010	7056674
00	130,990	1,327	490.0	M13486/1-15	.730 ± .010	None
000	163,985	1,661	548.0	None	–	–
0000	207,715	2,104	615.0	M13486/1-17	.865 ± .020	7056674-1

*Preferred cables

jacket is provided because cables frequently will be subjected to extreme mechanical abuse and extreme humidity and temperature conditions. Many existing vehicles employ this cable to interconnect radios, control boxes, antennas, and components in tank turrets. The shielded cable types are suitable for radio-frequency use in limited applications.

Light-duty cables are intended for use in test equipment in short lengths, or for interconnection of major components. They are intended to withstand severe flexing and frequent manipulation. Light-duty cables should not be used where they will be stepped on, run over by vehicles, beaten, or subjected to severe impacts. Light-duty cables are suitable for lightweight portable tools or small motor and generator leads where flexibility rather than long life is essential.

Medium-duty cables are intended to withstand the same usage as heavy-duty cables with the exception that they should not be used where they will be run over by vehicles or be subjected to severe impacts. They are intended to be a substitute for all uses of heavy-duty cables when the reduction in weight would be advantageous to the equipment in which they are used. Medium-duty cables are suitable for small portable tools, sound equipment, radio receivers, and motor leads which do not require the heavier, sturdier, heavy-duty cables.

Heavy-duty cables are intended for use where they will be subjected to extreme service impacts or will be run over by heavy vehicles—such as trucks or tanks. They are designed to withstand severe flexing and mechanical abuse over long periods of time without deterioration. Heavy-duty cables are suitable for portable tools, extension lamps, charging cables, and control cables[10].

MIL-C-915[11] describes several forms of rugged cable intended for shipboard use. Some of the single and multiconductor cables available to this specification are suitable for military vehicle applications. Types TRF, SHOF, DHOF, THOF, FHOF, and MHOF have been applied with success.

Aircraft interconnection wire has seen limited use in military vehicles. Such wire is described by MIL-W-5086. This specification covers three constructions of general purpose airframe wire rated for 600 V service throughout a temperature range of –67° to 221°F. This specification at one time accounted for 80% of all wire used on aircraft. It is still used on the majority of aircraft, but higher temperature, and lighter weight material requirements are gradually replacing it. All three constructions of this specification contain nylon jackets for increased mechanical toughness and resistance to fuels, solvents, and hydraulic fluids such as Skydrol 500[12]. The wire is compatible with wire sealing grommets in Military Standard connectors of the MS series with MIL-C-5015 inserts. However, it is not compatible with the wire sealing features of ordnance type vehicle wiring connectors[12], which were developed to include large grommet holes to seal around MIL-C-13486 cable.

As improvements in quality and reductions in cost of wire cable insulating materials occur, superior low-cost cable for interconnection applications may become available. However, new cable types, with insulation diameters that are not compatible with the connectors now in use, will be difficult to introduce in military vehicles unless the economic factors associated with the resulting redesign of connectors and components are outweighed by the benefits promised by the new cable.

8-8.2 HOOKUP WIRE

Hookup wires are used to make the internal connections between the various electrical parts of electronic assemblies. Some ruggedness is sacrificed in hookup-wire constructions to secure minimum physical size, lightness in weight, and a fair degree of flexibility. Such wires usually are laced into multiconductor, compact wire harnesses and securely supported by clamps to prevent movement under conditions of shock and vibration[13]. Typical properties are shown in Table 8-7.

Quite often hookup wire is thought of only as a means of conveying electrical energy from one point to another. As a direct result many design engineers are guilty of not giving hookup wire adequate design consideration. The purpose of the paragraphs that follow is to acquaint the designer with the type of hookup wire that is available and to describe the intended applications[12].

8-8.2.1 MIL-W-16878 WIRE

MIL-W-16878 is the most universally accepted specification for general purpose hookup wire for the electrical and electronic industry. This specification covers the construction details and performance requirements for hookup wire insulations of polyethylene, PVC, silicone, TFE Teflon, and FEP Teflon[12].

MIL-W-16878 contains three PVC wire constructions; Types B, C, and D which are rated for 600, 1000, and 3000 V, respectively. These wires are rated for 221°F continuous operating temperature[12].

MIL-W-16878 includes provisions for further outer coverings of nylon for the PVC and polyethylene insulated hookup wires. The nylon jacket greatly improves cut-through and abrasion resistance and adds resistance to a variety of solvents, fuels, and hydraulic fluids[12].

MIL-W-16878 also includes three configurations of TFE-fluorocarbon insulated wire; Type ET-ultra thin wall, Type E-thin wall; and Type EE-medium wall, with voltage ratings of 300, 600, and 1000 V, respectively. Silver- and nickel-plated copper or high strength copper alloys are used with TFE-fluorocarbon resin. TFE insulation with silver-plated conductor is rated for continuous high temperature operation at 392°F. Through the use of nickel-plated conductors the high temperature range is extended to 500°F continuous service[12].

TABLE 8-7. PROPERTIES OF STRANDED COPPER HOOKUP WIRE[13]

Size, AWG# aprox	Uninsulated conductor Number of strands	Strand diameter, nominal, in.	Strand area, circular mil	Conductor diameter, in. average	Finished wire DC resistance*, ohm/1000 ft
32	7	0.0031	67	0.010	183.0
30	7	0.0040	112	0.013	109.9
28	7	0.0050	175	0.016	70.4
26	1	0.0159	253	–	46.3
26	7	0.0063	278	0.020	44.3
24	1	0.0201	404	–	28.3
24	7	0.0080	448	0.025	27.5
24	19	0.0050	475	0.026	25.7
22	1	0.0253	640	–	17.9
22	7	0.0100	700	0.031	17.6
22	19	0.0063	754	0.032	16.3
20	1	0.0320	1024	–	11.2
20	7	0.0126	1111	0.038	10.9
20	10	0.0100	1000	0.038	12.3
20	19	0.0080	1216	0.041	10.1
18	1	0.0403	1624	–	7.05
18	7	0.0159	1770	0.048	6.89
18	16	0.0100	1600	0.048	7.69
18	19	0.0100	1900	0.051	6.48
16	1	0.0508	2581	–	4.43
16	19	0.0113	2426	0.058	5.02
16	26	0.0100	2600	0.061	4.73
14	1	0.0641	4109	–	2.79
14	19	0.0142	3831	0.072	3.18
14	41	0.0100	4100	0.076	3.00
12	1	0.0808	6529	–	1.76
12	19	0.0179	6088	0.090	2.00
12	65	0.0100	6500	0.096	1.89
10	104	0.0100	10380	0.121	1.16

*Maximum at 68°F.

Note: Values listed in this table have been adjusted to reflect the change in cross-sectional area of the conductors during stranding and insulating.

TFE Teflon insulated hookup wires in addition to their high operating temperature do not flow under contact with hot soldering irons, remain flexible at cryogenic temperatures, are chemically inert, and will not support combustion[12].

Although MIL-W-16878 is primarily a single conductor hookup wire specification, provisions are included for shielded and jacketed constructions. Tin, silver, and nickel-plated copper shields with 90% coverage, lay lengths of twisted components, jacket materials, and wall thickness are specified. It is well to keep in mind that the specification was not intended as a multiconductor cable specification. MIL-C-7078 and MIL-C-27500, which do not include single conductor constructions, cover the secondary cabling, shielding, and jacketing operations in far greater detail[12].

8-8.2.2 MIL-W-76 WIRE

Insulated hookup wire manufactured in accordance with MIL-W-76 also is used quite extensively. This specification includes PVC and polyethylene insulated wire constructions with or without glass braided jackets for improved flame resistance[12].

MIL-W-76 covers three (3) PVC wire constructions; Types LW, MW, and HW, which are rated for 300, 1000, and 2500 V, respectively. These wires can be rated for 176°F if used without nylon or 194°F with nylon[12].

PVC is the most commonly used of all hookup wire insulation materials, primarily due to its low cost and ease of processing. The major drawback of PVC insulated wire is its limited temperature range. It tends to become stiff and brittle at low temperatures, and soften at elevated temperature[12].

Polyethylene hookup wire, with or without nylon jacket, has been used quite extensively in missile ground support cables[12].

Thermoplastic insulations will cold flow when subjected to mechanical pressure. Insulation of this type tends to soften at the upper temperature limit for which it was designed, thus accelerating the cold flow process. If the mechanical pressure is excessive, the cold flow will continue to such an extent as to bare the conductor. Therefore, do not lace wire harnesses too tightly, and do not use wire clamps that exert excessive mechanical pressure to fasten down harnesses. Nylon jackets extruded over polyvinyl insulation restrict the cold flow of the insulation and offer some protection to the insulation from mechanical pressure due to lacing cords and wire clamps[13].

8-8.3 SHIELDED WIRE AND CABLE

A shielded-conductor cable or wire is an insulated conductor or conductors enclosed in a conducting envelope or envelopes constructed so that substantially every point on the surface of the insulation is at ground potential or at some predetermined potential with respect to ground.

Shields are most commonly constructed of soft annealed copper, or steel wires, coated or bare, as required, woven into a braid to give the coverage specified. Coverage is generally expressed as a percentage, calculated as

$$K = 100\,(2f - 1f^2) \tag{8-5}$$

where

K = coverage, %

f = $NPd/\sin a$

N = number of wires per carrier

P = picks per inch of wire or cable length

d = diameter of individual shielding wires, in.

a = angle of braid with axis of insulated wire or cable, deg; thus $\tan a = 2\pi(D + 2d)P/C$

D = diameter of cable under shield, in.

C = number of carriers

Normal coverage for a single braid is 85%. The electrical properties are improved very little by higher percentage. Where the design requires extra shielding, double braids may be used, one applied directly over the other. The diameter of the individual shield wires is generally 0.005 in. (#36 AWG) or 0.0063 in. (#34 AWG).

The principal reasons for shielding insulated wires and cables are to protect wires and cables from induced potentials; to obtain symmetrical radial stress distribution within the insulation to control tangential and longitudinal stresses or discharges on the surfaces of the insulation; and to provide increased safety to human life. Electromagnetic interference reduction with shielding is described in Chapter 18.

As shown in Fig. 8-11, the point at which two carriers cross is called the pick. The number of these per inch in a line parallel to the axis of the conductor is referred to as picks per inch.

In Fig. 8-11 the carrier is the group of parallel wires that are woven to form the shield. In the weaving process, half the carriers progress in one direction around the cable and half in the opposite direction.

Ends are the number of parallel wires in each carrier. Four ends per carrier are shown in Fig. 8-11.

The factors *d, N, C,* and *P* can be varied to give the desired percent coverage for the insulated wire or cable to be shielded. The numbers of carriers *C* is generally 12, 16, 20, or 24, and the picks *P* per inch are generally between 10 and 40. The number of wires per carrier *N* is generally between 2 and 6, inclusive.

When copper braid shields are used on wires, it is often necessary to provide an insulated jacket over the shield to prevent it from contacting live electrical circuits.

Shielded cable meeting the requirements of the previously described interconnection and hookup wire specifications is readily available with or without an outer insulating jacket.

8-8.4 COAXIAL CABLE[12,14]

The purpose of a coaxial cable is to transmit radio frequency energy from one point to another with the least possible power loss. Usually the radio frequency energy transmitted is in the range from 0.5 to 10,000 MHz. When used at frequencies lower than 0.5 MHz, coaxial cable is simply designated as shielded wire. A more accurate distinction between shielded wires and coaxial cable is that a coaxial cable is an RF transmission line for propagation of electromagnetic energy, whereas, with shielded wire, the outer conductor serves only as a screening ground plane to minimize electrical interference or hazards.

Coaxial cable designs employ a center or inner conductor, insulated with solid dielectrics of Teflon TFE, Teflon FEP, polyethylene, irradiated polyethylene, and foamed dielectrics of polyethylene and irradiated polyethylene. Over the dielectric core a braided metallic shield or outer conductor is applied. This outer conductor confines the signal within the cable, reduces extraneous interference to tolerable levels, as well as functioning as a return conductor and strength member. The braided metallic shield construction provides the highest degree of RFI shield effectivity and cable flexibility. A jacket is applied over the shield to isolate the shield from adjacent metal surfaces and to repel moisture and other contamination. Typical jacket materials are Teflon TFE, Teflon FEP, polyvinychloride, and polyethylene[12].

The four most important considerations in the proper selection of a coaxial cable are impedance, attenuation, capacitance, and temperature rating. These characteristics are interrelated and are determined by material selection and the mechanical design of the cable. These characteristics, as well as others, are described in the paragraphs that follow[12].

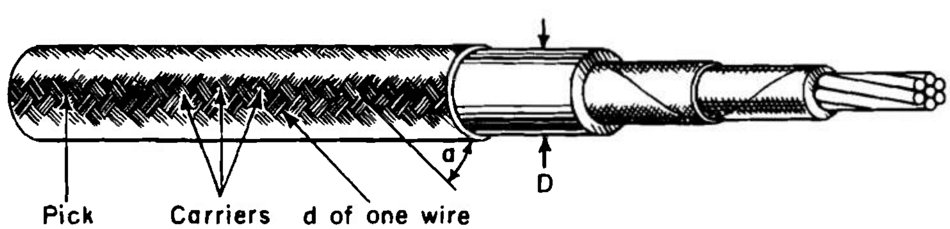


Figure 8-11. Shielded Cable Terminology

Impedance of a coaxial cable is expressed in ohms and usually is determined through known values of capacitance and velocity of propagation. Velocity of propagation is the transmission velocity of an electrical signal down a length of cable compared to velocity of light, and is expressed as a percentage of velocity of light[12].

By definition:

$$v = \frac{100}{\sqrt{K}}, \% \qquad (8\text{-}6)$$

where

v = velocity of propagation, %

K = dielectric constant, a dimensionless ratio $\frac{\epsilon}{\epsilon_O}$ where ϵ is the permittivity in farads/meter of the dielectric material between the center and outer conductors of the coaxial cable, and ϵ_o is the permittivity in farads/meter of a vacuum (8.85×10^{-12} F/m)

Capacitance is the ratio of the electrostatic charge on a conductor to the potential difference between the conductors required to maintain that charge. Capacitance c is expressed in picofarads per foot[12].

By definition:

$$c = \frac{7.36K}{\log_{10}\left(\frac{D}{d}\right)}, \quad \text{pF} \qquad (8\text{-}7)$$

where

c = capacitance, pF/ft

K = dielectric constant, dimensionless

D = dielectric diameter

d = conductor diameter

with D and d expressed in identical units.

The three common characteristic impedance values, designated Z_o, of most readily available coaxial cables are 50, 75, and 95 ohms. The characteristic impedance is determined by

$$Z_o = \frac{101600}{vc} = \frac{138}{\sqrt{K}} \log_{10} \frac{D}{d}, \quad \text{ohm} \qquad (8\text{-}8)$$

In application of coaxial cables, and of radio frequency transmission lines in general, it is important that the impedance of the cable be matched to the impedance of both the source and the load. An impedance mismatch causes a reflection of a portion of the signal back toward the signal source. The magnitude of this reflected wave is expressed as a Standing Wave Ratio (SWR). The effect of this impedance mismatch and wave reflection is increased losses and heating in the transmission line and a lower effective signal magnitude received by the load; i.e., system efficiency will be decreased and, in the extreme case, the system will be nonfunctional.

Attenuation is the power loss in an electrical system. Loss of electrical power in coaxial cables can be attributed to two causes[12]:

a. Conductor resistance that results in power loss due to heating by the RF currents passing through the conductor.

b. Dielectric loss caused by poor dielectric materials. It, therefore, is desirable to use dielectric materials having low power factors in order to minimize dielectric losses.

The total loss is expressed in decibels per unit length of cable (dB/100 ft). The decibel is a unit used to express the ratio between two amounts of power P_i existing at two points. By definition[12]:

$$\text{dB} = 10 \log_{10}\left(\frac{P_1}{P_2}\right) \qquad (8\text{-}9)$$

or if expressed as voltage V and current I ratios:

$$\text{dB} = 20 \log_{10}\left(\frac{V_1}{V_2}\right) = 20 \log_{10}\left(\frac{I_1}{I_2}\right) \qquad (8\text{-}10)$$

Temperature rating of a coaxial cable will depend on the dielectric and jacketing material used. A coaxial cable will fall within one of the following four groups[12].

1. −67° to +176°F polyethylene with PVC jacket

2. −67° to +239°F irradiated polyethylene with irradiated PVC jacket

3. −85° to +257°F irradiated polyethylene dielectric and jacket

4. −85° to +392°F Teflon dielectric and jacket.

SECTION III TERMINALS AND CONNECTORS

8-9 INTRODUCTION

Section III presents the designer with information necessary to choose the proper terminals and connectors for military vehicle applications. The unique factors affecting compatibility and durability of the various wire terminating devices are described, and the standard hardware used in the present system is identified. Significant savings in time, cost, testing, and documentation can be achieved through the use of these proven methods and components.

8-10 TERMINALS

Wire lug terminals are divided into two major classes: the solder type; and the solderless type, which are also called the pressure or crimp type. The solder type has a cup in which the wire is permanently held by solder, whereas the solderless type is connected to the wire by special tools that deform the barrel of the terminal and exert pressure on the wire to form a strong mechanical bond and electrical connection. Solderless-type terminals have gradually replaced solder-type terminals in military equipment[13].

Solderless terminals come in a variety of designs. Some of the more common recommended terminals are the ring-tongue, rectangular-tongue, and flag types. These are illustrated in Fig. 8-12. One of the major sources of trouble when a terminal is connected to a wire has always been the breakage of the wire near its junction with the terminal. Wire failures have been decreased by adding a sleeve to the basic terminal. The inside diameter of the sleeve is slightly larger than the outside diameter of the wire insulation. In the crimping operation, when the barrel is fastened to the end of the wire, the insulation-supporting sleeve is fastened around the insulation. This additional support prevents excessive bending of the wire at the point where it enters the barrel of the terminal, and also prevents fraying of the insulation or braid that is over the wire. This type of terminal is illustrated in Fig. 8-13. The introduction of insulation supporting features presents the designer with another mechanical interface to consider from a compatibility standpoint. The unwary may select a terminal of appropriate AWG and stud size only to find out later in distress that the insulation will not fit into the support sleeve[13].

The type of tongue to use on the required terminal depends upon the part to which the terminated wire is to be connected, space limitations, whether there is any need for ready removal, and the required degree of security of the connection. When space is at a premium, the ring shape gives the smallest outside dimension for a given current-carrying capacity[13].

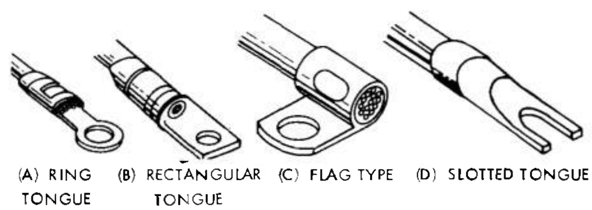


Figure 8-12. Terminals Classified According to Tongue Shape

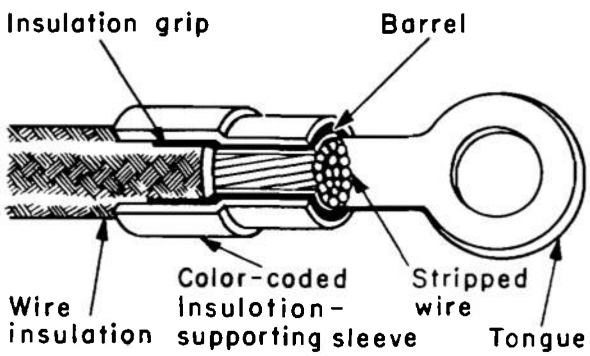


Figure 8-13. Insulation-supporting Sleeve Terminal

When terminals must be held under screw heads for easy removal, the slotted type is sometimes considered. Its major disadvantage is that the terminal may become disconnected if the screw becomes loose, and for this reason its use is not recommended in military applications[13].

Several Military Standard crimp-type terminals in accordance with MIL-T-7928[16] are available. These are listed in Table 8-8, and applicable test requirements are shown in Table 8-9. In general, the insulated varieties are designed for airframe or hookup wire and the insulation sleeves are, therefore, not large enough to fit over the heavy-duty insulation on MIL-C-13486 cables.

A special waterseal terminal, designed to fit MIL-C-13486 cable and grip the insulation so as to prevent water from reaching the conductor, is described on Drawing 19207-7056700 and illustrated in Fig. 8-14. This terminal should be used wherever MIL-C-13486 inter-

TABLE 8-8. CRIMP STYLE TERMINALS PER MIL-T-7928[16]

MS17143	Terminal, Lug, Crimp Style, Copper, Insulated
*MS20659	Terminal, Lug, Crimp Style, Copper, Uninsulated, Ring Tongue, Type I, Class 1
MS21003	Terminal, Lug, Uninsulated, Rectangular Tongue, Crimp Style, Copper, Type I, Class 1
MS21004	Terminal, Lug, Uninsulated, Rectangular Tongue, Crimp Style, Copper, Type I, Class 1
MS21005	Terminal, Lug, Uninsulated, Rectangular Tongue, Two Stud, Crimp Style, Copper, Type I, Class 1
MS21006	Terminal, Lug, Uninsulated, Flag Tongue, Crimp Style, Copper, Type I, Class 1
MS21007	Terminal, Lug, Uninsulated, Rectangular (Bent 90°), Crimp Style, Copper, Type I, Class 1 (Special Applications)
MS21008	Terminal, Lug, Uninsulated, Offset Rectangular Tongue, Crimp Style, Copper, Type I, Class 1
MS21009	Terminal, Lug, Uninsulated, Rectangular Tongue, Lipped Side, Crimp Style, Copper, Type I, Class 1
MS21010	Terminal, Lug, Uninsulated, Rectangular Tongue, Lipped End, Reinforced Boss, Crimp Style, Type I, Class 1
MS21011	Terminal, Lug, Uninsulated, Rectangular Tongue, Reinforced Boss, Positioning Slot, Crimp Style, Copper, Type I, Class 1
MS21012	Terminal, Lug, Uninsulated, Rectangular Tongue, Lipped End, Crimp Style, Copper, Type I, Class 1
MS21013	Terminal, Lug, Uninsulated, Rectangular Tongue, Off-Center Hole, Lipped End, Crimp Style, Copper, Type I, Class 1
MS21014	Terminal, Lug, Uninsulated, Rectangular Tongue, Two-Barrel, Crimp Style, Copper, Type I, Class 1
MS21015	Terminal, Lug, Uninsulated, Square Tongue, Lipped End, Rectangular Stud Hole, Crimp Style, Copper, Type I, Class 1
*MS25036	Terminal, Lug, Crimp Style, Copper, Insulated, Ring Tongue, Bell-Mouthed, Type II, Class 1
MS25189	Terminal, Lug, Flag Type, Crimp Style, Copper, Class 1

*Preferred Types

TABLE 8-9. TERMINAL TEST REQUIREMENTS PER MIL-T-7928[16]

Wire size, nominal AWG # or MCM	Voltage drop test current, A	Maximum allowable voltage drop, mV				Tensile strength psi, min
		Initial		After tensile test		
		Lug	Splice	Lug	Splice	
26	3	3	6	5	10	7
24	4.5	2	4	4	8	10
22	9	1	2	3	6	15
20	11	1	2	3	6	19
18	16	1	2	3	6	38
16	22	1	2	3	6	50
14	32	1	2	3	6	70
12	41	1	2	3	6	110
10	55	1	2	3	6	150
8	73	1	2	3	6	225
6	101	1	2	3	6	300
4	135	1	2	3	6	400
2	181	1	2	3	6	550
1	211	1	2	3	6	650
0	245	2	4	4	8	700
00	283	2	4	4	8	750
000	328	2	4	4	8	825
0000	380	2	4	4	8	875
250MCM	540	2	4	6	12	1,000
300MCM	595	2	4	6	12	1,120
350MCM	670	2	4	6	12	1,125
400MCM	740	2	4	6	12	1,325
500MCM	860	2	4	6	12	1,500
650MCM	1,000	2	4	6	12	1,750
800MCM	1,190	2	4	6	12	2,000
1,000MCM	1,375	2	4	6	12	2,350
1,600MCM	1,800	2	4	6	12	3,000

connecting wire is terminated in an area subject to bilge water, road splash, or corrosive spills. If waterseal terminals are not used in such circumstances, the stranded conductor will absorb moisture, and rapid corrosion of the individual strands will occur. Preferred waterseal terminals for use with MIL-C-13486 wire are listed in Table 8-10. These terminals must meet the test requirements of MIL-T-13513[17] as shown in Table 8-11.

Another method for achieving waterseal with lug-type terminals is available. This method employs crimp-type terminals per MS20659. Terminals are dipped in solder after crimping, and a small piece of heat shrink sleeving is assembled over the wire insulation and terminal barrel (Fig. 8-15). The solder dip prevents water from entering the conductor via the terminal hole, and the sleeving closes the leakage path between the conductor insulation and terminal barrel.

Terminals per MS20659 are the most economical of the preferred types. Terminals per MS25036 are four times more costly and the

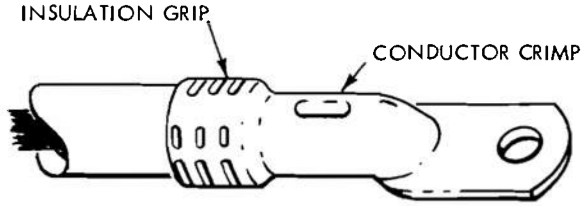


Figure 8-14. Waterseal Terminal per Drawing 19207-70567

TABLE 8-10. WATERSEAL TERMINAL APPLICATIONS (TERMINALS SHOWN ON DRAWING 19207-7056700)

Ordnance Part Number	Ordnance Cable Size & Type	Max Insulation Dia., in.	Stud Size	Net Wt, lb/C
7728640	M13486/1-3		#6	
7728764	#16		#8	
7728777	Single	0.145	#10	0.4
7728778	Conductor		1/4 in.	
7728779			5/16 in.	
7728780			3/8 in.	
7056706	M13486/1-5		#6	
7056707	#14		#8	
7056708	Single	0.166	#10	0.8
7056709	Conductor		1/4 in.	
7056710			5/16 in.	
7056711			3/8 in.	
7056700	M13486/1-7		#6	
7056701	#12		#8	
7056702	Single	0.245	#10	0.8
7056703	Conductor		1/4 in.	
7056704			5/16 in.	
7056705			3/8 in.	
7056712	M13486/1-9		#10	
7056713	#8		1/4 in.	
7056714	Single	0.370	5/16 in.	1.8
7056715	Conductor		3/8 in.	
8689218	M13486/1-11		#10	
8689219	#4		1/4 in.	
8689220	Single	0.495	5/16 in.	2.5
7064829	Conductor		3/8 in.	
8689221			1/2 in.	
7056731	M13486/1-14		5/16 in.	
7056732	1/0	0.682	3/8 in.	7.4
7355520	Single Conductor		1/2 In.	

C = quantity of 100

waterseal terminals per Drawing 19207-7056700 are eight times more costly than the MS20659 types. This comparison is based on terminals for #10 or #12 AWG wire sizes with #10 stud clearance holes.

MS35436 solder-type terminals with ring tongues per MIL-T-15659 are used primarily in field repair kits. These terminals have an insulation grip than can be wrapped around the insulation with common hand tools.

Special clamp-type terminals are used in military vehicles as battery connectors. These terminals are described in MS75004. They are designed to clamp on the battery post and are provided with separate features for connecting one or more lug-type terminals.

8-11 CONNECTORS

8-11.1 GENERAL

In order to select a connector that will perform adequately, the engineer must have a thorough comprehension of the electrical, mechanical, and environmental conditions

TABLE 8-11. TERMINAL TEST REQUIREMENTS PER MIL-T-13513[17]

Cable size, AWG#	Voltage drop test current, A + 5%	Max Voltage Drop, mV Initial	Max Voltage Drop, mV After tensile test	Pull Test Strength, min, lb
20	11	7	12	19
18	16	7	12	28
16	22	7	12	37
14	32	7	11	45
12	44	5	8	95
10	69	5	8	150
8	95	5	8	195
6	139	5	8	270
4	165	5	8	350
2	226	5	8	555
1	264	5	8	650
0	307	5	8	760
00	353	5	8	860
0000	460	5	8	1000

that may be encountered in the day to day operation of a military vehicle.

Connectors have evolved to facilitate the coupling and uncoupling of electrical equipment for replacement or service. The typical connectors used on military vehicles permit the elements of a system to be fabricated and serviced as individual assemblies or components so that the final system configuration is more easily built and maintained. The interconnection generally is accomplished using multiconductor or single conductor cable assemblies or wiring harnesses which permit convenient placement of the system components. Connectors and receptacles are also attached directly to individual components to permit the easy removal of items that are connected to mating parts without the use of interconnecting cables (circuit boards, relays, etc.).

A compatible connection system consists of a plug assembly, a mating receptacle assembly, and the wires or cables leading to them. Connector assemblies exist in a variety of configurations, each of which is intended for a particular environmental and/or mounting condition.

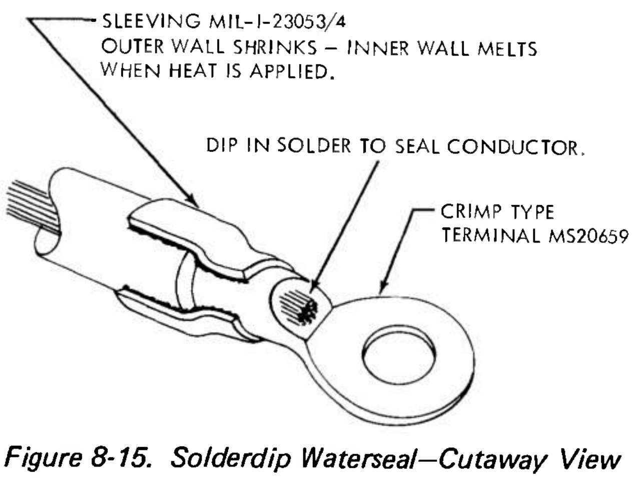


Figure 8-15. Solderdip Waterseal—Cutaway View

Plugs and receptacles are available with either pin or socket type contacts, i.e., with either male or female contacts. The placement of one in preference to the other is based on a general rule prescribing that sockets (female) are used on the power side of a connection. This arrangement is intended to preclude accidental shorting of the power side of the connection, which could injure personnel or damage equipment. Connectors are designed specifically for high or low voltage applications.

Connectors that are to be used for high frequency transmission (RF, video, pulses, etc.), demand additional considerations related to impedance. The impedance of a single pin connector is determined by the ratio of the pin diameter to the internal diameter of the case, or, in a two-pin connector, the impedance is determined by the ratio of the pin diameter to the pin spacing. In both cases the characteristic impedance of the connector must match the impedance of the attached cable.

The various connector receptacles that are available for vehicle usage are classified as in-line or cable, box, wall, or bulkhead types.

The in-line type has no means of supporting itself, is used on a cable end, and is joined to a mating element also cable connected. These in-line receptacles permit the interconnection of power distribution systems using two or more cable or harness assemblies to facilitate maintenance (Fig. 8-16).

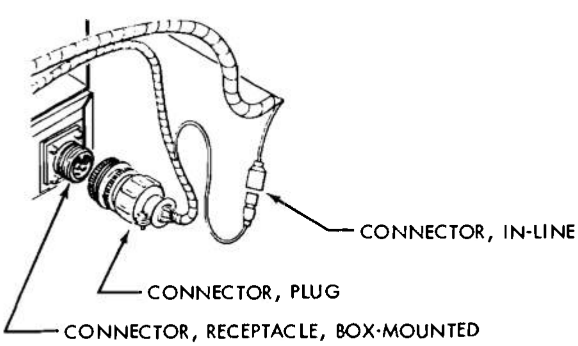


Figure 8-16. Wiring Connector Types

The difference between box- and wall-mounted receptacles is related to the environmental protection of the conductor connections. The box-mounted style (Fig. 8-17) has exposed conductor connections, and is intended to be mounted on a box or component that is sealed and thereby provides the conductor connections with protection from the environment. A wall-mounted receptacle is intended to be mounted on an exposed or unprotected enclosure; therefore, the connections to the conductors are sealed (Fig. 8-18).

The bulkhead receptacle is used to penetrate a panel while maintaining a seal between the compartments established by the panel. The unique feature of the bulkhead receptacle

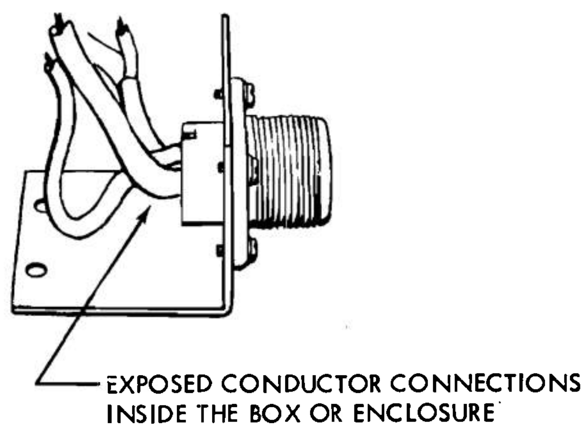


Figure 8-17. Box-mounted Receptacle

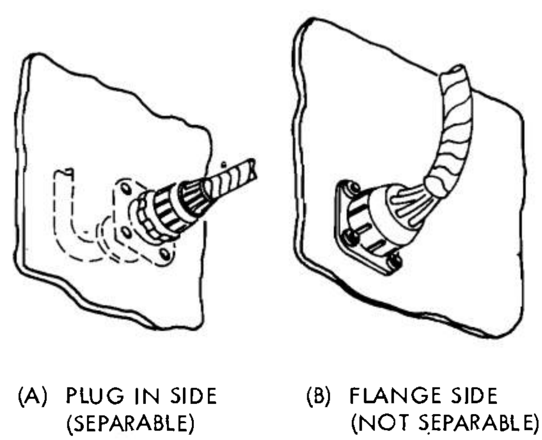


Figure 8-18. Wall-mounted Receptacle

is that it allows the connection on both sides of the panel to be removed easily. This is significantly different from box- or wall-mounted receptacles which have only one easily removable connection.

There is also a variety of connector plug assemblies used on vehicles, and the primary physical difference between them is the backshell configuration. This backshell is used to direct the connecting wire or cable either axially or in angles up to 90 deg from the axis of the connector, as well as to provide a waterseal and strain relief for the cable or wire.

A mating connector plug for each receptacle has the opposite pin/socket configuration and matching index features. Multipin connectors are provided with keyways to properly index the pin and socket connections when two mating connector halves are assembled.

Electrical connectors must be capable of withstanding the effects of the military environment. Protection against damage due to temperature extremes, water, oil, and physical abuse is mandatory. Material specifications for rubber components of electrical connectors are presented on Drawing 19207-8724206. The standard connectors used on military vehicles meet these requirements.

The waterproof connectors preferred for general use in tank-automotive applications should be specified whenever possible. These connectors are used for power and control applications operating at a nominal 24 VDC potential. One type is the threaded retainment Ordnance Series, using inserts which mate with the MIL-C-5015 AN connector series. These ordnance connectors have the necessarily rugged and watertight design features and they are compatible with the MIL-C-13486[9] cable that is used extensively in tank-automotive systems (Fig. 8-19). The Military Standard connector series per MIL-C-5015[18] is similar in form but restricted in application since it is not fully compatible with MIL-C-13486 cable.

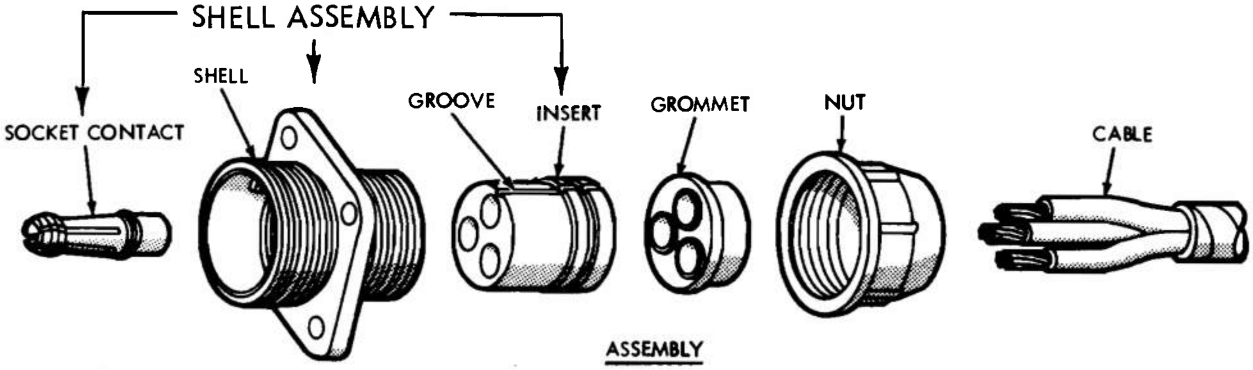
Another preferred style of connector, the friction retainment type (Fig. 8-20), commonly is used in control and instrumentation applications. It provides a quick-disconnect feature, waterproof connection, and mates with a wide variety of Military Standard equipment such as instruments, switches, lamps, horns, and fans. These connectors are most commonly used for circuits using MIL-W-13486 #16 AWG cable, but they are also available for #14 and #12 AWG cable sizes.

Other connectors designed in accordance with MIL-C-10544[19], MIL-C-55116[20], MIL-C-55181[21], and MIL-C-55243[22] are used extensively for interconnecting communication equipment installed in military vehicles.

In general, connector applications are governed by the following important factors:

1. Number of Contacts. It is good practice to provide one or more spare contacts in the connector pair over and above the actual number required for the circuits to carry. Then, any increase in circuits necessitated by functions added later will not require the use of another connector. It is well to keep the number of contacts per connector down to a number that can be mated and separated without excessive force. Where a large number of circuits must be handled, it may be advisable to use more than one connector pair. Every effort should be made to choose connectors that will allow signal and power leads to be bundled separately[18].

2. Current Rating. The current to be passed through each contact must be determined. The contact size can then be established with a safety factor sufficient to provide safe operation under conditions of temporary overload. Another important safety factor is mechanical strength. In many applications, size 12 contacts are used even though the current may be less than 100 mA because the mechanical strength of the size 12 contact is needed. In the Ordnance Series and MIL-C-5015 MS Series, the smallest pin contact has a diameter of 0.062 in. to insure adequate mechanical strength. Connectors



DISASSEMBLY

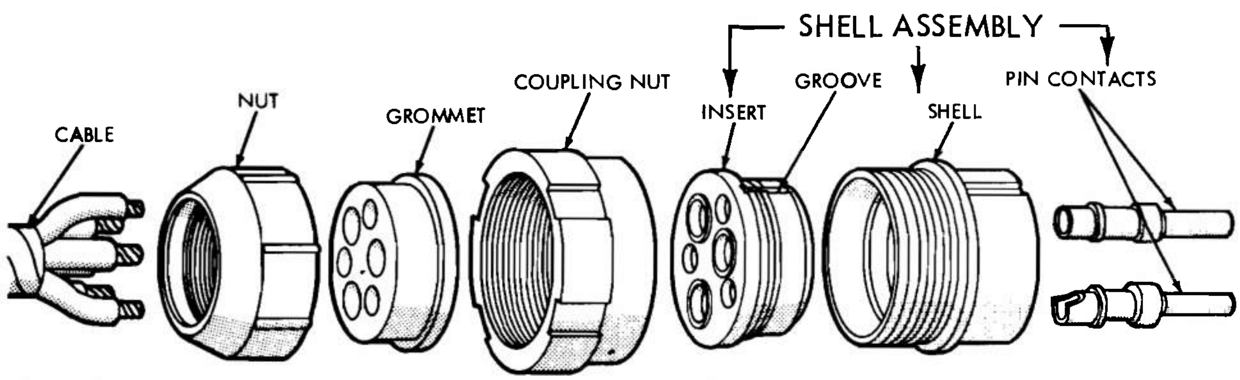
1. UNSCREW NUT FROM SHELL ASSEMBLY AND SLIDE BACK ON CABLE.
2. PUSH GROMMET BACK ON CABLE LEADS
3. UNSOLDER LEADS FROM SOCKET CONTACTS.
4. DRIVE SOCKET CONTACTS OUT THROUGH FRONT OF INSERT WITH SMALL DRIFT PIN.
5. PUSH INSERT OUT THROUGH REAR OF SHELL.

ASSEMBLY

1. SLIDE NUT OVER CABLE.
2. SLIDE CABLE LEADS THROUGH GROMMET HOLES.
3. STRIP CABLE INSULATION TO DEPTH OF SOLDER WELLS OF SOCKET CONTACTS.
4. PUSH INSERT INTO SHELL THROUGH REAR UNTIL SEATED. GROOVE IN INSERT MUST BE ALIGNED WITH GUIDE IN SHELL TO INSURE PROPER FIT.
5. PUSH SOCKET CONTACTS INTO INSERT FROM THE REAR UNTIL SEATED.
6. INSERT CABLE LEADS INTO SOLDER WELLS OF SOCKET CONTACTS AND SOLDER.
7. PUSH GROMMET DOWN CABLE LEADS AND OVER SOLDER WELLS OF SOCKET CONTACTS.
8. SCREW NUT ONTO SHELL ASSEMBLY.

INSTALLATION NOTE.
COAT INSERT LIGHTLY WITH SILICONE LUBRICANT.

(A) FEMALE RECEPTACLE



DISASSEMBLY

1. UNSCREW NUT FROM SHELL ASSEMBLY AND SLIDE BACK ON CABLE.
2. PUSH GROMMET BACK ON CABLE LEADS.
3. UNSOLDER CABLE LEADS FROM PIN CONTACTS.
4. SLIDE COUPLING NUT OFF SHELL ASSEMBLY.
5. DRIVE PIN CONTACTS OUT THROUGH FRONT OF INSERT WITH SMALL DRIFT PIN.
6. PUSH INSERT OUT THROUGH REAR OF SHELL.

INSTALLATION NOTE.
COAT INSERT LIGHTLY WITH SILICONE LUBRICANT.

ASSEMBLY

1. SLIDE NUT OVER CABLE.
2. SLIDE GROMMET OVER CABLE LEADS.
3. STRIP CABLE INSULATION EQUAL TO DEPTH OF SOLDER WELLS OF PIN CONTACTS.
4. PUSH INSERT INTO SHELL THROUGH REAR UNTIL SEATED. GROOVE IN INSERT MUST BE ALIGNED WITH GUIDE IN SHELL TO INSURE PROPER FIT.
5. PUSH PIN CONTACTS THROUGH REAR OF INSERT UNTIL SEATED.
6. SLIDE COUPLING NUT ONTO SHELL ASSEMBLY.
7. INSERT CABLE LEADS INTO SOLDER WELLS OF PIN CONTACTS AND SOLDER.
8. PUSH GROMMET DOWN CABLE LEADS AND OVER SOLDER WELLS OF PIN CONTACTS.
9. SCREW NUT ONTO SHELL ASSEMBLY.

(B) MALE PLUG

Figure 8-19. Disassembly and Assembly of Typical Threaded Retainment Connectors of the Ordnance Series

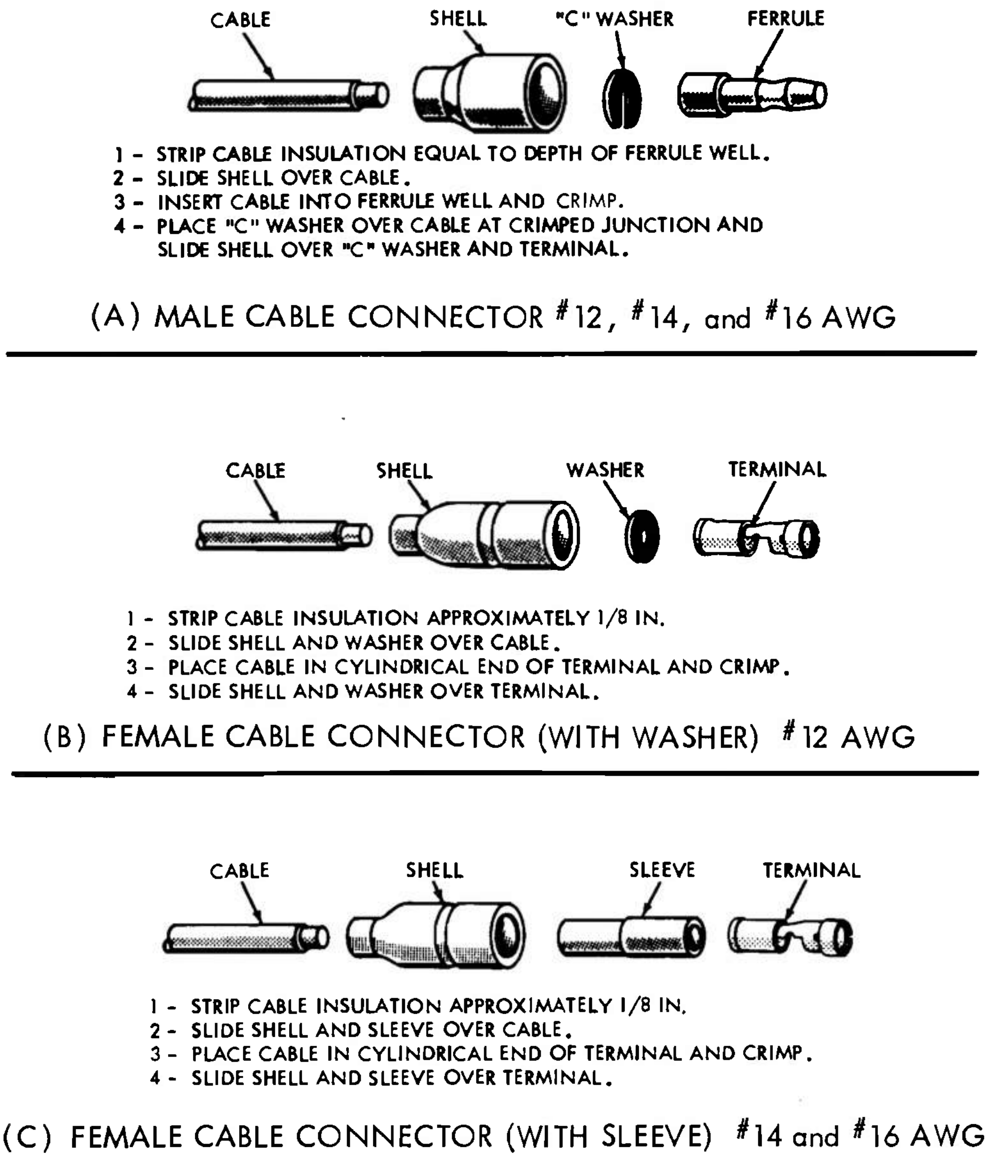


Figure 8-20. Assembly of Friction Retainment Connectors

with contacts smaller than size 16 are used only in cases where miniaturization requirements forbid the use of larger contacts. Table 8-12 shows the diameters and current ratings of contacts used in connectors covered by MIL-C-5015 along with voltage drop and rated current for Ordnance Series Connectors[18].

3. Voltage. The designer must determine the potential present between contacts and from each contact to ground under the most severe transient conditions that may exist under operation. Table 8-13 shows the service rating, mechanical spacing, and creepage distance across the dielectric between contacts

TABLE 8-12. CONNECTOR CONTACT CURRENT RATINGS[18]

	MIL-C-5015		Ordnance Series	
Contact size, AWG#	Nominal diameter, in.	Current rating, A	Voltage drop, mV	Current rating, A
16	0.0625	22	21	20
12	0.094	41	20	35
8	0.142	73	18	60
4	0.225	135	18	110
0	0.357	245	18	200

TABLE 8-13. MIL-C-5015 CONNECTOR SERVICE RATINGS[18]

Service rating	Mechanical spacing, in., nominal	Creepage distance across insulation, in., nominal	Test voltage, V	Working voltage, rms V
INST	–	1/16	1000	200
A	1/16	1/8	2000	500
D	1/8	3/16	2800	900
E	3/16	1/4	3500	1250
B	1/4	5/16	4500	1750
C	5/16	1	7000	3000

and the test potential, which connectors under MIL-C-5015 must withstand. Ordnance Series connectors are tested at 200 VAC rms at 60 Hz per Drawing 19207-10911317. The need for safe and reliable operation suggests the use of operating potentials not greater than one-half the rms value obtained by subtracting 1000 V rms from the 60-Hz test potential. DC voltages under maximum transient conditions must not exceed the peak AC potential derived from the test rms voltage. As an example, the A service rating provides contact spacing and creepage distance sufficient to withstand a test potential of 2000 V rms, 60 Hz, or a peak potential of 2820 V. If the rms value of 2000 V is reduced by 1000 V and the balance of 1000 V is halved, the safe rating will be 500 V rms or 705 V peak. This method of rating applies only at sea level. Lower values must be used at high altitude, although it can be considered safe to operate up to 275 VDC with an approved military connector at any altitude provided moisture and temperature conditions are not severe. Temperatures above 392°F will reduce this voltage by as much as 20%; high humidity can also reduce this figure by 20%. High temperature and high humidity are not likely to be encountered simultaneously[13].

4. Contact Resistance. In most types of military connectors, the contact resistance is determined by measuring the millivolt drop from tail-to-tail for the mated set of contacts with a specified current flowing. Thus, the resistance of the contact material as well as of the actual point or points of contact is investigated. Generally, the contact resistance is 0.001 ohm or less, although the resistance including the contact material may exceed that value[13].

5. Undesired Coupling (Crosstalk). Crosstalk between shielded circuits carrying frequencies below 100 kHz is not likely to be a problem when circuits are continued through connectors that do not contain coaxial contacts, because of the low capacitance between contacts in military electrical connectors. Alternate contacts should be used for the shield-through connection. The shell, when one is used, should be grounded. At frequencies over 100 kHz, tests must be conducted to determine the possible effect of intercoupling[13].

6. Mechanical Strength. Great care should be exercised in the selection of connectors to make certain that they will meet mechanical strains placed upon them in application. On vehicles, connector housings are used as personnel steps if they happen to be in the right location, and it is not an uncommon sight to see military equipment lifted or carried by one or more of its connectors even though connectors or thin housings are not intended for these purposes[13].

Especially important is the possible effect of pulling strains on cables where considerable leverage may appear with disastrous effects on a connector not adequate for that type of strain. Where connectors do not have protective housings, contacts and inserts are sometimes damaged, if not completely ruined, by withdrawal of a plug at an angle instead of straight away from the receptacle[13].

7. Dielectric Materials. The dielectrics used in signal and power connectors are for the most part thermosetting plastics. These dielectrics employ phenolic, melamine, or diallylphthalate resin with a variety of fillers that are best suited for the particular application. Resilient insert connectors use polychloroprene or silicone rubber. Certain pressure-sealed connectors may use both a hard

dielectric of the thermosetting type and one of the rubber compounds. Frequently, a hard thermosetting dielectric is used to hold contacts in correct position, and the soft rubber is employed for sealing purposes. Fully resilient types such as the Class E & R Military Standard MIL-C-5015 and Ordnance Series connectors use rubber for maintaining contacts in position and sealing around conductors[13].

8. Polarization. The selected connector must have built into it the means to prevent incorrect mating. This may be effected through dissimilar-size guide pins, through a nonsymmetrical arrangement of contact barriers, or through the design of the connector shell housing. Contact pins should never be used for alignment or polarization[13].

9. Sealing. Sealing of connectors usually applies to receptacles installed on pressure-tight bulkheads or on the cases of sealed equipment. The best sealing is found in connectors with fused glass dielectric in which the glass is fused to the contacts and the shell housing. Connectors in this category will hold a vacuum when solder sealed or brazed into their mountings. Equipment that is sealed at access openings by O-rings or rubber gaskets will exhibit a sufficiently high leakage at such openings to justify the use of rubber-gasketed "sealed" connectors instead of the fused dielectric type. Such connectors are generally considered "pressurized" types[13].

10. Operating Temperature. The operating temperature is limited by the mechanical and electrical properties of the materials used in the fabrication. The operating temperature is the ambient temperature plus the rise generated by the power dissipated. Heat is dissipated internally by conduction and externally by radiation. The operating altitude also affects the connector temperature.

Dielectric materials of the types normally used in vehicle electrical connectors are intended for a temperature range from approximately -85° to 250°F.

11. Grounding Provisions. Good engineering practice dictates that grounds must be carried through contacts and not through housing shells[13].

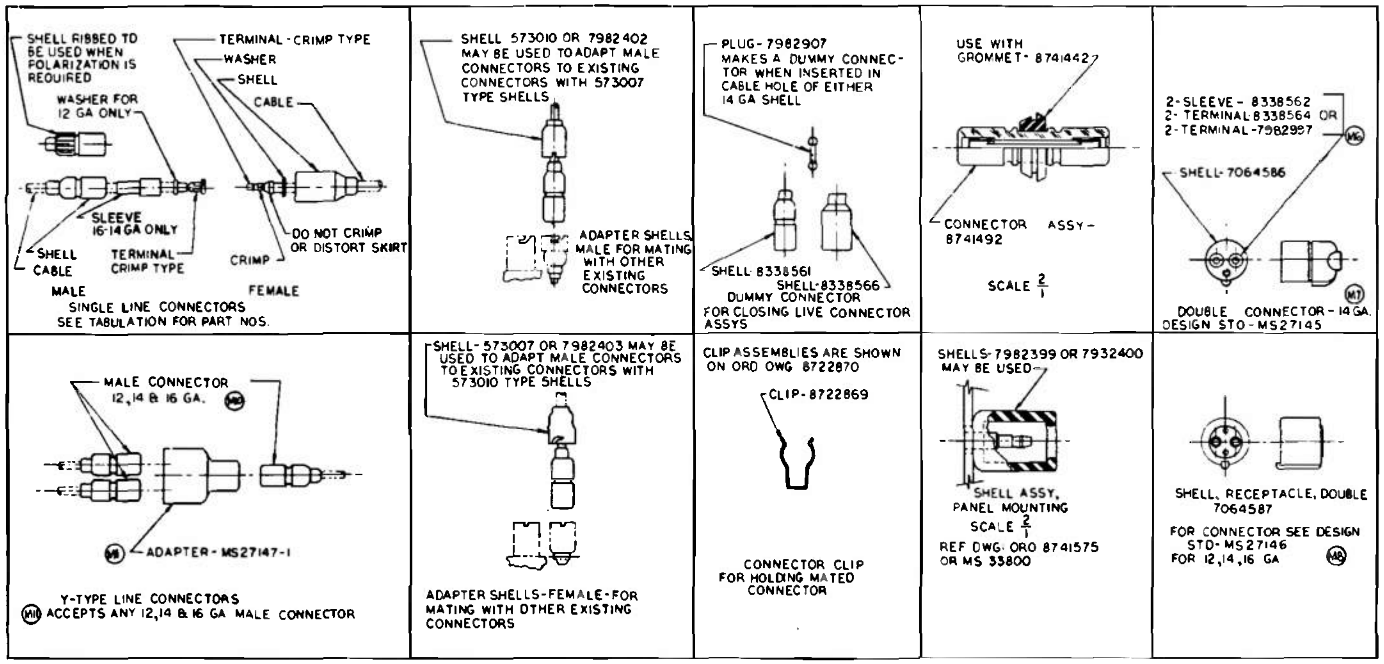
8-11.2 POWER AND CONTROL CONNECTORS

The two most widely used waterproof electrical power and control connectors employed to interconnect vehicle electrical equipment are the previously illustrated (Figs. 8-19 and 8-20) friction retainment and threaded retainment types. The various types are consolidated on Drawings 19207-7982736 (Fig. 8-21) and 19207-7723494 (Fig. 8-22), respectively. The connector types are elements of an established waterproof electrical interconnection system. The system was originally designed so that all wiring assemblies terminated in one or the other of these connector types, thereby mandating that the system components use appropriate mating connections. The connectors are unique in the respect that their wire entries are intended to accept and seal around MIL-C-13486 wire cable which has an extra heavy insulation to withstand the abuse encountered in the military environment.

For all practical purposes, the use of these connectors is limited to wiring assemblies using bundled individual conductors because the connector designs generally do not provide for waterproof termination and support of a multiconductor cable. One exception to this rule is found in shell size 22 of the threaded retainment type where accessory clamp 7973504 can be used to seal around multiconductor cable. The use of this clamp is limited because the cable seal is too close to the solder wells and reliable assembly is, therefore, difficult to achieve.

8-11.2.1 ORDNANCE SERIES THREADED RETAINMENT CONNECTORS

This waterproof connector series (Fig. 8-19) is limited to the shell types, sizes, and insert arrangements displayed on Drawing 19207-7723494 (Fig. 8-22).



SINGLE LINE CONNEOTOR COMPONENTS

USE WITH ORDNANCE CABLE NUMBER	TYPE AND OLD ASSY NUMBER	SHELL	SLEEVE	WASHER	TERMINAL (CRIMPED)	OPTIONAL TERMINAL (SOLDERED)	DESIGN STANDARD
M13486/1-3, TYPE I, CLASS A SPEC MIL-C-13486	MALE	8724494	8338562	—	8338564	7992997	MS27144
	FEMALE	8724495	—	8724497	MS 27148-3	—	MS27142
M13486/1-5 TYPE I, CLASS A, SPEC MIL-C-13486	MALE WAS ASSY 8338560	8338561	8338562	—	8338564	7982997	MS27144
	FEMALE WAS ASSY 8338565	8338566	—	8338567	MS27148-2	—	MS27142
	MALE RIBBED WAS ASSY 7982398	7982401	8338562	—	8338564	7982997	MS27144
M13486/1-7, TYPE I, CLASS A, SPEC MIL-C-13486	MALE WAS ASSY 8338568	8338569	—	8338570	8338564	7982997	MS 27143
	FEMALE WAS ASSY 8338571	8338572	—	8338573	MS 27148-1	—	MS27142

NOTE:
AT ASSEMBLY LUBRICATE RUBBER TO RUBBER MATING SURFACES WITH SILICONE COMPOUND SPEC MIL-S-8660

INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS AND/OR REQUIREMENTS OF MIL-D-70327

FURNISHED BY FMC CORPORATION CONTRACT NO DA-04-200-ORD-1062
CODE IDENT NO. 19207

CONNECTORS, WATERPROOF, ELECTRICAL
FOR REFERENCE ONLY
ORDNANCE CORPS DEPT OF THE ARMY DETROIT ARSENAL
7982736

Figure 8-21. Friction Retainment Connector Components

Available shell sizes range from 12 through 32 in a system where these numbers represent the coupling thread diameter in sixteenths of an inch. For example, shell size 16 has a coupling thread that is 16/16 or 1 in. in diameter. The number 16-12 under one of the contact arrangements on line 29 of Fig. 8-22 identifies a single-contact insert arrangement. Similarly, the contact arrangement view denoted as 16-10 represents a size 16 shell with a 10- or three-contact insert. The illustrated insert arrangements are identical to those with corresponding numbers described by MIL-C-5015 and the Military Standards listed therein.

Pin and socket contacts are limited to AWG Sizes of 0, 4, 8, 12, and 16. These contacts are fabricated from high-quality copper alloy and are silver-plated to assure good electrical continuity between connections.

The AWG size of the wire soldered to each contact should be the same or smaller than the corresponding contact size number. For example, it is intended that a Size 12 wire should be soldered to at least a Size 12 contact; and Size 6 wire should be soldered to a Size 4 contact because no Size 6 contacts are provided and Size 4 is the next larger. Where two or more wires are installed in a solder cup or wire barrel, moisture sealing is not possible with the standard grommet. Wires should be potted to achieve a proper seal in these circumstances.

Shells and nuts are made of aluminum, are cadmium plated, and are treated with a clear chromate which is electrically conductive and resistant to corrosion.

The resilient inserts and grommets provide high dielectric strength and vibration resistance throughout a temperature range from −65° to 257°F. Grommets are available to fit MIL-C-13486 cable in AWG Sizes of 0, 2, 4, 6, 8, 12, 14, and 16, but applications are limited to those shown on line 17 of Drawing 19207-7723494 (Fig. 8-22). Preferred cables listed in Table 8-6 are compatible with the available grommets.

As a general rule, all connectors are furnished with the insert and contacts installed in the shell. Therefore, a plug connection requires the selection of a shell assembly, coupling nut, grommet, and grommet retaining nut to be complete. A wall-mounted receptacle consists of a receptacle assembly, grommet, and grommet retaining nut, whereas a box-mounted receptacle is complete when only the receptacle assembly is obtained.

A selection of accessory components is provided for use with these connectors. Included are gaskets for wall- and box-mounted receptacles, caps for receptacles and plugs, a right-angle elbow, conduit couplings in ferrule and elbow configurations, and a multiconductor cable clamp assembly (Fig. 8-22).

Special connectors for use on ordnance vehicles are a part of this series and include the trailer receptacle and cover, the slave receptacle, slave cable plugs, and high tension cable connectors (Fig. 8-22).

8-11.2.2 ARMY FRICTION RETAINMENT CONNECTORS

These connectors, illustrated in Fig. 8-20 and Drawing 19207-7982736 (Fig. 8-21), are waterproof, oil-, ozone-, and fungus-resistant. They are suitable for service in temperatures ranging from −65° to 225°F and they can be connected or disconnected at temperatures as low as −25°F. The silver-plated electrical contacts are enclosed totally in a waterproof neoprene shell when properly mated.

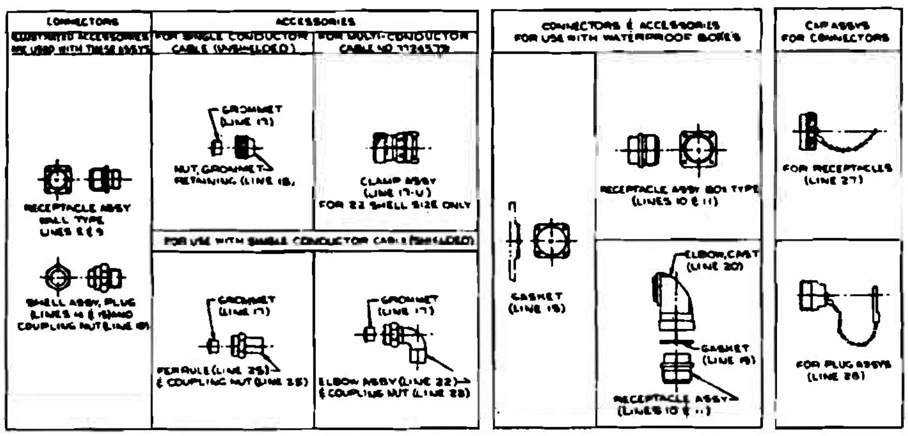
MS27142 through MS27148 have been introduced to further describe application of these connectors. Their assembly, connection, and disconnection are facilitated if silicone compound per MIL-S-8660[23] is applied to all mating rubber surfaces during the initial assembly.

The single-pin connectors are available in three sizes and two styles. Available sizes are

Line	Item			A	B	C	D	E	F	G	H	J	K	L	M
1	AMOUNT OF CONTACTS			1			2	3			4				5
2	CONTACT SIZE	16M									2	2			
3		12		1			3	3				2	2		3
4		8							3				2	4	
5		4			1					3					
6		0				2									2
7	SHELL SIZE			12	16	22	16	16	22	28	14S	16	22	22	32
8	RECEPT ASSY	WALL	P	7720496	7722347	7716780	7720486	7720484	7722351	7716791	7524930	7720482	7971515	7524944	7388353
9			S	7720497	7722348	7716781	7720487	7720485	7722352	7716792	7524931	7720483	7971514	7524945	7971717
10		BOX	P	7720498	7722224	7388320	7720492	7720490	7388318	7388330	7524936	7720488	7971516	7388326	7971718
11			S	7720499	7722225	7388321	7720493	7720491	7388319	7388331	7524937	7720489	7388349	7388327	7971719
⊖ 12	PLUG ASSY		P	7720494	7722349	7716879	7720480	7720478	7722367	7716892	7524940	7720476	7388350	7130893	X
⊖ 13			S	7720495	7722350	7716880	7720481	7720479	7722368	7716893	7524941	7720477	X	7524571	7388354
▷ 14	SHELL ASSY, PLUG		P	8724198	8724234	8724241	8724232	8724230	8724237	8724253	8724223	8724228	8724239	8724249	8724403
▷ 15			S	8724199	8724235	8724242	8724233	8724231	8724238	8724254	8724224	8724229	8724240	8724250	8724404
▷ 16	NUT, COUPLING			7527643	7527645	8701325	7527645	7527645	8701326	7716634	7527644	7527645	8701325	8701325	8701349
17	GROMMET WITH QUANTITY & SIZE OF CABLE USED WITH, INDICATED			7722343 1-#14 7527691 1-#12	7527690 1-#8 7527629 1-#6 8724521 1-#4	8576777 1-#2 8576776 1-#0	7552152 2-#14	7722344 3-#14	7524564 2-#8 7358500 2-#14, 1-#12 7527633 3-#12 7762684 2-#14, 1-#8 7762672 1-#14, 1-#8	8724251 3-#4	7527627 4-#16	7527628 2-#16, 2-#14	7388351 2-#16, 1-#8 & 1-#12	7751435 2-#16, 1-#8 & 1-#12	7359856 3-#14, 2-#?
18	NUT, GROMMET RET			7723306	7723307	7723308	7723307	7723307	7723308	7723309	7728598	7723307	7723308	7723308	7388355
19	GASKET			7358501	7358503	7388352	7358503	7358503	7388352	7388357	7358502	7358503	7388352	7388352	7358505
20	ELBOW, CAST			7722324	7722334	7716690	7722334	7722334	7716690	7716691	7527624	7722334	7716690	7716690	7527625
⊖ 21	ELBOW & NUT ASSY			7524924	7524926	7524929	7524926	7524926	7524927 / 7524928	X	7524925	7524926	7524928	7524928	X
▷ 22	ELBOW ASSY			8724497	8724236	8724220	8724236	8724236	8724211 / 8724220	8724222	8724227	8724236	8724220	8724220	8724278
▷ 23	NUT, COUPLING			X	X	7722325	X	X	7722325	7722326	X	X	7722325	7722325	8719853
⊖ 24	FERRULE & NUT ASSY			7524918	7524920	7524922	7524920	7524920	7524921 / 7524922	X	7524919	7524920	7524922	7524922	X
▷ 25	FERRULE			8724438	8724275	8724277	8724275	8724275	8724276 / 8724277	8724252	8724274	8724275	8724277	8724277	8724434
▷ 26	NUT, COUPLING			7722345	7722346	7722325	7722346	7722346	7722325	7722326	7722362	7722346	7722325	7722325	8719853
27	CAP ASSY, RECEPT			7261670	7261672	7261674	7261672	7261672	7261674	7261675	7261671	7261672	7261674	7261674	7527595
28	CAP ASSY, PLUG			7527664	7527666	7527667	7527666	7527666	7527667	7527668	7527665	7527666	7527667	7527667	7527669
29	VIEWS OF CONTACT ARRANGEMENTS			12-S	16-12	22-1	16-11	16-10	22-2	28-6	14S-2	16-9	22-4	22-22	32-1
				A	B	C	D	E	F	G	H	J	K	L	M

P - PIN CONTACT   S - SOCKET CONTACT

CONTACT LEGEND #16M - ○ #12 - ● #8 - ⊙ #4 - ◯ #0 - ⊕



NOTES:
⊖ PART NUMBERS LISTED IN THESE LINES ARE FOR REFERENCE ONLY AND ARE NOT TO BE USED ON ANY NEW WORK.
▷ PART NUMBERS LISTED IN THESE LINES ARE TO BE USED ON ALL NEW WORK IN PLACE OF ITEMS SYMBOLIZED BY ⊖

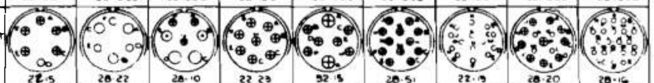
OLD WAY	NEW WAY	
PLUG ASSY ▭	SHELL ASSY ▭ NUT ▭	
FERRULE & NUT ASSY ▭	FERRULE ▭ NUT ▭	
ELBOW & NUT ASSY ▭	ELBOW ASSY ▭ NUT ▭	FOR SHELL SIZES 22, 28, & 32
	ELBOW ASSY ▭	FOR SHELL SIZES 12, 14S & 16

FOR APPLICABLE CABLE TO BE USED WITH THESE CONNECTORS SEE ORD DWG D7056674.
FOR OTHER WATERPROOF CONNECTORS SEE ORD DWG D7982736.

FOR MAXIMUM STANDARDIZATION IN THE USAGE OF THIS LINE OF WATERPROOF CONNECTORS, THE ORDNANCE DEPARTMENT HAS LIMITED THE SHELL TYPES, SIZES AND CONTACT ARRANGEMENTS TO THOSE APPEARING ON THIS DRAWING. NO SUBSTITUTION OR USE OF ANY OTHER CONNECTOR OR ACCESSORY IS ALLOWED WITHOUT APPROVAL OBTAINED THROUGH THE USE OF FORM NO. DAR-20-1588

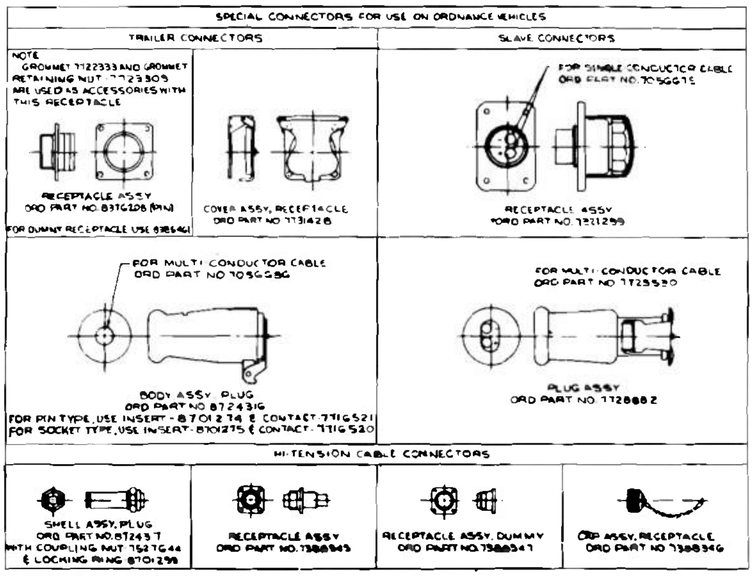
Figure 8-22. Threaded Retainment Connector Components

1	AMOUNT OF CONTACTS			6		7	8		12	14		20
2	CONTACT SIZE	16M			3					14	4	20
3		12		5		3	8	6	12		10	
4		8				2						
5		4			3	2						
6		0						2				
7	SHELL SIZE			22	28	28	22	32	28	22	28	28
8	RECEPT ASSY	WALL	P	7716784	8718568	8715566	7722353	7971739	7716793	7524942	7388358	7974698
9			S	7716785	8713569	8715567	7722354	7971734	7716794	7524943	7388359	7974694
10		BOX	P	7388322	7064429	7064427	7388328	7973920	7388382	7388324	7388362	7968365
11			S	7388329	7064428	7064706	7388329	7973921	[illegible]	7388325	7388363	7968275
12	PLUG ASSY		P	7716885	8376933	8376981	7722369	7064969	7716894	7729623	7388364	7968368
13			S	7716884	8376934	8376932	7722370	7064970	7716895	7729624	7388365	7968278
14	SHELL ASSY, PLUG		P	8724245	8724261	8724259	8724243	8724405	8724257	8724247	8724255	8724641
15			S	8724246	8724262	8724260	8724244	8724406	8724258	8724248	8724253	8724642
16	NUT, COUPLING			8701325	7716634	7716634	8701325	7971728	7716634	8701325	7716634	7716634
17	GROMMET WITH QUANTITY & SIZE OF CABLE USED WITH INDICATED			7722325 4-#16, 5-#14	8708184 5-#16, 3-#4	8724264 3-#14, 2-#12 & 2-#8	7722322 8-#14 8724625 8-#16	CLAMP ASSY 8724263 6-#14, 2-#0	1525211 3-#16, 9-#14 7722333 12-#14	CLAMP ASSY 7973504 FOR MULTI-CONDUCTOR CABLE	7388366 4-#16, 10-#14	7974632 20-#16
18	NUT GROMMET RET			7723308	7723308	7723309	7723308		7723309		7723309	7723309
19	GASKET			7388352	7388357	7388357	7388352	7358508	7388357	7388352	7388357	7388357
20	ELBOW, CAST			7716690	7716691	7716691	7716690	1527625	7716691	7716690	7716691	7716691
21	ELBOW & NUT ASSY			7524928		7524929	7524927		1524929		1524929	1524929
22	ELBOW ASSY			8724220	8724222	8724221	8724271		8724221		8724221	8724221
23	NUT, COUPLING			7722325	7722326	7722326	7722325		7722326		7722326	7722326
24	FERRULE & NUT ASSY			7524922		7524925	7524921		7524923		7524923	7524923
25	FERRULE			8724277	8724258	8724276	8724216		8724278		8724278	8724278
26	NUT, COUPLING			7722325	7722326	7722326	7722325		7722326		7722326	7722326
27	CAP ASSY, RECEPT			7261674	7261675	7261675	7261674	1527635	7261675	7261674	7261675	7261675
28	CAP ASSY, PLUG			1527667	1527668	1527668	1527667	1527659	1527668	1527667	1527668	1527668
29	VIEWS OF CONTACT ARRANGEMENTS			22-5	28-22	28-10	22-23	32-15	28-51	22-19	28-20	28-16
				N	P	Q	R	S	T	U	V	W



P-PIN CONTACT S-SOCKET CONTACT

CONTACT LEGEND #16M-○ #12-● #8-⊙ #4-◯ #0-⊕



STANDARD
TO BE CHANGED ONLY UPON CONCURRENCE OF SIMPLIFICATION COMMITTEE

ORDNANCE PART NO. 7723494

ELECTRICAL CONNECTORS, WATERPROOF

(FOR REFERENCE ONLY)

ORDNANCE DEPT
DEPT OF THE ARMY
DETROIT ARSENAL

K 7723494

Figure 8-22. (Cont'd.) Threaded Retainment Connector Components designed to provide a waterproof connection in conjunction with #12 AWG, M13486/1-7; #14 AWG, M13486/1-5; and #16 AWG, M13486/1-3 cable as specified in MIL-C-13486. The two styles available are plain and ribbed. The ribbed version (Fig. 8-23) is available only in the #14 AWG size. It is intended to facilitate correct connection of a plug and receptacle in restricted areas such as the rear of an instrument panel. In such circumstances, the difference in feel of the connector shell helps prevent misconnection. For this reason, the standard instrument assemblies are furnished with one plain and one ribbed receptacle shell.

Other components of this connector system include a bulkhead connector, a three-way adapter, a dual-contact plug and receptacle, a retainer clip, and a dummy wire plug (Fig. 8-21).

8-11.2.3 MILITARY STANDARD CONNECTORS—AN TYPE

These connectors are very similar to the ordnance threaded retainment connectors (par. 8-11.2.1). They are described by MIL-C-5015[18] and are intended for use in electrical power and control circuits. The various shell designs and insert arrangements are documented in MS3100, MS3101, MS3102, MS3106, MS3107, MS3108, and MS25183—which describe the wall mounting, cable connecting, box mounting, straight plug, quick-disconnect plug, 90-deg angle plug, and straight plug for potting, respectively.

The standard finish on AN connectors is olive drab. The shells are of aluminum or aluminum alloy, plated with cadmium. During the final steps of the plating process, the

Figure 8-23. Ribbed Connector Shells

shells are given a chromate conversion coating that produces a complex protective coating of chromium and cadmium salts. This particular treatment produces the olive drab color. An important feature of the finish is that it is conducting. Not all chromate conversion coatings are conducting.

All contacts are silver-plated for maximum corrosion resistance, maximum current carrying capacity, and minimum voltage drop. Inserts are resilient for maximum vibration resistance.

As previously stated, these connectors are not completely compatible with MIL-C-13486 cable. Furthermore, not all of the connector classifications are suitable for use in the military vehicle environment.

Connector classes are designated by a letter as follows (all Class E connectors and certain connectors in Classes A, B, and C are inactive for new designs):

1. Class A – Solid shell
2. Class B – Split shell
3. Class C – Pressurized
4. Class E – Environment-resistant
5. Class F – Environment-resistant (with cable clamp)
6. Class H – Hermetic seal
7. Class J – Environment-resistant (with gland seal for jacketed cable)
8. Class K – Firewall
9. Class P – Potting seal
10. Class R – Environment-resistant (with grommet seal – without cable clamp)
11. Class S – Environment-resistant (interface only).

Class R connectors are intended for use where the connector will be subject to heavy condensation and rapid changes in temperature or pressure, and where the connector is subject to high vibratory conditions. To ensure proper performance, a Class R plug must always be mated to a Class R receptacle to assure that sealing is accomplished (Fig. 8-24).

Class S connectors are intended for use where a short connector length is desirable. Class R moisture protection is provided by the mating part of the connector, but the back end does not have a moisture seal. The connector will meet all Class R performance requirements when the back end is potted (Fig. 8-25). An MS3185 potting form will fit on the rear threads and should remain on the connector after potting.

Class R and S connectors are recommended for military vehicle usage because they provide the required environmental protection and are adaptable for use with MIL-C-13486 cable when properly selected.

Table 8-14 gives the part numbers of MIL-C-13486 cables recommended for use with Class R connectors and relates the cable part number to the connector contact size based on the capability of the connector grommet to seal around the cable insulation.

The number MS3100R18-10PW is a typical part identifier describing an environment-resistant, wall-mounted receptacle assembly with pin contacts. The numbering system identifies the basic part, class, shell size, insert arrangement, contact style, and insert position (Fig. 8-26).

8-11.2.4 MIL-C-55181 CONNECTORS

MIL-C-55181[21] plugs and receptacles are waterproof connectors intended for terminating multiconductor cable. These connectors are designed for intermediate power requirements (power and control) and are used with cable per MIL-C-3432 to interconnect vehicular radio and communication equipment. Plugs are equipped with a jack-screw that aids in mating, disconnecting, and maintaining a vibration-resistant connection.

Plugs and receptacles (Fig. 8-27 and 8-28), which are polarized to prevent mismating, are available with 4, 9, or 18 contacts. Current ratings are 7.5 A (25 mV IR drop) with the #20 AWG contacts and 35 A (20 mV IR drop) with the #12 contacts. The environmental characteristics of these connectors also include resistance to impact, compression, and salt spray.

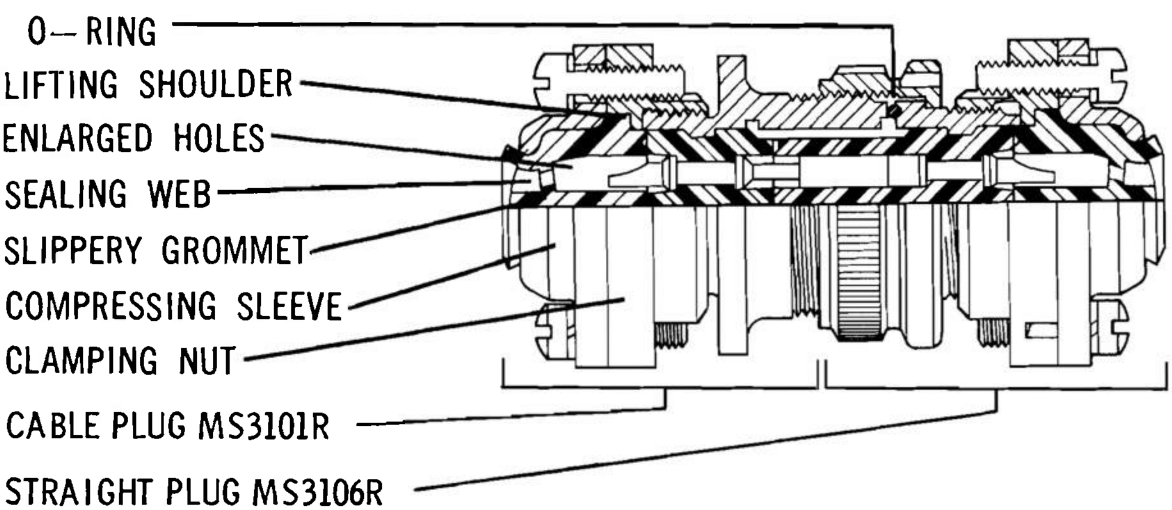
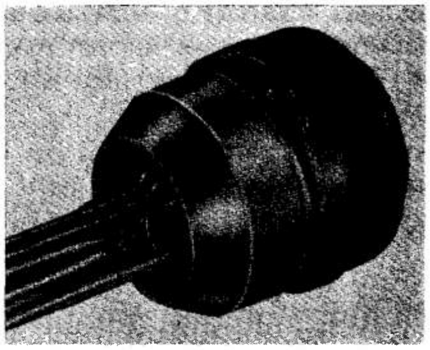
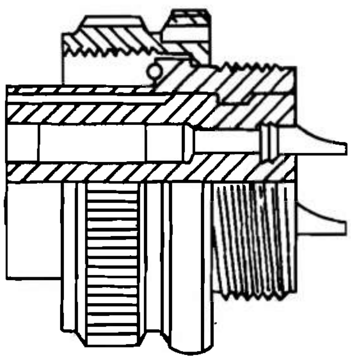


Figure 8-24. AN Type, Class R, In-line Connection[24]



(A) WITH POTTING FORM



(B) SECTIONAL VIEW

Figure 8-25. AN Type, Class S, Straight Plug, MS25183

8-12 AUDIO CONNECTORS

Connectors specifically intended for communication applications are described in MIL-C-10544 (ten contact) and MIL-C-55116 (five contact). These connectors conform to military environmental specifications for resistance to moisture, salt spray immersion, temperature cycling, and vibration. They are intended for use with multiconductor jacketed cable. The sealing grommet internal diameter is 0.290 ± 0.010 in. The plugs and receptacles mate quickly and easily with a bayonet twist-lock action that serves to wipe the contacts clean upon connection.

MIL-C-55116 connectors containing five contacts are used with communication operator's headsets and chest sets employing dynamic microphones. The components comprising this series are shown in Fig. 8-29. Although a variety of cable plug assemblies are available, the types U-228/U and U-229/U are preferred because they provide cable strain relief. U-228/U and U-229/U are preferred as they provide cable strain relief.

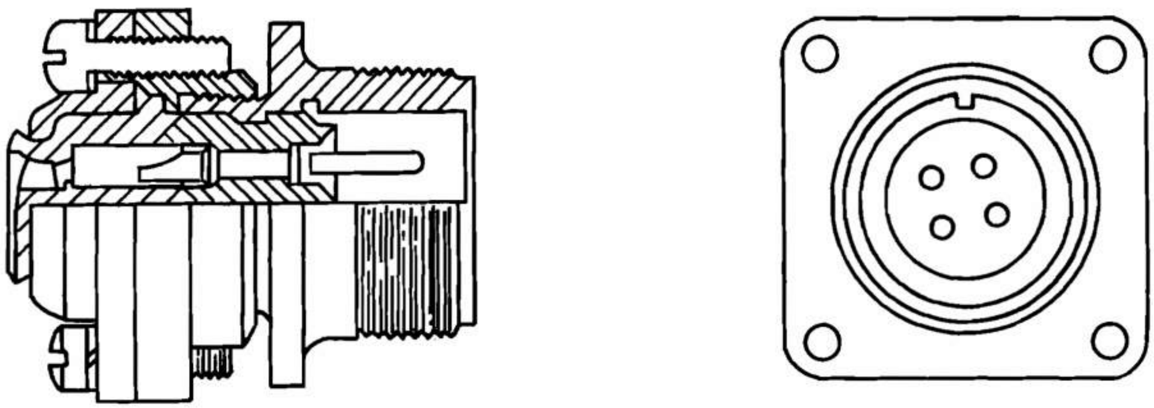
The panel receptacle U-183/U that mates with plug U-229/U is the most commonly used configuration for attaching headsets, etc., to radios and control boxes. The U-228/U and U-229/U cable plugs are used as in-line connections for extending cable lengths.

Connectors specified in MIL-C-15044 also are intended for audio applications and are the standard termination for carbon microphone circuits. These connectors feature more application flexibility than the five-pin variety since all plugs contain a strain relief, and a greater variety of connector configurations are available including a right angle cable plug. Fig. 8-30 illustrates the available receptacle and plug assemblies.

The distinguishing characteristic between audio and power connectors is the current-carrying capability. For example, the MIL-C-

TABLE 8-14. RECOMMENDED MIL-C-13486 CABLE TYPES FOR USE WITH MIL-C-5015 CLASS R CONNECTORS

Pin Contact Size, AWG#	Acceptable Conductor Insulation Diameter, in.	Recommended MIL-C-13486 Cable	
		Size AWG#	Part Number
16	0.064 (min) 0.130 (max)	None Recommended	None Recommended
12	0.114 (min) 0.170 (max)	16 14	M13486/1-3 M13486/1-5
8	0.164 (min) 0.255 (max)	12	M13486/1-7
4	0.272 (min) 0.370 (max)	8	M13486/1-9
0	0.415 (min) 0.550 (max)	6 4	M13486/1-10 M13486/1-11



MS3100	R	18	—	10	P	W
Basic part	Class	Shell size		Insert arrange-ment	Contact style	Insert position

Basic Part: Military Standard per MIL-C-5015

Class: Type of service

Shell size: Mating thread dia in 1/16-in. increments

Insert Arrangement: As selected from Military Standard for the basic part

Contact Style: P = pin contacts (as shown)
S = socket contacts (not shown)

Insert Position: Indicates insert position other than normal with respect to indexing features. See applicable Military Standard for the basic part

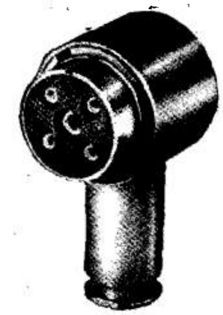
Figure 8-26. Identification of AN Type Wall-mounted Receptacle MS2100R18-10PW

55116 and MIL-C-10544 audio connectors have a maximum current rating of 500 mA which is sufficient to operate control relays and carry microphone excitation and audio level signals. This is very low when compared with the current-carrying capability of power connectors.

8-13 RF CONNECTORS

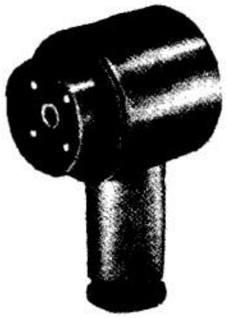
The radio frequency (RF) class of connectors make up a large and very important group. Frequently they are called coaxial connectors because a majority of them are coaxial in design and are used with coaxial cables. They are applied in most cases to circuits carrying RF current. The also are used in many system applications where they serve a shielding function for low-level signal circuits or for audio circuits over shielded single-conductor wire or coaxial cable. The shielding function is important whether it be to protect the center conductor from outside electrical fields or to protect nearby circuits

4-CONTACT PLUG (# 12 AWG Contacts)



MW 10F(M)A17
with nonremovable socket contacts

MW 10F(R)A17
with removable socket contacts



MW 10M(M)A17
with nonremovable pin contacts

MW 10M(R)A17
with removable pin contacts

NOTE: Available only with cable clamp,
accommodating cable OD 0.448 in. to 0.531 in.

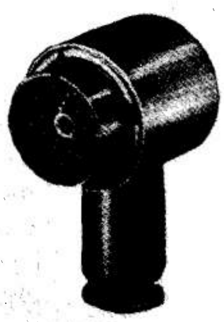
9-CONTACT PLUG (# 20 AWG Contacts)

MW 10M(M)B11
with nonremovable pin contacts

MW 10M(R)B11
with removable pin contacts

NOTE: Available only with cable clamp,
accommodating cable OD 0.292 in. to 0.343 in.

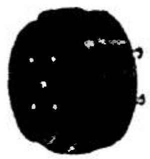
18-CONTACT PLUG (# 20 AWG Contacts)

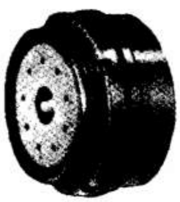


MW 10M(M)D17
with nonremovable pin contacts

MW 10M(R)D17
with removable pin contacts

NOTE: Available only with cable clamp,
accommodating cable OD. 0.448 in. to 0.531 in.

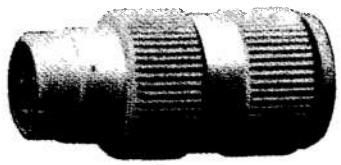
4-CONTACT MATING RECEPTACLE (# 12 AWG Contacts)		
	MW 20M(M)A00 with nonremovable pin contacts	MW 20M(R)A00 with removable pin contacts
	MW 20F(M)A00 with nonremovable socket contacts	MW 20F(R)A00 with removable socket contacts

9-CONTACT MATING RECEPTACLE (# 20 AWG Contacts)		
	MW 20F(M)B00 with nonremovable socket contacts	MW 20F(R)B00 with removable socket contacts

18-CONTACT MATING RECEPTACLE (# 20 AWG Contacts)		
	MW 20F(M)D00 with nonremovable socket contacts	MW 20F(R)D00 with removable socket contacts

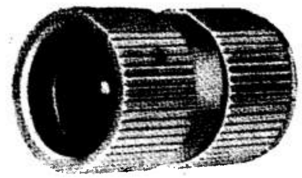
Figure 8-28. MIL-C-55181 Power Connector Receptacles[25]

(A) U-181/U CABLE PLUG



- 5 nonrigid contacts
- Barrel pin terminals
- Mates with U-182/U, U-229/U, U-230/U

(B) U-182/U CABLE PLUG

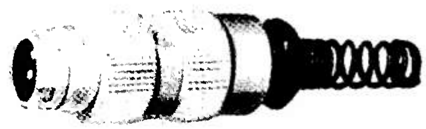


- 5 rigid contacts
- Barrel pin terminals
- Mates with U-181/U or U-183/U

(C) U-183/U PANEL RECEPTACLE

- 5 nonrigid contacts
- Solder terminals
- Mates with U-182/U, U-229/U, U-230/U

(D) U-228/U CABLE PLUG

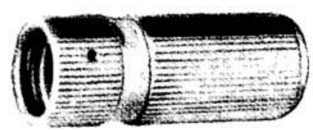


- 5 nonrigid contacts
- Barrel pin terminals
- Mates with U-182/U, U-229/U, U-230/U

(E) U-229/U CABLE PLUG

- 5 rigid contacts
- Barrel pin terminals
- Mates with U-181/U or U-183/U

(F) U-230/U CABLE PLUG



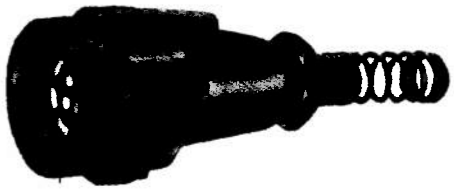
- 5 rigid contacts
- Barrel pin terminals
  (with built-in special purpose attenuator)
- Mates with U-183/U or U-228/U

SPECIFICATIONS

CURRENT RATING: 500 mA, max
VOLTAGE RATING: 60 V, max
CONTACT RESISTANCE: 40 mohm, max
INSULATION RESISTANCE: 1000 Mohm, min
DIELECTRIC STRENGTH: 500 VAC, rms
MILITARY SPECIFICATION: MIL-C-55116

Figure 8-29. Audio Connectors, 5-pin, per MIL-C-55116[25]

(A) U-77/U CABLE PLUG



- 10 rigid contacts
- Solder terminals
- Mates with U-78/U or U-79/U
- Grommet Dia, – 0.290 ± 0.010 in.

(B) U-78/U CABLE PLUG

- 10 nonrigid contacts
- Solder terminals
- Mates with U-126/U, U-127/U, U-161/U
- Grommet Dia, – 0.290 ± 0.010 in.

(C) U-79/U PANEL RECEPTACLE

- 10 nonrigid contacts
- Solder terminals
- Mates with U-77/U, U-127/U, U-161/U

(D) U-126/U PANEL RECEPTACLE

- 10 rigid contacts
- Solder terminals
- Mates with U-78/U

(E) U-127/U CABLE PLUG

- 10 rigid contacts
- Solder terminals
- Mates with U-78/U or U-79/U
- Grommet Dia, – 0.290 ± 0.010 in.

(F) U-161/U CABLE PLUG

- 10 rigid contacts
- Taper pin terminals
- Mates with U-78/U or U-79/U
- Grommet Dia, – 0.320 ± 0.010 in.

SPECIFICATIONS

CURRENT RATING: 500 mA, max
VOLTAGE RATING:
60 mV, min
50 V, max
CONTACT RESISTANCE: 15 mohm, max
INSULATION RESISTANCE: 1000 Mohm, min
DIELECTRIC STRENGTH: 500 VAC, rms, 60Hz
MILITARY SPECIFICATION: MIL-C-10544,

Figure 8-30. Audio Connectors, 10-pin, per MIL-C-10544[25] from the influence of the field around the connector center conductor[13].

True coaxial RF connectors are designed with a specific relationship between the outside diameter of the single contact, which lies on the axis of the connector, and the inside diameter of the outer sleeve or barrel of the connector shell. The relationship of these diameters, and the dielectric between them, determines the characteristic impedance of the connector. Coaxial connectors designed for RF use since World War II have been proportioned internally so that they will match particular RF cable impedance values. With these connectors, RF current in a coaxial cable circuit will not "see" any impedance discontinuity as it flows through connectors used either to extend the cable or to terminate it[13].

MIL-HDBK-216[15] is a technical information guide listing RF transmission lines and fittings which have been used by the Armed Services. It includes pertinent information regarding connector and cable compatibility, adapters for connecting different connector types, assembly techniques, and fabrication precautions. MIL-C-39012 describes requirements for the BNC, C, and N series of RF connectors.

RF connectors are used almost exclusively with flexible coaxial cables that employ either polyethylene or Teflon as the dielectric material. The basic purpose of the connector dielectric is to support the center contact of the connector. This support feature is shown in Fig. 8-31 in which Series C plug and jack assemblies are illustrated[13].

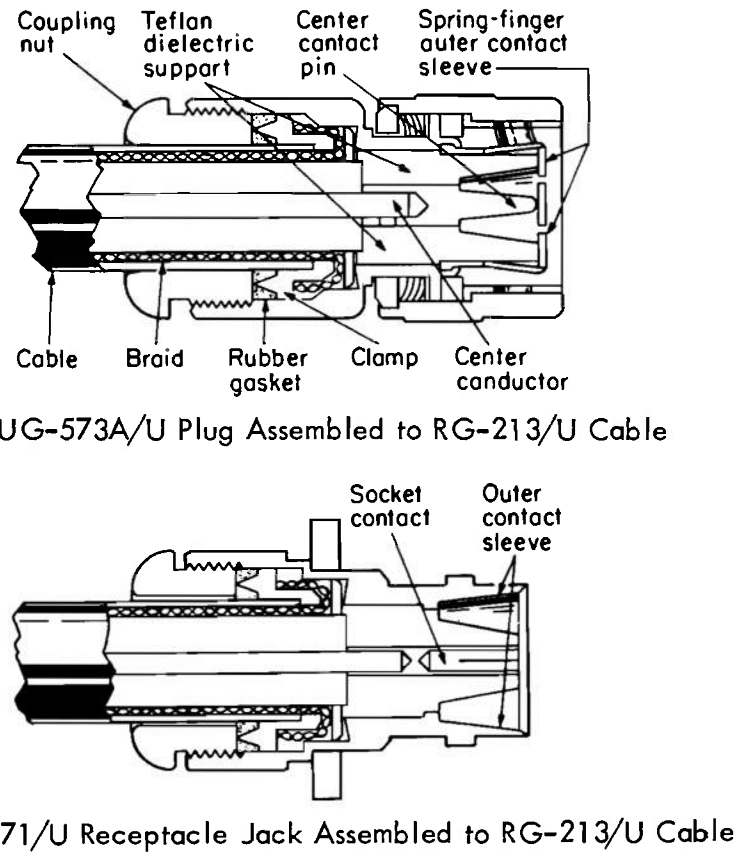


Figure 8-31. Series C,RF Connectors

Impedance discontinuity in RF connectors adversely affects circuits in which timing or, to be specific, phasing relationships are important. Radar applications are typical. An impedance discontinuity can produce reflections that result in multiple echo readings and ranging errors. The most commonplace example of reflection effects produced by impedance discontinuities in RF circuits is the multiple image or ghost pattern on a television receiver. The time difference in arrival of the signal and the signal echo or echoes produced by reflections at points of impedance discontinuity is measured by the spacing of the principal cathode ray indicator tube picture or pip and the echo pictures or pips[13]

Fig. 8-31 shows how continuity is preserved in passing through a mated pair of RF connectors. The UG-573A/U plug and UG -571/U receptacle jack are illustrated unmated to reduce the possibility of confusion. The plug carries the male center contact or pin and the male outer contact or sleeve. The receptacle jack has the socket contact at its center, and the inside wall of the shell is designed to accept the spring-fingered outer contact sleeve of the plug. Referring to the upper illustration of the assembled plug, the RG-213/U coaxial cable enters the back of the plug where accessory fittings including a rubber gasket provide clamp action over the cable jacket. The center contact pin of the connector is soldered to the center conductor of the cable, and the dielectric of the cable butts directly against the Teflon dielectric insulation of the connector. The cable shield braid, which is the outer conductor of the circuit, is clamped against the inside wall of the connector shell. The RF current on the inside surface of the cable shield passes on over the inner wall of the connector shell to the spring-fingered outer contact sleeve of the connector. The coupling nut of the plug does not enter into the electrical circuit at all. The UG-573A/U and UG-571/U connectors are examples of modern design that introduce very little impedance discontinuity into an RF circuit even at microwave frequencies[13].

RF connectors designated as the BN type are small lightweight connectors and are designed for use with small cables such as RG-58/U and RG-59/U. These connectors have been used for video, IF trigger pulse, and low-power RF applications. They are not constant-impedance connectors and therefore, are not recommended for applications where frequencies are in excess of approximately 200 MHz unless the electrical requirements of the circuit are not critical. They may be used at peak voltages up to 250 V.

Those connectors designated as the BNC series are small, lightweight, weatherproof connectors employing a bayonet-type coupling, a metal-to-metal cable clamp, and polytetrafluoroethylene dielectric. They have a nominal impedance of 50 ohms, a maximum peak voltage rating of 500 V, a practical frequency limit of 10,000 MHz, and are designed for use with small-size cables.

Connectors designated as C series are medium-size weatherproof connectors employing a bayonet-type coupling, a metal-to-metal cable clamp, and polytetrafluoroethylene dielectric. They have a nominal impedance of 50 ohms, a maximum peak voltage rating of 1,500 V, and a practical frequency limit of 10,000 MHz. These connectors are similar to series N connectors in that they are designed for use with medium size cable. These connectors are to be used by Departments of the Navy and Air Force and their contractors in preference to N, HN, QDS, and UHF series connectors wherever practicable. Where a more positive screw coupling is required, the SC series (threaded coupling) may be used.

The connectors designated as N series are medium-sized, weatherproof connectors employing a screw-type coupling, a metal-to-metal cable clamp and, with the exception of those used with cables RG-81/U and RG-82/U, polytetrafluoroethylene dielectric. They have a maximum peak voltage rating of 1,500 V and a practical frequency limit of

10,000 MHz. They are similar to series C connectors in that they are designed for use with medium sized cables. The N series consists of connectors having nominal impedance characteristics of 50 and 70 ohms. The 50-ohm connectors will not properly mate with the 70-ohm connectors; however, they may be used with 70-ohm cables where impedance matching is not important.

The series LN connectors are similar to but larger than Series N, and are used only with RF cables RG-14/U, RG-74/U, and RG-94/U. They are 50-ohm and are weatherproof. The approximate peak voltage rating is 1,000 V.

The connectors described as UHF connectors are available in small and large coaxial types, and may be used with numerous small- and medium-sized cables. They are not constant-impedance connectors and therefore will introduce some voltage reflection. They are generally satisfactory at frequencies up to 200 MHz and may be used with caution up to 500 MHz. They may be used at peak voltages up to 500 V. These connectors are general-purpose connectors, but they should not be exposed to the weather.

SECTION IV PROTECTIVE DEVICES

8-14 INTRODUCTION

Electrical system overcurrent protective devices serve to disconnect individual circuits, components, or equipment from a power source when a potentially damaging fault occurs in the system. Devices used to provide this protection include fuses and circuit breakers of various types, ratings, and interrupting characteristics.

In a military vehicle which may experience combat or tactical duty, it is desirable to protect critical and noncritical circuits independently. Circuit designs should preclude the possibility of losing mission capability through circuit interruptions that could occur as a direct result of faults in circuits nonessential to completion of the mission. As a general rule circuit protection is installed in a military vehicle to protect the wiring rather than individual components.

When selecting a fuse or a circuit breaker, the equipment designer should answer the following questions:

1. What is to be protected?

2. What voltage is to be interrupted by the protector?

3. What is the normal current through the component to be protected?

4. What is the maximum abnormal current through the component?

5. How long can the component carry this abnormal current without damage?

6. Will the protector interrupt the abnormal current before wiring or component damage occurs?

7. Will the circuit protector be subjected to any vibration, shock, or other environmental conditions affecting its performance[13]?

Generally, overcurrent protective devices operate on a time element principle, where, on a short circuit, the protective device operates practically instantaneously, but, on overloads, the operation has a definite time lag that varies inversely with the overload[4]. This overload dependent circuit clearing characteristic is illustrated in Fig. 8-32. In the protection of circuits, a great deal of confusion exists as to the necessity for speedy interruption of the circuit. Since the circuit protector must be considered from the viewpoints of protection against short circuits and/or protection against overloads, it is important to note that the conditions of protection are almost diametrically opposite for these conditions. To protect against short circuits, speed is wanted – the more speed the better. In protection against overloads, some

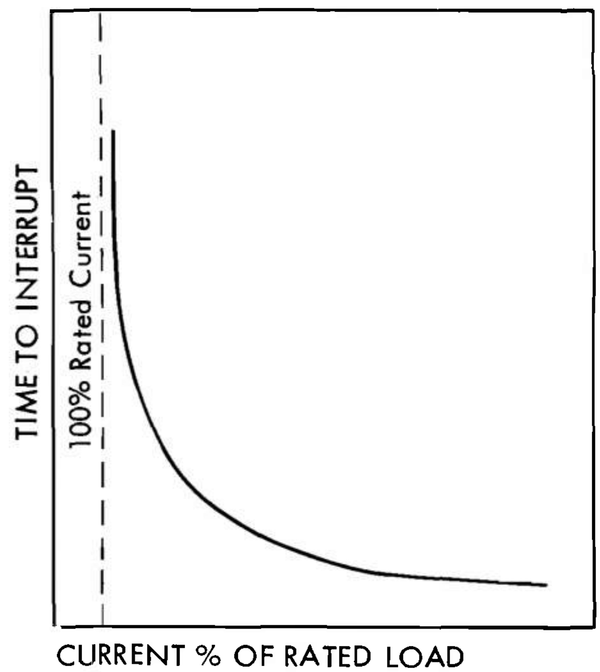


Figure 8-32. Basic Current-time-to-interrupt Characteristic

allowance has to be made for harmless temporary overloads that often occur in the warmup periods when equipment is first turned on. In this instance, the circuit protection device should not operate unless the overload persists.

The characteristics influencing current interruption in an AC circuit are different from those in a DC circuit. The current in an AC circuit periodically passes through zero. It is only necessary, therefore, to prevent reignition of the arc after one of these zero points to interrupt the circuit. It follows that deionization of the arc gap when current is near zero is very important. The arc will be extinguished when the dielectric strength of the gap permanently exceeds the voltage across the gap that tends to re-establish the flow of current in the circuit[4].

When there is direct current in a circuit, there is no periodic current zero; therefore, to open a DC circuit automatically, as required of a fuse or a circuit breaker, the current must be forced to zero by some means. There are two major ways of doing this. These are by increasing the arc resistance until the voltage drop across the arc equals the circuit voltage, and by decreasing the temperature of the arc and thereby decreasing the ionization in the arc.

Arc resistance is increased either by lengthening the path of the arc or by constricting the diameter of the arc. It also may be accomplished by a combination of the two[4].

In the method of circuit interrupting employing the principle of arc temperature reduction, a fusible element (usually silver) surrounded by a filler (usually silica) is enclosed in the protective tubing of a cartridge fuse. When the relation between current and time is such as to melt the fusible element, an arc is formed. The heat from the arc vitrifies the filler. Because the filler removes heat from the arc more rapidly than it is being generated, ionization is reduced and the current falls to zero.

When considering the selection of a protective device for use in a tank-automotive vehicle, the first choice should be an automatic reset circuit breaker. The next choice would be a manual reset type of breaker, and the last choice should be a fuse.

Circuit breakers can be reset in less time and with less trouble than is required to replace blown fuses, and repair parts are seldom required. They are, therefore, preferable where continuity of service is an important consideration or where frequent fuse replacement may be expected. The first cost of circuit breaker equipment is somewhat more than the cost of fuse equipment but, under severe service, circuit breakers will be less expensive over the life of the equipment[13].

The automatic reset circuit breaker is preferred because the recycling of the breaker produces an audible sound that alerts operating personnel to the fact that a fault exists. Conversely, the manual reset breaker will open to clear a fault, but the open circuit can remain undetected until a serious need arises for the functions in the protected circuit.

Although fuses generally are not used extensively in tank-automotive electrical systems, certain auxiliary equipment – such as electronic or radio communication systems – frequently contain fuses because of functional necessity and replacements are necessarily provided with this equipment. Extensive fuse application in a vehicle would require a number of replacements for each fuse rating employed, thereby requiring storage provisions and a repair part procurement effort to maintain the vehicle in the field.

8-15 FUSES

Cartridge fuses commonly used in electronic equipment are known as normal-lag, quick-acting, and time-delay. These descriptive names indicate the speed at which the fuses interrupt the current in a circuit. Physical sizes and available ratings are given in Table 8-15.

TABLE 8-15. PHYSICAL SIZES AND RATINGS OF CARTRIDGE FUSES[26]

Type	Physical size, in.	Ratings	
		V	A
Normal-lag	1-1/2 x 13/32	32, 250	1-50
	1-1/4 x 1/4	32, 125, 250	1/16-20
Quick-acting	1 x 1/4	32, 125, 250	1/500-5
Time-delay	1-1/2 x 13/32	32, 125	1-30
	1-1/4 x 1/4	32, 125	1/100-5

As previously described, fuses act on a time-element principle. All fuses are designed to carry rated load indefinitely and stated overloads for varying periods of time, as shown in Table 8-16. They also have a maximum voltage rating. This is the maximum voltage at which a fuse can permanently interrupt the current in a circuit within a predetermined time[13].

The basic rule in fuse application is: use the highest fuse rating consistent with adequate protection. Fuses, like any other device, are prone to aging. They should be operated below their rated current whenever possible[13].

Fuses should be connected to the load side of the main power switch. Holders for branch-line fuses should be such that when correctly wired, fuses can be changed without the hazard of accidental shock. At least one of the fuse-holder connections normally should be inaccessible to bodily contact, and this terminal should be connected to the supply; the accessible terminal should be connected to the load[13].

TABLE 8-16. TYPICAL INTERRUPTING TIMES FOR STANDARD FUSE TYPES[26]

Type	Rating, %				
	100	100	135	150	200
Normal-lag	life	life	0-1 hr	*	0-2 min
Quick-acting	life	*	*	0-10 sec	0-5 sec
Time-delay	life	life	0-1 hr	*	5-60 sec

* Not rated

Fusing of circuits should be such that rupture or removal of a fuse will not cause malfunction or damage to other elements in the circuit[13].

Provisions for storage of replacement fuses should be made at an accessible location[13].

Fuses may blow because of overheating brought about by poor contacts or overcrowding rather than because of any fault in the circuit or equipment[13].

Fuses with a rating of 1 A and less are fragile and susceptible to rupture by vibration or shock. The reliability of the fuse must be considered with the probability of circuit malfunction and the necessity for protection[13].

If simple element fuses are used to protect vibrators or choppers, they may be subjected to cyclic fatigue brought about by the expansion and contraction of the element because of the intermittent current flow. Time-delay fuses, which usually have elements capable of withstanding expansion and contraction, are better under these circumstances[13].

A very common error in circuit protection is the use of a protector with current-time-to-blow characteristics that do not correspond with the characteristics of the equipment or component to be protected. The outstanding example of this is the use of normal-lag fuses to protect motors, especially when the motor takes a high starting current. Time-delay fuses, which can carry both the starting current and running current of the motor, are the proper devices to be used in this instance[13].

8-15.1 CHARACTERISTICS OF TYPICAL FUSES

Normal-lag cartridge fuses are composed of an insulating cylinder surrounding a fusible element that is connected to metal end caps sealing the cylinder. Fuses that have a high interrupting capacity have a powder or sand filler in the cylinder around the fusible element to quench the arc that occurs during circuit interruption. Since they are used when no special requirements exist, except that equipment and components are to be protected against overloads, normal-lag fuses are the most widely used fuses in electronic equipment. Their current-time-to-blow characteristics are shown in Fig. 8-33[13].

As their name implies, quick-acting fuses have a shorter time-to-blow than normal-lag fuses for the same overload. They are used where the normal-lag characteristics would not give adequate protection to such items as instruments and delicate equipment that do not have any overload capacity. When quick-acting fuses are used in measuring circuits, their resistance should be taken into account. As indicated in Table 8-17, the resistance values of these fuses vary over a wide range. The values listed in the table should be used as guides only, since the resistance of any fuse will differ from the tabular values because of normal commercial tolerances, the degree of loading of the fuse, and variations between manufacturers[13].

Time-delay fuses are used to protect equipment that takes a high initial current that later drops off to the operating current. Examples of this are the high inrush current compared with the running current of an electric motor, or the initial surge current of a capacitor when voltage is first applied[13].

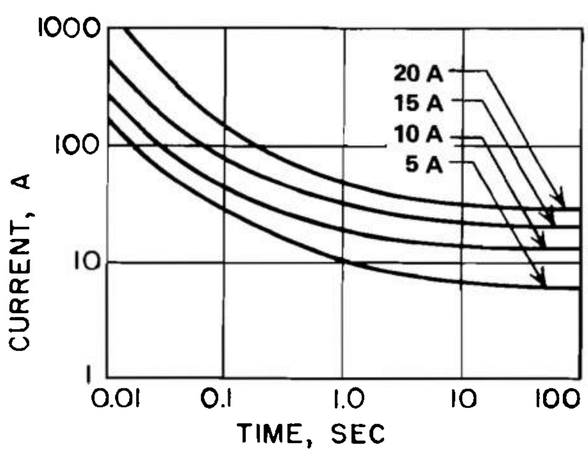


Figure 8-33. Current-time-to-blow Characteristics of Normal-lag Fuses (32-V Rating)

TABLE 8-17. RESISTANCE OF QUICK-ACTING FUSES[26]

Ampere rating	Cold resistance, ohm	Hot resistance, ohm
1/500	2500	3300
1/200	450	770
1/100	150	310
1/32	24	83
1/16	6.6	10.6
1/8	1.6	3.1
1/4	2.9	9.6
3/8	1.9	10.5
1/2	1.0	4.3
3/4	0.78	4.7
1	0.35	0.75
1-1/2	0.10	0.33
2	0.07	0.21

The construction of a time-delay fuse is different from that of either a normal-lag or a quick-acting fuse. Normal-lag and quick-acting fuses have simple elements that melt on overloads, but the time-delay fuse has a compound element composed of a fusible link and a thermal cutout. The fusible link operates only on short circuits or very high overloads, and the thermal cutout functions only on low or moderate overloads[13].

A limiter is an aircraft fuse with a high melting point compared with ordinary fuse elements. It has characteristics adapted to protecting a system by opening rapidly under heavy fault currents. The high melting point, 1750°F in some types, greatly reduces the effects of ambient temperature. Shown in Fig. 8-34 is a series of time-to-interrupt characteristic for the limits. Curves are for typical limiters; however, units are available in ratings as high as 500 A.

8-15.2 SPECIFICATIONS

Fuses, and the fuseholders associated with them, in common with other components used for military purposes, have specifications that cover their uses and requirements. Some of these specifications have a basic section

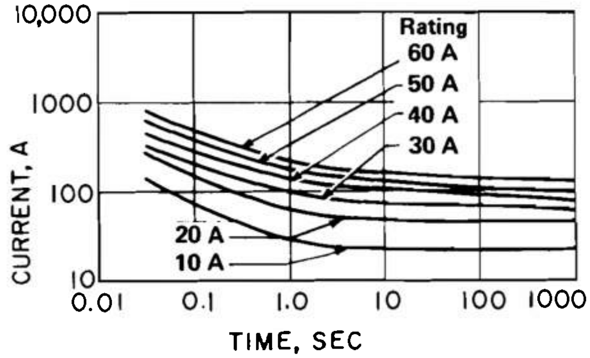


Figure 8-34. Current-time-to-blow Characteristics of Aircraft Fuse (Limiter)

that specifies materials of which the fuses are made and the test methods and requirements that fuses must meet. Appended to these specifications are detailed specification sheets that show dimensions and details of the fuses covered by these specifications. MIL-STD-1360 has been established to identify requirements for the selection of fuses, fuseholders, and associated hardware. The purpose of the Military Standard is to provide the equipment designer with a list of fuses and their associated hardware; control and minimize the variety of fuses used in military equipment; and establish criteria pertinent to the choice, application, and use of fuses, fuseholders, and associated hardware in military equipment applications. Therefore, the design engineer is referred to MIL-STD-1360 for a listing of current standards and specifications.

8-16 CIRCUIT BREAKERS

A circuit breaker, like a fuse, can be used to protect either circuits or equipment. Additionally, the circuit breaker has overload response characteristics comparable to a fuse in that it must be able to carry rated current indefinitely and to trip with a definite time-delay characteristic when an overload occurs. As a circuit protective device it also must be able to interrupt the short circuit current available in the circuit as well as withstand the maximum circuit voltage.

One class of circuit breakers can serve as a switch for energizing a circuit and, when closed, act as a protective device. When used as a switching device it should be able to make and break rated current without excessive arcing at the contacts.

The prime requisite of any circuit breaker is to provide proper circuit protection through its tripping characteristic. Such requirements as operating temperature, humidity, pressure, shock, vibration, and fungus resistance—while necessary for the proper functioning and reliability of the breaker—are secondary in importance to the tripping characteristic.

There are two basic circuit breaker types—magnetic and thermal. The magnetic breaker uses the current through a coil to sense circuit loading, and circuit interruption occurs in response to a preset magnetic field strength created by the coil. The thermal type employs the heat generated in a resistance element to cause a change in the position of a bimetallic element carrying the circuit contacts.

Each type is discussed in greater detail in the paragraphs that follow.

8-16.1 MAGNETIC CIRCUIT BREAKERS

The tripping mechanism of a magnetic circuit breaker is actuated by a solenoid that has a movable iron core within a hermetically sealed tube extending through and below the coil. The tube is completely filled with a viscous liquid that controls the rate at which the core will be attracted by the solenoid. This controls the time-delay characteristic of the circuit breaker on overloads[26].

When an overload occurs, the movable core, which is held away from the pole face by a compression spring, is attracted by the solenoid at a rate that is a function of the ampere-turns of the coil, the viscosity of the fluid, and the size of the orifice or the passage around the core. As the core moves further into the magnetic field of the solenoid, the flux increases until it is strong enough to attract the armature sufficiently to trip the breaker. Thus, any desired time-delay characteristic can be readily built into a circuit breaker. The working parts of a magnetic circuit breaker are shown in Fig. 8-35[26].

The action of a circuit breaker tripping on a short circuit is different from its action on overloads. When a short circuit occurs, the current through the coil is of such a high magnitude that the magnetomotive force produced overcomes the reluctance of the airgap, attracts the armature, and tripping is instantaneous. "Instantaneous" is a qualifying term indicating that no delay is purposely introduced in the action of the circuit breaker. There is necessarily a time delay (about 0.01 sec) between the occurrence of a short circuit and the tripping of the circuit breaker because of the inertia of the tripping mechanism[26].

Several types of circuit breakers are used in electronic circuits. The conventional type employs the series overload trip. Other methods commonly used are the shunt trip, and the relay trip. The distinguishing features of

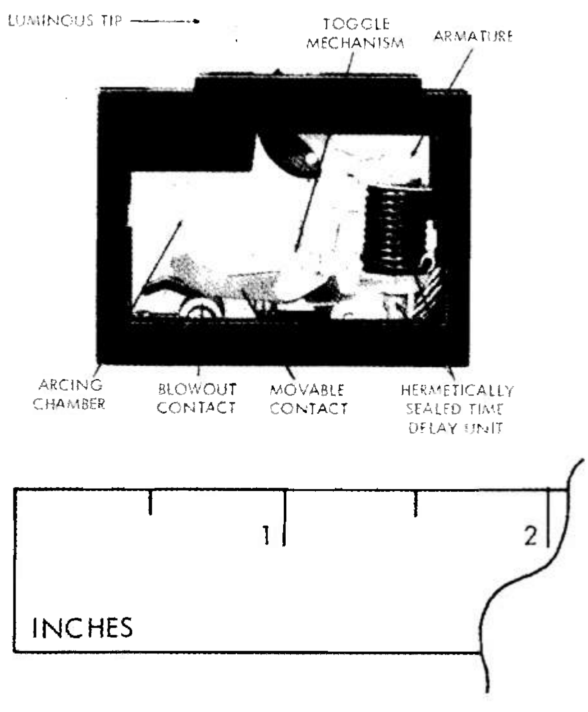


Figure 8-35. Working Parts of a Magnetic Circuit Breaker

each type are discussed in the paragraphs that follow[26].

The series overload trip circuit breaker application is the best known and most widely used to protect electronic circuits and equipment. The trip coil and contacts are in series with the load across the supply voltage. This arrangement is used when the circuit breaker acts as the main switch and overload protective device in electronic equipment, or is used for overload and short circuit protection of components[26].

In shunt trip applications the trip coil is in parallel with the load, and the contacts are in series with both the load and the trip coil. Circuit breakers of this type have three terminals per pole—line, load, and shunt-trip terminals. One end of the trip coil is connected internally to one of the load terminals and the other end to the shunt-trip terminal. By using this type of circuit breaker, remote switching is possible through circuit closing contacts located in a control or safety interlock. These interlocks can be sensitive to, and their operation dependent upon, temperature, pressure, humidity, time, or any other parameter that can be measured[26].

The relay trip type differs from the series and shunt-trip types by having the trip coil and the contacting element electrically isolated from each other. This type of circuit breaker has four terminals per pole, since the trip coil and the switching mechanism each need two terminals. Since the coil circuit is independent of the contact circuit, it may be operated at a different voltage from the line voltage. When the equipment to be protected is operating at high voltage or high current, the trip coil of the circuit breaker, therefore, may be operated at a low voltage or low current and still give all the protection required by the equipment[26].

From the standpoint of tripping characteristic, there are two types of magnetic circuit breakers. These are instantaneous circuit breakers, which are primarily used where there is no current inrush or surge and whose principal use is to protect meters and instruments; and time-delay circuit breakers, which are used to protect equipment wherein a certain amount of inrush and surge current is permissible if the duration of the current is not excessive[26].

Representative time-delay characteristics are shown in Fig. 8-36. Comparing these curves will illustrate the wide range of tripping characteristics that are available to the design engineer. In Fig. 8-36, Curve 1 allows the longest time delay and is used where a circuit is protecting an individual motor; Curve 2 is an intermediate characteristic used in circuits where there are several pieces of equipment; and Curve 3 allows a high inrush current for a relatively short time and is used in the protection of electronic equipment and components[26].

The curves in Fig. 8-36 show the trip characteristics of circuit breakers at 77°F ambient temperature. When the temperature varies from this value, correction curves are required to show how the time delay is affected by the ambient temperature. Different liquids used in the time-delay tube give vastly different ambient temperature characteristics. Although ambient temperature affects the time delay of a magnetic circuit breaker, it does not influence the current-carrying capacity or the instantaneous-trip point of the breaker. These points are determined by the magnetomotive force produced by the current through the trip coil, and this function is practically independent of temperature. The ambient temperature effects that do exist are desirable since at low temperatures equipment can carry an overload for a greater time, and at high ambient temperatures for a shorter time, than at normal temperature[26].

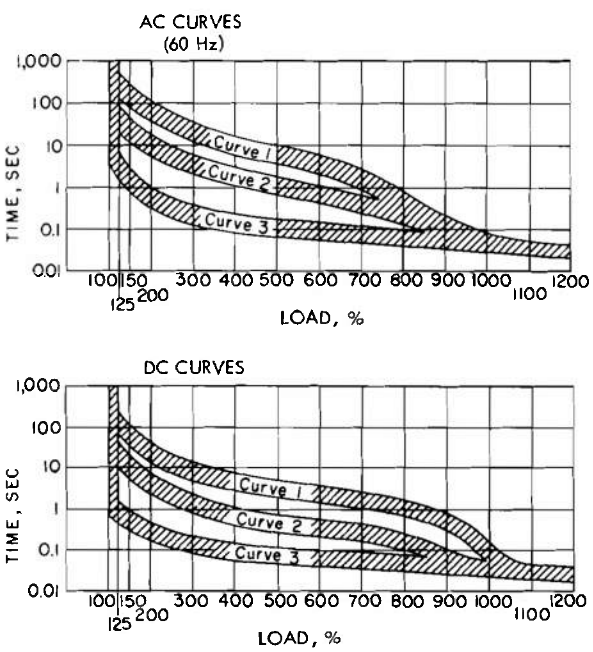


Figure 8-36. Tripping Characteristics of Magnetic Circuit Breakers for Ambient Temperature of 77° F

In tactical and combat vehicles the usage of magnetic circuit breakers is minimal compared with thermal breakers. Factors influencing this are component cost, requirement for resetting, and breaker location and identification.

Magnetic circuit breakers are described in MIL-C-5809, MIL-C-28710, and MIL-C-39019.

8-16.2 THERMAL CIRCUIT BREAKERS

The tripping action of thermal circuit breakers depends on the heating effect of an electric current in a bimetallic element. When rated current or less flows through the bimetal strip, the circuit breaker remains in the closed position. On overloads, the bimetallic element is bent by the heating effect of the current until a latch releases the movable contact or contacts and opens the circuit[26].

Thermal circuit breakers, like magnetic circuit breakers, have an inverse time-delay characteristic. A large current will cause the circuit breaker to trip in a shorter time than a small current. Since thermal circuit breakers require a finite time for the bimetallic element to heat up, regardless of the current, they do not have an instantaneous trip time as defined under magnetic circuit breakers. Their time-delay characteristics are shown in Fig. 8-37[26].

Variations in ambient temperature may change the characteristics of thermal circuit breakers to the point where adequate protection is not given to equipment, or else the circuit breaker may operate needlessly. At low temperatures the circuit breaker may not give adequate protection if the characteristics of the bimetallic strip are not coordinated with the equipment that the circuit breaker is to protect; while at higher temperature the bimetallic strip may be so heated that it causes unnecessary circuit interruptions.

Under short-circuit conditions, a thermal or time-delay protector with a relatively low current rating may require more time to open than a fast-acting type with a considerably higher rating[26].

Thermal circuit breakers are described in MIL-C-5809, MIL-C-7079, MIL-C-13516[27], and MIL-C-28710. Thermal breakers preferred for military vehicles are equipped with waterproof connectors of the friction retainment type (par. 8-11.2.2) and are listed in Table 8-18. These breakers conform to MIL-C-13516 and are illustrated in Fig. 8-38. They are waterproof in accordance with MIL-E-13856.

8-17 SLIP RINGS

The primary function of an electrical slip

TABLE 8-18. WATERPROOF CIRCUIT BREAKERS

AMPERE RATING	ORDNANCE PART NO.	MILITARY STANDARD
15	8376915	M13516/1-1
20	8376916	M13516/1-2
25	8376917	M13616/1-3
30	8376918	M13516/1-4

ring is to provide a continuous path for electrical power or signals between a stationary surface and a rotating surface. Slip ring capabilities range from conducting sensitive communication and instrumentation signals to carrying high currents supplying motor and other high-power devices. In a tank-automotive type vehicle, the most common slip ring application, aside from those in the generating system, is found in the rotating turret or cupola. Typical turret slip rings must have adequate circuit paths for carrying drive power, drive control and feedback signals, operator communications, and radio frequency energy to the turret.

Slip rings generally consist of circular metallic rings and mating conductive brushes. In tank-automotive applications, the low temperature requirement prohibits the use of rotating discs in a viscous metal such as mercury, although this normally would be a suitable scheme. The ring and brush combinations exist in many configurations and types. Rings are arranged in flat, concentric, and drum configurations.

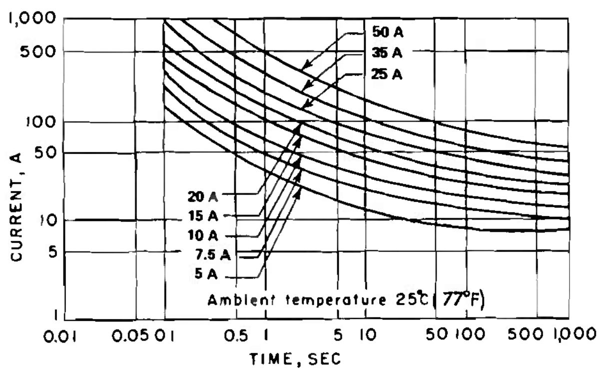


Figure 8-37. Thermal Circuit Breaker Time-delay Characteristics[26]

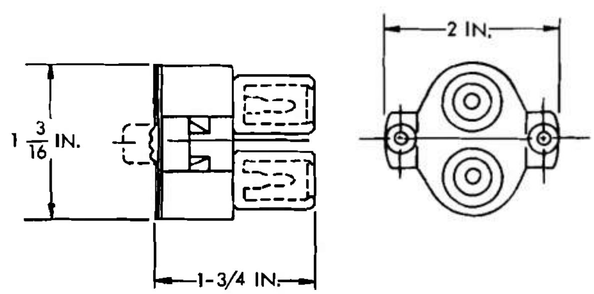


Figure 8-38. Waterproof Circuit Breaker per MIL-C-13516[27]

The flat ring assembly consists of slip rings mounted in pairs above and below insulating barriers which in turn are separated by spacers. As many as 16 rings may be stacked per inch depending on circuit voltage and current. Some assemblies incorporate 500 or more rings, requiring more vertical space than the concentric ring type, but less than the cylindrical type. This assembly, usually the least expensive, can be packaged as a self-contained unit complete with bearings, seals, and housing.

In the cylindrical or drum assembly, the rings run vertically around a shaft with the brush contact made on the vertical rather than the horizontal plane. An important feature is the low intercircuit capacitance that helps minimize crosstalk between circuits. It lends itself ideally for high current applications because the brush area can be greatly increased for a given ring size. When fabricated with raised barriers between the rings, the creepage path from ring to ring can be increased effectively. For a given shaft length, however, the total number of rings is only 1/2 to 2/3 the number of flat rings that could be installed.

The concentric or pan assembly consists of rings having various diameters mounted concentrically on a flat insulating support plate. These assemblies can be mounted back to back and brushed from both above and below. They can be made in multiples and stacked vertically with space between the sections for the brushes. A large number of circuits can be handled with this method since up to 30 or more concentric rings may be mounted on each side of the support plate. This most expensive method of assembly is preferred where the height or length of the shaft is limited.

Which type of ring arrangement is chosen depends upon size limitation, number of circuits, cost, current-carrying ability, crosstalk, or intercircuit capacitance requirements. The ring configuration dictates in part the brush type and arrangement. Brush configurations include the piston, leaf, or wire types.

The major factors to be considered in the design of a slip ring device are the mechanical, electrical, and environmental characteristics. Mechanical characteristics encompass surface speed, wear, torque, weight, structural strength, and configuration. Surface speed is a function of the speed of rotation and the placement of the ring with respect to the axis. High surface speeds cause rapid brush wear; however, tank-automotive turret applications do not experience high surface speeds. Wear is inherent in any system comprised of moving or sliding surfaces. A properly designed unit using proper combinations of brush and ring materials will reduce wear to a minimum. Protection against abrasive foreign material is also a necessity for minimizing wear.

Torque, or resistance to rotation caused by brush friction, should be a consideration only where the source of rotational effort is marginal or critical.

Loading of the slip ring assembly will determine bearing size and placement.

Electrical requirements essentially determine the size, complexity, and cost of the assembly. Electrical parameters include:

1. Current capacity. The current that the slip ring must transmit without excessive heating, voltage drop, or arcing. This will determine ring size, brush type and material, and contact area.

2. Noise. Sensitive circuits used in instrumentation and communications are affected by electrical noise. Slip ring noise is a direct result of variations in contact resistance due to position, motion, or thermal effects. This noise can be minimized by proper ring surface finish, brush and ring materials, brush pressure, relative sliding velocity, and mechanical precision in the fabrication of components.

3. Crosstalk. Crosstalk is the electrical interference between two circuits created by electrical leakage through the insulation, or by capacitive or inductive coupling between the rings. Crosstalk reduction can be realized through high insulation resistance and low ring-to-ring capacitance. Factors influencing crosstalk resulting from electrostatic coupling are the mechanical proximity of the conductors to each other and the dielectric constant of the insulating material. There are methods available to provide electrostatic shielding, and these can be employed in the assembly design when necessary.

4. Dielectric Strength. Determines the voltage breakdown limit between adjacent rings and conductors. In tank-automotive applications, the working voltage is generally low and dielectric strength of the ring assembly is not a major consideration.

Impedance matching becomes important in passing high frequency, particularly at high power, through the slip ring assembly. A special coaxial joint may be included to maintain a uniform impedance at the rotating surface. This requirement can occur in a tank-automotive type vehicle where a vehicle-mounted transmitter is feeding a turret-mounted antenna.

Environmental requirements for a slip ring employed in a tank-automotive vehicle are resistance to shock, vibration, moisture, dust, and temperature extremes. Slip ring units that are mounted in the lower portion of the vehicle, at floor level or below, are subjected to dirt, dust, and, in amphibious vehicles, are occasionally under water.

Tracked vehicles generally experience a high level of vibration and shock, thus subjecting the slip ring to mechanical excitations. This can result in brush bounce if brush mounting design is inadequate.

The tactical vehicle designer using rotary electrical couplings has two design alternatives in the basic slip ring configurations, either peripheral or center-of-rotation devices.

The peripheral ring, in a turret application, extends the entire circumference of the basket which can be in the order of 20 ft. The advantage of this configuration is found in the freedom to place it at any elevation within the vehicle in order to conserve space. Disadvantages of this design are the high relative speed, difficulty with shielding, practical limits on the number of circuits, and difficult mechanical alignment. Fig. 8-39 shows a single peripheral ring used in a tactical vehicle to provide high power to a turret-mounted machine gun.

Center-of-rotation designs permit the arrangement of a large number of rings in a compact configuration. In addition, the transfer of air or hydraulic fluid through this type of slip ring assembly is accomplished easily. A typical assembly of this type (Fig. 8-40) is used on the M60A1E2 Tank. Table 8-19 provides a list of slip ring assemblies now in use.

Specifications for new slip ring assemblies should include the number of circuits required, speed of rotation, voltage per circuit, amperage per circuit, frequency per circuit, noise limits, crosstalk limits, contact resistance limits, and definition of the operating environment.

8-18 ENCLOSURES

An enclosure is a mechanical device which surrounds electrical or electronic items to serve any or all of the following functions:

1. To provide physical protection for the enclosed items. Possible hazards that exist in a tank-automotive vehicle for which protection is required are water, moisture, dirt, oil, impact, fungus, and corrosion.

2. In addition to providing environmental protection for the internal electrical equipment, the enclosure provides protection to the external environment including shock protection for personnel, protection against burns or fires produced by conductive objects coming in contact with energized terminals,

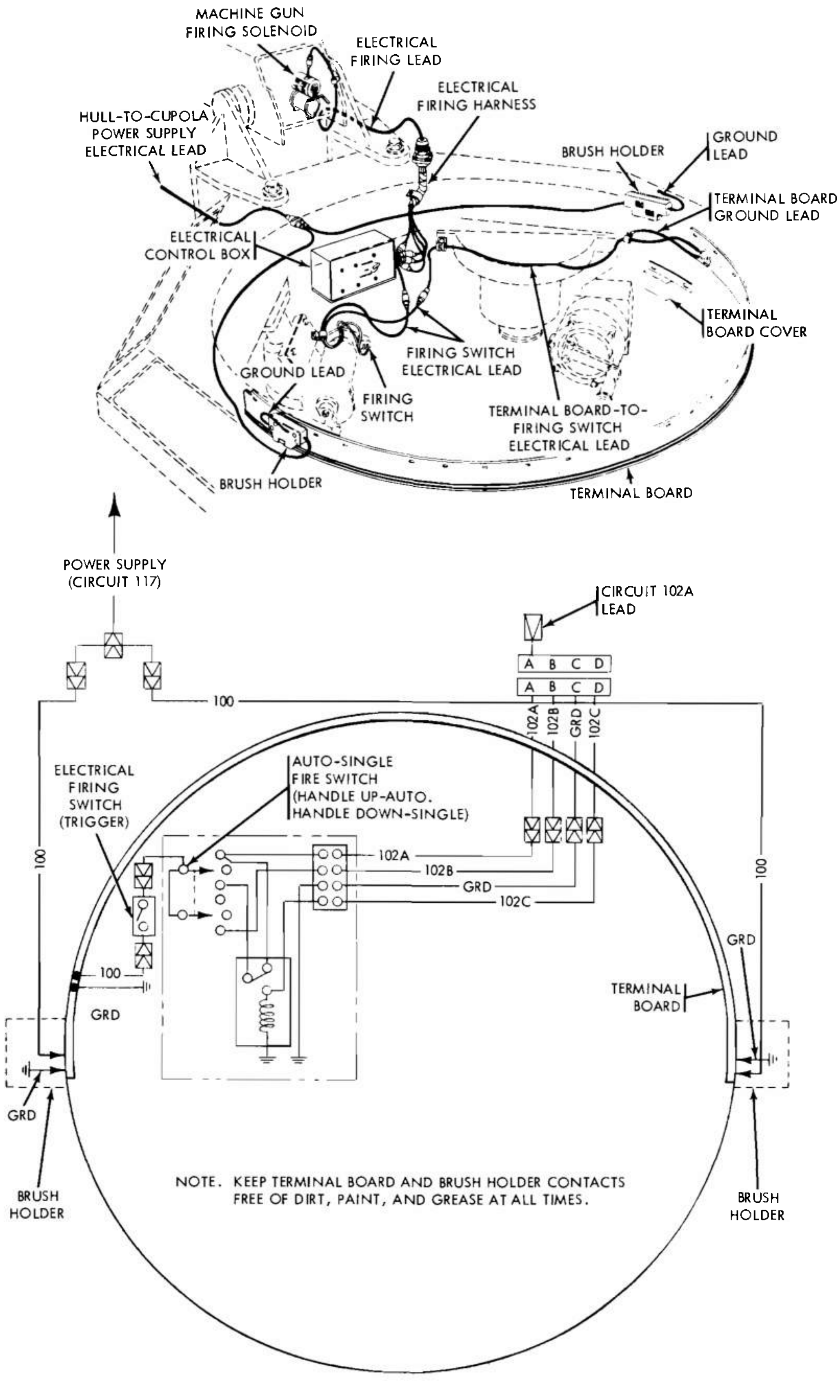


Figure 8-39. Peripheral Slip Ring Installation

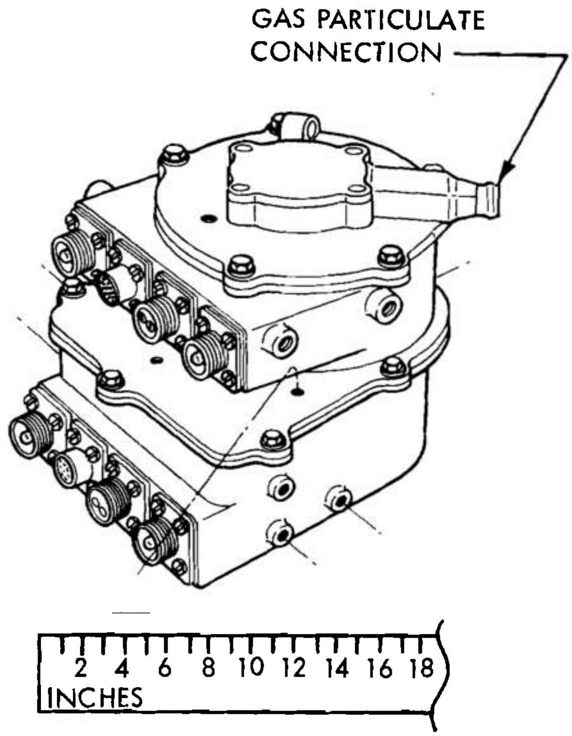


Figure 8-40. M60A1E2 Slip Ring Assembly

and protection against internally generated sparks igniting an explosive atmosphere.

3. To provide means for cooling or ventilating items within the enclosure. Internal components can be cooled by conduction, radiation, convection, or forced convection. Where an enclosure is to remain airtight or watertight, conduction is the prime cooling medium. Heat producing components are thermally connected to the internal surface of the enclosure so that heat conduction to the outside surface can occur where it is then dissipated by convection from the surface itself. The enclosure, if not sealed, can serve to provide component cooling by natural convection through openings designed to produce a chimney effect or by employing a fan to produce forced convection.

4. To provide support for internally mounted subassemblies, parts, and items. The internal structure of an enclosure generally provides mounting for components through enclosure-attached brackets, chassis, panels, and other structures.

5. To provide reduction or attenuation of internally generated noise or electrical interference. The enclosure can be so designed to provide soundproofing for internally generated noise which may originate from rotating machinery, vibrators, or from a magnetostriction source. Electromagnetic interference (EMI) can be attenuated by material selection and the use of conductive gasketing. EMI can originate in motors, static inverters, regulators, or other devices that control vehicle power.

6. To provide test points that will allow measurements to be made on an energized system. These points also can be used for troubleshooting or adjustment monitoring.

TABLE 8-19. SLIP RING APPLICATIONS

Application	Part Number	Power Rings		Signal Rings	
		Number	Capacity, A	Number	Capacity, A
M60A1E2 Hull/Turret	11607882	2	300	40	7.5
M60 Cupola	11615882	None		160	7.5
M551	10941028-1	2		14	
LVTP7	7389400	2	200	12	
XM741	8437092	2	100	24 Signal 2RF (30-70) MHz	

7. To provide shock and vibration isolation for internal components. Tracked vehicles in the tank-automotive category experience a high level of shock and vibration. One of the greatest requirements of the enclosure in a vehicle of this type is to provide shock isolation. The primary purpose of an enclosure is to protect against the environmental hazards encountered in a tank-automotive vehicle. In addition to dust, normal off-the-road dirt, and water exposure, the vehicle interior is subjected to hosing down and steam cleaning. These operations must be allowed for in the design of a protective enclosure. MIL-STD-108 provides guidance regarding the appropriate enclosure design for various environmental circumstances. In general, whenever steam cleaning is a factor, the enclosure should meet the splashproof requirements of MIL-STD-108. More stringent environmental protection may be required, depending on the individual equipment application.

The designs for enclosures should employ corrosion-resistant material or material protected against corrosion. Ideally, the material should be the lightest practical, as any weight saving in a vehicle is advantageous.

A typical tank-automotive vehicle enclosure is shown in Fig. 8-41. This is a power relay and distribution box. Input and output penetrations are made through box-mounted threaded retainment ordnance connector receptacles.

Although an enclosure may be well designed to serve adequately, covers improperly reinstalled or not reinstalled, damaged seals, or unsealed holes can negate the protective effectiveness of the enclosure. To minimize the effects of misuse, enclosures should be located so they will not experience splashing liquids, exposure to the weather, or accidental abuse.

Terminal blocks and cable sealing devices are used consistently with enclosures. Molded barrier screw and stud type terminal blocks are described by MIL-T-55164. Nylon stuffing tubes intended to seal around multiconductoı cables are described in MIL-S-19622. Grommets are available in oil- and coolant-resistant or general-purpose varieties. These are described, respectively, in MS35489 per MIL-G-3036 and MS35490 per MIL-G-20699.

8-19 WIRING ASSEMBLIES

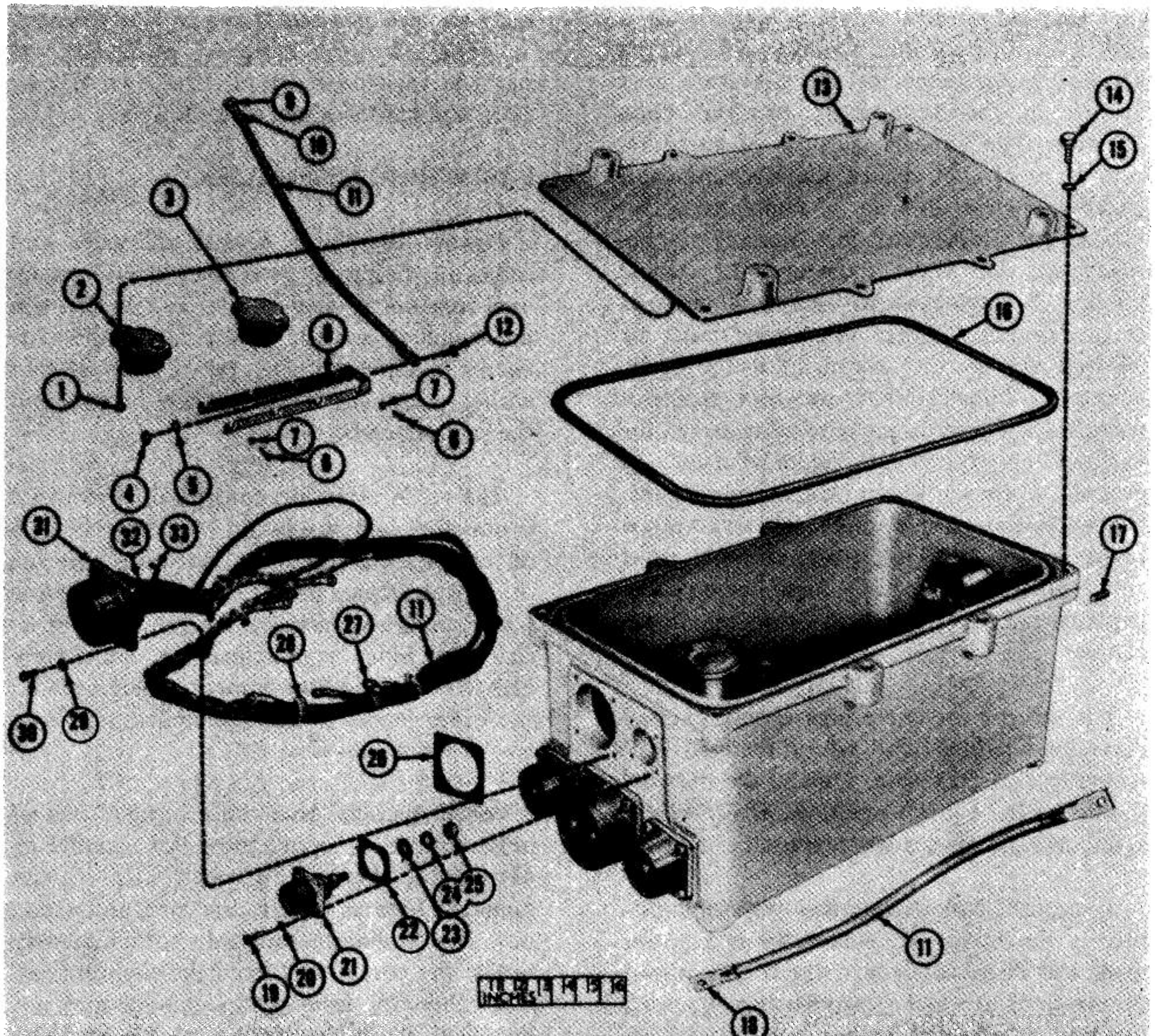
Wiring assemblies consist of wires and cables of definitely prescribed length, assembled together to form a subassembly that will interconnect specific electrical components and/or equipment. The two basic types of wiring assemblies are the wiring harness and the cable assembly.

The cable assembly consists of a stranded conductor with insulation or a combination of insulated conductors enclosed in a covering or jacket from end to end. Terminating connections seal around the outer jacket so that the inner conductors are completely isolated from the environment experienced by the outer jacket. Cable assemblies may have two or more ends (Fig. 8-42).

Wiring harness assemblies contain two or more individual conductors laid parallel or twisted together and wrapped with binding materials such as tape, lacing cord, and wiring ties. The binding materials do not completely isolate the conductors from the environment, and conductor terminations may or may not be sealed. Wiring harnesses may also have two or more ends (Fig. 8-43).

Wiring assemblies are difficult to design adequately in a two step, design and build, effort. Generally, the design will be more successful if the first harness fabrication is evaluated by manufacturing and design personnel so that the design can be optimized by incorporating tolerances that favor future production and by tailoring the assembly to fit neatly in the intended application.

The major deficiencies associated with inadequate wiring assemblies stem from poor design and/or drawing misinterpretations. The electrical design engineer can eliminate such



NONSUPPLY ITEMS

1	SCREW	420499
2	CIRCUIT BREAKER	7974398
3	CIRCUIT BREAKER	7974395
4	NUT	96906-35649-82
5	WASHER	96906-35338-17
6	SCREW	445651
7	WASHER	96906-15795-307
8	BUS BAR	10905639
9	TERMINAL	96906-20659-40
10	INSULATOR	80244-174-1727-11
11	WIRE	MIL-W-16878
12	SCREW	423533
13	COVER	10905692
14	SCREW	96906-35291-7
15	WASHER	96906-35337-23
16	GASKET	10905691

NONSUPPLY ITEMS

17	PLUG	118831
18	TERMINAL	96906-25036-20
19	SCREW	96906-35267-30
20	WASHER	96906-35337-22
21	RECEPTACLE ASSEMBLY	7972770
22	WASHER	96906-15795-610
26	GASKET	7388357
27	TERMINAL	96906-25063-53
28	TIE	10911124
30	SCREW	96906-35267-45
31	RECEPTACLE ASSEMBLY	7388333
32	INSULATOR	80244-174-1725-76
33	TERMINAL	96906-25036-7

Figure 8-41. M60A1 Turret Power Relay Enclosure

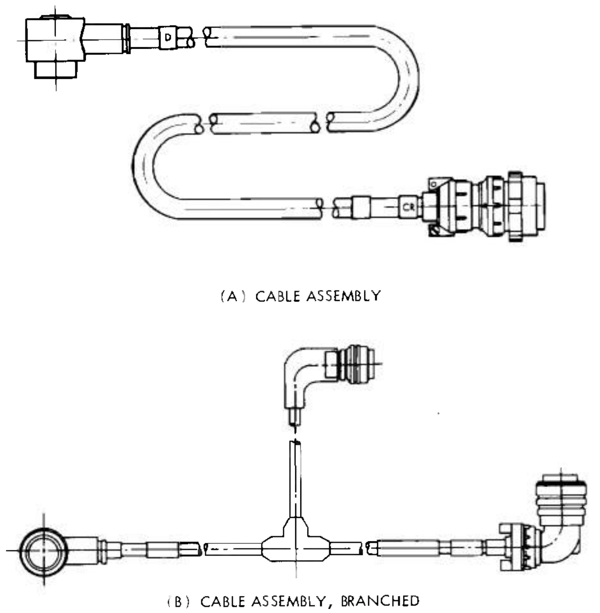


Figure 8-42. Typical Wire Cable Assemblies

deficiencies by eliminating the causes. Poor wiring assembly designs are generally the result of inadequate knowledge of the assembly components, inattention to the mechanical design details associated with fit and function, and underestimating military environmental requirements. Drawing misinterpretations are directly traceable to a lack of detail in the documentation and/or the presentation of requirements in an abstract way that forces the manufacturer to search several other documents to define assembly requirements.

Guidelines for the design of wiring assemblies fall into two basic categories. These are general requirements and binding requirements.

8-19.1 GENERAL WIRING ASSEMBLY REQUIREMENTS

General requirements include crimping, soldering, splicing, sealing, potting, identifying wires, terminating shields, and tolerancing.

8-19.1.1 CRIMPING

Crimping of pin contacts, ferrules, terminals, and splice conductors should be specified to conform with the pull test requirements of MIL-T-13513. In general, if crimping operations produce a crimp that will withstand this pull test, the voltage drop through the crimped connection will not be excessive.

8-19.1.2 SOLDERING

Soldering operations should be required to conform with MIL-STD-454, Requirement 5, for connecting conductors to pin and socket contact, solder-type terminals, and terminal assemblies.

8-19.1.3 SPLICING

Splices also should be required to meet the pull test requirements of MIL-T-13513. In addition, spliced conductors must be well insulated and the splice insulation must be sealed to the insulation of each cable. Therefore, the requirements of MIL-C-13486 for high voltage to ground, flammability, resistance to fungus, resistance to oil absorption, resistance to immersion in liquids, resistance to ozone, and resistance to high temperature, should be specified as splice qualifying requirements. This will assure that splices are

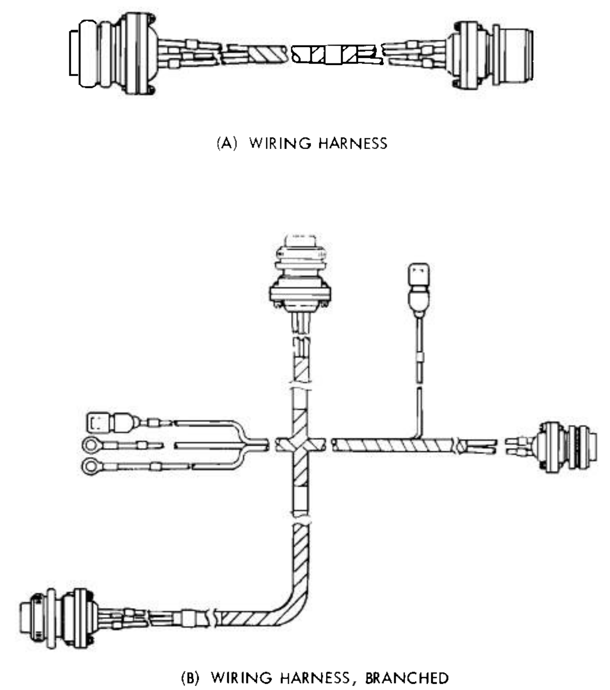


Figure 8-43. Typical Wiring Harness Assemblies

equal to the standard MIL-C-13486 vehicle interconnection cables in physical characteristics.

Successful splices have been made with MIL-C-13486 cable by using crimp ferrules (Table 8-20) and vulcanized or premolded rubber insulation to insulate the connection. Ferrule data for 3-, 4-, 5-, and 6-wire splices are shown in Table 8-21.

With rubber insulation, the thickness of rubber over exposed conductors should be 0.120 to 0.160 in. and overlap adjacent insulation for a distance of at least 0.190 in. with a minimum thickness of 0.030 in. Rubber, synthetic, grade SC515 or SC615, A1, B1, C1, F1, MIL-R-3065, has demonstrated ability to meet the necessary requirements.

When insulating splices with heat-shrinkable, premolded splice covers, application of adhesive between the cable jacket and the premolded insulation is necessary to achieve adequate sealing. In this case, rubber, heat-shrinkable, synthetic, Type I, Class 2, or Type V, Black, MIL-R-46846, sealed to the cable jacket with adhesive per Redstone Arsenal Spec MIS-16066, has demonstrated ability to meet the necessary requirements.

8-19.1.4 SEALING

All packing glands and seals in connectors, stuffing tubes, etc., should be selected to be tight fitting around cable outer jackets to provide water seal and/or strain relief to the degree intended by the specified connector or packing gland. Unused grommet holes in connectors should be plugged. Plugs per MS25251, or laminated, thermosetting rods,

TABLE 8-20. SPLICE CRIMP FERRULES

Ferrule	ID, in.		Color
	Min	Max	
MS21980-128	0.125	0.132	Blue
MS21980-156	0.153	0.159	Yellow
MS21980-187	0.184	0.190	Orange
MS21980-219	0.216	0.222	Green

TABLE 8-21. SPLICE FERRULE DATA

Splice Type	Splice Crimp Ferrule MS21980-	Splice Wire Sizes, AWG Wires Based on MIL-C-13486/1
3-Wire	-128	(1) 16 to (2) 16
	-156	(1) 16 to (2) 14, (1) 14, to (2) 16, (1) 14 to (2) 14
	-156	(1) 12 to (2) 16, (1) 12 to (1) 14 and (1) 16
	-187	(1) 12 to (2) 14
	-187	(1) 12 to (2) 12
	-156	(1) 16 to (3) 16, (1) 14 to (3) 16, (1) 16 to (2) 16 and (1) 14
	-187	(1) 14 to (3) 14, (1) 14 to (2) 14 and (1) 16 to (3) 14
	-156	(2) 16 to (2) 16, (2) 16 to (1) 14 and (1) 16
	-187	(2) 16 to (2) 14 to (2) 14
		(1) 12 to (3) 16, (1) 12 to (2) 16 and 14
4-Wire	-187	(1) 13 to (3) 14, (1) 12 to (2) 14 and (1) 16
	-187	(2) 12 to (2) 16, (2) 12 to (1) 16 and (1) 14
	-219	(2) 12 to (2) 14
	-157	(1) 16 to (4) 16
		(1) 14 to (4) 16, (1) 14 to (1) 14 and (3) 16
	-187	(1) 14 to (2) 14 and (2) 16, (1) 14 to (1) 16 and (3) 14
		(1) 14 to (3) 14
	-156	(2) 16 to (3) 16
		(2) 16 to (2) 16 and (1) 14,
		(2) 14 to (3) 16
	-187	(2) 14 to (1) 16 and (2) 14,
5-Wire		(2) 16 to (3) 14
		(2) 14 to (3) 14
		(1) 12 to (4) 16, (1) 12 to (3) 16 and (1) 14
	-187	(1) 12 to (3) 14 and (1) 16
	2-19	(1) 12 to (4) 14
		(2) 16 to (4) 16, (2) 16 to (3) 16 and (1) 14
		(2) 16 to (2) 16 & (2) 14,
	-187	(2) 16 to (1) 16 & (3) 14
6-Wire		(2) 16 to (4) 14, (2) 14 to
	-219	(3) 14 & (1) 16
		(2) 14 to (4) 14

Type I, Grade XX, Spec L-P-509, are suitable for plugging unused grommet holes. See Table 8-22 for appropriate selection.

TABLE 8-22. PLUGS FOR UNUSED CONNECTOR GROMMET HOLES

MIL-C-13486/1 Wire, AWG#	Dia, Over Insulation, in. ± 0.010	Seal Holes With Rod Spec L-P-509	Optional Method Seal Holes With Plug MS25251	Grommet Hole Dia, in.
16	0.135	0.125 in. Dia	-20 (0.115 in.)	0.105
14	0.160	0.156 in. Dia (NonSTD, Use option)	-16 (0.145 in.)	0.140
12	0.235	0.250 in. Dia (Use MS option)	-8 (0.228 in.)	0.215
8	0.360	0.375 in.	Not Avail.	0.340
4	0.485	0.438 in. Dia	Not Avail.	0.415
2	0.610	0.562 in. Dia	Not Avail.	0.540
0	0.672	0.625 in. Dia	Not Avail.	0.600

8-19.1.5 POTTING

Potting compound, MIL-M-24041, type optional, has demonstrated excellent adhesion to neoprene or PVC and good high and low temperature tolerance in the military environment. This material is a polyurethane compound curing to a hardness similar to that of a rubber shoe heel.

8-19.1.6 WIRE IDENTIFICATION

Wires should be identified within 2 or 3 in. of wire ends by one of the methods previously described (par. 8-5).

8-19.1.7 SHIELD TERMINATIONS

Shielding on wires and cables should be secured in a manner that will prevent contact or shorting between the shield and exposed current-carrying parts. The shielding should terminate at a sufficient distance from the exposed conductors to prevent shorting caused by arcing. The ends of the shielding, or braid, should be secured against fraying. Shield terminations should be prepared in accordance with the paragraph on "shielded braid termination" in MIL-S-45743, or in accordance with acceptable equivalent methods.

8-19.1.8 TOLERANCES

Recommended tolerances for wiring assemblies are given in Table 8-23. These tolerances are all on the plus side of the minimum length required to connect the assembly terminations.

8-19.2 WIRE HARNESS BINDINGS

There are several methods employed to bind the wire bundles together in wiring harness assemblies. Each method has an intended or preferred application in military vehicles. These methods include full taping, spaced taping, spaced sleeving, spaced straps or ties, lacing, and full sleeving for high-temperature protection. Descriptions of each are given in the paragraphs that follow.

8-19.2.1 FULL TAPE BINDING

This binding is intended for vehicle interior wiring applications where wires are unpro-

TABLE 8-23. RECOMMENDED TOLERANCES FOR WIRING ASSEMBLIES

LENGTH, in.		
OVER	INCLUDING	TOLERANCE, in.
0.00	0.50	+0.25
0.50	2.00	+0.38
2.00	6.00	+0.50
6.00	12.00	+0.75
12.00	36.00	+1.00
36.00	100.00	+2.00
100.00	200.00	+3.00
200.00	UP	+4.00

tected, and an additional measure of snag protection and abrasion resistance is required (Fig. 8-44(A)).

Cables should be bound together with one-half overlapping turns of tape. Tape, Type EF-9, Black, MIL-I-15126, has demonstrated suitable low-temperature flexibility (−10°F cold bend) in the military environment.

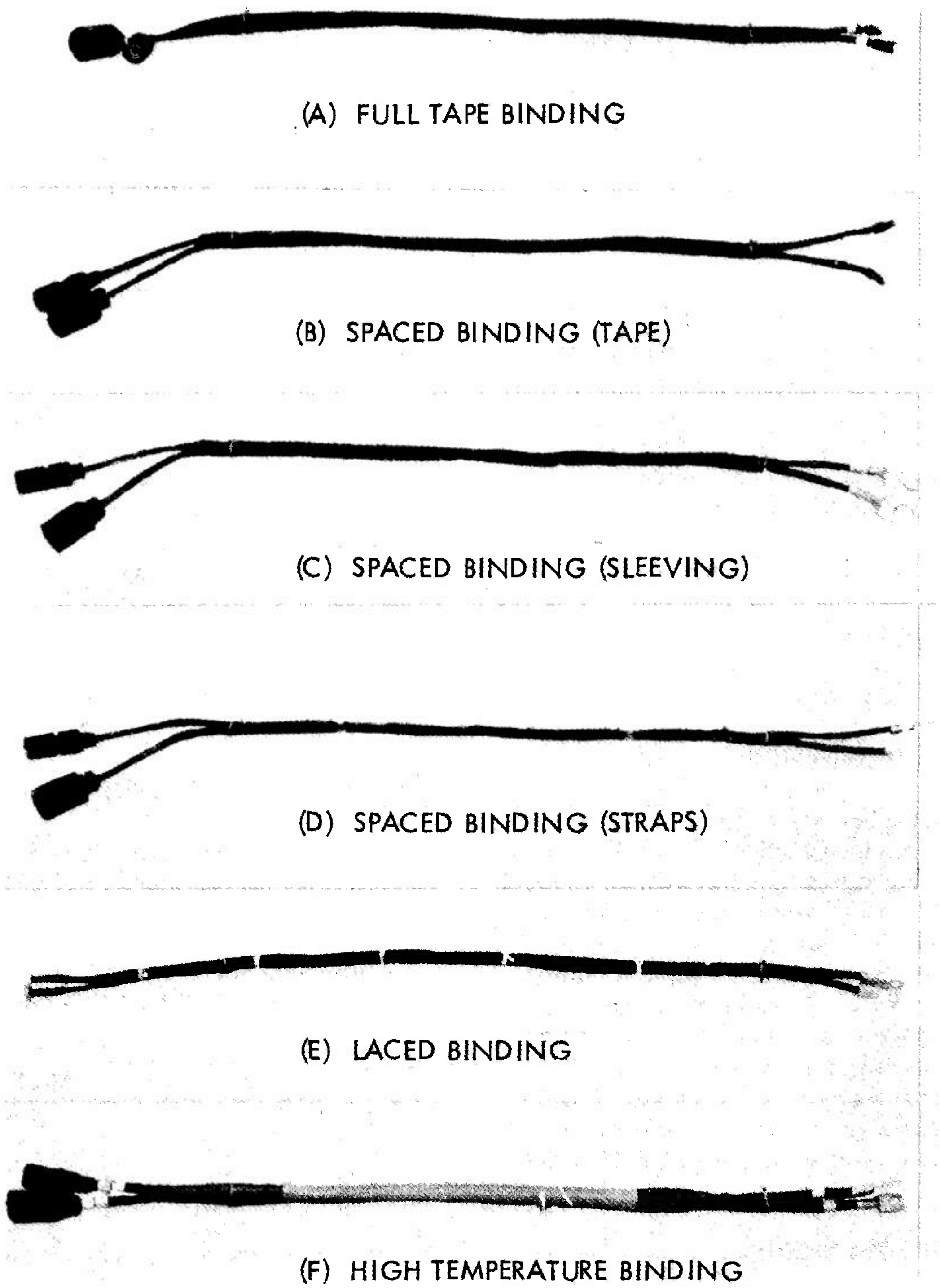


Figure 8-44. Wire Harness Binding Methods

8-19.2.2 SPACED BINDINGS

This binding is intended for vehicle interior wiring in protected locations, or in junction and control box applications (Fig. 8-44(B)).

Cables should be bound together with one-half overlapping turns of tape in spaced intervals. Tape should form 2.00- to 2.25-in. wrap lengths spaced at 8.00- to 12.00-in. intervals.

One alternative method for spaced binding uses sleeving in lieu of tape. A heat shrinkable modified neoprene rubber sleeving, MIL-I-23053/1, has demonstrated suitable low-temperature flexibility (–55°C brittleness) in the military environment and the cables should be bound together with 0.75- to 1.25-in. lengths of the heat-shrinkable sleeving spaced at 8.00- to 12.00-in. intervals (Fig. 8-44(C)). Another alternative spaced binding method uses wire ties or straps. Cable straps, adjustable, self-clinching, MS3367-1, MS3367-3, MS3367-4, or MS3367-5 are suitable for this application. Cables should be bound together with straps spaced at 8.00- to 12.00-in. intervals (Fig. 8-44(D)).

8-19.2.3 LACED BINDINGS

Lacing is intended for wiring used in junction and control box applications (Fig. 8-44(E)).

Cables should be bound together using lacing cord ties, spaced at intervals specified for the diameter of the assembly as given in Table 8-24. Lacing cord in accordance with MIL-T-43435, Size 3, Type I, Finish B, Waxed, Color Optional, has performed satisfactorily in the military environment.

8-19.2.4 HIGH TEMPERATURE BINDINGS

This binding method is intended for harnesses used on engines, transmissions, etc., where additional protection against high temperature is required.

Cables should be covered, or bound together with insulating sleeving. Sleeving ends and junctions should be bound to cables with one-half overlapping turns of tape. Tape endings must overlap fully (Fig. 8-44(F)).

Insulating sleeving, electrical, Class 200, Type C, Category C or D, MIL-I-3190, has demonstrated suitable high temperature and humidity resistance in these applications. Diameter and length should be specified on the harness assembly drawing. Tape 19207-10886484 has demonstrated adhesive qualities that withstand steam cleaning and the oily, high-temperature environment associated with vehicle power packs.

TABLE 8-24. RECOMMENDED LACING INTERVALS

ASSEMBLY DIAMETER, in.	INTERVAL, in.
0.25	0.50 to 1.25
0.50	1.25 to 1.75
1.00	1.75 to 2.25
Over 1.00	2.75 to 3.25

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15. MIL-HDBK-216, *RF Transmission Lines and Fittings.*

16. MIL-T-7928, *Terminals, Lug: Splices, Conductor: Crimp Style, Copper, General Specification For.*

17. MIL-T-13513, *Terminal, Lug: Splice, Conductor (Electrical, Solderless, For Automotive Use).*

18. MIL-C-5015, *Connectors, Electric, AN Type, General Specification For.*

19. MIL-C-10544, *Connectors, Plug and Receptacle (Electrical, Audio, Waterproof, Ten Contact, Polarized).*

20. MIL-C-55116, *Connectors, Miniature Audio, Five-Pin.*

21. MIL-C-55181, *Connectors, Plug and Receptacle, Intermediate (Electrical, Waterproof): General Specification For.*

22. MIL-C-55243, *Connectors, Plugs and Receptacles, Electrical, Quick Connect and Disconnect, 12 Contacts, Medium Power.*

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CHAPTER 9

CONTROLS

SECTION I SWITCHES*

9-1 INTRODUCTION

Switches are major electrical components. They require careful evaluation prior to selection because, in addition to possessing the necessary electrical characteristics, vehicular switches must have the ability to withstand rigorous environmental conditions such as high and low temperature, intense vibration, shock and acceleration, salt spray, and fungus growth. Furthermore, the success or failure of a vehicle mission may depend upon the reliable operation of these devices.

In the past, switches were always electromechanical devices. Now transistors and other solid-state components often are applied and referred to as switches; however, they are more similar to relays in actual function and, therefore, are described in Section II. The switch characteristics and application considerations described in this section are of the electromechanical type.

9-2 GENERAL CHARACTERISTICS

All switches of the types used in military equipment can be grouped into one of three categories. They are rotary, nonrotary, and sensing types. These basic types differ from each other in size, cost, actuation, construction, and general characteristics. The selection of an appropriate switch depends on both electrical and physical requirements and the environment in which the switch must exist[1]. The method by which contacts make or break a circuit, the physical configuration of the contacts, the load ratings, and the type of actuating mechanism are the most important switch characteristics that a designer must apprise in the selection process.

9-2.1 CONTACTS

Switch contacts can be classified by function, current-carrying capacity, and application. The contact arrangements vary in complexity from a simple make-or-break, break-before-make, make-make, break-break, etc., and from single throw to multiple throw, and single pole to multipole, and various combinations of these features.

Contacts usually are given multiple ratings dependent on the type of load being switched. These ratings cover resistive, low-level (dry circuit), lamp, motor, or inductive loads. Most switches are given the resistive load rating and, in most instances, at least one additional rating[1].

The two considerations that govern the rating of a switch for a given type of load are the inrush current and current-breaking capacity of the contacts. For some loads, the inrush current at the instant that the switch makes contact is considerably higher than the current present during normal operation[2].

Lamp, motor, and capacitive loads are examples of this. A high inrush current in a lamp-loaded circuit occurs because the resistance of a lamp filament is much lower when it is cold than after it has come to operating temperature. As a rule, the lamp load rating is one-eighth to one-fourth the rating for a normal resistive load. Inrush currents for motor loads may be as much as ten times the normal running load because of the lack of back emf. Inductive load ratings for both AC

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and DC currents are lower than the resistive load ratings, because of the longer duration of the arc on current break, caused by the energy storage in the inductor. Inrush current in a capacitive load circuit is high because the capacitor acts as a virtual short circuit until it has acquired some charge[2]. In many instances, the maximum current-making capacity may be the limiting factor rather than the running-current capacity of the switch. When these figures are not given, information must be obtained from the manufacturer or from conclusive tests conducted by the user. Therefore, in selecting the correct switch for a given application, the current, voltage, and the characteristics of the current during make, break, and continuous duty must be carefully considered[2].

Ratings of contacts, usually given for room ambient temperature, include some safety factor to provide for the temperature rise of the switch. Temperature has a marked effect on switch current ratings, as is shown in Fig. 9-1.

Contact resistance between two mated electrical contacts is measured at their external terminals. It is related to the power that will be dissipated in the contacts. Contact resistance includes the resistance of the contact material, of any oxide or other film on the surface of the contacts, and the resistance of the elements on which the contacts are mounted; e.g., springs, mounting, and the terminals and their connections[1].

Low level (dry circuit) applications require switch contact resistance ratings based on tests conducted with an open-circuit voltage of 30 mV maximum and a test current of 10 mA maximum, such as in Method 311 of MIL-STD-202. To meet such test requirements, switch manufacturers use contact materials such as gold, platinum, or palladium (or their alloys) to minimize formation of insulating films on the contacts, or they design the switch contacts so that they wipe across each other to remove such films. Other considerations that switch manufacturers generally observe include design provisions which prevent internal generation of dust particles due to the rubbing of insulated parts against metal; and which seal the switch contacts adequately from exposure to external dust and foreign matter. Otherwise, any of

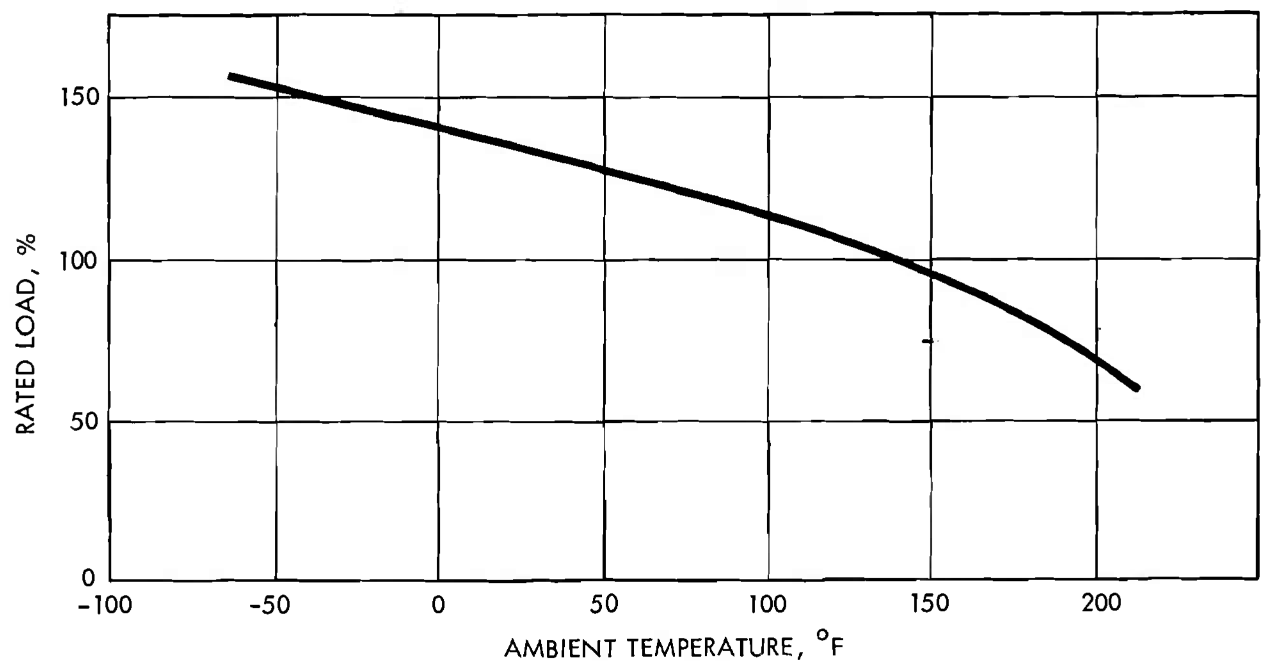


Figure 9-1. Typical Derating Curve for Switches

these conditions could cause switch failures due to deposition of foreign particles on the switch contacts. The preceding design characteristics should be sought when selecting switches for low level circuits. However, proper test and performance requirements before and after life tests should be the primary basis for the selection of any switch[1]. Additional electrical contact data are available in Refs. 14, 15, 16, and 17.

Switches are available with a variety of different contact arrangements. These are best illustrated in schematic form (Fig. 9-2). A single-pole, single-throw toggle switch appears schematically in Fig. 9-2(A). A similar switch with momentary contacts spring loaded to return to the open position is represented in schematic form by Fig. 9-2(B). The conventional use of a circle to designate maintained contacts and a solid triangle to signify momentary contacts also is shown in the single pole-double throw, and double pole-double throw switch schematics, Fig. 9-2(E) and Fig. 9-2(G).

Rotary or multiposition switches provide the circuit designer with a variety of contact arrangements. Single-pole (Fig. 9-2(H)), double-pole (Fig. 9-2(I)), and multipole configurations are available. Contacts can be arranged as nonshorting (break-before-make) or shorting (make-before-break) as dictated by the circuit requirements and as specified by the designer.

The mechanisms used to make-or-break switch contacts may feature simple pressure button contacts such as those commonly employed with door bells; sliding contact button actions as used in television tuners; snap action contacts similar to those in a household wall switch; or a drop of mercury to bridge the circuit terminals. Mercury switches avoid many of the mechanical wear and arcing problems that plague switches of other types, and they have a long life. However, they are not used in military vehicles because of environmental limitations.

The pushbutton switch is economical and mechanically very reliable, however, it is subject to pitting and oxidation when used to control high voltage circuits that carry appreciable currents. Arcing occurs across the contacts for a relatively long period after contact separation. Furthermore, this type of switch does not work well switching low power currents in the milliwatt range, because oxides form an insulating barrier on the contacts and there is no scraping action to remove this coating. However, there are techniques, such as sealing nitrogen in the switch chamber and plating the contacts with gold or silver alloy, which can eliminate these problems.

Sliding button action switches arc and cause pitting when they break circuits of appreciable power, but the sliding action scrapes the oxides from the contacts to prevent the buildup of an insulating barrier. Therefore, they work fairly well for making and breaking circuits of low power. Sometimes these contacts feature knife edges that enhance the scraping action and result in better performance.

Snap action switch mechanisms have a toggle-type action that is mechanically unstable in any position except open or closed. This feature also reduces the arcing time while the switch is closing, because the geometry of the mechanism produces high speeds during contact engagement. Minimum arcing time is advantageous since less heat dissipation is required and therefore contact deterioration is reduced.

9-2.2 ACTUATING MECHANISMS

The actuating mechanisms found on military vehicle switching devices include pressure and temperature sensing, pushbutton, toggle, and rotary types. Several switches in common use are shown in Fig. 9-3. These are the single-pole toggle switch with snap action contacts (Fig. 9-3(A)), the pushbutton switch with momentary contacts (Fig. 9-3(B)), a rotary starter-ignition switch (Fig. 9-3(C)), a double-pole toggle switch (Fig. 9-3(D)), a pull and turn master switch (Fig. 9-3(E)), and a

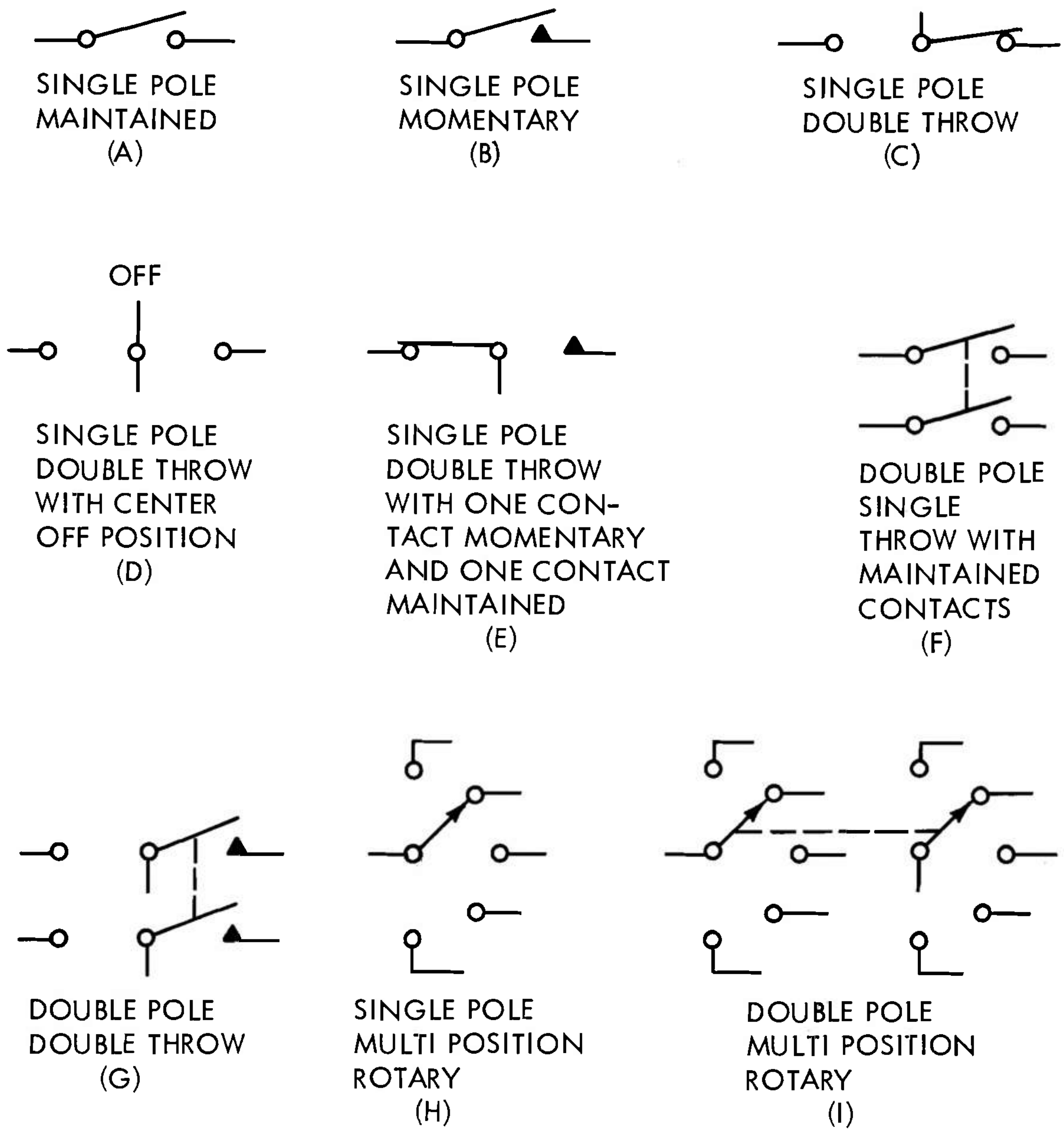


Figure 9-2. Switch Contact Arrangements

vehicle light selector switch (Fig. 9-3(F)). The latter is an assembly containing an internal circuit breaker and interlocking features that prevent energizing the service headlights without first taking action to release the lock.

The actuating elements of a typical low current rotary switch of the type used for intercom control include the index wheel; the shaft or rotating mechanism; the stator including insulating material and stationary contacts; the rotor, including commutator ring and moving contacts; and the holding screws (Fig. 9-4).

9-3 APPLICATION CONSIDERATIONS

Selecting a switch type to perform a particular function involves numerous factors. Proper selection, in its broadest sense, is the first step in building reliable equipment. This selection must be based upon a knowledge of the advantages and disadvantages of each

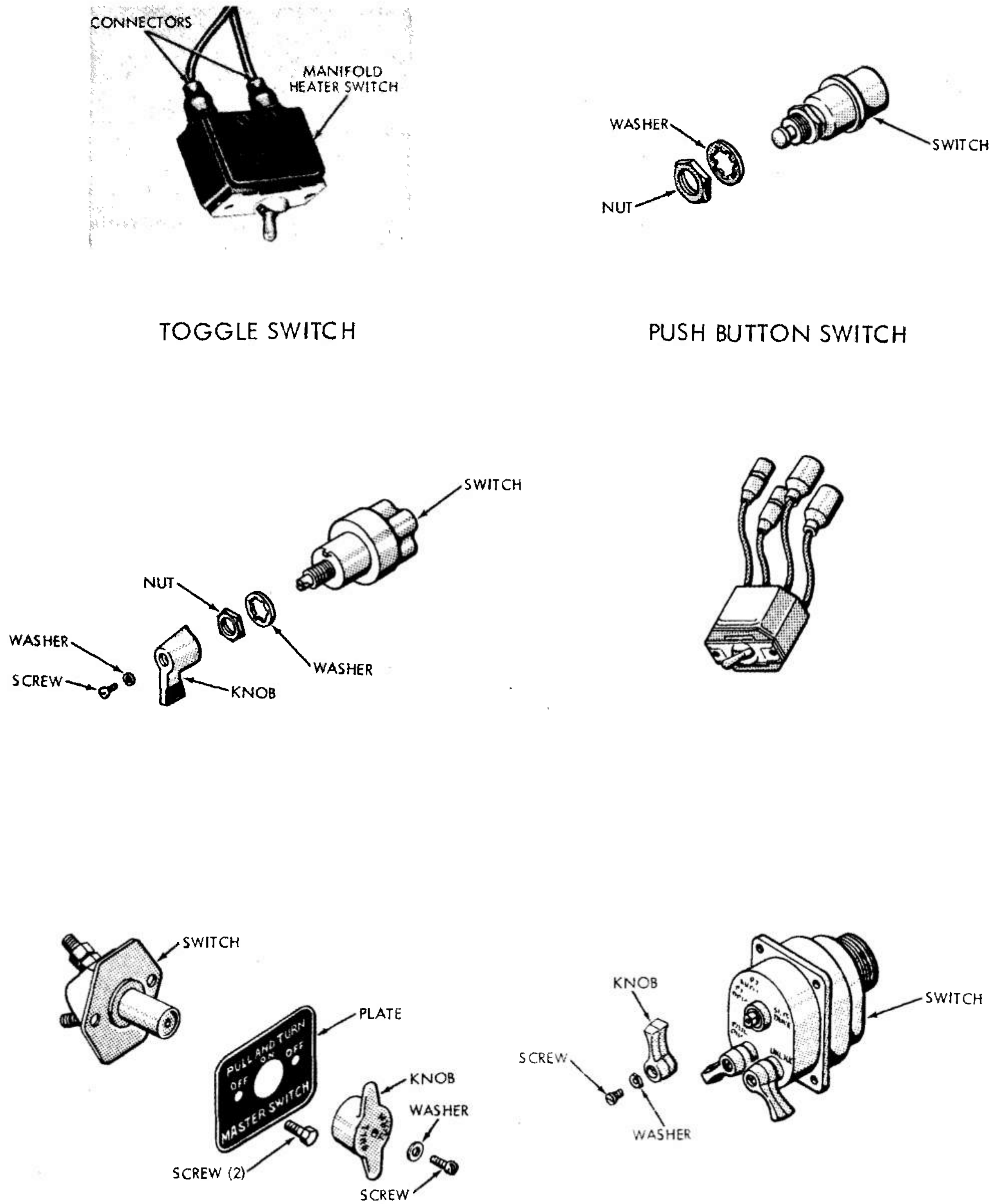


Figure 9-3. Vehicular Switches

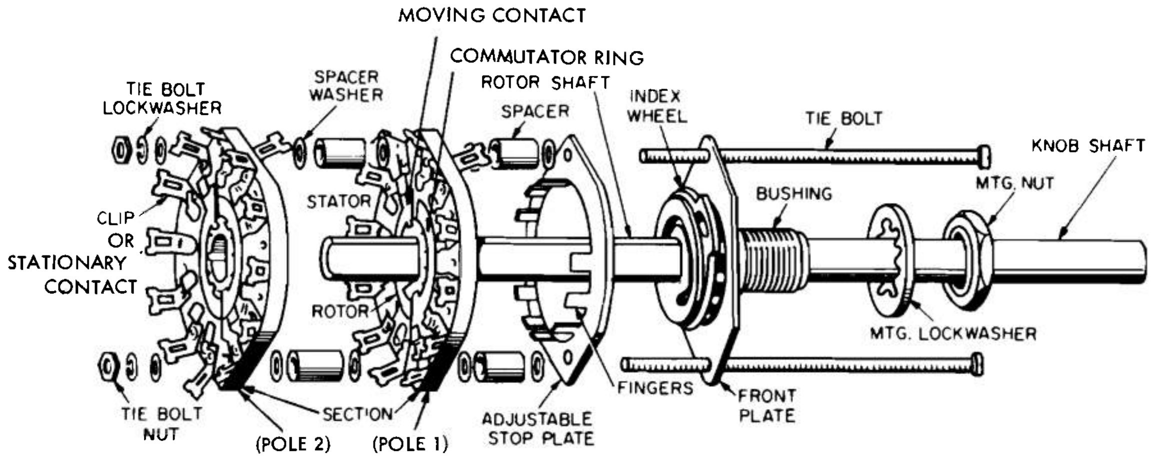


Figure 9-4. Rotary Switch Construction MIL-S-3786

switch type, performance under various electrical loads and environmental conditions, typical failure modes, effect of the switching action on the circuit, and the effect of the circuit upon the switch. Selection normally starts with a determination of the most important characteristic for the application, then considering alternatives and compromising with regard to other characteristics of available hardware. A careful analysis of the required life of the switch or total number of operations should be made. In most vehicular equipment, the required operational life of the switch is comparatively short[1]. Several other factors of importance are described in the paragraphs that follow.

9-3.1 HUMAN FACTORS

The proper mounting of switches is a subject not often covered by specifications or other discussions on switches. Studies in human engineering have shown that a few basic rules should be followed when panel layouts are designed or electronic equipment packaging is considered (see par. 4-16)[2].

9-3.2 ELECTRICAL NOISE

Electrical noise also must be considered in electronic equipment. Whenever an electrical circuit is closed or opened, a spark occurs. This spark may be very small or comparatively large, depending on the voltage and current in the circuit. When a spark occurs, electromagnetic radiations of a wide frequency band occur. These may interfere with high gain amplifiers or other sensitive receivers by inducing troublesome noise, giving false commands to sensitive computing equipment, or interfering with coding equipment. The radiation generated by the make or break of a switch may be great enough, depending on the equipment, to require suppression. This parameter must be included in the requirements or considerations for selecting an adequate switch[2]. Further discussion of contact arc suppression is presented in par. 9-5.

9-3.3 INSULATION

The insulation of switch spacers or of the switch disk (in selector or rotary switches) is important when using switches in high-resistance circuits. It is not uncommon to encounter insulation resistance of from 1 to 3 Mohms in unsealed switches after they have been subjected to climatic tests for temperature, humidity, and weathering. The degree of arc resistance of the insulation also merits consideration. Because most switches will form an arc when making or breaking, conducting material may be deposited on the insulation, resulting in a decrease in the insulation resistance. Eventually, insulation breakdown, caused by arcing over the surface of the insulation, may occur. Although the switch user seldom specifies the materials to be used in a switch, he should have some awareness of the limitations of various materials[2].

9-3.4 CAPACITANCE

Switch capacitance also may be important in some applications. A switch may be considered as a capacitor, because it consists of two plates separated by a dielectric (air). The two plates, connected in series with a circuit, may have a capacitance which is sufficient to cause complications in some circuitry. Take, for example, an RF attenuator consisting of π-networks in series with switches between each pad so that attenuation may be increased or decreased by means of toggle switches. For attenuation in the frequency range of 60 to 100 MHz, the capacitance of the toggle switches may be a limiting factor as far as insertion loss is concerned[2].

9-3.5 SPEED

Switching speed is often an important parameter to consider when choosing a switch. The term "switching speed" means the duration of contact travel during a make or break function. This parameter is important from the standpoint of reducing any interruptive arc that may be formed, or of decreasing the flashover time during the making of contact. During the actual making of contact, a spring action is sometimes used to increase the speed of closing. This decreases the length of time that an arc, caused by voltage breakdown between the contacts, can cause pitting or burning. If the arcing during the make function is very severe, the contacts may weld together.

During the break function, an attempt is made to decrease the speed to give the stored energy time to dissipate slowly, because an instantaneous opening will produce heavy transient currents accross the contacts. This is especially true of DC circuits and inductive AC circuits. Pitting of contacts is usually more severe during the opening of the contacts. With switches used to interrupt heavy currents, it is sometimes necessary to employ arc suppressors or arc extinguishers. These may take the form of either a capacitor across the contacts to act as an energy sink, or a permanent magnet near the contacts to deflect the arc[2].

9-3.6 CONTACT SNAP-OVER AND BOUNCE TIME

In many electronic applications, critical snap-over and bounce times of the contacts are important[2].

Snap-over time in a double-throw switch is defined as the time it takes the moving contact to separate from the normally-closed contact, travel to the normally open contact, and make the circuit. Where a switch is used to control a relay or a similar device, this time interval usually is too short to affect its operation seriously. In many electronic circuits, however, a millisecond is a long time and snap-over time becomes a critical parameter. With a double-throw switch, there is no circuit through either contact during the snap-over, and consequently there will be a definite interval between the time one circuit opens and the other one closes.

Similarly, although the bouncing of the moving contact resulting from its impact on the stationary contact is much too fast to be detected by most magnetic devices, each bounce appears to an electronic device as a separate pulse of energy.

Consequently, one object in switch design is to achieve the minimum snap-over and bounce time without sacrificing any desirable characteristics of operation or construction.

9-3.7 ENVIRONMENT

Switches should be selected which meet shock and vibration requirements. High-frequency vibrations will determine the effects of fatigue and resonance on the mechanical construction of the switch contact elements. When contact bounce at the time of closing of switch contacts is important, this requirement should be specified. Contact bounce causes arcing that will materially shorten contact life and may generate electrical noise.

Switches that are subject to acceleration forces in high-speed vehicles should be selected from those having acceleration resistant designs. Failures usually are due to internal construction that allows normally closed contacts to open and normally open contacts to close under acceleration conditions.

A combination of dust and small amounts of moisture will increase materially the possibility for voltage breakdown of the insulation between closely spaced terminals. Where low insulation resistance or high leakage currents may cause circuit malfunction, the switch must be capable of passing sand and dust test requirements.

Explosion resistance requires that switches operate in a volatile atmosphere without causing explosion. Switches to be used in an explosive atmosphere should be sealed.

Moisture in the dielectric will decrease the dielectric strength, life, and insulation resistance and cause corrosion by increasing the galvanic action between dissimilar metals. In general, switches that operate in high humidities should be hermetically sealed, or, if this is not practical, the use of accessories—such as boots, O-rings, or diaphragms placed over switch openings—is recommended to decrease moisture entry.

Variations of temperature must be considered, as moisture condensation within the switch could develop. In choosing a switch for a wide range of temperature, the entire temperature range must be considered carefully rather than only one extreme. Exposure to low temperature may cause certain materials of a switch to contract, which may cause cracking, or may permit moisture or other foreign matter to enter the switch, which may cause short circuits, voltage breakdown, or corona.

Chemical action to which switches are subjected is accelerated by high temperatures. Insulation resistance between the switch contacts and ground decreases as the temperature increases. In high resistance circuits with 3 Mohm in parallel with a circuit impedance of 1 Mohm, the circuit impedance will change to a point where operational failure of the equipment may occur. High temperature changes the dielectric strength and may affect the insulation from the standpoint of voltage breakdown. Also, the increased speed of corrosion of contacts and switching mechanisms is affected by high temperatures.

Many types of enclosures are available to protect a switch from external conditions, particularly high humidity and dirt. Switches may be classified according to the degree of protection offered by the enclosure. Such classifications include the following: open, sealed, enclosed, environmentally (resilient), and hermetically sealed. With the open construction switch, no effort is made to protect the switch or its parts from atmospheric conditions. The enclosed switch has contacts enclosed in an unsealed protective case made of plastic or metal. The environmentally (resilient) sealed switch is in a completely sealed case where any portion of the seal is a resilient material, such as a gasket or a seal in the bushing of a panel-mounted switch. The hermetically sealed switch is made airtight by a sealing process that involves sealing by fusing or soldering. Sometimes the enclosure is charged with nitrogen or inert gas. Hermetically sealed enclosures offer the greatest protection because they insulate against such elements as moisture, harmful gases, and dirt[1]; however, outgassing of materials within the enclosure may, on occasion, cause malfunction of switches and relays.

9-3.8 SWITCHES FOR MILITARY VEHICLES

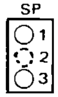
There tend to be two groups of switches used in military vehicle applications. One group has been designed specifically for vehicle use; whereas the other group includes

TABLE 9-1. MILITARY VEHICLE TOGGLE SWITCHES (ENVIRONMENTALLY SEALED)

Part No.	Switch action*	Description	Circuit at lever position: Up	Center	Down	Electrical rating (Amps at 24-28V): Res. load	Ind. load	Lamp load	Comments
MS 24658-21	SPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	OFF	ON 1-2	20	15	5	ALL LOCKING COMBINATIONS
MS 24658-22	SPST	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	NONE	OFF	20	15	5	3 LOCKING COMBINATIONS
MS 24658-23	SPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	NONE	ON 1-2	20	15	5	3 LOCKING COMBINATIONS
MS 24658-24	SPST	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	OFF	NONE	20	15	5	4 LOCKING COMBINATIONS
MS 24658-25	SPST	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	MOM OFF	NONE	15	10	4	LOCK IN UP POSITION
MS 24658-26	SPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	NONE	MOM ON 1-2	15	10	4	LOCK IN UP POSITION
MS 24658-27	SPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	MOM ON 2-3	OFF	MOM ON 1-2	15	10	4	3 LOCKING COMBINATIONS
MS 24658-28	SPST	LEVER LOCK - REOUIRES MANUAL RELEASE	NONE	OFF	MOM ON 1-2	15	10	4	LOCK IN CENTER POSITION
MS 24658-29	SPST	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	NONE	MOM OFF	15	10	4	LOCK IN UP POSITION
MS 24658-30	SPST	LEVER LOCK - REOUIRES MANUAL RELEASE	OFF	NONE	MOM ON 1-2	15	10	4	LOCK IN UP POSITION
MS 24658-31	SPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	OFF	MOM ON 1-2	15	10	4	6 LOCKING COMBINATIONS
MS 24658-32	SPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	MOM ON 2-3	ON 1-2	NONE	15	10	4	LOCK IN CENTER POSITION
MS 24658-33	SPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	ON 2-3	ON 1-2	NONE	20	15	5	4 LOCKING COMBINATIONS
MS 27408-1	DPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	2-3 ON 5-6	2-3 ON 4-5	1-2 ON 4-5	20	15	7	ALL LOCKING COMBINATIONS
MS 27408-2	DPDT	LEVER LOCK - REQUIRES MANUAL RELEASE	2-3 ON 5-6	2-3 ON 4-5	1-2 MOM ON 4-5	18	10	5	6 LOCKING COMBINATIONS
MS 27408-3	DPDT	LEVER LOCK - REQUIRES MANUAL RELEASE	2-3 MOM ON 5-6	2-3 ON 4-5	1-2 MOM ON 4-5	18	10	5	3 LOCKING COMBINATIONS
MS 27408-4	DPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	2-3 ON 5-6	1-2 ON 5-6	1-2 ON 4-5	20	15	7	ALL LOCKING COMBINATIONS
MS 27408-5	DPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	2-3 ON 5-6	1-2 ON 5-6	1-2 MOM ON 4-5	18	10	5	6 LOCKING COMBINATIONS
MS 27408-6	DPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	2-3 MOM ON 5-6	1-2 ON 5-6	1-2 MOM ON 4-5	18	10	5	3 LOCKING COMBINATIONS
MS 27408-7	DPDT	LEVER LOCK - REOUIRES MANUAL RELEASE	2-3 ON 5-6	1-2 ON	1-2 ON 4-5	20	15	7	Lock in Center and Down Position
MS 39061-1	SPST		OFF	NONE	ON 1-3	25	15	6	Lock in Center and Down Position
MS 39061-2	SPST		OFF	NONE	MOM ON 1-3	25	15	6	Lock in Center and Down Position
MS 39061-3	SPST		MOM OFF	NONE	ON 1-3	25	15	6	Lock in Center and Down Position
MS 39061-4	SPDT		ON 2-3	OFF	ON 1-2	25	15	6	Lock in Center and Down Position
MS 39061-5	SPDT		MOM ON 2-3	NONE	ON 1-2	25	15	6	Lock in Center and Down Position
MS 39061-6	SPDT		MOM ON 2-3	OFF	ON 1-2	25	15	6	Lock in Center and Down Position
MS 39061-7	SPDT		ON 2-3	NONE	ON 1-2	25	15	6	Lock in Center and Down Position
MS 39061-8	SPDT		MOM ON 2-3	OFF	MOM ON 1-2	25	15	6	Lock in Center and Down Position
7954899	DPST		1-3 ON 4-6	NONE	OFF	30	18	7	WITH 6" CABLE LEADS
7954900	DPDT		2-3 ON 5-6	OFF	1-2 ON 4-5	30	18	7	WITH 6" CABLE LEADS
7954901	DPDT		2-3 ON 5-6	NONE	1-2 MOM ON 4-5	30	18	7	WITH 6" CABLE LEADS
7954902	DPDT		2-3 ON 5-6	OFF	1-2 MOM ON 4-5	30	18	7	WITH 6" CABLE LEADS
7954903	DPDT		2-3 ON 5-6	NONE	1-2 ON 4-5	30	18	7	WITH 6" CABLE LEADS
7954904	DPST		1-3 MOM ON 4-6	NONE	OFF	30	18	7	WITH 6" CABLE LEADS
7954905	DPDT		2-3 MOM ON 5-6	OFF	1-2 MOM ON 4-5	30	18	7	WITH 6" CABLE LEADS
7954906	DPST		1-3 ON 4-6	NONE	MOM OFF	30	18	7	WITH 6" CABLE LEADS

*SPST = Single Pole Single Throw
SPDT = Single Pole Double Throw
DPDT = Double Pole Double Throw
DPST = Double Pole Single Throw
MOM = Momentary

SP



DP

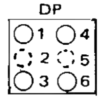


TABLE 9-2 24-28 V VEHICLE SWITCHES

Part No.	Switch * Action	Electrical Rating (Amps At 24-28V)			Description or Comments
		Res. load	Ind. load	Lamp load	
8389470	SPST MOM CLOSED	40	15	5	General Purpose Waterproof – Pushbutton
8720190	SPST MOM CLOSED	20	10	5	General Purpose Waterproof – Pushbutton
11614139	SPST MOM OPENED	5	–	–	General Purpose Waterproof – Pushbutton
10921898	SPST MOM CLOSED	3	2	–	Switch Assy – Horn Pushbutton – Waterproof
MS 27199-1	SPST MOM CLOSED	300	150	–	Switch Assy – Foot Operated Starter – Heavy Duty
MS 53001-1	DPDT	15	10	8	Headlite Dimmer Switch Foot Push – Waterproof
MS 39060-1	SPMT	10	10	5	Waterproof – Rotary Use Levers 5381088, 11613617
MS 39060-2	MPST	10	10	5	Waterproof – Rotary Use Levers 5381088, 11613617
MS 39060-3	MPMT	10	10	5	Waterproof – Rotary Use Levers 5381088, 11613617
MS 39060-4	SPST	10	10	5	Waterproof – Rotary Use Levers 5381088, 11613617
MS 51113-1	....	–	–	–	Switch, Vehicular Lights Waterproof Assy – Internal Circuit Breaker – Lockout Features
MS 75064-1	SPST	10	10	–	Switch, Rotary – Stoplights, Mechanically Actuated – Waterproof
11613450	SPST	40	20	–	Switch, Rotary – Panel Mount – Waterproof
11614140	SPST	40	20	–	Switch, Rotary – Panel Mount – Waterproof
2585795	SPDT	5	2.5	–	Switch, Oil Pressure – Waterproof
7771274-1	SPST MOM CLOSED	–	–	–	Temperature Switch Oper. Temp. Reset. Temp. – Waterproof – Thermostatic Temp. Actuated, °F 245 215
7771274-2	SPST MOM CLOSED	–	–	–	Temperature Switch Oper. Temp. Reset. Temp. – Waterproof – Thermostatic Temp. Actuated, °F 305 275
7771274-3	SPST MOM CLOSED	–	–	–	Temperature Switch Oper. Temp. Reset. Temp. – Waterproof – Thermostatic Temp. Actuated, °F 225 200
7771274-4	SPST MOM CLOSED	–	–	–	Temperature Switch Oper. Temp. Reset. Temp. – Waterproof – Thermostatic Temp. Actuated, °F 285 255
7771274-5	SPST MOM CLOSED	–	–	–	Temperature Switch Oper. Temp. Reset. Temp. – Waterproof – Thermostatic Temp. Actuated, °F 165 145
7771274-6	SPST MOM CLOSED	–	–	–	Temperature Switch Oper. Temp. Reset. Temp. – Waterproof – Thermostatic, Temp. Actuated, °F 265 235
7771274-7	SPST MOM CLOSED	–	–	–	Temperature Switch Oper. Temp. Reset. Temp. – Waterproof – Thermostatic, Temp. Actuated °F 325 295

*SPMT = Single-pole Multithrow
SPST = Single-pole Single-throw
DPDT = Double-pole Double-throw
MPST = Multipole Single-throw
MPMT = Multipole Multithrow
MOM = Momentary

aircraft or electronic equipment switches suitable for use in vehicle electrical systems. Some of the many switches that have been successfully used in vehicle applications are tabulated in Tables 9-1 and 9-2. Toggle switches appear in Table 9-1, and rotary, pushbutton, or specialized switches are in Table 9-2. Many other switches, switch specifications, and application information including associated hardware may be found in MIL-STD-1132.

SECTION II RELAYS*

9-4 INTRODUCTION

Relays can be defined as electrically controlled switches. These devices are used to control circuits with large power requirements by using only a portion of that power to open and close the circuit or to open and close several circuits from one remote location. They are used in many applications on tank-automotive vehicles.

Although a variety of relays have been designed in the past, all of the variations can be grouped into three basic categories: electromagnetic, thermal, and solid-state.

The electromagnetic relay is the original relay dating back to the mid-19th century. At the present time this relay is used in almost every conceivable type of electrical equipment that requires automatic or remote circuit control. Electromagnetic relays depend on current through a coil to either open or close the circuit.

9-4.1 CLASSIFICATION BY TYPES

The electromagnetic relay category includes the following types: armature (clapper), plunger, rotary, instrument, and reed. Each of these is considered to be an electromagnetic relay because the contacts are opened or closed by the electromagnetic force created by passing current through a coil. They differ in the manner in which the circuit is closed or in the type of contacts used. For example, the armature or clapper type relay (Fig. 9-5) has a hinged or pivoted lever of magnetic material which is attracted to a fixed pole piece when the electromagnet current is energized. The lever is called the armature.

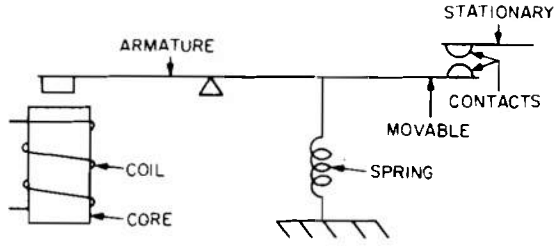


Figure 9-5. Simplified Diagram of Single-pole, Single-throw, Normally-open Relay[2]

The simplified diagram (Fig. 9-5) illustrates a normally open relay, where the contact points are held open by tension from the spring as shown. When current, usually from a remote source, is passed through the coil, the electromagnetic force created in the core attracts the armature. This overcomes the spring tension and causes the armature to pivot about the fulcrum, closing the relay contacts. When the circuit is broken, and the magnetic field around the coil collapses, the relay is again opened by tension in the spring.

The relay shown is a single-pole single-throw normally open (SPSTNO) relay and represents only one of the many possible variations in relay design. There are many other variable factors such as current and voltage ratings of the contacts, operate and release times, coil configuration, coil current, pivot position, spring characteristics, armature length, and number of contacts—all of which must be considered in the relay selection process.

Fig. 9-6 shows the essential parts required to operate the conventional armature type relay.

All of the variables previously mentioned could affect the electrical operation and physical appearance of this relay. For instance, some of the obvious differences between this relay and the previous example (Fig. 9-5) are the inclusion of both normally open and normally closed contacts and location of the fulcrum or pivot at one end. The

*Portions reproduced from:

Electronic Components Handbook, Chapter 5, Volume 1, Henny and Walsh, Copywright 1958, McGraw-Hill Book Company, by permission[2].

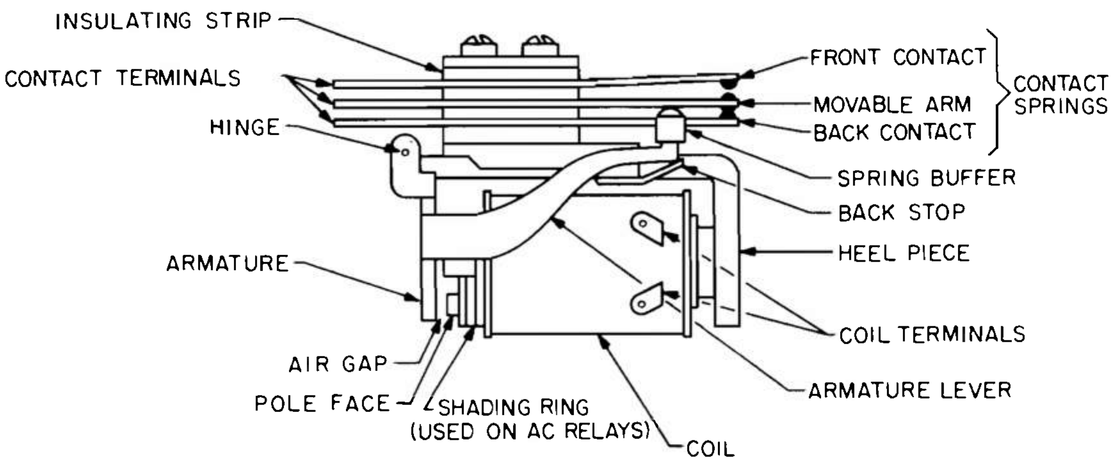


Figure 9-6. Essential Parts of Conventional Relay Structure[2]

relay in Fig. 9-5 has only one contact and has the fulcrum located at the center.

The plunger type electromagnetic relay, unlike the armature type, has a movable core or plunger that moves as the electromagnetic coil is energized. The movable contacts are attached to the plunger.

The rotary relay is an electromagnetic relay that closes or opens the circuit through a rotary motion. Although earlier conceptions of a rotary relay defined it as one operated by the rotation of a shaft from an electric motor, the term "rotary" is used by some manufacturers to mean any relay that is operated by rotary motion whether by electric motor, mechanical linkage, or by any physical rotation about a pivot, fulcrum, or shaft.

The instrument relay is one that employs movements similar to those used in measuring instruments; such as the electrodynamometer, iron-vane, or D'Arsonval movement. In this type of relay, the stationary contact is adjustable to different predetermined current or voltage operating points.

The reed-type electromagnetic relay is operated by an electromagnetic coil or solenoid, which when energized causes two magnetic reeds to be attracted to one another (Fig. 9-7). The magnetic reeds, in addition to forming part of the magnetic circuit, serve as the contacts. The reeds are protected from damage by enclosing them in an insulating and nonmagnetic enclosure as shown. The reed-type relay is used often where space is critical and electrical requirements are such that its long narrow shape can be utilized beneficially.

The thermal relay uses heat from a resistance element to distort or bend a bimetallic strip. The strip serves as the movable contact, and the circuit closes when the distortion causes the strip to touch an adjacent stationary contact. A disadvantage of the thermal relay for repetitive applications is the time it takes the contact to cool sufficiently in order to perform another operation. The average cooling time for this type of relay may range from 0.5 to 3 min[2]. This feature can, however, be used to advantage for time-delay purposes. In fact, delay times up to 5 min and release times up to 1 min are possible if environmental temperatures can be closely

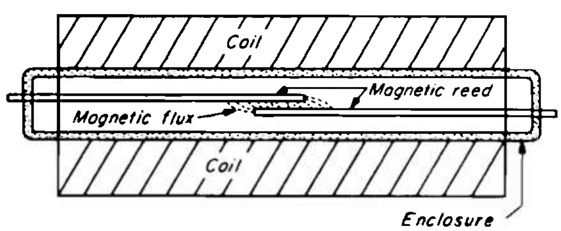


Figure 9-7. Basic Arrangement of Reed-type Relay[2]

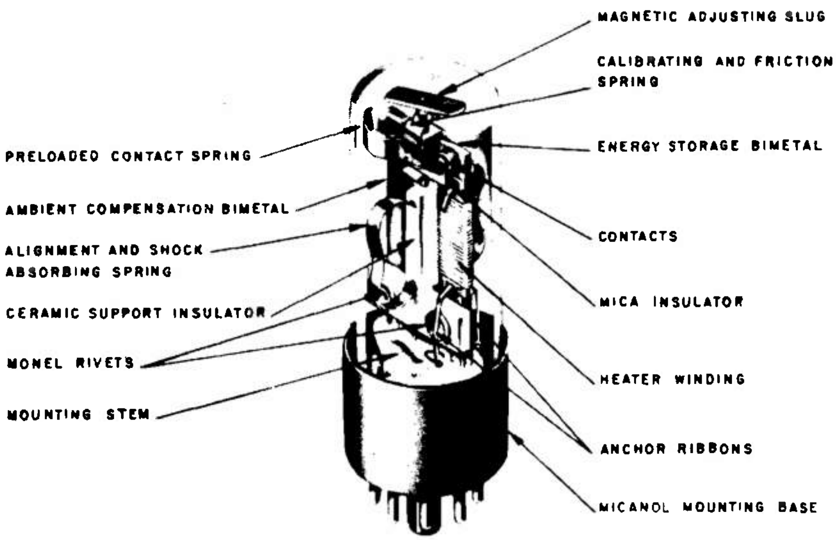


Figure 9-8. Thermal Time-delay Relay Having a Range from 2 sec to 5 min[2]

controlled. The thermal relay is usually enclosed in a vacuum tube (Fig. 9-8) to reduce the effects of ambient temperature.

Solid-state relays recently have been used to perform some of the functions historically accomplished with electromagnetic relays. The solid-state concept offers unique advantages because a relay system of solid-state components has no moving parts, and is therefore resistant to damage by shock and vibration. However, these devices necessarily will not obsolete the electromechanical relay because all other factors do not favor solid-state relays. For example, the ease with which additional contacts may be included in an electromechanical relay remains unchallenged. Furthermore, solid-state control of load currents above 10 A is not commonly offered, since the necessary heat sinks become large and prohibitive.

Fig. 9-9 shows a relatively simple solid-state relay which has a time delay feature. The essential components for this relay are the capacitor (C1), resistor (R1), and the transistor (Q1). When the switch (S1) is closed, C1 charges to line voltage, and an emitter base current appears in Q1. The emitter-base current causes the transistor to turn on and complete the lamp circuit to ground. After the switch is opened, the lamp circuit remains closed as long as the C1 discharge current in the emitter-base junction is large enough to keep the transistor conducting. A time delay of 4 to 5 sec may be achieved with this circuit. Although this relay is relatively simple, it serves to illustrate the principle of solid-state control. Most solid-state relays will require more transistor elements; however, the arrangement illustrated is suitable for use in commercial automotive applications to provide time delay for lighting circuits.

9-4.2 CLASSIFICATION BY USE

Not only are relays classified by type, but they can be classified by use—i.e., general purpose; special purpose, such as interlock, stepping, time-delay, latch-in; or differential relays.

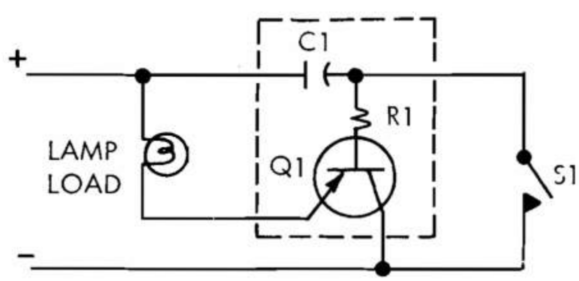


Figure 9-9. Solid-state Time Delay Circuit

The general purpose relay is the most commonly used relay. It is readily available and adaptable to a wide variety of uses due to its design, construction, operational characteristics, and ratings. Most of the general purpose relays are of the armature type (Fig. 9-8).

The interlock relay (Fig. 9-10) is a relay with two or more coils with armatures and contact points arranged so that movement of one armature depends upon the position of another. For example, the one shown, consisting of two relay units, requires one of the units to be operated after each operation to return the armature of the other unit to normal.

The stepping relay–sometimes referred to as rotary-stepping switch, rotary-stepping relay, or stepping switch–is a relay where the coil is energized momentarily to advance a wiper to a new contact position. This relay is used to perform a selecting or sequencing operation. The direct-driven stepping relay (Fig. 9-11) is usually an armature type. When the coil is energized, the armature drives the pawl and ratchet arrangement to advance the wiper one step. De-energizing the coil "cocks" the pawl for the next movement. Each cycle advances the wiper one step. The wiper is returned to the starting position only after disengaging the wiper detent normally or through use of a release solenoid. The wiper must return to the starting position to repeat the sequence.

Another type of stepping relay is spring-driven. This is usually an armature type where energy is stored in a spring when the armature is energized. This energy then drives a pawl, advancing the wiper one step when the coil is de-energized.

Both types of stepping relays can be operated by remote-controlled impulses. They can also be self-interrupted through the actuation of contacts as the armature moves.

Another relay which functions in a manner similar to the stepping relay is a sequence

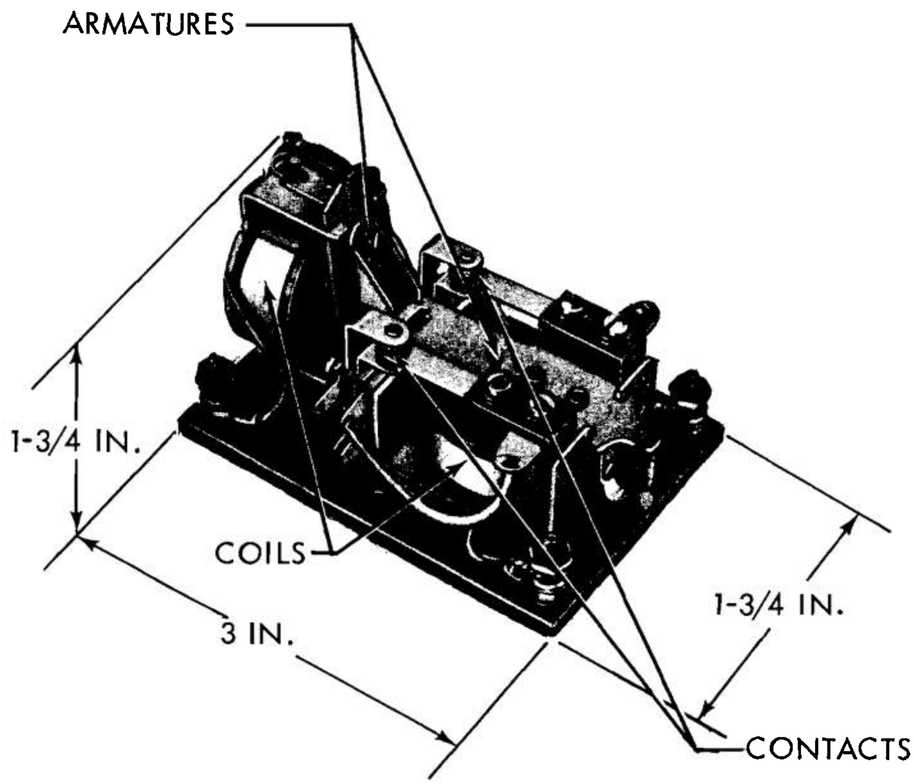


Figure 9-10. Interlocking Relay[2]

relay. In this type of relay, a series of contacts is opened and closed through action of a motor driven cam.

Another common relay is the time-delay type. Many applications will require a certain delay time in either or both the opening and closing of contacts. A solid-state time delay was illustrated in Fig. 9-9 and a thermal time delay in Fig. 9-8.

Another time delay relay (Fig. 9-12) employs a synchronous motor to obtain accurate timing. Here, the motor starts when the circuit is energized and continues to run until the contacts are operated. When the circuit is de-energized, the contacts return to the inoperative position, and the relay is reset for another cycle.

Time delay may also be built into armature-type relays by incorporating a conductive slug within the core or a conductive sleeve around it. Varying the position of this slug or sleeve varies the delay in operating time.

A latch-in relay uses contacts locked either in the energized or de-energized position until reset. This type differs from the interlock relay in that only the contacts of the latch-in are held in a fixed position, and it generally uses only one coil. One of these relays, a manual reset, is shown in Fig. 9-13. Although the armature motion is not restricted on this relay, the contacts are held in a fixed position by the snap action locking lever. This particular relay is reset by manually moving the locking lever; however, a solenoid could be attached to the reset arm to perform this function.

The differential relay has two or more windings that cause the relay to operate when the voltage, current, or power difference between the windings reaches a predetermined value. There are several different ar-

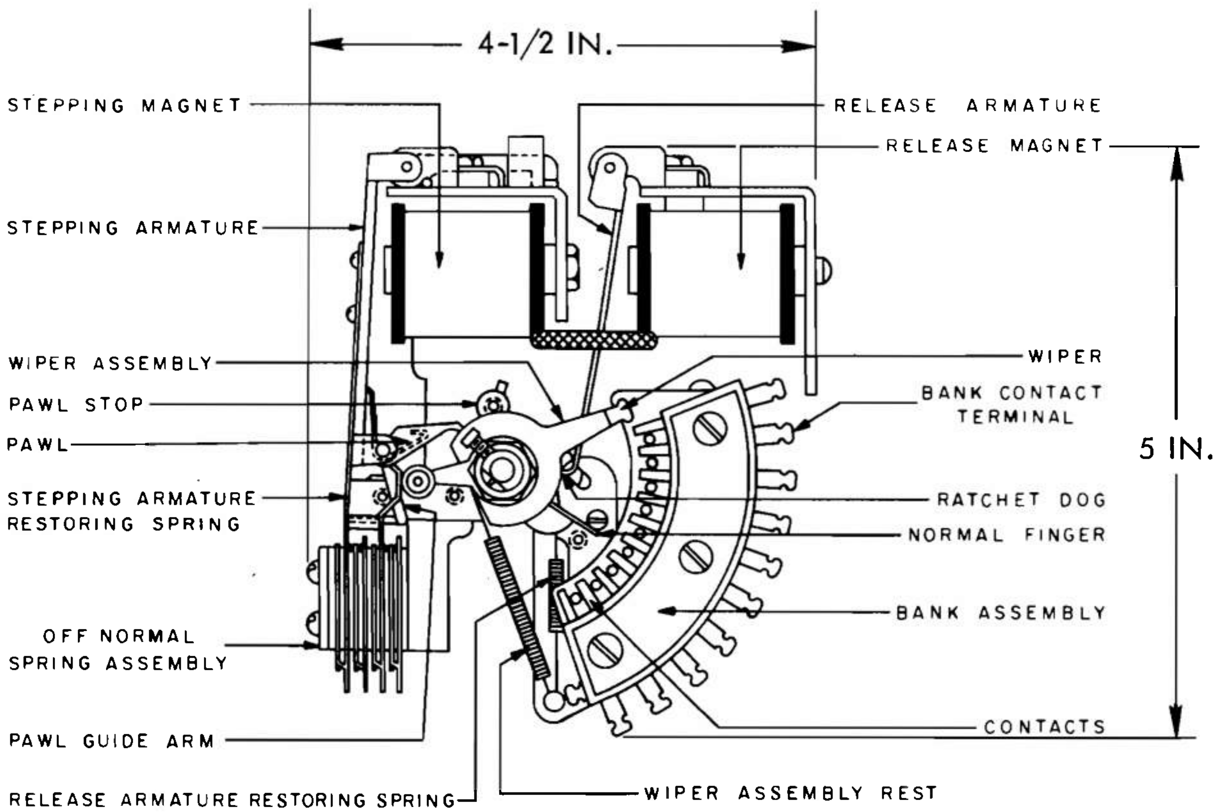


Figure 9-11. Direct-driven, 10-contact Stepping Relay[2]

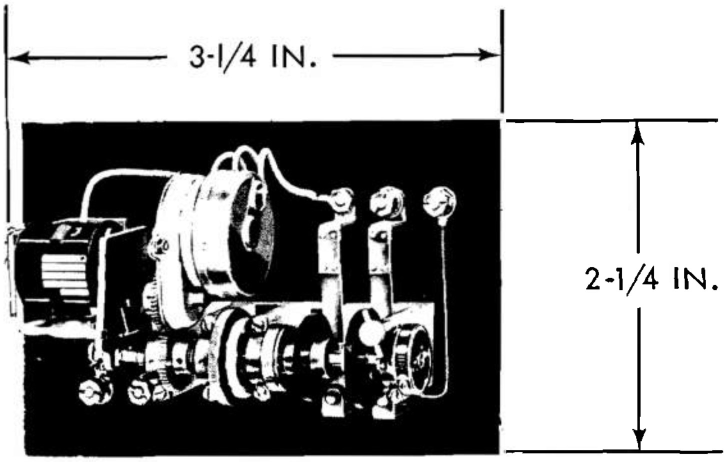


Figure 9-12. Time-delay Relay Using Synchronous Motor[2]

rangements possible with this relay. One of these (Fig. 9-14) uses two coils mounted side by side on opposite sides of a hinge. When the right coil has a stronger pull, the right-hand contacts operate and, similarly, the left-hand contacts operate when the left-hand coil has a stronger pull. Still another arrangement of the differential relay has two coils wound on the same core. The armature closes only in one direction, and the operation does not depend upon which coil has the greatest voltage, current, or power but rather upon a fixed difference between the two.

Another special purpose relay is the polarized relay. The operation of this relay depends upon the polarity of the voltage applied to the coil. This relay usually contains a permanent magnet. The magnetic force of the magnet is aided by the coil magnetic field on one side of the airgap and opposed by a force produced on the opposite side.

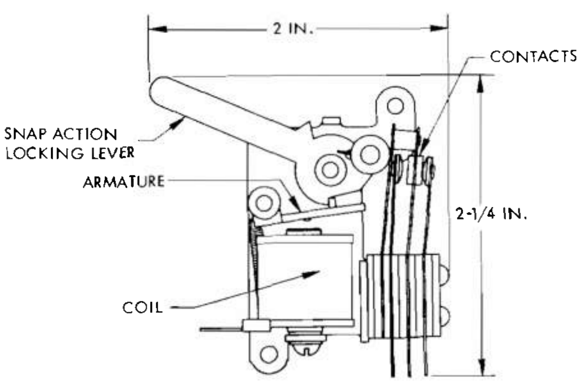


Figure 9-13. Latch-in or Locking Relay for Manual Reset[2]

9-4.3 METHOD OF RATING

All relays are categorized and rated in a manner similar in many respects to that used for switches; i.e., they have a specified number of contacts and arrangements, a specified operating voltage, and contact ratings. Relays also have other characteristics such as operating times, release times, time delay times, coil resistance or wattage, and operating temperatures.

9-4.4 CONTACT CONFIGURATIONS

Contact configurations are many and varied and depend upon the application. The National Association of Relay Manufacturers has approved standard relay contact nomenclature and symbols (Fig. 9-15) to help describe these configurations.

Contact descriptions are given in the following order: number of poles, number of throws, normal position, and DB or DM notation given only if the contacts are double-break or double-make. For example, SPSTNODM describes a single-pole, single-throw, normally open, double-make relay with form X in Fig. 9-15.

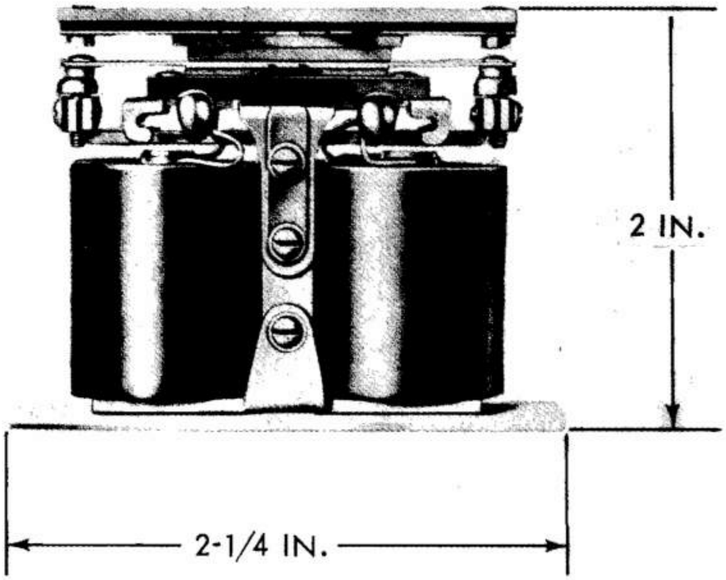


Figure 9-14. Typical Differential Relay—20 VDC, 0.05 W, 8000 Ohms[2]

Where relays have several sets of differently functioning contacts, the contact forms will be listed alphabetically as in Fig. 9-15. For example, 1A2B would refer to a combination relay with both SPSTNO and DPSTNC contacts.

9-4.5 FACTORS TO BE CONSIDERED IN SELECTION

Relay selection must satisfy a predetermined set of switching requirements. There are several factors that affect the switching performance of a relay. Some of these are the type of load; i.e., resistive, inductive, capacitive, lamp, the type of power (DC or AC frequency), contact type (Fig. 9-15), and the amount of loading (percent of contact rating).

Another important factor to be considered in relay selection is the switching function itself. For example, is the relay to be used for on-off, load transfer, or motor reversal functions? If used for on-off switching of DC power, is the power source single or multiple voltage?

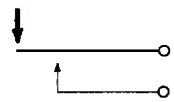
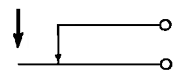
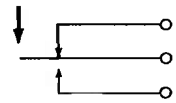
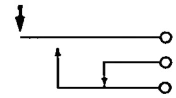
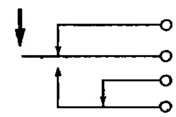
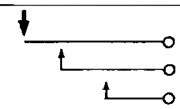
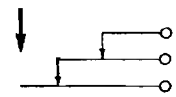
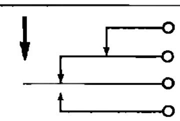
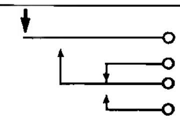
For AC power sources, is the power source single or polyphase, or single of different frequencies and voltages? If used for load transfer, is the load transfer between two DC sources or a transfer between two AC single phase or two polyphase sources? If used for motor reversal, is the motor DC, or if AC, is the action reversing two phases of a three-phase motor?

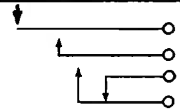
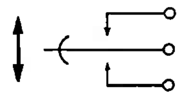
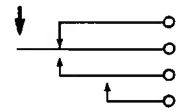
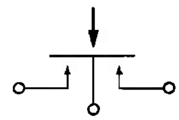
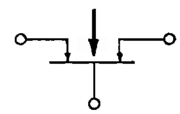
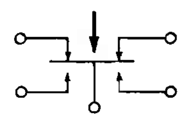
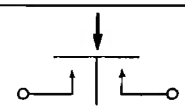
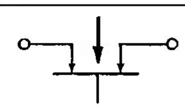
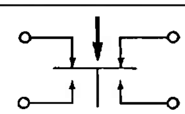
9-5 RELAY CIRCUITS

The vehicle designer should avoid entering into relay design, however, he should know exactly what performance is required in a given relay application. He can then select a relay from an applicable Military Specification or Standard, manufacturer's literature or, if necessary, through the manufacturer's recommendation.

9-5.1 FAIL-SAFE CIRCUITRY

The designer often will need to design a circuit fail-safe. To do this, he must make use of the closed circuit principle. The closed circuit principle requires that a circuit be closed and be continuously energized for *normal* operation. If the power fails, then an emergency condition normally is established. Fig. 9-16 shows such a fail-safe circuit. In this circuit, a failure of the normal power supply will not result in a complete system failure. Power to essential equipment is maintained by switching in an emergency power supply.

Form	* Description	Symbol
A	Make or SPSTNO	
B	Break or SPSTNC	
C	Break, Make or SPDT (B-M)	
D	Make, Break or SPDT (M-B)	
E	Break, Make, Break or SPDT (B-M-B)	
F	Make, Make or SPST (M-M)	
G	Break, Break or SPST (B-B)	
H	Break, Break, Make or SPST (B B-M)	
I	Make, Break, Make or SPST (M-B-M)	

Form	Description	Symbol
J	Make, Make, Break or SPST (M-M-B)	
K	Single Pole, Double Throw, Center Off or SPDTNO	
L	Break, Make, Make or SPST (B-M-M)	
U	Double Make, Contact on Arm or SPSTNODM	
V	Double Break, Contact on Arm or SPSTNCDB	
W	Double Break, Double Make, Contact on Arm or STDTNC-NO(DB-DM)	
X	Double Make or SPSTNODM	
Y	Double Break or SPSTNCDB	
Z	Double Break, Double Make or SPDTNC-NO(DB-DM)	

*SPST= Single Pole Single Throw

SPDT= Single Pole Double Throw

NC= Normally Closed

ND= Normally Open

Figure 9-15. Relay Contact Nomenclature and Symbols[3]

"A Dictionary of Relay Types", *Machine Design*, March 31, 1966, The Penton Publishing Company, reprinted by permission.[3]

At the same time all nonessential loads are switched out of the circuit. The design presented in this particular circuit would require relay contacts rated for load transfer.

Certain relays are not adaptable to a fail-safe circuit design. The latch-relay, for example, should never be used for fail-safe operation. This is because it requires a positive action to reset it once it is latched into position.

9-5.2 ARC SUPPRESSION

The amount of switched energy can determine, to some extent, the cycle life of a relay used in its normal application. If the energy is low, ionization and arcing may not occur. Even relays that are used incorrectly to switch voltages higher than the intended application may function if the currents remain small. Likewise, large currents may possibly be carried at very low voltages. However, these practices are not recommended.

The designer often will find that relays are rated at lesser current values for inductive loads than for resistive loads, and AC relays at lower values for 60 Hz than for 400 Hz inductive loads. Inductive loads at lower frequencies are usually more severe than at higher frequencies.

When a DC inductive circuit is energized, the amount of energy W stored is equal to[4]:

$$W = \frac{LI^2}{2}, \text{ J} \quad (9\text{-}1)$$

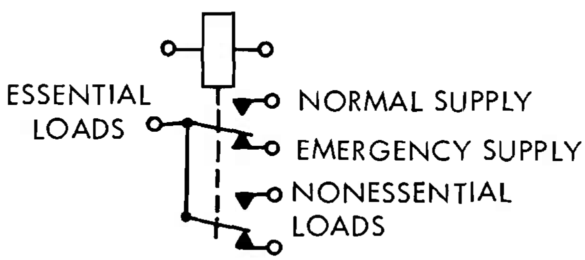


Figure 9-16. Fail-safe Circuit

where

L = inductance, H

I = coil current, A

When the circuit is opened by a contact, this energy is dissipated either through resistance loss, eddy currents, or through arc energy across the contacts.

When the voltage across the contacts exceeds the minimum breakdown potential of air, an arc will form. As the arc gap increases, the arc becomes more unstable, finally creating a voltage spike and extinguishing. If the contact motion is halted on a DC circuit before the arc is extinguished, the arc will continue until the contact points are destroyed. On AC circuits, arcing is generally not as severe since the voltage goes to zero as the current reverses, thus aiding the arc interruption. As indicated previously, lower frequencies generally have more severe inductive loads.

Arcing usually is suppressed by connecting a capacitor across the contact points. When the contacts open, the capacitor momentarily absorbs all the load current, thus preventing severe arcing. On closing, contacts may have a tendency to weld or erode due to current from the capacitor. To correct this tendency, a combination capacitor-resistor (Fig. 3-9) can be connected across the contact points.

A very effective arc interference suppression circuit (Fig. 9-17) consists of a resistor placed in series with the load circuit and a capacitor in parallel with the series combination of resistor and switch. This circuit is similar to the series capacitor-resistor combination (Fig. 3-9). Because the resistor must carry the normal load current with a negligible voltage drop, there is a practical limit to the maximum value of the resistance. (This requirement is in addition to those imposed by the interference reduction considerations.) In practice, this circuit is much more effective in reducing noise than the series capacitor-resistor unit. Whatever disturbance is produced is largely confined to the switch-resistor-capacitor loop. This circuit not only alters the phenomena occurring at the gap, thereby functioning as an interference reducer, but also provides containment for the interference that is produced.

Devices with nonlinear resistance-voltage characteristics, such as diodes and varistors, are useful components for arc interference-reduction. A diode has low forward resistance and high reverse resistance. Consequently, it may be used to present either a short-circuit or an almost infinite impedance, depending upon the direction of the current. A varistor conducts well at high voltage but not at low voltage. It is a nonlinear resistance that is very high at low voltage, but drops to a very low value at high voltage. The function of either a diode or a varistor in an interference reduction application is to provide an alternate shunt path for the induced current that presents a lower resistance than the contact gap.

Fig. 9-18(A) shows suppression being accomplished with a "flyblack" diode across the inductance. When the switch is opened, the voltage produced by the collapsing magnetic field will cause current to circulate in a forward direction through the diode. One disadvantage of this circuit is that accidental application of reverse battery polarity when the switch is on will cause a continuous high current to flow through the diode and burn it out. When vehicle power distribution circuitry is designed to preclude inadvertent application of reverse polarity, this circuit is an acceptable choice.

The addition of a series diode as shown in Fig. 9-18(B) appears to protect the "flyback"

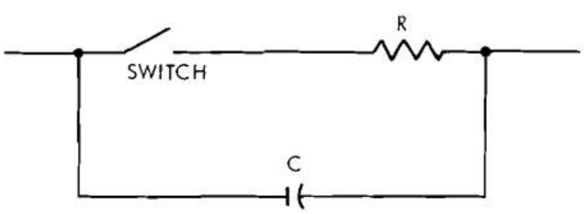


Figure 9-17. Capacitor-resistor Arc Suppression

diode from reverse polarity damage that could occur if the vehicle batteries were installed backwards. However, the designer must realize that the peak inverse voltage rating of the series diode must be selected to resist the reverse voltage that may be developed by switching any other inductance in the system, rather than reverse battery potential alone, or it will be damaged (Fig. 9-18(C)).

The various forms and characteristics of arc interference suppression circuits are described in detail in the *Interference Reduction Guide for Design Engineers, Volume 2*[8].

Although excess arcing can have a serious effect on the life of relay contacts, continuous switching operations at minimum current levels, i.e., in the area of 50 mA to 300 mA, can also lead to contact problems due to carbon contamination. This is because at lower current levels minimum arcing occurs, and there is insufficient energy to clean the contacts. After prolonged switching at minimum current, carbon buildup leads to excess contact resistance and eventual contact failure. Switching at higher energy levels does not cause this problem because the contaminants are burned away.

9-5.3 PARALLELING CONTACTS

Paralleling relay circuit contacts can be beneficial under the right conditions. However, incorrect paralleling of contacts can lead to circuit damage. For example, contacts should not be paralleled to increase the switching capacity. Two 5-A contacts in parallel will not carry a 10-A current. This is because the contacts do not close simultaneously, and the one that makes first will have to carry all of the amperage for a finite period of time.

On the other hand, relay contacts may be installed in parallel to reduce the effects of contact bounce and vibration, and to add redundancy. However, contacts should not be paralleled on the assumption that they will work together. Contacts will not make and break simultaneously, and in relays where

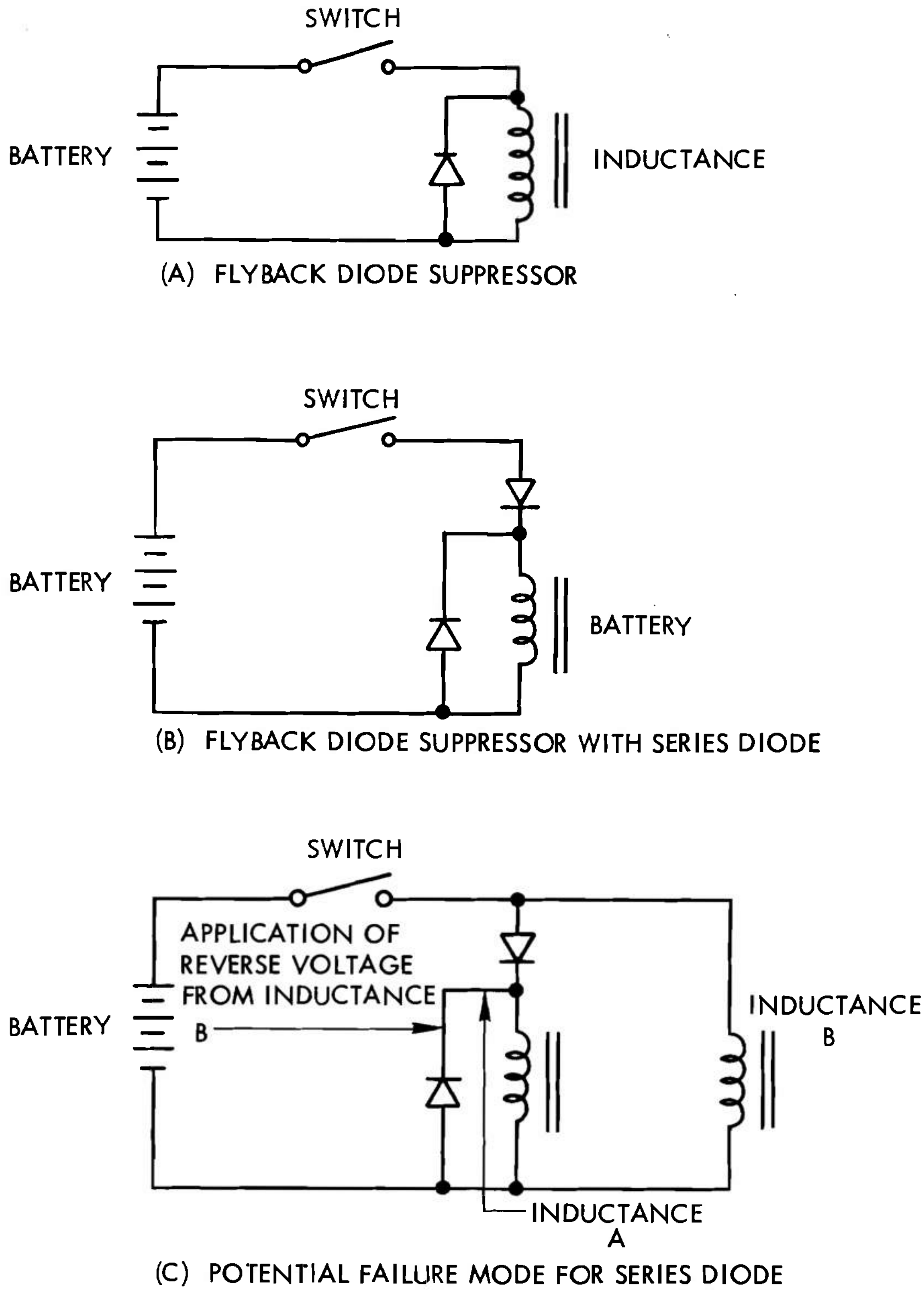


Figure 9-18. Diode Suppressor Circuits

contact travel is short, one contact may transfer before the other breaks. In a critical circuit where a break-before-make (form C, Fig. 9-15) operation must be maintained, paralleling could result in a make-before-break (form D, Fig. 9-15) operation and cause serious problems.

9-6 RELAY APPLICATIONS

The proper application of any relay depends upon the analysis of factors that may affect its performance. A relay that is adequate for most applications may not be suitable for a circuit with critical requirements. Circuit analysis is a must to prevent the improper use of relays.

The vehicle electrical designer should consider the entire system to avoid misapplications. This includes the environment the system operates in as well as worst-possible conditions, such as power failures and overloads. He should analyze the type of loads carried on the circuit and the switching functions required of the relay. He must consider the technical suitability. Is the design basically sound? Does the relay manufacturer have controlling techniques to assure good workmanship? He must also consider the economics of his design, while at the same time contemplating the consequences of a system failure, to verify that the selected relay fits the application.

The designer can simplify his relay selection by consulting applicable Military Specifications and associated application sheets. MIL-STD-1346, *Relays, Selection and Application*[5], is a guide for the selection of relays for use in military equipment. Table 9-3 contains a partial list of relays that have been used successfully in vehicle electrical systems.

Although Military Specifications and Standards can aid the designer, they do not provide him with all the answers, particularly where sophisticated applications are involved. In cases where he has some doubt over a particular selection, he should not hesitate to consult reliable relay manufacturers. Coordination with the manufacturer's staff of highly trained and specialized engineers early in the design phase can ensure fewer problem areas and decrease the possibility of misapplication.

The designer should seek the simplest, most acceptable solution to an application problem. Often relay activated circuits can become very complex, particularly with the increased use of solid-state devices. The designer should become familiar with relay-system diagrams and with circuit-logic diagrams. The use of Boolean algebra can help him formulate logic diagrams for different switching arrangements and circuit configurations.

Relay misapplication often results from failure to understand the nature of circuit switching requirements. Basic factors may be overlooked, such as the fact that contact ratings vary with loads. Cost, space, or weight savings may be attempted by adapting smaller relays without the application of suitable circuit safeguards.

To select the proper relay, circuit designers must be familiar with the considerations previously mentioned. There are many other considerations as well. A complete description of these is beyond the scope of this handbook; however, a summary of the more important dangers of relay misapplication which the designer should be cognizant of follows:

1. Improperly using existing Military Specifications by erroneous interpretation or even using the incorrect Specification. A given set or sets of conditions are given in the Specifications. Variations from these conditions will affect performance of the relay accordingly.

2. Paralleling contacts to increase capacity. Contacts will not make or break simultaneously, and one contact will carry all the load under the worst conditions. Contacts can be paralleled for reliability in the low level or minimum current (contamination test current) areas.

3. Not allowing for circuit transient surges.

TABLE 9-3. MILITARY STANDARD AND ORDNANCE RELAYS

Military Standard or Ord. Drwg. No.	*Contact Type	Contact Form (Refer to Fig. 9-15)	Contact Rating, A 28VDC				Terminal Style				Type Mtg	Remarks
			Res	Ind	Motor	Lamp	Potted leads	Solder hooks	Plug in	Screw or post		
7355708	SPSTNO	X		50					●		Bracket	
MS24143	3PSTNO		25					●				
MS24171	SPSTNO	X	200							●	Bracket	Unsealed
MS24183	SPSTNO	X	200							●	Bracket	Sealed
MS24185	SPSTNO	X	400							●	Bracket	
MS24187	SPDTNC	Z	50							●	Bracket	
MS24568	MPDT	C	10	10	6	3				●	Bracket	1P, 2P, 4P, 6P Avail.
MS25024	4PDT	C	10							●	Bracket	
MS25200	MPDT	C	10	6	4	2		●			Bracket	2P, 4P, 6P Mag. Latch
MS25271	MPDT	C	10	6	4	2		●			Stud	1P, 2P, 4P, 6P Avail.
MS25272	MPDT	C	10	6	4	2	●				Stud	1P, 2P, 4P, 6P Avail.
MS25327	MPST	C	10	6	4	2			●		Socket	1P, 2P, 4P, 6P Avail.
MS25395	2PDT	C	5					●			Stud	
MS25461	MPDT	C	10	6	4	2			●		Socket	2P, 4P, 6P Mag. Latch
MS25467	4PDT	C	5					●				
MS25468	MPDT	C	10	6	4	2		●			Stud	2P, 4P, 6P Mag. Latch
MS27254	MPDT	C	10	10	5	3			●		Socket	1P, 2P, 4P, 6P Avail. Contact Cycles Vary
MS27255	MPDT	C	10	10	5	3		●			Bracket	1P, 2P, 4P, 6P Avail. Contact Cycles Vary
MS27400	MPDT	C	10	8	4	2		●	●		Socket Brkt	2P, 4P Polarized Coil
MS27418	3PSTNO	C	20					●		●	Stud Brkt	
MS27709	MPDT	C	10	8	4	2		●	●		Socket Brkt	1P, 2P, 4P, 6P Avail. Contact Cycles Vary

*SPSTNO = Single Pole Single Throw Normally Open
3PSTNO = Three Pole Single Throw Normally Open
SPDTNC = Single Pole Double Throw Normally Closed
MPDT = Multipole Double Throw

Circuit designers must be careful not to expect relays to handle circuit transient surges in excess of their ratings.

4. Using relays under load conditions for which ratings have not been established. Contact ratings should be established for each type of load. Many relays will work from low level to rated load; however, don't ask a relay to do both.

5. Using relays, which are rated for low-level and high-level rated loads, at low-level loads after having been tested or used for a short period of time at high-level rated loads. High capacitive inrush currents and inductive break currents require oversized contacts. A cold filament lamp draws very high currents until warmed up. Contacts for switching lamps must be able to take the current surges.

6. Using relays on higher voltages than those for which they were designed; for example, switching 300-V power supplies with relays only rated at 115 V maximum.

7. Using contact ratings with grounded case. Some relays with small internal spacing or lack of arc barriers, when switching 115 VAC with grounded case, must have the contact ratings significantly lower than in the ungrounded case mode of operation. Typically, the maximum AC rating of such a nominally rated 28 VDC, 2-A resistive relay, is of the order of 0.300 A. Relays with sufficient spacing or arc barriers may be used at full rating on 115-V AC or 115/200V, 3-phase AC with case grounded when so rated on the detail specification or MS standard. Switching high voltage with the relay case ungrounded results in a potential personnel hazard.

8. Transferring load between unsynchronized power supplies with inadequately rated contacts. When the load is switched, the voltages can range from being in phase to 180 deg out of phase; therefore, the relay contact voltage may vary from zero volts to two times peak voltage and maximum current.

9. Switching polyphase circuits with relays tested and rated for single phase only. A typical misapplication is the use of small multipole relays (whose individual contacts are rated for 115-V single-phase AC) in 115/200-V three-phase AC application. Phase to phase shorting at rated loads is a strong possibility in these instances with potentially catastrophic results.

10. Using relays with no established motor ratings to switch motor loads. Caution should be used in applying relays to reverse motors, particularly where the motor can be reversed while running, commonly called "plugging". This results in a condition where both voltage and current greatly exceed normal. Many power relays are rated for "plugging" and reversing service, but a relay should not be used in potential "plugging" situations unless so rated by the manufacturer.

11. Using relays with no established minimum current (contamination test current) capabilities. It must not be assumed that because a relay is used in an application considerably below its rated contact load, that the consideration of minimum current (contamination test current) capability can be ignored; this is especially true if there is no established level of minimum current (contamination test current) for the relay.

12. Using relays rated for 115 VAC only on 28 VDC or higher voltage DC applications. If contacts in these devices are of the single break form AC type, it may be necessary to derate severely for use on DC applications, at 28 V or higher.

SECTION III

VARIABLE CONTROLS

9-7 INTRODUCTION

Relays and switches apply full voltage or no voltage to the power consumer. As mentioned in previous sections, some control situations require varying this power. Examples of items that do this are radio volume controls, variable light dimmers, and fuel gage sending units.

Many design situations on tank-automotive vehicles require devices that measure a physical quantity property, or condition, and then vary either the voltage, resistance, inductance, capacity, or reluctance (AC) of a circuit to provide a useful representation of this measurement through visual readout or other means. Devices used to accomplish this function are categorized as transducers. Although the term "transducer" has been used in a broader sense, it should be limited to the field of measuring and control instrumentation in order to prevent confusion.

Par. 9-8 describes transducers that have existing or possible future applications on tank-automotive vehicles, while par. 9-9 describes the common potentiometer used for current or voltage control.

9-8 TRANSDUCERS

As indicated in the introduction, the transducer is a device that converts information about a measured quantity into a corresponding variance in the electrical circuit. This change in the electrical circuit causes a resultant change in the circuit output. The output usually is converted into the form of a mechanical motion to provide a measure of the change through a display or readout device such as a fuel quantity indicator, coolant temperature indicator, or flow rate meter.

Many types of transducers are used in tank-automotive vehicles. These include not only those to provide input to servomechanisms and temperature, pressure, and quantity indicating circuits, but those also used on special equipment to record the presence of chemicals, atomic radiation, or electromagnetic fields.

The types of transducers commonly used, listed by their method of operation, are shown in Fig. 9-19. Of the types shown, all but the electromagnetic, photovoltaic, and piezoelectric require some form of external electrical excitation for their operation. These three exceptions are self-generating types which do not require separate power inputs.

The capacitive type (Fig. 9-19(A)) varies the capacitance of the electrical circuit by one of two methods. The capacitance between the two plates is changed by either a moving plate that moves with a sensing element such as a diaphragm, or by a changing dielectric, such as a gas or liquid fuel between fixed plates. This type of transducer commonly is used to measure acceleration, pressure, displacement, force and torque, humidity and moisture, liquid level, velocity, and sound.

The electromagnetic type (Fig. 9-19(B)) is a self-generating transducer. An output voltage is generated in the circuit by the relative motion between the permanent magnet, connected to a mechanical sensing element, and the electromagnet as shown. This type of transducer commonly is used to measure displacements, flow rate, and velocity.

The inductive transducer (Fig. 9-19(C)), changes the self-inductance of a coil. This change usually is brought about by a displacement of the coil core that is attached to a mechanical sensing element. This type of

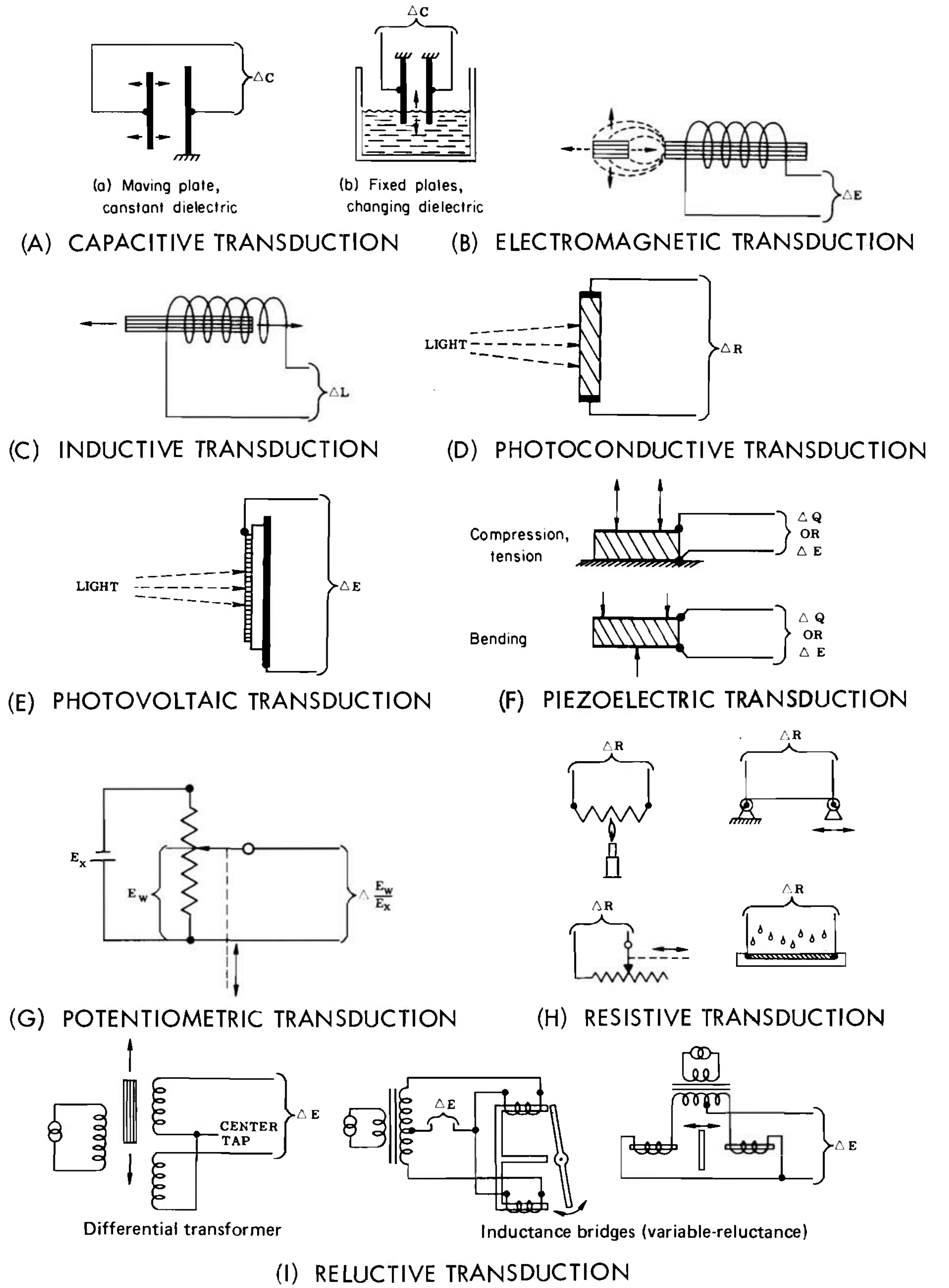


Figure 9-19. Transducer Types[6]

transducer commonly is used to measure pressure, displacement, and sound.

The photoconductive transducer (Fig. 9-19(D)), varies the resistance of a photoresistive material to effect a change in the electrical circuit. Two versions of photoconductive transducers are used. One is a light-intensity transducer where the resistance change is a direct result of a change in light intensity. The other has a moving shutter mounted between the light source and the photoresistive material. The shutter is connected directly to a sensing element such as a pressure capsule or seismic mass. These transducers are used to measure displacement, velocity, and light intensity.

The photovoltaic transducer (Fig. 9-19(E)) is a self-generating type that produces a voltage when the junction between certain dissimilar materials is illuminated. This type of transducer is used primarily for direct measurement of light intensity.

The piezoelectric transducer (Fig. 9-19(F)), a self-generating type, changes the electrostatic charge Q or voltage E generated by certain crystals when mechanically stressed. The stress is imposed either in compression, tension, or bending by a mechanical motion of the sensing unit. This type is used for measuring acceleration, pressure, force and torque, liquid level, and sound. This same principle is also used in the piezoelectric ignition system described in Chapter 11.

The potentiometric transducer (Fig. 9-19(G)) is a type commonly used for indicating circuits. This type offers advantages in that it is rugged, reasonably accurate over a wide range, inexpensive, and usually requires no amplification. This type is often referred to as a "voltage divider" since the voltage output is a ratio of the AC or DC excitation voltage E_x. The voltage varies with the position of the wiper arm on the resistance element, since any wiper arm displacement causes a change in the resistance ratio between one element end to the wiper arm and the total element resistance. Potentiometric transducers are used for a wide variety of measurements using many different mechanical sensing elements such as diaphragms, seismic masses, or direct mechanical linkages. They are used to measure acceleration, pressure, altitude, displacement, and liquid levels. Potentiometers are used, other than in indicating circuits, for variable circuit control such as controlling audio levels in radio and intercom equipment. The potentiometer is discussed in detail in par. 9-9.

The resistive transducer (Fig. 9-19(H)), widely used in tank-automotive applications, varies the resistance R of a circuit by several methods. These include heating and cooling, applying mechanical stresses, sliding a wiper arm along a rheostat-connected resistance element, or varying the moisture content of certain materials such as electrolytic salts. These transducers are used to measure acceleration, pressure, temperature, displacement, flow flow-rate, humidity and moisture, and liquid level. A special version, called the strain-gage transducer, employs a Wheatstone bridge arrangement where the resistance of the bridge arms are varied by the imposed strain. This special version is used primarily to measure strain, but is also employed for other measurements.

Fig. 9-20 shows a cross-sectioned resistive transducer used to measure temperature variations. This is the MS24537-1 temperature sensor commonly used in tank-automotive vehicles and to measure temperatures of engine and transmission oil or coolant, over a range of 120° to 280°F. This type of transducer often is referred to as a thermistor. The key element is the semi-conductive resistance material, which is generally an oxide of nickel, manganese, iron, cobalt, copper, magnesium, or titanium. The material generally has a negative temperature coefficient, i.e., it decreases in resistance as the temperature increases.

Fig. 9-21 shows another resistive type of transducer employing the wiper arm and the wire wound resistance element. This is the MS24539-1 pressure transducer used to meas-

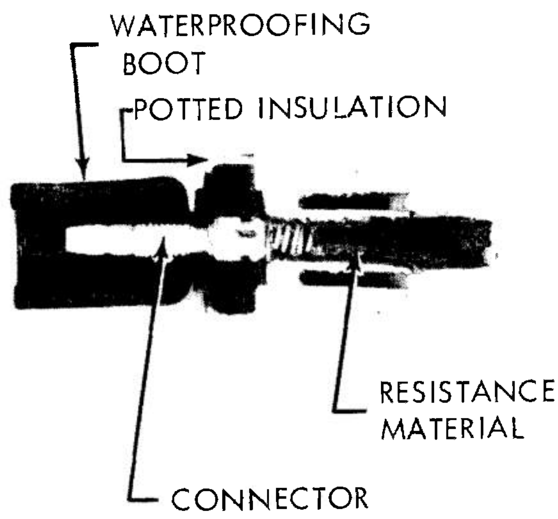


Figure 9-20. Thermistor

ure pressures in the range of 0 to 120 psi. Fig. 9-22 shows the circuit diagram for this transducer.

The reluctive transducer (Fig. 9-19(I)) controls an AC circuit by varying the reluctance. This usually is accomplished by displacement of the magnetic core or "armature". The "differential-transformer" and the "inductance-bridge" or "variable-reluctance" circuits are illustrated. The reluctance transducer is used to measure acceleration, pressure, temperature, displacement, flow rate, humidity and moisture, and liquid level.

Other types of transducers, or special versions of those previously mentioned are the nucleonic, thermoelectric, ultrasonic, turbine, gyroscopic, electromechanical, and psychrometric. These transducers are described in detail in Ref. 6. Additional information regarding these devices may be found in Refs. 9, 10, 11, 12, and 13.

Many of the transducers listed require some form of amplification before the output signal is strong enough for indicating purposes. Also the types of sensing elements (the device that responds directly to the measurement) employed are many and varied. These include several versions of the Bourdon-tube, seismic masses, diaphragms, springs, coils, liquid electrolyte, sensing shafts, vanes, calibrated wires, and expansion bellows, to mention a few. A general guide line for the designer to follow in selecting a transducer for a given tank-automotive application is to evaluate it for desirable features which include:

1. Ability to withstand severe environments
2. Commercial availability
3. Direct current transmission
4. High level output
5. High zero stability
6. High span stability
7. High reliability
8. High degree of linearity
9. High overrange protection
10. Low source impedance
11. Low frequency response
12. Low maintenance
13. Low unit cost
14. Ruggedness
15. System compatibility
16. Military Standard or Specification availability.

9-9 POTENTIOMETERS

The potentiometer is a precision variable resistor used to alter the output voltage of an electrical circuit as a function of input voltage and wiper position. It often is used in conjunction with a sensing unit to provide control in indicating circuits as described in par. 9-8.

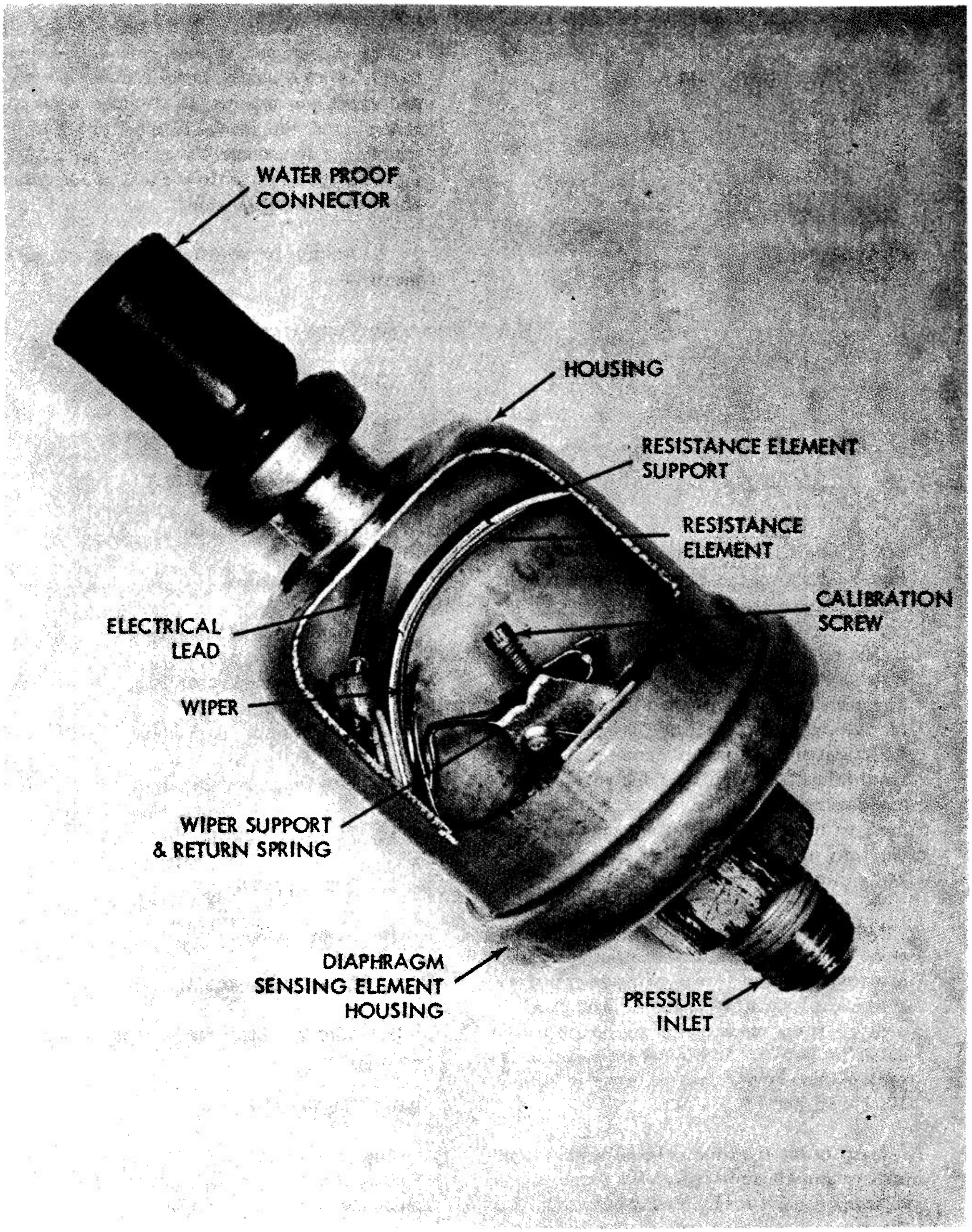


Figure 9-21. Resistive Pressure Transducers

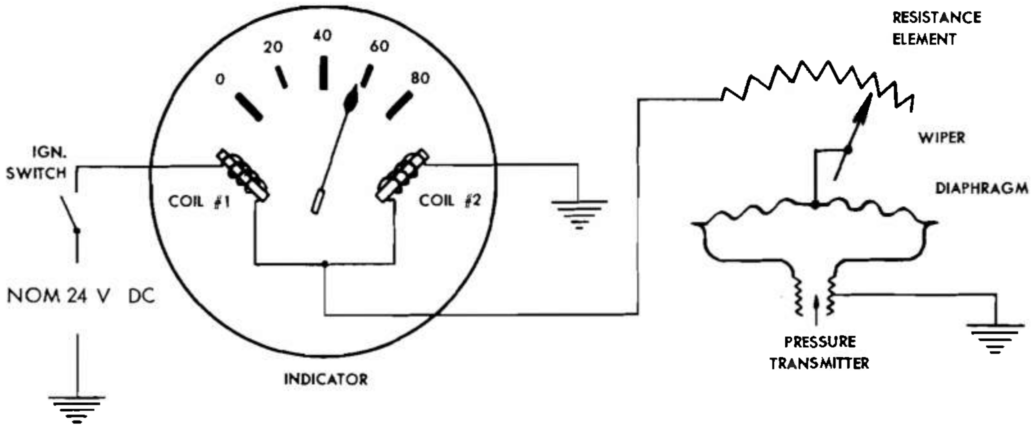


Figure 9-22. Pressure Transducer Circuit

Another use for the potentiometer is found in servomechanisms that operate on the principle of electrical feedback. Position feedback potentiometers are found in remote controlled weapon systems, missile launcher erectors, automatic radio antenna systems, and in vehicle attitude positioning circuits. The servomechanism is discussed in Chapter 16.

9-9.1 CONSTRUCTION FEATURES

The potentiometer consists of three main parts: the resistance element, the slider, and the housing. The housing has the dual function of holding the other parts in proper relation to one another and to serve as a mount for the complete unit.

The electrical circuit voltage is varied as the slider moves on the resistance element (Fig. 9-23). This motion is caused by turning a shaft or pushing a lever either manually or by mechanical action of a cam, motor, or hydraulic cylinder (as in a servomechanism). Any slider displacement causes a change in the resistance ratio between one resistance element end to the slider and the total element resistance. The output voltage e_{out} at terminals C and D (Fig. 9-23) is thus a ratio of the constant-magnitude excitation voltage e_{ex} at terminals A and B. In an actual potentiometer, terminals B and D are combined into a single terminal. Note also, that the potentiometer can be made to function as a rheostat by eliminating the electrical connection between the resistance element and line B-D.

There are two basic types of potentiometers, the rotary and the translatory. Most of the potentiometers produced are of the rotary type, where the slider rotates around a center shaft. These can be either a single turn or multiturn design.

Single turn potentiometers are designed for slider rotation of one revolution or less. Multiturn potentiometers are designed for slider-travel limits of several revolutions.

The translatory potentiometer has more precise voltage control than the rotary and is

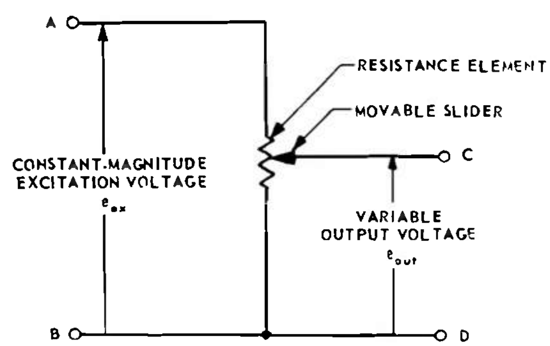


Figure 9-23. Electrical Representation of a Potentiometer

used where precision is a requirement and space allows.

A potentiometer can be constructed to provide a linear or nonlinear output. A linear potentiometer will produce a voltage output that changes at a near constant rate with the displacement of the slider. The nonlinear potentiometer will produce an output that is not linear but rather some other function that describes the slider position[7]. Most tank-automotive applications require a linear potentiometer, since it is usually desirable to have the voltage vary constantly as the slider position changes. Intercom and radio volume controls employ nonlinear potentiometers.

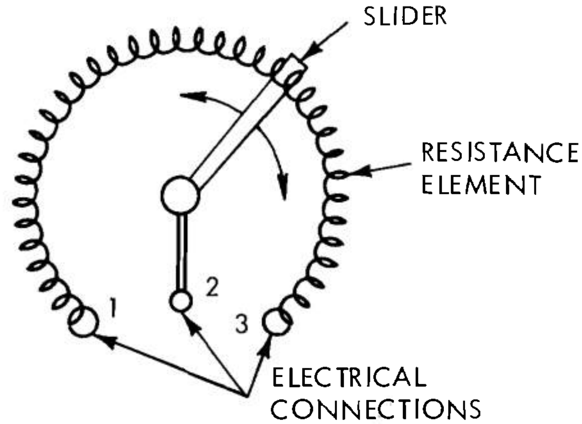


Figure 9-24. Wire-wound Rotary Potentiometer

There are four types of resistance elements commonly used in potentiometers. These are wire-wound, slide wire, film, and conductive plastic. Of the four, the wire-wound is currently by far the most commonly used potentiometer.

Wire-wound elements generally are made by wrapping an insulated wire around stiff insulative material or around an insulated metal rod. If the potentiometer is a rotary type, the metal rod is then bent into a circular shape. After the wire is wound, the insulation is removed along the path the slider contacts. The resistance element and slider are then mounted in or molded into the potentiometer housing.

In operation, the slider of the wire-wound potentiometer moves successively across each turn of the winding (Figs. 9-24 and 9-25).

The resistance between the slider and one end point of the resistance element and the output voltage thus will vary in discrete steps as the slider moves along the element. The finer the wire and the greater the number of turns, the smaller the individual voltage steps and the smaller the travel of the slider arm over which the voltage is constant. Thus, the number of turns determines the accuracy to which a desired voltage can be adjusted.

Although potentiometers with slide wire, film, or conductive plastic resistance elements do not suffer from the stepped nature of the resistance function as does the wire-wound, they do have other disadvantages. For example, the film and conductive plastic types are difficult to manufacture with a uniform resistance, and are more susceptible to extreme environmental conditions than the wire-wound. The sliding wire type is limited by its relatively low total winding resistance.

9-9.2 APPLICATION FACTORS

The power rating of a potentiometer is based on the maximum recommended power that it can dissipate continuously and still perform according to specifications. This rating usually is specified at a given ambient

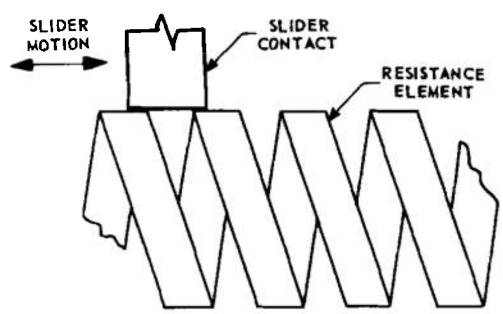


Figure 9-25. Wire-wound Element and Slider

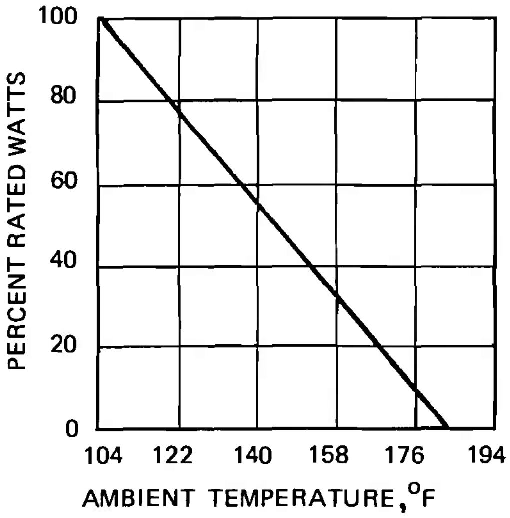
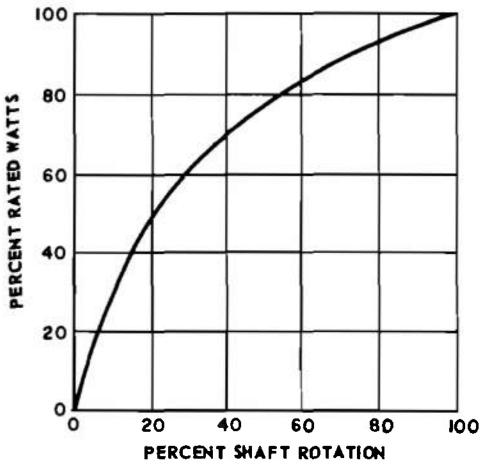


Figure 9-26. Power Derating Curve for Continuous Duty



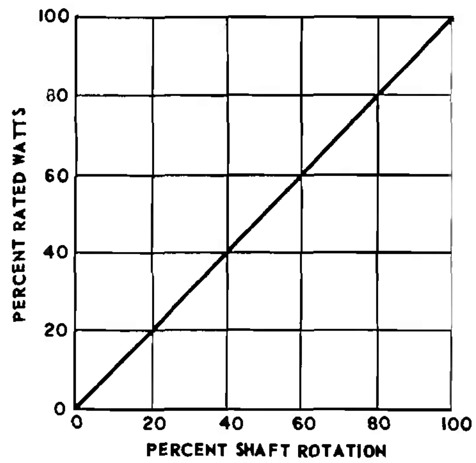
OPERATING TEMPERATURE 176°F OR LOWER
AMBIENT TEMPERATURE 77°F
% WATTS = $(-0.8\ \theta^2 + 114\ \theta - 49)^{1/2} + (0.46\ \theta - 5.6)$
WHERE θ 15% ROTATION

Figure 9-27. Wattage Derating Curve for Rheostat-connected Metal-base Potentiometers[7]

temperature. Above this temperature, the power rating must be derated. For example, in the instance of potentiometers for which the power rating is given at 104°F, it is customary to apply a derating curve as shown in Fig. 9-26[7].

If a potentiometer is used as a rheostat rather than as a voltage divider—i.e., connecting the center tap and only one of the end taps (Fig. 9-24) to vary circuit resistance—the maximum power dissipation must also be derated. Derating curves to accomplish this are available from manufacturers. Typical derating curves for metal-base and Bakelite-base rotary potentiometers are given in Figs. 9-27 and 9-28[7]. The difference between the two curves occurs because of the better heat dissipation properties of the metal-base potentiometer.

Humidity, fungus, salt spray, and altitude are other factors that should be considered when selecting a potentiometer. It is always desirable to select hermetically sealed units for military applications. Also, units that are resistant to shock and vibration should be the preferred choice.



OPERATING TEMPERATURE 176°F OR LOWER
AMBIENT TEMPERATURE 77°F

Figure 9-28. Wattage Derating Curve for Rheostat-connected Bakelite-base Potentiometers[7]

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CHAPTER 10

MOTORS AND ACTUATORS

SECTION I

ELECTRIC MOTORS

10-1 INTRODUCTION

The DC motor, rather than the AC motor, is used for virtually all motor applications in military vehicles; therefore, the scope of this Section I is limited to the DC motor. All DC motors, except for the brushless type, generally have the same type of armature. The typical armature consists of wire coils wound on a steel core, with each end of the coil terminating at a separate commutator bar. The armature coils are generally lap-wound, but may be wave-wound[1]. The nature of the armature has little bearing on the performance of a DC motor because it is the type of field winding which distinguishes one DC motor from another. Each motor type has operating characteristics directly related to the nature of the field windings as described in the paragraphs that follow.

10-2 MOTOR TYPES

Certain mathematical relationships defining motor operation remain the same for each type of motor, regardless of the type of field windings[1].

For example:

1. Torque is directly proportional to field strength and armature current.

2. Speed is directly proportional to the applied line voltage minus the voltage developed across the armature, and is inversely proportional to the field strength.

3. Power is directly proportional to torque and speed.

Equations for these mathematical relationships are:

Torque

$$T = K_1 \phi I_a - T_\ell, \text{ lb-ft} \tag{10-1}$$

Speed

$$S = \frac{E - I_a R_a}{K_2 \phi}, \text{ rpm} \tag{10-2}$$

Power

$$P = \frac{TS}{5250}, \text{ hp} \tag{10-3}$$

where

E = supply voltage, V

I_a = armature current, A

K_1, K_2 = motor constants

P = output power, hp

R_a = armature-circuit resistance, ohm

S = speed, rpm (rev per min)

T = torque, lb-ft

T_{ℓ} = loss torque, lb-ft

ϕ = field flux, lines per in.^{2}

MIL-STD-454 requires that DC motors conform to CC-M-645, MIL-M-8609, MIL-M-13786, MIL-M-17413, or MIL-M-17556. Other motors may be used where uniquely required by the design of the equipment if they meet the applicable requirements of the specification covering that type of motor and the additional requirements of the detail equipment specification. Motors for military vehicle applications generally are required to meet the requirements for waterproofness and fungus resistance as specified in MIL-E-13856 and MIL-F-13927.

10-2.1 PERMANENT MAGNET MOTOR

The permanent magnet (PM) motor, as its name implies, has permanent magnet fields rather than wire-wound electromagnetic fields. Certain ceramic magnets, made with barium ferrite and strontium ferrite, have an extremely high intrinsic coercive force. This property makes it possible to design a permanent magnet motor particularly applicable to high torque at low speed applications (Fig. 10-1). Some specific applications for permanent magnet motors are:

1. Windshield wiper drive
2. Bilge pump

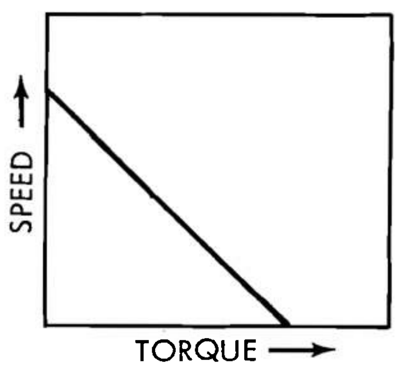


Figure 10-1. Typical PM Motor Speed-torque Curve (see Eq. 10-1)

3. Fan drive
4. Hand tool drive.

There is one major disadvantage with PM motors. Excessive armature current can have a demagnetizing effect on the permanent magnet fields. This establishes a new magnetization level and, consequently, causes the negative slope of the speed-torque characteristic curve to become more negative. Remagnetization of the permanent magnet fields is necessary if a high percentage overload occurs.

Advantages of this type of motor are the inherent simplicity of construction, high efficiency, smaller size and weight, lower manufacturing costs in the smaller sizes, and simplicity of control.

10-2.2 STRAIGHT SERIES MOTOR

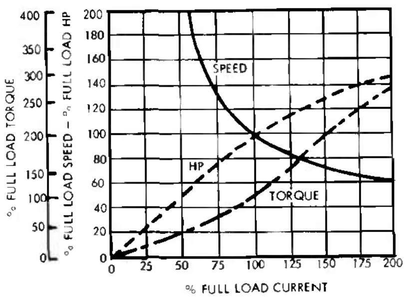
Field coils, wound with relatively few turns of a large size wire, connected in series with the armature are characteristic of series motors. Use of square or rectangular conductors in the field windings of large series-wound motors results in very efficient use of the available space and produces an extremely rugged motor.

Load current affects both speed and torque, resulting in the speed-torque characteristics shown in Fig. 10-2. Any application that requires high torque at low speed can be served by a series motor if the load does not become too light (less than 20% of full load) or uncoupled from the motor. A series motor tends to overspeed when unloaded.

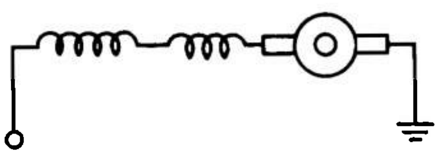
Saturation of the field poles prevents the motor torque from being a function of the square of motor current. Even so, the series motor puts out more starting torque in proportion to armature current than any other DC motor (Fig. 10-3).

10-2.3 SPLIT-SERIES MOTOR

The field poles of a split-series motor have two separate windings on each pole. The two



(A) CHARACTERISTIC CURVES



(B) 2-POLE STRAIGHT SERIES MOTOR SCHEMATIC

Figure 10-2. Straight Series Motor Characteristics

windings are wound in opposite directions, setting up opposite field polarities. Only one winding is used at any one time. Switching to the other winding facilitates a motor rotation reversal. Obviously, such a scheme allows only half the field strength and consequent torque available for a given motor size. Series motor reversal also can be obtained by reversing the connections of one field. Of course, more hardware is required.

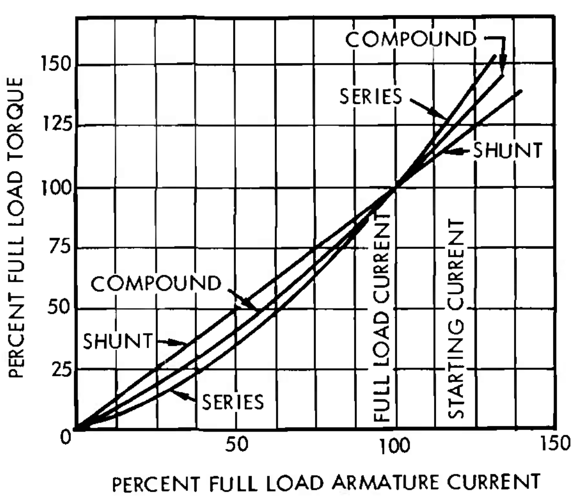


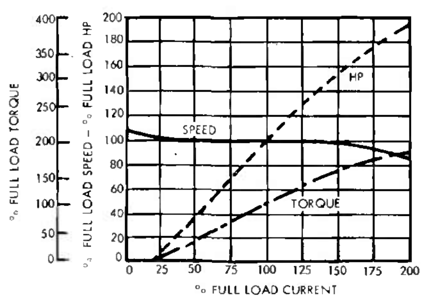
Figure 10-3. Torque Characteristics for DC Motors

10-2.4 SHUNT MOTOR

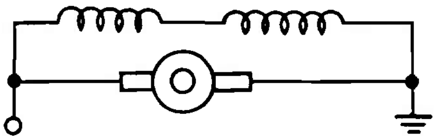
The field poles of shunt motors consist of individual electromagnets wound with many turns of fine wire carrying currents less than 5% of the full load armature current. The field poles (usually 2 or 4) are connected in series and energized by a constant external voltage (separately excited) or by line voltage. This voltage establishes a constant magnetic field essentially independent of armature currents. Actually at high torques, the armature field begins to cancel the field produced by the field poles and results in a decrease in motor speed as torque increases beyond a certain limit (Fig. 10-4).

High inductance is characteristic of a shunt field and must be considered when applying shunt field control. A sudden reduction in field current will cause an "inductive kick" that will tend to cause arcing at controlling contacts. Arc and transient suppression may be required. Transients, if not suppressed, can puncture or otherwise damage the field insulation.

A shunt motor is applied most often to constant speed loads which require low starting torques. Classic examples are fans, blowers, and centrifugal pumps. The most notable



(A) CHARACTERISTIC CURVES

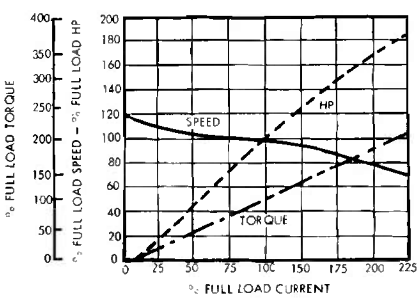


(B) 2-POLE FULL SHUNT MOTOR SCHEMATIC

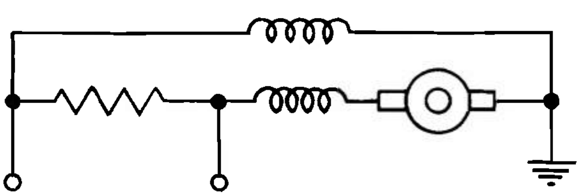
Figure 10-4. Shunt Motor Characteristics disadvantage of shunt motors is their inability to start heavy loads; however, this deficiency can be overcome with specialized controls. By designing the shunt field strength as a particular function of armature current, the operating characteristics can be modified to duplicate any motor characteristic desired—including that of a series motor.

10-2.5 COMPOUND MOTOR

The compound motor has both shunt and series field pole windings (Fig. 10-5). By using a combination of windings in varied proportions, the compound motor can be made to act more or less like a series or shunt motor as desired. The series and shunt fields can be connected to provide aiding fields or opposing fields. A motor with opposing fields (differentially compounded) can have better speed regulation than the shunt motor, and the speed can be made to increase with increasing load. However, a poor starting torque (lower even than for a shunt motor) is a by-product of the differentially compounded motor. The series and shunt fields are more often connected to provide aiding fields (cumulative compounded). With such connection, adequate starting torques can be obtained and the possibility of motor speed runaway is eliminated. Motor speed control can be accomplished by shunt field manipulation but only in about a 1.5:1 speed ratio in comparison with the typical 4:1 speed ratio for a shunt motor. Speed regulation with changing loads will be poorer than for a shunt motor.



(A) CHARACTERISTIC CURVES



(B) 2-POLE COMPOUND MOTOR SCHEMATIC

Figure 10-5. Compound Motor Characteristics

A shunt motor of large size will not commutate very well. To combat this condition (at increased cost), larger motors are compounded with low-effect interpoles located between main field poles. These interpoles are wound with a few turns of heavy wire. The interpoles (usually 2) are connected in series with each other and with the armature. The interpoles cancel flux and thereby reduce currents in the armature conductors. This in turn reduces arcing.

In another form of compounding, a separate low effect series field may be wound on the main field poles to compensate for the tendency of some shunt motors to speed up with increased load and weak field conditions. This winding, also connected in series with the armature, is called a stabilizing winding.

10-2.6 BRUSHLESS DC MOTOR

A brushless DC motor could more aptly be called an AC motor capable of being run on DC. The principle of operation involves switching consecutive portions of the field on and off to produce a continuously rotating magnetic field around the circumference of the motor. Since a brushless DC motor field is designed to act somewhat like an AC induction motor field, it follows that a typical induction motor rotor is used (permanent magnet rotors are also used). As with an AC induction motor, no brushes or commutator are required and the speed-torque characteristics of a brushless DC motor are similar to that of an AC induction motor with its inherently low starting torque.

To facilitate accurate switching of the field, a feedback loop that senses the position of the rotating member must be employed. Sensors may be of the following types:

1. Optics and photocells

2. Electromagnetic or electrostatic pickups

3. Hall effect devices

4. Magnetoresistors

5. Auxiliary stator windings

6. Reed switches.

To actually accomplish the switching, a power amplifier is required with the last stage employing either a transistor or silicon controlled rectifier (SCR) according to the power level required. If three switches are used, meaning only 1/3 of the field would be energized at any one time, the power transistors or SCR's would have a one-third duty cycle. Switching speed and attendant motor speed are controlled by an oscillator or other such device. Very close speed control can be obtained.

To summarize and compare DC motors applied to vehicle applications, Table 10-1 is presented.

10-3 DUTY CYCLE AND MOTOR ENCLOSURES*

All electrical equipment is affected by temperature to some extent. In the case of motors, insulation will char and eventually break down if the temperature is allowed to exceed the design limits. Motors may be designed, by virtue of the insulation selected, to operate continuously or intermittently.

The continuous torque rating of an electric motor is determined by heating considerations and is always less than its peak torque capability. Several National Electrical Manufacturers Association (NEMA) type motor enclosures are available for matching the continuous torque of a motor to that of the load, while protecting the motor from dirt and moisture. The degree of cooling needed for a particular application can be determined by the manufacturer when speeds and torques for the most severe duty are known. Fig. 10-6 illustrates a typical motor torque characteristic. Superimposed are continuous torque capabilities, as limited by heating considerations, for several enclosures. These are:

1. *TENV (Totally Enclosed Nonventilated).* There is no air exchange through the motor or over the motor frame except by natural convection. The motor is well protected from contaminants. As allowable continuous torque capacity is very low, TENV motors are usually used where duty cycles demand low average power dissipation.

2. *TEFC (Totally Enclosed Fan-cooled).* The motor is totally enclosed as in par. 10-3.1. An external fan driven by the motor shaft blows air over the end bracket and frame. This substantially increases continuous torque capability at moderate speeds.

3. *OFC (Open Fan-cooled).* An internal fan draws air through the motor. Continuous torque capability increases with increasing speed. In dirty, wet, or hot locations, clean cool air can be ducted to the air intake.

4. *BV (Blower Ventilated).* An external motor-driven blower forces air through the motor. This provides highest continuous torque rating at low and intermediate speeds. The blower motor may be operated by a thermally activated switch attached to the motor winding.

10-4 MOTOR-SELECTION FACTORS

Motor selection for military vehicle applications should be guided by the following factors:

*SAE Paper 690126, *Motors for Electric Vehicles,* January 1969, reprinted by permission.

TABLE 10-1. CHARACTERISTICS AND APPLICATIONS OF DC MOTORS

Type	Starting torque, %	Max. running torque momentary, %	Speed-regulation or characteristic, %	Speed control, %	Typical application and general remarks
Shunt, constant speed	Medium—usually limited to less than 250 by a starting resistor but may be increased	Usually limited to about 200 by commutation	5-10	Increase up to 200 by field control; decrease by armature-voltage control	Essentially constant-speed applications requiring medium starting torque. May be used for adjustable speed not greater than 2:1 range. For centrifugal pumps, fans, & blowers.
Shunt, adjustable speed	Same as above	Same as above	10-15	6:1 range by field control, lowered below base speed by armature voltage control	Same as above, for applications requiring adjustable speed control, either constant torque or constant output.
Compound	High—up to 450, depending upon degree of compounding	Higher than shunt—up to 350	Varying, depending upon degree of compounding—up to 25-30	Not usually used but may be up to 125 by field control	For drives requiring high starting torque and only fairly constant speed; pulsating loads with flywheel action.
Series	Very high—up to 500	Up to 400	Widely variable, high at no-load	By series rheostat	For drives requiring very high starting torque and where adjustable, varying speed is satisfactory. This motor sometimes is called the traction motor. Loads must be positively connected, not belted. To prevent overspeed, lightest load should not be much less than 15 to 20% of full-load torque.
Permanent Magnet	High—comparable to series motor	High	Varying linearly with load up to 20-30	Decrease by armature-voltages control	For drives requiring high starting torque and where somewhat varying speed is satisfactory. This motor must not be greatly overloaded.
Brushless	Very low	Low	Comparable to shunt motor up to 100% torque. Drastic variation beyond	Function of oscillator frequency	For drives requiring very low starting and running torque-OK for certain blower applications.

1. Required Horsepower. Compute from the basic power formula (Eq. 10-3) once the desired torque and speed are known.

2. Duty Cycle. A motor which is turned on manually and left on should be rated for continuous duty. A motor which is turned on automatically in a periodic manner can be rated for less than continuous duty. Duty cycle is specified in percent and is derived from an analysis of the temperature rise of the motor over a period of time.

3. Starting Torque. If no particular duration of time is required to come up to speed, a starting torque for the motor just above that of the load is sufficient. Otherwise, the type of motor selected will be influenced by the

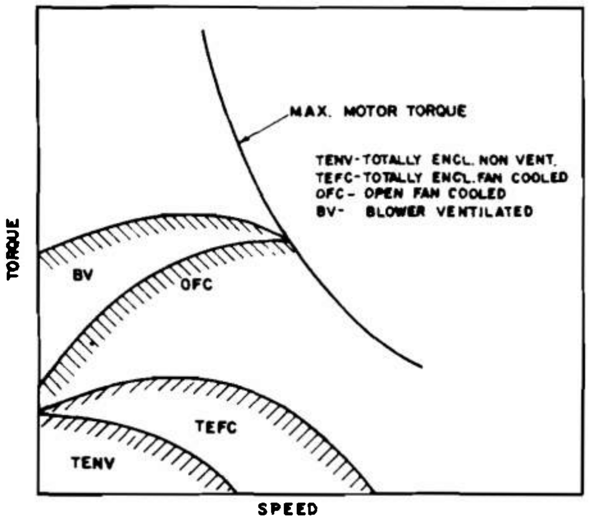


Figure 10-6. Effect of Enclosure on DC Motor Continuous Torque Rating

starting torque requirement. Ability to come up to speed fast is a function of available motor torque in excess of that required to overcome the load torque.

4. Environment. To operate in a probable environment of water, dirt, and oil, a sealed motor enclosure is preferred for most applications.

5. Speed-multispeed. A higher speed means more horsepower required for the same torque. Also, motor vibration is greater at higher speed; therefore, lower operational speeds are generally preferable. Multispeed motors are preferred for certain applications, e.g., windshield wiper motors.

6. Shock and Vibration. Military vehicle vibration and shock can be severe; therefore, a ruggedly constructed motor with safety wired bolts is desirable. Shock mounts are usually used when apparatus around a motor must be isolated from the vibration of the motor. Shock mounts are not necessary or desired for most vehicle motor applications.

7. Required or Preferred Mounting. Electric motors for vehicles usually can be mounted in any position; however, the mounting position should be evaluated for possible effect on performance.

8. EMI Requirements. Military vehicles must be relatively free of electromagnetic interference (EMI) from motor commutation or control. Several methods for suppressing such interference are employed. For example, leads passing through motor housings are filtered with feed-through capacitors. Ground leads purposely are made short (less than 6 in.). Filter networks also are used. The most important EMI suppression factor in motor application is to include the suppression requirements as part of the purchase specification for the motor. Expensive rework can be avoided in this way.

10-5 MOTOR APPLICATIONS

Various types of motors with different torque, speed, and horsepower ratings are found on military vehicles. Many of the most common applications are described in the paragraphs that follow.

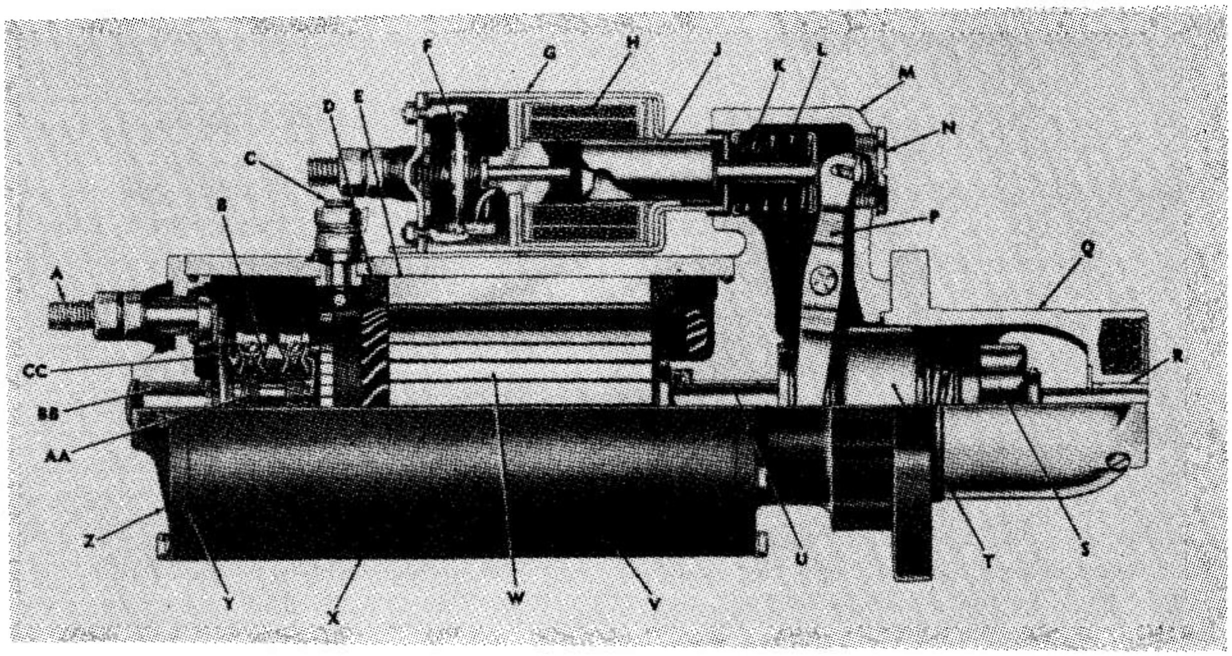
10-5.1 ENGINE STARTERS

Engine starters for military vehicles are generally intermittent-duty, series-wound, DC motors designed for operation at 24 V (Fig. 10-7). Exposure to water and grime is common and, therefore, starter motors generally are required to be totally enclosed and waterproof. Since starter motors must be small in size, develop very high torques (10 to 60 lb-ft), and be operable on the limited power available from storage batteries, high-speed motors operating through large gear ratios are used. Gear ratios may be approximately 11:1, 12:1, or 16:1. Current requirements vary from 40 A in the M151 to 800 A in the M60A2 under conditions of sustained operation, with momentary surges upon first energizing the starter from 1.5 to 2 times these values depending on battery condition and ambient temperature. Military vehicle starters are described by Military Standards as shown in Table 10-2. These standards will require conformance to MIL-S-3785. Supplementary drawings are required to define the desired mounting flange position and repair parts. Motor size (horsepower), torque, and speed requirements are dictated by the design of the engine that must be cranked and the associated cranking ratio. Minimum temperatures at which engine starts must be possible will also influence starter motor selection[2].

10-5.1.1 STARTER MOTOR OPERATION

The starter mounted solenoid relay makes it possible to control the starter from an outside source and permits operation on full battery voltage (see Fig. 3-5). When the switch circuit to the starter relay is closed, the solenoid coils are energized, producing a magnetic field in the solenoid. The magnetic field causes a pull on the solenoid plunger, moving the plunger into the solenoid (Fig. 10-7).

As the plunger moves into the solenoid case, it exerts a pull on the shift lever which shifts the drive clutch pinion into mesh with the ring gear on the engine flywheel.



A - Brush holder terminal stud
B - Brush
C - Field coil terminal stud
D - Field coil
E - Pole shoe
F - Contact assembly
G - Solenoid relay assembly
H - Solenoid relay coil
J - Solenoid plunger
K - Rubber bellows
L - Plunger spring
M - Lever housing
N - Lever housing inspection plug
P - Shift lever
Q - Drive housing
R - Sleeve bearing
S - Drive pinion
T - Drive clutch assembly
U - Sleeve bearing
V - Pole shoe screw
W - Armature
X - Frame assembly
Y - End plate gasket
Z - Commutator end plate assembly
AA - Brush spring
BB - Sleeve bearing
CC - Brush holder assembly

Figure 10-7. Starter Motor Assembly[3]

TABLE 10-2. 24 V ENGINE STARTER MOTOR CHARACTERISTICS

MILITARY STANDARD	FRAME DIA, in.	OUTPUT, hp	TYPICAL APPLICATION	MIN STALL TORQUE, lb-ft	MAX STALL CURRENT, A	MAX SOLENOID CURRENT, A
MS53008	5.56 Heavy Duty	11	Diesel engines up to 1800 in.^{3} displacement	52	900	81
MS53010	5.12 Short Frame Light Duty	5	Gasoline engines to 700 in.^{3} and diesel engines to 350 in.^{3} displacement	18	500	47
MS53011	5.12 Long Frame Heavy Duty	9.5	Gasoline engines near 1000 in. diesel engines to 900 in.^{3} displacement	16	500	81
MS53012	4.50 Light Duty	2.25	Gasoline engines to 400 in.^{3} displacement	12	250	29
MS53013	3.00 Light Duty	1.1	Small gasoline engines	3	150	46

After the plunger has moved the distance necessary to engage the pinion with the engine flywheel ring gear, the end of the plunger presses against the shaft of the solenoid relay contact assembly*. This movement causes the contact disk of the contact assembly to close the circuit between the battery and motor terminals of the solenoid relay.

When the circuit is closed the pull-in winding is shorted out and electrical current flows to the starter, forming magnetic fields about the field coils and the armature. The interaction of the magnetic fields causes the armature to rotate.

The armature torque is transferred to the engine through the drive clutch. When the engine starts and exceeds the speed of the armature, the clutch slips, protecting the starter.

When the outside control circuit to the solenoid relay is opened, the solenoid circuit is de-energized. The solenoid no longer holds the solenoid plunger, and spring pressure returns the plunger to its original position. This breaks the circuit to the starter motor as the contact disk in the solenoid moves away from the battery and motor terminals. At the same time, the shift lever pulls the drive clutch back to its original position and the pinion is disengaged from the engine flywheel ring gear[3].

Due to the high currents associated with starter solenoid operation, the starting switch must be of high capacity or a relay must be used. Fig. 3-5 shows a relay in the circuit to control the solenoid.

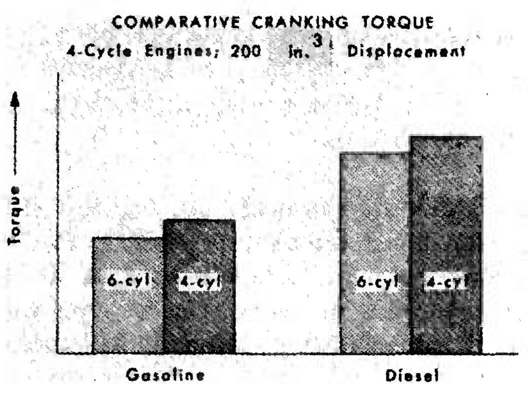
Interlocks are common on vehicles with automatic transmissions to preclude an engine start in any gear other than neutral. A switch interlocked with the drive selector lever and wired in series with the starter control circuit provides this protection. Nevertheless, starters are often damaged because they have been engaged while the engine is operating and the transmission is in neutral. A starter lockout switch that opens the starter-control circuit when the engine is operating therefore should be considered as a desirable feature to prevent

*Another style solenoid has the shaft of the contact assembly connected to the solenoid plunger.

such starter damage. Some starter protective devices automatically disengage the starter at an optimum engine starting speed. The combined device is called "automatic-disengage and lockout".

10-5.1.2 ENGINE CRANKING LOAD

Displacement, bore, number of cylinders, and type of ignition (spark or compression) are all engine design parameters that can affect the cranking requirement. The relative effect of engine design on cranking load is best illustrated by comparing the torque required for cranking typical 200-in.^{3} displacement gasoline and diesel 4-cycle engines with both 4 and 6 cylinders (Fig. 10-8). It may be seen that with gasoline engines a 4-cylinder engine requires a slightly greater torque for cranking than the same displacement 6-cylinder engine. Similar differences exist for diesel engines between 4- and 6-cylinder versions. This difference in load requirements for the same type of engine is due primarily to the larger bore with fewer cylinders. Also note the higher torque required for cranking diesel engines in relation to gasoline engines. The increased torque required for diesel engines largely is attributed to higher compression ratios, the larger mass of rotating parts, and high fuel pump pressures[2].



SAE Paper 894-B, Cold Cranking Team: Battery, Cables, Cranking Motor, Engine Oil, reprinted by permission[2].

Figure 10-8. Effect of Basic Engine Design on Cranking Torque

Table 7-5 illustrates typical cranking speeds required for the same 200-in.^{3} engines. The number of cylinders in a gasoline engine has little effect on the nominal cranking speed required for starting. On the other hand, although the typical starting speed range for a 6-cylinder diesel engine is from 60 to 100 rpm, the range for a 4-cylinder diesel engine is approximately 100 to 150 rpm. In general, fewer cylinders for the same displacement increase the average cranking speed required for consistent diesel engine starting. Table 7-5 also provides a relative comparison of the same engines in terms of horsepower required for cranking. Since horsepower combines both speed and torque, the chart graphically shows the large differences in size of battery and cranking motor that would be necessary to develop the horsepower for cranking various engines. For the same total displacement, diesel engine requirements may exceed gasoline engine requirements by a factor of more than 3 to 1 for 6-cylinder engines and a factor of more than 4 to 1 for 4-cylinder engines.

10-5.1.3 CABLE CONSIDERATIONS

Since vehicle battery voltages are inherently low, it follows that currents are relatively high when it is necessary to transmit high power. Therefore, voltage drops in starter motor wiring connections and conductors may be considerable if attention is not given to appropriate sizing and assembly requirements. It is recommended that voltage drop be held to 0.2 V per 100 A as the maximum allowable difference between voltage across the battery and voltage across the starter motor during engine cranking.

10-5.1.4 BATTERY CONSIDERATIONS

Battery cranking ability is equally important in establishing a satisfactory starting system. At the high currents required for starting, the battery capacity can be expended in a few minutes. A curve of battery voltage vs time for the applicable discharge rate will give the required information (Fig. 7-17). If the increment of time up to the knee of the curve is insufficient to start the engine, additional battery capacity will be required.

Battery horsepower output curves as shown in Fig. 7-19 provide a graphic illustration of the drop in battery horsepower output capability that occurs at lower temperatures after prolonged cranking.

10-5.1.5 STARTER-GENERATORS

The typical starter-generator is a double duty unit that supplies the torque to start an engine and, once the engine is brought up to speed, is driven by the engine to operate as a generator. Series generators, though theoretically operable, very seldom are used. The output of the generator is controlled by regulating the field voltage. Starter-generators are used most often with auxiliary power units or gas turbine engines.

10-5.2 WINDSHIELD WIPERS

The electric motors used to drive windshield wipers in military vehicles have in general been shunt or compound-wound units. Recently, permanent magnet windshield wiper motors were introduced on the Truck, Utility, 1/4-ton, 4 X 4, M151 as standard equipment.

Windshield wiper motors are available with single-speed or two-speed capability for military applications. Some units include automatic parking circuitry. Low-speed stall torque T_L generally is higher than high-speed stall torque T_H in two-speed assemblies; therefore, the drive linkage must be designed to handle T_L. On the other hand, the maximum load should not exceed the capability of T_H. Typical torque values for a shunt motor driving a 15 in. arm with 15 in. blade are 750 oz-in. at high speed and 1350 oz-in. at low speed. Compound-wound and permanent magnet two-speed motors may be designed to bring these two torque values closer together which tends to produce similar performance results at different motor speeds[4].

Fig. 10-9 shows typical windshield wiper compound motor control circuitry for a two-speed application. A park switch, which keeps power flowing to the motor until the park position has been reached, is included in the motor assembly. Windshield wiper motors, because they have brushes, will produce continuous electromagnetic interference and must be suppressed. Feed-through capacitors rated 2μF-50 VDC generally are employed.

Automotive and safety engineers now specify 1 oz of wiper arm force per inch of blade length for a safe, clean wipe under all weather conditions.

The complete windshield wiper assembly consists of the motor assembly, the arm and blade assembly, and the pivot and link assembly. Lists of these assemblies are tabulated in Table 10-3 as an aid in future component selection.

10-5.3 FANS AND BLOWERS

Fans and blowers are classified according to how they move air, i.e.:

1. Axial Flow. Propeller fan blades or vane axial fan vanes move air in a direction parallel to the axis of rotation.

2. Centrifugal Flow. Squirrel cage blower and radial wheel blower impellers drive the air in a circular orbit within a scroll housing. Centrifugal force is imparted to the air, and then the air is expelled through an outlet in a direction tangent to the impeller motion.

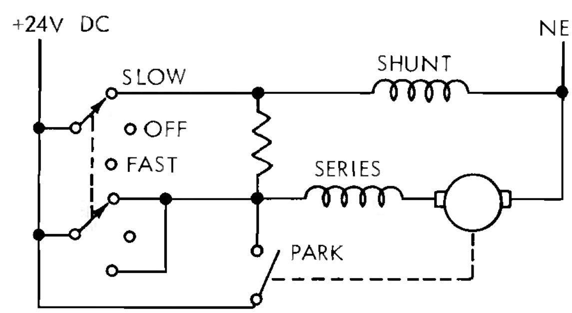


Figure 10-9. Wiper Motor Control Schematic Diagram

TABLE 10-3. WINDSHIELD WIPER DATA

WIPER MOTOR PART NUMBER	MAXIMUM TORQUE, lb-in.	MAXIMUM CURRENT, A	AVAILABLE WIPES, DEG	WIPER ARM	WIPER BLADE	PIVOT ASSEMBLY	EMI SPECIFICATION	REMARKS
19207-11644874	5.0±0.2 Operating high or low speed	2.5 at low speed	75,80,100	19207-11641116		Integral with motor assembly	MIL-STD-461	Used on M151, submersible, two-speed with integral circuit breaker
19207-10947312	75.0 Stall		20-85 Range	19207-10947309 (13.5 in.)	19207-10947308 (15 in.)	19207-10947311	MIL-S-10379	Used on M548-single-speed motor drives 3 arms and blades through an 85 deg arc. See installation dwg. 19207-10950030
19207-CPR100450	81.0±31.0 High-speed stall 100.0 ± 31.0 Low-speed stall	5.0±0.5 High-speed stall 6.0±0.5 Low-speed stall 1.5±0.5 Operating on wet glass	20-85 Range	See Remarks Column and above	See Remarks Column and above	See Remarks Column and above	MIL-STD-461	Used on XM746. two-speed version of 19207-10947312

Fans and blowers move large quantities of air from the inlet to the outlet, imparting a velocity to the air. If the outlet feeds into a duct or partially closed compartment, back pressure will develop which the fan or blower must work against and overcome. This work must be accomplished at some peak efficiency. Table 10-4 shows the approximate ranges and maximum values of typical characteristics for the different impeller types.

For most fan and blower applications, DC motors of the shunt-wound or compound-wound types are used. In the smaller sizes (approximately 1/20 hp and below), shunt-wound motors are standard, whereas the larger motors are generally compound-wound.

The selection of a motor to drive an impeller should be based on the nature of the power source to be used, the needed horsepower delivery, shaft speed, direction of rotation, weight, and physical dimensions. Additional considerations involve mounting methods and details, maintenance requirements, and accessibility. Motor life and ease of replacement are other prime points to be investigated, as well as availability and interchangeability of parts. The range and nature of anticipated operating environments also should be weighed in the selection of the drive motor. Brush sparking at the commutator may be a significant concern in blower motor applications if volatile or explosive elements are present. Therefore, the type of motor enclosure requirements must also be considered.

Some motors are available in finned cases which dissipate heat readily, thereby maintaining low motor winding temperatures. In "up-stream" installations, the motor-temperature rise is held down by the intake airflow, but is passed on to the chamber to be cooled. In "downstream" locations, the motor winding-temperature may be increased by a warm exhaust airflow, and this circumstance requires a special motor featuring a low winding-temperature rise characteristic.

A wide variety of motors is available and the design engineer who must specify a fan or blower motor will find many which will do the job he has in mind. Operating characteristics and performance figures are readily available from motor manufacturers.

The efficiency of fans and blowers is quoted in terms of "Air Horsepower-to-Shaft Horsepower Input" without regard for losses through the driving motor.

TABLE 10-4. FAN AND BLOWER CHARACTERISTICS ACCORDING TO IMPELLER TYPES[5]

Design Parameter	Axial Flow		Centrifugal Flow	
	Propeller Fan	Vane Axial Fan	Squirrel Cage Blower	Radial Wheel Blower
Capacity, ft^3/min, (ranged)	10–1000	20–5000	Low to 2500	14–53
Back Pressure, in. of H_2O (max)	1.7	3	3.5	3.3 – 9.2
Speed, ft/min (max)	500 – 1500		1500 – 5000	
Peak Efficiency, % (max)	75 – 80		60 – 65	

This practice stems from the fact that normally one manufacturer designs and manufactures the fan while a different manufacturer supplies the driving motor. A fan, as such, may have an efficiency of 75%. However, if the motor is also 75% efficient, overall efficiency is only 56%.

Engineers responsible for the preparation of a fan specification should be explicit as to whether the efficiency requirement is to be based on air horsepower output-to-electrical horsepower input or air horsepower-to-shaft horsepower input. A clear specification can prevent many misunderstandings, particularly when a project is to be bid on a competitive basis.

Refer to Chapter 14 for additional fan and blower information.

10-5.4 PUMPS

Tank-automotive vehicles use electric motors to drive fuel, hydraulic, and bilge pumps (Table 10-5). Accordingly, some understanding of pump types is necessary to select or specify the driving motor. Pumps are classified as positive displacement and centrifugal pumps.

10-5.4.1 POSITIVE-DISPLACEMENT PUMPS

Positive-displacement pumps are used to develop the high pressures required in hydraulic systems. Different types of pumps may use gears, vanes, or pistons to create the pumping action. Fuel pumps may be of the displacement type. Displacement pumps are classified further as fixed or variable displacement according to whether capacity can be varied or not for each cyclic operation of the pump.

Neglecting slip, the capacity of displacement pumps varies directly with speed, regardless of the pressure head. For constant head, the horsepower required varies almost directly as the speed and as the capacity.

Displacement pumps under constant head require practically constant driving torque at all speeds and at all capacities. Variable speed at constant torque is achieved by use of field control of a shunt motor. A variable stroke

TABLE 10-5. STANDARD ORDNANCE FUEL, HYDRAULIC, AND BILGE PUMP MOTOR PUMP ASSEMBLIES

ASSEMBLY NO.	PUMP DATA		MOTOR DATA		
	Type	Capacity	Enclosure	Continuous Current, A	EMI Spec.
19207-8763300	Bilge	50 gpm	Submersible explosion proof	20 Max 6 Dry	MIL-S-10379
80064-2584088	Bilge	125 gpm	Submersible explosion proof	40 Max 12 Dry	MIL-S-10379
19207-10947344	Fuel	220 gph at 3.75 psi	Submersible in fuel	2.0 Max	MIL-S-10379
19207-10922764	Coolant	1.5 gpm at 3-ft head	Winterized low temperature bearings	1.0 Max	MIL-S-10379
MS51321-1	Fuel	10-15 gph at 3.0 psi	Waterproof	0.5 Max	MIL-S-10379
MS51321-2	Fuel	12-28 gph at 3.0 psi	Waterproof	0.5 Max	MIL-S-10379

pump, by means of which the capacity may be varied from zero to maximum, allows the motor to operate at constant speed.

Displacement pumps require filtering of the system fluid to assure that particles present in the fluid are below a certain micron size.

10-5.4.2 CENTRIFUGAL PUMPS

The output of centrifugal pumps is a function of pump geometry and speed of rotation. Since ingestion of foreign material does not affect the performance of centrifugal pumps, they are often applied as bilge pumps. Centrifugal pumps rarely exceed 125 gpm in quantity of fluid pumped or 100 psi discharge pressure. They perform best with low fluid viscosities and are better suited for transporting fluid than for building up high pressures. Abrasive or dirty fluids are handled easily by a properly designed centrifugal pump. Centrifugal pumps may be used for fuel pump applications since required fuel discharge pressures are not high.

It is the head which the pump must work against that determines starting motor currents. Since the centrifugal pump works against low head pressures, starting currents are low. Start-up of displacement pumps, however, may require considerable starting torque and associated current. A compound, permanent magnet or series motor may be required to obtain the starting torque required.

SECTION II

ACTUATORS

10-6 INTRODUCTION

When it is necessary to convert electrical energy into limited linear motion, an electromagnetic actuator often is used. Two types of electromagnetic actuators are applicable to military vehicles. They are the solenoid and the magnetic clutch.

10-7 SOLENOIDS

A solenoid consists basically of a coil of wire centered with an iron or steel plunger. When current flows in the coil the plunger, being free to move, will assume a position allowing maximum self-inductance. This position is achieved when the plunger is centered geometrically in the coil. At this position all forces are balanced; however, until this balance occurs a force will be exerted between the coil and plunger.

DC solenoids generally are classified by the type of motion imparted when they are energized, the duty cycle for which they are designed, and the type of coil construction employed.

The majority of applications require a linear "push" or "pull" force when the solenoid is energized, the return force being provided by a mechanical spring. Where two modes of operation are required with a neutral center position, a combination "push-pull" unit may often be used in lieu of two separate solenoids with a resultant saving of space and weight.

A rotary motion usually is obtained by using a linear action solenoid connected through appropriate linkages to the actuating mechanism. For special applications, pure rotary motion solenoids may be designed.

Continuous duty solenoids are designed for operation in the energized position for indefinite periods of time. If the solenoid is to be energized for relatively short periods of time, with longer periods of inactivity, a saving in size and weight can be realized by designing the solenoid for intermittent duty only. The maximum duty cycle must be specified and cannot be exceeded without materially shortening the life of the solenoid.

The solenoid may be of the single-coil or two-coil type. In the single-coil solenoid, the same coil is used to move the load through its required stroke and to hold the load in the energized position. Thus, the same amount of electrical energy must be supplied for all conditions of operation, unless some external method is used to reduce the excitation. A more efficient type of solenoid, particularly for continuous duty operation, may be obtained by providing a separate coil for actuating the load and another coil for holding the load in the energized position. The transition between the two coils is made at a preset point in the stroke by a switch mechanism operated by the solenoid plunger. When the solenoid is de-energized, the switch automatically cuts in the actuating winding for the next operation. "Pull" type solenoids are the most readily adaptable to the double-coil construction.

There is a maximum amount of work which can be obtained from any given solenoid size. The degree to which this maximum is approached depends upon the skill with which the solenoid is designed and the limitations imposed by the operating specifications. Where possible, the actual operating conditions should be specified and safety factors reduced to a minimum. When the actual conditions are not known, the best estimate possible should be given. Some of the major factors affecting efficient solenoid design are described in the paragraphs that follow.

As the solenoid temperature is increased, the work the solenoid can do is decreased in almost direct proportion. Since most of the electrical energy supplied to the solenoid is dissipated as heat, the temperature will continue to rise as long as the solenoid is energized—or until a stabilized temperature is reached.

In continuous-duty solenoids, the rated pull can be given only for this stabilized temperature when the solenoid is operated at the maximum ambient temperature with maximum operating voltage impressed. The heat rise for intermittent duty solenoids usually is not of major consequence if a sufficient off time is provided between excitation periods.

Typical amperage requirements for solenoid operated valves used in military vehicles average about 1.0 A. The largest solenoid current requirement is generally the engine starter motor solenoid. This solenoid is a two-coil type. For example, the M113A1 Starter Solenoid requires 50 to 60 A for pull in and 8-A holding current.

Solenoids produce inductive voltage transients of high magnitude. The usual arc-suppression measures used to prevent EMI or protect solid-state equipment should be employed as necessary in conjunction with solenoid applications (see par. 9-5 and Chapter 18).

Solenoids can be made extremely reliable even when employed in a military vehicle environment. To combat thermal degradation, moisture, corrosive contamination, and mechanical stress, the following design features are used:

1. Molded epoxy coils
2. Triple chrome-plated plunger
3. Oilite bearing surface.

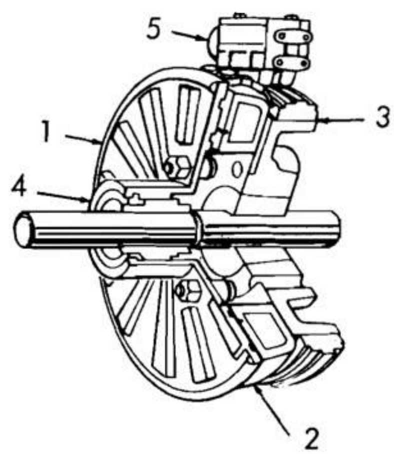
10-8 MAGNETIC CLUTCHES*

Magnetic clutches can be classified as actuators, since one of the clutch elements moves relative to the other and is controlled remotely. This type is known as the friction-disk magnetic clutch. The most common friction-disk units are direct-acting, single disk and are discussed herein.

Fig. 10-10 illustrates an electric clutch coupling. As a general rule, the magnet or field member is fixed to the load shaft and the armature mounts on the drive shaft. Slip rings and brushes carry the current from a control switch to the magnet.

When the magnet is not energized, no physical contact occurs between armature and magnet. With the current on, a magnetic field holds the armature against the friction face on the magnet.

Friction between the rotating armature and the magnet facing brings the load shaft up to motor speed.



1. ARMATURE
2. ROTATING FIELD
3. COLLECTOR RINGS
4. HUB
5. BRUSH HOLDER

Figure 10-10. Magnetic Clutch Construction[6]

**Power Transmission Design*, Industrial Publishing Co. Reprinted by permission[6].

Electric clutches nominally are rated by torque. Torque developed is based on friction surface area (a function of diameter), flux density (a function of current), and any slip between the armature and the magnet.

Clutches generally are rated according to their static torque at rated current. This is the torque at zero slip, the maximum running torque of a lock-in clutch.

When a clutch or brake is energized, slip occurs. The torque transmitted to the load is accordingly less than full static torque, but, as the load comes up to speed the slip decreases and the torque transmitted increases.

Control power requirements are slight. Less than 40 W will control a 700 lb-ft clutch capable of handling a 200 hp drive; the smallest units operate on as little as 3.5 W.

One of the main advantages of electric clutches is that the torque setting can be adjusted precisely and changed merely by varying the current through the coil. This can be done remotely and automatically.

Torque setting of a clutch influences acceleration time. The higher the torque setting, the less time required to bring the load up to speed.

In tension-control applications, the clutch current (i.e., torque setting) may be purposely set low for continuous clutch slip and reduced output speed.

For instantaneous lockup, special overexcitation controls are available to shorten torque buildup time (i.e., the time interval between the moment the clutch is energized until the armature is in firm contact with the magnet or rotor) to a fraction of normal—as low as a few milliseconds when necessary. When extremely slow clutch operation is required, time-delay controls can extend the acceleration period.

Pushbuttons, limit switches, photocells, electron tubes, proximity pickups, or practically any electrical or electronic control device can be used for actuation.

Sizing electric clutches involves choosing the smallest unit that can pick up the load in the required time without overheating.

For demanding applications—where acceleration or deceleration has to be extremely fast or unduly prolonged, where there is considerable load inertia, for rapid duty cycles or continuous slip applications—selection can involve a series of calculations. However, most applications can be sized strictly from motor horsepower, shaft speed, and the basic formula:

$$T = \frac{5250 \times hp \times K}{rpm}, \text{ lb-ft} \tag{10-4}$$

where

T = torque, lb-ft

hp = driving horsepower

rpm = slip speed at time of engagement

K = service factor: ranging from 1 for a light-duty cooling fan to 5 or more for an IC engine clutch coupled to a single-stage compressor, dimensionless.

A clutch whose nominal pickup curve exceeds this calculated torque can transmit the full torque output of the prime mover. The higher the shaft speed, the lower the torque required, and the smaller the clutch that is needed. Wherever possible, locate a clutch on the highest speed shafts[6].

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CHAPTER 11

IGNITION SYSTEMS

11-1 INTRODUCTION

This chapter presents the different types of ignition systems used in military vehicles and the characteristics of those systems affecting the design of the overall vehicle electrical system. The ignition system is one of the most vital systems in a vehicle and it can produce adverse effects on other systems if not properly interfaced.

A military vehicle engine fuel mixture is generally ignited by one of two basic ignition systems; the compression ignition system (diesel engine) and the spark ignition system (gasoline engine).

Multifuel compression-ignition engines are used in most vehicles in the present military inventory. The compression-ignition engine depends upon a combustible fuel mix combined with high compression in the cylinders for proper ignition. The fuel-air mix ignites from the high temperature caused by the heat generated during the compression stroke. Since the compression-ignition engine does not employ a spark, the method of ignition is only of general interest to the electrical equipment designer. However, engine cranking speed is directly related to ignition capability at low temperatures.

The spark-ignition engine depends upon a spark to ignite the fuel mixture in the engine cylinders. The spark must be produced at the spark plug gap at a precise time to obtain maximum efficiency. The function of the ignition system is to produce the high voltage necessary for sparking and to distribute the sparking energy to each cylinder at the appropriate time.

The high voltage required for ignition in the spark-ignition engine creates its own special design problems. Such factors as wire size, type of insulating materials, contact points, and spark plug design become extremely important. Furthermore, the high voltage sparking produces high-level electromagnetic fields. This requires special shielding devices to prevent interference with radio communications. In addition, signals produced by an unshielded ignition system will register on sensitive electrical detectors, thus disclosing vehicle location. This can be extremely hazardous for the combat vehicle. Further discussion of these and other design considerations are given in paragraphs that follow.

11-2 SPARK-IGNITION SYSTEMS

The purpose of any spark-ignition system is to generate and distribute the voltage for adequate and properly timed sparking at the spark plug gap. The voltage generated is usually in excess of 15000 V and often in the 25000-V range. This high voltage is required to overcome the high resistance caused by pressure in the combustion chamber.

The electrical spark ignition may be divided into two classes: battery ignition and magneto ignition. One of these, battery ignition, may be further subdivided into two types: conventional ignition and electronic ignition. While variations exist in the systems within these categories, each has certain common features. For example, each depends upon change of flux in a magnetic field to induce voltage into the circuit. Each also has a timing and distribution device to direct the spark to the right spark plug at the right time.

Although the three basic ignition systems represent nearly all of those presently in use, others are under consideration or in the development stage, and the electrical designer should accordingly be on the alert for new developments. For example, the piezoelectric ignition system, though not in widespread application, has been receiving serious attention in the research and development field. This system operates on the principle of converting mechanical to electrical energy by applying pressure to quartz or artificial quartz crystals. Pressure is introduced into a generator assembly, containing the crystal, by means of a cam follower and lever arrangement operated by the engine cam shaft. The pressure causes electrical dipoles in the quartz to be slightly displaced from an equilibrium position. This in turn causes the charge balance to shift in the crystal so that one side becomes positive and the other negative, causing a high voltage potential with each pressure cycle. This voltage is then delivered through the ignition harness to the spark plug.

The three basic ignition systems are described in the paragraphs that follow.

11-2.1 BATTERY SPARK IGNITION

A schematic of a typical battery spark-ignition system is shown in Fig. 11-1. An explanation of the function of each of these components follows.

11-2.1.1 BATTERY

The battery and generator (not shown) furnish the source of electrical energy for the ignition system. The battery is necessary to start the vehicle, both for ignition current and for power to the starting circuit. When the engine is running and up to speed, the generator takes up the ignition load, and recharges the battery.

11-2.1.2 AMMETER

Although the ammeter is not essential for spark ignition, it is often included in the circuit because it indicates whether the battery is being discharged or charged.

11-2.1.3 IGNITION SWITCH

This is simply a circuit-closing device which completes the electrical connection for the ignition primary circuit.

11-2.1.4 IGNITION COIL

This device is simply a transformer that converts the low voltage of the vehicle battery and charging system to the high voltage required for the ignition system.

The ignition coil consists of a primary winding of several hundred turns of wire and a secondary winding of many thousand turns. The primary winding carries current from the battery, which is converted to pulsating direct current by the opening and closing of the breaker points. The amperage drawn in the primary winding is approximately 3 to 5 A and thus it has relatively heavy wire as compared to the secondary winding. A common size is No. 18 for the primary and No. 38 for the secondary. The pulsating direct current causes a magnetic field buildup and collapse in the ignition coil. The counter voltages induced in the primary, caused by rapid collapse of the magnetic field, may reach 200 V or more. Since the secondary coil often has 100 turns or more for each turn in the primary, the induced voltage in the secondary may reach 20,000 V or more.

In addition to the primary and secondary windings, the ignition coil contains a soft iron core around which the coils are wound and an insulated case. The high voltage generated in the secondary is fed into a high tension cable at the top of the coil. This cable delivers the voltage to the distributor.

11-2.1.5 DISTRIBUTOR BREAKER POINTS

The distributor breaker points (Fig. 11-1) trigger the electromagnetic action in the ignition coil. They act as a switch for the primary circuit. The opening and closing action of the points is caused by rotation of the distributor cam. As each lobe of the cam passes by the breaker assembly, it pushes against the rubbing block, causing the contacts to open. This triggers the spark for a particular spark plug. After the lobe rotates past the rubbing block, the contacts are closed by spring action.

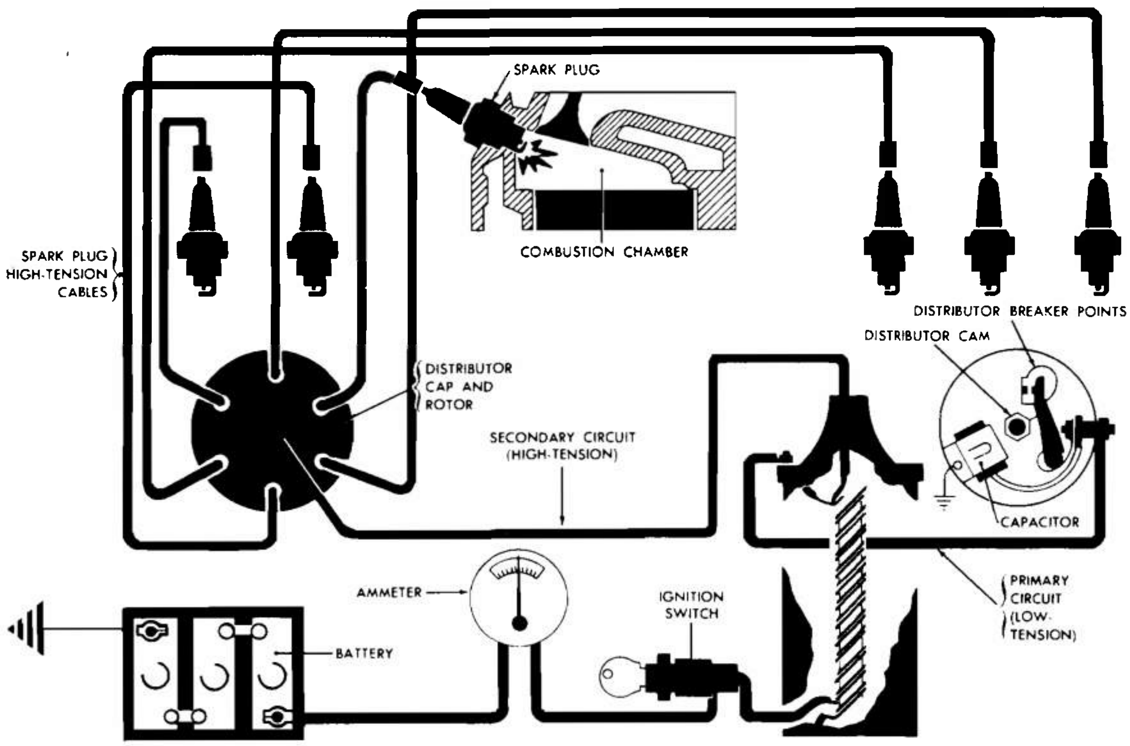


Figure 11-1. Battery Spark Ignition System

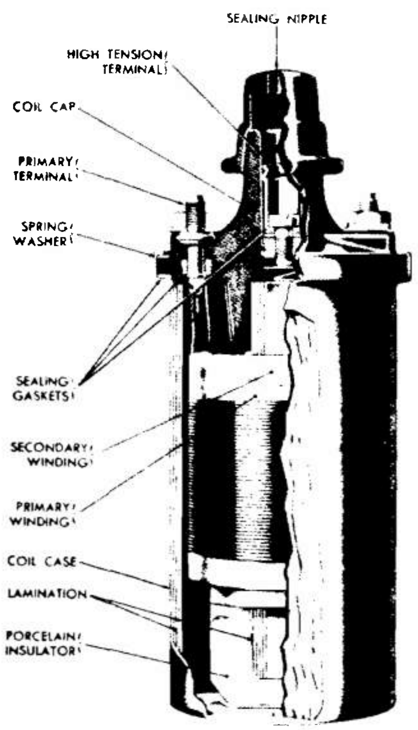


Figure 11-2. Ignition Coil, Sectional View

11-2.1.6 CAPACITOR

The capacitor (Fig. 11-1) performs the function of preventing arcing across the contact points, thus insuring that the total energy available is dissipated in an arc at the spark plug. The capacitor limits the rate of rise of voltage across the points so that it never exceeds the breakdown voltage of the air gap established as the points open.

11-2.1.7 DISTRIBUTOR, ROTOR, AND HARNESS

Fig. 11-3 shows a typical distributor for an eight-cylinder engine.

The top view, with the rotor and cap removed, shows the elements of the primary circuit described previously: the capacitor, the cam, and the breaker points located at the end of the breaker arm where it opens and closes against the contact support.

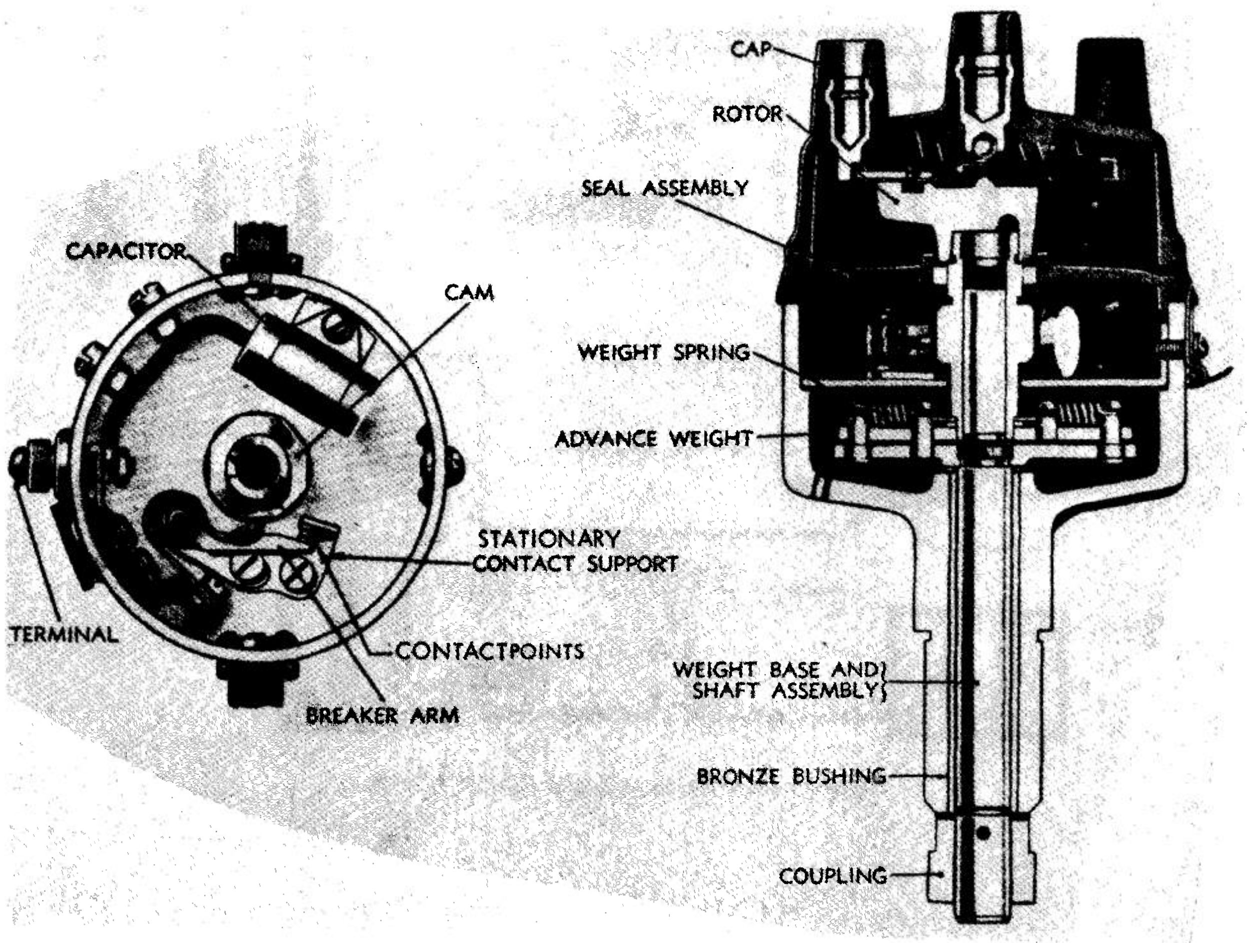


Figure 11-3. Ignition Distributor Assembly

The side view shows the complete distributor with the rotor and cap installed. The cap and rotor are part of the ignition secondary circuit, and they carry and distribute the 15 to 25 kV for sparking. The cap and rotor are constructed (with the exception of the current-carrying elements) from insulative-type material and are isolated well from other elements in the distributor, thus eliminating the possibility of short circuit.

The drive shaft to the distributor is driven by the engine camshaft and turns in direct relationship to engine speed. The shaft rotates the distributor cam, which has the dual function of forcing the breaker points open in the primary circuit and rotating the rotor to the correct spark plug terminal in the secondary circuit. The rotor is simply a rotary switch that completes the secondary circuit from the center terminal in the rotor cap to the spark plug wire terminals located on the inside perimeter of the cap. Fig. 11-3 illustrates these components in the side sectional view, and Fig. 11-4 gives an exploded view of the parts in a similar type distributor.

Figs. 11-3 and 11-4 also show the spark advance mechanism, which causes the spark to be delivered to the spark plug earlier as the speed of the engine increases. This is necessary to get maximum efficiency from the engine. At low or idle speeds, the spark normally is timed so that it reaches a particular cylinder an instant before the piston reaches top dead center (TDC) on the compression stroke. This is measured in terms of degrees of crankshaft rotation and is typically 4 deg or more before TDC, thus allowing the fuel time to ignite. The resultant combustion occurs when the piston reaches TDC to give maximum thrust to the piston. At higher

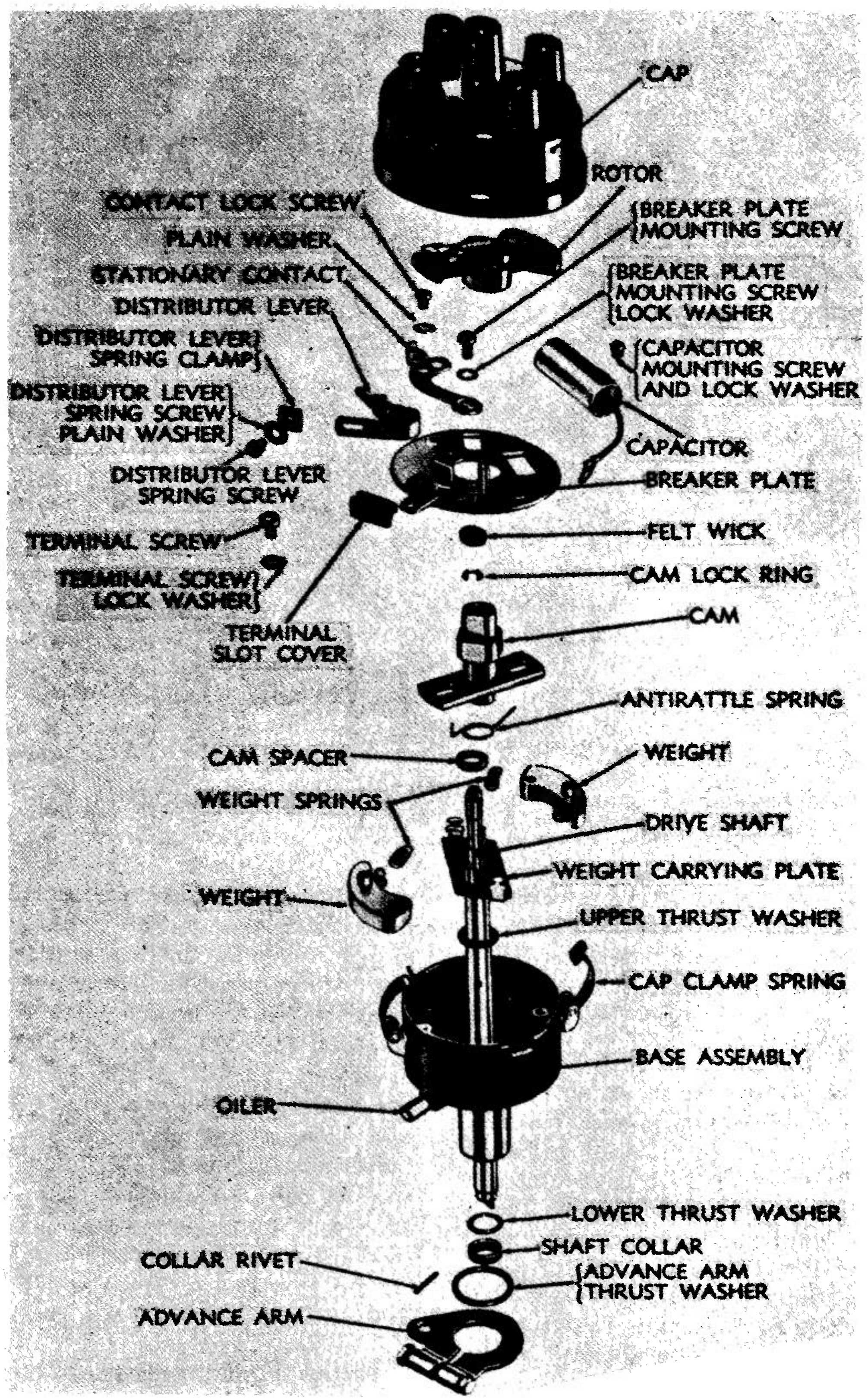


Figure 11-4. Ignition Distributor, Exploded View

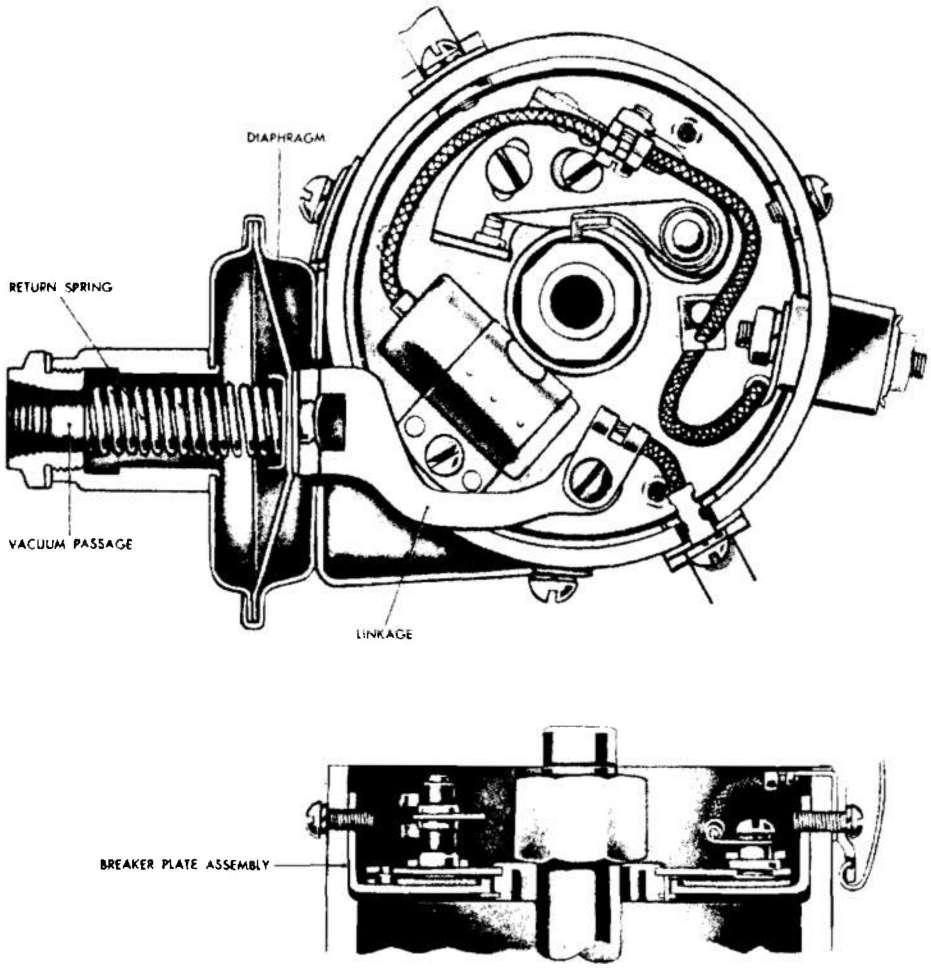


Figure 11-5. Ignition Distributor Vacuum Advance Mechanism

engine speeds, the spark must be advanced often as much as 30 deg before TDC. Although the fuel begins to burn well before the power stroke actually begins, the piston is up over TDC and moving down before the pressure begins to build up.

The advance mechanism shown in Figs. 11-3 and 11-4 is a centrifugal advance. This is a relatively simple device consisting of weights mounted on the cam. The weights are normally restrained by weight springs. As the speed of the distributor shaft increases, the weights move outward due to centrifugal force and in turn force the cam to rotate forward in relation to the shaft. This causes the breaker points to open sooner, thus advancing the spark.

Another type of spark advance, often used in conjunction with the centrifugal advance, is the vacuum advance. This consists of a diaphragm mounted on the outside of the distributor with a lever arm leading from the diaphragm to the breaker plate. A vacuum line leads from the intake manifold to the diaphragm chamber. When the throttle is advanced, it creates a vacuum in the advance line, allowing atmospheric pressure to move the diaphragm inward. This forces the lever arm to move the breaker plate, which is allowed to turn a few degrees, causing the spark advance. An illustration of a typical vacuum advance mechanism is shown in Fig. 11-5.

There are other methods of advancing the spark, such as vacuum brakes and vacuum advances using more than one line to the carburetor. The most common advance mechanisms, though, are the two previously described.

The high voltage generated in the ignition coil is delivered to the center terminal of the rotor cap by a high tension cable. The cable is designed to carry the high voltages, and to be resistant to heat, moisture, corrosion, oil, and fungus. The wall thickness of the insulation must be adequate to prevent voltage leaks and be flame resistant. When shielding is used on the cable it must be of the proper material and be the correct size. Military specifications for high tension ignition cables may be found in MIL-C-3702[1].

11-2.1.8 SPARK PLUG

The function of the spark plug is to conduct the high voltage into the cylinder and provide a fixed gap, at the right location in the cylinder for spark ignition of the fuel. Fig. 11-6 shows a sectional view of the typical spark plug. This type is used in most commercial vehicles. Slightly modified and shielded versions are used in most military applications[3]. The plug consists basically of a porcelain insulator that contains a center electrode. This is supported by a threaded metal shell that is screwed into the cylinder. The ground electrode is welded to the shell. When the distributor rotor directs the high voltage to the plug, it causes an arc across the spark plug gap to the ground electrode. The arc ignites the fuel mixture in the cylinder. The positioning of the gap in relation to the cylinder walls is very important and determines the heat range of a spark plug. When the heat path from the center electrode to the cylinder head is long, the plug will run hotter. When the heat path is short, the plug will run cooler. An illustration of the heat path is shown in Fig. 11-7.

The firing end of the plug should operate within a definite temperature range. If the tip temperature falls below 700°F, carbon fouling will occur. If the tip temperature goes above 1700°F, the spark plug can pre-ignite and cause damage to the piston, or the high temperature will cause rapid plug wear.

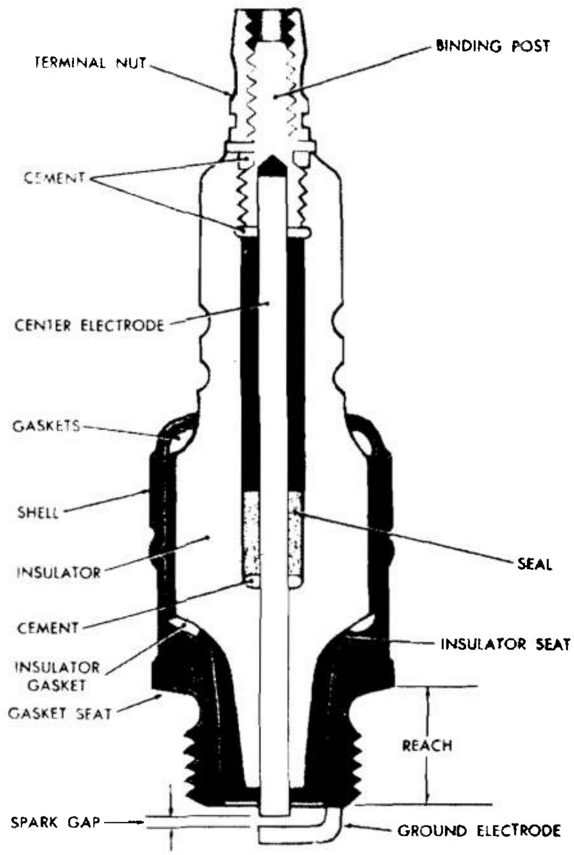


Figure 11-6. Typical Spark Plug

The selection of a proper heat range plug often depends on the vehicle usage. If the vehicle is used for light load or slow speed service, a hotter plug may be required to prevent carbon fouling. On the other hand, if the vehicle is used for severe service, a colder plug may be required to give longer electrode life and decrease the chance of damage to the piston.

11-2.1.9 IGNITION TIMING

The ignition is timed to synchronize the firing of a spark plug with the position of the piston in the cylinder (or position of the crankshaft). Most engines have timing marks located on the flywheel or the crankshaft vibration damper. When these marks align properly with a pointer or index mark at the exact moment No. 1 cylinder fires, the engine is in correct time. Fig. 11-8 shows typical flywheel and vibration damper timing marks.

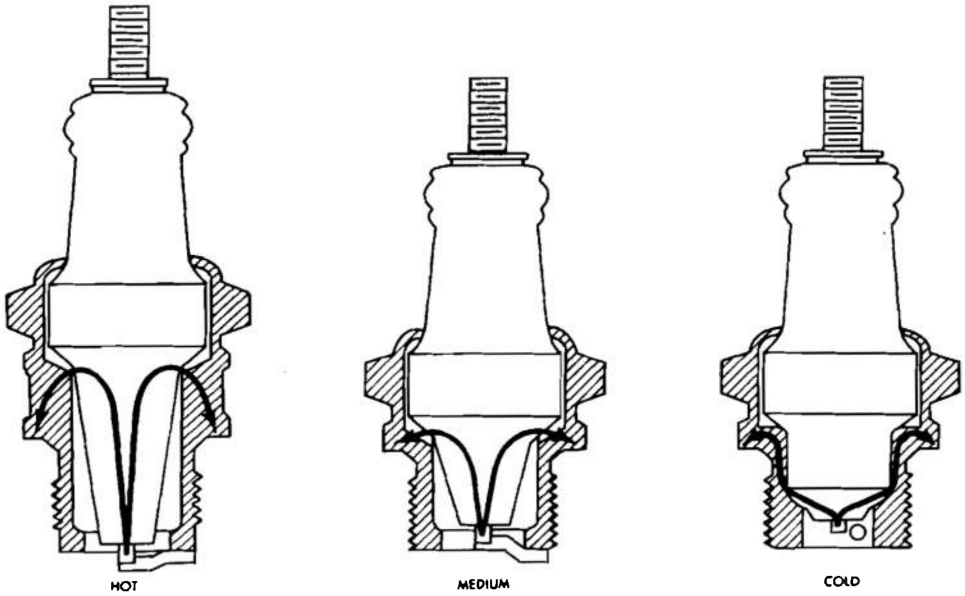


Figure 11-7. Spark Plug Heat Paths

A common method for timing an engine is to connect a neon timing light in series with the No. 1 cylinder spark plug. The light flashes each time the No. 1 cylinder fires, so that if directed at the timing mark shown in Fig. 11-8, the mark will appear to stand still to an observer. The actual timing adjustment is accomplished by loosening the distributor in its mounting and turning it one way or the other.

Another method of adjusting the timing is to connect a low voltage test light across the contact points, (Fig. 11-3) and crank the engine to the No. 1 contact position with the distributor cap removed and the ignition switch on. The test light will come on as the contacts open for the No. 1 firing position. The index mark, or pointer, and the timing mark will be aligned at the instant the light comes on when the engine is in proper time.

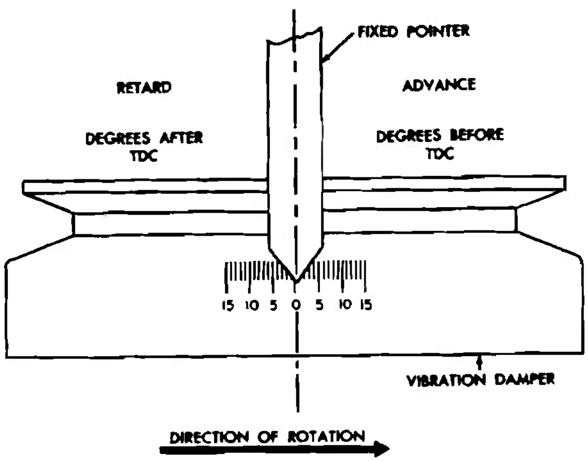


Figure 11-8. Ignition Timing Marks

11-2.1.10 CIRCUIT VARIATIONS

The previous paragraphs described a basic single circuit battery spark ignition system. There are many variations to this basic circuit. For instance, there is the dual ignition circuit, an example of which is shown in Fig. 11-9.

This dual arrangement has been used in military applications to add redundancy and to improve efficiency. It has two independent ignition circuits. The distributor contains two sets of breaker points and two rotors. The system has two ignition coils, two spark plugs in each cylinder, and two sets of wiring harnesses. Each system functions exactly as the single circuit ignition previously described.

Another variation to the basic circuit uses parallel breaker points. In this arrangement, the breaker points are adjusted so they open

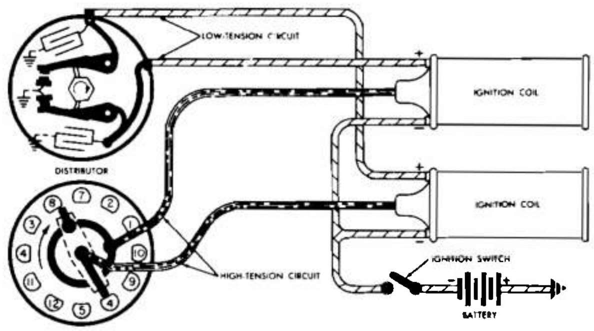


Figure 11-9. Dual Ignition System

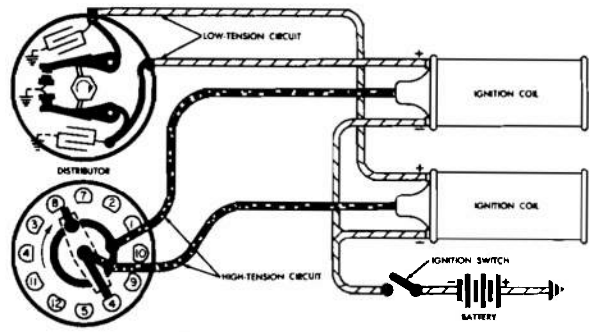


Figure 11-10. Two Circuit, Positive Ground, Ignition System for V-12 Engine

at the same time. This counteracts a tendency for breaker points to bounce open at high speed and prevents overloading the contact points. Two sets of breaker points are less likely to bounce open at the same instant.

Alternate operation is still another arrangement used in ignition systems. This system has two sets of breaker points mounted in parallel but uses a cam with only half as many lobes as there are cylinders. The points are arranged around the cam so that one set opens as the other closes. One set sparks half the cylinders and the other, the other half. Since the cam has only half as many lobes, this arrangement increases the duration of point contact and allows better magnetization of the coil.

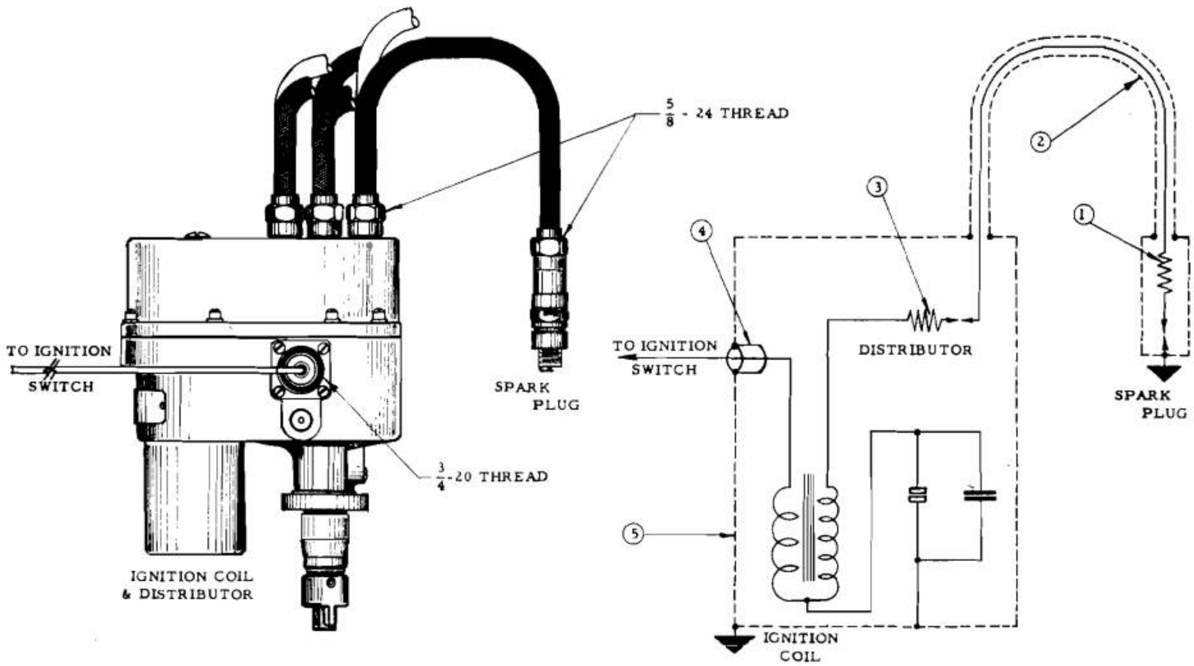
Another breaker arrangement, similar to the system of alternate operation, uses breaker points operating alternately, but has two coils and two rotor arms. In effect, this is two separate ignition systems, each firing half the cylinders. This arrangement is called two circuit operation and is shown in Fig. 11-10.

11-2.1.11 WATERPROOFING AND SHIELDING

In many military applications it is necessary to waterproof and shield all of the ignition components. Most military vehicles must be capable of operating under very wet or humid conditions, often with the ignition system partially immersed. Also the ignition must be shielded to prevent interference with radio communication or detection by enemy forces.

The waterproofing and shielding are accomplished by enclosing and wiring the ignition units as shown in Fig. 11-11. This figure shows a typical waterproofed and shielded military ignition system. Basically all of the ignition components are enclosed in a waterproof metal shroud, consisting of a distributor and coil housing, shielded high tension cables, and shielded spark plugs. Good electrical contact is assured at all shroud points, and the shroud is bonded to the engine block. The diagram illustrates the shield continuity. Waterproof distributors are described by MIL-D-13791[2], spark plugs by W-S-506[3], and high tension cable by MIL-C-3702[1]. The QPL for these specifications provides the Military Standard and Ordnance part numbers for parts qualified by various manufacturers.

Additional suppression devices are used to reduce radio interference. Two 10,000-ohm resistors are added to the secondary circuit for suppression. One is built into the distributor rotor and the other into the shielded spark plug to reduce emission caused by arcing at these points. Usually it is difficult to shield the ignition lead from the switch to the coil due to its long length and a resistor to suppress emissions cannot be used on the primary circuit due to its low voltage. Suppression, therefore, is accomplished by adding a feed-through capacitor at the point where the ignition switch wire enters the distributor housing.



1. RESISTOR SPARK PLUG
2. BRAIDED METAL SHIELDING
3. DISTRIBUTOR ROTOR RESISTOR
4. FEED THROUGH CAPACITOR
5. METAL SHIELD

Figure 11-11. Waterproofed and Shielded Ignition System

11-2.2 ELECTRONIC SPARK IGNITION

Electronic ignition is a relatively new concept. Testing of new component arrangements is currently going on, and more reliable electronic components are being developed. If these efforts are successful, then the electronic ignition system may be the next step toward realizing the ultimate goal; i.e., giving lifetime troublefree service with maximum performance.

The electronic ignition uses electronic components to replace or reduce the stress on the more troublesome elements of the conventional ignition system – the breaker points and the spark plug gaps. The design goals for electronic spark ignition are not only to improve the reliability and durability of ignition components, but to improve engine performance, to reduce or eliminate ignition maintenance between major overhauls, and to reduce the overall cost of the system.

Before discussing the various types of electronic ignitions, the two basic methods for generating the voltage for sparking should be considered. These are the inductive and capacitive methods. The conventional ignition and many of the electronic ignitions depend upon inductance, i.e., the voltage in the ignition coil secondary is produced by interrupting the current flow in the ignition coil primary. Counter-voltages are induced in the primary and secondary as the magnetic field collapses. The capacitive-type system, however, uses the action of a capacitor discharging through the primary. This causes a transformer-type action in the secondary circuit, generating the sparking voltage. Thus, the inductive system fires the spark plug upon interruption of the ignition coil primary current, while the capacitive system fires the plug by current buildup in the coil.

There are many variations of electronic ignition being considered for use at present. For the purpose of illustration, these can be classified into three basic electronic ignition systems: contact controlled, full transistor-magnetic controlled, and the capacitive discharge systems.

11-2.2.1 CONTACT CONTROLLED SYSTEM

The contact controlled electronic ignition is illustrated in Fig. 11-12. This system differs from the conventional system in that the circuit now contains a transistor which carries the main current and performs the "on" and "off" switching. The breaker points are still used, but serve only to trigger the transistor. The points carry approximately 1 A compared to 3 to 5 A in the conventional system. Although the transistor could be triggered with much less current, experience indicates that 1 A of current across the contact is the optimum current to obtain maximum life from the points[1] and yet keep them free of dirt and oxides. This decrease in current combined with the fact that it is now a resistive lead rather than inductive, increases point life by many times.

The contact controlled system operates as follows. When the breaker points shown in Fig. 11-12 are closed, current flows through the primary coil and the transistor to ground. When the contacts open, base current is broken, making the transistor nonconductive. This breaks the primary current, causing a high voltage surge in the coil as the magnetic field collapses.

11-2.2.2 FULL TRANSISTOR-MAGNETIC CONTROLLED SYSTEM

The full transistor-magnetic controlled electronic ignition system shown in Fig. 11-13 is much the same as the contact controlled system, except it replaces the contact points with an impulse generator. The impulse generator is a rotating device consisting of pole pieces and a pickup coil. It is turned by the engine much the same as the cam in the conventional system. As the pole piece passes the pickup coil, it causes voltage impulses in the pickup circuit. These pulses turn the transistor circuit "on" and "off". When the transistor circuit E to C opens, it interrupts the ignition coil primary current causing the spark plug to fire. Often this system will have two transistors rather than the one shown in Fig. 11-13. One is a trigger transistor that receives the signals from the impulse generator. This in turn controls an output transistor that carries the actual current load. The advantage of this system over the contact controlled system is that the contacts have been eliminated completely, removing one of the more troublesome parts of the ignition system. It is still capable of generating the same high secondary voltages.

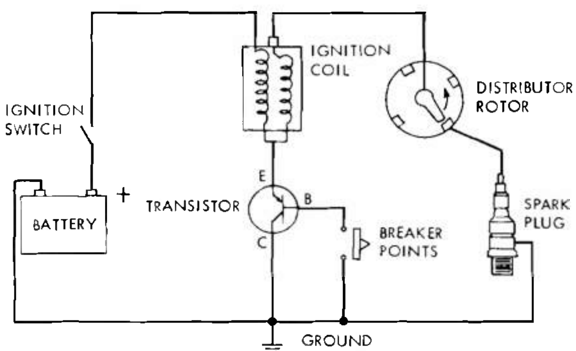


Figure 11-12. Contact-controlled Electronic Ignition

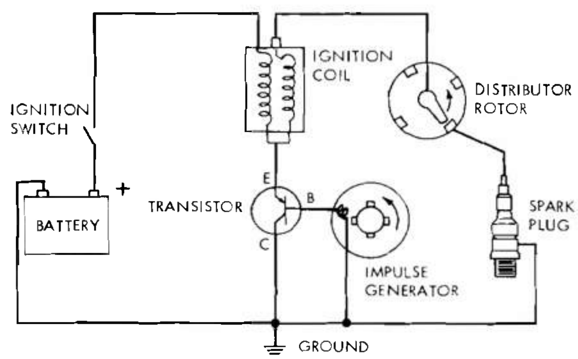


Figure 11-13. Full Transistor-magnetic Controlled Electronic Ignition

11-2.2.3 CAPACITIVE DISCHARGE SYSTEM

The capacitive discharge system, which offers several advantages over the other systems, is shown in Fig. 11-14. This system is similar to full transistor-magnetic control, except that certain components have been added to the primary circuit. These are the power converter, the capacitor, and the thyristor or silicon controlled rectifier (SCR) which replaces the transistor of Fig. 11-13. The power converter has an output voltage of 250 V to 300 V. This voltage is used to charge the capacitor shown in Fig. 11-14 with the thyristor in its off condition. When the thyristor gate G receives a signal from the pulse generator, the circuit from the anode A to the cathode C is closed, and the capacitor immediately discharges at a high rate through the primary. A high secondary voltage can be reached about 100 times faster with the capacitive discharge system than with the inductive systems. This decreases spark plug fouling, materially increasing potential spark plug life. Another advantage is that it uses less current than either the conventional system or the other solid-state systems. This means less demand on the battery during starts and a potentially longer battery life.

11-2.2.4 ADVANTAGES

All of the electronic ignition systems offer certain advantages over the conventional systems. They reduce or eliminate breaker point wear (a weak point in the conventional system), eliminating frequent point replacement or adjustment. They all offer better high speed performance by maintaining high voltage output at high engine rpm. They accomplish this through providing a longer dwell time due to faster buildup, even at high speeds. With a consistent high voltage, the spark plug can be operated with a wider gap and at a lower temperature leading to longer plug life. The capacitive discharge system offers the additional benefit of operating with much lower average current requirements.

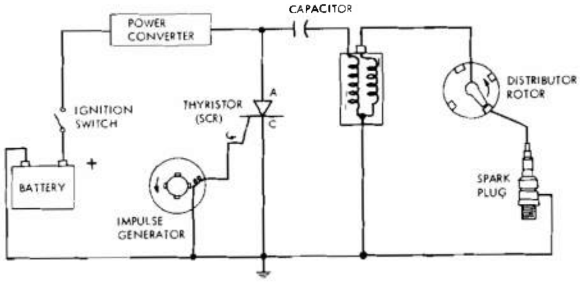


Figure 11-14. Capacitive Discharge Electronic Ignition

11-2.2.5 DISADVANTAGES

Disadvantages of the electronic system include its greater complexity as compared with the conventional systems, requiring more complex test equipment and retraining of mechanics. In addition, the higher voltages generated cause more strain on high voltage cables, connectors, and insulators and cause higher radio interference that is difficult to suppress. A further disadvantage—that possibly can be overcome with increased production and offset by decreased maintenance—is the higher cost of the present electronic systems over conventional ignition systems. Electronic systems are also more apt to fail with no warning than are conventional systems.

11-2.3 MAGNETO IGNITION

Magneto ignition is similar to the conventional battery ignition in many ways. The system generates sparking voltage with an induction coil like the battery ignition system. It has a transformer device to develop and boost electrical energy and contains an interrupting device to determine the proper timing of the electrical impulses. In addition, a distributor to direct the electrical impulses in the proper order to the different cylinders is used. The most obvious difference between the two systems is that the magneto requires no external power source such as the battery or generator once it is up to speed. Instead, a rotating magnet is used to develop the necessary electrical energy.

One of the major disadvantages of the magneto system is that the magneto rotor turns so slowly during starting that it is difficult to generate adequate sparking voltage, particularly on larger engines. This difficulty is overcome by adding a booster magneto, or a high-tension coil, to which primary current is supplied by a battery or by providing an impulse starter that rotates the armature at engine crank speeds.

In the magneto ignition system, a permanent magnet supplies the magnetic field, and a wire coil is the conductor. Relative motion between the magnet and the wire coil is provided by mechanical energy from the engine. There are basically two types of magnetos. One is the armature wound type where the coil moves while the magnet is stationary, and the other is the inductor type, where the magnets move and the coil is stationary. The latter arrangement provides certain advantages. Connections to the magneto are simpler because the winding is stationary. Fig. 11-15 shows a diagram of a simple inductor type magneto, illustrating the field pole and armature. As the armature is rotated, the magnetic field reverses inducing current flow in the winding.

To generate the high voltage necessary for sparking, the current flow in the primary winding must be interrupted when it is at maximum flow. This causes the lines of force in the field to collapse at an extremely high rate across the secondary winding. As in the conventional ignition coil, the secondary winding of the magneto is made up of many turns of fine wire, whereas the primary winding has fewer turns of heavier wire. The rapid collapse of the magnetic field induces a momentary high voltage in the secondary, in proportion to the wire turns ratio of primary to secondary windings. Fig. 11-16 shows the primary and secondary circuits of a simple single cylinder inductor magneto.

This figure also shows other components needed to generate sparking voltage. The breaker points interrupt the primary circuit, causing the magnetic field to collapse. The breaker points are actuated, as in the conventional battery system, by a cam that forces the points open at the correct time.

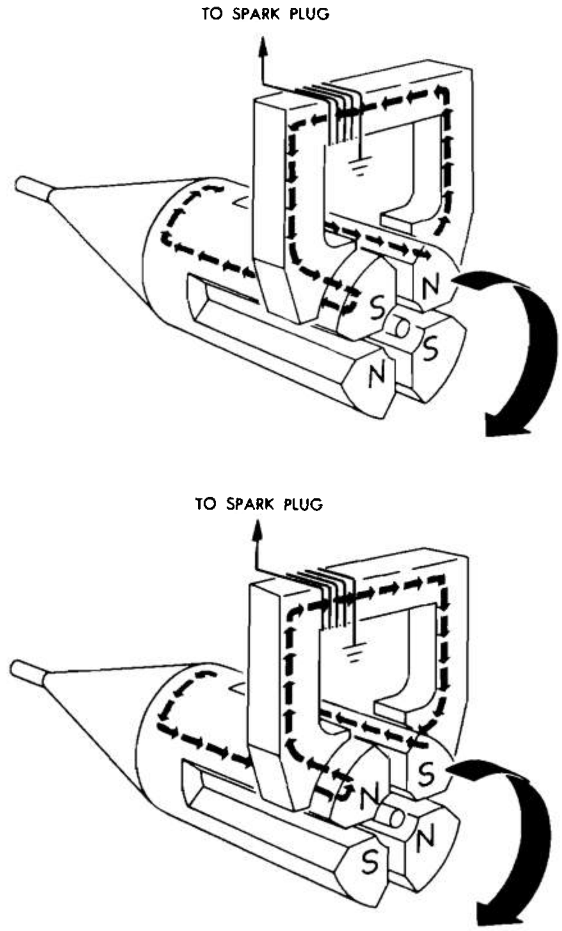


Figure 11-15. Magneto Rotor

Another component shown in Fig. 11-16 is the capacitor. The capacitor performs exactly the same function as in the conventional battery ignition, i.e., it prevents excess arcing across the breaker points and hastens the collapse of the magnetic field around the primary.

Not shown in Fig. 11-16, but required on multicylinder engines, is the distributor to direct the spark to the proper cylinder at the correct time. This device contains a rotor, driven from the engine, and includes distributor electrodes similar to the conventional battery ignition. The provisions for switching off the magneto circuit also have been omitted. The magneto is self-sustaining, and does

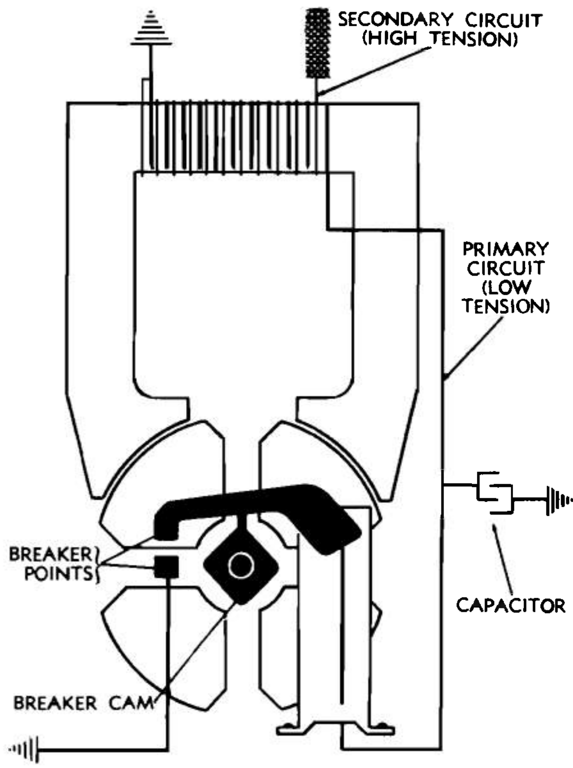


Figure 11-16. Magneto System Diagram

not have an external power source to disconnect. The magneto circuit is "switched" off by using a grounding switch to ground the circuit at the breaker point end. This prevents the magneto from producing high-voltage surges and effectively shuts down the engine.

The magneto circuit on military vehicles must be water-proofed and shielded as is the conventional ignition system. Many different arrangements of magneto circuits have been used. For example, most air-cooled engines will have a dual magneto system with two magnetos, two distributors, two wiring harnesses, and two spark plugs for each cylinder.

11-2.4 EXCITER IGNITION

The exciter ignition system is used to provide a pulsed spark for a short period of time. The system does not provide a continuous spark related to engine revolutions as the conventional battery, electronic, or magneto ignition systems do. The exciter ignition system is the usual method employed for starting a gas-turbine engine. Such engines are self-sustaining once they are up to speed and therefore require no further ignition. The exciter circuit is energized usually at the time the starter is engaged and either is disengaged as the starter circuit is opened or is disengaged by a timing device that opens the exciter circuit after a predetermined length of time.

The exciter ignition system consists of a battery, an ignition or starter switch, an exciter assembly, and an ignitor plug. The exciter assembly is essentially a coil, vibrator, and capacitor. When the switch is closed, the circuit is completed from the battery to the primary of the coil through the vibrator to ground. The vibrator makes and breaks the circuit about 10 times per sec. The lines of force induced in the coil by action of the vibrator produce a voltage of approximately 15 kV in the secondary winding which is conducted by high tension cable to the ignitor plug located in the combustion chamber. The spark generated across the ignitor plug gap ignites the fuel-air mixture in the chamber. The ignitor plug is similar to the conventional spark plug, but often will have a larger gap.

The ignitor spark is needed until the temperature of the combustion chamber is high enough to sustain ignition of the incoming fuel mixture. Once the temperature is up, the ignitor circuit is switched off, since it is no longer required.

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CHAPTER 12

INDICATING INSTRUMENTS, DISPLAYS, AND WARNING DEVICES

SECTION I

INSTRUMENTS

12-1 INTRODUCTION

This section is presented to familiarize the vehicle electrical system designer with the instruments currently used in, or contemplated for, military vehicles. Although a vehicle will operate without instruments, these devices are of vital importance in military applications because they provide the driver with information regarding the operating capability of his vehicle at any instant. This is particularly important in a tactical situation where an unrecognized vehicle malfunction could jeopardize the mission, vehicle, or crew.

The instruments in a vehicle generally are operated by either mechanical or electrical means. Nearly all of the electrical types utilize two basic units. One is the indicator and the other the sending unit or transmitter. Devices to measure pressure, speed, rpm, temperature, and liquid level generally employ these two units connected together electrically. A calibrated galvanometer (ammeter) has been used to measure and indicate the flow of current directly to or from the battery, however, recent applications are rare. System voltage is monitored with a battery-generator indicator (voltmeter) which relates pointer position to a red (danger), yellow (low), or green (normal) color range or band displayed on the dial. This indicator is widely used in the present inventory in preference to an ammeter. Speedometers and tachometers may be of the mechanical or electrical type. Further discussion of these instruments will be presented in the paragraphs that follow.

12-2 STANDARD INSTRUMENTS

The process of selecting instruments for a given application has been greatly simplified by the development of Military Standards for instruments and sending units. Standard instruments and/or sending devices are available for pressure, temperature, liquid level, battery-generator, ammeter, speedometer, and tachometer applications. These units are completely waterproofed and equipped with standard friction retainment connectors.

Standard indicators are illuminated through windows in the instrument housings. This allows light to be introduced from a separate panel-light source. This method of instrument lighting offers several advantages. One is that the light introduced to the indicator dial originates behind the instrument panel and therefore does not cause the glare associated with spot or flood lighting, which is so detrimental to night vision. In addition, the total power requirements are less for panel-type lighting since one light, located near the indicators, can be used to provide illumination for two, three, or four indicators. Finally, the panel light itself is a standard waterproof unit that is easily maintained. The same unit is used as a warning light by installing a slightly different lens. Further discussion and illustration of the panel light unit follow in Section II.

Indicators are by nature delicate devices. They are balanced and calibrated to provide accurate readings. Severe shock or vibration encountered on a military vehicle will destroy this calibration unless some protection is provided. For this reason, it is standard practice to isolate indicating instruments from shock and vibration by mounting the instrument panel on appropriate shock and vibration isolators.

As stated previously, most of the electrical-type instruments consist of two basic units, the transmitter and the indicator. Fig. 12-1 presents the schematic diagram of a standard coil-type indicating instrument. Although only the fuel level circuit is illustrated, the same basic principle is used for other standard indicating gages.

The fuel level indicator illustrated in Fig. 12-1 is referred to as the sliding coil type. The indicator contains two coils, the limiting coil and the operating coil. When the ignition switch is turned on, current passes through the limiting coil to a common connection between the limiting and operating coils. At this point, the current is offered two paths to ground. One is through the case-grounded operating coil, and the other is through the wire to the rheostat contained in the sending unit. The resistance of the rheostat varies from 0 to 30 ohms, depending on the position of the rheostat arm. When the tank is empty the float moves the rheostat arm to the zero resistance position. This causes nearly all of the current to flow through the limiting coil directly to ground. The current flow, in turn, sets up a magnetic field in the limiting coil which magnetically pulls the indicator pointer to the empty position. As the liquid level rises, the float moves the rheostat arm toward the 30-ohm position. This increased resistance causes some of the current to flow through the operating coil to ground. The resultant magnetic field in the operating coil overcomes some of the pull from the limiting coil, thus allowing the pointer to rotate toward the full position[1].

One advantage of the sliding coil indicator is that only a small amount of current, approximately 0.2 A, is required. The low current advantage is offset somewhat by mounting restrictions associated with this indicator. For example, the indicator dial must be mounted in a nearly vertical position. Any mounting position exceeding 10 deg from vertical, will degrade the normal accuracy. A properly calibrated gage is accurate within ± 4 angular degrees at all scale deflections over an arc of approximately 60 deg, when mounted at a 10-deg inclination from the vertical. This rating holds true over an input voltage range of 24 to 31 V at 70° ± 5°F ambient temperature[1].

Fig. 12-2 shows the standard MS24544 fuel quantity indicator which functions as previously described. This figure illustrates the mounting features and the standard waterproof connectors. The right side view also shows the side windows that are used to introduce edge lighting from an adjacent panel-light assembly. The clamp-type mount-

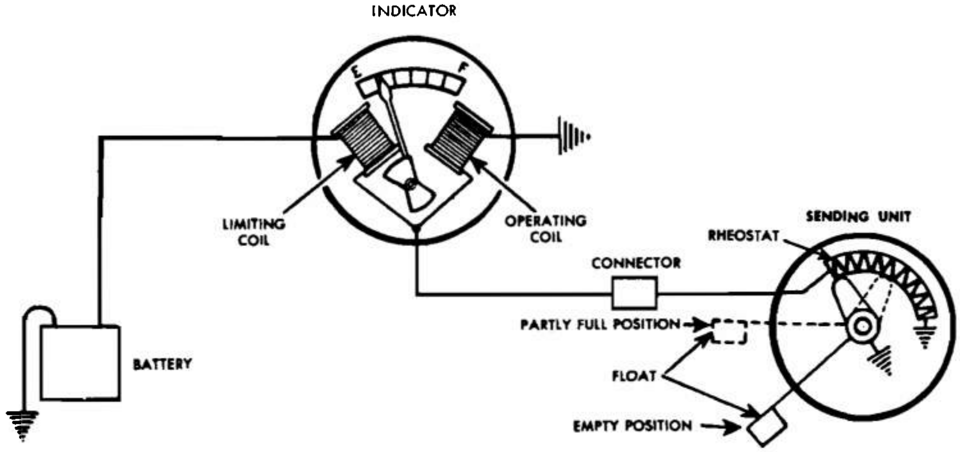


Figure 12-1. Sliding Coil Type Fuel Level Indicator Circuit[1]

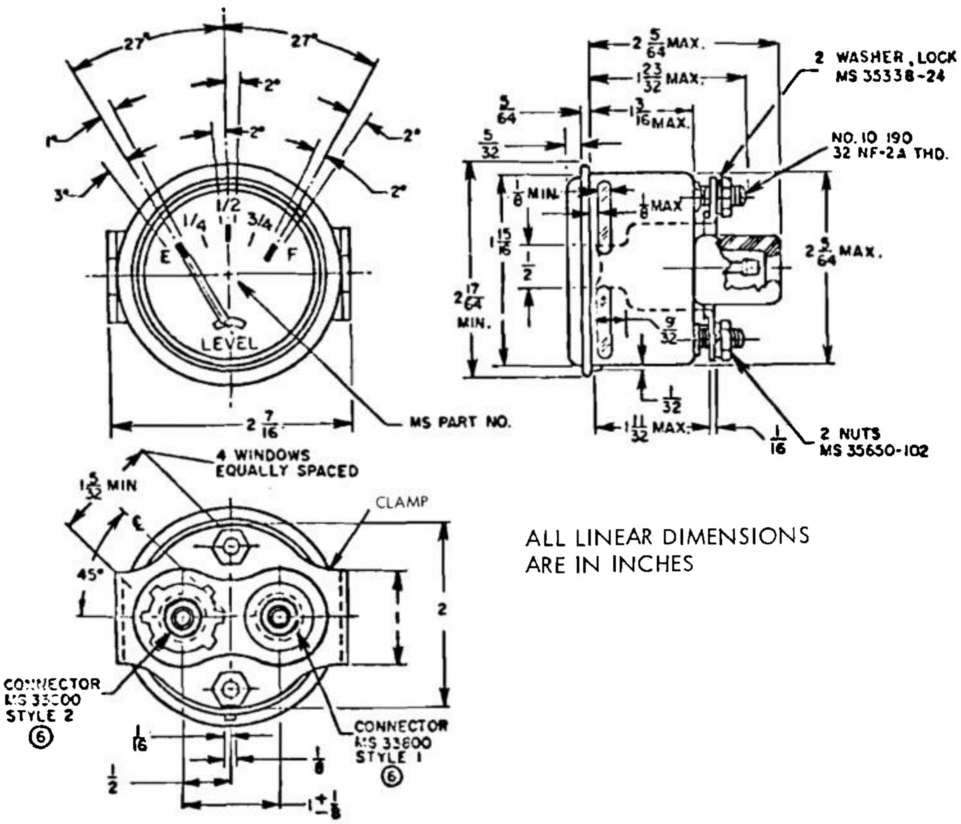


Figure 12-2. Indicator, Liquid Quantity

ing features are common to other Military Standard gages. The case ground for these instruments is dependent upon good electrical contact between the back of the instrument panel and the pointed barbs on the mounting clamp. It follows that shock mounted panels must be well grounded in order to complete the return path to the battery.

Table 12-1 illustrates the standard 24-V indicators available to the designer. This table also lists the associated transmitter, when applicable. Each of the Military Standard gages listed must conform to the requirements specified in MIL-I-10986[2].

12-2.1 SPEEDOMETERS AND TACHOMETERS

In the introduction, it was pointed out that the speedometer and tachometer are available

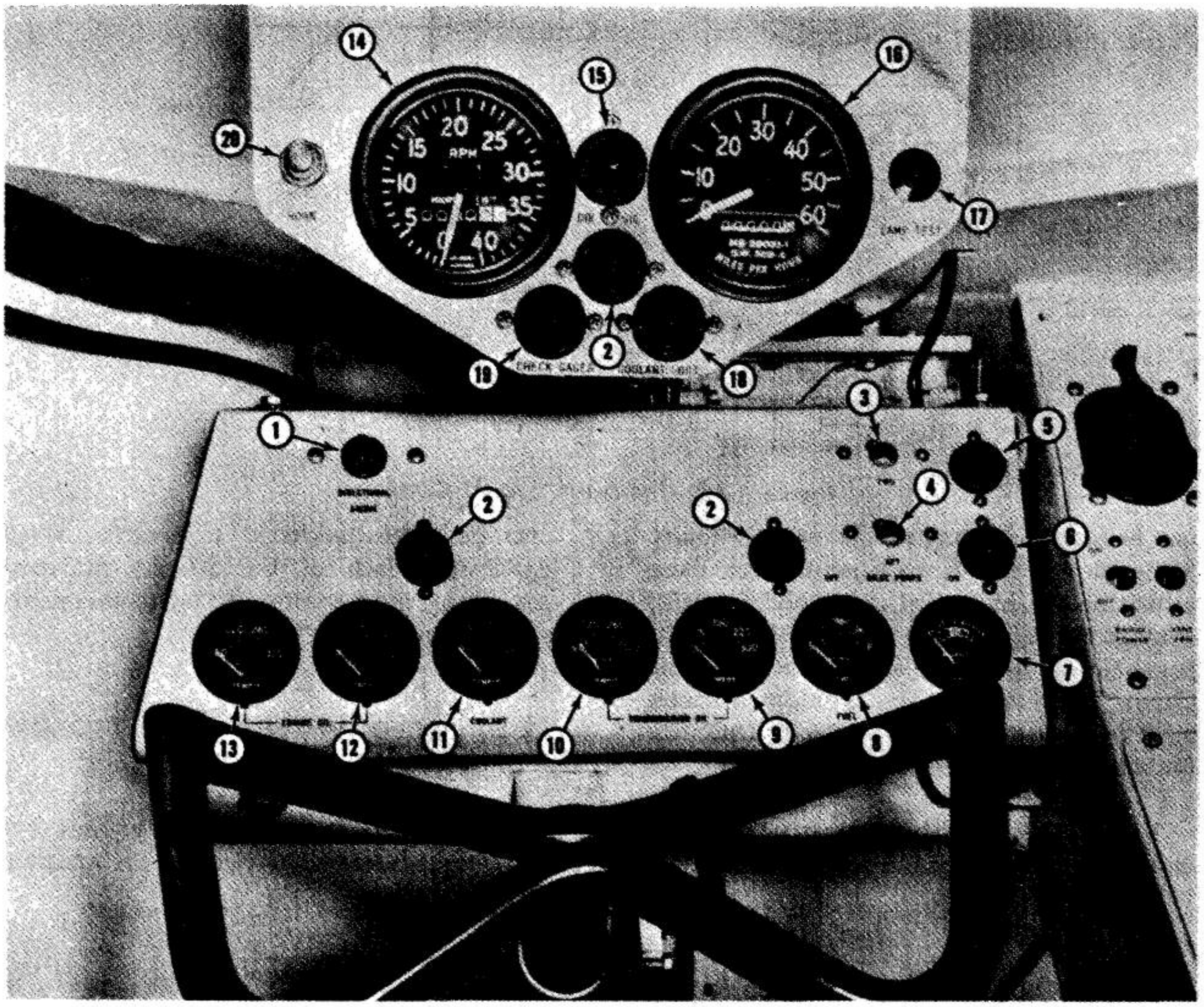
TABLE 12-1. STANDARD GAGES

Part Number	Title	Range	Associated Transmitter
MS24532	Indicator, battery-generator	18-30 V	None
MS24540	Indicator, pressure	0-120 psi	MS24539
MS24541	Indicator, pressure	0-60 psi	MS24538
MS24542	Indicator, temperature	160°-320°F	MS24537
MS24543	Indicator, temperature	120°-240°F	MS24537
MS24544	Indicator, liquid quantity, engine fuel	Empty-full	MS500040
7728854	Ammeter	Chg-dischg	None

in either mechanical or electrical types. The mechanical speedometer-tachometer system employs an indicator mounted on the instrument panel, a flexible drive shaft, and a drive unit.

The mechanical speedometer and tachometer operate on basically the same principle, except the speedometer indicates vehicle miles per hour and total miles accumulated while the tachometer indicates engine revolutions per minute and hours of operation (based on an average number or revolutions per hour).

A typical panel arrangement including a mechanical speedometer and tachometer is shown in Fig. 12-3, items 14 and 16. This



LEGEND

1–Directional signal switch
2–Panel reading light
3–Forward bilge pump switch
4–Aft bilge pump switch
5–Forward bilge pump indicator light
6–Aft bilge pump indicator light
7–Battery-generator indicator
8–Fuel quantity indicator
9–Transmission oil pressure indicator
10–Transmission oil temperature indicator
11–Engine coolant temperature indicator
12–Engine oil pressure indicator
13–Engine oil temperature indicator
14–Tachometer
15–Directional signal light
16–Speedometer
17–Lamp test switch
18–Coolant lost warning light
19–Check gages warning light (Master)
20–Horn button

Figure 12-3. Main and Auxiliary Instrument Panels, LVTP7 figure also shows many of the standard gages described in the previous paragraphs.

A vehicle with a mechanical-type speedometer normally requires an adapter, located on the transmission or final drive, to drive the flexible drive shaft leading to the instrument panel. This shaft, in turn, drives the rotating parts of the speedometer. The odometer or mileage indicator portion of the speedometer consists of a series of gears driven by the drive shaft. This gear set ends with a series of pinion gears inside the visible figure wheels. These figure wheels are constructed so that as one finishes a complete revolution, it turns the next wheel one-tenth of a revolution. Most odometers are arranged to record 99,999.9 miles before automatically returning to zero.

The speed-indicating portion of the speedometer is illustrated in Fig. 12-4. This operates through a magnetic coupling that consists of a magnet, field plate, speed cup with pointer, and hair spring. The magnet is driven directly from the drive shaft and rotates inside the field plate and speed cup as shown in Fig. 12-4. As the magnet rotates inside the movable speed cup, it sets up a rotating magnetic field. This field, in turn, exerts a pull on the speed cup, causing it to rotate in the same direction. The speed pointer itself is mounted on the speed cup shaft and rotates with it. The movement of the speed cup and pointer is retarded by the hair spring, attached to the speed cup shaft. The speed cup and the pointer come to rest at the point where the magnetic pull from the rotating magnet and the retarding force from the hair spring are equal. The amount of speed cup

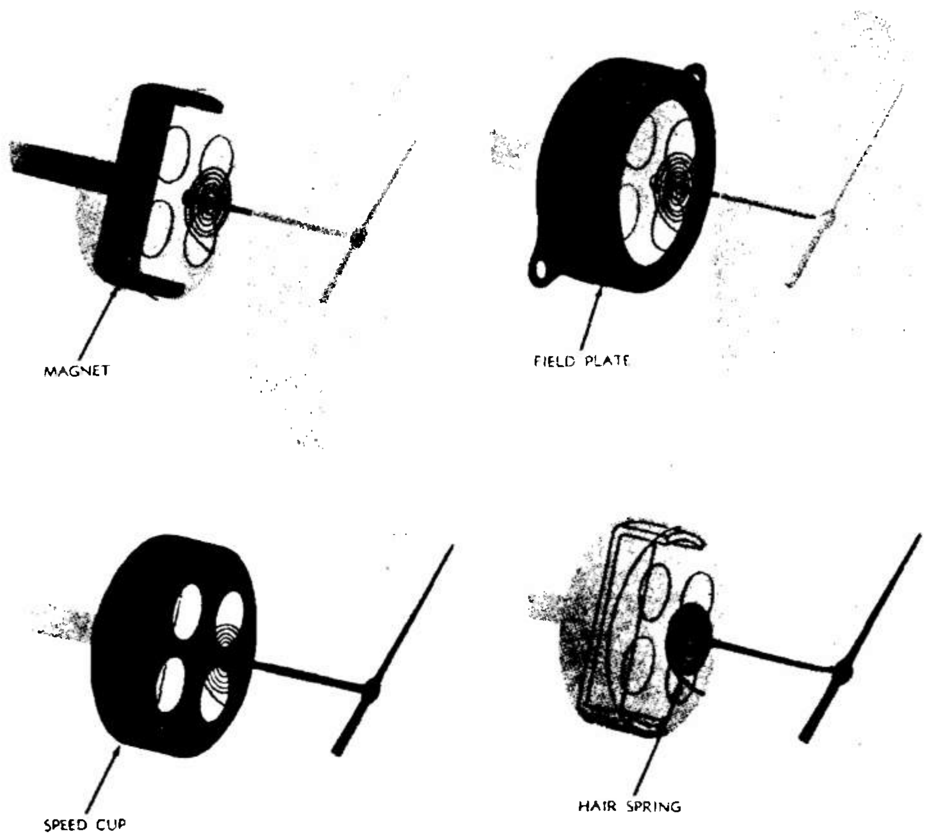


Figure 12-4. Phantom View of Basic Components of Speed-indicating Portion of Speedometer

deflection is proportional to the speed at which the magnet is being turned.

An electrical speedometer or tachometer system consists of a generator or transmitter assembly and an indicator assembly, both units connected electrically.

The transmitter is a small generator which produces a voltage output proportional to the speed of rotation. The speedometer generator normally is driven from the final drive of the vehicle, whereas the tachometer generator is driven from the engine accessory drive. The obvious advantage of the electrical approach is elimination of the flexible drive cable that is necessary in a completely mechanical system.

Older designs for electrical speedometers and tachometers employ a synchronous motor as shown in Fig. 12-5. Once operational speed is reached, the motor turns at the same speed as the generator. The motor, in turn, rotates a magnet in a speed cup similar to that described for the mechanical instruments. This arrangement is illustrated in Fig. 12-5.

To conserve space and reduce the total number of parts, electrical speedometer and tachometer generators have been connected so that a single instrument assembly displays either revolutions per minute or miles per hour. This arrangement is used on the M551 Indicator Panel Assembly as shown in Fig. 12-6. Here, a selector switch is employed to display either tachometer or speedometer readings by connecting the appropriate generator to the display unit. The two generators in this system are small case-grounded permanent magnet types, and each is connected to the display unit with a single wire. The display unit is a millivolt meter marked to indicate the voltage output from the generator in mph or rpm.

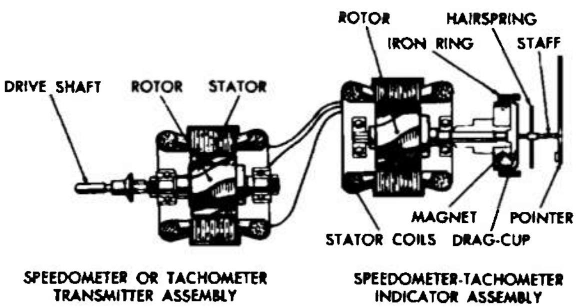


Figure 12-5. Electrical Speedometer-tachometer

The instrument cluster for the M551 shown in Fig. 12-6 was developed as a result of research and development efforts at USATACOM[3]. USATACOM engineers fostered the design of a basic, compact, and versatile instrument panel suitable for many military general-purpose vehicles. The temperature and fuel indicators installed in this panel utilize a multitorque-type "air-core" gage. These gages are designed for operation through 90 deg compared to 60 deg for the sliding coil type. In addition to the larger scale reading they provide, the gages are rugged, durable, compact, have fewer parts, and are more accurate than the sliding coil type[3].

The circuit for the air-core gage is shown in Fig. 12-7. This system also uses a linear resistive transducer, and the gage operates on electromagnetic principles. However the air-core gage differs from the sliding coil gage in that it employs three coils and a fixed resistance to control the pointer movement. The circuit shown includes the sensing unit, R_S; the indicator resistance coils, R_1, R_2, and R_3; and a fixed resistance, R_A. The I_1 and I_2 represent coil currents.

When the sensing unit is set at zero resistance, I_2 is insignificant, and a strong magnetic flux is produced only in coil R_1. The needle armature aligns itself with this flux and indicates the zero position.

When the sensor is set at one-half scale, as shown, it has a resistance of approximately 45 ohms. This resistance causes a partial current I_2 through coils R_2 and R_3 to ground. The

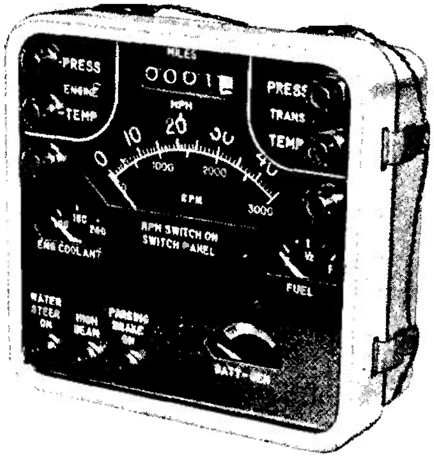
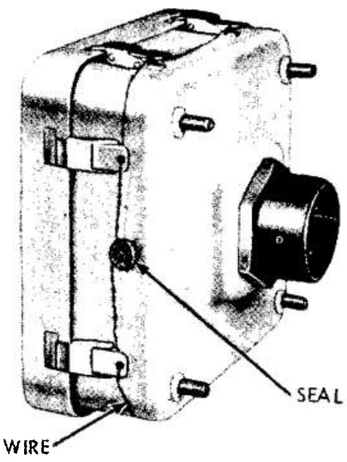



Figure 12-6. Indicator Panel With Electric Tachometer-speedometer, M551

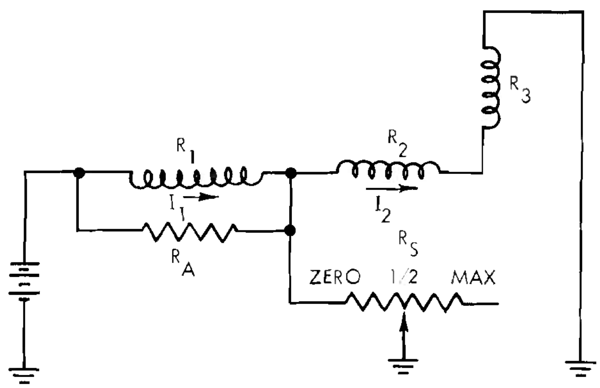


Figure 12-7. Air-core Indicating Circuit

additional flux produced in these coils pulls the needle armature to the one-half scale position.

When the sending unit is at a maximum resistance of 84 ohms, current I_2 is at a maximum, and the flux generated in coils R_2 and R_3 pulls the pointer to the maximum position.

12-2.2 DESIGN TRENDS

The standard tachometer and speedometer units available to the vehicle designer are summarized in Table 12-2. This table lists either the Military Standard or standard Ord-

TABLE 12-2. STANDARD TACHOMETER AND SPEEDOMETER UNITS

Part number	Description
MS-35916	Tachometer, mechanical, fixed mounting (4,000 rpm)
MS-39021	Speedometer; mechanical (0-60 mph)
MS-39130	Adapter, speedometer-tachometer, 90-deg drive
MS-39132	Adapter, speedometer-tachometer, straight drive
MS-51071	Shaft assembly, flexible metallic-tachometer and speedometer
MS-51072	Core, flexible shaft assembly-tachometer and speedometer
MS-53099	Adapter, coupling/bulkhead speedometer-tachometer drive
8713233	Tachometer, mechanical, fixed mounting (6000 rpm)
10948076	Speedometer-tachometer, electric (45 mph, 3000 rpm)
10948078	Odometer, electric (9999.9 miles)
10918249	Generator, electric, tachometer and speedometer

nance part number that describes the unit. In addition, the requirements for performance and testing of these units may be found in MIL-S-10215[4].

Nearly all of the military vehicles in the present inventory have mechanical-type speedometers and tachometers. Cost evaluations have shown them to be more economical than the electrical type, and they have proved also to be accurate enough for military requirements.

The mechanical units do have certain disadvantages, however, such as cable maintenance, panel mounting, and cable routing restrictions. For these reasons, further development of electrical-type tachometers and speedometers such as the one illustrated in Fig. 12-6 could lead to their adoption as the standard instrument in the future.

Recently efforts were made to reduce all suspected hazards to the vehicle crew inherent in standard equipment. This trend is reflected in a recent revision to remove luminous paint from all standard military instrument dials to avoid radiation hazards. Such dials no longer are considered acceptable for general military use.

SECTION II

DISPLAY AND WARNING DEVICES

12-3 INTRODUCTION

This section presents warning devices and displays used on current military vehicles.

Whereas the indicators described in the previous section indicated increasing and decreasing trends by means of a pointer and dial, warning and indicator light displays are used to indicate a specific equipment state or an other-than-normal condition.

Auditory devices—such as horns, sirens, and buzzers—serve separately or in conjunction with warning lights as alert mechanisms to warn of a potentially hazardous condition.

Each of the devices described in the paragraphs that follow is intended to perform one basic function. That function is to provide an interface between man and the machine. They are the means for conveying to the man the condition and characteristics of the vehicle and its subsystems.

12-4 WARNING LIGHTS AND INDICATORS

The requirement for selecting warning and indicator lights to implement a given application has been simplified by the development of standard waterproof units. These units can be used as warning, indicator, or panel lights depending on the lens selected.

Fig. 12-3 illustrates the basic lighting assembly in use for all three applications. A larger view of a simple truck instrument panel is shown in Fig. 12-8. This shows the basic assembly applied as panel lights and as an indicator light.

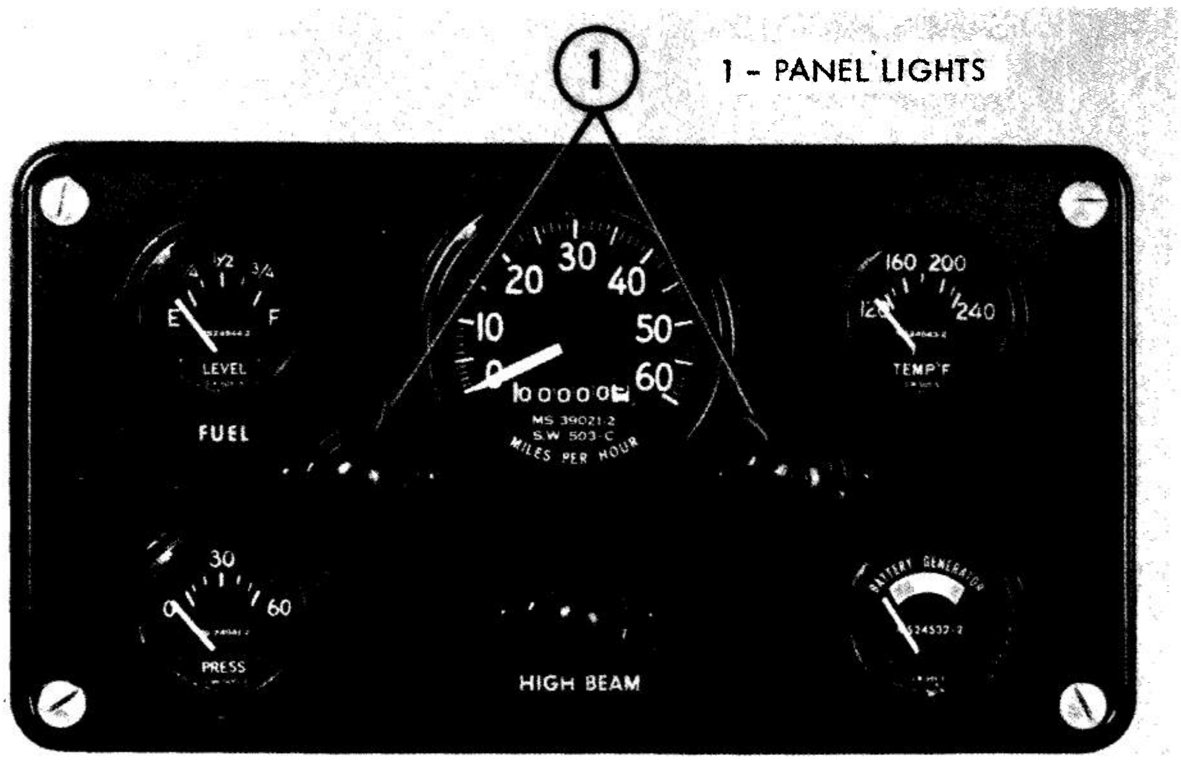


Figure 12-8. Instrument Cluster—Lighting Arrangement

When used as a panel light, the standard unit is equipped with a capped lens that only allows light to escape behind the instrument panel. This light illuminates the gages shown in Fig. 12-8 through the side windows described in par. 12-2.

When the basic assembly is employed as an indicator light, such as the high beam indicator in Fig. 12-8, a relatively small area of light is emitted through the lens cap to the front of the instrument panel. A red dot appears in the center of the high beam indicator as shown. The typical indicator light is used to signify an energized condition for certain functions. In addition to the illustrated high beam indicator usage, these lights are used to signify other conditions such as bilge-pump "on", master-switch "on", or directional signal "on".

Warning lights are used to alert the vehicle operator that an unsafe operating condition exists. There are many applications for warning lights, such as low engine or transmission oil pressure, high engine or transmission oil temperature, loss of coolant, fire. When the standard unit is used as a warning light, there is no lens cap and the entire lens surface is illuminated.

Actuating units are required in conjunction with any warning light; i.e., circuit closing devices that are sensitive to temperature, pressure, or other effects. Specifications for the temperature type may be found in MIL-S-12285[5], while MS90530 describes the pressure type.

The standard two-conductor warning light assembly is shown in a partially exploded view in Fig. 12-9. This illustration includes

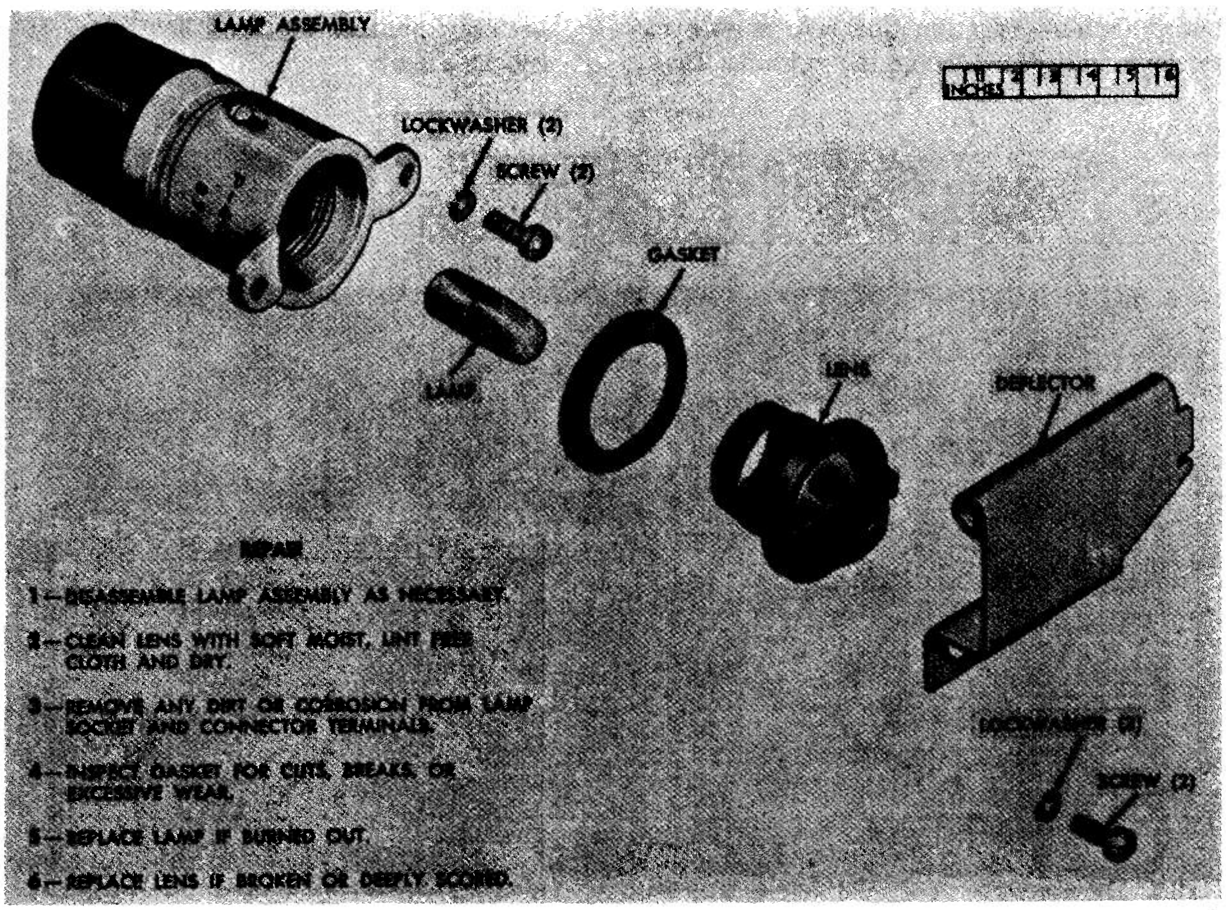


Figure 12-9. Standard Warning Light Assembly

the lamp assembly, lamp, lens, lens gasket, and attaching hardware. The lens in the assembly is always red. This is to help the operator retain his night vision. The lamp used is a standard 24-28 V, MS25231-1829.

Another standard light assembly, not shown, has a single terminal. This unit differs from the dual contact light assembly in that it has only a single contact friction retainment receptacle for the power input and is internally case grounded.

Table 12-3 will aid the designer in the selection of a standard panel, indicator, or warning light assembly. This table lists the standard Ordnance part number, the applicable drawing number, recommended usage, and the type of terminal used.

12-5 HORNS

Horns are used on military vehicles for several reasons. Primarily, the horn is used to warn bystanders that the operator is about to start or move a vehicle, or to warn of a potentially hazardous operation such as lowering the ramp. On some vehicles, a horn is used to indicate low oil or air pressure.

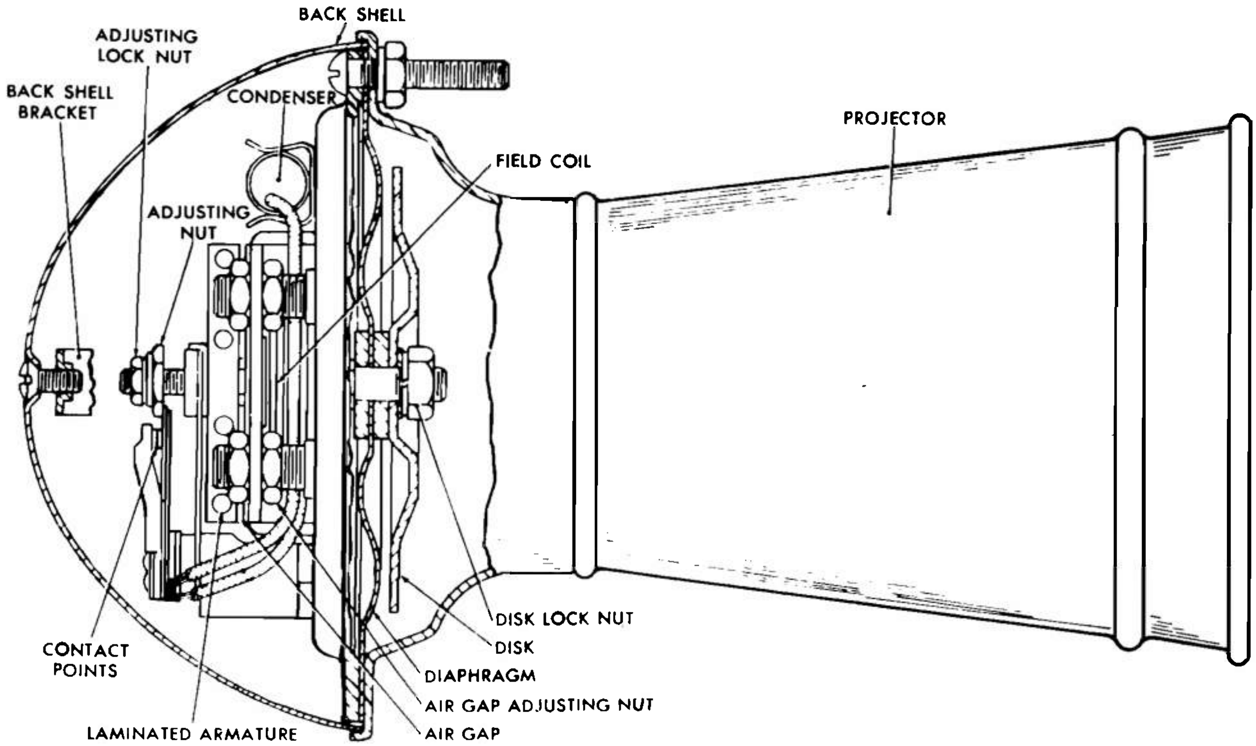
Most horns used on military vehicles are of the vibrator type. The specifications for this type of horn are given in MIL-H-10201[6]. The Qualified Products List (QPL) covering this specification lists approved sources. The horn most frequently used for 24-V applications, is depicted on MS51074. An air-actuated horn, MS51301, is also in common usage.

The vibrator-type horn is shown in Fig. 12-10. The field coil operates both the diaphragm and contact points. When the circuit is closed by the horn button, current flows through the control points and the field coil, causing a magnetic field to build up in the coil. The magnetism produced in the coil pulls the diaphragm towards the coil and at the same time forces the contact points open. The opening of the contact points breaks the current flow through the coil, and the diaphragm and breaker points return to their original position. This cycle is repeated as long as the horn button or switch remains closed. The vibration of the diaphragm in the column of air produces the sound of the horn.

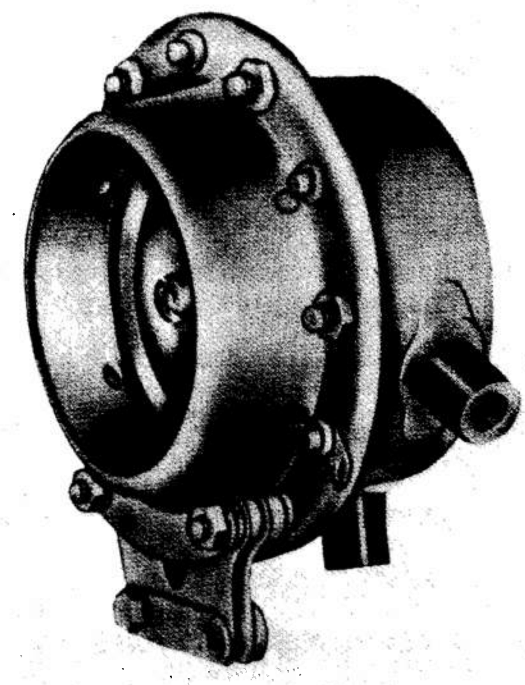
The adjustment of a vibrator-type horn is accomplished by loosening the locknut and turning the adjustment screw shown in Fig. 12-10. This increases or decreases the amount

TABLE 12-3. STANDARD PANEL, INDICATOR, OR WARNING LIGHT ASSEMBLIES

Part number	Drawing number	Lens number	Usage	Terminals
7971111	8376499	7358672	Warning	Single terminal case grounded
8376499-1	8376499	7358622-1	Indicator	Single terminal case grounded
8376499-2	8376499	7358621-1	Panel	Single terminal case grounded
8376499-3	8376499	7358672-1	Warning	Single terminal case grounded
8376499-4	8376499	7358672-2	Warning	Single terminal case grounded
8729064-1	8729063	7358622-1	Indicator	Dual contact
8729064-2	8729063	7358672-2	Warning	Dual contact



(A) CROSS-SECTIONAL VIEW (AUTOMOTIVE HORN)



(B) MILITARY STANDARD HORN, MS 51074

Figure 12-10. Electric Horn (Vibrator Type) of current flow through the horn, causing a change in the horn volume and tone.

12-6 SIRENS AND BUZZERS

Sirens and buzzers sometimes are used on military vehicles. In some cases a buzzer may be used in place of a horn. For example, some of the pressure systems on the M88 and GOER vehicles use buzzers to warn of low pressure, while the M48 and M60 use horns in similar applications. It should be noted that the effectiveness of a buzzer may be reduced on heavy duty military vehicles due to the high ambient noise level.

Sirens have been used to some extent as audible alarms on military vehicles. They have been used in chemical alarm systems and the radiac alarm system. These systems employ sensing devices and control units which activate the siren circuit when the presence of a deadly chemical or an excess amount of radioactivity is detected. The designer who is interested in these particular alarm systems may obtain more detailed information from the USATACOM Electrical Laboratory.

In addition, buzzers and sirens are described by MIL-H-10201[6] and MIL-S-3485[7], respectively. The QPL for each of these specifications will list approved sources.

12-7 DISPLAYS

The indicators described in Section I are visual displays that convey information by means of a pointer and dial. This is the preferred method of displaying direction of movement, orientation in space, or increasing and decreasing trends.

There are basic factors that affect the visual effectiveness of a dial indicator. Among these, of course, is the location of the indicator with respect to the viewer. Accordingly, a location guide has been presented in Fig. 4-12.

In addition to dial location, other factors such as scale design and pointer design are important considerations. The direction the pointer moves, the location and size of graduation marks and numerals, the brightness contrast between the markings and the background, the pointer location, and the pointer size are examples of these. Table 4-6 presents indicator dial and pointer design recommendations.

A display system that projects a visual image of a reticle to facilitate the location of one object in relation to another is used in optical gunsights to facilitate accurate aiming of the weapon. These optical weapon sights and reticles are described in par. 17-4.

Alphanumeric displays are easiest for the human to comprehend rapidly and therefore are preferred in many applications. Typical examples of alphanumeric displays are the speedometer, odometer, and tachometer hour meter described previously.

More sophisticated alphanumeric displays are now available in panel meters, clocks, electronic test equipment, etc., and are currently in development for other instruments that require some form of variable readout. The alphanumeric display can be used for any indicating application where the rate of change for consecutive readings does not exceed 2 displays per second.

Alphanumeric displays have been constructed with electro-luminescent strips, electrochemical cells, light emitting diodes, or cathodes in a glow discharge tube. They also may use engraved plastic panels that are edge lit with neon or incandescent lamps. The systems include sensing devices and control units that illuminate the proper character pattern at the display panel.

Fig. 12-11 illustrates two types of alphanumeric display patterns. Fig. 12-11(A) consists of 13 segments which display alphanumeric characters when different segments are illuminated. For example, the number 7 is displayed by illuminating segments 1, 2, and 3 as shown. Fig. 12-11(B) shows a different approach using a 35-element pattern of dots. The same number 7 is displayed by illuminating elements 1 through 9 as shown.

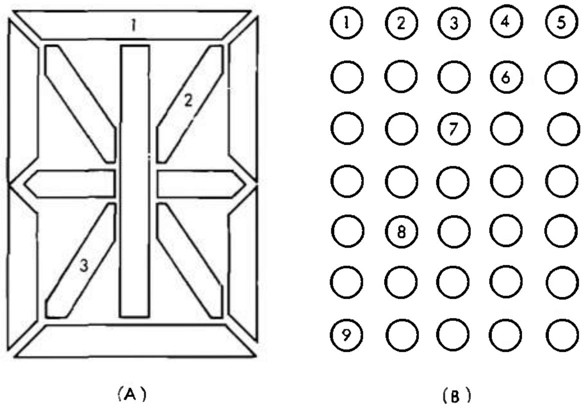


Figure 12-11. Alphanumeric Displays

These alphanumeric displays are but two among many variations of display patterns and alphanumeric systems being used or under consideration. Some of the new systems in research and development utilize such phenomena as piezoelectric, ferroelectric, ferromagnetic, thermochromic, photochromic, or magneto-optic effects[8].

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4. MIL-S-10215, *Speedometers, Tachometers, Flexible Shaft Assemblies, Flexible Shaft Assembly Cores, Adapters, and Transmitters.*

5. MIL-S-12285, *Switches, Thermostatic.*

6. MIL-H-10201, *Horns, Sound-Warning, Air-Actuated; Horn, Electrically-Actuated; Buzzer, Electrically-Actuated.*

7. MIL-S-3485, *Sirens, Electrical Motor-Operated, Vehicular.*

8. R.I. Klein, A. R. Elsea, Jr., and I. Hegyi, *Batch-Processed Alphanumeric Displays,* Technical Paper Presented at 1968 Western Electronic Convention, IEEE and WEMA, Session 10, Flat-Panel Displays.

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CHAPTER 13

ILLUMINATION SYSTEMS

SECTION I INTERIOR ILLUMINATION

13-1 INTRODUCTION

The ability of a person to perform a task inside a military vehicle often depends upon how well he can see essential equipment. Actuating knobs and levers, observing dials and position indicators, reading labels, and locating handholds, footrests, and steps all require adequate lighting.

The ability to see a given object depends upon the size of the object, the length of time it is observed, the light contrast level, and the luminance. Interior lighting in a vehicle can be designed to control, to some extent, the latter two.

Contrast level and luminance are altered by both the position of the light source and its intensity. These are important because of the physiological makeup of the human eye. People with normal vision are usually restricted to a relatively small visual angle for seeing tasks that require concentration. The fovea is the part of the human eye where much of the critical seeing takes place, and it subtends only about 1 deg of the center of vision. For discriminating seeing, however, the eye has a field of vision, called the binocular field, which extends 60 deg to the right and left of center in a horizontal direction and 60 deg above and 70 deg below center in the vertical direction.

For example, seeing tasks such as reading fine print are accomplished in the 1-deg zone, while tasks to determine size, shape, and numbers are accomplished in the binocular zone. Thus, the nature of the task determines where a light should be placed for the most efficient performance.

13-2 GENERAL REQUIREMENTS[1]

The interior illumination on tank-automotive vehicles is limited to the areas in which illumination is required for a crew member to perform his regular duties. For example, the vehicle commander should have a dome lamp near his station for map reading. In addition, all potentially hazardous areas of the vehicle should be lighted adequately and all essential gages properly illuminated.

The instrument panel of a military vehicle generally employs backlighting to provide illumination for the various gages and controls. Backlighting, described in Chapter 12, offers several advantages. One is that the light does not cause the glare associated with spot or flood lighting. Glare is one of the most serious of all illumination problems. Two separate types of glare are associated with vehicular lighting: direct glare from a light source within the visual work field, and indirect glare caused by reflections from bright surfaces in the visual field.

Direct glare can be controlled by:

1. Avoiding bright light sources within 60 deg of the center of the visual field

2. Placing light sources high above the work area, because most visual work is at or below the horizontal position of the eyes

3. Using several relatively dim light sources, rather than a few very bright ones

4. Using indirect lighting (such as the backlighting on instruments)

5. Using polarized light, shields, hoods, or visors to block the glare in confined areas.

Reflected glare can be controlled by:

1. Using surfaces that diffuse incident light rather than reflect it without diffusion

2. Arranging direct-light sources so the angle of incidence to the visual work area is not the same as the operator's viewing angle.

The amount of illumination required in a vehicle is dependent upon two factors: glare recovery time, and the type of task to be performed.

Glare recovery is the time required to see clearly inside the illuminated vehicle after exposure to light outside. The time varies with the amount of illumination both inside and outside the vehicle. The curves in Fig. 13-1 show various fixed levels of outside illumination in combination with different intensities of interior illumination. The interior illumination represents practical ranges of lighting in military vehicle fighting compartments, whereas the outside illumination levels represent practical levels of daylight. This ranges up to an extreme of 10,000 foot-candles (ft-c) representing the illumination produced by bright sunshine or snow at high latitudes or on white sand near the equator.

The type of task to be performed requires different levels of illumination, as illustrated in Table 13-1. For example, map reading requires the highest level and stowage requires the least. Also, much less light is needed for night operation than for day, because at night there are no disturbing sources of light and the eyes are adapted to low light levels.

White light is incompatible with dark adaptation requirements and, for this reason, is seldom used at night in any tactical situation. Red light extends the dark adaptation period for the human eye less than any other color. Therefore, night illumination systems should use red rather than white light. Furthermore, the red light at low intensity levels is less

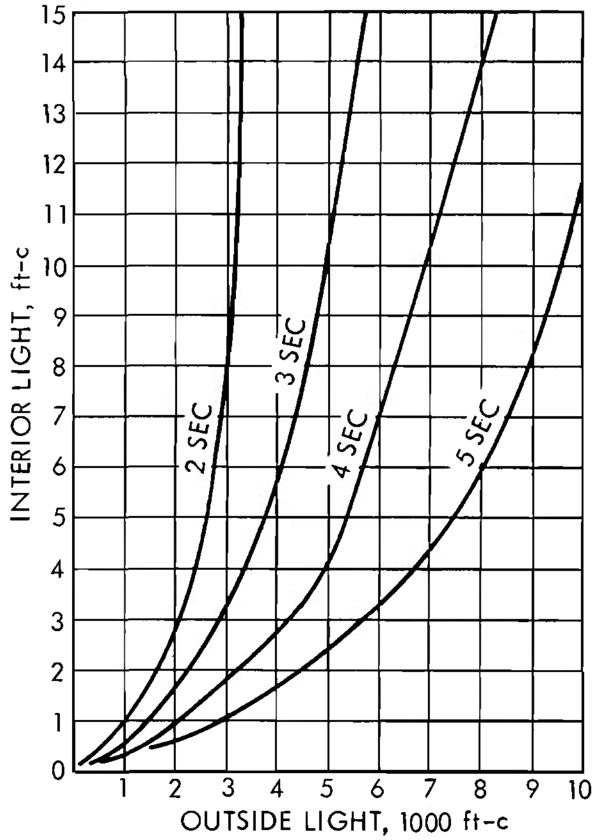


Figure 13-1. Glare Recovery Time Curves for Map Reading After 5-min Exposure to Outside Light[6]

likely to be detected by the enemy if light leakage occurs from hatches or vision blocks. (Some vehicles are equipped with blackout kits containing vision block masks designed to prevent light leaks.)

One might ask, why not use red light for both night and day operations? The principal reason this is not done is that the electrical energy required to produce red light of a given brightness is much more than that required for white light of equal brightness. Thus, a dual lighting system, supplying each crew position with white light for daytime operation and red light for night operation, with both controllable in intensity throughout the proper range, should be provided.

13-3 INTERIOR LIGHTING ASSEMBLIES

Military vehicles experience extreme shock and vibration during their operating lifetimes.

TABLE 13-1. LEVELS OF ILLUMINATION FOR EFFICIENT PERFORMANCE OF VARIOUS TASKS IN TANKS

Task	Night Operation (red light)	Daylight Operation
	Footcandles	Footcandles
Map reading	1	10
Clearing machine gun	0.4	4
Operation of controls	0.3	4
Stowage	0.002	0.1

For this reason, all lighting assemblies, both interior and exterior, must be protected adequately. Most standard light assemblies, including exterior lights, have internal shock mounts to protect lamp filaments from damage. Instrument panels are always shock mounted to protect not only the instruments but the panel lights as well. In all cases where a light assembly is not internally shock protected, the designer should build shock protection into the mounting bracketry.

The standard dome light, MS51073-1, is a very rugged, shock-protected assembly (Fig. 13-2). This assembly includes a red and a white lens mounted in a waterproof metal housing containing a MS35478-1691 lamp bulb, (15 candlepower (cp), 0.61 A at 28 V) behind the white lens and an MS15570-623 lamp bulb, (6 cp, 0.37 A at 28 V) behind the red lens. In addition, the assembly features a lock switch which prevents turning on the white light without first operating a manual release. This light assembly is used on many combat vehicles, such as the M60A1, M113A1, M106A1, M125A1, and M132A1.

Other dome light assemblies, used on command post vehicles are a 5-1/8 in. dia assembly (10923524) with white lens and 15-cp bulb, and a 5-1/8 in. dia assembly (10918048) with red lens and 6-cp bulb. These lights are used in conjunction with one another and require a separate interlock switch to prevent inadvertent operation of the white light. They also must be externally shock mounted.

Several different types of panel lights are available to the designer. The recommended assemblies for use as panel lights in military vehicles are given in Table 12-3.

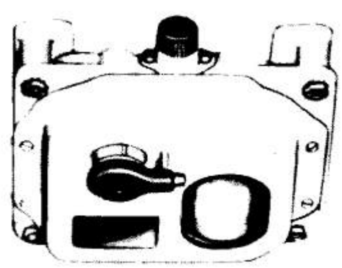


Figure 13-2. MS51073-1 Dome Light

SECTION II EXTERIOR ILLUMINATION

13-4 INTRODUCTION

Exterior lighting requirements on a tank, personnel carrier, or automotive vehicle depend to a large extent on the type of vehicle and on the nature of its mission. For example, the requirements for tanks, armored personnel carriers, and self-propelled weapons are different from those of military trucks, trailers, and ambulances.

Many military vehicles, specifically those used in combat operations, have three different exterior illumination systems, namely:

1. Service lighting system (normal operation)

2. Blackout lighting system (combat operations)

3. Active infrared (combat, invisible to the naked eye).

Any of these three systems allows operation of the vehicle in darkness with varying degrees of visibility for the vehicle operator. These systems, as well as general lighting requirements for each, are the subject of the paragraphs that follow.

13-5 GENERAL REQUIREMENTS AND STANDARD LIGHTING

A general requirement that applies to all military vehicles is provision for adequate protection of the lighting system. Lighting components, because of their fragile nature, must be protected from physical damage from foreign objects, extreme shock and vibration, and excess moisture. This is particularly true for exterior lighting components that are exposed to the elements and receive much abuse from the operating environment.

When vehicles are to be used for off-the-road operations, the designer must provide adequate brush guards around the light fixtures. When possible, lights also should be recessed. Approved military-vehicle lighting assemblies should be used. These incorporate waterproof features and use standard waterproof connectors. They also have shock-mounting features to increase bulb life.

A typical tank-automotive light assembly is shown in Fig. 13-3. This is the MS51329-1 service tail, stop, and blackout marker light used on many military vehicles. The exploded view illustrates some of the design features required for reliable service. These include the waterproof connectors, O-ring seal, wire seal, mounting gasket, and the rubber shock mounts for the lamp receptacles. Also illustrated is the MS35478-1683, 32-cp 1-A bulb used for the service stop light, and the two MS15570-1251, 3-cp 1-A bulbs used for the service tail light and the blackout marker light. A similar blackout stop and marker light assembly, MS51330-1, is also available.

Recently USATACOM participated in an effort to standardize lighting systems and bring the military systems more in line with the National Highway Safety Bureau. This effort has resulted in a new military standard, MIL-STD-1179, that should facilitate the lighting equipment selection task[5].

Typical lighting circuits and equipment locations for the M656 Cargo Truck are shown in Figs. 13-4, 13-5, 13-6, and 13-7.

An example of the lighting circuit for the M113A1, M577A1, M106A1, M125A1, and the M132 family of vehicles is shown in Fig. 13-8. The schematic shows the three types of exterior lighting introduced previously: service, blackout, and infrared (IR). Circuits in all of these vehicles are controlled (Fig. 13-9) through the MS51113-1 lighting switch. This switch has a unique locking feature that prevents accidental use of the stop light or service drive switch positions.

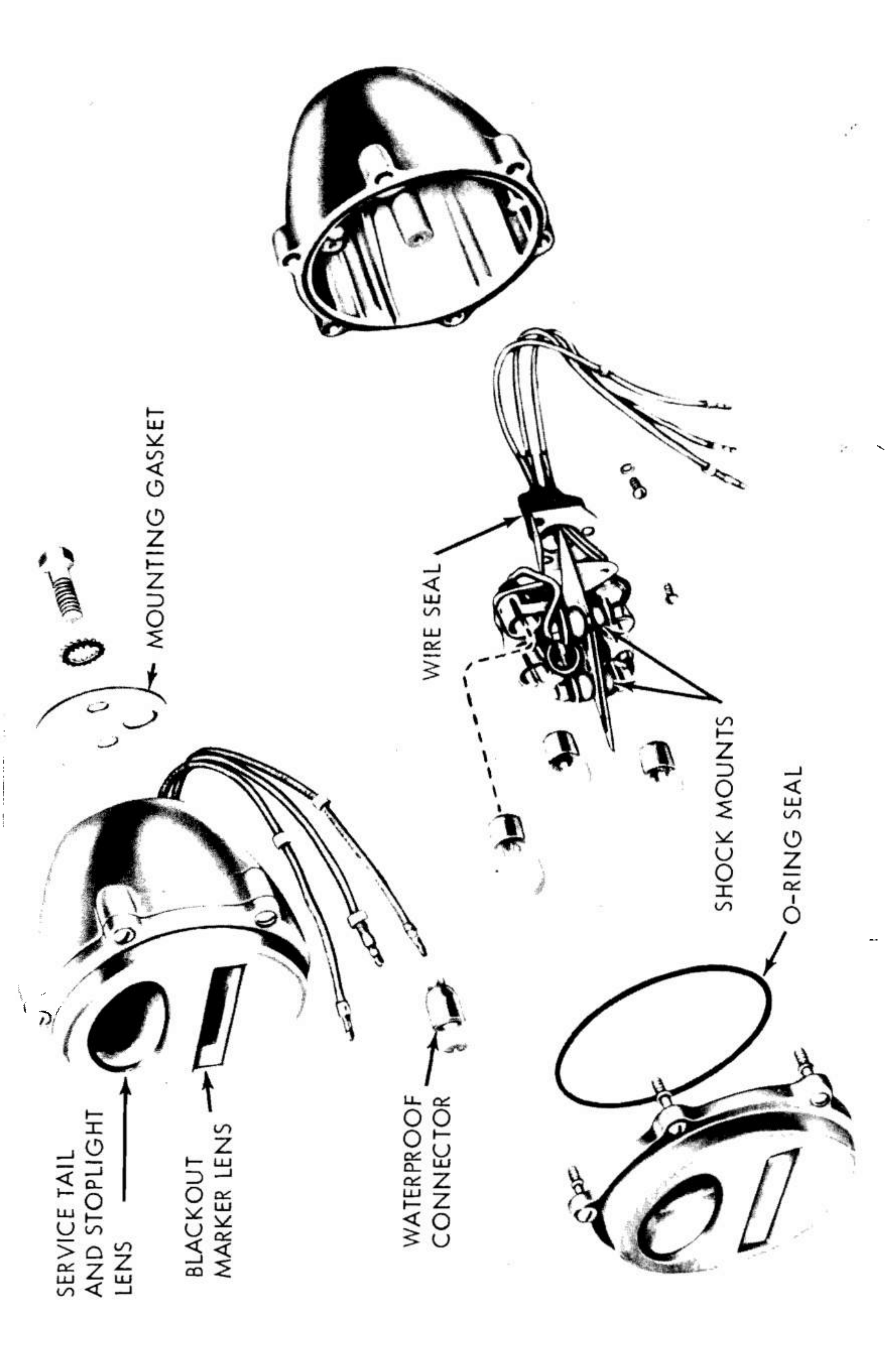


Figure 13-3. Service Tail, Stop, and Blackout Marker Light Assembly

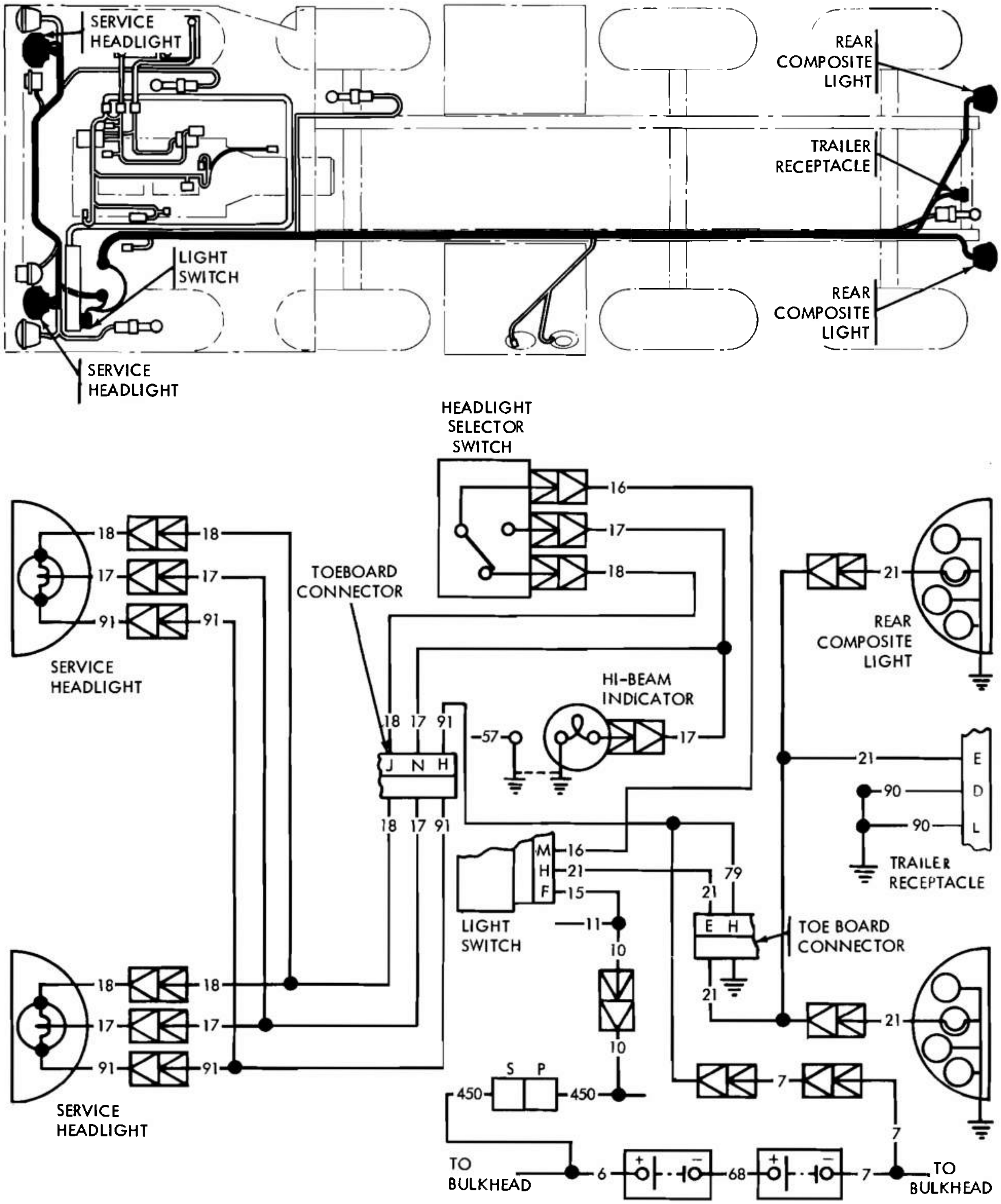


Figure 13-4. Service Headlamps Circuit, Wiring Diagram (M656 and XM747)

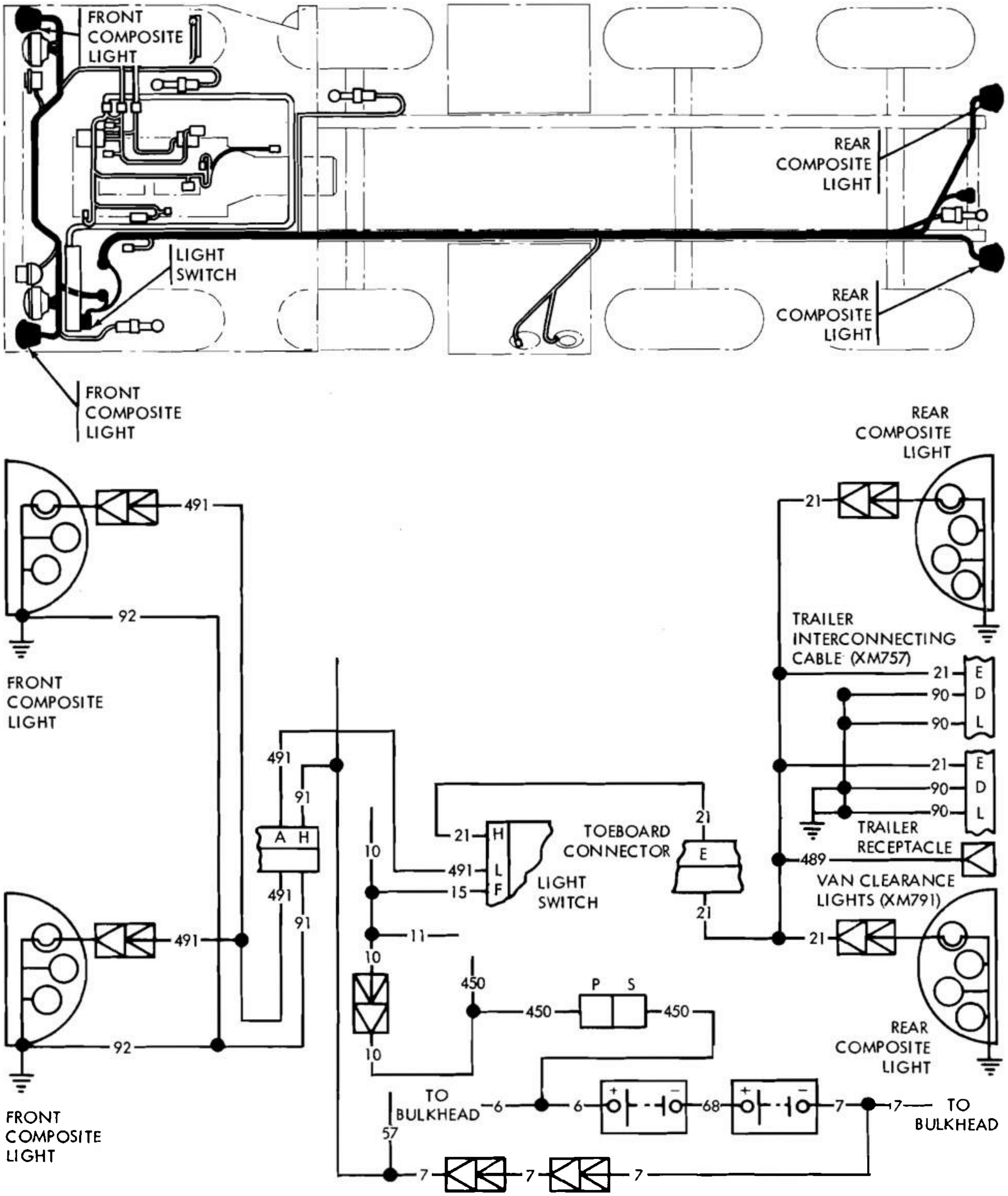


Figure 13-5. Service Parking Lamps Circuit, Wiring Diagram (M656 and XM757)

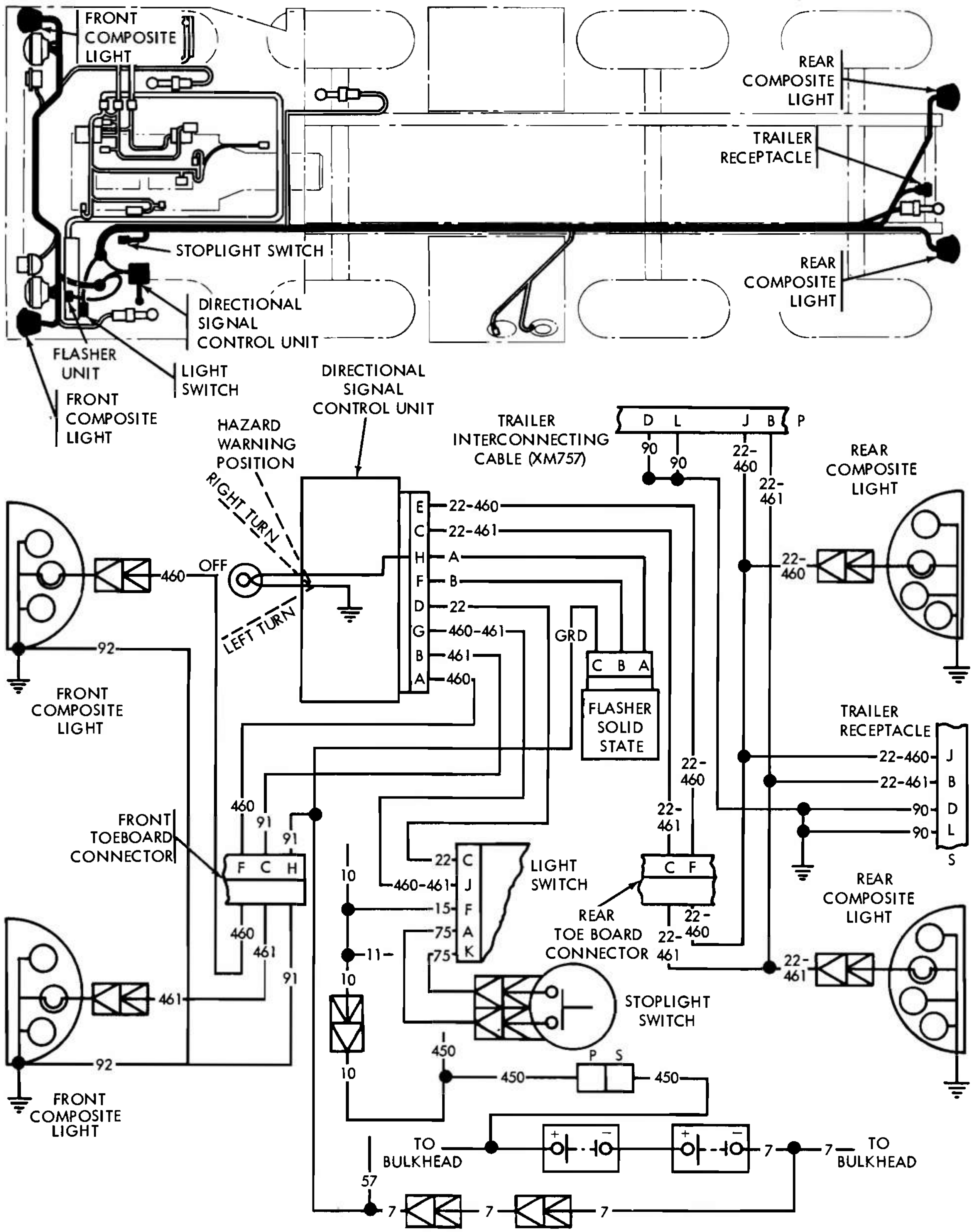


Figure 13-6. Directional Signal, Parking and Stoplight Circuit Wiring Diagram (M656 and XM757)

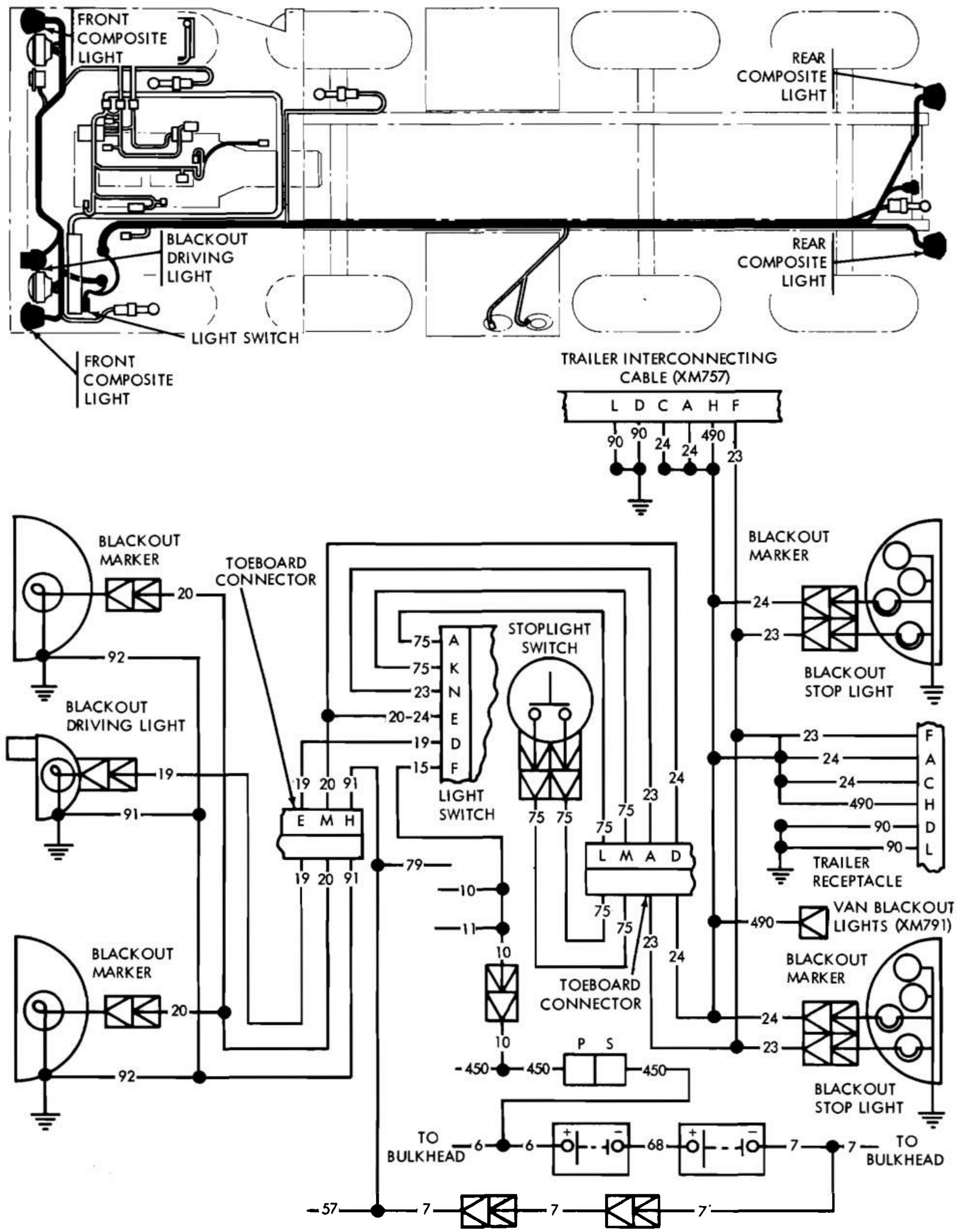


Figure 13-7. Blackout Drive and Marker Circuit, Wiring Diagram (M656 and XM757)

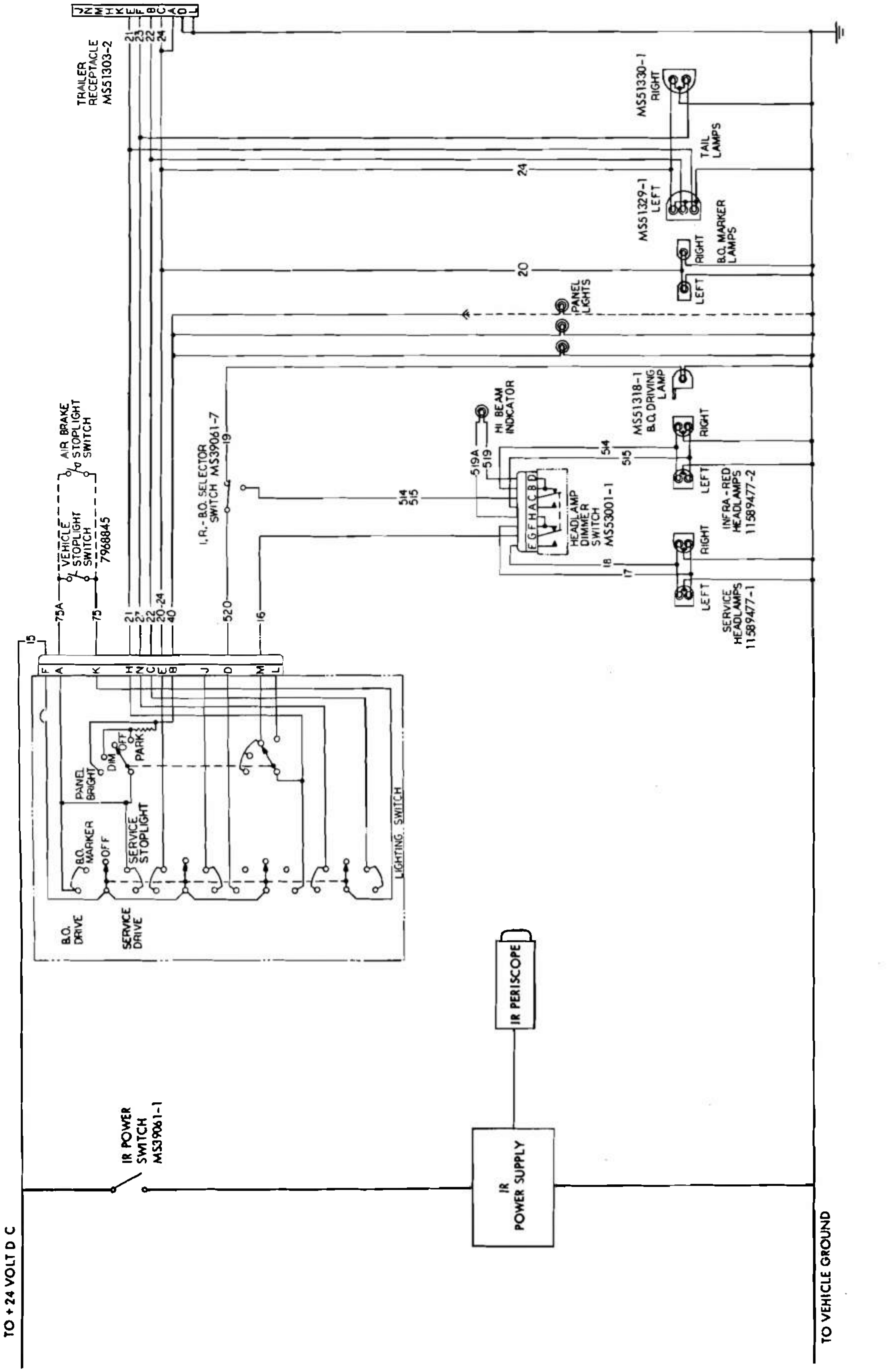


Figure 13-8. M113A1 Lighting Circuit

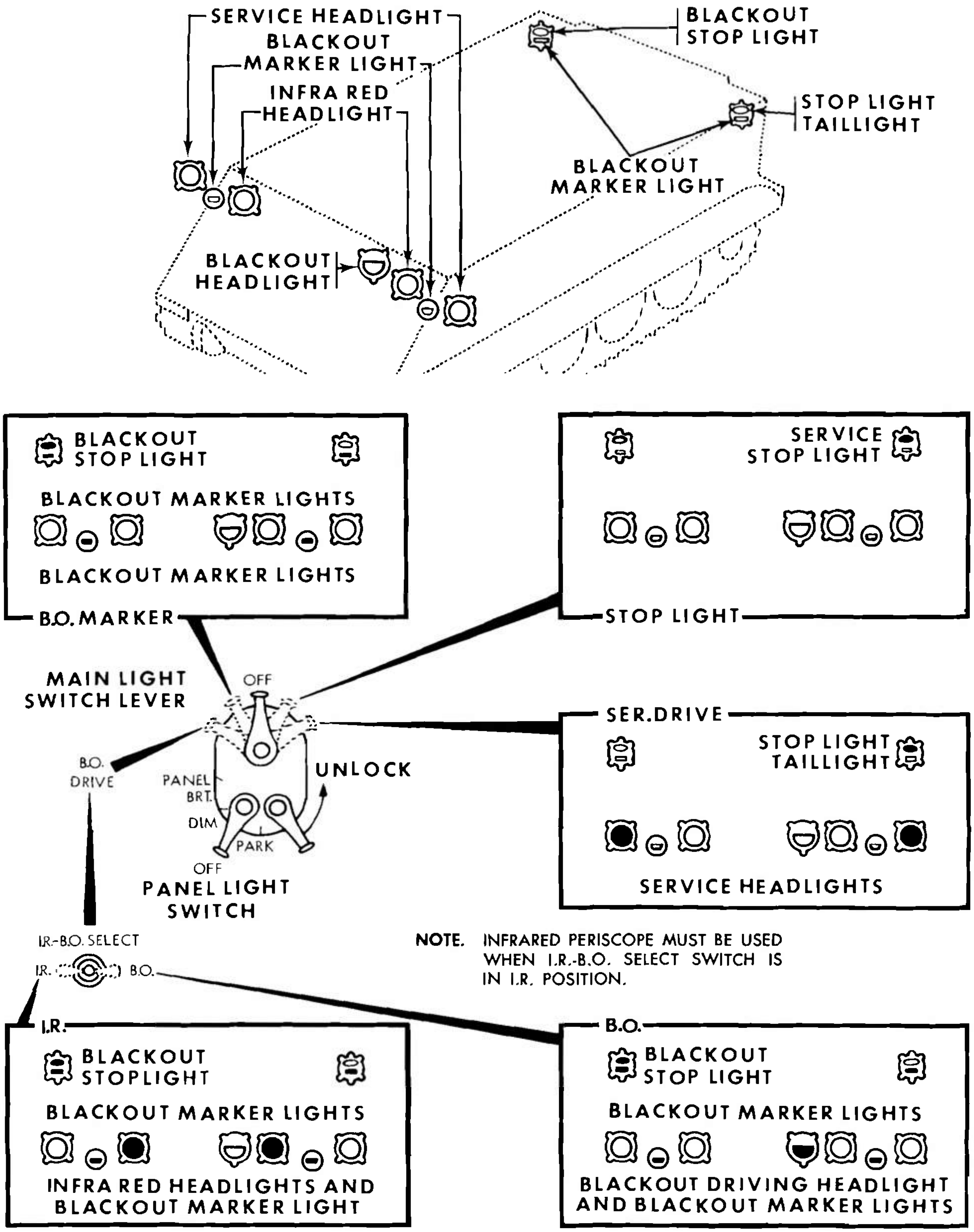
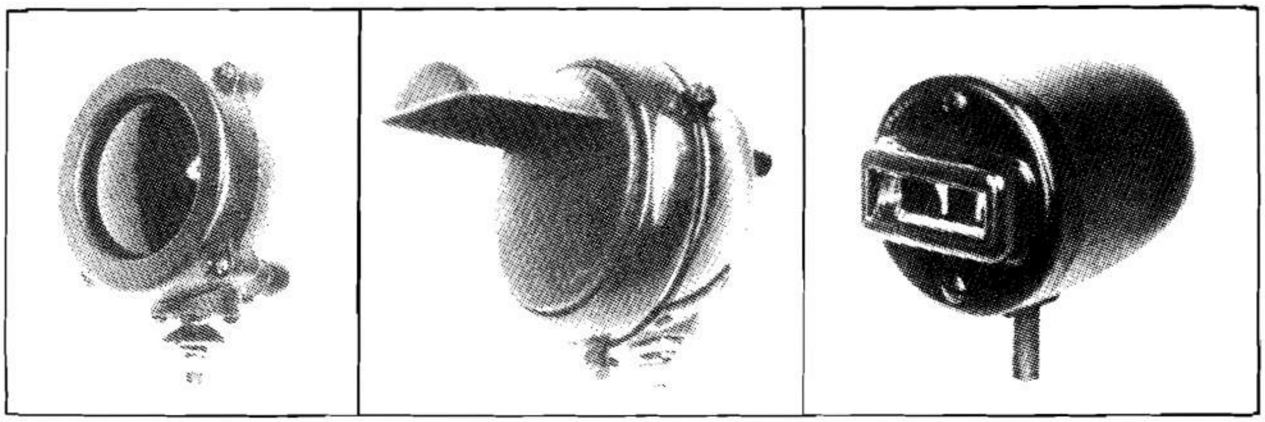
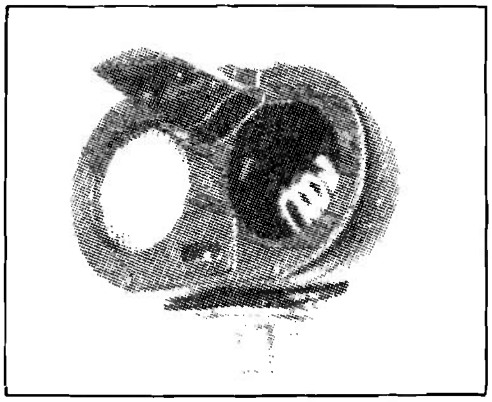


Figure 13-9. External Lighting, M113A1



HEADLIGHT BLACKOUT DRIVING LIGHT BLACKOUT MARKER LIGHT

(A) LIGHTING ASSEMBLIES FOR LIGHT ARMORED VEHICLES



(B) COMPOSITE HEADLIGHT ASSEMBLY

Figure 13-10. Combat Vehicle Lights

The circuit shown in Fig. 13-8 is one of several possible lighting circuits for combat-type vehicles using the MS51113-1 switch. As an alternative, the external switch connections can be wired so that the blackout marker lights are off rather than on when the infrared selector switch is in the IR position.

The trailer receptacle, MS75021-2, shown in Fig. 13-8 is the standard connection used to provide lighting to a trailed vehicle. Ordnance drawings 8347200, 8347201, and 8347202 show typical trailer wiring diagrams describing the requirements for trailed vehicles.

Although most vehicles have been designed with service headlamps, infrared headlamps, blackout driving lamp, and blackout marker lamps that are individual units (Fig. 13-10(A)), some vehicles, particularly tanks in the medium and heavy categories or heavy weapon carriers, are equipped with composite light assemblies that contain all of these components (Fig. 13-10(B)). These light assemblies have lamp bodies made of aluminum sand castings and primarily are designed for ballistic protection. Examples are the M60A1 Tank with assembly MS53022-1 (7972325), M551 with assembly 10947046, and the M108 and M109 with assembly 10922310.

13-6 BLACKOUT LIGHTING

Blackout lighting is a requirement for certain combat operations. One purpose of blackout lighting is to provide the vehicle operator with sufficient light to operate the vehicle in total darkness. Another is to provide minimum lighting to show vehicle position to leading or trailing vehicles when the illumination must be restricted to a level not visible to a distant enemy.

The blackout driving light (Fig. 13-10(A)) is designed to provide a white light of 25 to 50 cp at a distance of 10 ft directly in front of the lamp. The lamp is shielded so that the top of the light beam is directed not less than 2 deg below the horizontal. The beam distribution on a level road at 100 ft from the lamp is 30 ft wide on a properly designed light.

The blackout stop light, marker light (Fig. 13-10(A)), and tail light are designed to be visible at a horizontal distance of 800 ft and not visible beyond 1200 ft. The lights also must be invisible from the air above 400 ft with the vehicle on upgrades and downgrades of 20%. The horizontal beam cutoff for the lights is 60 deg right and left of the beam centerline at 100 ft.

The ability of a driver to operate under blackout driving conditions has been measured. One of these studies, summarized in Table 13-2, measured tank speeds under different lighting conditions, including blackout and active infrared, with the driver's hatch both open and closed. The results indicate that tank speeds near normal can be maintained with the lights in blackout, especially with the driver's hatch in the open position.

13-7 INFRARED LIGHTING[3]

The infrared region of the spectrum is located between the longest visible wavelengths and the shortest microwave wavelengths. The visible portion of the optical spectrum ranges from about 00.3 μ at the violet end to 0.72 μ at the red end. Wavelengths in this range are visible to the human eye. The infrared, or invisible, position of the optical spectrum is divided roughly into the following regions:

1. The near *IR* between 0.72-1.2 μ
2. The intermediate *IR* between 1.2-7.0 μ
3. The far *IR* between 7.0-1000 μ.

There are two basic systems used by the military to take advantage of the infrared portion of the spectrum: the active system and passive infrared system.

TABLE 13-2. RELATIONSHIP BETWEEN LIGHTING CONDITIONS AND ACCEPTABLE DRIVING SPEEDS[2]

	Driver's Hatch Open, mph	Driver's Hatch Closed, mph
Road		
Day	15	15
Night (headlights)	15	11
Night (blackout drive light or blackout marker lights)	13	7
Night (infrared headlights)		10
Cross-country		
Day	8	7
Night (headlights)	7	6
Night (blackout drive light or blackout marker lights)	7	3
Night (infrared headlights)		5

13-7.1 ACTIVE SYSTEM

The active system employs a light source combined with a red lens to emit light in the near IR range. The emitted light is reflected back from the illuminated object and focused in an image-converter tube. The tube converts an image formed in one wavelength of radiation into an image in a visible wavelength for viewing. The tube contains both the sensor and display in one unit. The infrared lighting system employed on present tank-automotive vehicles is of this type.

A typical tank-automotive active IR lighting system consists of an IR headlamp, serving as the IR light source, and an image-focusing periscope. The IR headlamp is identical to the service headlamp (Fig. 13-10(A)) except that the standard MS18003-4811 lamp bulb is fronted by a red lens to filter out all light not in the IR range. The reflected light is collected in the driver's IR periscope, serving as the image converter tube. The periscope is powered by a high voltage source (Fig. 13-8). The M19 Periscope is shown in Fig. 13-11.

The active IR system has the disadvantage of being detectable by an enemy equipped with IR detectors operating in the same range. For this reason, the active IR equipment is expected to be phased out completely and replaced by passive systems.

13-7.2 PASSIVE SYSTEM

A passive IR system is impervious to detection and countermeasures by methods that are effective against active systems. Furthermore, most natural objects radiate in the IR region, making a passive system very attractive.

There are basically two types of passive IR systems: light intensification, and far-infrared.

Light intensification systems are expected to eventually replace the present active IR systems for tank-automotive applications. In the light intensification system, images formed by the ambient light from starlight or moonlight are intensified by image converter-type tubes. The image converter tubes have a high detective photo-cathode sensitivity in the visible and in the near-infrared region. The light intensification system is characterized usually by its relatively small size and is less complex than active systems because of the elimination of transmitting hardware. The major disadvantage of this system is that, like normal viewing, range and performance depend on atmospheric conditions.

The far-infrared IR systems operate in the region of 8 to 14 μ. Wavelengths in this region are transmitted fairly well by the atmosphere except in extreme humidity or rain. These systems utilize the natural radiation from a given object to provide the power by which the object is detected. Systems of this type can be highly sensitive and have been designed to detect even the "shadow" left by an object removed from its surroundings. These are receiving much attention in target location systems. A disadvantage at the present time is the large size of the equipment compared to the light intensity systems.

13-8 SEARCHLIGHTS[4]

Searchlights are used in night combat operations to serve as battle field boundary markers or as a guideline for advancing troops or fire support. They provide screening for troop movements by creating an apparent "cloak of darkness" behind the light beams. They are used for counterillumination against light from opposing forces, and they also are used extensively to provide diffused visual or IR lighting for battlefields by direct illumination of targets or by reflecting light from the overhanging cloud cover.

The basic requirements for a military searchlight are ruggedness, transportability, and brilliance. The types of searchlights currently in use are incandescent, xenon, and carbon arc.

The incandescent light is a simple wire filament used generally in spotlights or small searchlights.

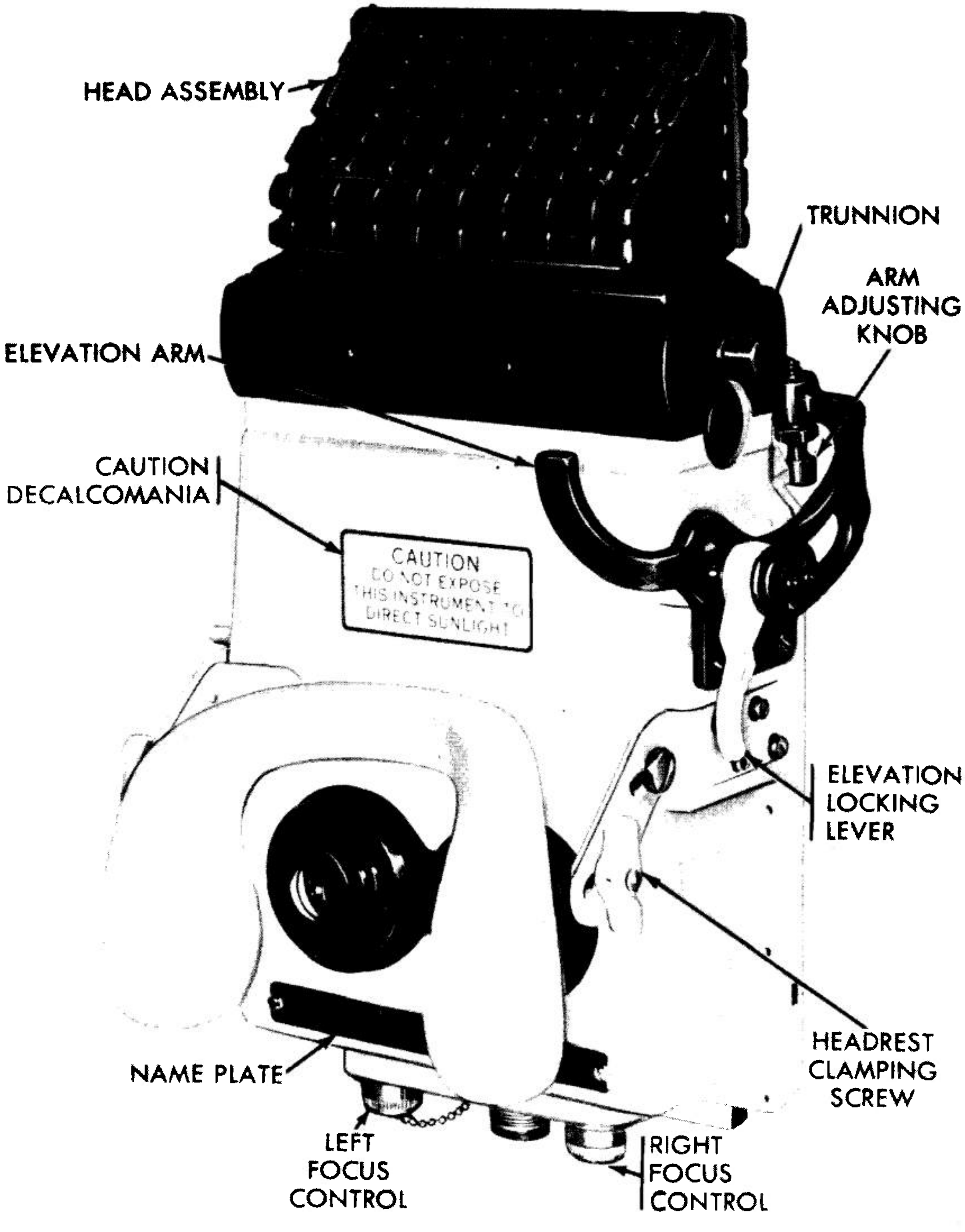


Figure 13-11. Infrared Periscope, M19

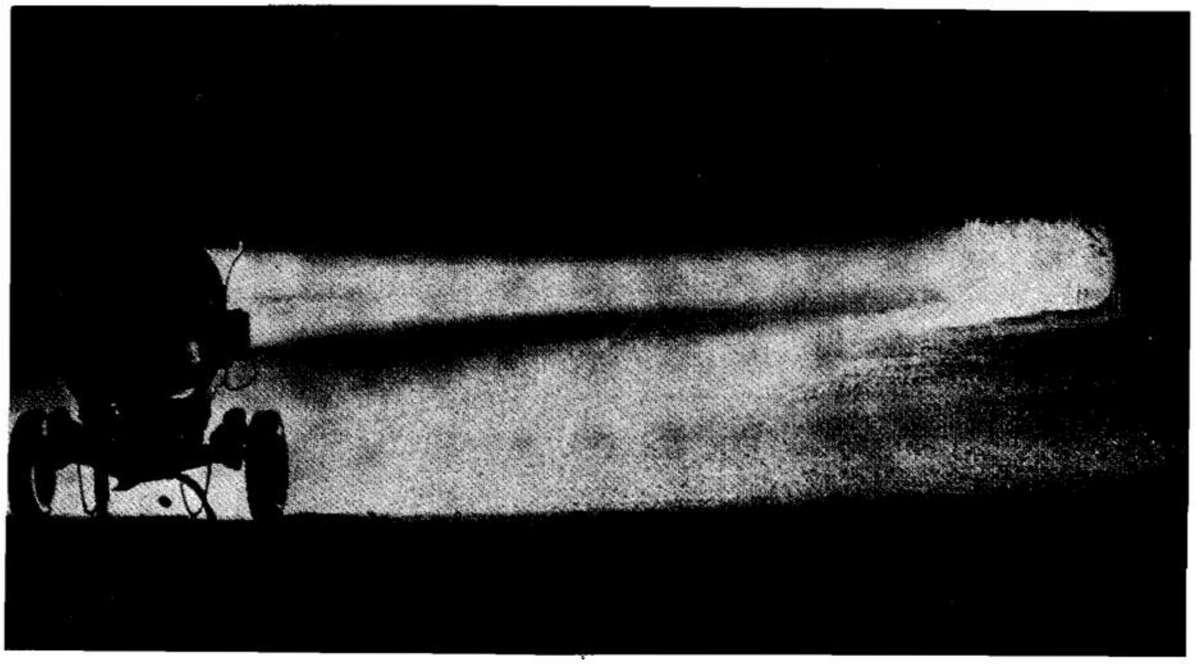


Figure 13-12. Searchlight, General Purpose, 30-in.

The xenon searchlight is an arc type light that uses a high potential (approximately 30 kV) to establish an arc through a xenon gas tube. Once the arc is established, it can be sustained by any 28 VDC power source.

The carbon-arc searchlight provides light from a high voltage arc which eventually consumes the negative carbon electrode. Both the carbon-arc and the xenon searchlights are capable of extreme brightness.

One of the searchlights included in the Army inventory is the 30-in. AN/TVS-3 (Fig. 13-12). This is a general-purpose, blown carbon-arc light most commonly used for diffused illumination by reflection from cloud cover. It also is used with appropriate filtering as an IR source for very long range IR viewing. The light consists of two major components: the light itself with its control mounted on one trailer, and a gasoline engine-driven 20-kW DC generator on a second trailer. The light will operate for 6 hr continuously before the negative carbon disc is replaced. Some of the operating characteristics are:

1. Viewing range: 10,000 m (indirect employment)

2. Beam spread: 3.25 to 10 deg

3. Peak beam: 400 million cp

4. Weight: 1200 lb, searchlight and trailer

5. Operating time: 6 hr per disc

Two tank-mounted xenon searchlights are described in Chapter 17 of this handbook. The lights are used to provide both visual and IR lighting. One light is the AN/VSS-2 (2.2 kW) which provides 75 million peak cp and requires 50 A at 28 VDC. The other is a smaller 15-in. 1.0-kW, AN/VSS-3 searchlight that provides 50 million cp and also requires 50 A at 28 VDC. Chapter 17 shows an illustration of the longer AN/VSS-2 and describes the principle of operation.

Incandescent lights are mounted on vehicles to serve as spot or floodlights. These generally are sealed beam lamps and are available as standard military parts. MS51320 is an example of the type mounted on tank-automotive vehicles.

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2. AD-156 766, *Illumination and Terrain as Factors Affecting the Speed of Tank Travel,* U.S. Army Armor Human Research Unit, Fort Knox, Kentucky, March 1968.

3. AMCP 706-127, Engineering Design Handbook, *Infrared Military Systems, Part One.*

4. FM 31-36 (Test), *Night Operations,* Dept. of Army, April 1968.

5. MIL-STD-1179, *Lamps, Reflectors, and Associated Signalling Equipment for Military Vehicles.*

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CHAPTER 14

ENVIRONMENTAL CONTROL SYSTEMS

SECTION I

ENVIRONMENTAL CONTROL

14-1 INTRODUCTION

Responsibility for control of the environment to which crew members and equipment are subjected is shared by many vehicle subsystem designers. However, the electrical designer is almost always involved in environmental control problems because of the requirement for connection of such equipment to a source of electrical power.

Environmental control, for the purposes of this chapter, will be limited to control over temperature, humidity, ventilation, and movement of air inside a military vehicle. Associated with equipment for these functions are special devices for preventing contamination of the vehicle interior atmosphere from chemical, biological, and radiological (CBR) warfare.

In addition to specifying power connections to environmental control equipment, the electrical designer should be prepared to make value judgments on trade-offs among electrical power demand and other factors such as efficiency, performance, reliability, noise levels, safety, and external detection. Furthermore, the design interface with vehicle environmental control systems is the specific responsibility of the electrical designer where electromagnetic interference (EMI) suppression requirements exist.

14-2 TANK-AUTOMOTIVE APPLICATIONS

Most tank-automotive vehicles employ ventilation fans and heating systems to provide the crew compartment with a supply of fresh air and a degree of comfort for the personnel on board.

Ventilation fans supply fresh air for the crew, maintain the crew areas at a positive pressure relative to the engine compartment to prevent contamination by combustion products, and provide some crew comfort in warmer climates.

Heating systems are employed on most vehicles to provide personnel comfort in colder climates. For operation between $-25°$ and $-65°F$, heaters are required for both personnel and equipment; i.e., to maintain the engine in a state of readiness, engine coolant is heated and circulated through the engine. The heated coolant also is circulated through the battery box to enable the batteries to start the engine even though ambient temperatures may be as low as $-65°F$.

Mechanical cooling and humidity control have not been used widely in tank-automotive vehicles because of use effectiveness, weight, space, and durability considerations. However, cooling and humidity control often are required when sophisticated electronic gear is installed in trailer vans. Only the increased sophistication of on board equipment in tank-automotive vehicles is likely to change this status.

Personal gas masks are required for chemical, biological, and radiological protection in tank-automotive vehicles because mission requirements frequently involve operation in areas where exposure to one or more of these hazards is probable. Where better CBR protection is required, additional blower-aided filters are installed ahead of the crew members' gas mask canisters. These devices operate from the vehicle power supply and are equipped with hoses that connect directly to each crew member's gas mask canister.

SECTION II VENTILATION AND HUMIDITY CONTROL

14-3 INTRODUCTION

Proper ventilation is a critical part of environmental control in a military vehicle. Electrical power requirements have been established reliably by fan manufacturers. However, fan selection from the large number of individual designs requires some knowledge of the aerodynamic properties of the various types.

14-4 VENTILATION

The ventilation system is the most important environmental control in a tank-automotive vehicle for the following reasons:

1. Natural convection is lacking.

2. Air conditioning is generally not employed.

3. High solar heat loads are present as a result of dark exterior colors.

4. Personnel crowding is a constant problem as a result of space limitations.

5. Electronic gear may be damaged if heat is not removed.

6. Positive crew area pressure is necessary to prevent entry of toxic fumes from the engine compartment.

A minimum air flow of 15 ft^3/min-man is required; however up to 30 ft^3/min is recommended for personnel to assure adequate dilution of pollutants.

For a properly designed ventilator fan installation, electrical power requirements are directly proportional to mass flow rate and pressure differential between fan inlet and outlet. Power requirements and noise level increase with increased turbulence resulting from abrupt changes in airflow direction, improper ducting transitions, and high fan blade tip velocities [1,2]. Turbulence is proportional to the fourth power of air velocity in many installations. Therefore, to minimize noise and electrical power requirements, preference should be given to low velocity systems. Unfortunately, volume and weight restrictions in military vehicles usually require relatively small ventilating systems which operate at high air velocities in order to deliver sufficient air volume.

Improper outlet and inlet ducting can degrade efficiency to the point where a more powerful fan than necessary may be specified. Therefore, it is important that the electrical design engineer guard against the inadvertent substitution of increased electrical power in lieu of proper aerodynamic design.

Axial flow (propeller) fans and centrifugal flow (blower) fans are similar in their efficiency, but serve different purposes. Axial flow fans are used when high discharge pressures are not required. Centrifugal flow fans are used when pressure differentials representing up to a 7% density increase are desired [2].

Axial flow fans have a weight and space advantage because of their lower enclosure requirements. Centrifugal fans must be mounted in an enclosed casing. Large pitch-angle axial fans may generate unstable air flows resulting in periodic power surges that will increase the uncertainty of specifying electrical power requirements. Small pitch-angle (below 17 deg) axial fans are generally efficient and stable, but their low capacity generally requires high propeller speeds and increased air velocity. Axial fans are therefore noisier for a given application and, owing to the higher air velocities and lower discharge pressure capability, will be more demanding on duct-work efficiency.

Table 14-1 lists some of the fan assemblies in the present inventory. Generally these units originally were qualified to meet the electromagnetic interference suppression require-

TABLE 14-1. VENTILATOR FANS

Ord Part No.	Description	Application
7404400	Ventilating, turret, w/motor, 1 hp, 24 V, DC, 5000 rpm, 35 A	Light tank
7536738	Ventilating, turret, w/motor, 1 hp, 24 V, DC, 5000 rpm, 35 A	Medium tank
7770609	Ventilating, turret, w/motor, 1.5 hp, 24 V, DC, 5800 rpm, 55 A	Medium tank
7954925	Ventilating, turret, w/motor, 1.5 hp, 24 V, DC, 5800 rpm, 55 A, 1500 cfm at 2 in. H_2O	Heavy tank
7954990	Ventilating, turret, w/motor, 1.3 hp, 27.5 V, DC, 5400 rpm, 50 A, 1000 cfm at 4 in. H_2O	Medium and heavy tank
7985883	Ventilating, turret, w/motor, 1.5 hp, 24 V, DC, 5800 rpm, 55 A	Medium and heavy tank
10898759	Fan, electrical equipment 150 cfm at 6 in. H_2O 27 V, DC, 12 A Specification MIL-B-62062	Generator cooling

ments of MIL-S-10379, which has been superseded by MIL-STD-461.

14-5 HUMIDITY CONTROL

Humdity control in the military vehicle generally is limited to dehumidification. Of the three popular methods used to dehumidify, the absorption method is most widely used. With this method, the moisture in the air enters into chemical combination with a drying agent and the water-vapor content of the air is thus decreased. In the very similar absorption method, water-vapor is collected on the surface of a drying agent but does not enter into a chemical combination. The third method accomplishes dehumidification by lowering inlet air temperature to a value below the dew point temperature so that moisture is condensed out of the air. Systems employing the third principle are most likely to interface with the electrical system since they may require fan or compressor drive power. Dehumidification is inherent whenever air conditioning is applied. No standard units or applicable specifications are currently available because of the limited military application for dehumidifying equipment that is not an integral part of an air conditioning system.

SECTION III HEATERS, AIR CONDITIONERS, AND CBR UNITS

14-6 PERSONNEL HEATERS

Electrical heaters are rarely employed in vehicles because of the high currents required when operating from a 28-V system. Hot water heaters are sometimes employed, but fuel-burning heaters are the most popular because they are independent of engine operation, and have very little warmup time. Heaters generally are supplied as part of a winterization kit where operation in temperatures below +40°F average temperature for the coldest month of the year is predicted. Most tank-automotive vehicles do not include heaters as standard equipment.

14-6.1 FUEL-BURNING HEATERS

Operation of a typical fuel-burning personnel heater is outlined in Fig. 14-1. Electrical power and control circuitry is shown in Fig. 3-16.

Fuel is delivered to the heater from the vehicle fuel supply by a separate electrically operated fuel pump. Positive pressures of between 3 and 15 psig are required for heater operation. Electrical power to the fuel pump is controlled by the heater ON-OFF switch. Multifuel heaters are designed to burn any fuel used by the vehicle engine, providing fuel temperatures are maintained above the cloud point of the fuel. The fuel control valve contains solenoid valves to restrict fuel flow (for low-range operation) or to interrupt fuel flow when the heater is shut down. A thermostat and electrical heater element keep the control valve assembly at temperatures between 40° and 75°F for proper metering of the fuel in −60°F ambient air temperatures. Fuel temperature varies depending on system

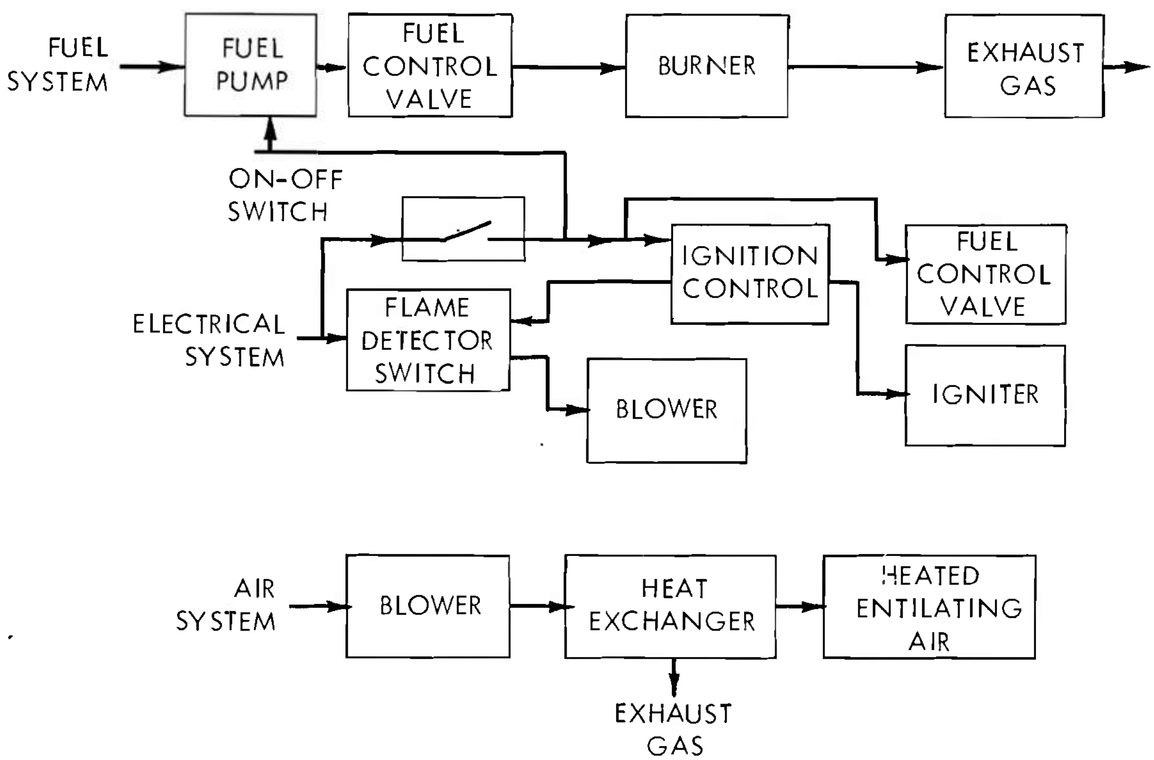


Figure 14-1. Fuel Burning Heater Block Diagram[3]

voltage, heater Hi-Low switch setting and heater capacity.

In normal operation, electrical power is supplied continuously to the fuel shut-off solenoid to keep the valve open. Power is routed to the blower through a flame detector switch which prevents blower shut-down while flame is still present in the burner. Further protection is provided by an overheat switch that closes the fuel solenoid in the event of higher than normal air temperatures.

During heater startup, the flame detector switch inserts voltage-dropping resistors into the blower motor circuit to provide low-speed blower operation. An electrically-heated igniter starts the combustion process. When the flame detector switch senses steady combustion, the igniter is removed from the circuit and full vehicle voltage is applied to the blower.

Part of the inlet air flow is used for combustion inside the burner canister. The combustion products are vented to the outside of the vehicle. The remainder of the air is directed around the outside of the hot canister and becomes heated ventilation air.

Air temperature rise in most of the multifuel personnel heaters used in tank-automotive applications is about 200°F. To provide adequate heated air distribution and minimal hazard to personnel, location and direction of the heater discharge must be carefully considered. Also, the heater should be accessible for maintenance.

All personnel heaters should be mechanically isolated from shock and vibration, especially in tracked vehicles. Early failure may be expected if this is not done.

Vehicular fuel burning personnel heaters suitable for new designs are described in MIL-STD-1407[4] and Table 14-2. Applicable Specifications for these heaters define the

TABLE 14-2. RECOMMENDED* FUEL-BURNING PERSONNEL HEATERS

Identification	Nominal Capacity, Btu/hr	Operating Current, A	Features
MIL-H-46792[5] Capacity A	20,000 (high)	20 (start)	Multifuel
	10,000 (low)	8 (run)	
Capacity B	30,000 (high)	20 (start)	
	15,000 (low)	11 (run)	
Capacity C	60,000 (high)	23 (start)	
	30,000 (low)	16 (run)	
MIL-H-3199[6]			Use only automotive combat Gasoline Per MIL-G-3056
Type I, Capacity A	20,000 (high)	12 (start)	
	8,000 (low)	4 (run)	
Type I, Capacity B	30,000 (high)	18 (start)	
	18,000 (low)	7 (run)	
Type I, Capacity C	60,000 (high)	21 (start)	
	30,000 (low)	11 (run)	

*MIL-STD-1407[4]

fuel-per-hr requirements and information in Ref. 8 will prove useful in the determination of heat load requirements.

14.6-2 HOT WATER HEATERS

Hot water heaters utilize the engine coolant for heating by circulating coolant through a radiating core. Ventilating air is warmed as it is forced through a water-to-air heat exchanger. This type of heater, dependent on engine operation, generally is not employed below −20°F as the only source of personnel heating.

The capacity of a hot water heater is limited by engine coolant temperature. In very cold weather coolant temperature is not adequate to provide much heating capacity because the engine is adequately cooled by mechanisms other than the coolant. Electric power is required for a blower which circulates air through the heat exchanger core.

Table 14-3 lists hot water personnel heaters suitable for new-design applications.

14-6.3 ELECTRICAL HEATERS

Military vehicles do not employ electrical personnel heaters for environmental control because of the high current requirements in a 28-V electrical system. At 28 V, 100 A is equivalent to only 10,000 Btu hr. Electrofilm

TABLE 14-3. HOT WATER HEATERS

Identification	Capacity, Btu/hr	Blower Motor Current, A Start	Blower Motor Current, A Run
MIL-H-3199[6]			
Type II, Capacity A	12,000 to 20,000	12	4
Type II, Capacity B	15,000 to 28,000	18	7

oil pan and fuel line heaters have been used in some installations.

14-7 ENGINE HEATERS

Diesel engines are equipped with air box heaters for cold start assistance. A fuel pump, solenoid valve, switch, and igniter comprise the system that provides flame heating of the induction air. However, when engines must be started in temperatures between −25° and −65°F, preheating of the engine lubricant, engine coolant, and battery electrolyte is required. Separate multifuel liquid coolant heaters are employed with water-cooled engines for this purpose. These heaters function in the same manner as the fuel-burning personnel heaters except that heat from the burning fuel is transferred to the engine coolant rather than to ventilation air. Coolant is circulated through the heater to a warming plate under the batteries and then through the engine (Fig. 14-2). Centrifugal pumps commonly are used to circulate the warm engine coolant. The thermal siphon principle is not applied when fast response is required and therefore has limited application. To assure pump priming, a centrifugal pump should be located at the lowest elevation in the circulatory system. Provision for removal of entrapped air is necessary if the engine cooling system does not provide this feature. The effectiveness of such a coolant heater system is clearly shown by data presented in Fig. 14-3 and Table 14-4.

Fig. 14-3 shows that a coolant heater can raise the temperature of battery electrolyte and oil in the engine gallery over a 12-hr period with a vehicle soaking in −65°F ambient temperature. Normally, coolant heaters are turned on immediately after a vehicle engine is shut down to maintain the vehicle in a standby or "ready-to-start" condition so under actual conditions electrolyte and oil temperatures are higher at the start of coolant heater standby periods than those shown in Fig. 14-3. The figure illustrates warmup from a "cold-soaked" condition. Table 14-4 shows the increase in average engine starting time

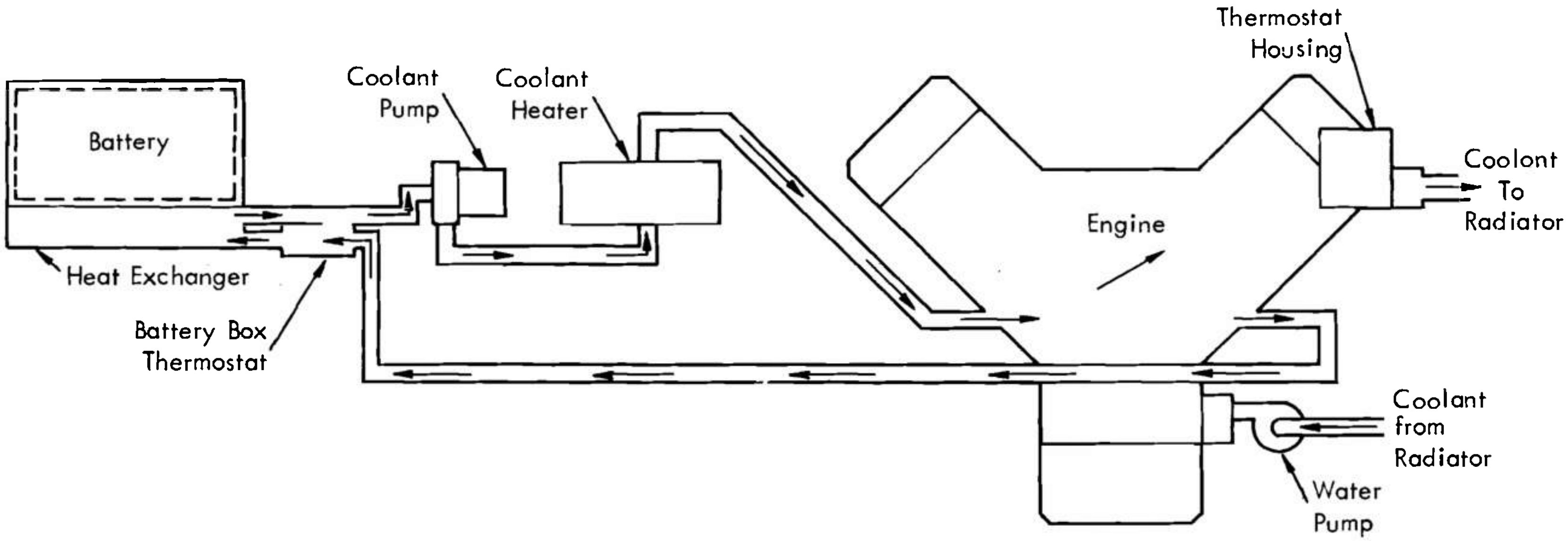


Figure 14-2. Coolant Heater System, M113A1[7]

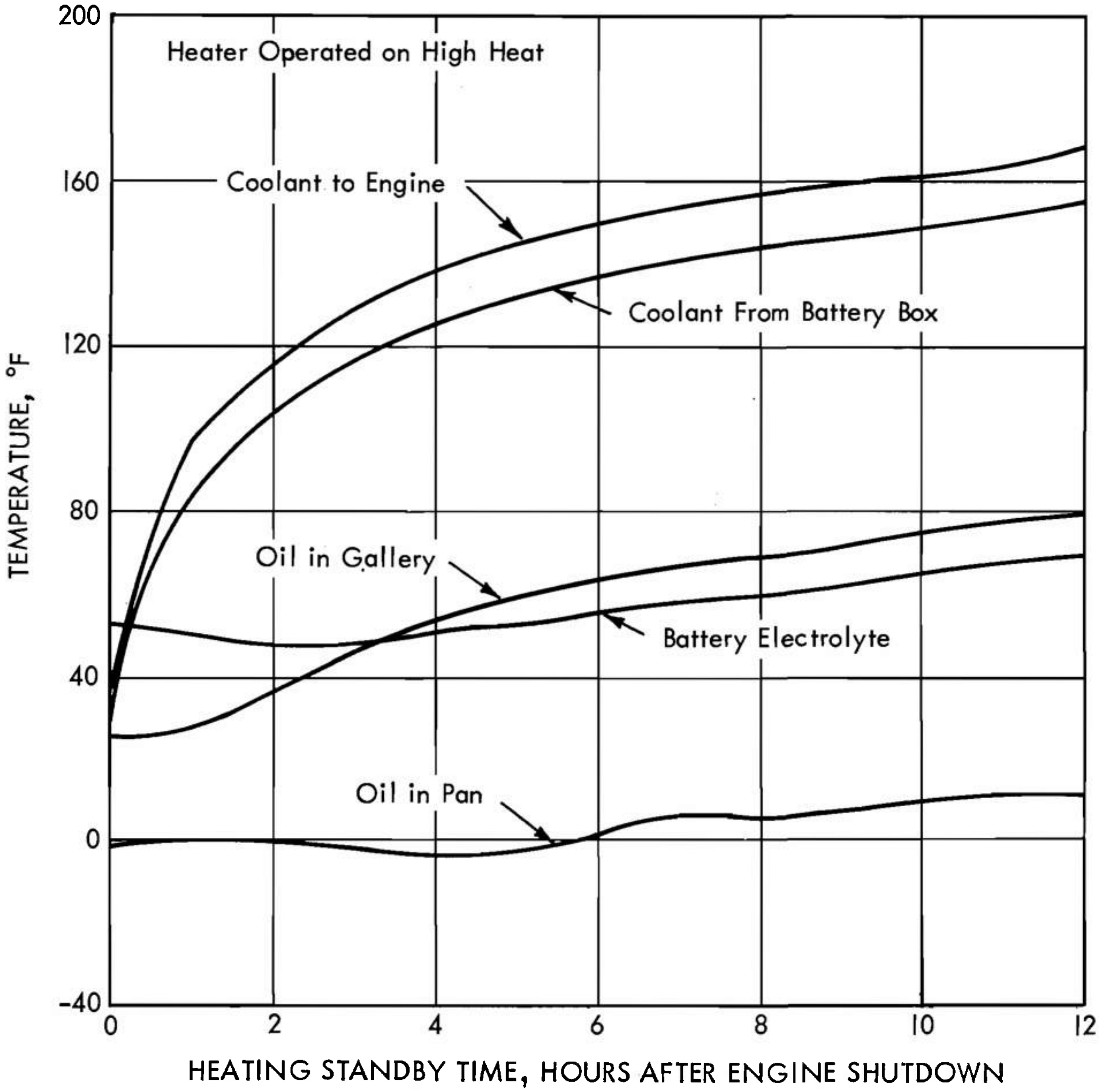


Figure 14-3. Engine Temperature During Coolant Heater Operation at −65°F, M113A1[7]

that occurs with the decreasing ambient temperatures and also illustrates that use of a coolant heater will reduce significantly engine starting time under −65°F ambient temperature conditions.

Electrical engine coolant heaters frequently are specified as part of a winterization kit which can be attached to a vehicle without major mechanical modifications. Electrical heaters are restricted to power sources other than the vehicle electrical system by MIL-STD-1407[4] because extended engine heating requirements between missions can drain the vehicle batteries below the point that engine cranking is possible. Electrical heaters usually are not carried on vehicles.

Where external power sources are not available readily, preference should be given to a multifuel type coolant heater with electric coolant and fuel pumps. Care must be taken that battery capacity is adequate to assure engine cranking after extended opera-

TABLE 14-4. LOW TEMPERATURE ENGINE STARTS, M113A1[7]

Temp, °F	Fuel	Oil	Avg Starting Time, sec
40	DF-2	OE-10	1
15	DF-2	OE-10	9
0	DF-2	OE-10	14
−10	DF-A	OE-10	37
−10	DF-A	OE-S	32
−25	DF-A	OE-S	49
−65*	DF-A	OE-S	1

*After 12 hr stand-by operation of coolant heater.

tion of the coolant and fuel pumps according to vehicle mission requirements. M113 vehicles with two 6TN batteries will start successfully after 12 hr of standby coolant heater operation in ambient temperatures of −65°F. Battery electrolyte and engine oil gallery temperatures are maintained at +40°F by the heater during the standby period[7]. Current required during operation of this heater system is 3.5 A.

All types of engine coolant heaters suitable for new design applications are specified in MIL-STD-1407[4] and tabulated in Table 14-5. Hot air systems are required to preheat air-cooled engines. Standby systems for heating air-cooled engines do not exist.

14-8 AIR CONDITIONING

Air conditioning, when required in military vehicles, is confined almost always to van-type vehicles containing sophisticated electronic equipment operated by skilled personnel. Limited space and limited power virtually prohibit the application of air conditioners to tank-automotive vehicle applications.

Application of air conditioners to military vehicles in general is described in AMCP 706-120, Engineering Design Handbook, *Criteria for Environmental Control of Mobile Systems*[8].

Potential application of air conditioners to military vehicles should be discussed with the U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, before firm decisions are made.

TABLE 14-5. ENGINE COOLANT HEATERS

Identification	Capacity, Btu/hr	Power Requirements	Features
MIL-H-62078 Type II class I	15,000 min (coolant) 8,000 max (exhaust)	15 A (start) 28 VDC 4 A (run)	Multifuel External coolant and fuel pumps required
MIL-H-3177 Type II class II (A)	13,500 min	150 W (19 VDC)	Electric Integral coolant and fuel pumps
(B)	27,000	250 W (19 VDC)	
(C)	54,000	400 W (19 VDC)	
W-H-150 Type I class B size 300	2,560	0.75 kW (115 V, 60 Hz)	Electrical
600	3,415	1.00 kW	
800	5,120	1.50 kW	
1200	7,700	2.25 kW (230 V, 62 Hz)	
2000	13,660	4.00 kW	

14-9 CHEMICAL, BIOLOGICAL, AND RADIOLOGICAL PROTECTION

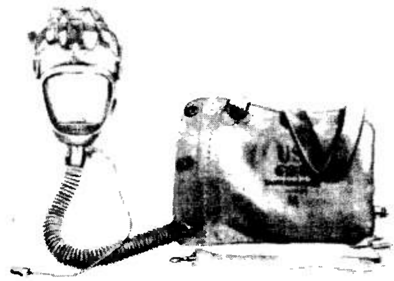
CBR units are employed to protect military personnel from the hazards of breathing air containing chemical, biological, or radiological warfare agents.

In tank-automotive vehicles, protection against CBR agents usually is restricted to personnel gas masks. Additional protection is gained by adding a blower-aided CBR filter ahead of the gas mask canister. Fig. 14-4 illustrates the M8A3 system used in the M113 Armored Personnel Carrier. The blower motor is this unit demands 5 A during normal operation, and it is powered from the vehicle electrical system.

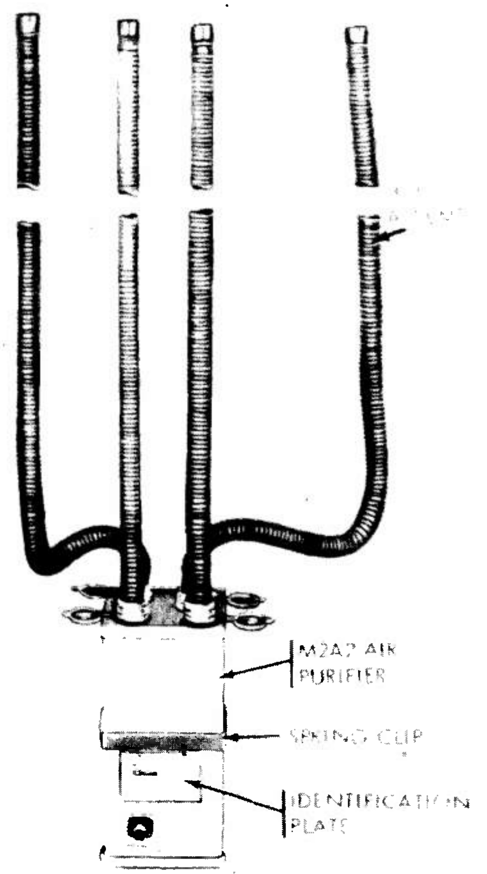
The M8A3, 12 ft^3/min, Gas-particulate Filter Unit consists of an M2A2 Air Purifier, hose assemblies, a circuit breaker and switch assembly, and electrical cable assemblies. An M14A1-type Tank Gas Mask is used with the M8A3 Filter Unit. One or two filter units are installed in the carrier, depending on the type of carrier. The M2A2 Air Purifier is held in a frame assembly mounted on resilient mount supports.

The hose assemblies carry purified air from the air purifier to the masks when worn by crew members inside the carrier. Each hose is equipped with two coupling halves and hose clamps. The coupling half on one end of the hose fits into an outlet socket on the manifold of the air purifier. The other coupling half on the hose receives the plug from the tank protective mask canister coupling assembly.

A circuit breaker and switch assembly is connected between the electrical power source and the motor on the air purifier. This assembly provides the controls for the M8A3 Filter Unit and protection against an electrical overload.



(A)
MI4AI Tank gas mask



(B)
M2A2 AIR PURIFIER
AND HOSE ASSEMBLIES

Figure 14-4. M8A3 Gas Particulate System[9]

Collective CBR protection for a crew not wearing individual protection devices requires that purified air at a positive pressure be supplied to the protected area. These systems usually include an air-lock to prevent contamination by personnel entering or leaving. Air conditioning is usually required in applications where extensive collective CBR protection is required. Collective CBR protection methods are described in AMCP 706-120[8].

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3. Service Manual, *SouthWind Model 10530-A24 Heater*, Form No. 09-1012, Stewart Warner Corporation, Indianapolis, Ind.

4. MIL-STD-1407 *Heaters, Vehicular Compartment; Heaters, Coolant, Engine; Heaters, Space.*

5. MIL-H-46792, *Heater, Vehicular Compartment; Multifuel Burning, 24 Volt, D.C.*

6. MIL-H-3199, *Heaters, Vehicular Compartment, 28 Volt D.C.*

7. *Winterization Kit Test of Carrier, Personnel, Armored, M113A1,* Report DPS-1475, USATECOM, October, 1964.

8. AMCP 706-120, Engineering Design Handbook *Criteria for Environmental Control of Mobile Systems.*

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CHAPTER 15

COMMUNICATION AND ELECTRONIC EQUIPMENT

SECTION I

COMMUNICATION EQUIPMENT

15-1 INTRODUCTION

Most combat and troop support vehicles are equipped with VHF-FM radio transceivers to enable the crew to communicate with battalion radio nets and other vehicles crews. Fig. 15-1 depicts the types of communication generally employed in such operations. The battalion establishes a command net (FM-voice) to link the commander, principal staff members, and subordinate elements. Other nets that a battalion may establish or maintain stations in are the battalion surveillance net (FM), the battalion administrative/logistics net (FM), the brigade command net (FM), the brigade radio teletypewriter net (RATT), the brigade administrative/logistics net (FM), the division air request net (SSB-voice), the division warning broadcast net (AM), and the spot report receiver system (UHF). As a rule, vehicles carrying more than one person as crew members are also equipped with intercom systems to provide vehicle commander-to-crew communication[1].

Only special-purpose vehicles, such as command posts, are equipped with telephone switchboards, teletype equipment, UHF radio for ground-to-air use, and high-frequency radio sets for long-range communication.

Reference to Table 15-1 listing radio frequency spectrum designations and Table 15-2 listing frequency transmission characteristics will clarify the terminology and limitations associated with radio communications.

As a rule, military communication equipment is specified, furnished, and installed by the Government, whereas unique mounting features for installing the equipment and any necessary noise suppression devices are developed by the vehicle electrical system designer. It follows that close coordination among the designer, the design agency, and the Vehicle-Application Group at the U.S. Army Electronics Command (ECOM) is necessary to successfully complete any communication installation design.

Therefore, prior to contacting the Vehicle Application Group at ECOM or the project manager, the designer should prepare a list of questions pertaining to any new communication equipment installation. The following questions are typical unknowns that must be resolved:

1. What is the insert arrangement and the size of connector required to supply power to the communication equipment?

2. What are the current requirements in the various modes of operation of the communication equipment?

3. What are the dimensions and weights of the various components?

4. How many control boxes will be required on the vehicle?

5. What are the interface dimensions for mounting all the various pieces of equipment?

6. Who supplies the special-length cables required for interconnecting the equipment in the vehicle?

7. When installed, should the transmitting equipment be used by more than one occupant of the vehicle?

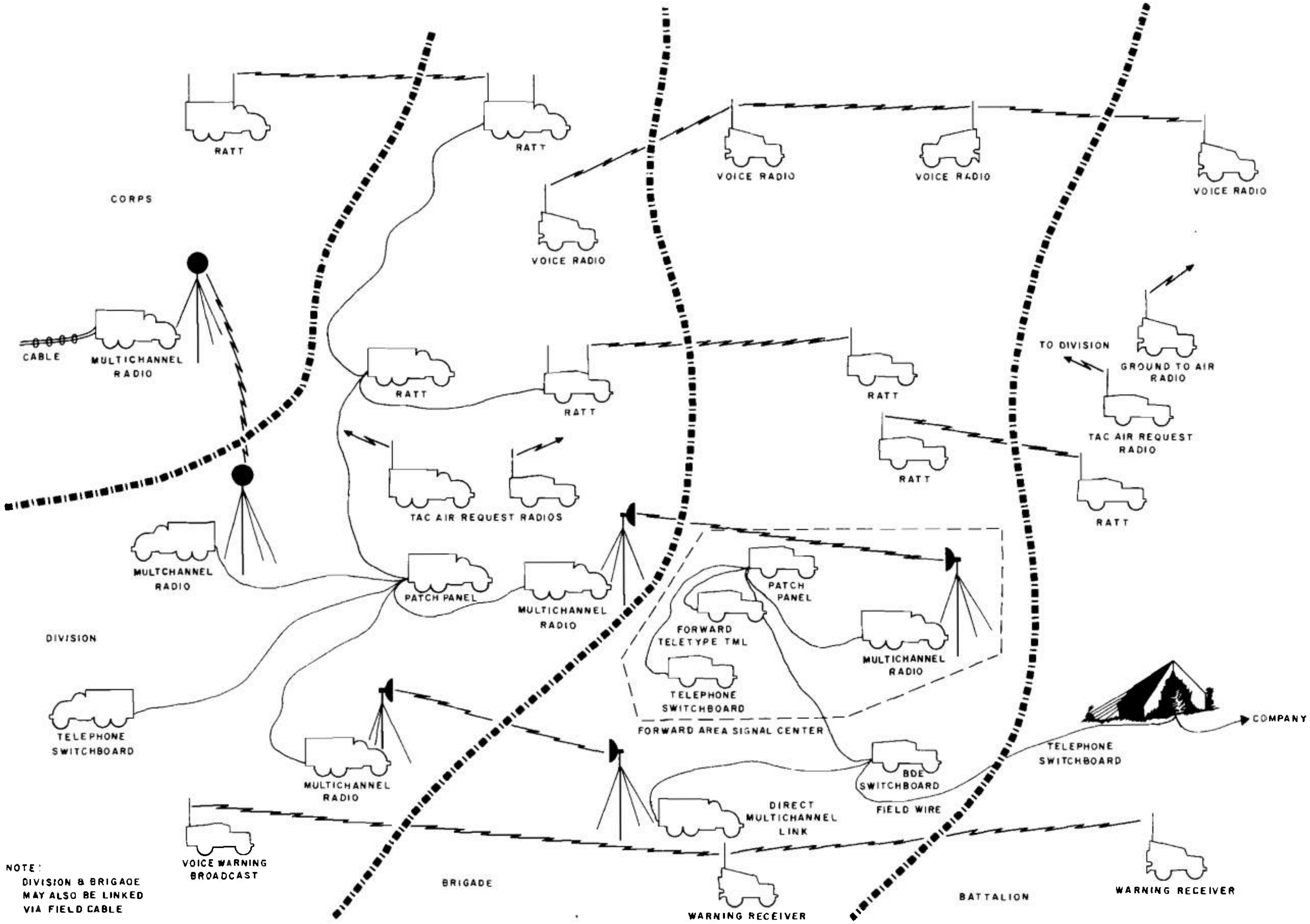


Figure 15-1. Typical Means of Communication Employed Within a Division, Brigade, and Battalion[1]

TABLE 15-1. FREQUENCY SPECTRUM DESIGNATIONS[2]

Frequency	3 kHz*	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz
Wave Length		10 km	1 km	100 m	10 m	1 m	10 cm	1 cm	0.1 cm
Band Designation	VLF	LF	MF	HF	VHF	UHF	SHF	EHF	
Band Number	4	5	6	7	8	9	10	11	12
Corresponding Metric Subdivision	Myriametric Waves	Kilometric Waves	Hectometric Waves	Decametric Waves	Metric Waves	Decimetric Waves	Centimetric Waves	Millimetric Waves	Decimillimetric Waves

LEGEND

VLF — Very Low Frequency
LF — Low Frequency
MF — Medium Frequency
HF — High Frequency
VHF — Very High Frequency
UHF — Ultra High Frequency
SHF — Super High Frequency
EHF — Extremely High Frequency

ABBREVIATIONS

Hz — Hertz (internationally accepted for cycles per second)
k — Kilo (10^3)
M — Mega (10^6)
G — Giga (10^9)
T — Tera (10^{12})

* Frequencies below 3 kHz have been referred to as ELF—Extremely Low Frequencies.

TABLE 15-2. FREQUENCY TRANSMISSION CHARACTERISTICS

Band	Range (Note)		Power required	Antenna required
	Day	Night		
VLF	Long	Long	Extremely high	Very long
LF	Long	Long	Very high	Long
MF	Medium	Long	High to medium	Long
HF (3 to 10 MHz)	Short	Medium to long	Medium	Medium
HF (10 to 30 MHz)	Long	Short	Low	Short
VHF	Short	Short	Low	Very short
UHF, SHF, and EHF	Line of sight	Line of sight	Low	Extremely short

Note. Long range: over 1,500 mi
Medium range: 200 to 1,500 mi
Short range: under 200 mi
Line-of-sight: under 50 mi

8. Does the radio operator require lighting provisions or writing space near the radio to perform his normal duties?

9. What clearance is required around the equipment for air circulation and what is the maximum ambient temperature allowed for continuous operation?

10. How many antennas are required and what limitations are applicable as to the distance between antennas?

11. What is the worst duty cycle that might occur with the engine running; also with the engine not running?

12. How many power receptacles are required to be installed by the manufacturer of the vehicle?

13. Are all components furnished with adequate vibration-isolation equipment?

14. Are there any provisions for remote control? If so, how often does the operator have to get to the basic equipment to preset different frequencies which are to be used?

15. What magnitude of transients will the equipment tolerate in its power source?

16. What provisions must be made for vehicle noise suppression devices?

As further guidance, the following Technical and Field Manuals are recommended sources for basic information describing radio communication circuits and equipment:

1. TM 11-665, *CW and AM Radio Transmitters and Receivers*[3]

2. TM 11-666, *Antennas and Radio Propagation*[4]

3. TM 11-668, *FM Transmitters and Receivers*[5]

4. TM 11-685, *Communications, Single-Sideband Fundamentals*[6]

5. FM 24-19, *Communications – Electronics Reference Data*[2].

15-2 RADIO INSTALLATIONS

The latest version of vehicular FM communication equipment standardized by the United States Signal Corps is designated as the AN/VRC-12 series.

The AN/VRC-12 radio set includes two units, an automatic Receiver-Transmitter RT-246 and Receiver R-442. These two units, and a manual Receiver-Transmitter RT-524, are combined to provide seven other configuration options to meet a diversity of operational tasks (Fig. 15-2). In normal operation, the AN/VRC-12 series operates over a 25- to 30-mi range utilizing Narrow Band Frequency Modulation, covering the 30- to 75.95-MHz range with 920 channels and offering completely automatic tuning. Power requirements are 1 A receive and 10 A transmit.

Rugged and compact, the AN/VRC-12 is one-seventh the size and one-fourth the weight of the equipment it replaces. The AN/VRC-12 is operationally compatible with portable and airborne FM radio systems (Fig. 15-3) developed for use in forward combat areas. It can be installed in a variety of vehicles–jeep, tank, weapons and personnel carriers. Physical data are given in Table 15-3.

This radio offers new standards for ease of operation–push button selection of any of ten preset channels; remote, automatic, or manual tuning; and simplified bandswitching.

Increased overall reliability and reduced downtime for maintenance are the result of such system design features as maximum utilization of transistors, elimination of servo motors in the manual tuning circuit, simplification of the heat exchanger unit by utilizing beryllium oxide heat sinks to eliminate complicated "plumbing" problems, use of a ceramic tube in the final amplifier, and utilization of modular construction throughout to ensure component accessibility for test and repair.

Another widely used radio set, the AN/VRC-24, employs a compact, VHF-UHF, vehicular AM radio providing ground-to-air radiotelephone voice communication over a frequency range of 225-399.9 MHz. The set may be used as a retransmission device for radio sets AN/GRC-3 through -8 and the AN/VRC-12 series of radio sets. Range for this set is 30 mi for aircraft at 1000-ft elevation; 100 mi at 10,000 ft. It requires 24 VDC for operation. Transmitter power output is 15 W minimum. This equipment is employed throughout the combat zone to communicate with aircraft in close support of ground operations. A typical cording diagram is shown in Fig. 15-4, and other data are listed in Table 15-4.

Most of the modern-day military communication equipment is transistorized. Since it is transistorized equipment, it does have limited ability to withstand voltage transients and the vehicle electrical designer must design his power distribution circuitry with this factor in mind.

Accordingly, radio input-power leads should be routed directly from the battery or main power distribution point and careful consideration should be given to the need for isolating radios from the system during the engine start sequence. Furthermore, the vehicle electrical system should be in accordance with MIL-STD-1275[12] so that the battery cannot be disconnected from the system while the engine is operating.

15-3 ANTENNA INSTALLATIONS

The AS-1729/VRC whip antenna and matching network is an advanced centerfed design offering optimum performance under extremes of environment and terrain (Fig. 15-5). It is equally adaptable to all combat and support vehicles or base locations for application in a diversity of frequency ranges and operational tasks. This design concept minimizes the effects of physical ground plane configurations upon system performance. One of these antennas is required with each receiver transmitter in any AN/VRC-12 series radio installation. Mounting instructions are given on Signal Corps Drawing SC-D-189021. The base has a flexible section which allows the antenna to fold when struck by tree branches or gun barrels. A matching unit in the antenna base automatically loads the antenna to suit the frequency tuned in at the receiver-transmitter.

The receiver antenna for the R-442/VRC (AN/VRC-12 series radio receiver) is illustrated in Fig. 15-6. One of these antennas may be connected to as many as four R-442/VRC

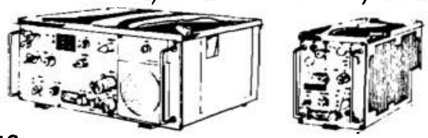
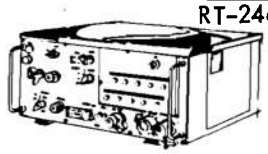
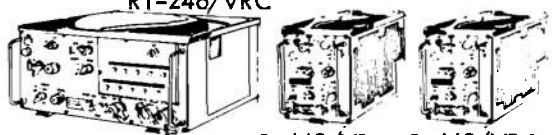
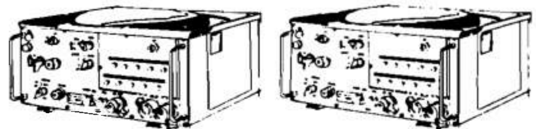
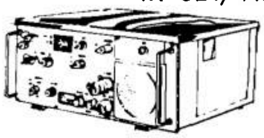
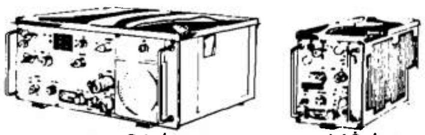
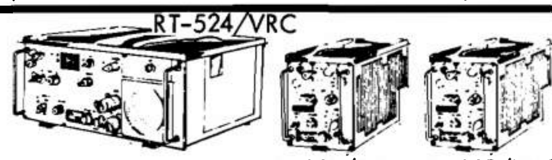
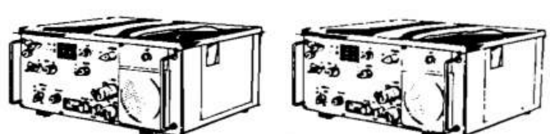
RT-246/VRC R-442/VRC  AN/VRC-12	Transmitting and receiving one channel while simultaneously monitoring an additional channel
RT-246/VRC  AN/VRC-43	Transmitting and receiving on one channel
RT-246/VRC  AN/VRC-44 R-442/VRC R-442/VRC	Transmitting and receiving on one channel while simultaneously monitoring two additional channels
 AN/VRC-45 RT-246/VRC RT-246/VRC	Simultaneous two-way operation on two different channels Retransmission station to relay communications between two distant points.
RT-524/VRC  AN/VRC-46	Transmitting and receiving on one channel
 AN/VRC-47 RT-524/VRC R-442/VRC	Transmitting and receiving one channel while simultaneously monitoring an additional channel
RT-524/VRC  AN/VRC-48 R-442/VRC R-442/VRC	Transmitting and receiving on one channel while simultaneously monitoring two additional channels
 AN/VRC-49 RT-524/VRC RT-524/VRC	Simultaneous two-way operation on two different channels Retransmission station to relay communications between two distant points

Figure 15-2. AN/VRC-12 Radio Equipment Configurations

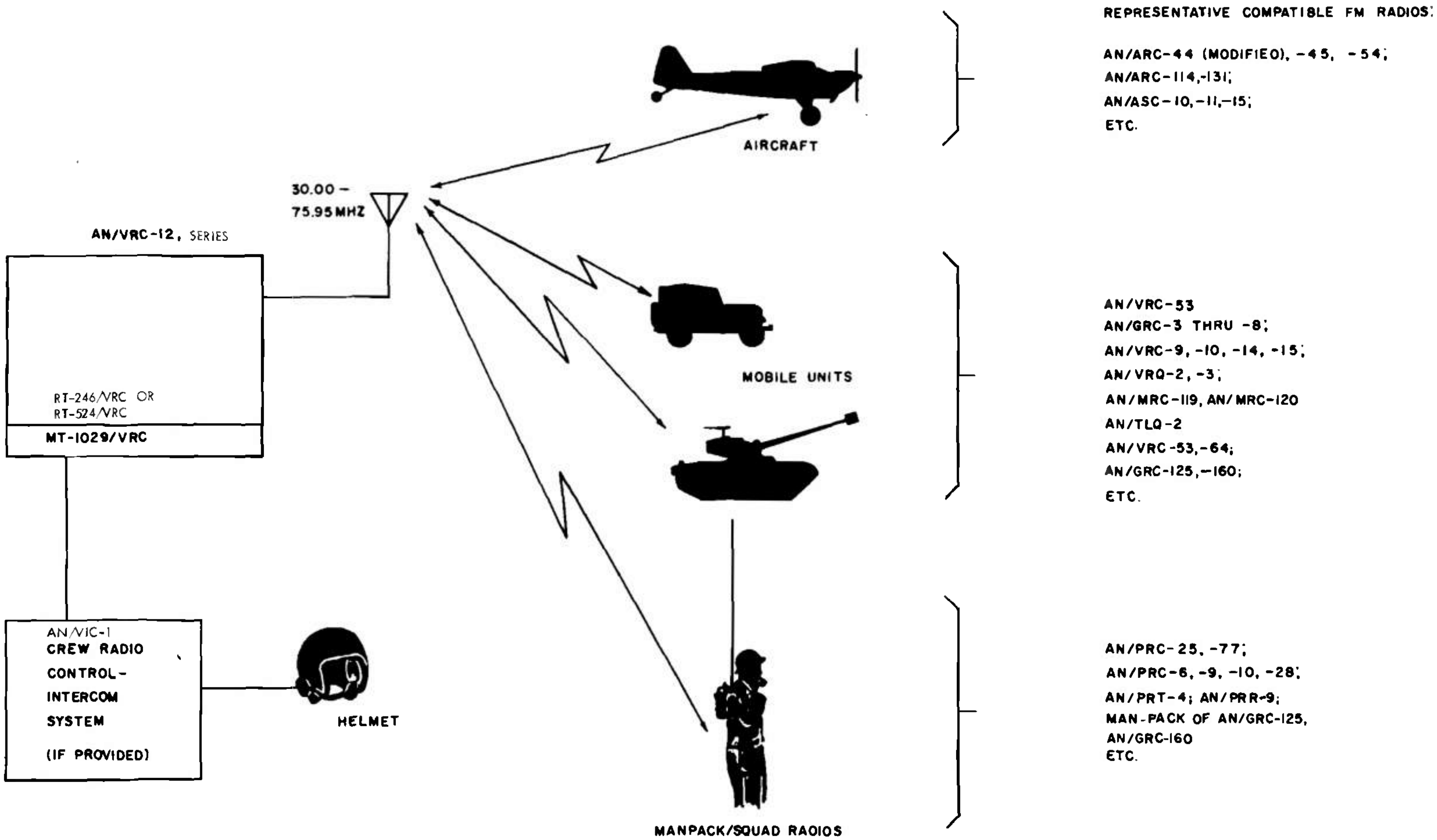


Figure 15-3. Typical Radio Systems Compatible With AN/VRC-12 Series Radios[7]

TABLE 15-3. AN/VRC-12 RADIO DATA[2]

Nomenclature	Dimensions, in. length	width	height	Area, ft^2	Volume, ft^3	Weight, lb
Radio Sets AN/VRC-12 and AN/VRC-43 through AN/VRC-49						
References: TM 11-5820-401; Signal Corps Drawings: SC-F-49658, SC-F-49659, SC-D-189021						
Major Components:						159
Radio Receiver-Transmitter RT-246/VRC	15.343	13.156	6.593	1.401	0.770	61
Radio Receiver R-442/VRC	5.343	13.093	6.593	0.485	0.266	18
Mounting MT-1029/VRC	15.900	13.690	5	1.511	0.629	20
Mounting MT-1898/VRC	5.790	13.690	4.370	0.550	0.200	8
Antenna AS-1729/VRC	-------	-------	-------	------	----------	10
Receiver Antenna and spares in bag	43	11	4	3.284	1.094	12

ELECTRICAL CHARACTERISTICS

Equipment	Potential, V	Current, A	Operating Condition
RT-524 or RT-246	22	1.5	Receive
	30	3	Receive
	22	5	Low Power Transmit
	30	7	Low Power Transmit
	22	9.5	High Power Transmit
	30	13.5	High Power Transmit
R-442	25.5	0.43	Squelch On
	25.5	0.625	Squelch Off
AS 1729	22	2.2	Peak Current, Ledex Switching
	30	3.0	Peak Current, Ledex Switching

auxiliary receivers. Installation data for this antenna may be found on Signal Corps Drawing SC-D-8573. The base is also flexible.

Antenna AT-803/VR is designed for mobile operation in conjunction with Radio Set AN/VRC-24 (Fig. 15-4). The unit is approximately 10 in. long and has a UG-484/U connector at the base. This antenna is rigid and must be located in a position protected from brush damage.

Theoretical data on antennas and radio propagation are available to the design engineer in TM 11-666[4].

The normal radiation pattern produced by a typical grounded quarter-wave vehicle antenna is shown in Fig. 15-7. Maximum radiation (or reception) of energy occurs at right angles to the antenna and along the surface of the ground. The radiation falls off as the vertical angle is increased, until directly over

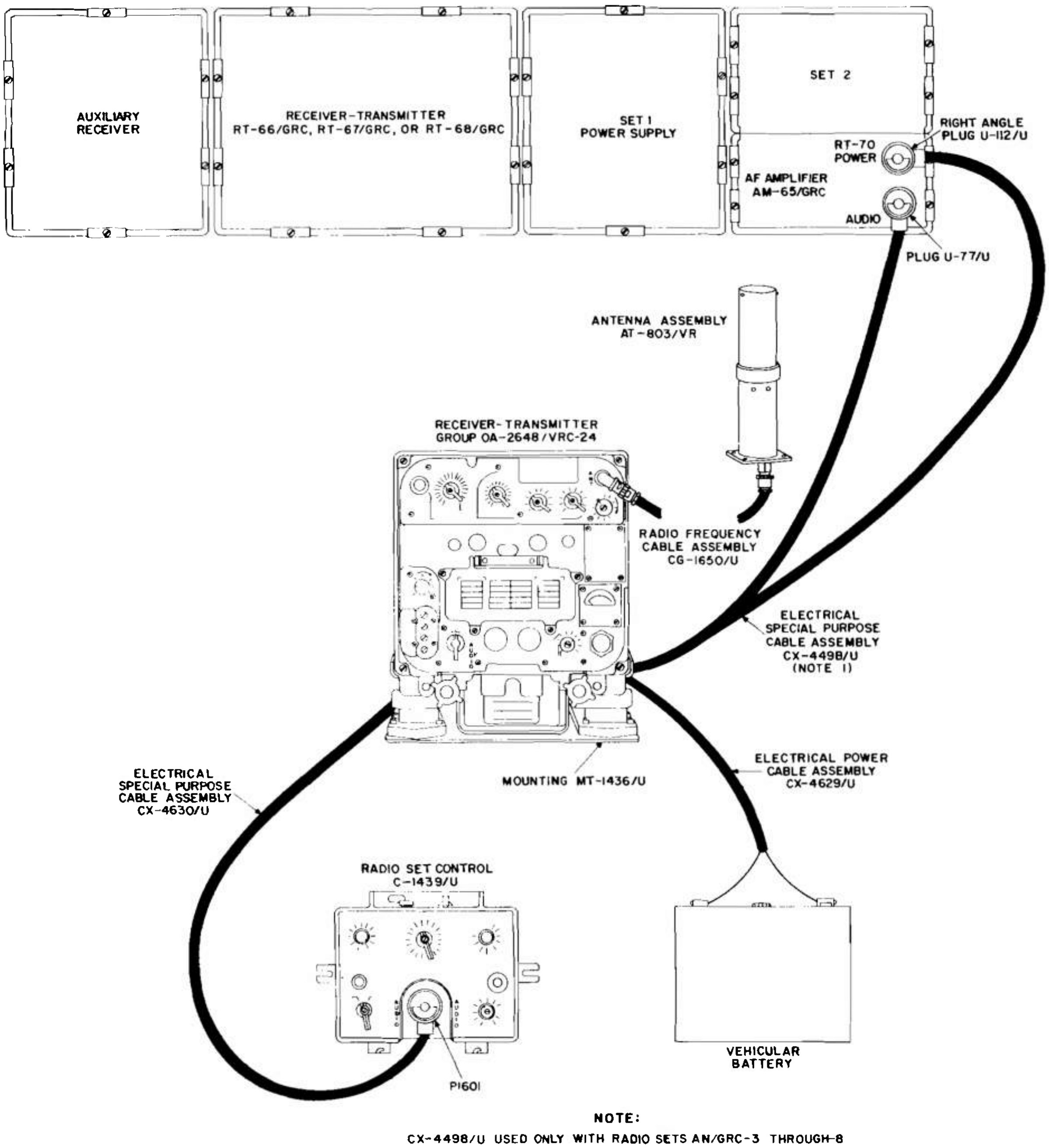


Figure 15-4. Radio Set AN/VRC-24 as Used With Radio Sets AN/GRC-3 Through -8, Cording Diagram[8]

the antenna (at a vertical angle of 90 deg), no radiation of energy occurs. A true semicircle is shown so that a comparison can be made with the radiation pattern.

A top view of the radiation pattern shows that this pattern is circular. The antenna, therefore, is omnidirectional in the horizontal plane, and radiates equally in all horizontal directions. However, obstructions on a vehicle or the proximity of other antennas will produce distortions in the actual radiation pattern.

Grounded antennas often are tuned with loading coils so that their length can be made

TABLE 15-4. AN/VRC-24 RADIO DATA[2]

Nomenclature	Dimensions, in. length	width	height	Area, ft^2	Volume, ft^3	Weight, lb
Radio Set AN/VRC-24						88
Reference: TM 11-5820-222						
Major Components						
Receiver-Transmitter Group OA-2648/VRC-24 in Case CY-2557/VRC-24	16.500	10.625	12	1.217	1.217	62
Radio Set Control C-1439/U	6.500	2.875	6.500	0.129	0.070	5
Mounting MT-1436/U	18	10.500	5.750	1.312	0.628	20
Loudspeaker LS-166/U	5.500	3.500	5	0.133	0.055	1

ELECTRICAL CHARACTERISTICS

RECEIVE

BATTERY DRAIN

INPUT, V	INPUT, A	POWER INPUT, W
22.3	7.4	165
26.35	8.35	220
30.3	9.3	281

TRANSMIT

BATTERY DRAIN

INPUT, V	INPUT, A	POWER INPUT, W	RF POWER, W
82.0	10.0	224	9
26.4	12.0	317	18
30.0	13.5	405	25

CHANNEL SELECTION POWER INPUT - 12.5A AT 26.4V, 330 W

AUDIO OUTPUT	RECEIVE, mW	INTERPHONE, mW	SIDETONE, mW	LOAD, ohms
Speaker	1000	1350	17	600
Headset	570	700	94	600
Remote	780	1080	632	82
Remote, Low Level	375	326	52	600
Retransmission	375			600
Headset	82	101	94	600+SPKR
Remote, Low Level	45	56	52	600+SPKR
Retransmission	45			600+SPKR

to resonate at shorter than a quarter-wave, i.e., the AS-1729/VRC antenna. The radiation patterns produced by such antennas are similar to the pattern shown in Fig. 15-7 except that the amount of radiation is reduced and the side view of the pattern is practically a true semicircle.

15-4 INTERCOMMUNICATION INSTALLATIONS

In the AN/VIC-1 intercom system, the audio frequency amplifier AM-1780/VRC and associated intercom control sets C-2296/VRC, C-2297/VRC, and C-2298/VRC are designed to work in conjunction with AN/VRC-12 radio sets (Fig. 15-8) or an independent intercom sets. System operation is described in TM 11-5820-401[9]. When the AN/VIC-1 is used with AN/VRC-12 radio equipment, each crew member is provided the capability to monitor 3 receivers and the vehicle intercom. In addition each crew member can transmit over either of two receiver-transmitters. The intercom system uses approximately 1 A at 28 VDC.

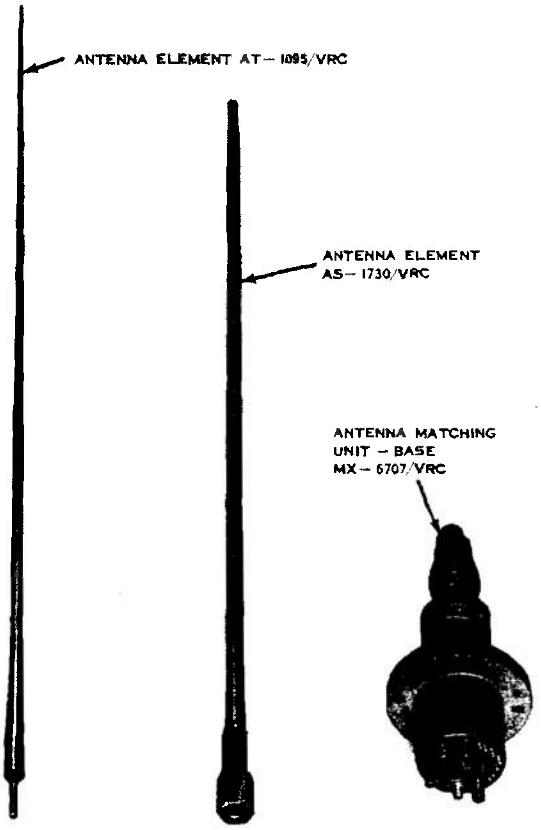


Figure 15-5. Antenna AS-1729/VRC[9]

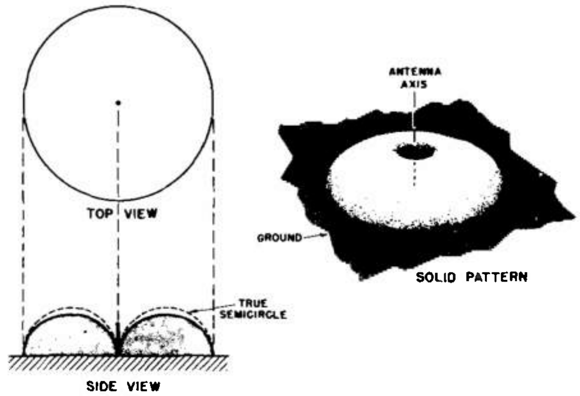


Figure 15-7. Radiation Pattern Produced by a Grounded Quarter-wave Antenna[4]

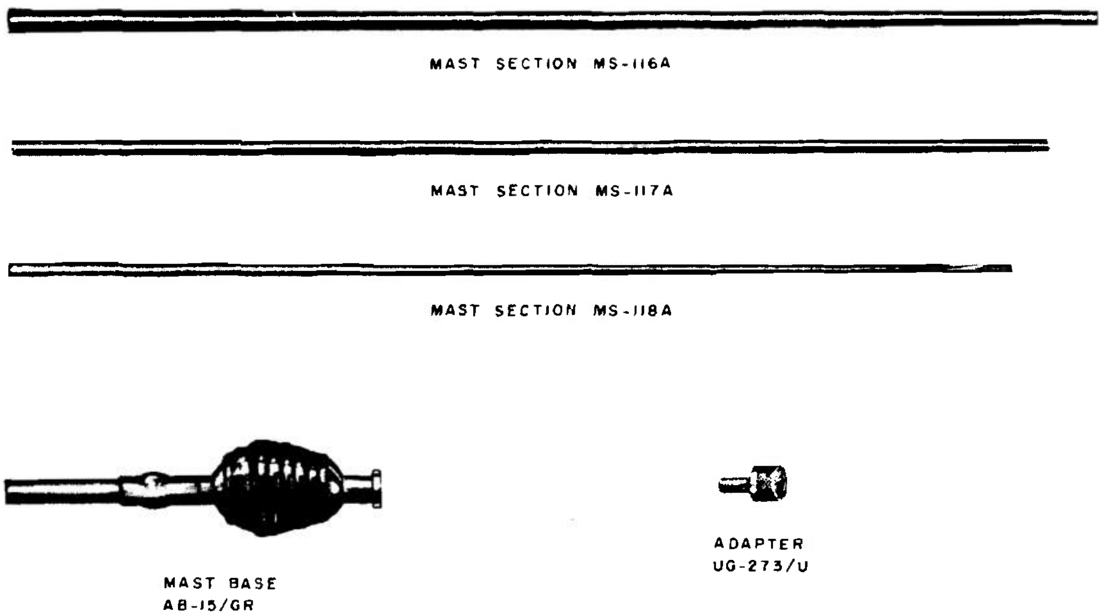


Figure 15-6. Receiver Antenna[9]

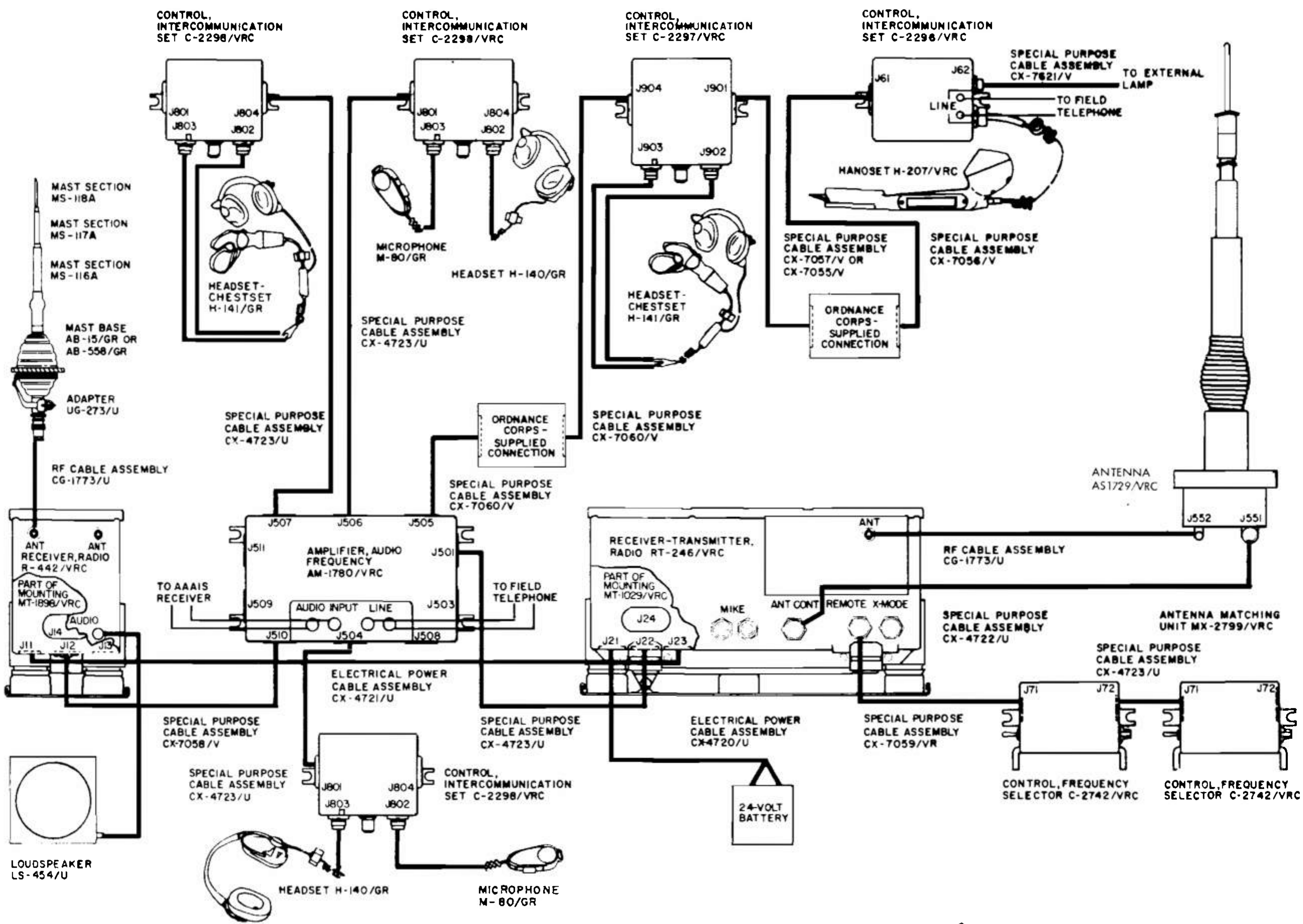
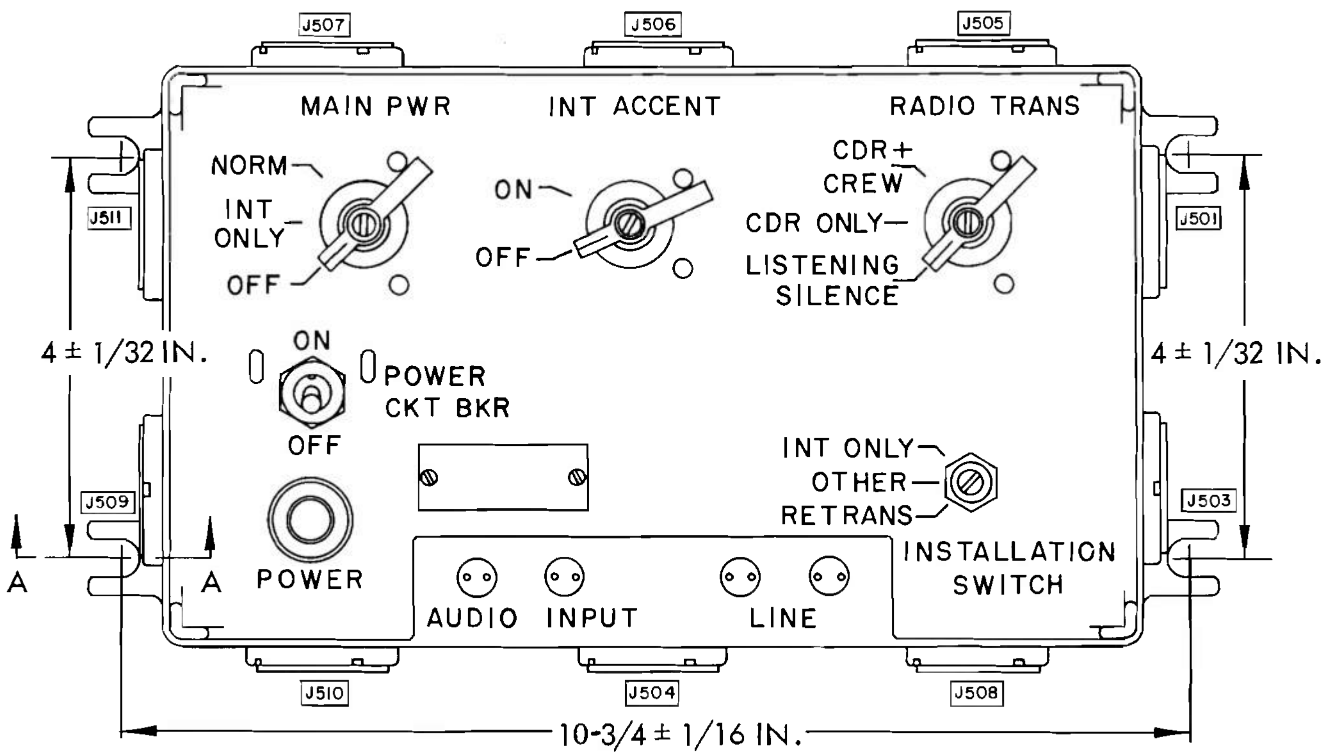


Figure 15-8. Radio Set AN/VRC-12, Typical Cording Diagram[9]

Audio frequency amplifier AM-1780/VRC (Fig. 15-9), amplifies the intercom and receiver outputs and is the main junction box for the components of a radio-intercom system installed in a vehicle or crew-served weapon. All operating controls and connectors are external. Ten connectors are located on the top, bottom, and sides. Operating controls, a power indicator lamp, and two pairs of binding posts are located on the front. Eight captive screws attach a gasket-sealed cover to the rear of the AM-1780/VRC. The cover has four mounting lugs that are used to mount the AM-1780/VRC.

Intercom control set C-2296/VRC provides communication between the radio set and personnel outside a vehicle or crew-served weapon. It has a handset H-207/VRC connected at the right side. A power and control



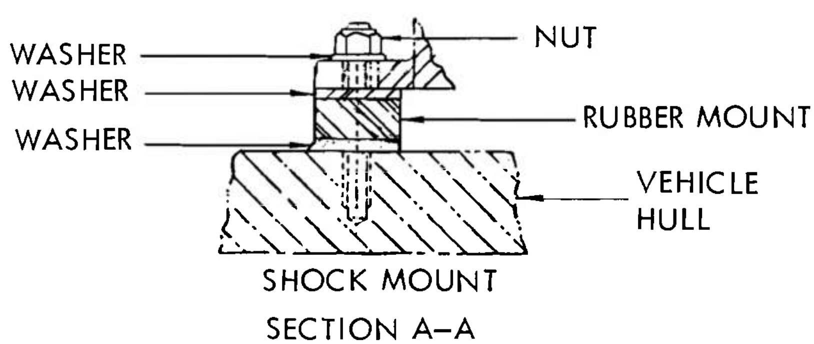


Figure 15-9. Amplifier, Audio Frequency AM-1780/VRC, Controls, Indicators, and Connectors[9]

cable connector and a signal lamp connector are located on the sides. Operating controls and a pair of binding posts are located on the front. Four captive screws attach a gasket-sealed cover to the rear of the C-2296/VRC. The cover has two mounting lugs for use in installing the C-2296/VRC on the outside or shell of a vehicle or crew-served weapon.

Intercom control set C-2997/VRC provides connections between the radio set and the audio accessories used by a crew member of a vehicle or crew-served weapon. It is used to connect a C-2296/VRC to the radio and intercom. All operating controls and connectors are external. Power and control cable connectors are located at the sides. Audio connectors and a volume control are located on the bottom. An indicator and the remaining operating controls are located on the front. Four captive screws attach a gasket-sealed cover to the rear of the C-2297/VRC. The cover has two mounting lugs for use in installation.

Intercom control set C-2298/VRC (Fig. 15-10), provides connections between the radio set and the audio accessories used by a crew member or commander of a vehicle or crew-served weapon. All operating controls and connectors are external. Power and control cable connectors are located at the sides. Audio connectors and a volume control are located on the bottom. Tapped holes on the sides allow a C-2742/VRC to be mounted above the C-2298/VRC. Four captive screws attach a gasket-sealed cover at the rear of the C-2298/VRC. The cover has two mounting lugs for use in installation.

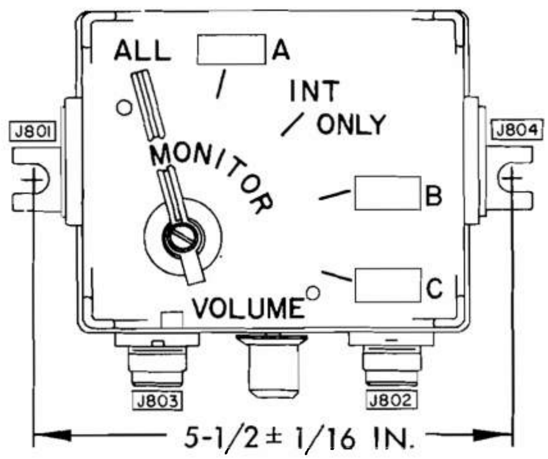


Figure 15-10. Control, Intercommunication Set C-2298/VRC, Controls and Connectors[9]

The use of rubber shock mounts is recommended when intercom equipment is installed in tracked vehicles (Fig. 15-9).

SECTION II

ELECTRONIC EQUIPMENT

15-5 INTRODUCTION

Electronic equipment is defined as that class of electrical equipment utilizing electron devices. In these devices conduction is principally accomplished by charge carriers moving through a vacuum, gas, or semiconductor[10,11]. Prior to the development of transistors in 1948 the majority of electronic devices in general use were either gas-filled tubes or vacuum tubes, the most important exception being metal-oxide rectifiers. Since then, development of new semiconductor devices has proceeded at a continually accelerating pace. While there are many ways in which the various developments and devices now available may be categorized, they will be discussed here in terms of major functions, i.e., power handling and signal processing.

In the past 20 yr there has been a significant increase in the variety of available semiconductor devices and in their power handling capability. Transistors that can handle 30-kW loads, carry 250 A, or switch 1500 V are available. Rectifiers and thyristors may be obtained with power ratings up to 2400 kW, current capacities up to 1400 A, and voltage ratings up to 2500 V.

Continued improvements in the design and manufacture of semiconductor junctions and packaging methods promise even higher power capabilities in the future. Recent developments have included power function modules, containing the power semiconductor plus associated circuit elements as required to perform specific circuit functions. These functional modules are available with 100-W linear output capabilities. Switching modules rated at 75 A and optically isolated relay modules with contact capacities up to 25 A are also available.

While power semiconductors have increased in both power handling capability and physical size, the development of signal processing devices has taken the opposite direction. Although the discrete transistor represented an order of magnitude reduction in size and weight as compared to a miniature vacuum tube, even greater relative size and weight reductions—spurred mainly by the requirements of the computer and aerospace industries—were to follow. Integrated circuits (IC's) consisting of up to 50 or more individual components (resistors, transistors, diodes, etc.) on a single semiconductor chip smaller than a tack head, arranged to perform specific predetermined circuit functions, are in common use today for both linear and digital circuits. Medium-scale integration (MSI) and large-scale integration (LSI) followed, extending the number of circuit elements on a single chip to several thousand. Hybrid circuits are available combining both digital and linear circuits on a single chip or combining discrete components with integrated circuits in a single assembly. Thin film techniques are being used to fabricate passive elements (resistors, capacitors) from a thin metal or metal-dielectric film for packing as part of an integrated circuit with active elements, or as a separate passive element network. Development of field-effect transistors (FET), metal-oxide semiconductors (MOS), and in particular, complementary MOS (CMOS) technology has reduced power dissipation in IC's to a virtually negligible level, permitting further reduction in both the IC package sizes and the cooling requirements for the assemblies and equipment in which they are used.

Only a few of the more common types of semiconductor electronic devices available have been mentioned in this paragraph. Many excellent books and manuals are available containing detailed information on the types and applications of electronic devices. For information on actual hardware availability and performance data, it is generally best to consult data books published by major manufacturers. These not only have the most complete data, but also are updated periodically to keep pace with the rapid developments taking place in this field.

15-6 ELECTRONIC EQUIPMENT INTERFACES

As a general rule, equipment which has been designed specifically for military vehicle use has built into it the necessary power conversion components as mentioned in Section III of Chapter 7. However, a great deal of equipment, chosen for vehicle use, was originally designed for nonvehicle applications and as a result may not survive in the rather hostile electrical environment of a military vehicle without proper attention to its interface with the vehicle system and mission.

Because of this, the electrical system designer must investigate very carefully the power requirements of each unit of electronic equipment with special attention given to the failure modes which can be produced by high and low voltages, loss of voltage, accidental reversal of voltage polarity, voltage ripple, voltage and current transients, and conducted and radiated electromagnetic interference. He must also be aware of the anomalies that are common in vehicle electrical systems. MIL-STD-1275[12] establishes the limits allowed for transient characteristics in 28 VDC electrical circuits in military vehicles. In the case where a slave start is performed to start a vehicle in which the battery has been removed from the electrical circuit, the peak to peak ripple voltage may be as high as 10 V. Voltage regulator failures may result in steady-state voltages as high as 40 V and voltage transients may go as high or low as the limits specified in Fig. 15-11.

On the other hand, circuit steady-state voltage with battery only operation may drop to as low as 20 V.

Any equipment which cannot operate reliably over this range of limitations or, in itself, will cause the circuit characteristics to go beyond the specified limits, must be redesigned or used in conjunction with some other appropriate interface equipment such as active or passive filters, transient suppressors, or converters. Control of all transients of 1-msec duration or less must be accomplished within the utilization equipment.

Due to the extremely low signal levels, high input impedances, and high gains utilized in much of the present electronic equipment, it is highly susceptible to electromagnetic interference. This characteristic places the added burden on the electrical system designer of determining the electromagnetic compatibility of each item of electronic equipment with its host vehicle environment. Electromagnetic interference is generated in common vehicle electrical systems by such items as brush-type motors and generators; inductive loads such as solenoid switches and valves; switching-type regulators; mechanical switches making and breaking heavy currents, and spark-type ignition systems.

The problem is compounded by the proximity of the interference generator and the susceptible electronic package dictated by vehicle design considerations other than electrical, i.e., distribution of weight and space. Also adding to the problem is the usual requirement for both power and signal level conductors to be run in the same harness assembly and the use of the vehicle hull as a system ground.

The reader is directed to Chapter 18 for a discussion of design considerations regarding electromagnetic compatibility.

15-7 VEHICLE ELECTRONIC EQUIPMENT DESIGN

The rapid technical advances in semiconductor design have led to a multitude of devices which have stimulated designers to apply more and more electronic technology

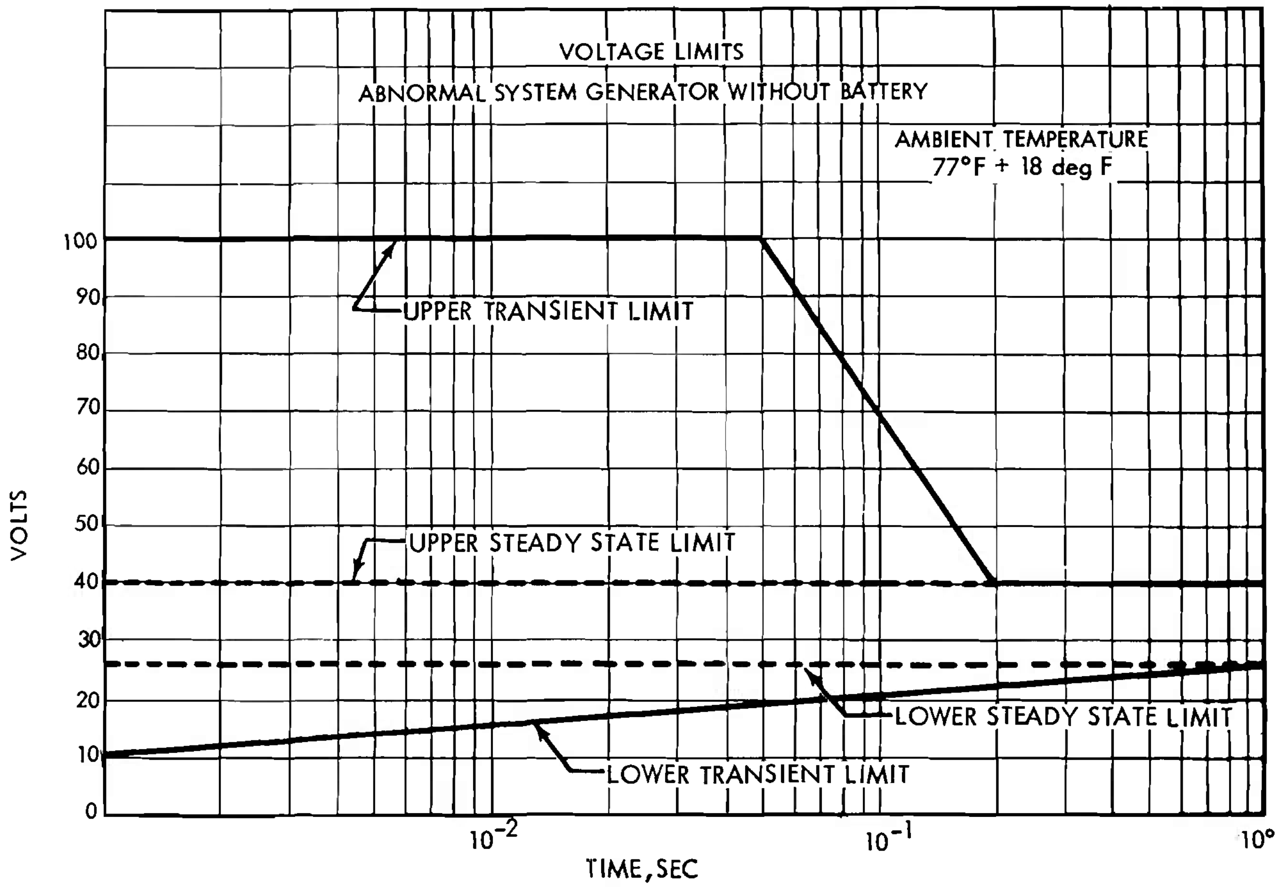


Figure 15-11. Vehicle Electrical System Voltage Limits[1 2]

to vehicular electrical system applications. The cost declines prevalent in the semiconductor field also have added impetus to their incorporation in vehicle systems, and the vast amount of reliability data which has been collected over the years has given the designer confidence that electronic components can be used successfully in the vehicle environment.

Items presently used in tank-automotive vehicles which employ electronic methods to advantage over older methods are presented in Table 15-5. The advantages which normally result from the use of such electronic devices include small size and weight, low power requirements, long life, reduced electromagnetic interference production, and in many cases just the ability to perform a function that could not be done feasibly by any other means.

Items which are now under development and which undoubtedly will be available for use in military vehicles within a few years are listed in Table 15-6. This list gives some indication of the wide range of applications to which electronic techniques can and will be applied in the future.

Past experience in the design of electronic equipment for tank-automotive application has shown that proper attention to certain techniques pays off in reliable and long-lasting service of the equipment. These techniques include the following:

1. Incorporate protection against the application of reversed polarity power in all electronic devices. It is a simple protection to provide, and its lack is a major cause of equipment failure in the field.

2. Incorporate electronic current limiting in any circuitry that contains electronic devices that may be destroyed by downstream short circuits. Set the current limit at a value

TABLE 15-5. ELECTRONIC EQUIPMENT USED IN TANK-AUTOMOTIVE VEHICLES

Item	Item	Item
Turn Flasher	Coolant Loss Indicator	Steering Control Servo System
Voltage Regulator	Fire Detection Circuits	Communication Interface Equipment
Audio Warning Tone Oscillator	Under Voltage Detector	

TABLE 15-6. ITEMS BEING DEVELOPED FOR POSSIBLE FUTURE USE IN TANK-AUTOMOTIVE VEHICLES

Item	Item	Item
Electronic Fuel Injection System	Engine Temperature Indicator	Electronic Transmission Control
Electronic Ignition System	Automatic Speed Warning	Engine and Crew Compartment Temperature Controls
Tire Pressure Indicator	Oil and Fuel Level Indicator	Antiskid Braking Control
Rain Detector and Wiper Control	Battery Charge Indicator	Solid-state Displays Using Light Emitting Diodes
Speedometer-Tachometer-Odometer	Collision Warning Detector	Multiplexed Control and Feedback Signals
Contacts and Switches,for Horn, Lights, Keyswitch, etc.	Engine Temperature Control	

which will prevent burnout of any device in the series path.

3. Recognize the requirements for electromagnetic interference suppression and make the required suppression devices part of the circuit design—not an add-on to be installed in the vehicle separately.

4. Use Military Standard components to the maximum extent possible to take advantage of multiple sources, a better chance of repair parts already being in the supply line, and increased reliability due to required test procedures and documentation. If nonmilitary standard parts are used, they should be thoroughly tested and "burned-in" to eliminate those devices subject to early failure or "infant mortality"[13].

5. Electronic assemblies of items whose total cost is less than $100 should be encapsulated in solid epoxy blocks for maximum resistance to the military vehicle environment of shock, vibration, dirt, and humidity and treated as throwaway units when repair is needed.

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4. TM 11-666, *Antennas and Radio Propagation.*

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CHAPTER 16

SERVO CONTROL SYSTEMS

SECTION I SERVOMECHANISMS

16-1 INTRODUCTION

A control system controls a source of power. The input to the system is a command which causes the power to vary within the system, resulting in an output dependent upon the input. The output could be the position of a gun turret, the pitch attitude of a missile, or even the temperature of a room. The input is a small signal which must be amplified by the control system so as to influence the output.

An open-loop control system (Fig. 16-1) can be depicted as an amplifier and motor attempting to position a large, heavy wheel. One turn of the handcrank (input) should result in one turn of the wheel (output). But, after the wheel has rotated to its new position, there is no guarantee that the output will equal the input position. An open loop system cannot correct for natural imperfections in the linkages, gears, and motors. Such a control system is evidently too inaccurate for precision control requirements. The remainder of this chapter will discuss closed-loop control systems which are capable of self-correction, and are, therefore, inherently accurate.

16-2 CLOSED-LOOP SYSTEMS

An open ended system, as discussed, can be improved by the addition of a feedback loop and an error detecting device called a differential. The feedback loop sends the magnitude of the output θ_o back to the differential, which compares the output with the input θ_i. If there is a discrepancy between the input and output positions, an error signal ϵ, equal to their difference $\theta_i - \theta_o = \epsilon$, continues to keep the system in motion until $\theta_i = \theta_o$ ($\epsilon = 0$). This type of system is the most basic type of servomechanism and is called a position control servo.

It follows from Fig. 16-2 that a servomechanism may be defined as a combination of elements for the control of a source of power in which the output of the system or some function of the output is fed back for comparison with the input, and the difference between these quantities is used in controlling the power.

In a closed-loop system (servomechanism), if the output is not behaving properly by following θ, the physical system senses this at the input end and reacts by driving the output

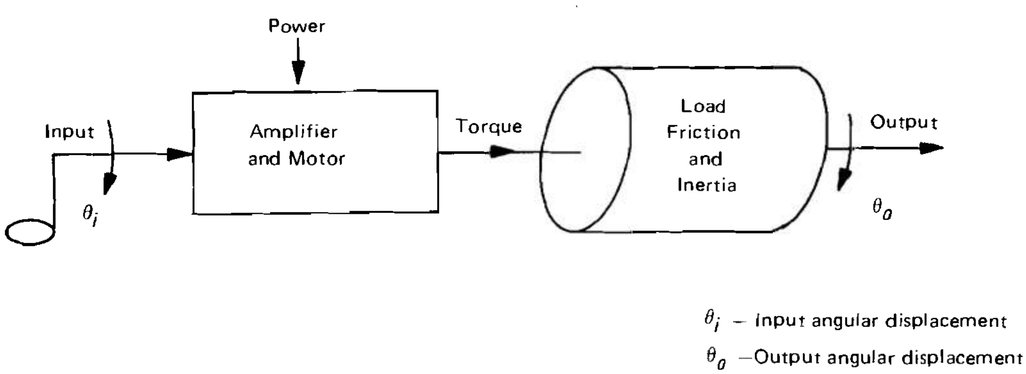


Figure 16-1. Schematic of an Open Loop Control System[1]

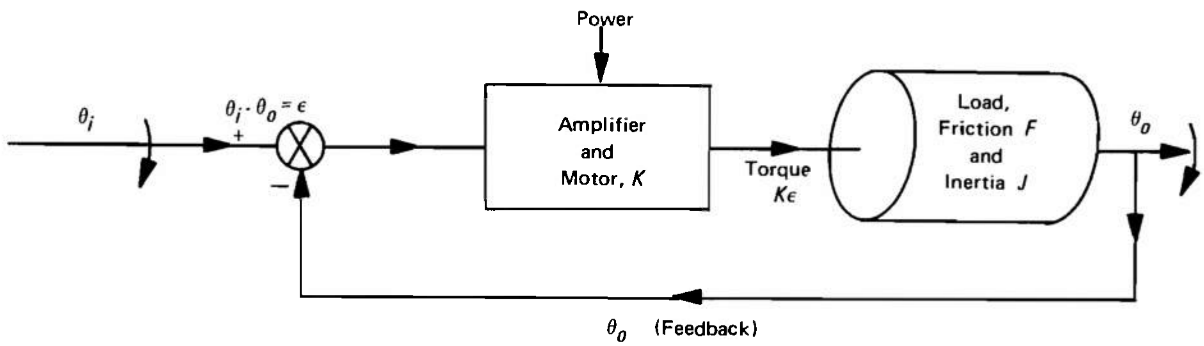


Figure 16-2. Schematic of a Closed-loop Control System[1]

θ_o toward agreement with the input θ_i. This advantage, of course, is not obtained without a price. Unless the system is properly designed with the elements correctly calibrated, the response time lag of the output may be excessive; the system may have excessive oscillations in the output; or the system may not even be stable (i.e., the output response may diverge and never approach the input).

16-3 SYSTEM ANALYSIS AND ELEMENTS OF SERVOMECHANISMS

A servomechanism in its simplest form requires five basic elements:

1. Input. The driving signal which initially activates the system, here considered as an angular position, with the designation θ. The input is considered as an angular position because many servomechanisms are used in conjunction with shaft rotation devices. (This does not preclude servocontrol of variables other than angular position.)

2. Differential. Error detecting device which mechanically or electrically subtracts the output from the input and determines the magnitude and direction of the error signal ϵ where $\epsilon = \theta_i - \theta_o$.

3. Controller. Power amplifier and servo motor combination. The controller acts upon the error signal ϵ from the differential, driving and positioning the output. The magnitude of the amplification will be K, therefore the error signal ϵ goes into the controller, and a torque $K\epsilon$—which may move a load—comes out.

4. Output. Load or mechanism which is positioned to correspond to a given input. Its motion will also be considered to be an angular displacement, designated as θ_o.

5. Feedback. The process (and component) which detects the actual amount of output displacement and sends a signal proportional to this amount back to the differential for comparison with the input. Feedback may be accomplished either mechanically or electrically.

The standard approach to servo theory is through mathematical analysis. This involves developing the equation which describes the system in terms of input and output, and then solving the equation for given inputs to determine the response. A typical input signal might be a step function, ramp function, sinusoidal function, or pulse function. The equation of a system is obtained by equating the accelerating forces (or torques) to the decelerating forces (or torques) that act on the system (Fig. 16-2).

Consider the following torques:

1. Accelerating torque. The only accelerating torque in this system is the torque $K\epsilon$ produced by the controller.

2. Decelerating torque.

a. Inertia torque. The load has mass and hence acts to retard the response of the output. The torque is proportional to the acceleration of the output and designated $J\ddot{\theta}_o$ where J is moment of inertia of the load, and

$$\ddot{\theta}_o = \frac{d^2\theta_o}{dt^2}. \quad (16\text{-}1)$$

b. Friction torque. The viscous friction proportional to output velocity. It is due to friction between lubricated surfaces, such as gears and bearings. As will be seen, a certain amount of this retarding force may be desirable and certain devices such as fluid dashpots are sometimes introduced into the system to improve response. The torque due to viscous friction, whether inherent or added, is designated $F\dot{\theta}_o$ where F is the friction torque per unit speed, and

$$\dot{\theta}_o = \frac{d\theta_o}{dt} \quad (16\text{-}2)$$

Equating the accelerating torque to the decelerating torques produces the equation of motion, in terms of the error signal ϵ and the output θ_o. This is a second-order linear differential equation with constant coefficients of the form:

$$K\epsilon = J\ddot{\theta}_o + F\dot{\theta}_o \quad (16\text{-}3)$$

But

$$\epsilon = \theta_i - \theta_o$$

So

$$J\ddot{\theta}_o + F\dot{\theta}_o = K(\theta_i - \theta_o) \quad (16\text{-}4)$$

or

$$J\ddot{\theta}_o + F\dot{\theta}_o + K\theta_o = K\theta_i \quad (16\text{-}5)$$

Eq. 16-5 is the general equation of motion of a position control servo. The equation relates the output acceleration, velocity, and position to the input position. Note that this is mathematically the equation encountered in electricity which describes the behavior of a circuit containing inductance, resistance, and capacitance. It is also the equation describing the motion of a mass, damper, and spring in mechanics. The only difference is in the interpretation of the symbols.

In order to state Eq. 16-5 in even more general terms, the following definitions will be introduced:

$$\omega_n = \sqrt{\frac{K}{J}}, \text{ rad per sec} \quad (16\text{-}6)$$

$$\zeta = \frac{F}{2\sqrt{KJ}} \quad (16\text{-}7)$$

The term ω_n in Eq. 16-6 is defined as the undamped natural frequency. It is the resonant frequency in radians per second at which a frictionless system will oscillate.

The term ζ in Eq. 16-7 is defined as the damping ratio. It is a dimensionless constant which indicates the relative amount of damping, or viscous friction F in a system.

By substituting ζ and ω_n for the constant coefficients of Eq. 16-5 a completely general equation of motion of any second-order linear system is obtained[1].

$$\left(\frac{1}{\omega_n^2}\right)\ddot{\theta}_o + \left(\frac{2\zeta}{\omega_n}\right)\dot{\theta}_o + \theta_o = \theta_i \quad (16\text{-}8)$$

16-4 STEP AND RAMP INPUTS

16-4.1 STEP INPUT

A step input is defined as an instantaneous jump to a new and constant position. For example, an instantaneous rotation of the input shaft in Fig. 16-2 through 90 deg would be a step input of angular position. Fig. 16-3 illustrates a general step input plotted against time.

For a step input of $\theta_i = A$, the servo will drive the output until $\theta_o = \theta_i = A$, or in other words, until there is no steady-state error.

$\theta_i(t) = 0$ for $t < 0$
$\theta_i(t) = A$ for $t > 0$

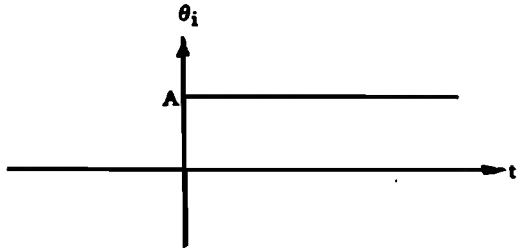


Figure 16-3. Step Function[1]

However, before arriving at the steady value A the output must first experience a transient or intermediate response since no physical system is capable of an instantaneous jump through space. This transient response may take one of several forms, depending primarily on the magnitude of the damping ratio ζ.

1. $\zeta < 1$: The output is underdamped and will oscillate one or more times about the steady position A.

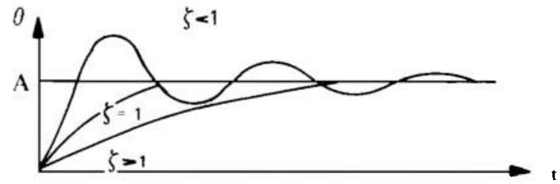
2. $\zeta = 1$: The output is critically damped and will curve smoothly into A on an exponential path.

3. $\zeta > 1$: The output is overdamped and will curve more slowly, but still smoothly, into A.

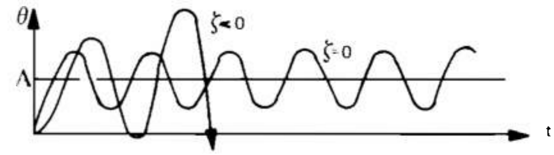
4. $\zeta = 0$: The output is undamped and will oscillate on a sine wave at a frequency ω_n

5. $\zeta < 0$: The system is negatively damped, is unstable, and will ultimately destroy itself in ever increasing wild gyrations.

From the preceding list, the advantage of rewriting the equation of motion in the form of Eq. 16-8 is clear. A qualitative analysis of the system may be made quickly without resorting to a rigorous solution of the differential equation. A quantitative analysis requires either a mathematical solution or a graphical solution with the aid of an analog computer. In Fig. 16-4 responses to step inputs are shown for each of the ranges of the damping ratio described.



(A) OVERDAMPED, $\zeta > 1$, CRITICALLY DAMPED $\zeta = 1$ AND UNDERDAMPED $\zeta < 1$ SYSTEMS



(B) UNDAMPED, $\zeta = 0$ AND NEGATIVELY DAMPED $\zeta < 0$ SYSTEMS

Figure 16-4. Responses to Step Input $\theta_i = A$ (Ref. 1)

16-4.2 RAMP INPUT

Another type of input which is perhaps even more frequently encountered is the ramp input; i.e., one which varies with time at a constant rate. This could be represented by a man turning a handwheel at a constant angular speed ω_i. Fig. 16-5 illustrates a general ramp input plotted against time.

For a ramp input of $\theta_i = \omega_i t$ the servo will attempt to drive the output until $\theta_o = \theta_i$, but, due to the inherent inertia of the system, the output can never quite catch up to the input. After the transient effect has died out a steady-state error, or time lag, will remain and the output will follow along behind the input.

In order to determine just what amount of lag will be present, it will be necessary to

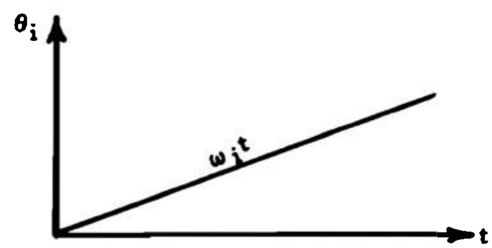


Figure 16-5. Ramp Function[1]

solve for the steady-state response. The equation of motion is first rewritten in terms of operator p notation, as follows.

$$\text{Let } p\theta_o = \frac{d\theta_o}{dt} = \theta_o$$

$$p^2\theta_o = \frac{d^2\theta_o}{dt^2} = \theta_o$$

then using Eq. 16-8

$$\left(\frac{1}{\omega_n^2}\right)p^2\theta_o + \left(\frac{2\zeta}{\omega_n}\right)p\theta_o + \theta_o = \theta_i \qquad (16\text{-}9)$$

or

$$\left[\left(\frac{1}{\omega_n^2}\right)p^2 + \left(\frac{2\zeta}{\omega_n}\right)p + 1\right]\theta_o = \theta_i \qquad (16\text{-}10)$$

Solving Eq. 16-10 for θ_o:

$$\theta_o = \left[\frac{1}{1 + \left(\frac{2\zeta}{\omega_n}\right)p + \left(\frac{1}{\omega_n^2}\right)p^2}\right]\theta_i \qquad (16\text{-}11)$$

By long division the right side of Eq. 16-11 may be converted to an infinite power series in p.

$$\theta_o = \left[1 - \left(\frac{2\zeta}{\omega_n}\right)p + \left(\frac{4\zeta^2 - 1}{\omega_n^2}\right)p^2 + \ldots\right]\theta_i \qquad (16\text{-}12)$$

Applying Eq. 16-12 to the ramp input $\theta_i = \omega_i t$ the steady-state output becomes,

$$\theta_o = \left[1 - \left(\frac{2\zeta}{\omega_n}\right)p\right]\omega_i t$$

($p^2\omega_i t$ and higher terms are zero since the second and higher derivatives of t vanish)

or

$$\theta_o = \omega_i t - \left(\frac{2\zeta}{\omega_n}\right)\omega_i = \omega_i\left(t - \frac{2\zeta}{\omega_n}\right) \qquad (16\text{-}13)$$

The output will then lag behind the input by $2\zeta/\omega_n$ seconds in time, or $(2\zeta/\omega_n)\omega_i$ rad in position. Eq. 16-13 indicates that a system with zero damping ($\zeta = 0$) will have no lag, but such a system will oscillate indefinitely and so is not practical. In Fig. 16-6 responses to ramp inputs are shown, again for each of the ranges of the damping ratio[1]

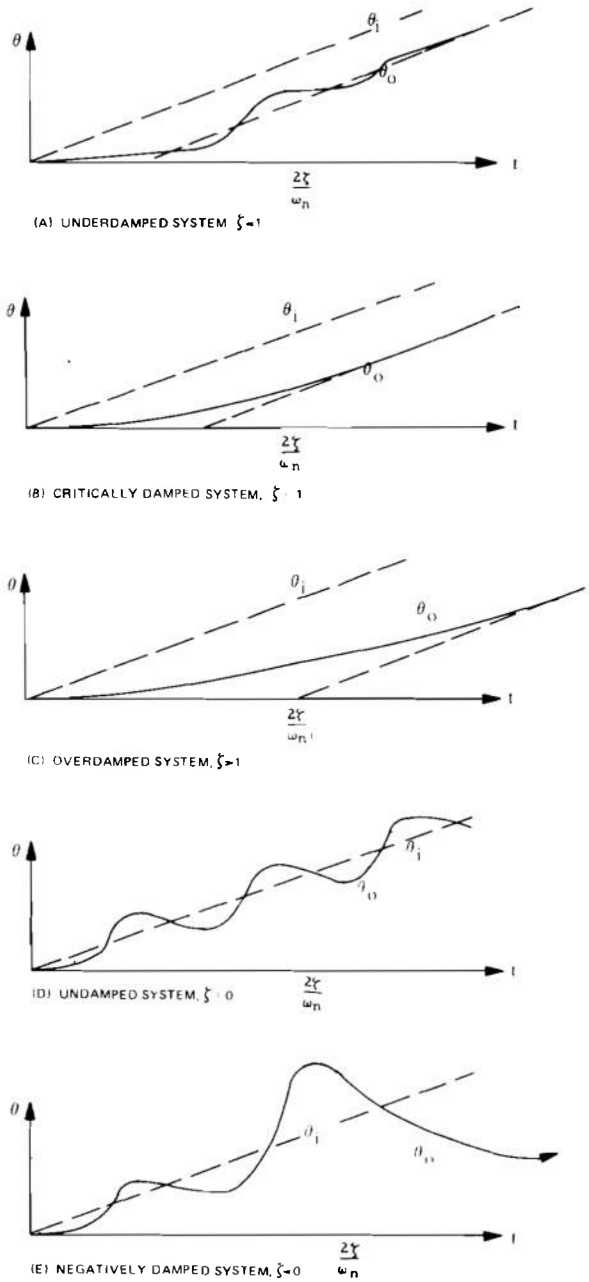


Figure 16-6. Responses to Ramp Input $\theta_i = \omega_i t$ (Ref. 1)

16-5 METHODS OF IMPROVING SYSTEM RESPONSE

The basic servomechanism uses a control signal that is proportional to the difference of the input and output signals. This type of servo is commonly called a position servo, since it compares only the positions of the input and output.

In an analysis, the most descriptive parameter was found to be

$$\zeta = \frac{F}{2\sqrt{JK}} \tag{16-14}$$

As ζ increases, the response becomes more sluggish and less oscillatory. An optimum servo control system should have a very rapid speed of response, and very little oscillation, or hunting. In practice, it has been found that ζ generally should lie in the range of 0.3 to 1.0.

The system moment of inertia J is usually fixed, which leaves F and K as variables. Decreasing the controller gain K reduces the available ouptut torque $K\epsilon$, used to drive the system, so K should be as large as possible. The viscous friction F is usually a rather small quantity in a well designed system, since losses due to friction are not desirable. A small F and a large K indicate that ζ will be a small quantity, i.e., the system will be highly oscillatory, and apparently there is nothing that can be done about it. However, there are techniques available which add artificial damping; two of these methods will now be described[1].

16-5.1 DERIVATIVE FEEDBACK

In this scheme we feed back not only the output position, but also the output velocity multiplied by a suitable constant, so that we have position plus velocity control. The velocity is obtained by taking the first time derivative of the output, hence, the name derivative feedback.

Using the technique developed for Eq. 16-5, the equation of motion of the derivative feedback servo becomes:

$$J\ddot{\theta}_o + (F + KC_d)\,\dot{\theta}_o + K\theta_o = K\theta_i \tag{16-15}$$

where C_d is the coefficient (or multiplying constant) of the derivative feedback so that now

$$\zeta = \frac{F + KC_d}{2\sqrt{JK}} \tag{16-16}$$

and the damping ratio has been effectively increased without dissipating additional energy through friction. Using derivative feedback it is theoretically possible to operate a system with zero friction F and still maintain sufficient damping for proper control[1]. Fig. 16-7 gives a block diagram of a derivative feedback servo.

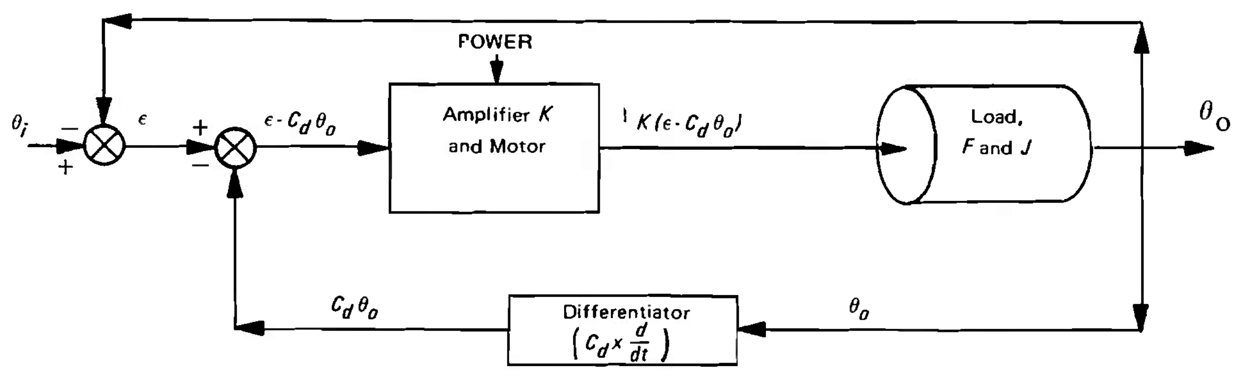


Figure 16-7. Derivative Feedback Servo[1]

16-5.2 ERROR-RATE CONTROL

In this scheme the output position is fed back, as in position control, but the error signal produced is differentiated to produce an error-rate signal. The input to the controller is the sum of the error signal and the error-rate signal.

The equation of motion of this device is

$$J\ddot{\theta}_o + (F + KC_e)\dot{\theta}_o + K\theta_o = KC_e\dot{\theta}_i + K\theta_i \tag{16-17}$$

where C_e is the coefficient (or multiplying constant) of the error rate feedback so that now

$$\zeta = \frac{F + KC_e}{2\sqrt{JK}} \tag{16-18}$$

and again the damping ratio has been effectively increased[1]. Fig. 16-8 gives a block diagram of an error-rate control servo.

16-5.3 INTEGRAL CONTROL

The improvement in response with the use of derivatives next leads to an investigation of response with the use of integrals. As in error-rate control, output position is fed back to obtain an error signal, then position error plus the integral of error is used as an input to the controller. The equation of motion of this system is

$$J\ddot{\theta}_o + F\dot{\theta}_o + K\theta_o + KC_i\int\theta_o dt = K\theta_i + KC_i\int\theta_i dt \tag{16-19}$$

where

C_i = coefficient (or multiplying factor) of the integral feedback

Differentiating once,

$$J\dddot{\theta}_o + F\ddot{\theta}_o + K\dot{\theta}_o + KC_i\theta_o = K\dot{\theta}_i + KC_i\theta_i \tag{16-20}$$

Eq. 16-20 now represents a third-order differential equation, for which ζ and ω can no longer be defined. A mathematical solution and a computer analysis will show that the transient response of this system becomes increasingly oscillatory as the integral constant C_i is increased. Ultimately, for large values of C_i, the system becomes completely unstable.

The steady-state solution, however, can be determined readily by use of the operator-division process outlined in par. 16-4. The result is

$$\theta_o = \left[1 - \left(\frac{F}{KC_i}\right) p^2 + \ldots\right]\theta_i \tag{16-21}$$

The surprising conclusion drawn from Eq. 16-21 is that for ramp inputs, as well as for step inputs, there will be no steady-state error, i.e., no lag in the response. This removal of lag is, therefore, the most important trait of an integral control system. Fig. 16-9 gives a block diagram of an integral control servo.

If, as often occurs, the addition of integral control creates too much oscillation in the system output, the further addition of error-rate control will provide sufficient artificial damping for stable operation. Such multiple,

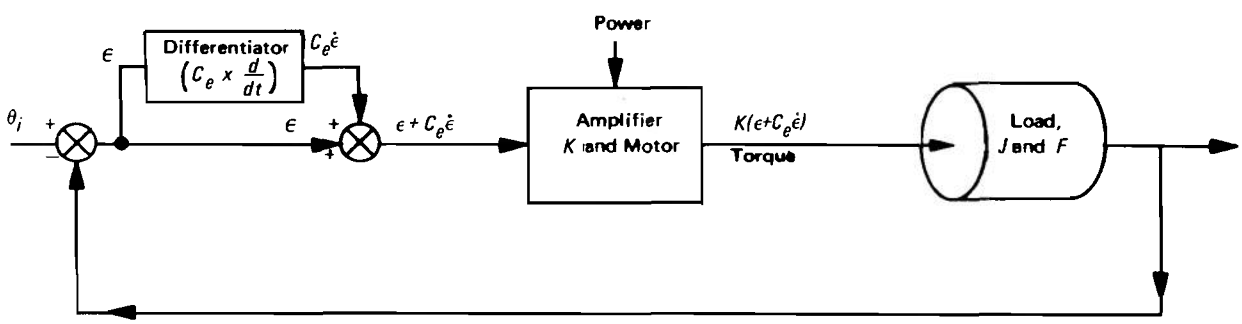


Figure 16-8. Error-rate Control Servo[1]

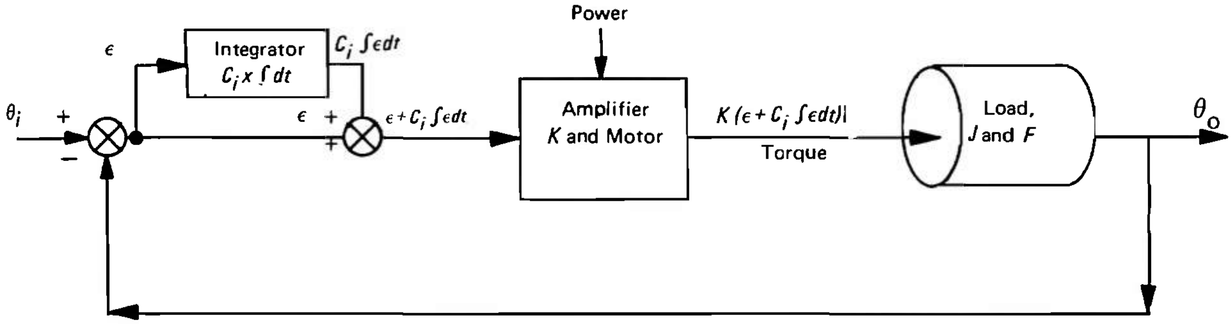


Figure 16-9. Integral Control Servo[1]

or compound, control systems are, of course, much more complicated and are beyond the scope of an introductory lesson on servomechanisms[1]

16-6 NONLINEAR SYSTEMS

The discussion of servo control systems presented in the preceding paragraphs of this chapter was restricted to linear systems. Physically, linearity implies the property of superposition, i.e., an input which is the sum of two or more separate signals will produce an output which is the sum of the outputs that would be produced by each of the separate signals. Mathematically superposition means that if $\theta_{i_1} \longrightarrow \theta_{o_1}$

and $\theta_{i_2} \longrightarrow \theta_{o_2}$

then $\theta_{i_1} + \theta_{i_2} \longrightarrow \theta_{o_1} + \theta_{o_2}$

For nonlinear systems this relationship, in general, will not be true. In addition while the differential equations of linear systems contain only first-degree derivatives of the form $d^n\theta,/dt^n$ where n is the order of the derivative, the equations for nonlinear systems will contain terms of second- or higher degree, of the form $(d^n\theta/dt^n)m$, $(d\theta/dt)(d^n\theta/dt^n)$, or combinations of these forms, where n is the order of the derivative and m is the degree of the term.

In practice, relative linearity may be achieved over specific ranges of operation. However, linear operation over a wide range of variation in the amplitude and frequency of the input signal would require components of extremely high quality The cost, size, and weight factors would in many cases make such a system impractical. In addition, a linearity requirement limits the realizable system characteristics, the types of systems, and the tasks that can be accomplished.

Nonlinearities are generally of two types—incidental and intentional. Incidental nonlinearities are secondary effects that limit performance in otherwise linear systems. Examples of phenomena that introduce incidental nonlinearities include backlash, saturation, dead zone, hysteresis, and coulomb friction. On the other hand, intentional nonlinearities are those introduced purposely to improve the characteristics of systems or to alter them in specified ways. The contactor (on-off or relay) servo is the most extreme example of such an intentionally nonlinear system[2]

The nonlinearities incidental to an intended linear system must be studied carefully to determine their effect on system operation and the need for corrective measures. If the nonlinearities are not dominant, various linearization techniques may be employed to simplify the analysis. The simplest of these techniques is approximation, in which a linear function is used to approximate a known, but very small, nonlinearity Common examples of approximation are assumptions of linearity in the speed of a servo motor as a function of voltage, and the gain of an amplifier. Other linearization techniques include incremental linearization in which only the first term of a Taylor series expansion of the nonlinear term around a given operating point is used, and piecewise linearization, in which the operating range is divided into a number of subranges and each is analyzed separately by linear methods and approximations. These techniques, along with describing function and phase plane methods for analysis of nonlinear systems, are described in detail in Refs. 2, 3, and 4 and are noted here only to emphasize the importance of recognizing the existence and possible effects of nonlinearities in designing a servo system, and to point out the available methods for accounting for such nonlinearities in analyzing system performance.

Some requirements are met best by nonlinear systems and in such cases the nonlinearities are intentional. The most important class of nonlinear systems are on-off systems in which the power amplifier is a relay, contactor, or other switching device. Characteristics of switching systems, in comparison with linear servo systems, are low cost, slow response, high power level capability, and generally less accuracy. Typical applications include thermostatically controlled heating systems and liquid level controls. In other cases, "nonlinearities may be intentionally introduced into a system in order to compensate for the effects of other undesirable nonlinearities, or to obtain better performance than would be achieved using linear elements. A simple example of an intentional nonlinearity is the use of a nonlinear damped system to optimize the response of a system in accordance with the magnitude of the error"[4]

16-7 SAMPLED DATA SYSTEMS

In the previous discussion of servo systems it was assumed that all signals in the system were continuous in time. One type of feedback control system exists, called a sampled data system, in which the signal at one or more points in the system appears as a train of pulses rather than as a continuous signal. If T is the length of time between pulses, the signal may be considered as being applied at times T, $2T$, $3T$, . . ., and the pulse repetition frequency is $\Omega = 2\pi/T$.

Fig. 16-10 shows the elements of a typical sampled data system. The input $r(t)$ may be composed of sampled or continuous data. The sampling device periodically samples the actuating signal $e(t)$ under control of the carrier signal supplied to it. The holding circuit is used to smooth the sampled output from the sampling device, and smoothed output of the holding circuit then drives the output member. It is evident that the components and signals in the system are combinations of discrete and continuous elements. Because part of the system operates on sampled data and part on continuous data, the analysis of system behavior is not easily carried out by conventional methods. For that part of the system operating on continuous data, conventional methods are best. For that part operating on sampled data, the use of sequences and linear difference equations is best. However, methods have been developed which treat sampled data systems from a unified viewpoint. These methods are covered in detail in Refs. 2 through 5 inclusive.

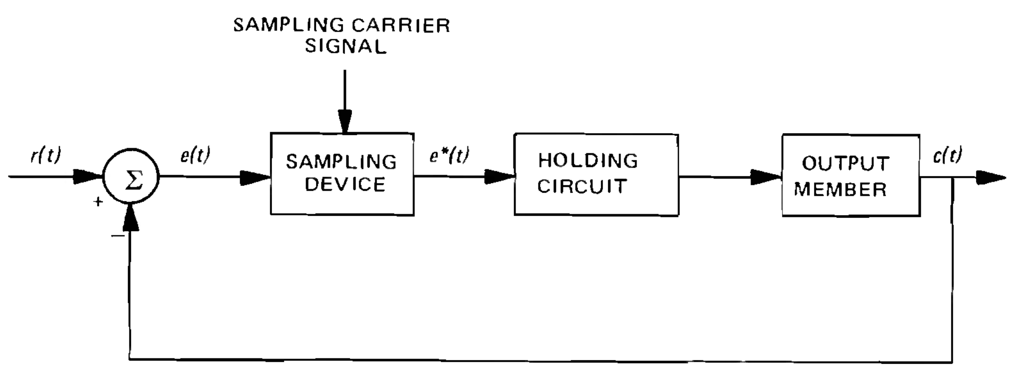
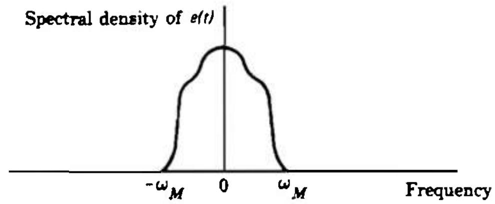
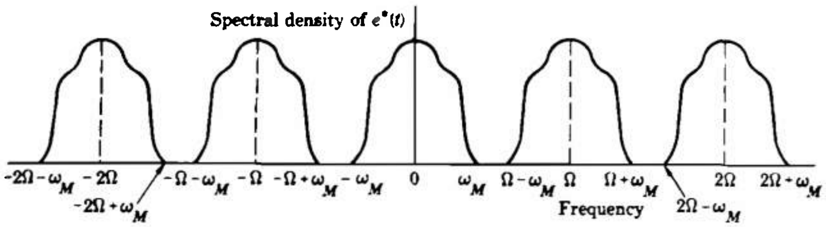


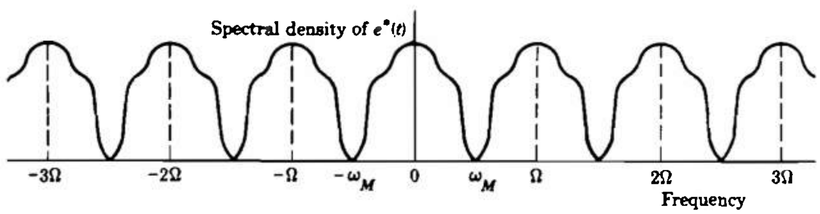
Figure 16-10. Sampled Data System



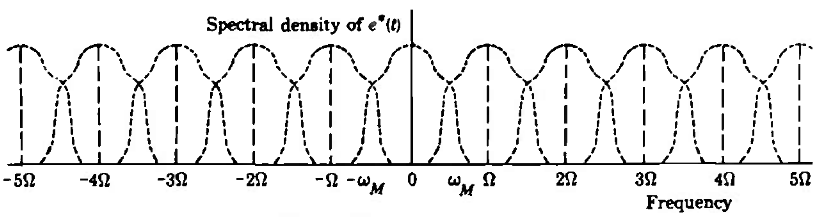
(A) SPECTRAL DENSITY OF UNSAMPLED ERROR SIGNAL $e(t)$



(B) SPECTRAL DENSITY OF SAMPLED ERROR SIGNAL $e^*(t)$ for $\omega_M < \Omega/2$



(C) SPECTRAL DENSITY OF SAMPLED ERROR SIGNAL $e^*(t)$ for $\omega_M = \Omega/2$



(D) SPECTRAL DENSITY OF SAMPLED ERROR SIGNAL $e^*(t)$ for $\omega_M > \Omega/2$

Figure 16-11. The Relation Between the Spectral Density of e(t) and That of e(t) (Ref. 5)*

If the sampling frequency is high compared to the signal frequency and the critical frequencies of the system, then the fact that the data are sampled has little bearing on system behavior. Otherwise, the effect of sampling may become quite pronounced. This may be illustrated as follows. If the frequency spectrum of the error is continuous as in Fig. 16-11(A), with a maximum frequency ω_M less than half the sampling frequency Ω then the frequency spectrum of the sampled error is as shown in Fig. 16-11(B). As the sampling frequency is decreased, the frequency interval between adjacent portions of the spectral density curve in Fig. 16-11(B) decreases also. It should be noted, however, that there is no overlapping of the separate sections of the spectral density curve as the sampling frequency is reduced to $2\omega_M$, as in Fig. 16-11(C)[5]. At this point there is still no overlapping, but the separate sections of the spectral density curve just touch each other.

If the sampling frequency if further reduced to a value less than $2\omega_M$ as in Fig. 16-11(D), the various portions of the spectral density curve for $e^*(t)$ overlap. If the harmonic components of $e^*(t)$ are in phase, then the resultant spectral density curve can be obtained by graphical addition of the individual curves shown by the broken lines in Fig. 16-11(D). If the harmonic components are not in phase, the resultant spectral density curve cannot be obtained so simply. However, in any event, it is evident that if $\Omega < 2\omega_M$ the spectral density curve for $e^*(t)$ no longer has the appearance of a periodic extension of that for $e(t)$ (Ref. 5).

Although the preceding shows the theoretical lower limit of the sampling frequency Ω to be twice the highest signal frequency ω_M, it is frequently necessary for practical reasons to use a sampling frequency much higher than twice the highest signal frequency. In addition, since signals generally do not have finite frequency spectrums and filters (holding circuit) do not have ideal frequency response characteristics, the recovered signal always has a certain amount of distortion. This distortion is called ripple. It occurs at the sampling frequency, and its harmonics should be treated as noise of the sampled data control system. Sampled data systems are used extensively in control systems employing digital computers in the control process, since these computers operate only with discrete numbers, and their signals are periodic by nature. Systems in which one or more of the elements are located remotely from the other elements also make frequent use of sampled data techniques. In these systems the signals are transmitted by telemetry. By using time domain multiplexing, in which each signal being transmitted is sampled periodically and the time between samples of one signal is used to sample other signals, many signals can be transmitted over a single communication link (hard wire, RF channel, etc.) at a substantial savings in cost, size, and weight of equipment. Control systems using signals from radar equipment may also employ sampled data techniques since radar signals are also periodic in nature.

16-8 SUMMARY

The necessary ingredients for a servomechanism are:

1. An input that activates the system.

2. A differential that detects the error between input and output.

3. A controller that drives the output in response to the error signal.

4. An output that is the desired motion.

5. A feedback signal that indicates the amount of motion or position of the output.

Without the feedback device we would have an open-loop system with its inherent disadvantage of inaccuracy. With feedback we have a servomechanism with greater accuracy, speed of response, and flexibility.

A servo can become unstable under certain conditions. However, with the addition of compensating elements—such as integrators or differentiators—stability is restored and overall response is vastly improved. The basic servomechanisms are described in terms of second-order linear differential equations which may be solved easily by either classical mathematics or modern computers. By varying the constants of these equations and observing the effect on system response, a control system designer is able to build a device which will satisfy his requirements. For example, he may want a system capable of (1) holding a missile on a prescribed course; (2) maintaining a chemical process at a certain temperature; or (3) rotating a gun turret to a desired heading. For each requirement a different design problem must be solved, i.e.,

1. *Position control*

$$\theta_o = \left[1 - \left(\frac{2\zeta}{\omega_n}\right) p + \ldots\right] \theta_i \qquad (16\text{-}22)$$

No steady error for step inputs.

$\left(\frac{2\zeta}{\omega_n}\right)$ sec lag for ramp inputs

2. *Derivative feedback*

$$\theta_o = \left[1 - \left(\frac{2\zeta}{\omega_n}\right) p + \ldots\ldots\ldots\right] \theta_i \tag{16-23}$$

No steady error for step inputs.

$\left(\frac{2\zeta}{\omega_n}\right)$ sec lag for ramp inputs

Artificial damping introduced.

3. *Error-rate control*

$$\theta_o = \left[1 - \left(\frac{2\zeta}{\omega_n} - C_e\right) p + \ldots\right] \theta_i \tag{16-24}$$

No steady error for step inputs.

$\left(\frac{2\zeta}{\omega_n} - C_e\right)$ sec lag for ramp inputs

Artificial damping introduced.

4. *Integral control*

$$\theta_o = \left[1 - \left(\frac{F}{KC_i}\right) p^2 + \ldots\right] \theta_i \tag{16-25}$$

No steady error for step or ramp inputs.

Engineering Design Handbooks AMCP 706-136 (Ref. 2) through -139 provide extensive coverage of servomechanisms supplementing the brief introduction to the subject that has been presented in this section. (Also see Bibliography.)

SECTION II

SERVOMECHANISM APPLICATIONS

16-9 INTRODUCTION

Servomechanisms are applied to a limited extent on military vehicles. They are regularly employed to control military vehicle weapon systems. Steering, suspension, and vehicle remote control systems comprise the majority of other servomechanism applications that the military vehicle electrical system designer may encounter.

16-10 VEHICLE REMOTE CONTROL

Vehicle remote control may be described as a system in which the velocity (speed and direction of motion) of a vehicle*, and the functional operation of auxiliary or special purpose equipment on the vehicle, are controlled from a point physically remote from the vehicle. The system must include communication links between the vehicle and the control point, through which control signals are sent from the control point to the vehicle, and feedback signals are sent from the vehicle to the control point.

A remote-control system as defined here is a closed-loop system that must consist of at least the following elements:

1. Sensors of information

2. A transmission system to communicate information to a remote control point

3. A control point which includes a human or automatic decision-making system

4. Devices to translate information into appropriate control signals

5. Links to communicate information to actuators at remote action points

6. Actuators operated by control signals to effect responsive controlled operations[3]

The interrelationship of these elements is shown in Fig. 16-12.

As applied to military vehicles, Items 1 and 2 preceding, which comprise the feedback function of a closed-loop system, may consist of transducers (speed sensors, gyro compass, position sensors, television cameras, etc.) which convert sensed and measured physical data to electrical signals and either a hard wire or radio wave communication link. However, these functions may be served entirely by human vision, in that the remote (human) controller is in a position to see the vehicle that he is controlling. The system is still closed-loop, in spite of the absence of "technological" hardware in the feedback circuit.

The communication link used for transmission of control signals, Item 5, may consist of hard wire lines or a radiation link (radio, microwave, laser, or ultrasonic). Signals sent via a radiation link usually will require modulation of a carrier frequency with the control signals; while hard wire signal transmission may or may not include carrier modulation. The modulation method may be amplitude modulation (AM), frequency modulation (FM), pulse modulation (Pulse-Code, PCM; Pulse Duration, PDM; Pulse Amplitude, PAM), or some variation or combination of these. If more than a few signals must be carried by either the control or feedback communication link, it may be advantageous to use multiplexing techniques to reduce the number of communication channels required. The decision of whether or not to use multiplexing generally will be based on the

*Vehicles under consideration here are automotive, ground vehicles. The term vehicle in its broader sense includes aircraft, ships, missiles, satellites, etc., for which the same basic principles of remote control apply, but for which many other factors must be considered. These vehicles and factors are not considered in this handbook.

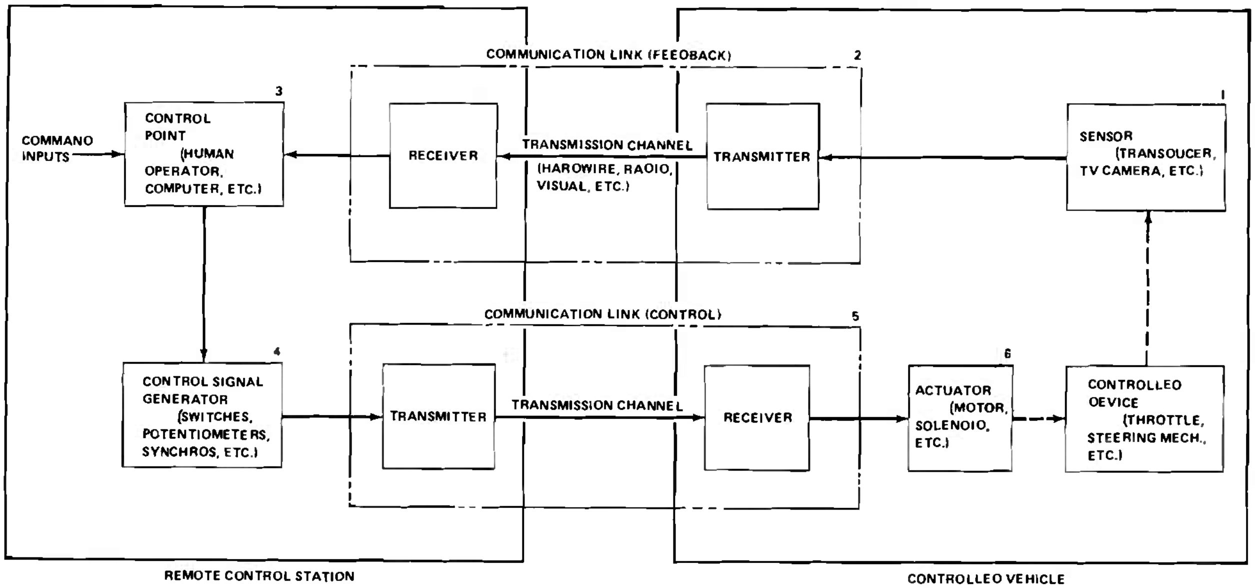


Figure 16-12. Interrelationship of Essential Elements of a Vehicle Remote-control System

results of a trade-off study involving cost, weight, size, reliability, electromagnetic spectrum requirements (in the case of radiation links), and all other relevant factors.

Detailed engineering and design data relating to remote control systems are beyond the scope of this handbook. For this information, the reader is referred to Ref. 3, references noted therein, and the many other available books on the subject of remote control.

In military vehicles, the decision making function, Item 3, will include almost always a human operator. For this reason it is essential that human factors be given adequate consideration in the design of the system in order to assure successful operation. This consideration should include both the physical aspects of the system design—such as arrangement of control and indication equipment, illumination, color selection, environmental factors—and the operational aspects such as operator response time requirements, necessity for simultaneous operations, and simplicity and "naturalness" of both normal and emergency operating procedures. These factors may necessitate the inclusion of an automatic secondary control loop for those functions which require a fast response time or which, by unnecessarily complicating the operational requirements placed on the human operator, would increase the probability of human error. Assessment of these human factors prior to making system operational and physical design decisions also should include the effect on the probability of mission success when trade-offs are made between a simplification in human operator requirements accompanied by an increase in hardware complexity, and vice versa.

16-10.1 APPLICATIONS OF REMOTE CONTROL

Applications of remote control operation to military vehicles are, in comparison to normal operation, very expensive and complex. Its use must, therefore, be restricted to those applications in which it is undesirable or impracticable to include a human operator on or in the vehicle itself during its intended mission. In most cases in which remote control of a vehicle is used, the reason is based on factors involving hazardous environments which threaten the safety of personnel. In some cases the reason is improved performance capabilities with the operator removed from the vehicle.

Examples of application in which safety is the motivation would include the following:

1. Material retrieval or other operations in a radioactive area

2. Removal and disposal of live explosives or other dangerous material

3. Control of vehicles being used as gunnery targets

4. Control of fire fighting vehicles to permit them to get closer to a fire for more effective application of water, foam, chemicals, or other fire extinguishing agents

5. Destructive or nondestructive testing of vehicle beyond specified performance parameters to determine performance capabilities, or to test ability to withstand enemy action.

Experimental applications of remote control to earth-moving equipment have indicated a marked increase in efficiency is possible through reduced driver fatigue and the ability of the operator to position himself for better observance of the bulldozer blade operation.

Since remote control of vehicles is a relatively new field, applications may be expected to expand considerably as more experience and knowledge are accumulated, and as costs are reduced through technological advances and increases in production volume of components.

16-10.2 SYSTEM CONFIGURATIONS

Several examples of vehicles built with remote control systems are described:

1. Mobile Remote Manipulator Unit (MRMU), built for U.S. Air Force, consists of a remotely controlled tracked vehicle on which are mounted two manipulator arms. The remote control station is a van which may be located up to a mile away. The vehicle permits an operator in a safe environment to accomplish recovery and salvage operations in a hazardous environment. Control signals are multiplexed and transmitted over an FM modulated microwave link. Feedback is visual, through the use of four TV cameras arranged to give a three-dimensional display to the operator for depth perception. The TV signals are transmitted from the manipulator to the control van via an FM modulated microwave link. See Fig. 16-13.

Electrical actuators (motors, solenoids, linear actuators) up to 1 hp are controlled by the MRMU servo system. Those actuators associated with the manipulators are the final power elements, while those associated with vehicle control are pilot devices for the mechanical traction and steering systems.

2. Remote Underwater Manipulator (RUM), built for the Office of Naval Research, U.S. Navy, is a remotely controlled tracked vehicle designed for bottom crawling on the ocean floor at a distance of up to five miles from the operator. The RUM is equipped with TV cameras for search and visual feedback, and a manipulator arm for retrieval of material. Both the control and the feedback communication links are passed through a 5-mile long cable that is played out as the vehicle advances. See Fig. 16-14.

3. Radio Remote-controlled Traxcavator. This vehicle, shown in Fig. 16-15, is a caterpillar 977H traxcavator which was modified to be remotely operated by an off-vehicle operator controlling the vehicle bulldozing or other earth moving activities. Control signals for 14 separate vehicle functions are generated on a portable, operator-held, control panel, and transmitted on amplitude modulated radio units, using 10 tone signals. The feedback loop is entirely visual, with the operator directly viewing the operation of the vehicle and the equipment mounted on it.

The final electrical elements in this system are solenoid values of less than 50 W. These values serve as pilot devices in the hydraulic

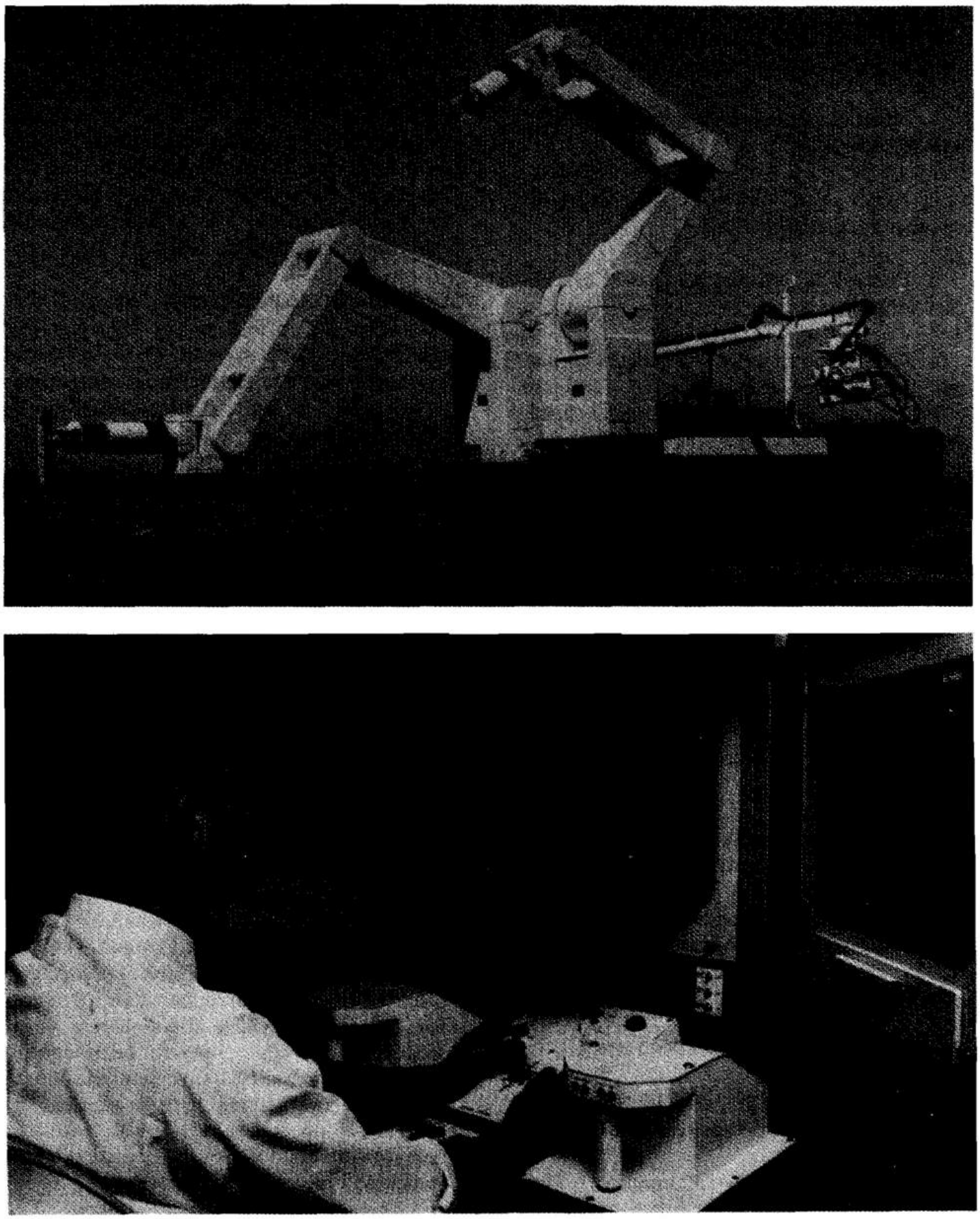


Figure 16-13. Mobile Remote Manipulator Unit (MRMU)

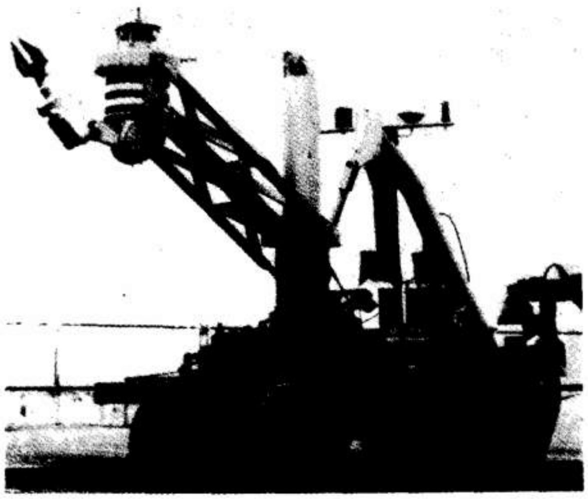


Figure 16-14. The Remote Underwater Manipulator (RUM) (U.S. Navy Photograph)

power transmission system operating the dirt bucket, and in the mechanical traction and steering systems.

16-11 WEAPON SYSTEMS

Control of weapon systems was one of the earliest applications of modern linear closed-loop servo systems and components. Indeed, the need for highly accurate means of controlling weapon systems was one major impetus behind the significant advances made during the past 50 yr in both the theoretical methods of system design and analysis, and the variety and quality of actual hardware components.

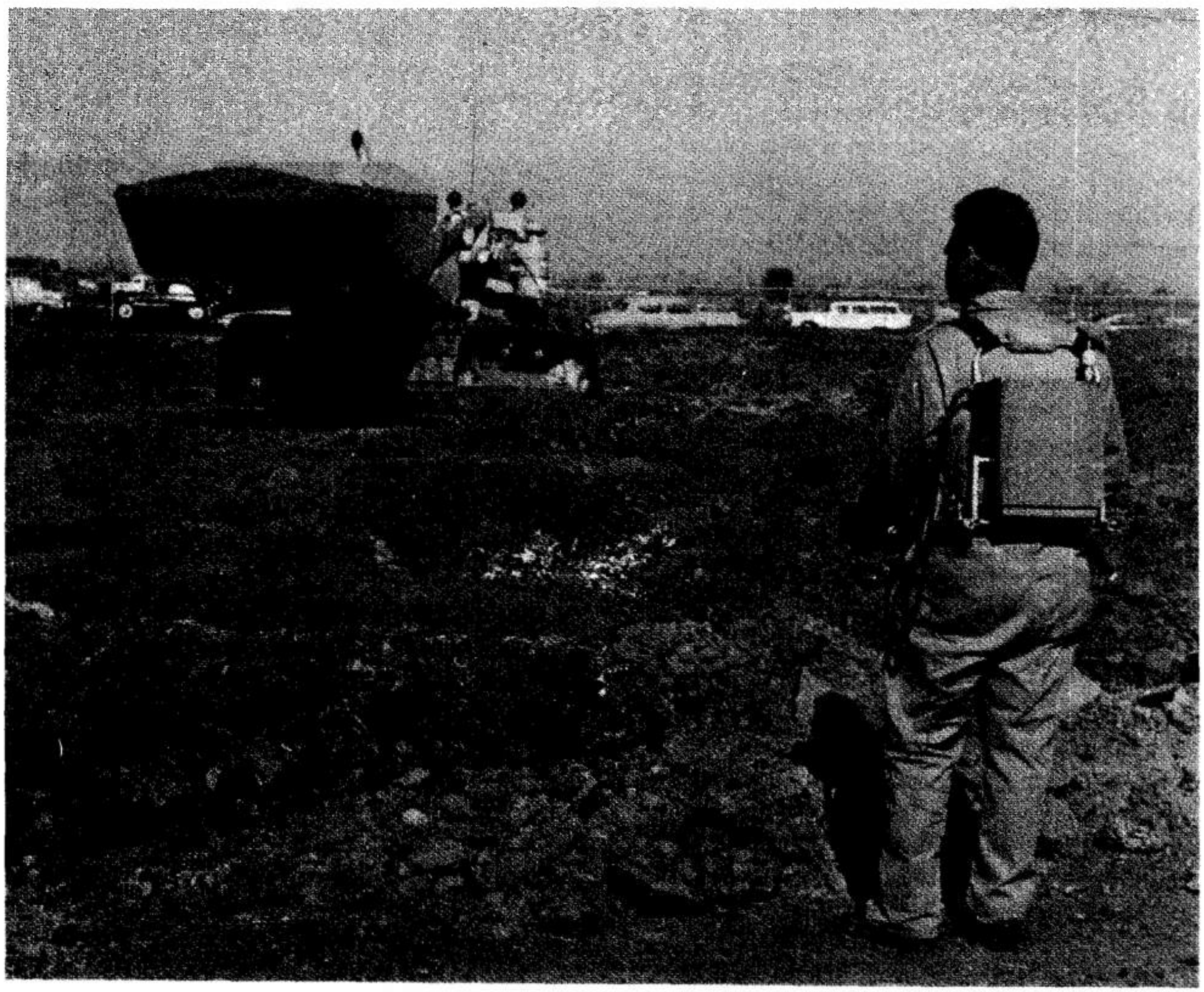


Figure 16-15. Radio Remote-controlled Traxcavator

Applications of servo systems on modern weapon systems are many, including aiming (both elevation and azimuth), stabilization of the weapon platform on a moving vehicle, and–in some cases–launching. For guided weapons–including missiles, torpedoes, and guided bombs–servo systems continue to control the projectile after it has left the launching device and may continue until impact, or may end at some intermediate time, at which point the projectile becomes ballistic.

For more detailed data on weapon systems in vehicles and the application of servo systems to weapons, the reader is referred to Chapter 17 and to Refs. 1 and 6.

16-12 SUSPENSION SYSTEMS

The application of electrical servomechanisms to military vehicle suspension systems is in its early and still experimental stages. The specific areas being given attention are load leveling and dynamic ride control. Load leveling is essentially the same function as performed by the stabilization servos in a weapon control system except that in some cases output loads might be much greater and rates of motion slower. An example of this application is the transporter vehicle used by NASA for moving large rockets from the assembly building at Cape Kennedy to the launch pad. In this vehicle, the large forces required–combined with low response speed and relatively small response displacement–made the use of hydraulically powered actuators advantageous for the power output stage.

Dynamic ride control systems are being studied as a means of making increased speeds feasible for military vehicle on off-road operation. This application uses remote terrain sensors to detect obstacles or ground level variations in front of the vehicle. These signals are used to activate a controlled suspension system to soften the impact stresses on the vehicle, the operator and other occupants, permitting higher speeds to be attained before limits of stress on man and machine are reached. A more complete description of this type of system is contained in Ref. 7.

16-13 STEERING SYSTEMS

Servo control concepts have been used for many years in the familiar power steering systems of automotive vehicles. However, these systems, while employing the same principles contained in Section I of this Chapter, have almost all been implemented with hydraulic components and circuitry rather than electrical. While this has been based primarily on cost factors that have favored hydraulic systems in the past, the same may not always be true in the future. This would be particularly so in the case of what might be called unconventional or special-purpose vehicles. For example, electric drive vehicles–with comparatively large amounts of electrical power available for propulsion purposes–might use electric steering control of speed ratio of left and right drive wheels. Remote-control vehicles would obviously require electric or electrohydraulic steering servo systems, and vehicles with special steering requirements would justify the consideration and possible use of electric or electrohydraulic steering. A recently developed fork-lift truck for shipboard missile handling operations required four-wheel steering control to effect normal, pivot, or "crab" steering. The various modes of steering in this situation made an electric steering system the most suitable to use.

Electric and electrohydraulic servo systems have been used for many years for ship steering control. A recent unique application of servo-controlled water steering on a military vehicle was made on the LVTP , a Marine Corps amphibious, tracked landing craft. When operating in the water, this vehicle is steered by controlling the position of deflectors which divert the water stream emanating from the water jet propulsion units. The control system is a nonlinear, electrohydraulic servo system, with the command signal being supplied by a potentiometer linked to the steering wheel; and position feedback is supplied by a potentiometer linked to the deflector mechanism.

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CHAPTER 17

WEAPON SYSTEMS

SECTION I

VEHICLE WEAPONS

17-1 INTRODUCTION

A weapon system is defined as a weapon and those components required for its operation. Weapon system components (or subsystems) are frequently electrical in nature or have electrical requirements.

This chapter includes weapon systems ranging in size from light machine guns to howitzers. The chapter is limited, however, to those systems in which the vehicle designer has some degree of responsibility for the function of the weapon and, therefore, some control over the design of the subsystems and components. The HAWK and CHAPARRAL missile systems are among those excluded. Although these systems utilize a ground vehicle for mobility, they are designed to operate as independent weapon systems and their subsystems and components are an integral and unique part of the weapon system. Therefore, the vehicle becomes an auxiliary part of the weapon system.

The SHILLELAGH system is included because it was specifically designed for use as the primary armament in tanks and therefore has a special importance for vehicle system designers.

Weapon station subsystems are categorized into four groups for discussion in this chapter, i.e.,

1. Fire control systems which include equipment required to acquire targets, determine the correct lead, and traverse and elevate the weapon. In addition, weapon stabilization systems are included.

2. Ammunition feed and armament systems which include equipment to charge, feed, and fire the weapon.

3. Missile systems which include equipment required to aim, fire, guide, and track the missile.

4. Support systems which include power distribution, lighting, and ventilation equipment.

Weapon systems utilize these subsystems to varying degrees depending on the complexity and size of the weapon. The complexity of the subsystems is often at the discretion of the designer. Functions which can be performed manually or mentally by the vehicle commander or gunner can normally be automated by an electrical or electronic system. In each case, however, the designer must consider the trade-offs between increased system performance and possible decreases in maintainability and reliability.

The M60A2 (Fig. 17-1) Weapon Station mounts a 152 mm combination gun and missile launcher (SHILLELAGH) as primary armament. Secondary armament consists of a coaxial M73 Machine Gun and a cupola-mounted M85. Electrohydraulic power controls allow the commander or gunner to traverse and elevate or depress the primary and secondary armament at low tracking rates or high quick-reaction rates. The primary and

Figure 17-1. M60A2 Tank

secondary armament are independently space stabilized. Synchro resolver links between the commander's and gunner's sights and memory circuitry allow the commander to take control of the primary armament and bring it to bear on his line of sight at any time. Fire control equipment includes a laser rangefinder, passive (image intensifier) night sights, and solid-state ballistic computer.

Fig. 17-2 shows the M27 Weapon Station mounted on the M114A2 vehicle. The M27 Weapon Station allows the vehicle commander to fire the M139 (20 mm Automatic Cannon) during open or closed hatch operations. The M27 has electrohydraulic power controls, an electrical charger, an electrical firing mechanism, and an externally mounted passive (image intensifier) night sight. New developments in weapon stations include stabilization systems, laser rangefinders, and passive night sights.

Weapon station stabilization systems provide a "fire on the move" capability that dramatically increases the effectiveness of combat vehicles. These systems have been tested extensively and are currently standard equipment on the M551 and M60A2 Tanks.

Laser rangefinders provide increased accuracy over optical rangefinders, especially at long range. In addition, the laser rangefinder offers advantages with regard to physical integration into the weapon station and functional integration into the fire control systems.

Considerable development work has been accomplished on night vision sights. Generation I image intensifiers are in production and are utilized in the M60A2 and M551 Tanks. Generation II image intensifiers are being produced in limited quantities and are speci-

Figure 17-2. M27 Weapon Station, M114A2 Vehicle

fied for new vehicle programs. Far infrared or thermal imaging equipment has been evaluated and offers significant advantages for future applications if technical problems can be resolved and costs reduced.

17-2 WEAPON TYPES

Large caliber weapons may be categorized into mortars, howitzers, and guns. These are functional definitions dependent on muzzle velocity and trajectory. Mortars have low velocities and high trajectories. Guns have high velocities and flat trajectories. Howitzers have medium velocities, and high or low trajectories[1].

Each type of weapon has unique subsystem requirements. Mortars are normally operated without electrical subsystems and therefore will not be further discussed. Howitzers are normally used against area targets at long ranges. They, therefore, require elevation and azimuth drives capable of accurately laying the weapon. Guns are often used against moving point targets. The elevation and azimuth drives therefore must be capable of smooth low tracking rates as well as accurate pointing. In addition, ballistic computer, firing circuits, and other electrical subsystems may be required.

The 152 mm gun launcher used in the M551 and the M60A2 is a combination gun and missile launcher capable of launching the SHILLELAGH missile or firing 152 mm conventional ammunition. This system has all the requirements of a conventional tank gun. In addition, special requirements are imposed by the SHILLELAGH missile. These requirements are discussed in par. 17-17.

Small and medium caliber weapons used on combat vehicles include the cal .30, 7.62 mm, and cal .50 machine guns, and M139 or M61 Automatic Cannons.

Machine gun (MG) installations vary in complexity. The M2 cal .50 Machine Gun installation on the M113A1 vehicle (Fig. 17-3) is completely manual in operation. The M85 cal .50 Weapon Station on the LVTP7 (Fig. 17-4) has an electrohydraulic power drive and an electrical firing circuit with safety interlocks.

The M139 20 mm Automatic Cannon (Fig. 17-5) normally is fired by a solenoid firing circuit. The M27 Weapon Station, which incorporates this cannon (Fig. 17-2), also provides an electric charger and a burst control selector that limits the number of rounds fired per burst as well as the rate of fire of the weapon. In addition, the M27 has backup mechanical systems so that the M139 still can be fired although at a lower performance level in the event that the vehicle electrical system fails.

The M61 Automatic Cannon (Fig. 17-6) cannot be fired without electrical power. The ammunition (different from the M139 ammunition) is fired by an electrical primer, and the weapon is driven by an electric motor. The electric drive motor increases reliability because it will cycle misfired rounds through the weapon and eject them. Normal weapons operated by recoil or blowback are stopped by misfired rounds. The maximum firing rate of the M61 (6,000 rounds/min) necessitates a rather sophisticated ammunition feed system.

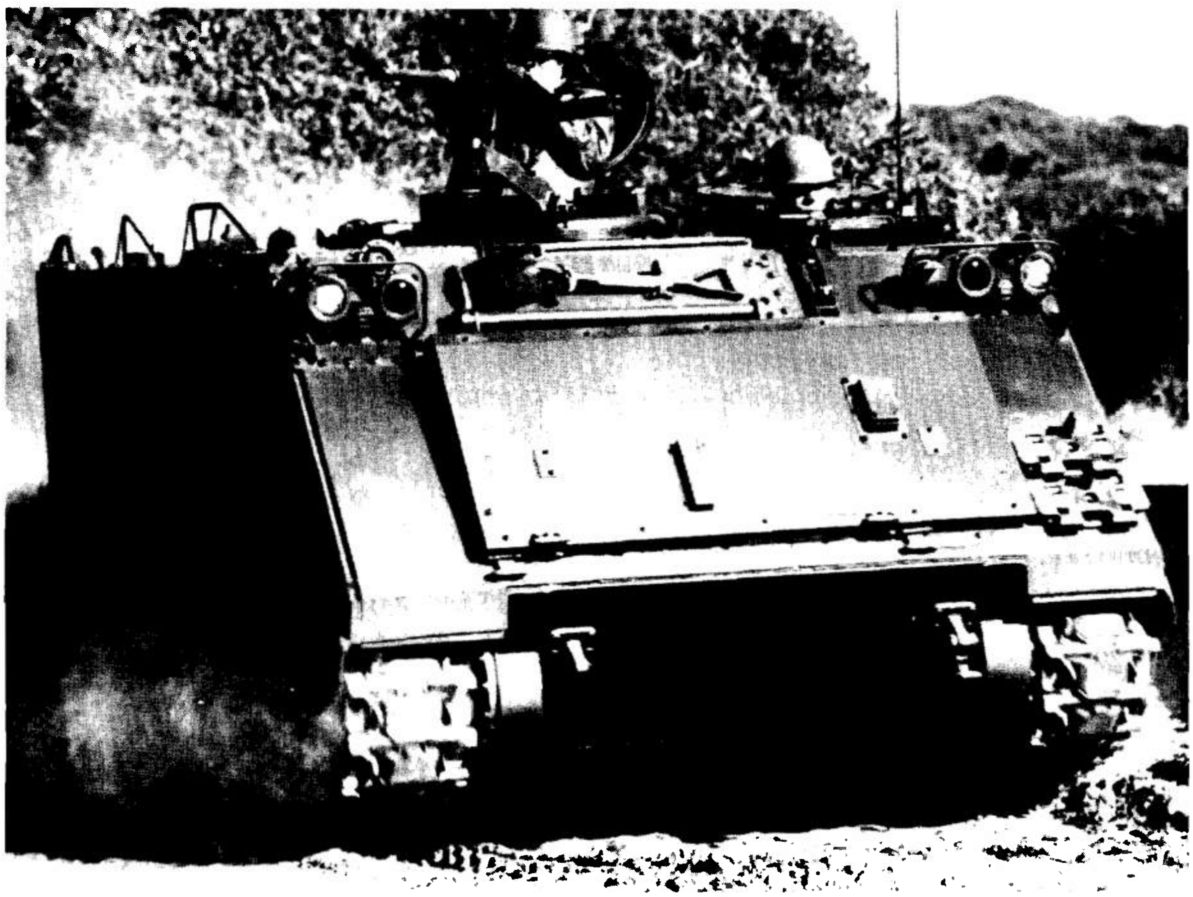


Figure 17-3. M113A1 With Cal .50 M2 Machine Gun

Figure 17-4. LVTP7 With Cal .50 (M85) Weapon Station

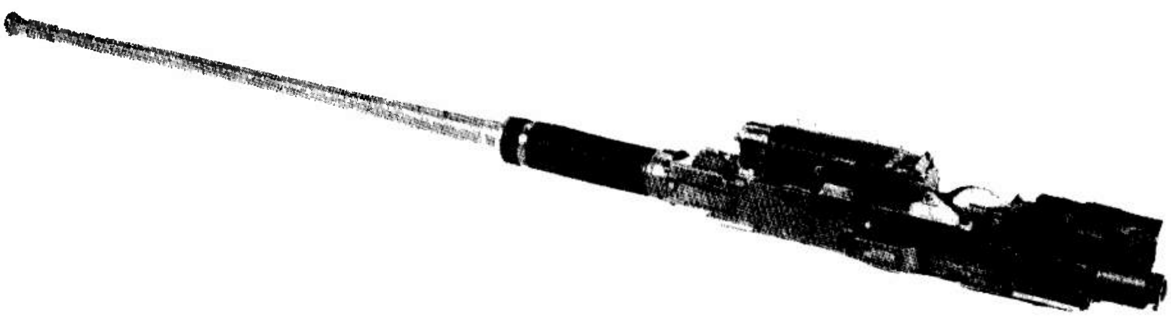


Figure 17-5. M139 20 mm Automatic Cannon

Figure 17-6. M61 20 mm Automatic Cannon

SECTION II

FIRE CONTROL SYSTEMS

17-3 INTRODUCTION

Fire control systems include all equipment required to align a weapon with a target and to compensate for target movement, weapon movement, and projectile trajectory. Hardware includes sights, rangefinders, ballistic computers, elevation drives, azimuth drives, and stabilization systems.

The trend in each hardware area is toward more electrical equipment. Optical sights for daylight use are being replaced by electro-optical day/night sights. Optical rangefinders are being replaced by electro-optical (LASER) rangefinders. Mechancial analog computers are being replaced by electronic computers.

17-4 WEAPON SIGHTS

A weapon sight provides a reticle focused at infinity and bore-sighted with the weapon axis. In addition, optical magnification is normally provided.

Functionally, sights are categorized into day sights, night sights, and integrated day/night sights. Physically, sights can be categorized into telescopic sights (used during open hatch operations), periscopic sights, and articulated telescopic sights.

Figs. 17-7 through 17-10 illustrates typical sights used on combat vehicles. The M51 (Fig. 17-7 and Fig. 17-8) is the integrated day/night periscopic commander's sight for the M60A2 Tank. The M127 Articulated Telescopic Sight (Fig. 17-9) is used in the M551 SHERIDAN Tank. Fig. 17-10 illustrates the ANTVS-2 Telescopic Night Sight, the XM61 Lead Compensating Reflex Sight, and the XM134 Telescopic Day Sight mounted on XM163 VULCAN Air Defense System. The reflex sight is a wide field of view sight without magnification used against high speed (aircraft) targets.

The integrated day/night sight utilizes common optical and electrical components in the day and night channels to the maximum possible extent to minimize system volume, weight, and cost.

The topics discussed in pars. 17-4.1 through 17-4.4 that follow pertain to sights in general. Par. 17-4.5 discusses night sights in particular.

17-4.1 RETICLES

There are two types of reticles used in optical systems. The first type of reticle is placed in a focal plane and is edge lighted (i.e., illuminated from the side). This is referred to as a focal plane reticle. The second type is a projected reticle. The projected reticle normally requires more illumination than the focal plane reticle, but has optical advantages for some systems. In some applications, the focal plane reticle may not require illumination or may be used in an emergency without illumination. The comments that follow apply to both types of reticles:

1. The reticle must be evenly illuminated. This is primarily an optical problem, but is affected by the size and type of lamp filament.

2. The reticle illumination must be continuously variable. This usually is accomplished by a rheostat.

3. The life of the illumination lamp and ease of replacement are of prime importance. In the M20 Periscopic Sight (Fig. 17-11) the reticle is edge lit by an M36 Instrument Light shining through a hole in the side of the sight. This allows easy replacement of the lamp. Use of the M36 is not recommended, however, since it uses flashlight batteries and has no provisions for using vehicle electrical power.

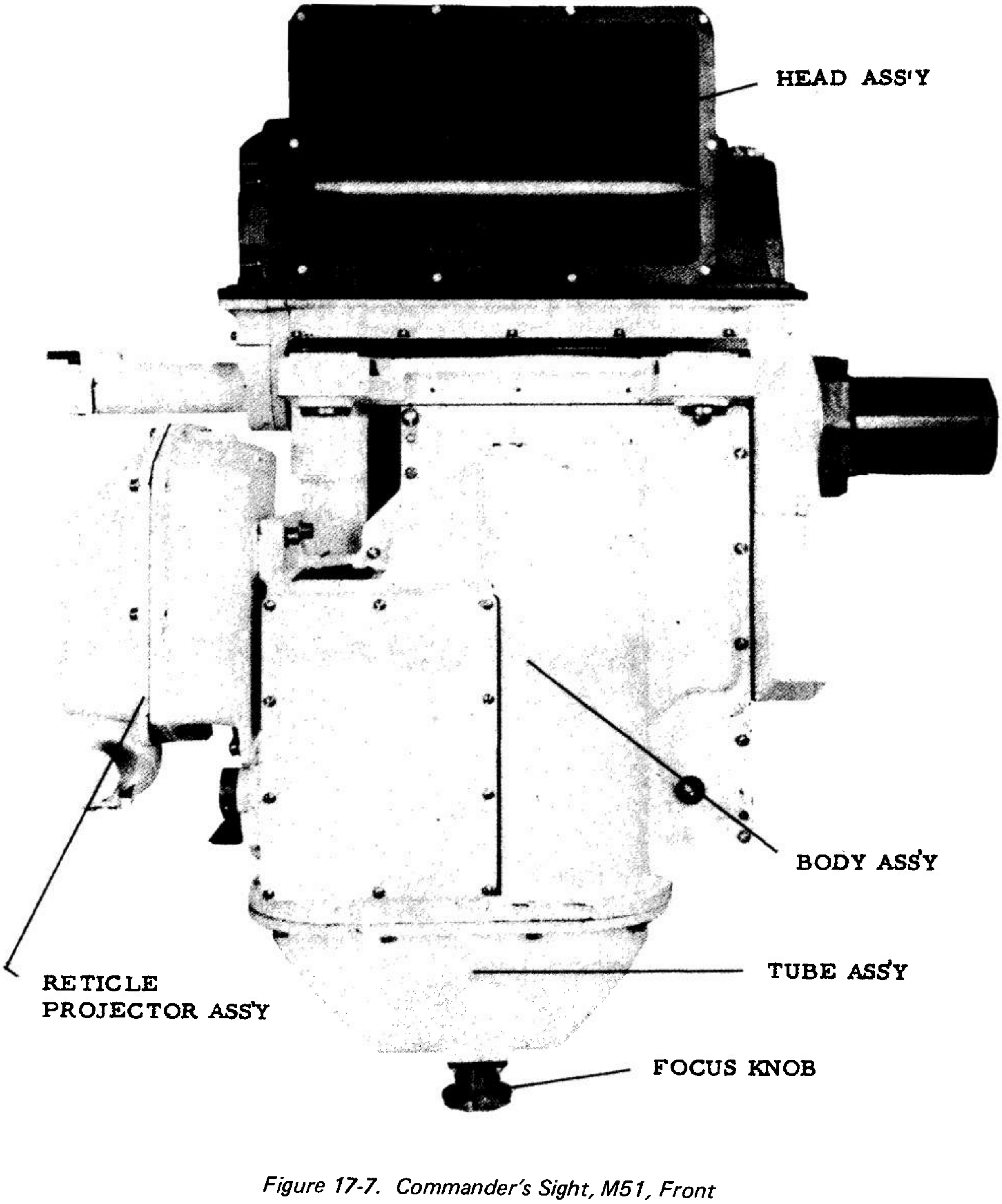


Figure 17-7. Commander's Sight, M51, Front

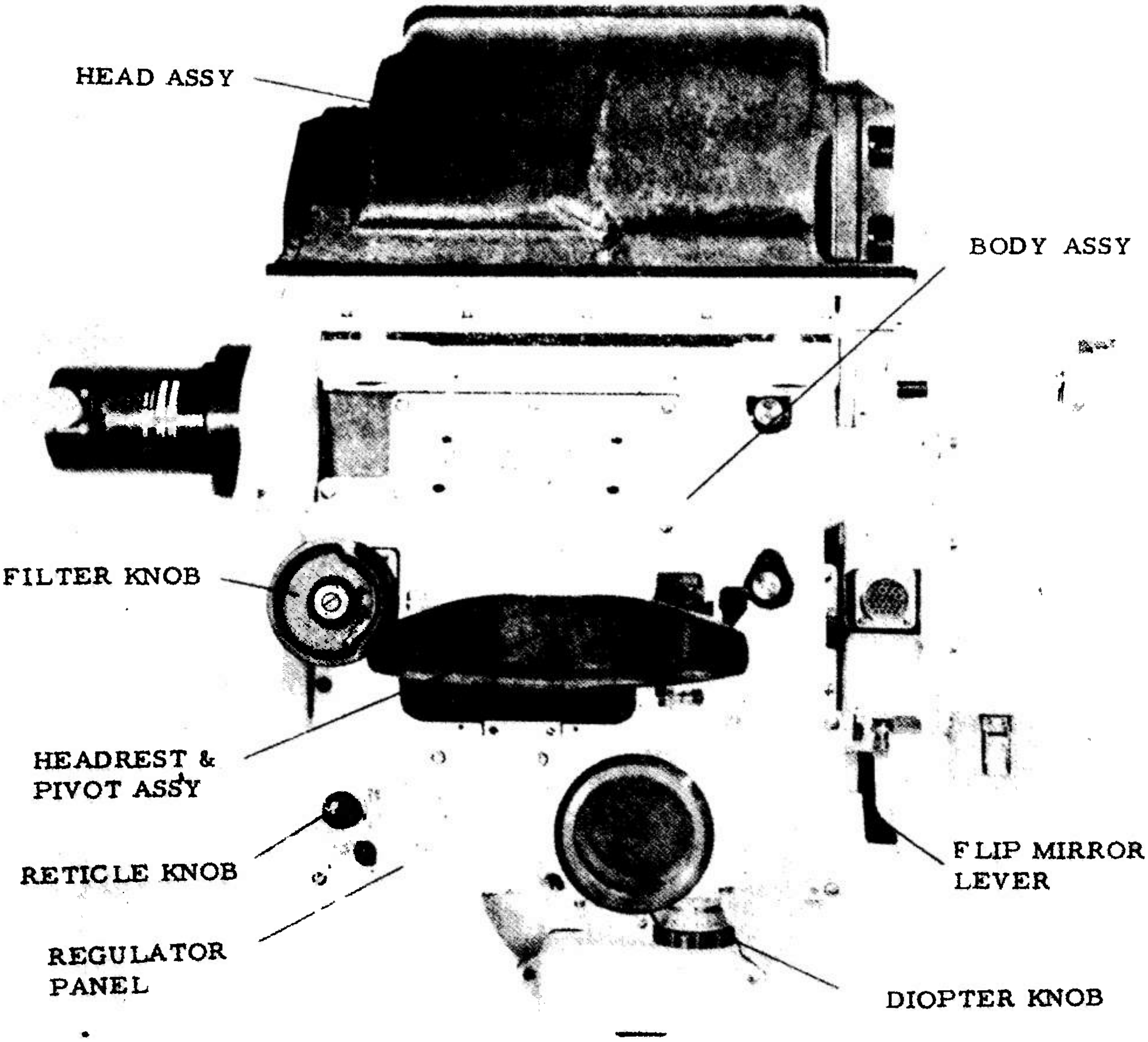


Figure 17-8. Commander's Sight, M51, Rear

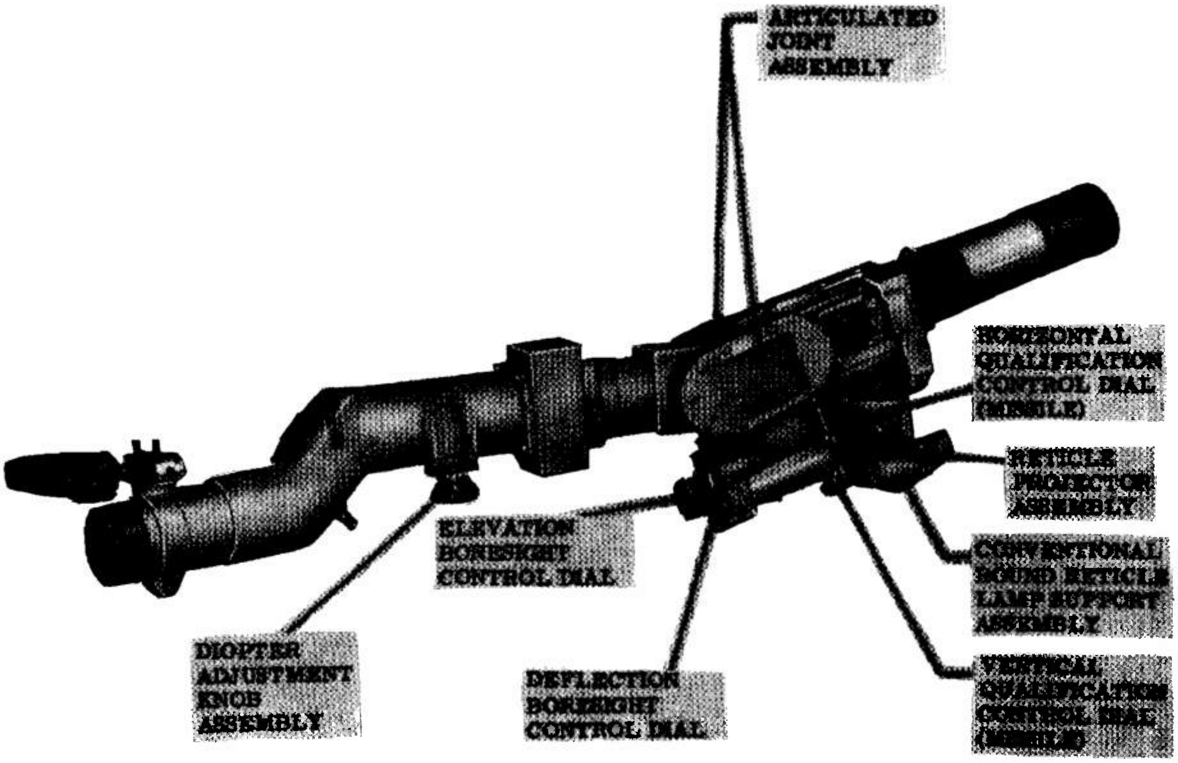


Figure 17-9. M127 Articulated Telescope

In some applications where the reticle is inaccessible, fiber optic light guides could be used to pipe light to the reticle from an externally mounted (accessible) illumination source[2].

17-4.2 SIGHT ARTICULATION

Periscopic sights are rigidly fixed in azimuth with respect to the weapon. In elevation, however, the line-of-sight is elevated and depressed coaxially with the weapon by a prism or mirror in the head of the periscope (Fig. 17-12). The mirror or prism normally is driven by the weapon through a parallel bar linkage.

The mirror or prism however can be driven by a servo system. A servo system is used between the primary armament and the M51 Commander's Sight in the M60A2. A servo system is normally more expensive than a parallel bar linkage, but offers the following advantages:

1. The sight can be rotated in azimuth with respect to the weapon. The servo signal can be fed through a slip ring. In the M60A2, this allows the commander's cupola and sight to be slewed independent of the primary armament without eliminating the commander's ability to sight and fire the primary armament. When he fires the primary armament, his cupola and sight are aligned in azimuth (by an azimuth servo system) with the primary armament and aligned in elevation by an elevation drive servo system. Fig. 17-13 shows the elevation drive servo system including the elevation servo motor. The commander's sight is coupled to the secon-

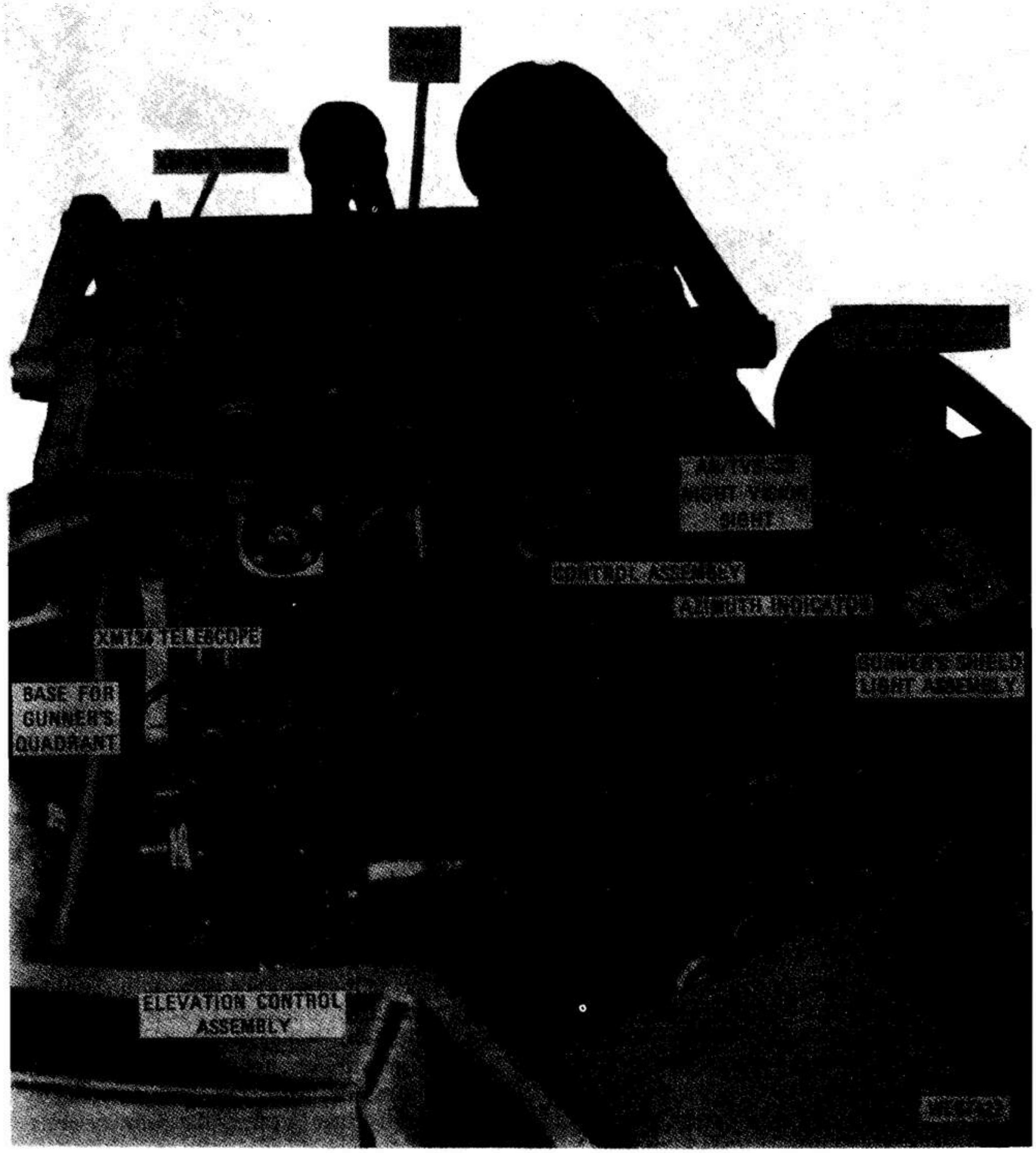


Figure 17-10. VULCAN XM163 With Telescopic Day Sight, Reflex Sight, and Telescopic Night Sight

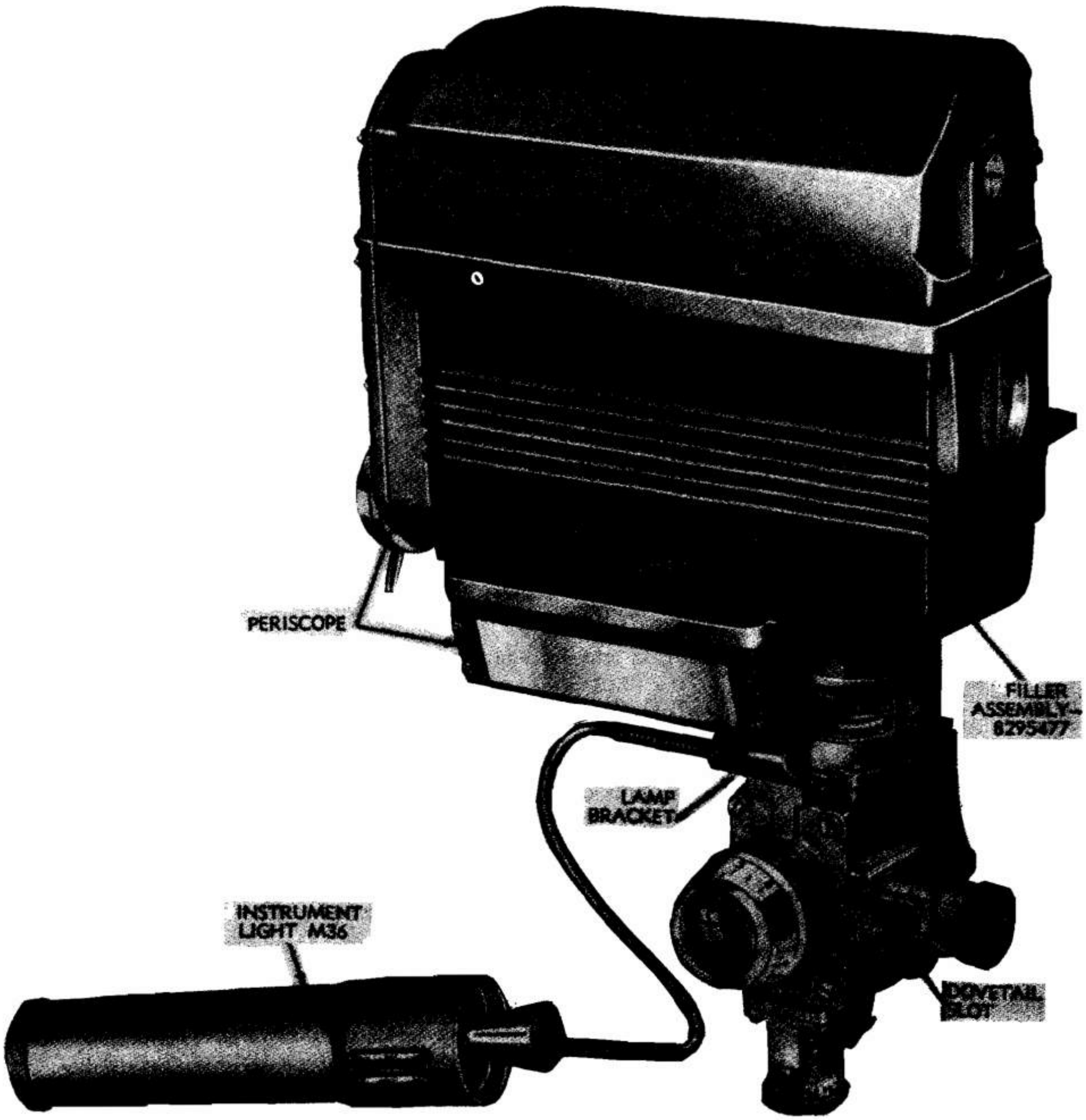


Figure 17-11. M20 Sight With Reticle Illuminator

dary armament (cal .50) in his cupola by a four-bar linkage.

2. Resonant vibrations in parallel bar linkages can be a serious problem resulting in fluttering of the elevation mirror and blurring of the image. Parallel bar linkages characteristically have low resonant frequencies, often in the range of vehicle resonant frequencies. This is especially critical in stabilized weapon systems where a blurred image may eliminate fire on the move capability. A properly designed servo system can eliminate resonance present in the linkage and dampen vehicle resonance vibrations.

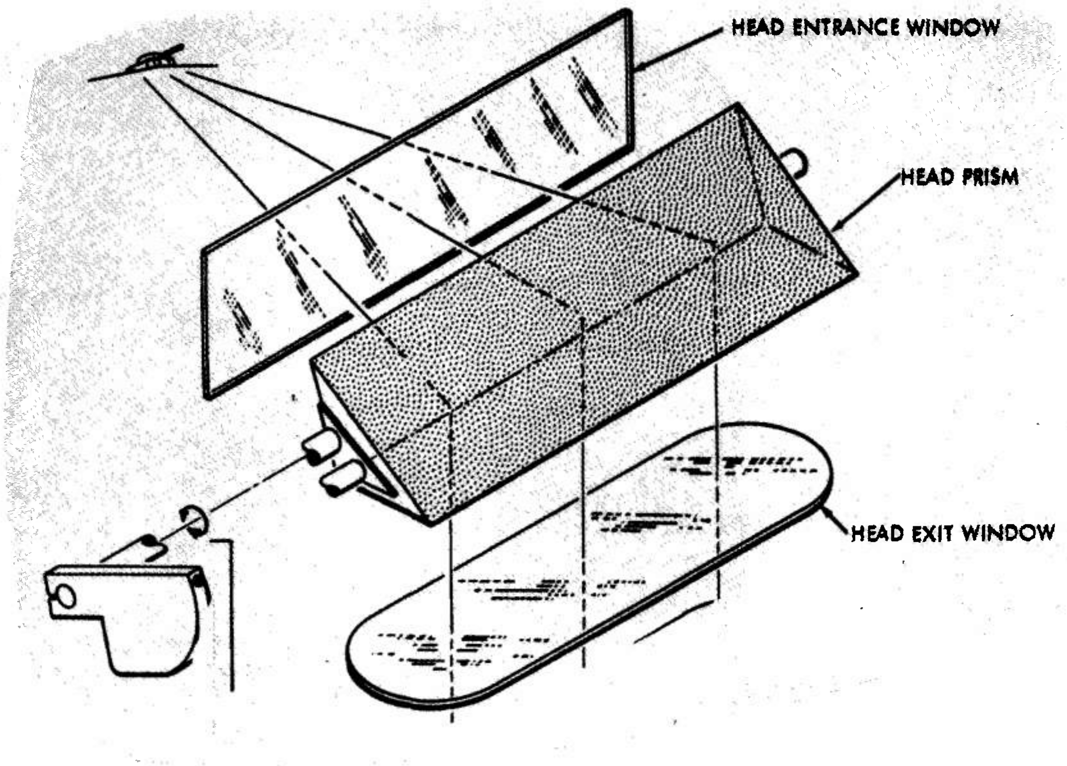


Figure 17-12. Periscope Elevation Prism

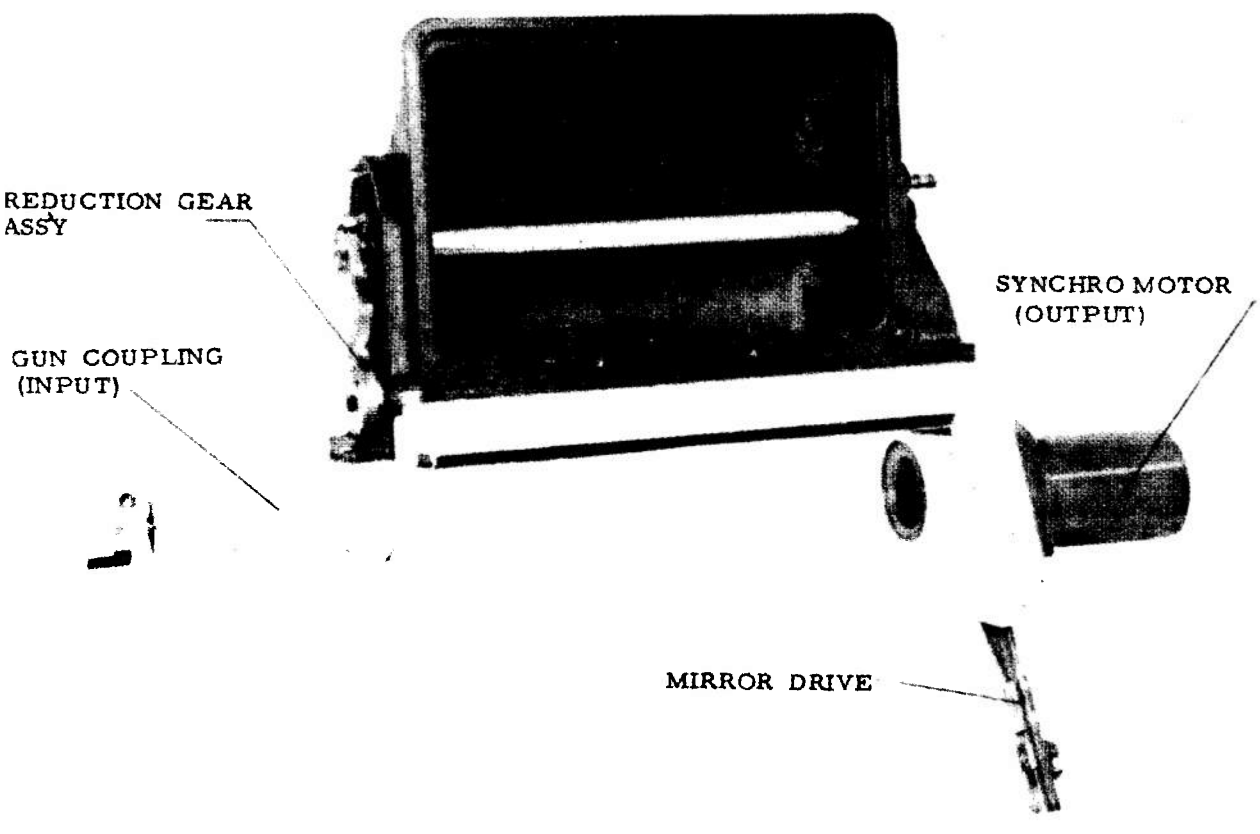


Figure 17-13. M51 Sight, Elevation Drive

3. Temperature compensation can be provided easier in a servo system than a mechanical system.

4. A servo system is easier to integrate into a weapon station than a parallel bar linkage. This is especially true where a common sight must be adapted to more than one vehicle weapon station, because of the variety of physical constraints that arise.

5. Use of a servomechanism permits independent stabilization of the line of sight, permitting significantly improved area surveillance which the vehicle is on the move.

17-4.3 DATA LINK (COMPUTER TO SIGHT)

Tank fire control systems employ a ballistic computer to compute necessary line-of-sight corrections to improve first round hit capability. The corrections correct for projectile drop as a function of muzzle velocity and range, gun wear, and vertical parallax. The corrections are fed automatically into the sight by a data transmitting link so that the gunner continues to aim directly at the target.

Tanks through the M60A1 have employed a mechanical data transmitting link between the computer and the sight. The corrections are made only in elevation and are made by rotating the head mirror through the necessary angle without changing the linkage between the mirror and the weapon.

With the adaption of electronic ballistic computers and a requirement to correct for deflection deviations (cant, drift, etc.), servo data transmitting links offer significant advantages. The M60A2 has an electronic computer and uses a servo data link. Corrections are made by driving the reticle in azimuth and elevation.

The reticle projector with servo drive components for the M51 Sight is shown in Figs. 17-14 and 17-15. The reticle of the optical system is a component of the unit's slide assembly. The vertical and horizontal planes of reticle travel are coplanar, and are at right angles across the periscope line-of-sight. Reticle movement is actuated by the elevation or azimuth lead screw, which in turn is actuated by the related servo motor of the servo system. The servo system comprises elevation and azimuth channels which are identical to each other, except for differences in the lead screw and gear ratios.

Elevation channel servo components comprise a gear train with a motor tachometer and gearhead which drives a lead screw through a slip clutch. A potentiometer, also driven by the motor tachometer, provides followup control.

The total elevation correction signal produced by the servo amplifier in the computer is fed to the motor of the elevation motor-tachometer. The signal causes the motor-tachometer to rotate in a direction to null the signal. Motor rotation drives the gear train to rotate the elevation lead screw, thereby moving the reticle in a vertical plane. The motor drives through a slip clutch which prevents the motor from stalling by limiting the load on the motor. In addition to the feedback signal transmitted from the potentiometer, the tachometer of the motor-tachometer transmits a damping feedback signal to the servo amplifier to eliminate oscillation. In servo operation as described previously, the motor of the motor-tachometer drives the elevation lead screw through the gear train and the gear of the differential.

In addition to the advantages of interfacing with an electronic computer, servo system data links offer advantages in temperature compensation and integration.

17-4.4 ANCILLARY EQUIPMENT

Ancillary equipment required in sight assemblies may include washer/wiper mechanisms and deicing devices for the exit window.

Fig. 17-16 shows a washer/wiper used on the M551 SHERIDAN Tank. Special precau-

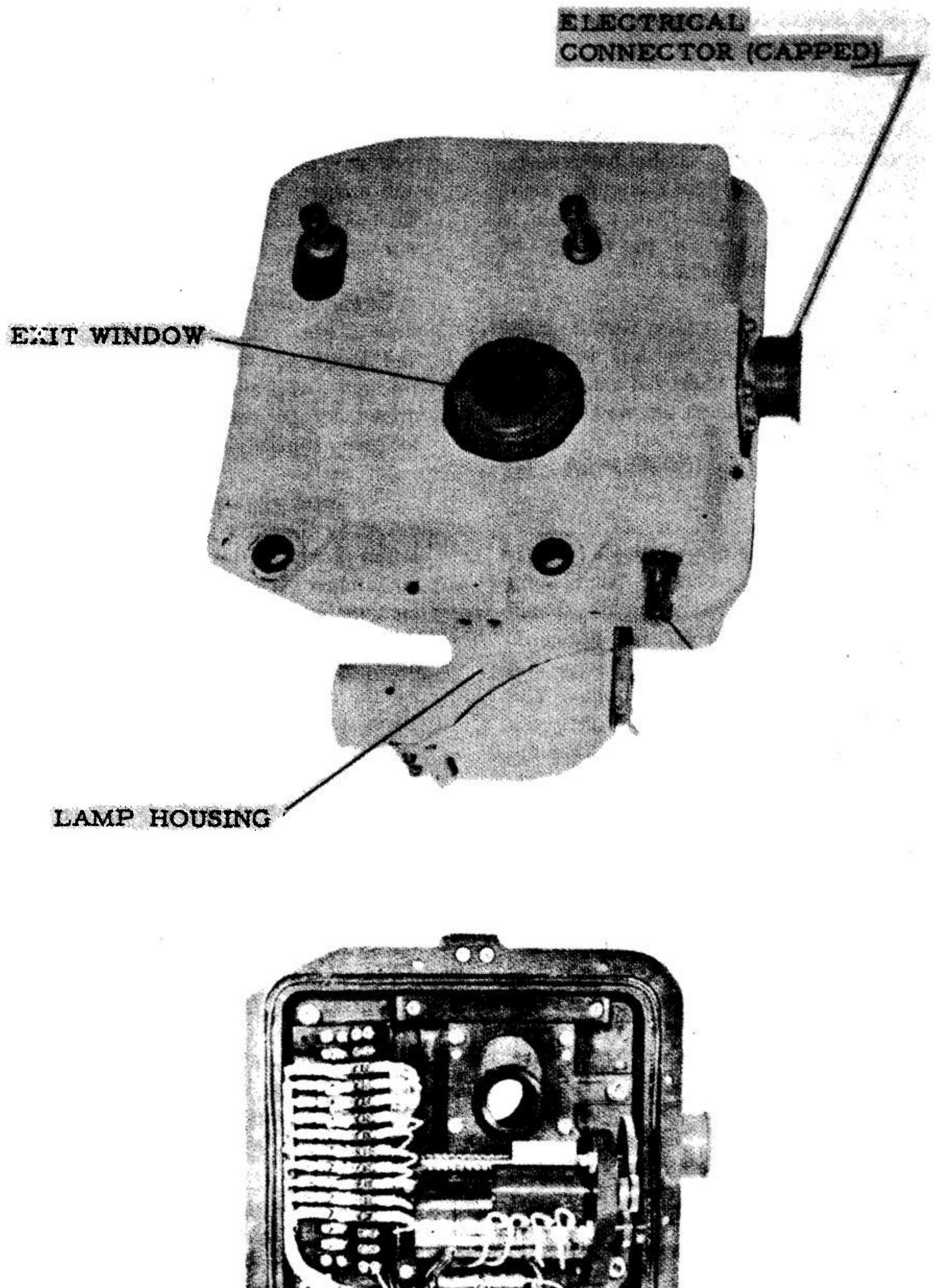


Figure 17-15. Reticle Projector, M51 Sight (Cover Removed)

tions must be taken in the area of electromagnetic radiation when these units are used with night sights. The image intensifier commonly used in night sights employs electrostatic focus, and stray electromagnetic fields will cause image shift and degradation.

Several techniques are available for deicing sight exit windows. Transparent conductive coatings constitute one method. Another method involves laminating small conducting wires between two plates of glass. These methods have been used in aircraft windshield applications.

Another method utilizes a heating element and fan inside the head assembly so that warm air is blown across the inside of the exit window.

Precautions must be taken to prevent uneven heating and warping of the exit window since this will result in image degradation. This is critical in night sights since they normally have a large aperture and exit window. In addition, the light attenuation and scattering caused by conductive coatings may not be tolerable in a night sight.

17-4.5 NIGHT SIGHTS

A 24-hr battlefield capability and recent component developments have required night sights on new combat vehicles.

Four basic techniques are available to facilitate fire control at night. These techniques are pictured in Fig. 17-17. In the white light battlefield illumination systems (Fig.

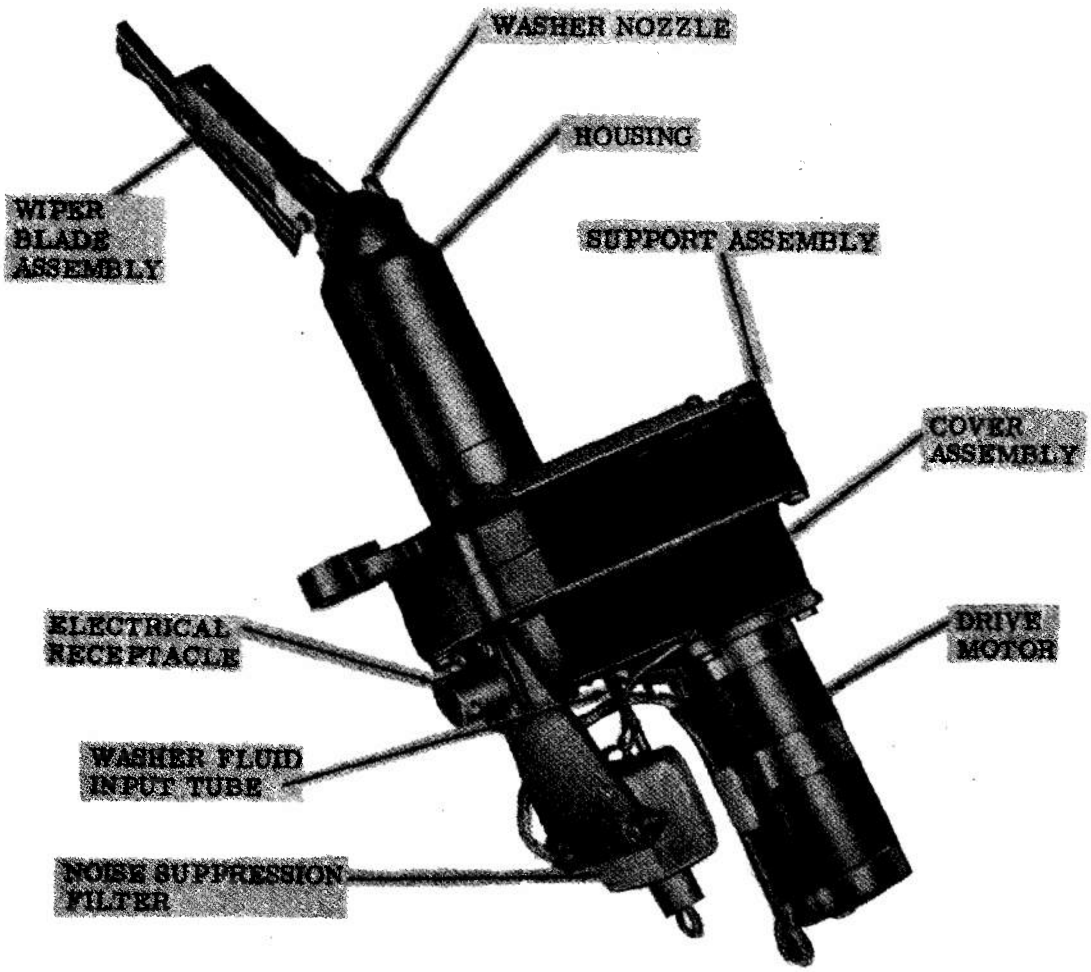


Figure 17-16. Washer/Wiper Mechanism

17-17(A)), illumination is provided by a searchlight, and the gunner uses his naked eye or daylight gunsight for target acquisition and fire control.

The standard near infrared active system is shown in Fig. 17-17(B). The target is illuminated by infrared covert (i.e., invisible to the naked eye) illunimation from a searchlight. Infrared illumination reflected by the target is focused on an infrared converter tube in the sight. The converter tube converts the infrared image to a visible image.

Fig. 17-17(C) illustrates the image intensification system. This system operates on available light from the night sky such as moonlight and starlight. Since no artificial source of illumination is required, the system is not detectable and is referred to as a passive system. Under very low illumination levels, such as an overcast night or under a jungle canopy, supplemental illumination may be required for optimum performance. This supplemental illumination can be provided by an infrared searchlight. The system is then covert rather than passive.

Fig. 17-17(D) illustrates the far infrared or thermal imaging system. This system images and converts to visible the far infrared radiation emitted from the target. The performance of the far infrared system is a function of target temperature and is independent of illumination level.

Active near infrared systems are currently in use, but are being replaced by image intensifier systems in new vehicle designs. Far infrared systems offer advantages in perform-

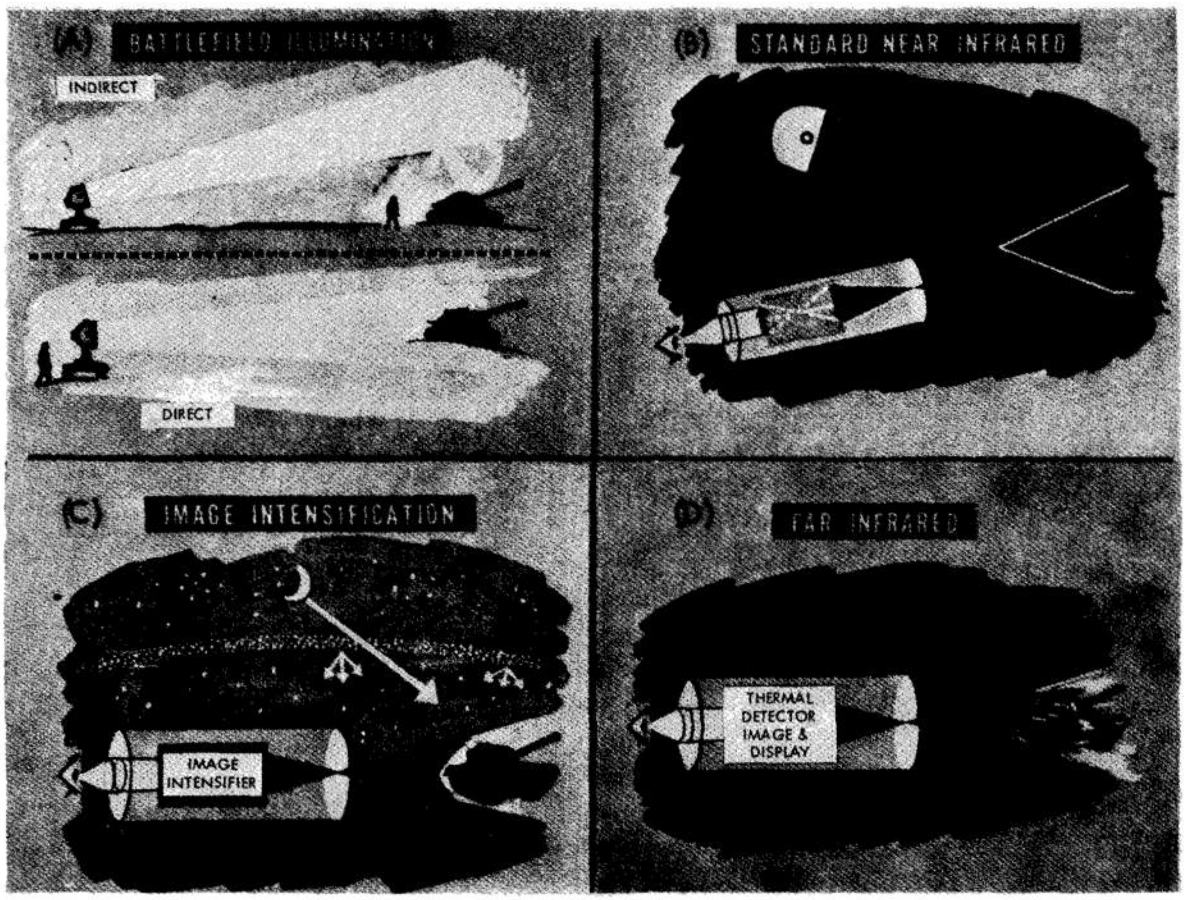


Figure 17-17. Basic Night Vision Techniques

ance over image intensifier systems, but are more complex. They are used in reconnaissance helicopter and aircraft applications and may be adapted for ground vehicle use in the future.

17-4.6 SEARCHLIGHTS

Short arc xenon searchlights, currently in use on combat vehicles, provide visible and covert (infrared) illumination. In the infrared (IR) mode, a visible light-absorbing filter absorbs the visible light from the xenon spectrum.

Fig. 17-18 shows the AN/VSS-2 (2.2 kW) searchlight used on the M60 and M48 Tanks. This unit provides 75 million candlepower and operates off 28-VDC vehicle power (110 A). A smaller 1.0-kW searchlight (AN/VSS-3) has also been developed. This unit provides 50 million candlepower and requires 50 A 28 VDC.

Short arc xenon lamps require a high voltage to initiate the arc. Once the arc is initiated, however, it can be sustained by a low DC voltage. In the AN/VSS-2, the arc is initiated by a 40-kW radio frequency (RF) signal. The application of 100 VDC then increases conductivity of the xenon gas by causing its temperature to increase. When conduction increases to approximately 100 A, it can be maintained by 28 VDC. The RF signal and the 100-VDC arc then are removed[5]. During the ignition period, RF interference is difficult or impossible to eliminate. Since the ignition time is short (less then 3 sec) this normally can be tolerated.

The AN/VSS-2 and -3 have a remote control panel (inside the vehicle) with servo

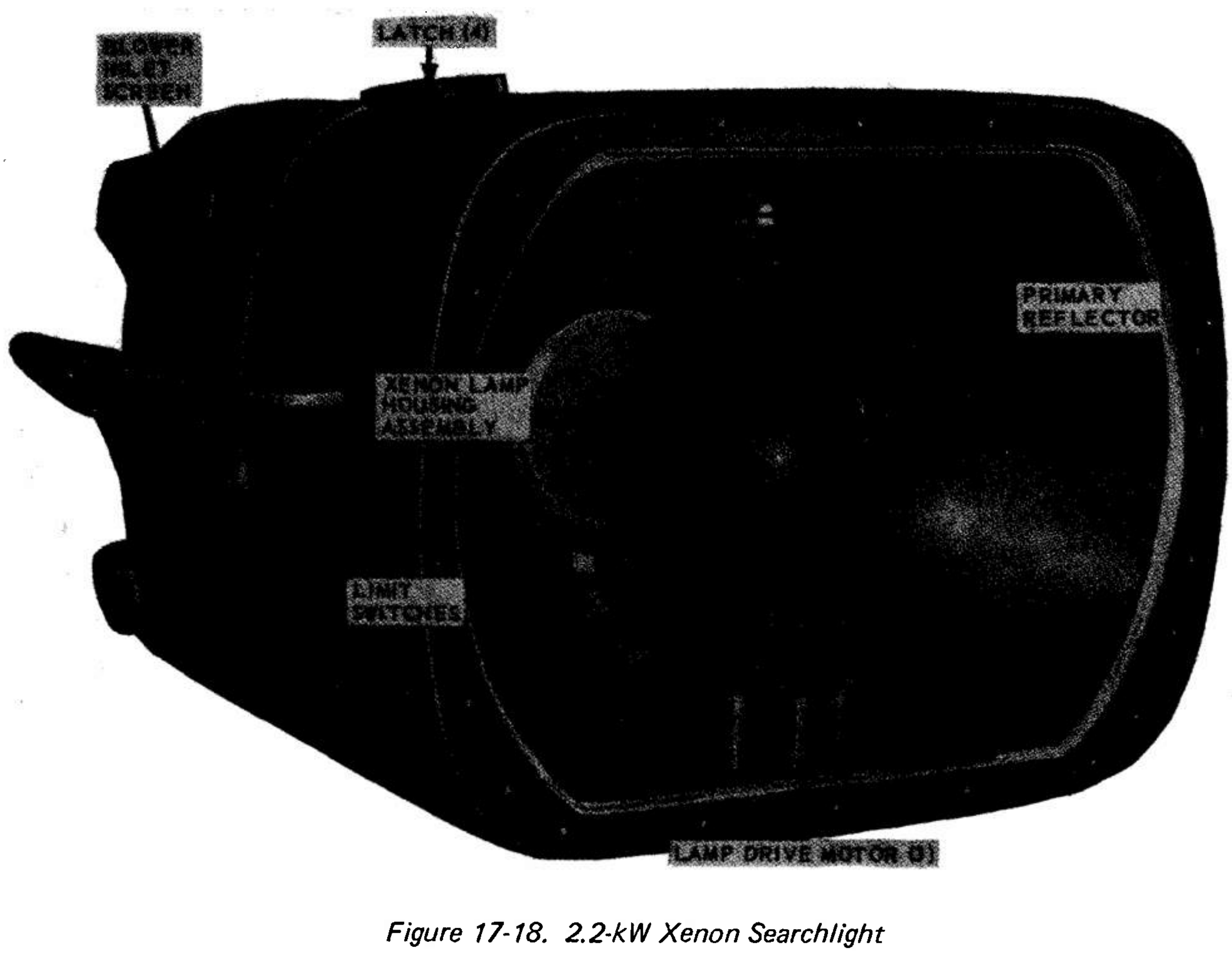


Figure 17-18. 2.2-kW Xenon Searchlight

controls for changing the beam angle and changing the lighting mode (visible or IR). These units also include a closed-cycle cooling system (air-to-air heat exchanger) to prevent the entrance of dust into the unit.

17-4.7 IMAGE INTENSIFIERS

Image intensifiers are categorized into Generation I and Generation II devices. Generation II intensifiers offer advantages in performance and are smaller in size, but they are not readily available at this time.

Table 17-1 presents information on available Generation I and II image intensifiers. The Generation I image intensifiers are all three-stage, cascaded units. The three stages typically provide a brightness gain of not less than 35,000[6,7]. The three stages are coupled mechanically and optically, and potted in a common assembly. The 18-mm intensifier assemblies have a built-in high voltage oscillator.

The 25-mm and 40-mm units require a 2700-V, 1200- to 200-Hz supply[6,7]. This can be provided by a standard high voltage oscillator (FSN 5855-904-0684). The oscilla-

TABLE 17-1. IMAGE INTENSIFIERS

Federal Stock No.	Description	Image Format, mm	Automatic Brightness Control	Reticle	Size, in.
5855-054-8490	Generation I 3 stage	18	No	Yes	2 dia x 5-7/8 long
5855-051-2792	Generation I 3 stage	25	No	No	2-3/4 dia x 7-1/8 long
5855-908-9314	Generation I 3 stage	40	No	Yes	3-3/4 dia x 12 long
5855-167-7636	Generation I 3 Stage	40	No	No	3-3/4 dia x 12 long
5855-177-3502	Generation I 3 stage	25	Yes	Yes	2-3/4 dia x 7-1/8 long
5855-401-3442	Generation I 3 stage	25	Yes	No	2-3/4 dia x 7-1/8 long
5855-147-2508	Generation I 3 stage	40	Yes	Yes	3-3/4 dia x 12 long
	Gen II micro channel wafer tube—fiber optic inverter*	18	Yes	No	1-5/8 dia x 1-1/8 long
	Gen II micro channel tube-electro static inverter**	25	Yes		2-1/2 dia x 3 long

*Developed for night vision goggles (AN/PYS-5) by ITT.

**Developed for Generation II crew served weapon sight (AN/TVS-5) by Varo, Inc.

tor connects directly to the intensifier and requires 50 mA at 6.7 VDC, which can be provided by a standard mercury battery (FSN 6138-926-0827). The 18-mm intensifiers require a 2.65 VDC supply[8].

The operating principle of the Generation I image intensifier is relatively simple (Fig. 17-19). Each stage is essentially an evacuated cylinder with a fiber optic faceplate or window (item 1, Fig. 17-19) at each end. A photocathode is deposited on the inner surface of the input window (item 2). A phosphor (item 3) covered by a thin aluminum layer is deposited on the inner surface of the output window.

An optical image is focused by a lens on the photocathode. Photoelectrons are emitted from each point on the photocathode surface at a rate proportional to the intensity of the image at that position. The photoelectrons are accelerated toward the phosphor (anode) by an electric (E) field created within the tube by application of an external potential between the photocathode and anode. At the anode, the photoelectrons penetrate the aluminum layer and strike the phospor, exchanging their kinetic energy for light energy. Thus a replica of the input image is generated at the output faceplate.

The brightness gain of each stage of an intensifier is a function of the sensitivity of the photocathode, the efficiency of the phosphor, and the strength of the E field within the tube. The gain can be varied through a limited range by varying the E field. This range is limited by a degradation of optical performance as the field is lowered. When the E field is high, the velocity of the photoelectrons resulting from the E field is substantially greater than the randomly directed initial velocities of the emitted electrons, resulting in the image geometry being preserved between the photocathode and the phosphor. When the E field is lowered, however, the image degradation resulting from the random initial velocities becomes significant.

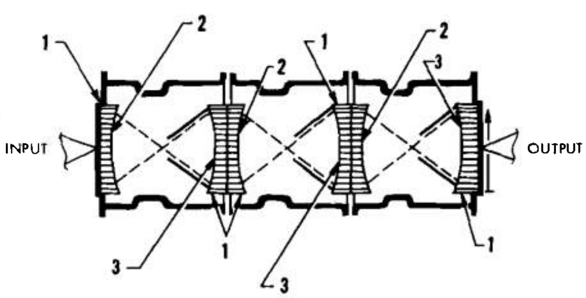


Figure 17-19. Image Intensifier, Generation I

Gain control is required to provide optimum performance under varying illumination levels and to prevent temporary or permanent damage to the intensifier. High gain coupled with high illumination level can result in damaging photocathode current densities.

Some intensifiers have a built-in automatic brightness control (ABC mechanism). The data in Table 17-1 indicate which intensifiers have this feature.

If the gain control range is not adequate for a particular application, or if the resulting image degradation at low gains cannot be tolerated, the input illumination can be controlled. This can be accomplished by stepping down the optics in front of the intensifier with an iris diaphragm or with a neutral density filter. Either the iris diaphragm or the neutral density filter can be operated by a servo system. A photodetector in a focal plane in front of or at the intensifier input can be used to sense the illumination level. The output of the photodetector is fed into a servoamplifier that compares the signal with a reference. The servoamplifier then generates a signal to open or close the iris diaphragm or drive the neutral density filters. The resulting change in illumination at the focal plane (where the photodetector is placed) provides a feedback loop.

Particular attention must be given to protecting the photocathode from bright point sources such as a searchlight. A current sensing and limiting device such as a built-in ABC senses the total photocathode current. A bright source such as a searchlight will be imaged at one point on the photocathode. This can result in very high (damaging) local current densities without significantly raising the total photocathode current.

Special precautions must be taken to prevent grounding of the outer surface of the fiber optics faceplate of the last stage. Typically, each stage of the tube has an operating potential of about 15 kV, and the photocathode of the first stage is grounded. The anode (phosphor) of the last stage then has an operating potential of 45 kV. Grounding of the outer surface of this faceplate can result in electrical breakdown and permanent damage to the fiber optics. If the fiber optics do not fail, image quality may be degraded by visible scintillations. Some intensifiers are supplied with a window over the output fiber optics to prevent grounding.

Two types of Generation II image intensifiers are being developed. Both types are single-stage devices that utilize a micro-channel plate (MCP) as the primary means of amplification. Power requirements are 20 to 30 mA at 2.0 to 2.7 VDC.

Fig. 17-20 illustrates a Generation II electrostatic inverter image intensifier. As in the Generation I intensifier, an image is focused on the photocathode. Photoelectrons are accelerated and focused by the anode cone and corrector electrode. An inverted electron image is focused on the MCP input. The output of the MCP is proximity-focused on the phosphor screen. Gain can be controlled over a wide range by varying the potential across the MCP.

The second type of Generation II tube is referred to as the fiber optic inverter tube. The photocathode, MCP, and phosphor are very close together. Photoelectrons generated at the photocathode are proximity-focused on the input of the MCP. Photoelectrons from the output of the MCP are then proximity-

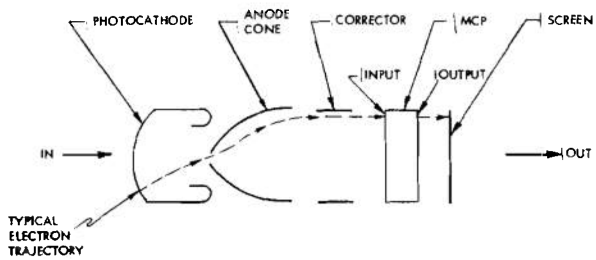


Figure 17-20. Image Intensifier, Generation II

focused on the phosphor screen. The image at the phosphor is next inverted by a fiber optic inverter. The image is inverted in the tube for optical reasons. If this inversion is not required, the fiber optic inverter can be eliminated, and the tube is thereby shortened.

17-4.8 ADVANCED SYSTEMS (FAR INFRARED AND PULSE GATED)

Systems currently being developed that have promise for ground vehicle operation are those known as far infrared imaging systems and pulse gated systems.

Far infrared (FIR) systems, as indicated in par. 17-4.5, operate from target emitted far infrared (thermal) radiation. These systems are designed to work either in the 3 to 5 or 8 to 12 micron region of the spectrum.

State-of-the-art far infrared systems use a linear array of discrete detectors operating in the photovoltaic or photoconductive mode. Typical detector materials are indium antimonide (InSb), mercury-doped germanium (Ge:Hg) and mercury cadmium telluride (HgCdTe). Currently available detectors require cooling to cryogenic temperatures for optimum performance.

Two system block diagrams are shown in Fig. 17-21. Both systems require a scanner to scan the scene to be imaged across the detector array. The direct view FIR system is illustrated further in Fig. 17-22. The operation of the remote view FIR system (as diagramed in Fig. 17-21) follows. Infrared energy is collected by the optics and focused on the linear detector array through a me-

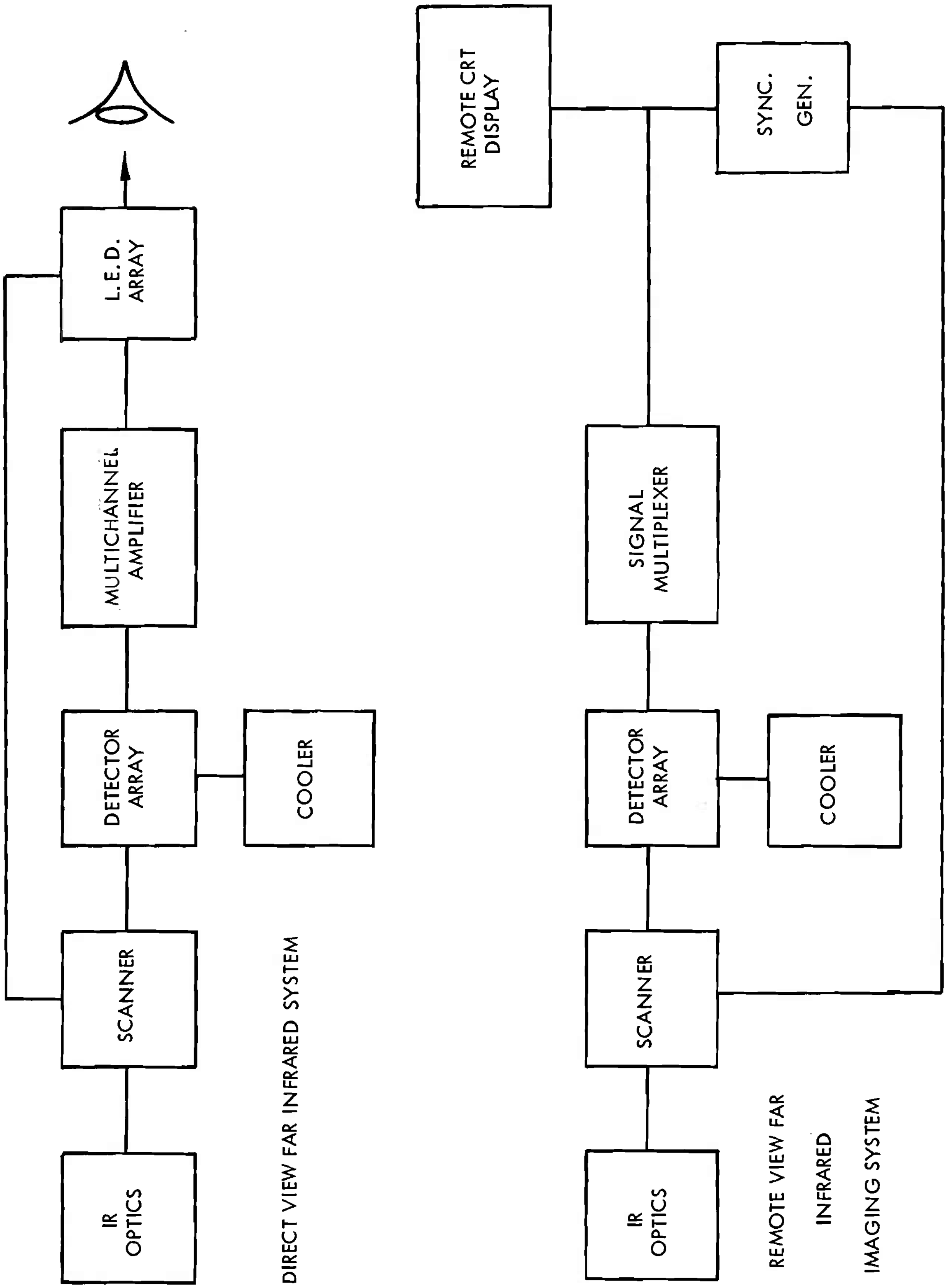


Figure 17-21. Far Infrared Imaging Systems

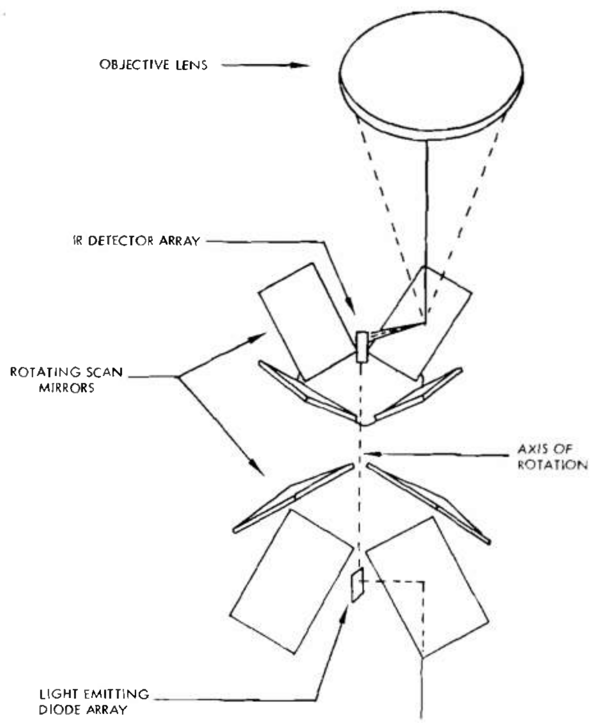


Figure 17-22. Direct View Far Infrared Systems

chanical scanner. The scanner moves the image of the scene across the IR detector array. The output of each detector in the array is amplified and modulates the light output of a corresponding light emitting diode (LED) in the display. The output of the LED array is scanned at the same rate as the incoming radiation. The scan rate is made high enough so that the output of the LED array is integrated by the eye, creating an image of the IR scene.

The remote view system uses a signal multiplexer to drive a cathode ray tube display.

Pulse gating (or range gating) is a technique originally developed for radar which improves scene contrast by minimizing backscatter. Basic hardware for this system consists of a laser illuminator and an image intensifier viewer. The laser must operate in a pulsed mode, rather than continuous, and the intensifier must be a special "gated" type that can be turned off and on. The operation of the system follows. The laser source emits a very short high energy discrete pulse of light that travels outward to the target and is reflected back. When the laser transmits the pulse of energy, it simultaneously triggers a variable electronic delay. The delayed trigger in turn applies a "range gate" or "on" pulse to the receiving intensifier. Thus the intensifier will display that light reflected from objects located within a discrete range interval. The depth of this interval is determined by the duration of the range gate. The target area distance from the system is dependent upon the delay time and is approximately equal to ½ the delay time multiplied by the speed of light. This eliminates backscatter from all areas in front of and behind the target. If the laser is pulsed and the intensifier gated at a high enough frequency, the image in the viewer appears continuous because of the integrating properties of the eye and the persistence of the phospor in the image intensifier.

Far infrared and pulse gated systems provide significant performance advantages over conventional intensifier systems. For this reason some future combat vehicles, especially reconnaissance vehicles, will probably be equipped with these systems.

17-5 RANGEFINDERS

Accurate range information is essential for tank weapon systems where first round hits are of prime importance. Optical, or base line, rangefinders have physical limitations restricting their use at long range and at low light levels[11]. The recently developed pulsed, or laser, rangefinder does not have these limitations and also has advantages in vehicle integration.

The M17C Optical Rangefinder (for the M60A1 Tank) is shown in Fig. 17-23. It is interfaced mechanically to the primary armament and to the ballistic computer, and can be used only by the commander. The electrical system for the M17C is relatively simple (Fig. 17-24), consisting of reticle and scale illumination lights and necessary switches and

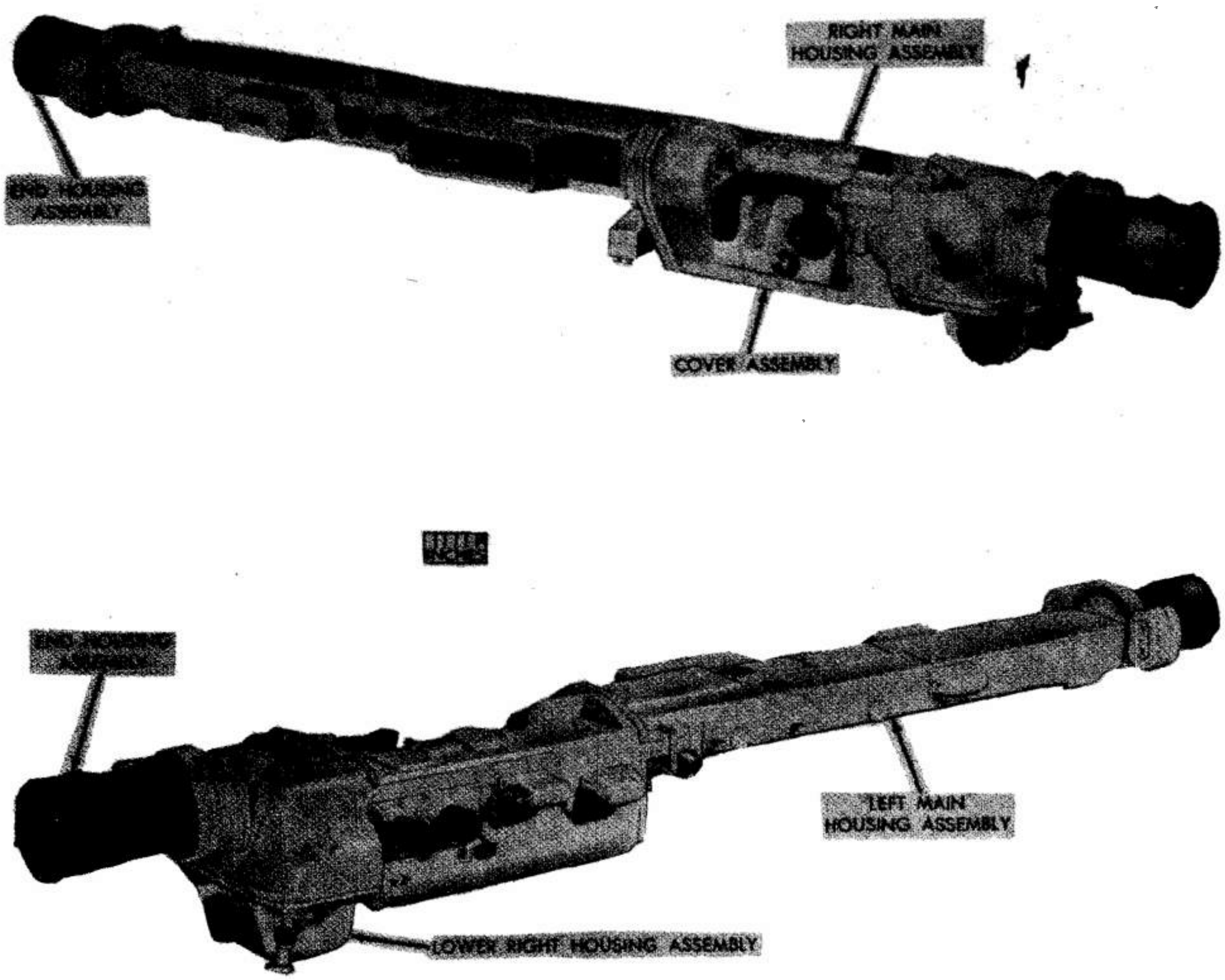


Figure 17-23. M17C Rangefinder[9]

controls. A power switch for the ballistic computer also is included.

The laser rangefinder (Fig. 17-25) provides ± 10-m accuracy over an operating range from 20 to 4000 m. The use of discrete system components interconnected by wiring harnesses allows easier integration into the vehicle and allows the gunner as well as the commander to range on targets.

The laser rangefinder operates by transmitting a pulse of light, receiving the reflected light from the target, and converting the time from transmission to reception into range. The minimum time between rangings is determined by heat dissipation in the laser and by the time required to charge the pulse forming network (PFN) discussed in par. 17-5.1. The minimum time between ranging in the AN/VVS-1 is 2 sec, and maximum sustained ranging rate is 3/min sustained or 6/min for 2 min with 3-min intervals between each 2-min ranging period[10]. Input power required is 2 A nominal at 18-20 VDC. During the 2-sec charging cycle, 8.2 A are required.

Par. 17-5.1 briefly explains the operation of the Q-switched ruby laser used in laser rangefinders. Par. 17-5.2 discusses the rangefinder system using the XM23E2 as an example.

17-5.1 LASER THEORY

The laser provides a very intense narrow beam of coherent light. The Q switch technique increases the intensity of the beam by

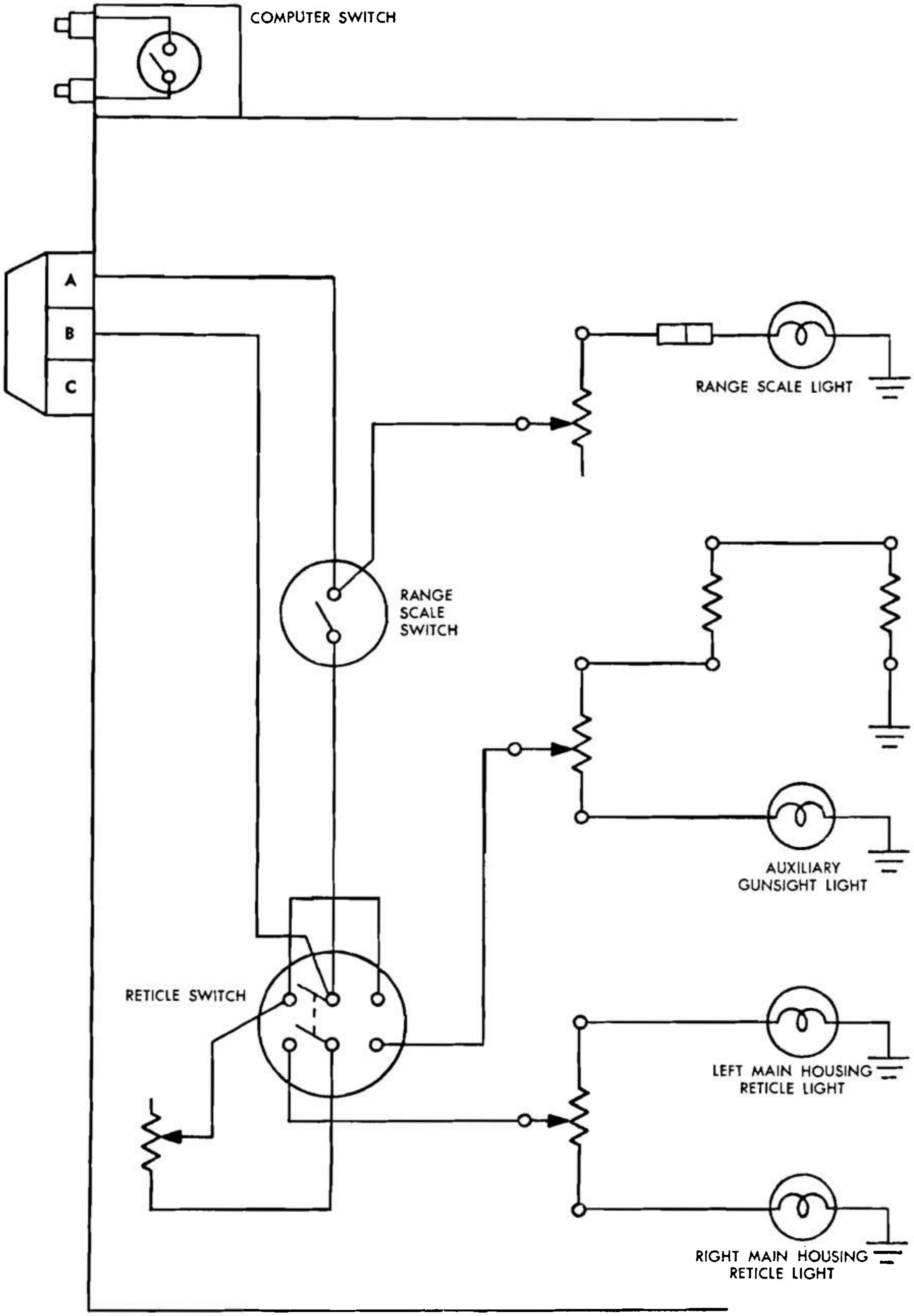
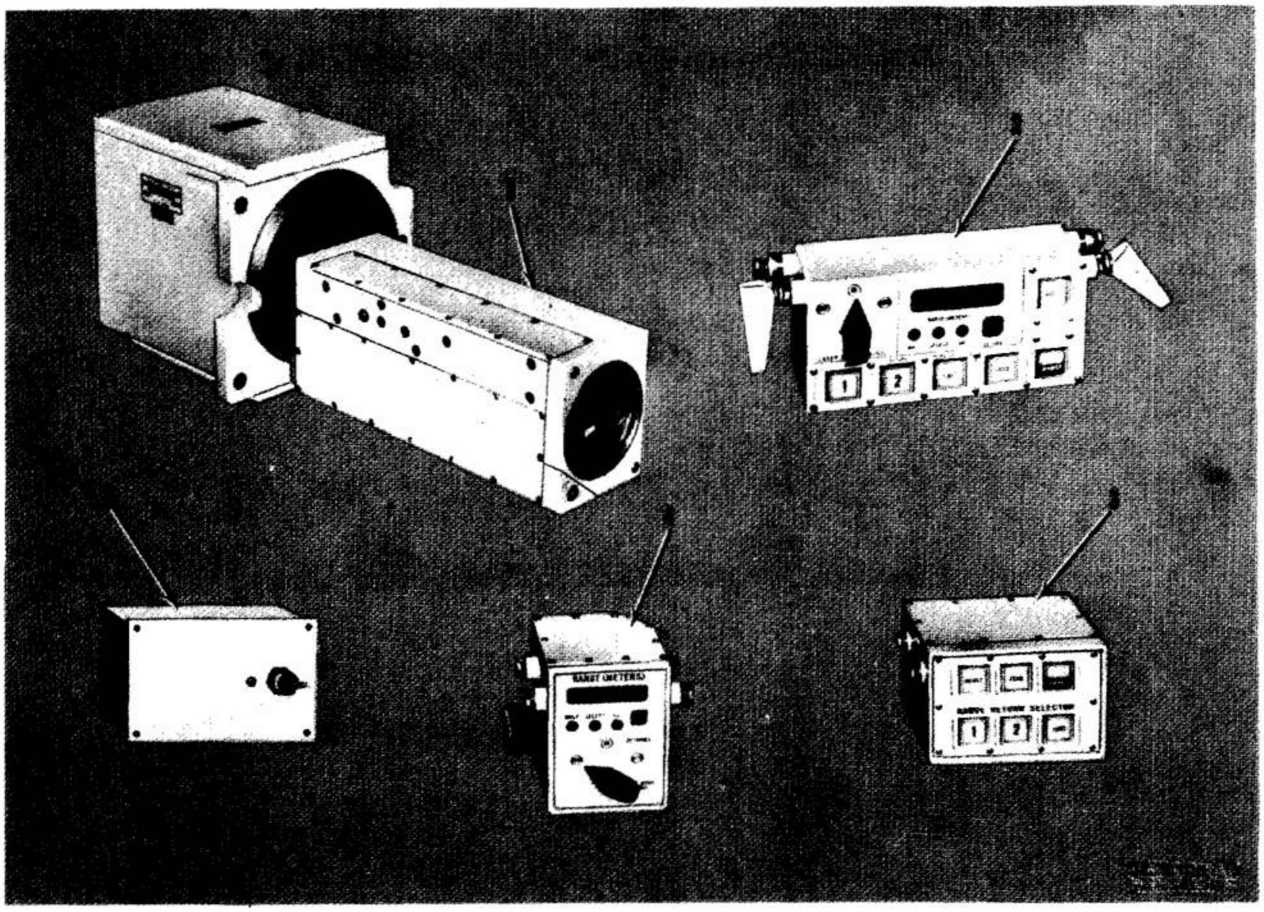


Figure 17-24. M17C Rangefinder Wiring Diagram[9]



1—Receiver-transmitter 6A1 **2—Commander's control 6A2** **3—Gunner's control 6A3** **4—Digital indicator 6A4** **5—Power suppy control 6A5**

Figure 17-25. Laser Rangefinder, AN/VVS-1[10]

preventing laser action until a large amount of energy is available in the laser cavity.

The basic phenomenon involved in the operation of the laser is that an atom, which has absorbed excess energy, will release this energy in the presence of radiation of a particular frequency.

When an atom at its normal energy, or ground state (Fig. 17-26, black dot), absorbs a photon of light (wavy arrow), the atom becomes excited or is rasied to a higher energy state (black and white dot). The excited atom (Fig. 17-27, black and white dot) will radiate spontaneously, emitting a photon in a random direction while reverting to the "ground" state (black dot). The photon is always of the specific frequency associated with the change in energy levels of the atom. However, an excited atom (Fig. 17-28, black and white dot) can also be made to revert to the ground state (thus emitting a photon) by being struck by a photon of this same frequency. Under this circumstance (stimulated emission), the radiated photon will be of the same wavelength (Fig. 17-28, black dot) in the time phase with, and moving in the same direction as, the stimulating photon.

Examining the ruby crystal (see Fig. 17-29) will aid in understanding laser theory, as it is used in rangefinders. Ruby is aluminum oxide

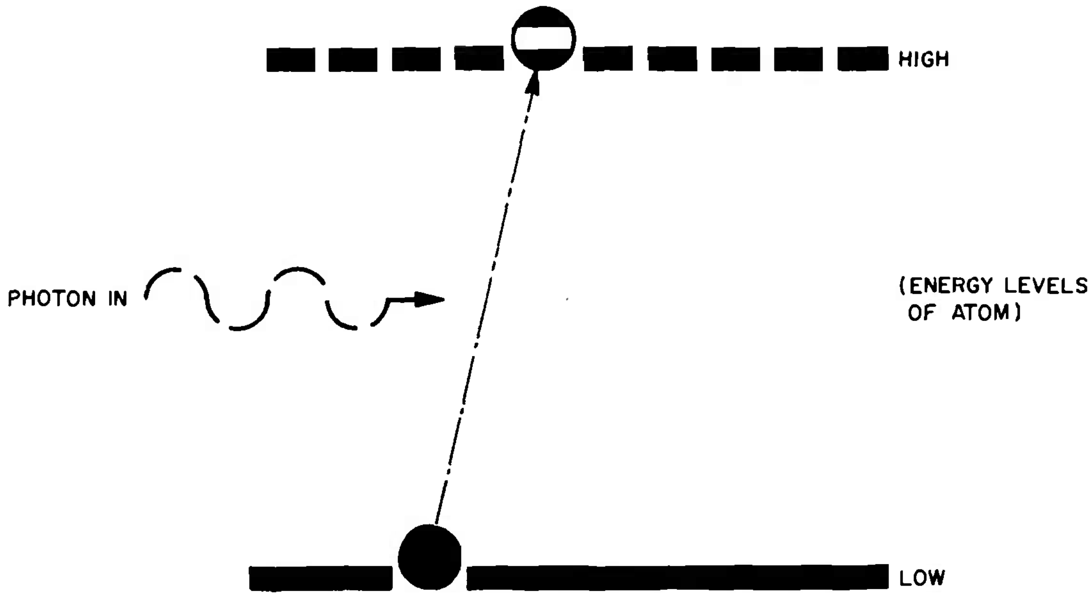


Figure 17-26. Absorption of Photons[4]

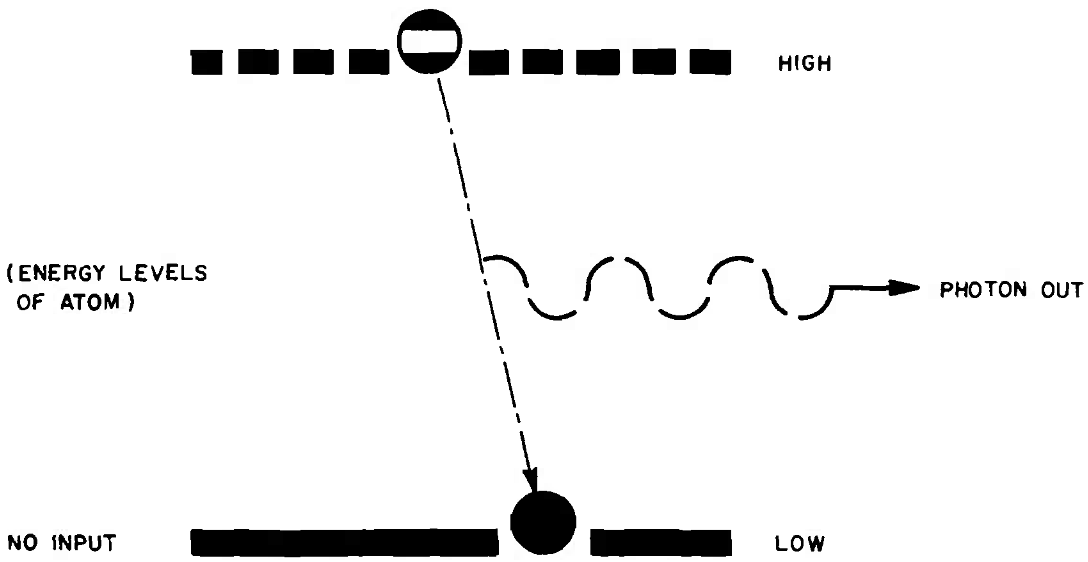


Figure 17-27. Spontaneous Emission of Photons (Fluorescence)[4]

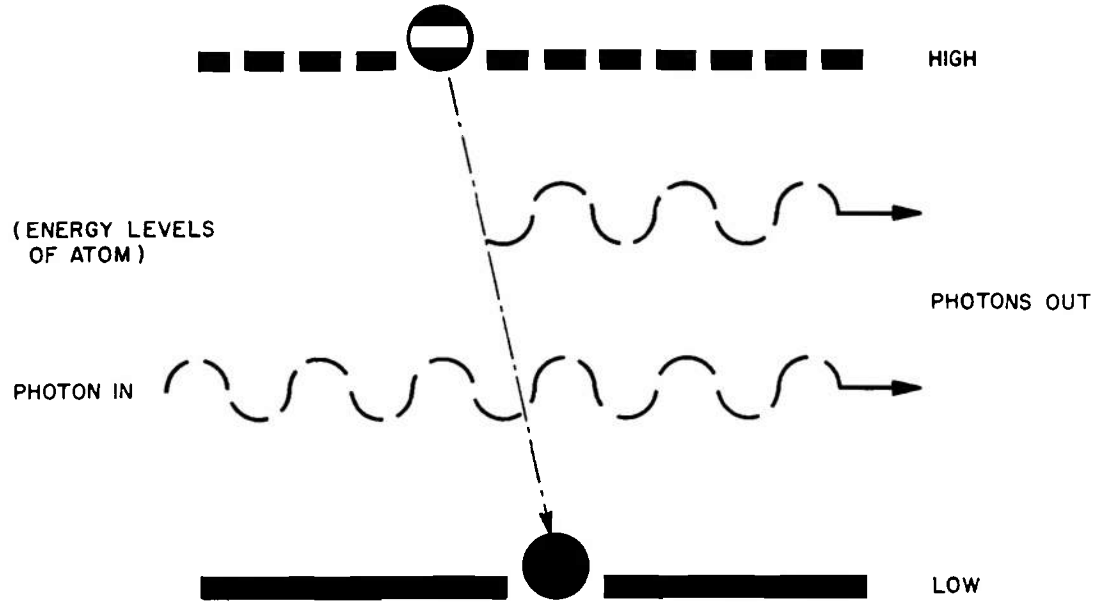


Figure 17-28. Stimulated Emission of Photons[4]

with several of the aluminum atoms replaced (doped) by chromium atoms. Rangefinders utilize a ruby crystal that contains approximately 0.03 percent chromium.

The chromium atoms in the ruby crystal absorb broad bands of green and blue light, thereby becoming excited as discussed previously. From this state, these chromium atoms revert back to their ground state in two steps. In the first step, the chromium atoms quickly give up some of their energy to the crystal lattice and land temporarily in what is called a metastable state. If there is no stimulation, their stay at this level will last a few milliseconds before dropping at random to the ground level (Fig. 17-29). Each chromium atom emits a photon having a wavelength of 694.3 millimicrons in the process. This process is known as fluorescence. In laser action, however, the first few photons released at this wavelength stimulate other still excited chromium atoms, forcing them to emit photons much sooner than they would normally. The result is a cascade of photons, all at the 694.3 millimicron wavelength, in phase, and traveling in the same direction.

Stimulated emission causing light amplification is shown in Fig. 17-30. The ruby crystal is shown at top left of Fig. 17-30. A reflector is shown to the right of the ruby crystal and a partial reflector is shown at the left. The ruby rod is located near a flash lamp that provides broadband optical pumping. Up to a certain critical flash intensity, the ruby rod emits only a burst of its typical red fluorescence, spread over the usual decay period for the excited atoms. However, above this critical level, laser action takes over as shown in Fig. 17-30. Before excitation by the flash lamp (pumping), the atoms in the crystal are practically all in the ground state (black dots). The optical pumping raises the atoms to the excited state (white dots). A necessary condition to insure the predominance of stimulated emission over absorption is that there must be an excess of excited atoms, which is called inversion. The cascade begins when an excited atom spontaneously emits a photon (Fig. 17-30, black arrow). The photon stimulates another excited atom to produce another photon, both of which can stimulate excited atoms, thereby producing two additional photons, etc. This process continues as the

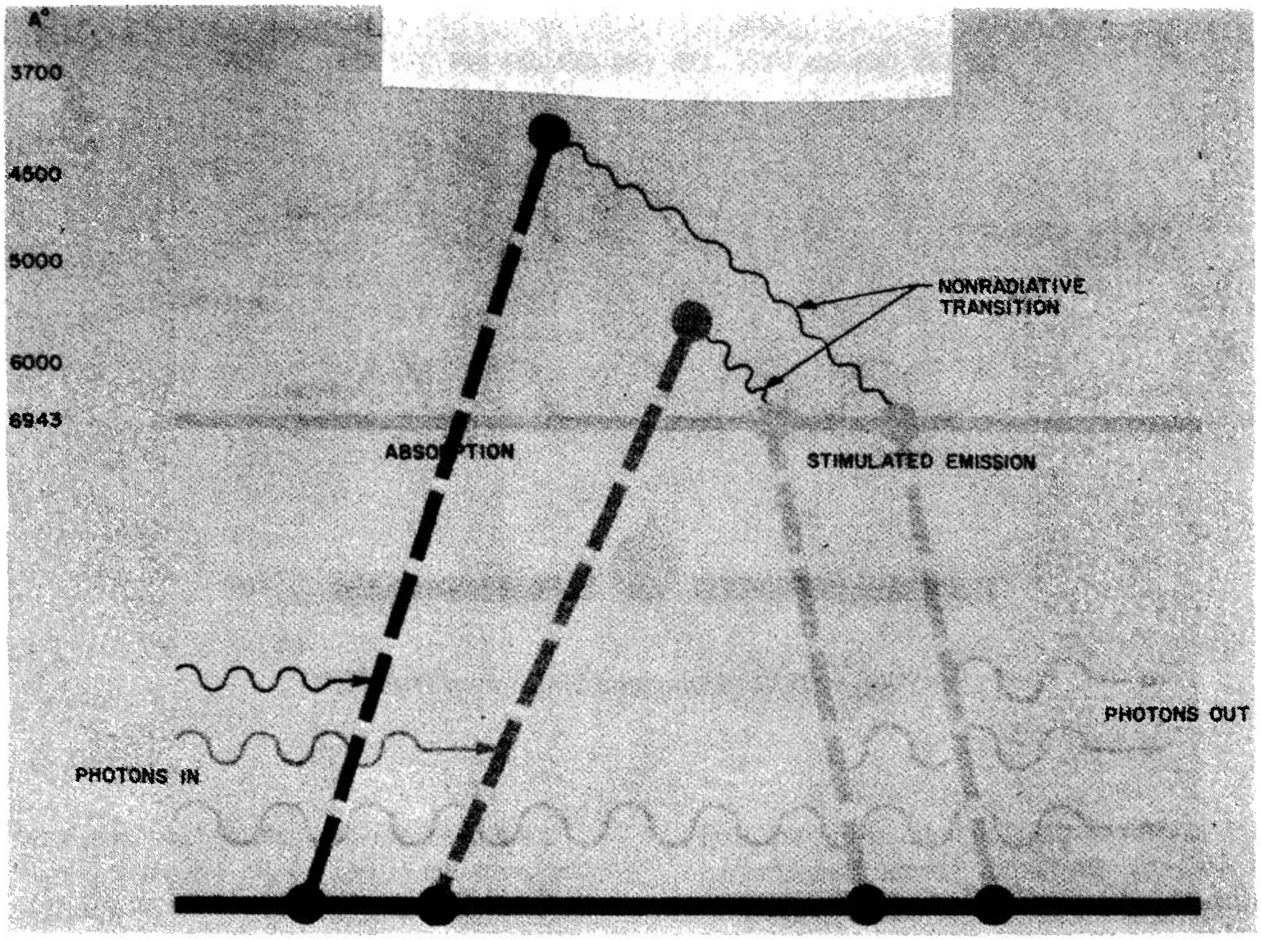


Figure 17-29. Stimulated Emission in Chromium-doped Aluminum Oxide (Ruby)[4]

photons are reflected back and forth between the reflecting surfaces located at the ends of the crystal. Photons emitted in other directions pass out of the crystal. As the amplification takes place, some of the beam passes out through the partial reflector located at the left of the ruby crystal. The stimulated emission will cease as soon as enough excited atoms return to the ground state to cause an excess of ground-state atoms over excited atoms. If the pumping lamp is still flashing, the ground-state atoms once again will be raised to the excited state, resulting in another cascade of photons, when "inversion" is achieved again. The output light beam, lasting about 50 nsec, will be as shown in the lower right section of Fig. 17-30, with the pulses representing the large number of cascades that occur during a pumping cycle. Since the frequency of the pulses cannot be easily controlled, and since the peak power level of the pulses is low (2 to 10 kW), such a light beam would be of little use for rangefinder application.

A technique for significantly increasing peak power output, which consists of reducing the resonating efficiency of the cavity and then suddenly creating a highly efficient resonator, is called Q-switching. This technique allows the energy to be stored by limiting laser action until a strong inversion is achieved. This technique also allows resonant laser action (reflection of a beam back and forth through the ruby) to occur only at a time when the inversion percentage is very

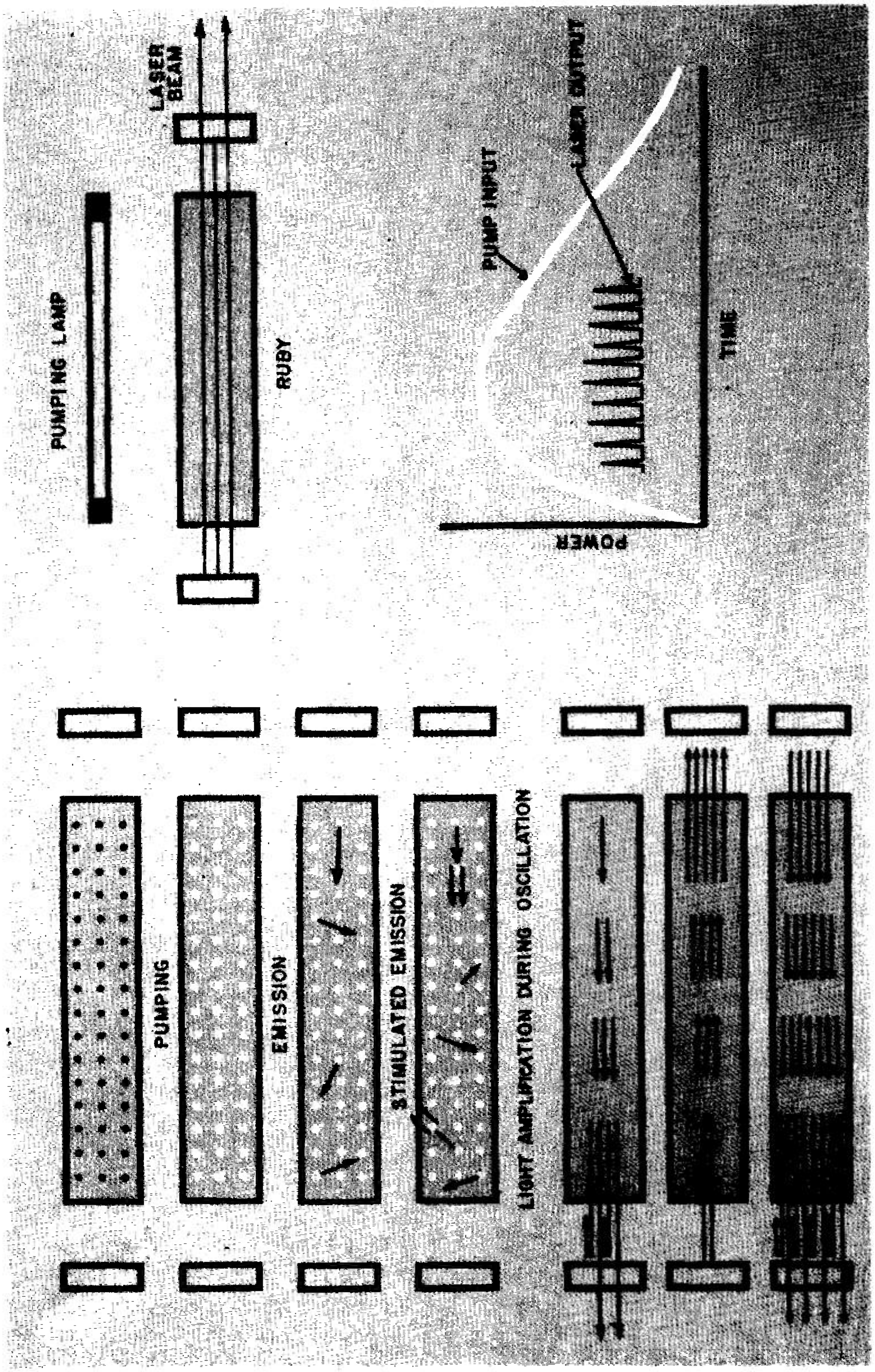


Figure 17-30. Light Amplification by Stimulated Emission[4]

high. Fig. 17-31 shows what occurs when laser action is controlled by changing the Q of the resonating cavity. The upper views illustrate the pumping process during which the atoms are excited, as previously described, with no resonance since the left-hand reflector is not in position. During the time required for the left-hand reflector to come into position pumping action continues, and—since no large scale release of energy is possible by laser action because of the open cavity—the number of excited atoms will be increased to an amount much greater than the threshold value required to cause laser action. When the cavity is suddenly provided with a second reflector parallel with the stationary mirror, at a time when a very large majority of the atoms are excited, the ratio of stimulation over absorption will be very high because of the presence of relatively few ground state (or absorbing) atoms. As a result, a single pulse of extremely high-peak power occurs, with the rise to peak power taking place in a very short time.

17-5.2 LASER RANGEFINDER

The continuous power requirements for laser rangefinders used on military vehicles may be from 5 to 3 A at 28 VDC.

The XM23E2 is a lightweight tripod-mounted laser rangefinder used by artillery forward observers. Functionally it is similar to units currently used on combat vehicles.

A functional block diagram for the electronic circuitry of the XM23E2 is shown in Fig. 17-32. The block diagram is separated into three sections—transmitter assembly, optical assembly, and receiver and control assembly.

The transmitter assembly generates the laser beam and is made up of the components shown in Fig. 17-32.

The xenon flash lamp and the ruby laser rod are mounted inside a reflector that concentrates the energy from the flash lamp into the laser rod. The flash lamp is triggered by 15 kV from the flash lamp trigger circuit. The pulse-forming network stores energy to sustain the flash lamp once it is triggered.

The Q-switch motor assembly consists of a motor with a prism attached to the shaft. The function of the Q-switch is discussed in par. 17-5.1.

The flash lamp and Q-switch timing circuits perform the functions that start the Q-switch motor when a "turn-on" signal is received from the PFN power supply, sample Q-switch motor speed through the magnetic sensor, supply a trigger pulse to the flash lamp trigger circuit when the Q-switch motor has attained proper speed, turn off the Q-switch motor immediately after proper speed is attained, and provide a "turn off" pulse to the photomultiplier power supply and counter power control circuits approximately 0.6 msec after occurrence of the trigger pulse.

The optical assembly (Fig. 17-32) consists primarily of optical components for shaping and transmitting the laser beam and for sighting, receiving, and focusing the reflected signal. The optical assembly also contains the sampling photodiode and start amplifier. These components detect the transmitted laser beam pulse and generate the start signal which initiates the counting cycle.

The receiver and control assembly contains the components for detecting the pulse reflected back from the target, controlling the rangefinder, and calculating and displaying the range.

The photomultiplier tube detects reflected pulse and provides a signal to the preamplifier. The preamplifier amplifies the signals to the proper level for use by the target select circuits. The backscatter suppression network provides proper voltage distribution to the dynodes of the photomultiplier to suppress backscatter return without attenuating low-power target signals.

The target select circuits count the number of stop pulses (target echos) and permit the

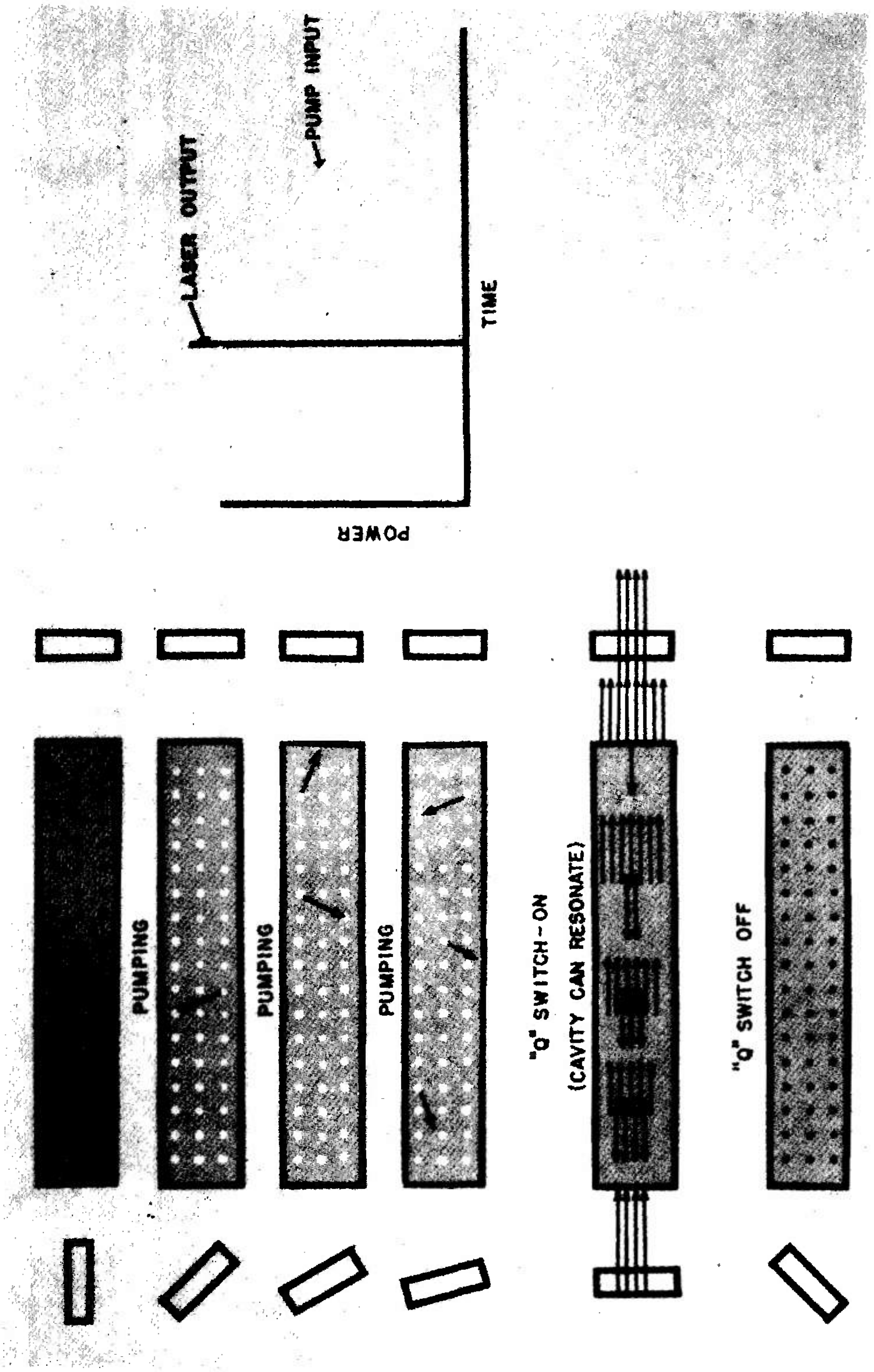


Figure 17-31. Laser Action Controlled by Q Switching Techniques[4]

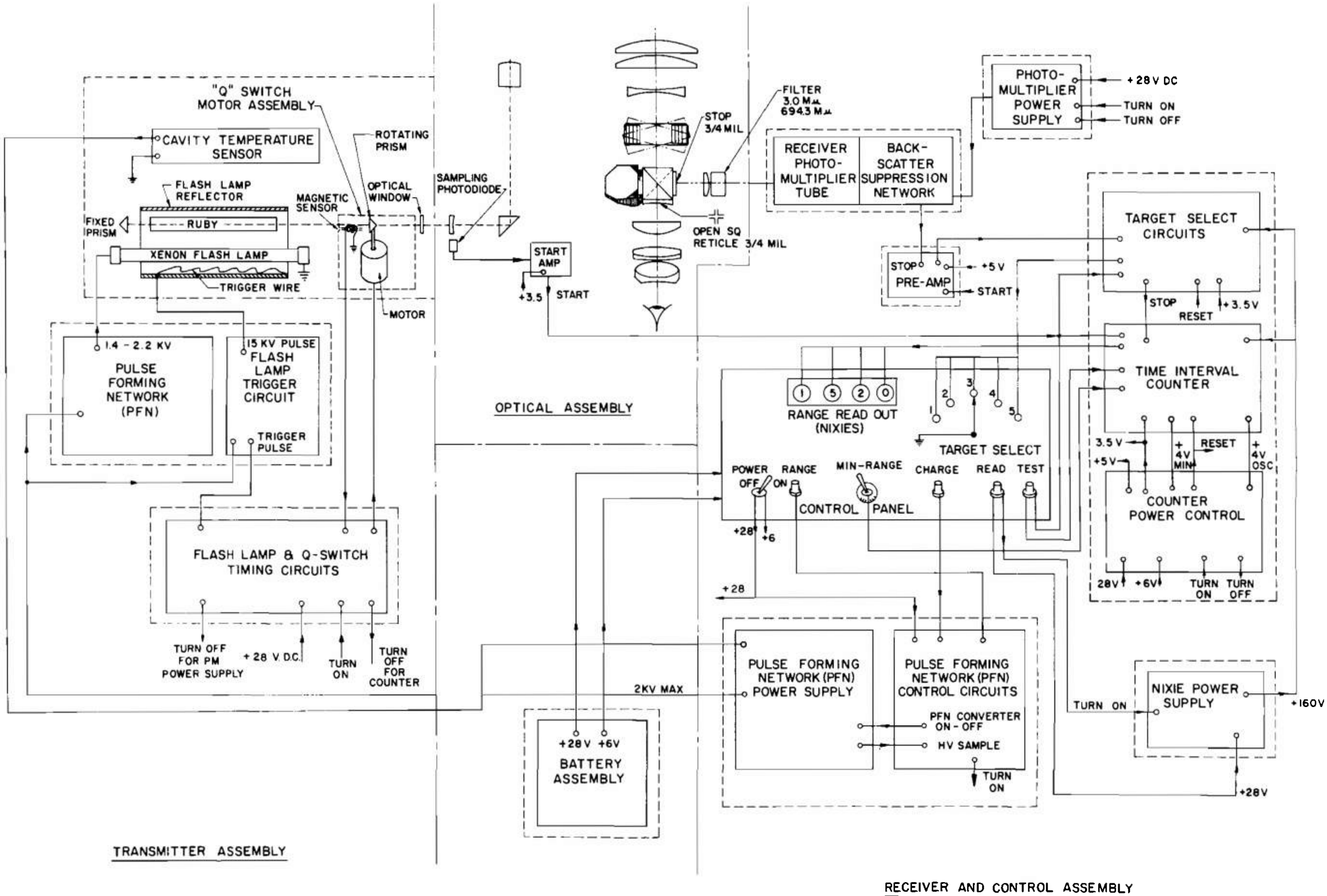


Figure 17-32. XM23E2 Laser Rangefinder Block Diagram[4]

selected stop pulse to stop the time interval counter.

The time interval counter counts the cycles of an internal oscillator for the interval between the start signal and selected stop pulse. This time is converted to a range reading in meters.

The counter power control performs the following functions:

1. Sets time interval counter from "memory" condition to "operating" condition upon receipt of turn-on signal.

2. Resets time interval counter after receipt of turn-on.

3. Returns time interval counter to "memory" condition upon receipt of a turn-off signal.

The nixie power supply supplies 160 V to illuminate the cold cathode neon glow discharge tube range readout (nixies) and target indicators.

The photomultiplier power supply supplies a negative 1400 to 2300 V to the dynodes of the photomulitplier tube through the backscatter suppression network. The power supply is controlled by turn-on and turn-off signals during normal operation. The power supply is also turned on whenever the TEST pushbutton switch is depressed.

17-5.3 SAFETY PRECAUTIONS

Precautions must be taken to prevent eye damage caused by laser radiation. Safe limits of radiation are specified in TB-MED-279[3].

The effect of laser radiation upon the retina of the eye may be a temporary reaction without residual pathologic changes, or it may be more severe with permanent pathologic changes that may heal by fibrosis. Laser rangefinders therefore incorporate optical filters to protect the user. However, radiation from enemy lasers or reflected radiation from friendly lasers present special hazards.

17-6 BALLISTIC COMPUTERS

Most of the computers with which one is concerned in fire control applications are mechanical analog or electronic analog computers that operate with physical rather than mathematical variables as inputs and outputs. These computers operate in real time and serve as a functional element of the fire control system. Real-time computers are characterized by the same elements (input, program, computation, memory, and output) that are universal to computers. Their distinguishing characteristics are an ability to perform computations at the same rate at which the input data change, and the provision of equipment to convert the input data into a form acceptable to the computer. Equipment also is provided to convert the computer output into a form suitable for use by the fire control system. The requirement for real-time operations makes the fire control computer a highly specialized design. (General purpose digital computers generally operate slower than real time; their speed is limited by the time of access to the magnetic tape memory most commonly employed for large volume storage.) Real time analog computers require highly stable electronic amplifiers and electromechanical elements that have good dynamic response.

17-6.1 MECHANICAL ANALOG COMPUTERS

The M13 Ballistic Computer (Fig. 17-33) used in the M60 Tank is a typical mechanical analog computer. It provides elevation corrections to the line-of-sight to compensate for range and ammunition type. Electrical power is required only for illumination.

The M13 has a precision cam for each type of ammunition. The cam is a model of the trajectory of the ammunition. A servo system compares the line-of-sight to the cam and makes corrections.

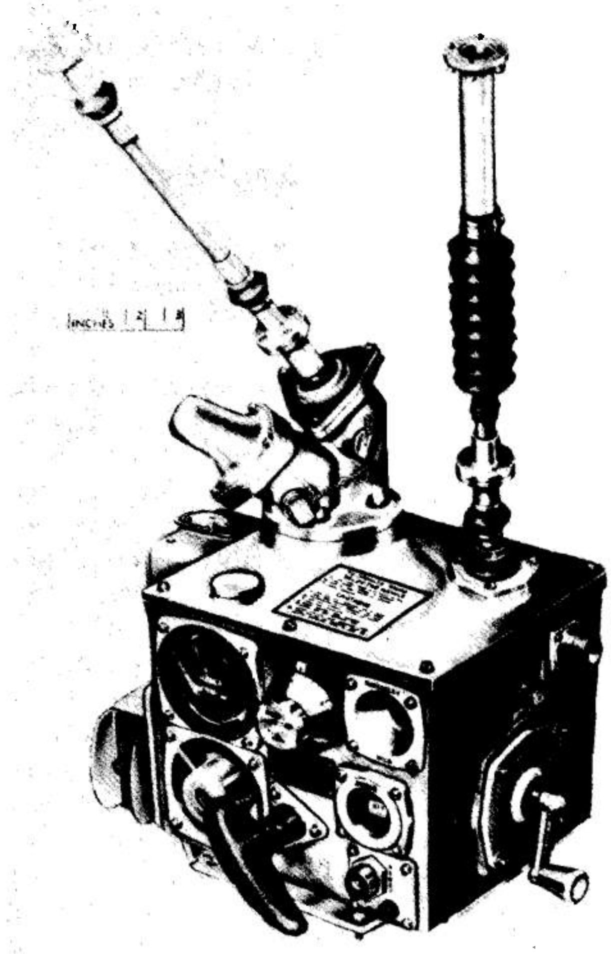


Figure 17-33. M13 Ballistic Computer

17-6.2 ELECTRONIC ANALOG COMPUTERS

Electronic computers require 2 to 4 A at 28 V. They provide the capability to correct for additional sources of error. The XM16 Computer (Fig. 17-34) corrects for the following sources of vertical error: jump, cant, vertical parallax, gun wear, and gun droop as well as range and type of ammunition. In addition, the XM16 corrects for the following lateral effects: lateral parallax, gun droop, cant, and lateral jump.

The XM16 uses a linear potentiometer with ten tap points to model each type ammunition. By changing the values of the resistors tapped into these points, the slope of the voltage (which represents range) can be changed. Utilization of this system allows the range-elevation relationship for a given ammunition to be approximated by ten straight line segments. The principle is illustrated in Fig. 17-35. The resistors needed for any one ammunition are packaged in a plug-in assembly that is somewhat smaller than a package of cigarettes. When the ballistics for a new ammunition are required, a new package can be fabricated and installed with a minimum of effort.

The components of the XM16 Ballistic Computer are shown in Fig. 17-34. The input unit functions as a target range input device. It contains the potentiometers of the four range-related function generating networks. Three of the networks produce the functions for the ballistic corrections. They produce voltage signals analogous to corrections for the superelevation multiplied by the cosine of the cant angle, superelevation multiplied by the sine of the cant angle, and the projectile drift. The fourth network produces a voltage analogous to the parallax correction.

The cant unit generates the voltages analogous to the sine and cosine of the gun trunnion cant angle. The cant unit consists of an aluminum pendulum suspended from the shaft of a resolver unit. Two matched permanent magnets, constituting the principal mass of the pendulum, are mounted on two separate surfaces at the lower end of the arm. The magnets provide for damping the pendulum by hysteresis effects.

Fine zeroing of the elevation and deflection channel correction signals is provided by the adjustment of variable resistors in the zeroing control unit.

The effective full charge (EFC) switch unit is mounted on the gun mount. It provides a signal to the EFC unit in the computer each time the gun is fired. The EFC unit compensates for barrel wear.

The commander's and gunner's control units are identical. They provide ammunition selection capabilities and visual indicators of

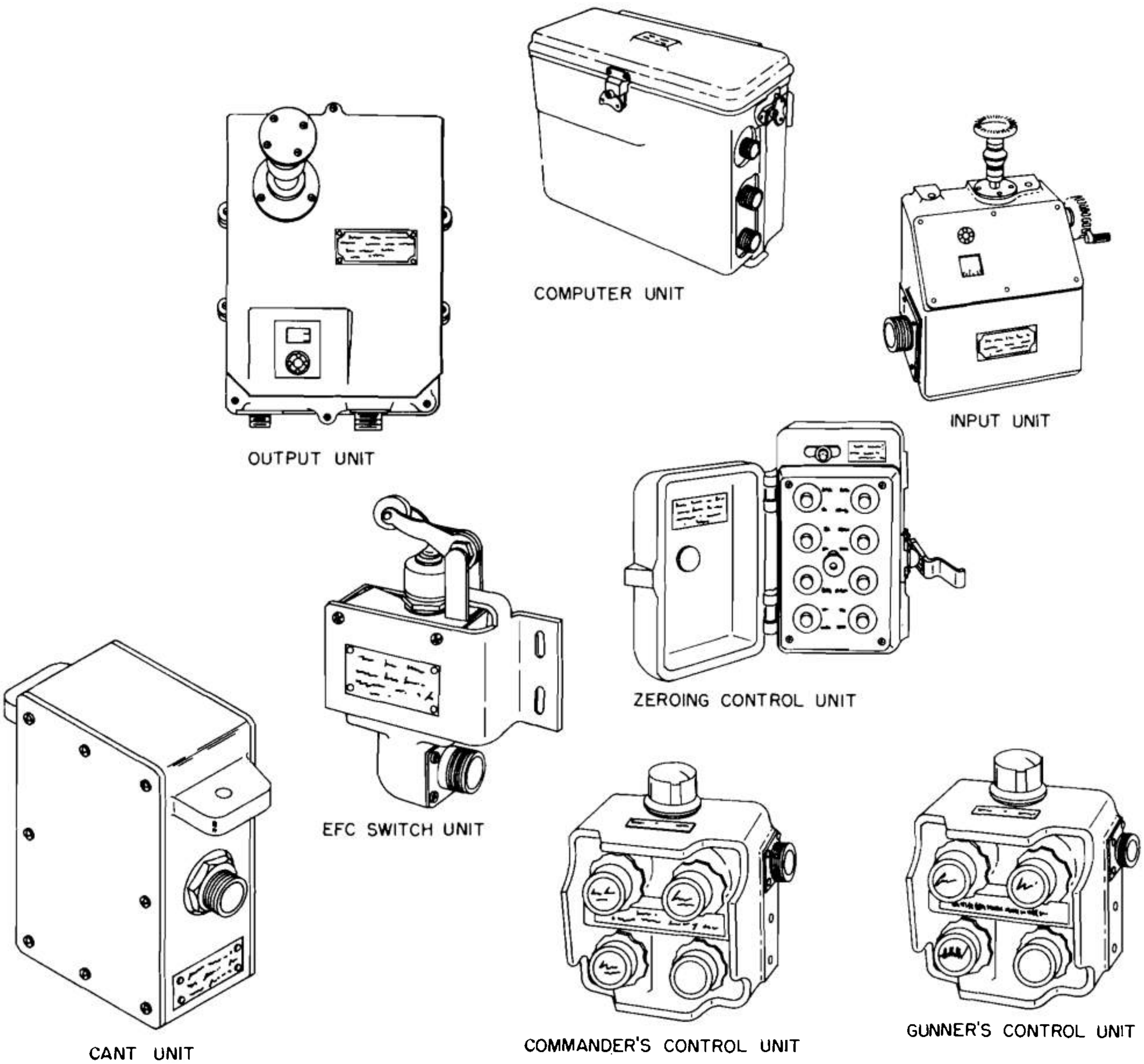


Figure 17-34. XM16 Ballistic Computer

the selected ammunition to the gunner and commander. These units are capable of selecting four types of ammunition.

The computer unit is the central unit of the ballistic computer. It computes the total elevation and deflection correction signals.

The output unit converts the electrical elevation solutions from the computer unit into mechanical shaft rotation for use in the ballistic drive of the fire control systems and in the superelevation actuator of the hydraulic servo used within the main armament.

17-7 AZIMUTH AND ELEVATION DRIVES

Weapon pointing in combat vehicles normally is accomplished by slewing the weapon station (or turret) in azimuth and elevating or depressing the weapon. In small, unarmored weapon stations manual drives may be adequate. Normally, however, weapons larger than cal .50 machine guns require power

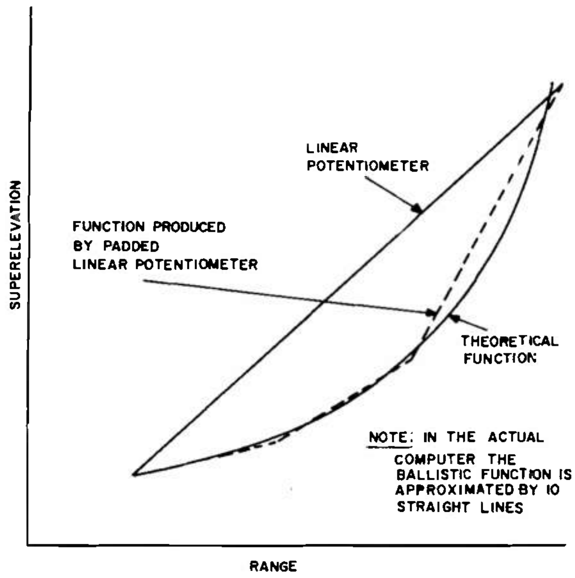


Figure 17-35. Generation of Ballistic Functions in the XM16 Ballistic Computer

drives because of the weight and bulk involved.

The design of a power drive system becomes a servo design problem once all the design parameters have been defined. The paragraphs that follow will discuss typical weapon station design parameters and review power control system designs currently used.

17-7.1 DESIGN PARAMETERS

Defining the design parameters for azimuth and elevation drives requires careful examination of the vehicle system performance requirements and the weapon station characteristics.

Examination of the vehicle system performance requirements must consider the following:

1. Smooth Tracking Rate. If the weapon is to be used against moving point targets then it must be able to track smoothly at slow speed without jerking or jumping. Smooth tracking rates for vehicles currently being developed (i.e., MICV-XM723 and ARSV-XM800) are on the order of 1/4 mil per sec (17.7 mils = 1 deg of arc).

2. Maximum Slewing and Elevation/Depression Rates. Typical rates for current vehicles are shown in Table 17-2.

3. Elevation and Depression Limits. Typical values are given in Table 17-2. Large caliber tank guns normally do not require elevation greater than 20 deg. Small caliber weapons (17.62-mm and cal .50) that may be used for firing at low flying aircraft or helicopters, however, normally are required to elevate to 60 deg.

4. Fine Laying. The capability to fine lay the weapon on point targets must be evaluated. Fine laying is affected by the servo system gain-stability characteristics, friction, and the type of control system used. The control system is normally nonlinear. Any deflection of the gunner or commander's control about the zero point results in small movement of the weapon station or gun. As the control handle is deflected further, the sensitivity increases.

5. Azimuth Mass Moment of Inertia and Unbalance. Determine from the weapon station design.

6. Elevation Mass Moment of Inertia and Unbalance. Determine from the weapon design and its installation. Tank guns normally have a long barrel and are therefore unbalanced. This unbalance can be partially offset by an equilibrator spring. The equilibrator will balance the weapon at zero elevation

TABLE 17-2. TYPICAL WEAPON SLEW AND ELEVATION RATES[13,14,15]

Vehicle	Weapon	Slewing Rate, deg/sec	Elevation/ Depression Rate, deg/sec	Max Elevation, deg	Max Depression, deg
M60A1	105 mm	24	4	20	10
M60A2	152 mm	45	40	20	10
M551	152 mm	24	4	19.5	8.5
LVTP7	M85 cal .50	60	60	60	15

when the vehicle is static. The equilibrator will not provide dynamic balance. In addition, its effect will be diminished when the weapon is elevated or depressed from the zero elevation point.

7. Recoil Force. Weapon recoil forces and their effect on the azimuth and elevation torque requirements of the drive system must be evaluated. Mounting the weapon off the centerline of the weapon station can result in significant increases in the azimuth drive torque requirement.

8. Vehicle Dynamics. The dynamic inputs to the weapon station and their effect on the weapon station and weapon unbalance must be evaluated.

9. Vehicle Electrical Power. Power controls are normally used intermittently and may have high peak power requirements during short (intermittent) periods. The vehicle electrical supply system, including batteries, should therefore be evaluated. Vehicle electrical systems may have large voltage spikes resulting from the switching of bilge pumps, starter motors, firing solenoids, etc. Electronic circuits, required for the power drives, therefore should be operated off regulated power supplies or contain spike suppression filters.

17-7.2 POWER CONTROL SYSTEMS

There are two basic azimuth and elevation power drive systems currently used in combat vehicles. These systems can be classified as electrohydraulic and electric systems. Electrohydraulic systems are discussed in par. 17-7.2.1 and electric systems are discussed in par. 17-7.2.2. Par. 17-7.2.3 discusses components and subsystems common to both system types.

Making a choice between an electric and an electrohydraulic system for a particular application requires a thorough trade-off analysis. Traditionally, electrohydraulic systems have been used in tank weapon stations. The recently developed M551 SHERIDAN Tank, however, utilizes an all-electric system. Advances in the state of the art of electric systems (especially power amplifiers) have provided the added advantages for application in new vehicles [17,18].

17-7.2.1 ELECTROHYDRAULIC SYSTEMS

A block diagram for a typical electrohydraulic system is shown in Fig. 17-36. An electric motor driving a hydraulic pump provides hydraulic power. The hydraulic energy is stored in an accumulator. When the pressure in the accumulator drops below a predetermined level, a pressure-sensitive switch turns the motor on through the control relay. When the pressure builds back up to a predetermined level, the pressure-sensitive switch turns the motor off.

The power to the hydraulic actuators is controlled by servo valves. The servo valves in turn are controlled by inputs from the gunner's and/or commander's azimuth and elevation controls. In addition, the servo valve may receive inputs from other sources such as the deck clearance or elevation limit systems (discussed in par. 17-7.2.3).

Two types of hydraulic elevation actuators are available. A hydraulic motor can be used to drive a gear sector on the rotor through a pinion, or a hydraulic cylinder with one end fixed to the turret structure and one end fixed to the rotor can be used. Use of a hydraulic cylinder results in a nonlinear relationship between displacement of the piston and rotation of the weapon rotor. This nonlinear relationship may require compensation in the gunner/commander controls.

Because of the pressures involved (typically 1500-2000 psi), positive-displacement pumps normally are used to charge the accumulator. A compound wound DC motor is the best candidate for this application.

Sizing the motor requires a knowledge of the pump characteristics, the system working pressure, the pressure differential, the flow requirements for the actuators, and the sys-

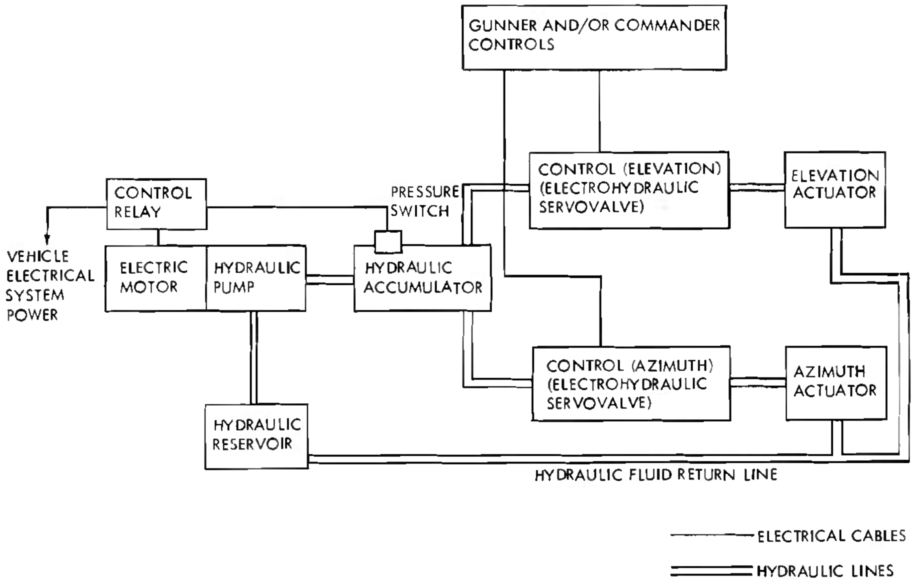


Figure 17-36. Electrohydraulic Power Controls

tem duty cycle. The pressure differential is normally on the order of 200 psi. Therefore, the pump essentially has a constant head. The required capacity is determined from the actuator flow requirements, the capacity of the accumulator, and the system duty cycle. The capacity of positive displacement pumps with constant head varies directly with speed. In addition, the torque requirements of the pump are essentially constant at all speeds.

The power requirements P of the motor are directly related to the speed (and capacity) of the pump, and can be determined by

$$P = \frac{TS}{5250}, \text{hp} \tag{17-1}$$

where

T = torque, lb-ft

S = speed, rpm

If the pump used is a gear pump (fixed displacement) rather than a variable displacement type, special consideration must be given to the motor starting torque. Because of the low starting torque of DC shunt motors, a special control (par. 10-2.3) or a DC series or compound motor may be required.

Because of space constraints the motor is normally flange-mounted and directly coupled to the pump.

Control valves may be manual or electrohydraulic. Valve types are explained thoroughly in Ref. 24. Electrohydraulic servo valves receive electrical signals and provide proportional control of the hydraulic fluid flow, resulting in smooth and accurate control of the actuators. A servo valve (Fig. 17-37) employs a torque motor (typical operating current in milliamperes) that operates a swing plate. The swing plate uncovers hydraulic ports thereby controlling the rate and direction of fluid flow.

In some systems the hydraulic fluid flow is controlled by a manually operated spool valve rather than a servo valve. The system in the LVTP7 functions in this way. These systems offer simplicity and low cost provided there is no requirement to interface with other electrical systems such as stabilization, deck clearance, or elevation limits. Simple hydraulic deck clearance and elevation limit systems utilizing solenoid valves to restrict flow rates

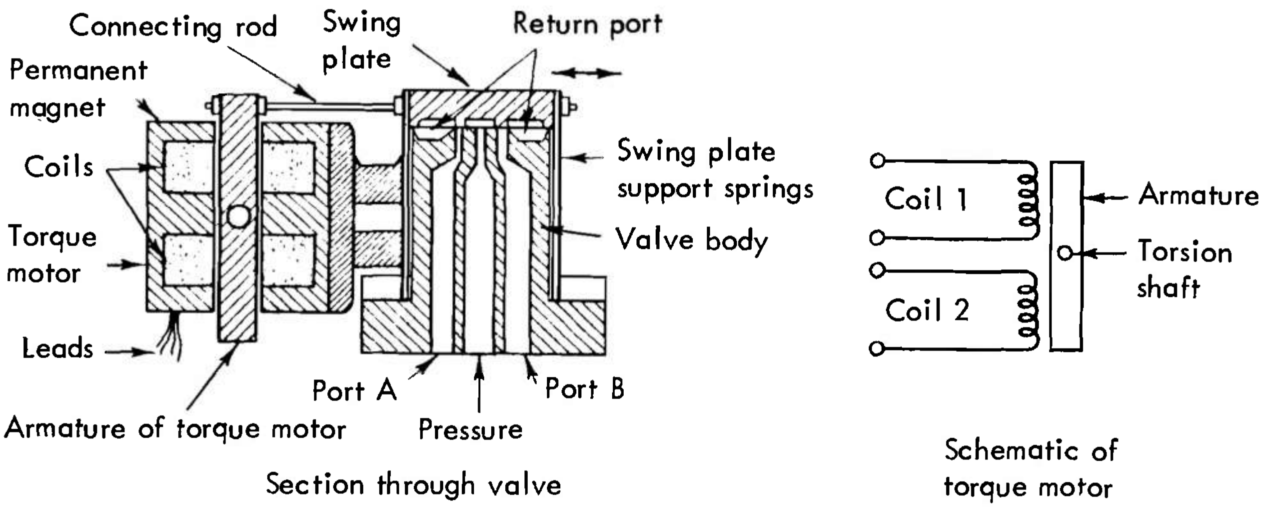


Figure 17-37. Electrohydraulic Servo Valve

may be interfaced with manual control valve systems, however, weapon stabilization systems require electrohydraulic servo valve control of the weapon azimuth and elevation drives.

17-7.2.2 ALL-ELECTRIC SYSTEMS

The block diagram of an all-electric power control system (Fig. 17-38) indicates considerable simplification over the electrohydraulic system (Fig. 17-36). This may be misleading in that a detailed schematic of the servo amplifier would reveal a complex subsystem. The availability of solid-state electronic components, however, has resulted in the development of relatively small, efficient, reliable servo amplifiers. All-electric systems presently are used in the XM163 Self-propelled Antiaircraft Gun and the M551 SHERIDAN.

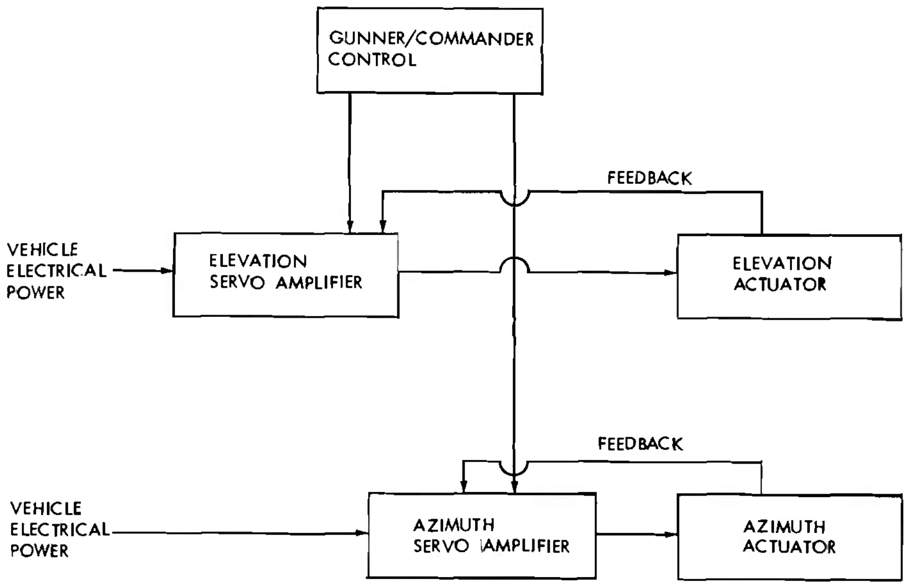


Figure 17-38. Electric Power Controls

The M551 SHERIDAN is an Armored Reconnaissance/Airborne Assault Vehicle with a 152-mm combination gun/SHILLELAGH missile launcher for primary armament. The all-electric power control system it contains provides smooth tracking from 0.5 to 71.0 mils/sec in elevation and from 0.5 to 427.0 mils/sec in azimuth. In addition, the commander's cupola has a two-speed power assist for slewing.

The power controls for the SHERIDAN were developed before the availability of high power transistors. To handle the power required for the actuators (servomotors), it utilizes a motor-generator.

The motor-generator (Fig. 17-39) consists of a constant-speed DC motor and an amplidyne generator that supplies current to the actuators. Both armatures are mounted on a common shaft so the motor armature rotates the generator armature. The amount of power generated by the motor generator is regulated by the amount of generator field current. The amplidyne generator has short circuit and compensating windings that permit small electrical signals to control large amounts of electrical power. Power demands for M551 turret control are given in Table 17-6.

When the motor is energized and rotating (accomplished by depressing either the commander's or gunner's control handle palm switch), the generator is also rotating. No voltage output is generated until a differential current flows in the generator field windings. This differential current is caused to flow when the commander or gunner control handle is deflected.

All-electric systems normally use split field series wound motors (Fig. 10-5) with tachometers for actuators. The tachometer provides

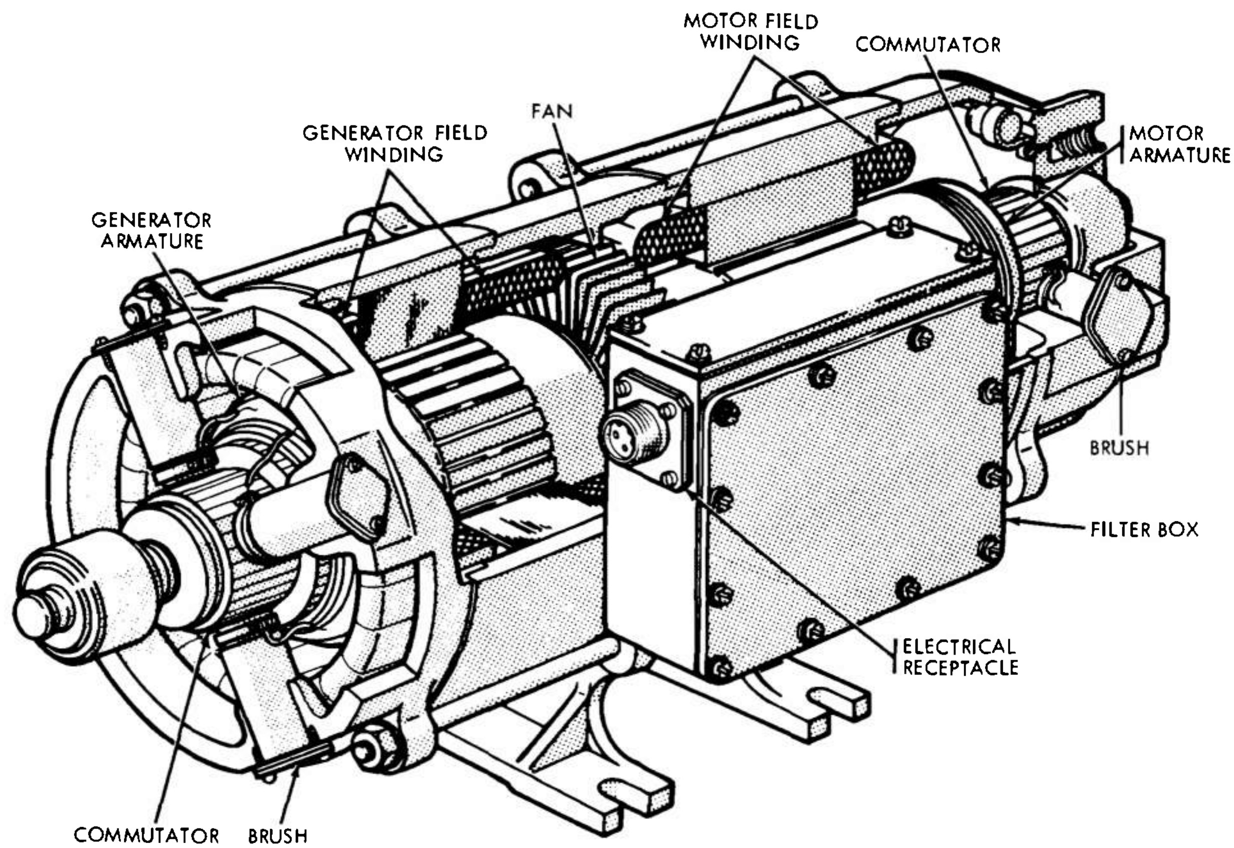


Figure 17-39. Motor-Generator

feedback to the servo amplifier. The split field is required to reverse direction. Although shunt motors have performance characteristics (linearity) that make them desirable for this application, they are normally not used because of weight and cost disadvantages.

The XM163 System (Fig. 17-40) uses three identical motors and servo amplifiers to drive the weapon in elevation and azimuth. One of the units is used for the elevation drive and the other two are used for the azimuth drive. The motors are DC split field types rated at 6 hp at 6300 rpm (Ordnance Dwg #8436840). The servo amplifiers control the motors by the pulse width modulation technique (see discussion that follows).

General Electric-Ordnance (GEO) Systems Division has developed an all-electric power control system (with stabilization) that utilizes a solid-state servo amplifier. This system has been installed and tested in the M60A2 Tank[18] and the XM701 (MICV-65). GEO is presently developing a similar system for the XM800 (ARSV).

Five power system design options are available to the designer of weapon station electric power controls. These options are listed in Table 17-3.

For many years motor-generators (amplidynes) have been the primary means for providing power amplification in electrical drives. However, the response, weight, noise, standby losses, and requirement for routine maintenance limit the usefulness of these devices. Other systems employ one or the other of two basic concepts available to the designer of static (solid-state) power amplifiers.

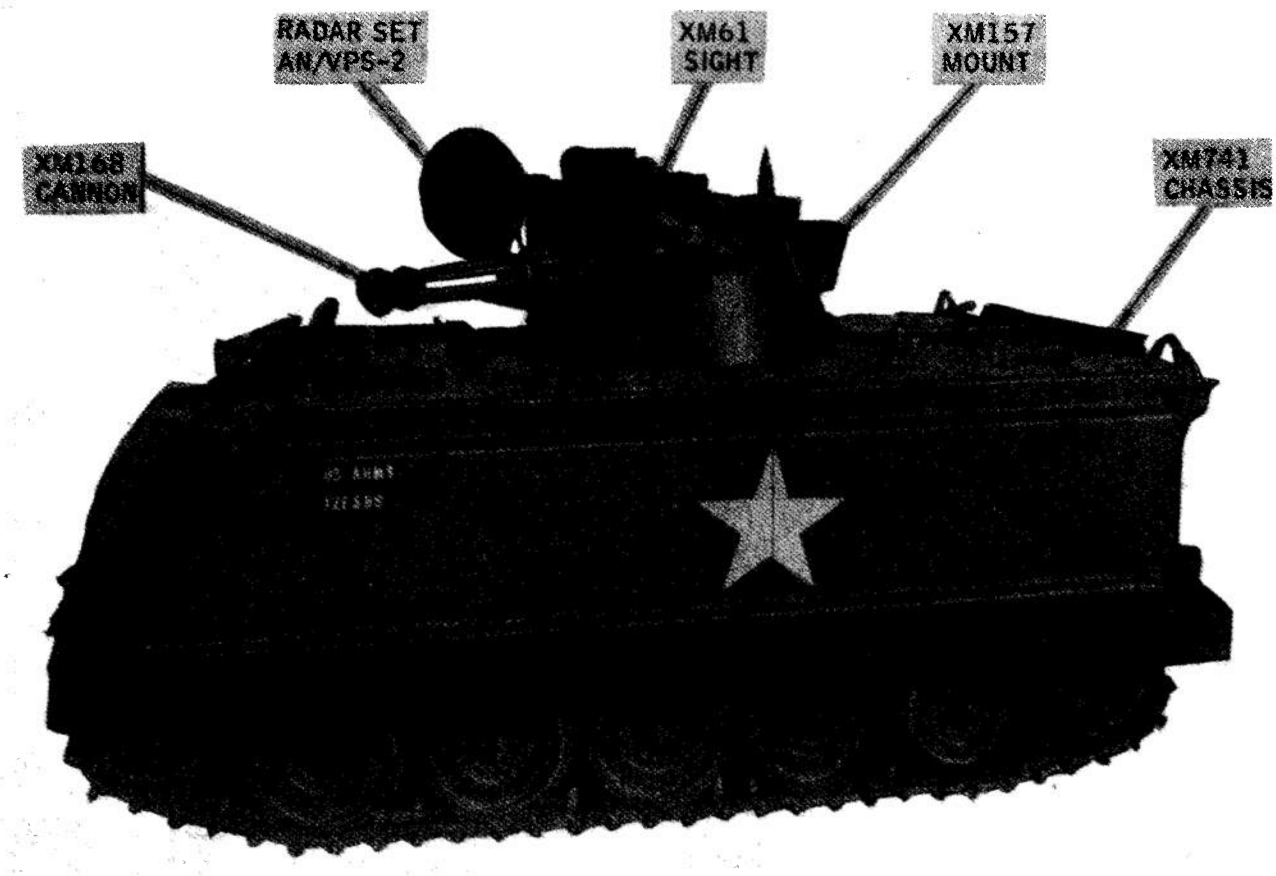


Figure 17-40. XM163 Self-propelled Antiarcraft System

TABLE 17-3. CHARACTERISTICS OF ELECTRIC POWER CONTROLS FOR WEAPONS

Type	Comments
1. Motor-generator (amplidyne)	• Excessive weight • Limited bandwidth • High losses • Routine maintenance required
2. AC generator and SCR phase control amplifier	• Simple power amplifier • Auxiliary equipment required for engine off operation
3. Inverter and SCR phase control amplifier	• Double handling of power with semiconductors
4. Inverter, rectifier and switching amplifier	• Triple handling of power with semiconductors • Difficulty with regenerative braking of motor
5. Switching amplifier directly off battery	• High efficiency • Wide bandwidth • Single handling of power with semiconductor

One utilizes a silicone-controlled rectifier (SCR), phase-controlled power amplifier operating off an AC power source. SCR's are similar to normal rectifiers in that they only conduct current in one direction. Unlike normal rectifiers, however, they will not conduct unless they have been turned on by applying a voltage to a gate grid. Once they are turned on, they continue to conduct until the voltage across them drops to zero. If an AC power supply is connected across the SCR, the average power out can be controlled by varying the phase – with respect to the power supply – of a pulsing network that turns the SCR on.

The second amplifier design approach utilizes power transistors in a switching mode of operation. Low losses are achieved because the transistors are either saturated, with very low voltage drop, or cut off with no losses. The switching losses are minimized by the use of high-speed transistors. The average voltage applied to the motor is a function of the ratio of the switch-on time to the switching period. This technique is called pulse width modulation.

Because the SCR phase-control amplifier requires an AC power source not normally aboard combat vehicles, either an AC generator or a static inverter must be provided (second and third type, Table 17-3).

The inverter approach requires double handling of the power with semiconductors and thus will be inherently less reliable. Also, a relatively large and heavy transformer is required.

The use of an engine-driven AC generator appears advantageous if used in conjunction with a simple SCR phase control amplifier. However, "battery only" operation normally is required for combat vehicles and auxiliary AC power provisions would therefore be necessary to operate the weapon station when the vehicle engine was not running. Thus, the apparent advantage of a simple phase control amplifier requirement is offset.

The fourth approach (Table 17-3) takes advantage of the fact that motor weight can be reduced if the switching amplifier is operated off a voltage substantially higher than 28 V. However, triple handling of the power with semiconductors would be required to convert 28 VDC to a higher DC voltage and absorption of energy during motor regenerative braking would necessitate large capacitors.

The fifth approach (Table 17-3), utilizing a switching amplifier operating directly off of the vehicle battery, may be the best candidate for most applications.

A basic switching amplifier circuit is shown in Fig. 17-41. The motor will rotate in one direction if switches S1 and S4 are closed and opened at a given switching frequency. The actual average voltage across the motor is dependent on the time the switches remain closed during the switching period. During low voltage operation, the switches are closed for a short time during each switching period. To achieve maximum voltage, the switches are closed continuously. The motor will rotate in the opposite direction if switches S1 and S4 are left open while S2 and S3 are alternately closed and opened. The diodes provide a path for the motor current produced by generator action when the motor is being turned and the switches are open. Regenerative braking is realized when this power is fed back to the input power source.

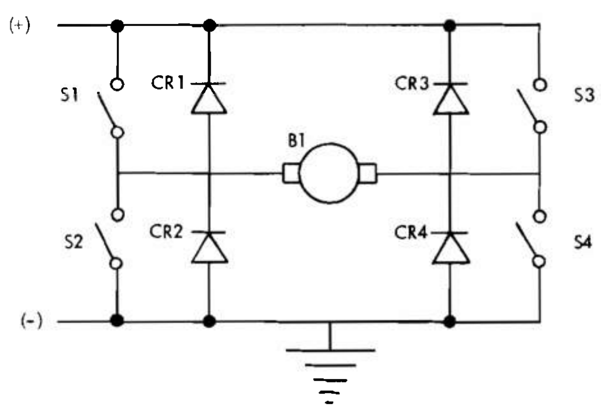


Figure 17-41. Basic Switching Power Amplifier

In Fig. 17-42 the switches of the basic switching amplifier have been mechanized using transistors, resulting in a typical pulse width modulation power amplifier.

The gearless power drive concept (Fig. 17-43) may find application in future vehicle applications. In this system, the stator is connected directly to the main load supporting structure (vehicle hull); while the rotor windings and commutator are mounted on the base of the rotating structure (weapon station). This system eliminates all gearing and associated backlash and resonance. The motor is a specially designed low speed, high torque, DC machine.

Such systems have been used for driving radar antennas, fire control directors, missile trackers, and other rotating equipment. Their application to combat vehicles has been limited because of weight. The weight results from the large masses of ferrous material required to prevent magnetic saturation. This problem may be overcome in future vehicles if the stator and rotor are designed as integral parts of the vehicle hull and weapon station, respectively.

17-7.2.3 POWER CONTROL SUBSYSTEMS

Figs. 17-36 and 17-38 show the basic components of electrohydraulic and all-electric power control systems. Table 17-6 presents a comparison of power requirements for electric and electrohydraulic systems in the present inventory. The following subsystems and components normally are required for either type system:

1. Summing Amplifier. A summing amplifier is required to integrate the signals from subsystems such as deck clearance, stabilization, and elevation limit with the signals from the gunner/commander's control unit. In the electrohydraulic system, this unit is placed between the gunner/commander control and the servo valve. In the all-electric system, it is placed between the gunner/commander control and the servo amplifiers.

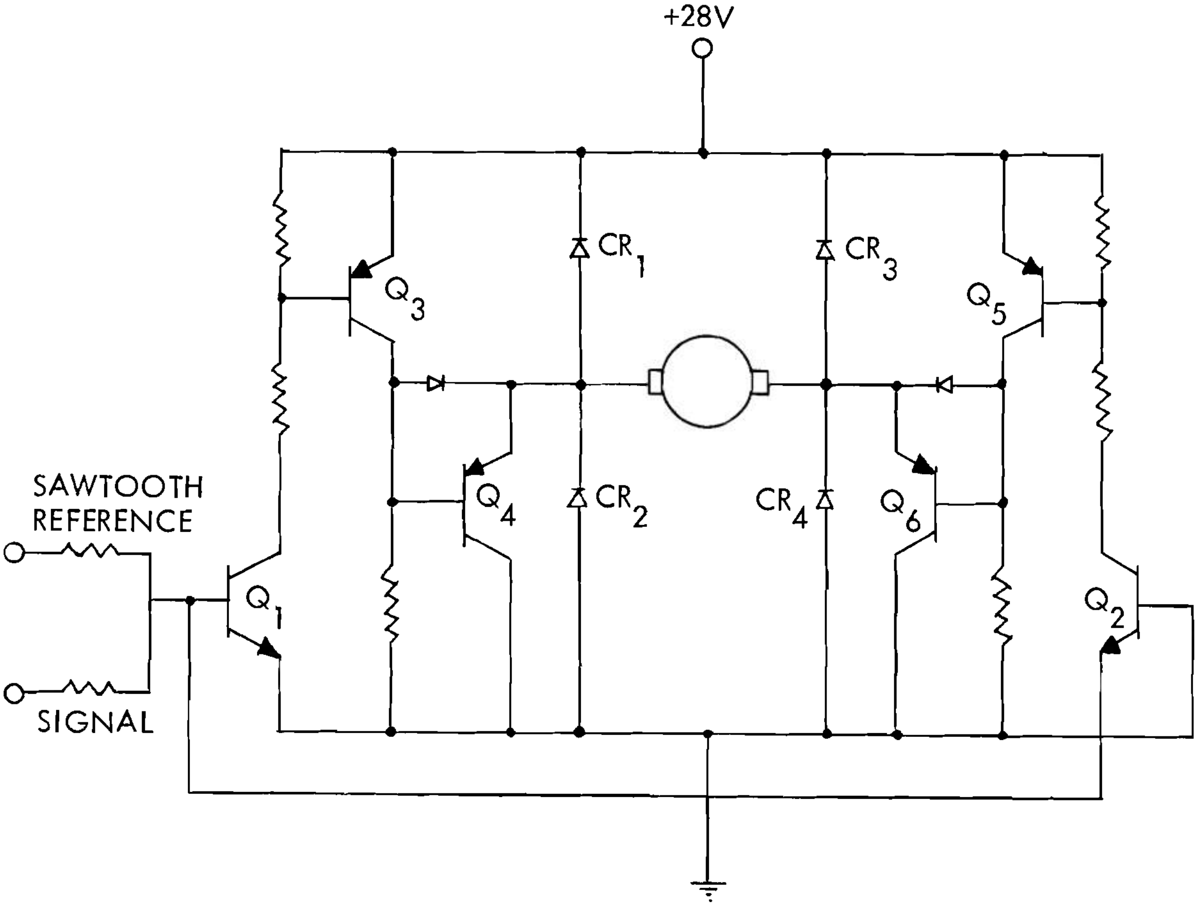


Figure 17-42. Pulse Width Modulation Power Amplifier

2. Deck Clearance. Maximum depression of the weapon, on combat vehicles, normally is provided when the weapon is trained forward over the front of the vehicle. As the weapon station is slewed to the rear, the weapon usually must be elevated to clear the corners of the vehicle and any local protrusions.

A deck clearance system must actuate the elevation servo to prevent the weapon from physically striking the vehicle hull. In some applications, the deck clearance system must prevent the weapon from entering zones where it could hit the vehicle when fired.

A deck clearance system normally consists of an elevation potentiometer, an azimuth potentiometer, an azimuth tachometer-generator, and necessary summing and logic circuitry. Signals from the potentiometers indicate forbidden zones for the weapon.

The tachometer-generator provides an azimuth velocity feedback to determine at which point the weapon elevation actuator must be actuated so the weapon will clear the forbidden zone.

In some applications, it is desirable to provide some built-in memory in the deck clearance system so the weapon will return to its original elevation after clearing local protrusions. This will aid in tracking moving targets.

3. Elevation Limit. An elevation limit system is required to prevent the weapon

from slamming into the mechanical elevation limits. This system normally consists of an elevation potentiometer and tachometer-generator. The signals from these two units are summed to determine at what point the elevation drive must be decelerated.

4. Gunner Control. A typical gunner's control is shown in Fig. 17-44. The vehicle commander may or may not have a similar control, depending on the particular application. The output of the control handle is normally nonlinear as shown in Fig. 17-45. This nonlinearity results in low sensitivity about the zero handle deflection point and high output at maximum handle deflection. The nonlinearity is achieved by using nonlinear potentiometers. Traverse and elevation centering potentiometers are provided to eliminate drift when the handle is in the neutral position.

5. Brakes. Locking devices to prevent external forces from moving the weapon station are normally required. Two methods commonly are used. One method is to use no-back gears in the drives. The other is to use a magnetic brake. In electric systems, the magnetic brake can be wired in series with the fields of the electric motors (actuators).

17-8 STABILIZATION

The battlefield effectiveness of a modern combat vehicle is a result of a balance among four major design factors – observation, firepower, mobility, and armor. Unfortunately, these factors are interdependent and generally negative in their effect on one another.

In combat vehicles without stabilization, observation and firepower capabilities are directly reduced by mobility. Conversely, mobility is limited by the requirements for maximum observation and defensive firepower.

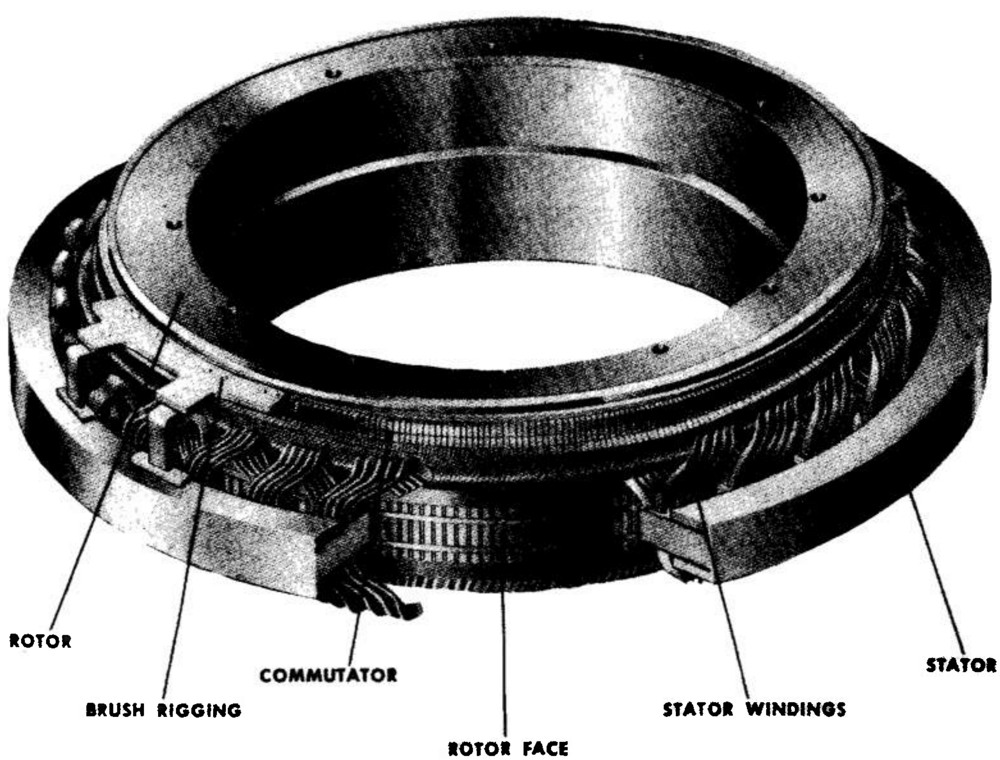


Figure 17-43. Gearless Power Drive

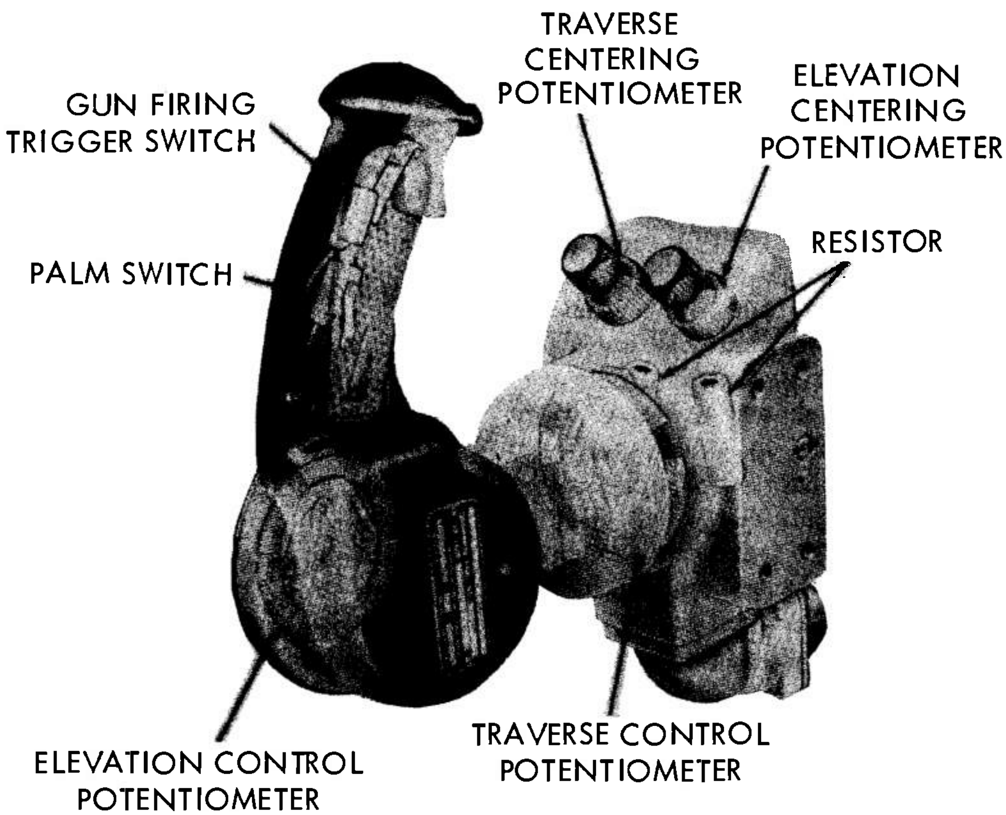


Figure 17-44. Gunner's Control Handle

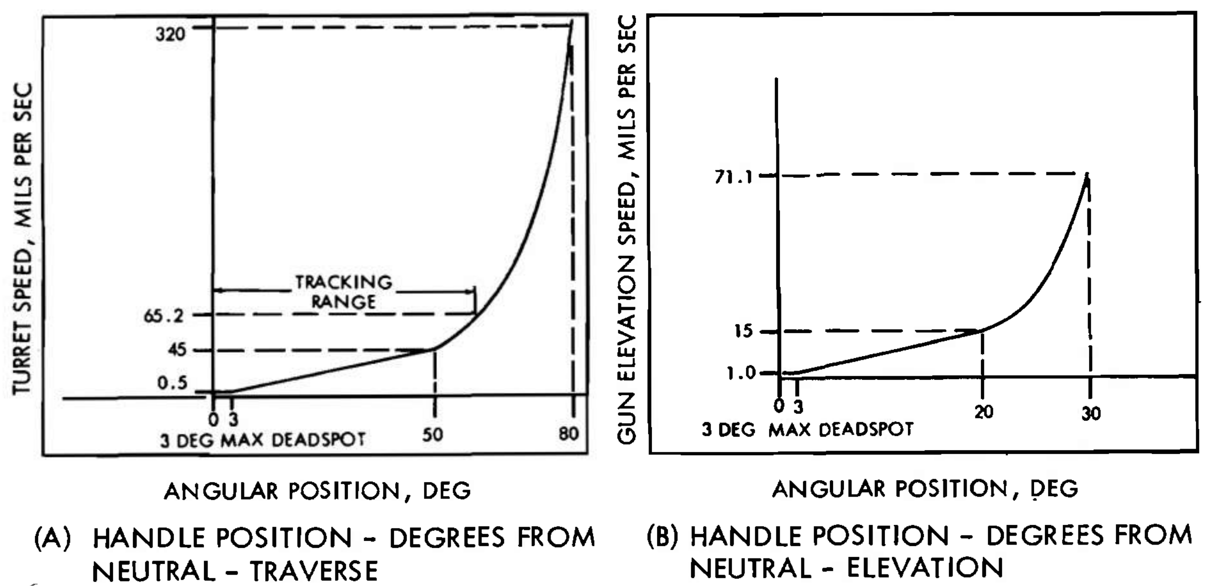


Figure 17-45. Gunner's Control Handle Response

This impasse is due to the inherent inability of an operator to react with sufficient speed and precision to nullify the angular excursions of the vehicle and turret experienced during vehicle motion. Human factors studies have shown that the response rates required are well outside human capabilities and cannot be achieved by training.

The solution to the requirement for maximum observation and firepower and maximum mobility, therefore, lies in the use of a high frequency response, inertially referenced weapon stabilizing system that relieves the operator of those tracking duties associated with the vehicle angular motions. The operator must still correct for vehicle and target translation. This will allow the operator to concentrate on the purpose of acquiring, identifying, and tracking the target.

The principles of stabilizing weapons and fire control systems are not new. Naval vessels and turret carrying aircraft have been using systems similar in concept for many years. The development of stabilization systems for weapon carrying Army vehicles has proceeded more slowly because the interferential inputs to the land vehicles were found to be much greater in amplitude and in frequency content than those found in naval and aircraft service.

Successful stabilization systems have been developed and tested, however, and are standard equipment on the M60A2 Tank and the M551 SHERIDAN.

17-8.1 DESIGN PARAMETERS

The size, weight, and cost of stabilization system components, and the number and type of response elements, are dictated by the performance requirements and the disturbance inputs caused by motion of the vehicle. The magnitude of the disturbance inputs are a function of the cupola, gun, and servo parameters combined with the type and magnitude of the vehicle motions.

17-8.1.1 CUPOLA

Thc key cupola parameters that dictate the servo system requirements and thus the optimum servo configuration are:

1. Friction. Friction in the bearings and seals causes the gun and cupola to move with the vehicle until the servos provide sufficient torque to overcome the friction. Large friction-to-system inertia ratios require high bandwidth servos.

2. Unbalance. Gravity and linear accelerations cause torques on gun and cupola. Torques which are large are a major source of system error.

3. Dynamic Torque. A traverse torque is produced by the angular velocity of the cupola around the pitch axis times the angular velocity around the roll axis times the difference in the cupola inertia around these axes. Since the rotational velocity seldom exceeds 0.5 rad/sec, this torque is generally considerably smallcr than the friction torque.

4. Cupola Roll. If the gun elevation is not zero and vehicle motion rolls the cupola, the required traverse velocity can become large and introduce an error. For elevation angles below 20 deg, this is not a major source of error.

17-8.1.2 SERVOMECHANISM

The selected servomechanism also may be a source of disturbance inputs and errors. The power drive parameters, however, are dependent on the cupola and gun parameters. The servo disturbance inputs are:

1. Motor and Gearing Acceleration Torque. Vehicle pitching and rolling motions require acceleration of the motor and gearing mass. The torque required is a source of stabilization error. If the motor and gearing inertias are chosen properly, the cupola and gun unbalance torques can bc made opposite and equal for most gun and cupola angles, but cannot be eliminated for all cupola angles and for linear accelerations of the vehicle.

2. Motor Generated Voltage. The servo must supply the voltage necessary to run the motor at the required speed. A high servo loop gain, obtained by using current feedback, can produce the voltage with a small error.

3. Sensors and Feedback Devices. Gyros are selected for null stability, gradient, and drift characteristics. Tachometers are used to provide a high bandwidth servo loop to reduce errors caused by friction, unbalance, and motor acceleration torques.

4. Motor and Gearing Friction. This has the same effect as, and adds to, the gun and cupola friction.

17-8.2 GYROS

Gyros for military vehicle applications are motor driven and use approximately 0.5 A at 28 VDC.

The first law of gyroscopic action is the principle of rigidity in space. A gyro that is free to move in any direction will maintain its original orientation in space. Conversely, a gyro which is restrained in one or more directions will attempt to resist any overturning torque. This resistance gives rise to the second law, which is the law of precession. Any attempt to change the orientation of the spin axis will cause the gyro to precess, or move its spin axis at right angles to the applied torque so as to reduce the applied torque to zero. Fig. 17-46 illustrates a gyro mounted in three gimbals, a so-called three-degree-of-freedom gyro, which will maintain the orientation of its spin axis in space. The rigid mounting may be rotated in any direction without disturbing the gyroscope itself.

Fig. 17-47 illustrates a single-degree-of-freedom gyro which is able to move in only one direction. An applied torque about the input axis will be resisted and will produce precession about the output axis. This precession will change the orientation of the spin axis.

The rate of rotation about the output axis due to precession is directly proportional to the rate of rotation about the input axis due to the applied torque is determined from Eq. 17-2

$$w_p = Kw_i, \text{ rad/sec} \qquad (17\text{-}2)$$

where

K = proportionality constant, dimensionless

w_p = output axis precession, rad/sec

w_i = input axis rotation, rad/sec

Since w_p is the rate of change of θ, the angular position of the spin axis:

$$\frac{d\theta}{dt} = w_p = Kw_i \qquad (17\text{-}3)$$

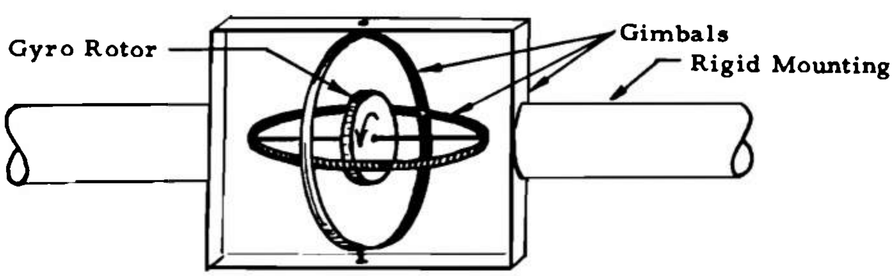


Figure 17-46. Gyro With Three Degrees of Freedom

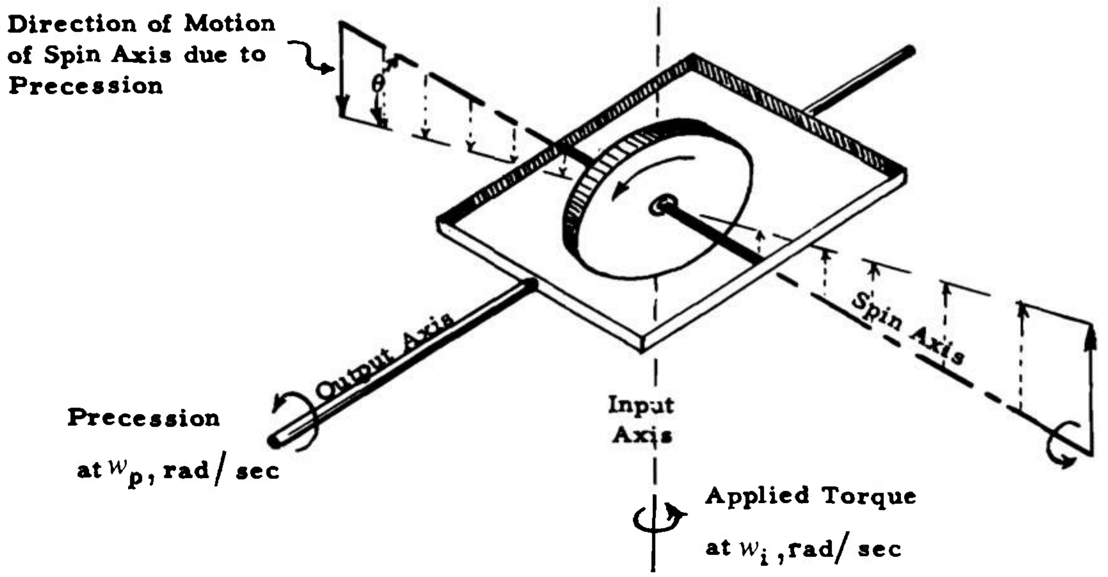


Figure 17-47. Gyro With Single Degree of Freedom

$$d\theta = Kw_i\, dt \quad (17\text{-}4)$$

$$\theta = K\int w_i\, dt \quad (17\text{-}5)$$

From Fig. 17-47, it is seen that the single-degree-of-freedom gyro will actually integrate, thus the more common name of "integrating gyro". If, around the output axis, a signal generator is mounted which produces an electric signal proportional to the angle θ, any attitude change about the input axis will be translated into a voltage proportional to that change. The assembly, therefore, produces the first requirement for an analog computation, a voltage proportional to a physical quantity.

The assumption that the precessional rate is proportional to the angular input rate is only valid when the angle θ is at or very near zero. If θ is allowed to get too large (such that the approximation $\cos\theta = 1$ no longer holds), additional nonlinear terms will be introduced due to cross-coupling effects.

To keep θ at the null position, the output voltage from the signal generator is used to drive a motor, also on the output shaft, which will exactly balance the torque due to precession. Thus, very small output angles are produced keeping the system linear, while a voltage proportional to the integral of the input rate is still obtained. This voltage therefore is used to keep the three axes mutually perpendicular at all times.

In one commonly used commercial gyro, the gyro wheel and its spin motor are encased in a sealed cylindrical can. This can, in turn, is encased in a slightly larger oil-filled can, so that the gyro case is free to rotate only about the common axis of the two cylinders. The spin axis of the gyro is at right angles to the axis of the cylinders. The signal generator and the torque motor are mounted on the axis of the cylinders; which is the output axis. The whole unit then is mounted at right angles to the desired input axis. An illustration of the unit is shown in Fig. 17-48.

For vehicular applications, a less expensive gyro called a spring restrained rate gyro is often used. This gyro uses a spring to limit precession of the spin axis. The spring-restrained rate gyro has less resolution and less null stability resulting in increased drift. For many applications, however, it is adequate.

The fundamental inertial reference used for stabilization systems is provided by rate gyros. System configurations using 5, 3, and 2 gyros are discussed.

1. System I. This system uses five sensing gyros. The arrangement of the drives and error sensing components of the system are shown in Fig. 17-49. The primary gyros on the gun are rate gyros—selected for low drift, high null stability, and high resolution characteristics. An inner tachometer loop, as shown on the functional block diagram of Fig. 17-50, is used to provide the high servo bandwidth necessary to reduce the errors caused by dynamic loads due to unbalance and friction.

The errors due to vehicle angular motion, which would be caused by using relative velocity feedback from the tachometers, are prevented by using hull- and turret-mounted rate gyros to feed compensating rate signals to the servo amplifiers.

2. System II. This system uses three sensing gyros. The gun traverse and elevation gyros shown on Fig. 17-49 are omitted, and the two turret-mounted and one vehicle-mounted gyros provide the stabilization signals. The functional diagram is shown in Fig. 17-51 and is similar to that shown on Fig. 17-50 except the gun gyros are omitted. The gyros measure the vehicle motion in space and feed this as a velocity command to the gun and turret servos. The servos are velocity servos with tachometer feedback, and thus the gun and turret relative velocity is equal and opposite to the vehicle motion velocity. The gun and turret then remain stationary in space. The command gradient in volts per radians per second must be matched to the tachometer gradient to keep the stabilization errors small. Any mismatch results in stabilization errors. The bandwidth of the servo is high so that the errors caused by friction and unbalance are small. Gearing errors and backlash do produce errors as the motor velocity is matched against the gyro command velocity. Thus, any deviations between motor and load result in stabilization errors.

The primary power drive elements (motors, power amplifiers, and gearing) are the same as System I and the system modes and protection circuits are the same.

3. System III. This system uses two sensing gyros mounted on the gun for the stabiliza-

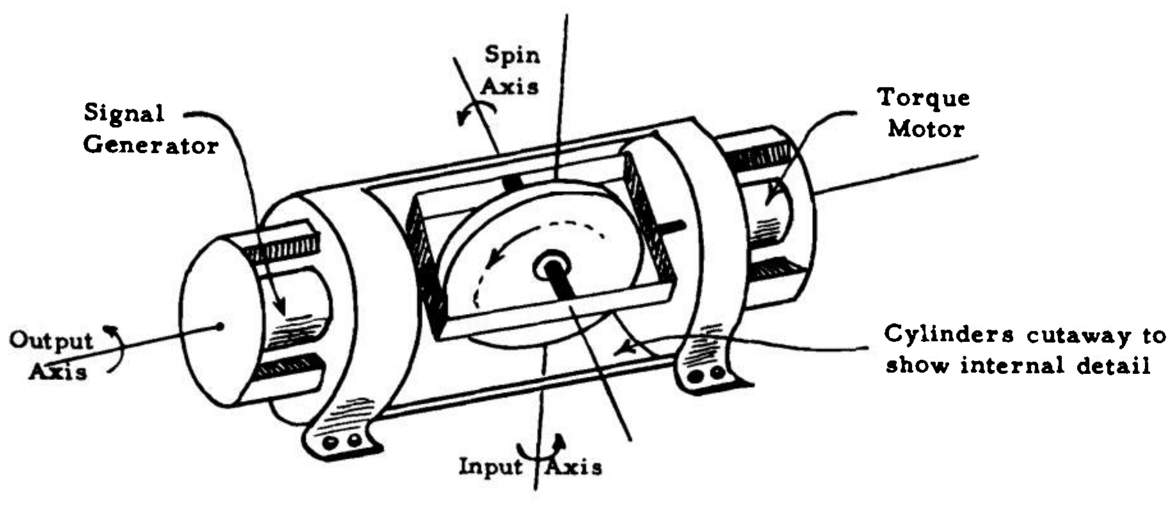


Figure 17-48. Integrating Rate Gyro

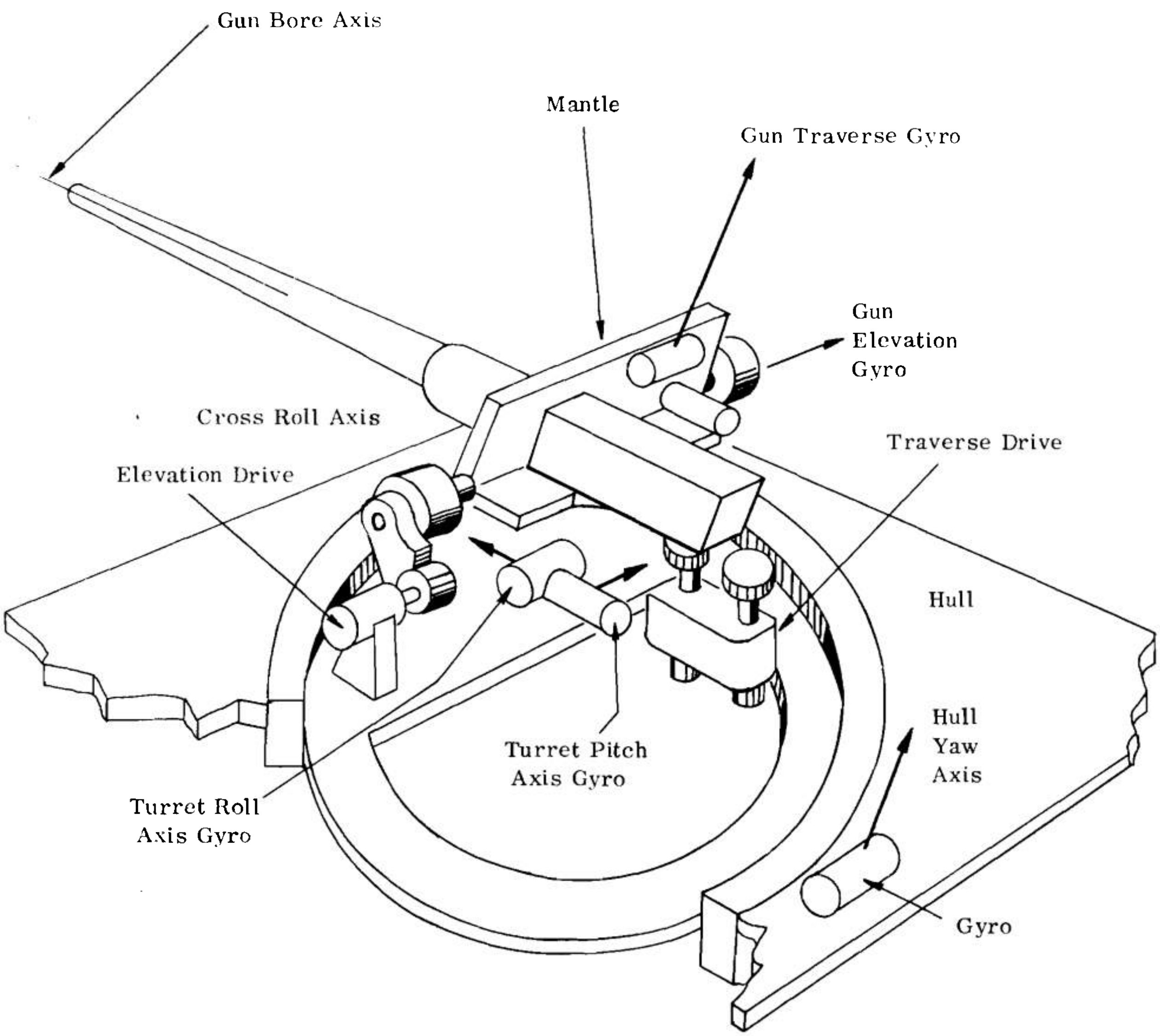


Figure 17-49. Five Gyro Stabilization System Concept[1 2]

tion signal. The three gyros shown on Fig. 17-49 mounted in the turret and vehicle are eliminated. The functional block diagram is shown on Fig. 17-52. The gyros are used as the rate feedback in the stabilized mode. The tachometer feedback is used only in the power mode. The gyro rate loop crossover is limited by the mechanical resonance due to the gearing spring and phase shift in the gyro transfer function so that the bandwidth of the gyro loop is lower than the tachometer loop. Torque disturbances due to friction and unbalance cause larger errors.

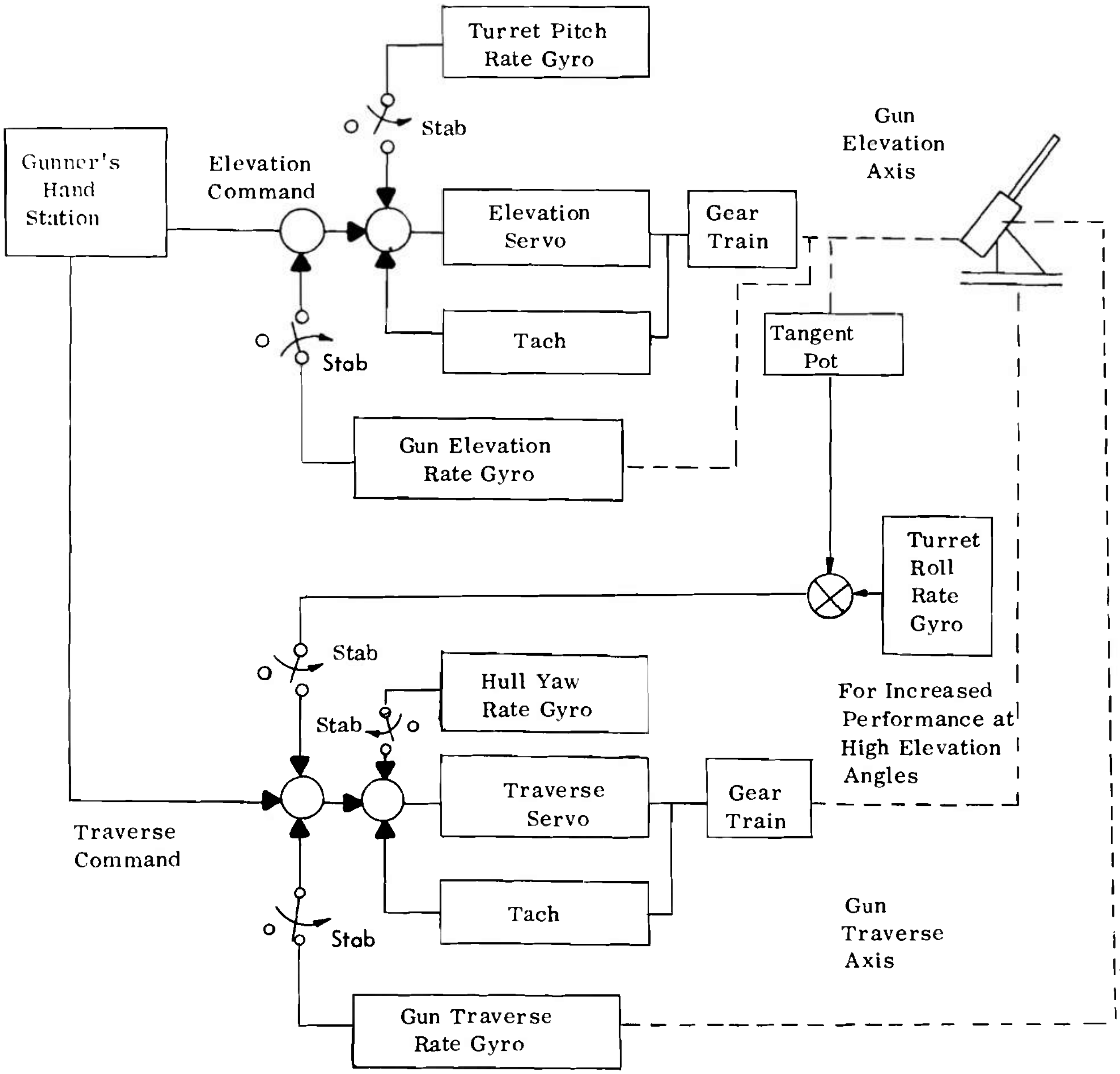


Figure 17-50. Five Gyro Stabilization System Functional Diagram

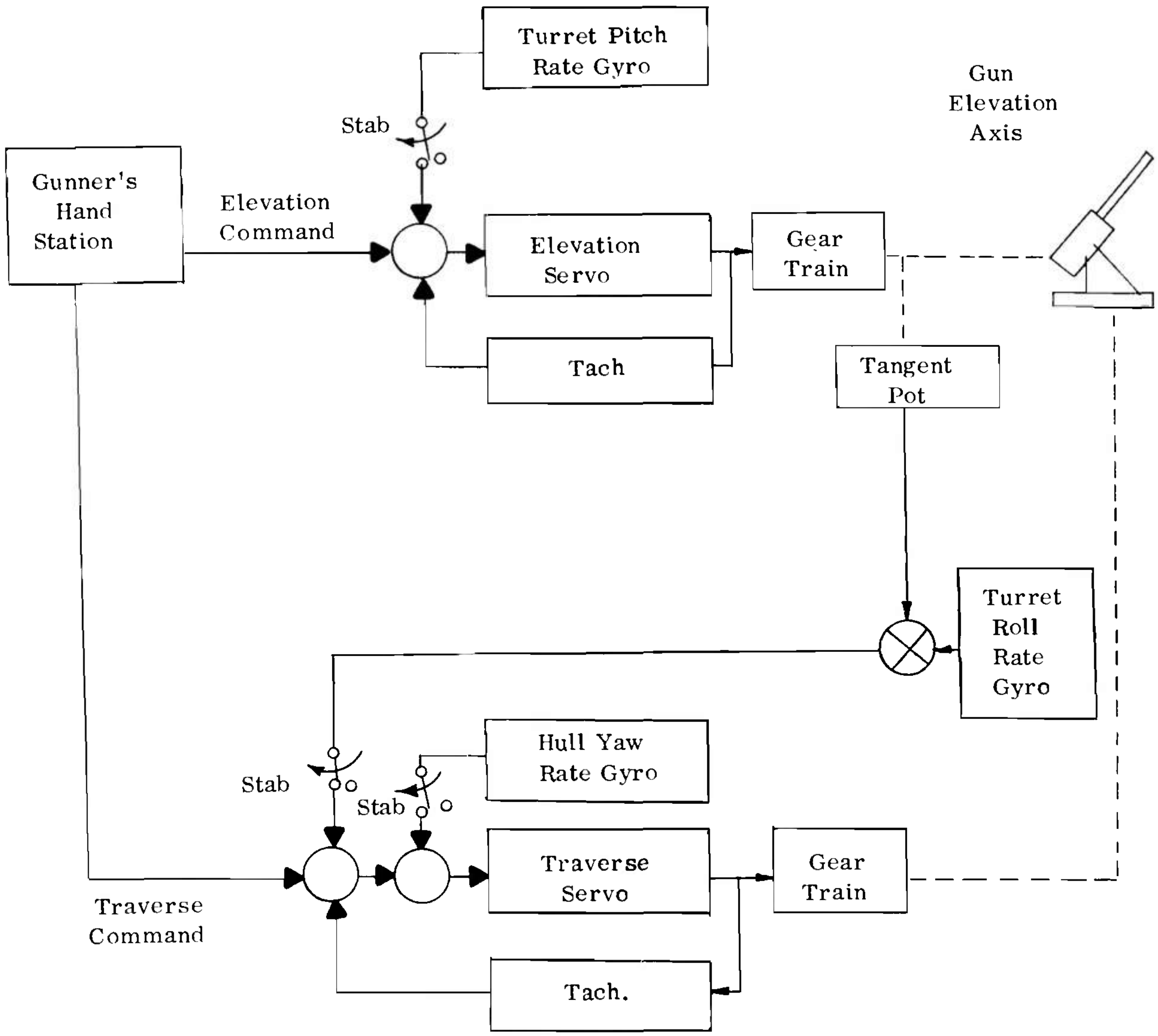


Figure 17-51. Three Gyro Stabilization System Functional Diagram

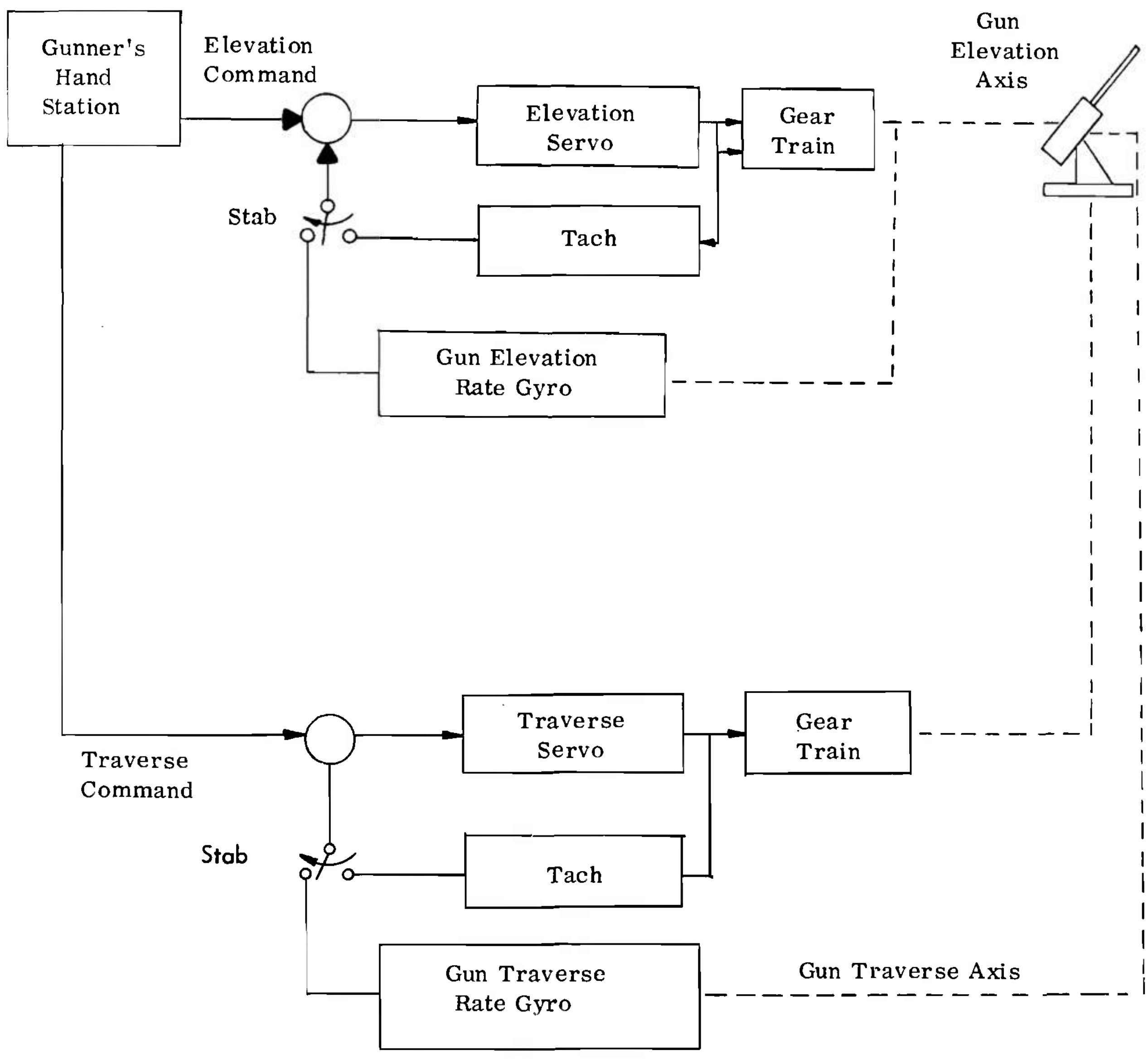


Figure 17-52. Two Gyro Stabilization System Functional Diagram

SECTION III

AMMUNITION HANDLING AND WEAPON ARMING SYSTEMS

17-9 INTRODUCTION

Ammunition handling systems include all equipment required to feed or make ammunition available to the weapon. In addition, any equipment required to handle the spent casing after the ammunition has been fired is included. Weapon arming systems include equipment required to arm (or cock) the weapon as well as weapon firing circuits.

Vehicular mounted weapons range in size from the 28-lb M73 (7.62 mm) Machine Guns to the 10,000-lb, 8 in. howitzer on the M110 vehicle. Typical ammunition weights and weapon firing rates are given in Table 17-4.

TABLE 17-4. AMMUNITION WEIGHT AND RATES OF FIRE FOR U.S. WEAPONS[14,15,20,21,22]

Weapon	Caliber	Rate of Fire, rpm	Weight of Ammo, lb	Application
M73	7.62 mm	350-600	0.06	M60A2 (coax.)
M85	Cal .50	High 1050 Low 400	0.292	LVTP7
XM168	20 mm	High 3000 Low 1000	0.69	XM163
M139	20 mm	High 850-1050 Low 200 Single shot capability		M114A2
	90 mm	Limited by crew		
M68	105 mm	Limited by crew	AP 41 HE 46 HEAT-T 48	M60, M60A1 Tank
M58	120 mm	Limited by crew	(separate loading type) Projectile Charge AP 51 55 HE 50 39	M103A1 Tank
XM162	152 mm		Missile 61.5 Conventional (Heat) 49 (Canister)48	M81E1 M60A2
	155 mm Howitzer	Limited by crew		M109
M113	175 mm	Limited by crew	Separate loading 147 (projectile only)	M107
M2A1E1	8 in. Howitzer	Limited by crew	Separate loading 200 (projectile only)	M110

17-10 POWERED OR AUTOMATIC LOADERS

Weapons that use separate loading ammunition normally require some type of powered loader because the ammunition is too heavy to handle manually. The M107 and M110 vehicles use an electrohydraulic system to lift the rounds and ram them into the weapon breech. Power is provided by an hydraulic pump driven by a 5 hp electric motor.

In tanks where the ammunition is handled manually, the development of a successful automatic loader could increase the rate-of-fire and eliminate one crew member.

Fig. 17-53 and Fig. 17-54 show automatic loader concepts developed for the 90 mm and 105 mm tank guns[16] Problems causing particular difficulty in developing an automatic loader include round selection and gun elevation.

Because tanks normally carry a minimum of two types of ammunition (high explosive (HE) and armor-piercing (AP)) the automatic loader must be capable of selecting and chambering the designated round.

Elevation of the weapon causes a problem because the magazine, where the rounds are stored, is normally an integral part of the loader and elevating and depressing the magazine is not practical. The weapon therefore is required to come to a particular elevation for loading. To maintain a high rate of fire, the weapon must move automatically to the

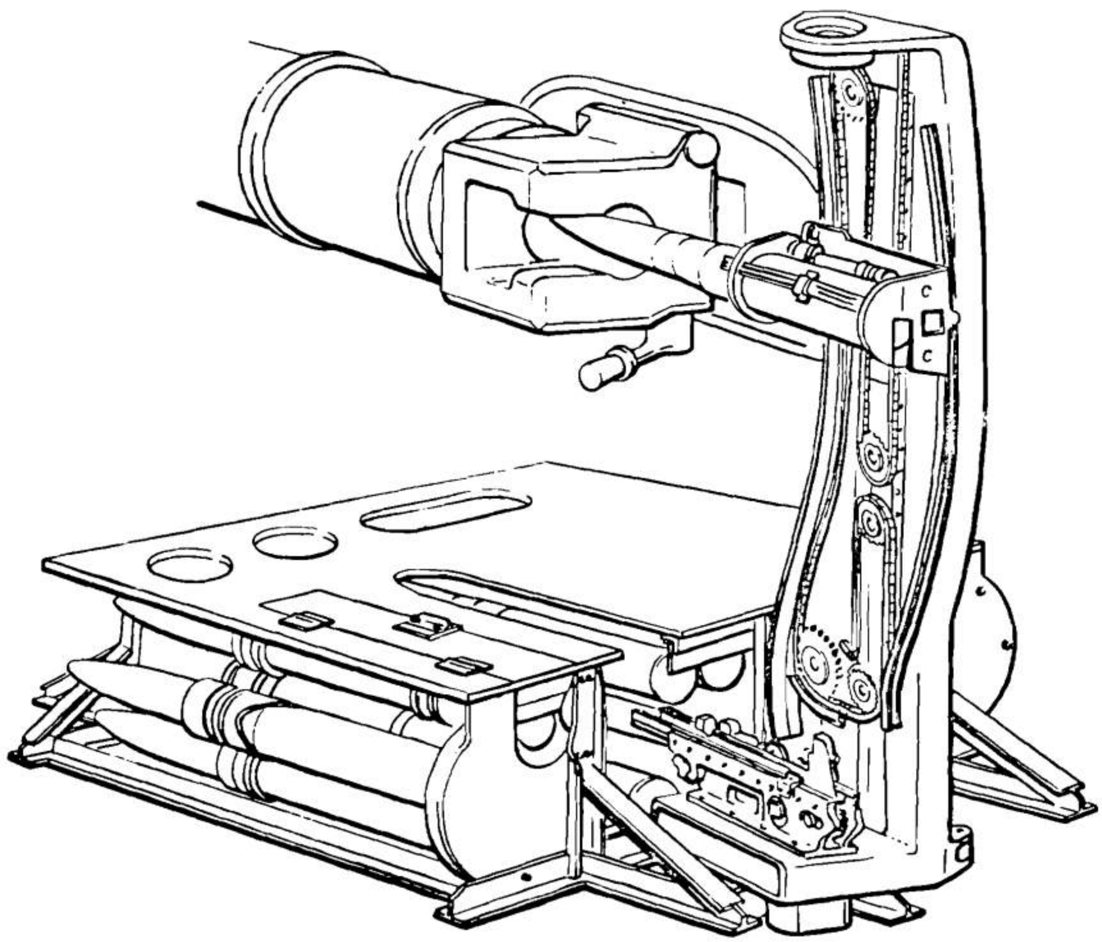


Figure 17-53. Automatic Loader, 90 mm Gun[16]

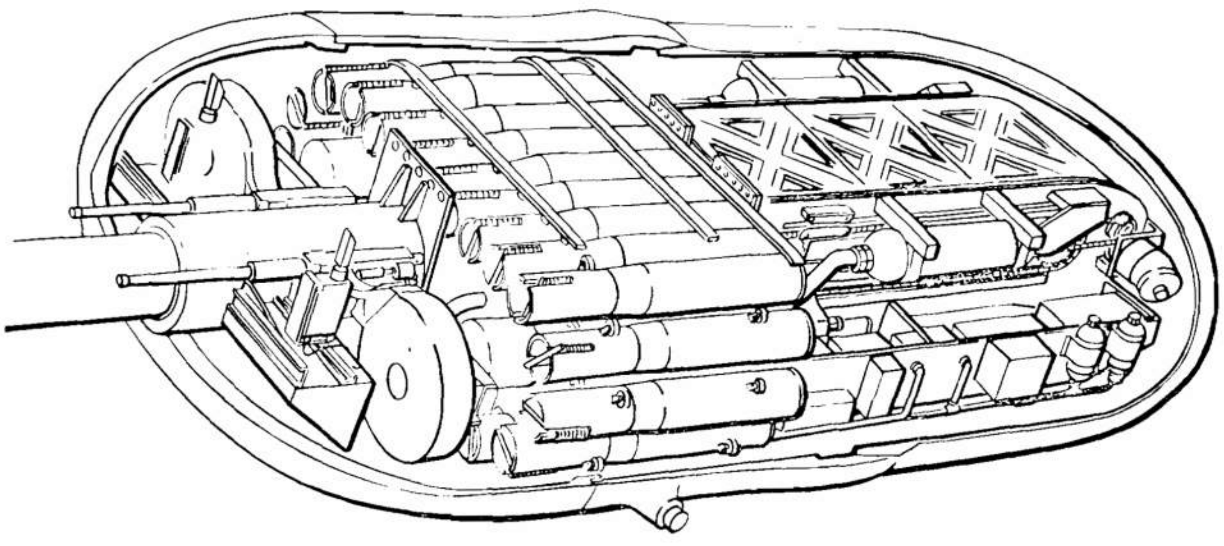


Figure 17-54. Automatic Loader, 105 mm Gun[16]

loading position after firing and automatically move back to the firing position after loading. These operations must be accomplished in a matter of seconds and the weapon must be repositioned with an error of less than 1.0 mil.

At the present time, there are no automatic loaders in any production U.S. tanks.

Fig. 17-55 shows the electrical powered breech mechanism used on the M551 SHERIDAN and the M60A1E2 Tank. The electric motor drives a gear train, through a planetary gear group, that unlocks the breech and rotates it out of position for reloading. A manual backup (hand crank) is provided in the event of power failure.

17-11 AMMUNITION FEED SYSTEMS

Automatic weapons present special problems in feeding ammunition to the weapon. High rates of fire, gun elevation, and the jerking action of the gun result in a very difficult material handling problem. As an example, the M139 Automatic Cannon has a maximum firing rate of 1050 rounds per minute and each round, with link, weighs 0.809 lb. This results in a material handling rate of 849 lb/min. The ammunition is linked and belt fed (Fig. 17-56). Vehicle installations may require the weapon to elevate from −20 deg to +65 deg (85 deg total). This results in considerable bending and deflection of the ammunition belt.

The belt is pulled into the weapon by recoil energy when the weapon is fired. Excessive kinking or bending of the belt can result in excessive force required to pull the ammunition into the weapon. This can result in stalling or jamming of the weapon. This problem has necessitated the use of booster motors in some vehicle installations.

Boosters decrease the tension in the belt by driving a sprocket. The motor may be built into the sprocket as it is in the cal .50 booster shown in Fig. 17-57. The booster must turn off when the tension in the belt is decreased to prevent overfeeding. Boosters are often developed for a particular installation; however, Table 17-5 lists some available units.

The booster must accelerate the ammunition from zero velocity to the maximum rate of the weapon almost instantaneously. Excessive acceleration, however, may cause the

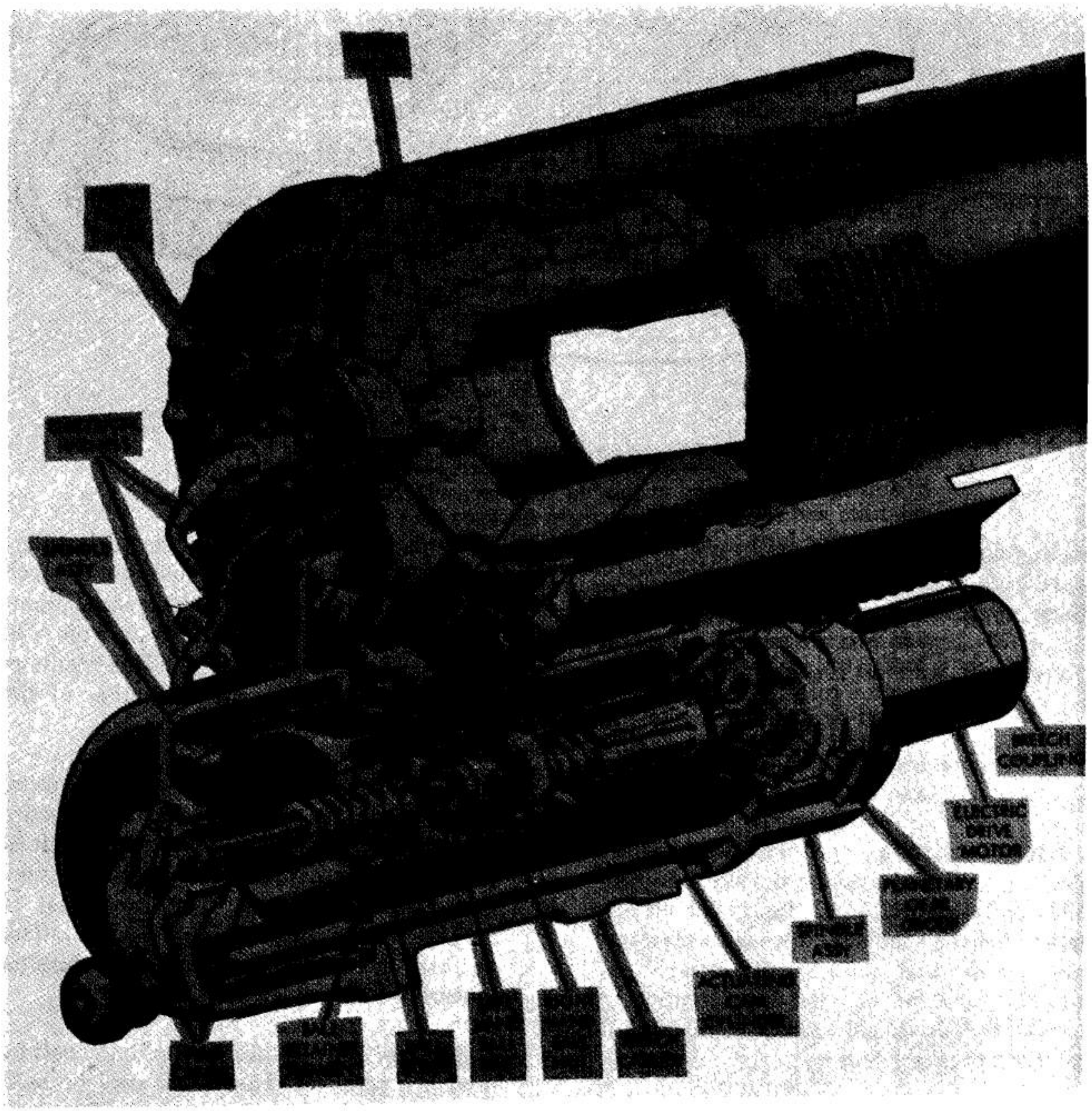


Figure 17-55. XM81E12 Gun Launcher Breech Mechanism

Figure 17-56. M139, 20 mm Linked Ammunition

belt to separate or the links to deform. The booster must provide free wheeling in the direction of the feed. This prevents the booster from holding the gun back in the event it is feeding faster than the feeder is driving.

MIL-B-45530 covers cal .50 boosters for the M3 Machine Gun. These boosters can also be used for the M85 since the firing rate and feed are similar.

In the event the weapon has more than one rate of fire, the booster must have more than one rate.

17-11.1 LAST ROUND LIMIT SWITCHES

Automatic weapons normally will continue to fire until the last round of ammunition is expended. The weapon must then be rearmed and charged before firing. Since this may occur at an inopportune time, most weapon feed systems have a last round limit switch.

The switch is placed in a position in the feed system where the tension in the belt or weight of the ammunition keeps it closed. Fig. 17-58 shows the position of the switch actuator in the M27 weapon station. After the last round is pulled from the magazine and across the actuator, the actuator springs up

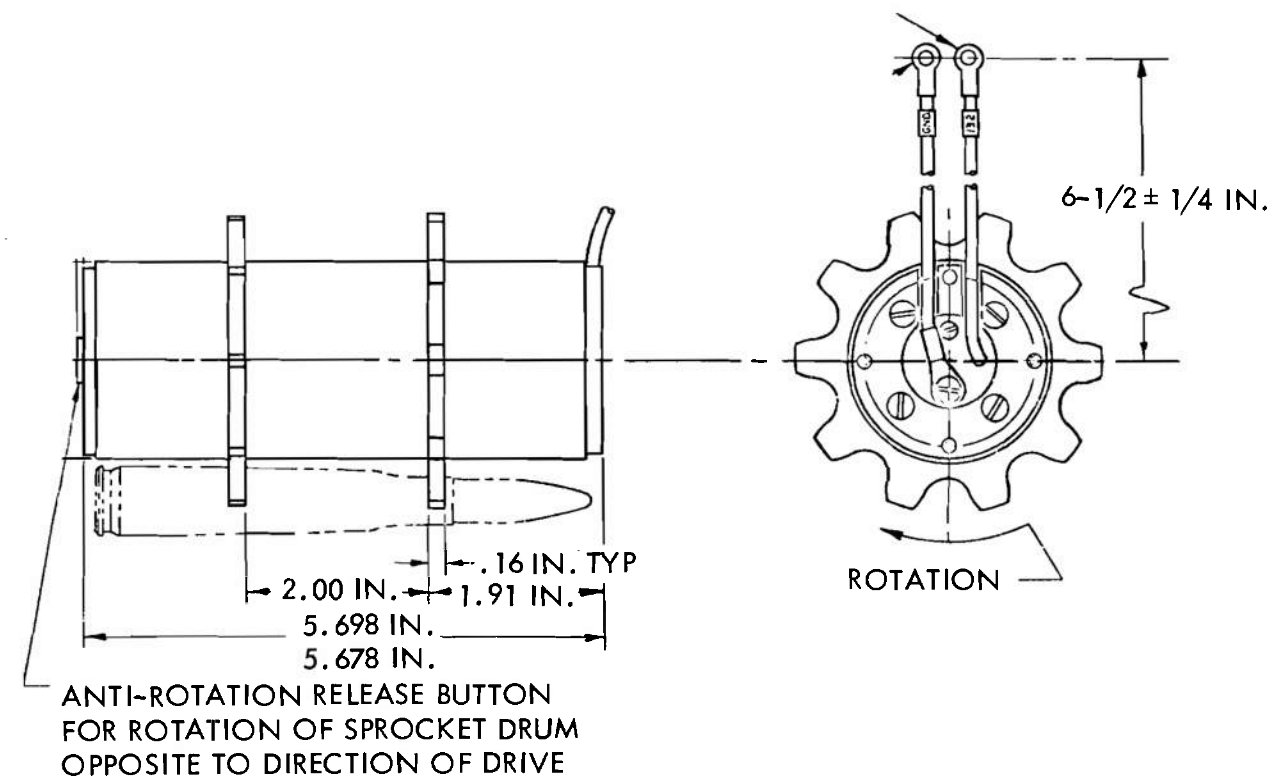


Figure 17-57. Cal .50 Ammunition Booster

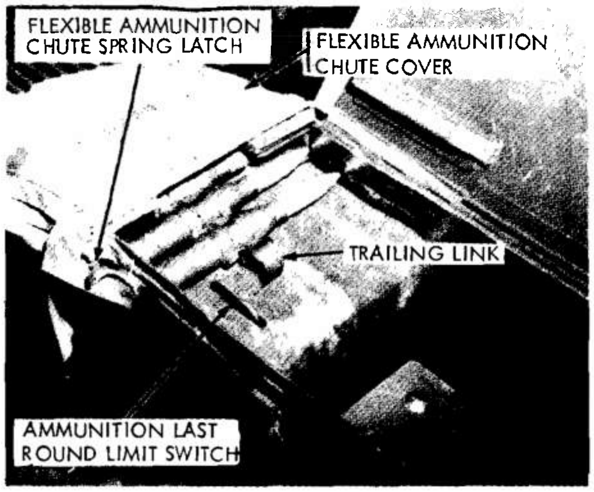


Figure 17-58. Last Round Limit Switch

opening the switch and the firing circuit. The weapon will not fire until the magazine is reloaded or a last round limit switch override is closed.

Some weapon stations are equipped with a low ammunition warning switch rather than a limit switch.

17-11.2 DUAL FEED SYSTEMS

Weapons in the 20-mm and above range normally have at least types of ammunition—armor-piercing (AP) and high explosive (HE).

In a vehicle installation, it is highly desirable to have the capability of selectively firing either type ammunition from a single weapon. For this reason dual feeders have been developed. Dual feeders have *not* undergone any valid U.S. Government test programs. Prototypes have been demonstrated. However, reliability, functional suitability, etc., have *not* been evaluated.

If the trajectory of the different types of ammunition is significantly different, two reticles will be required. The reticles should be interlocked with the ammunition selector to insure that the gunner uses the correct reticle. This can be accomplished if the reticles are projected reticles.

17-11.3 CASING AND CLIP EJECTION

Before each round is fired, the clips (or links) that hold the rounds in a belt are

TABLE 17-5. AMMUNITION BOOSTERS

Caliber	Part (Ord Dwg) No.	Manufacturer	Comments
.50	Ordnance part No. 8705751		26 VDC, 50 A starting current, 10 A at rated load
.50	7550M2	Air Associates, Inc., Teterboro, N.J.	3 phase, 400 Hz 200 V
.50	7550M2DC	Air Associates, Inc., Teterboro, N.J.	26 VDC
.50	H250A	Hughes Tool Co. Aircraft Div.	28 VDC, 16 A
20 mm	1103700	Standard precision	22.5 to 31 VDC 30 A at 27.5 V when pulling 1000 rounds of ammo/min

stripped from the round. After the round is fired the clips and spent casings must be ejected, preferably outside the vehicle.

When the weapon is not being fired, a ballistic door or cover is required to protect the ejection area of the weapon from enemy fire.

The door can be opened and closed by an electrical solenoid or a hydraulic cylinder. The opening mechanism should be interlocked with the firing circuit to prevent firing the weapon with the door closed.

17-12 AMMUNITION CONVEYOR SYSTEMS

The VULCAN air defense system (XM163) uses an ammunition conveyor system to feed the weapon rather than the conventional belt.

The linkless 20-mm rounds are stored in an ammunition drum. When the weapon is fired, the drum is driven, automatically loading the rounds into the conveyor. The conveyor transports the rounds to the weapon feeder assembly. After the rounds are cycled through the weapon and fired, the empty casings are reloaded into the conveyor and transported back to the drum.

This type of system requires that the velocity of the ammunition conveyor be closely matched to the firing rate of the weapon. The rate of fire of the VULCAN weapon is proportional to the driving motor speed (electrically driven). The speed of the drive motor then is matched to the conveyor rate. Power requirements range from 300 to 400 W.

In the case of free firing weapons, (i.e., weapons operated by blowback or recoil forces) matching the conveyor rate to the firing rate may be difficult or impractical. The firing rate of free firing weapons is affected by many variables including ambient temperature, heating up due to previous firing, wear, and fit of parts.

17-13 WEAPON CHARGERS

Automatic weapons require cocking or charging before each round is fired. The cocking action normally is performed by energy from the previously fired round. If the weapon is reloaded, however, or if it does not fire due to a bad primer it must be recharged.

Small-caliber weapons normally are manually charged. The forces involved in charging a larger weapon require a power charger. In vehicle applications, the location of the weapon may also prevent manual charging.

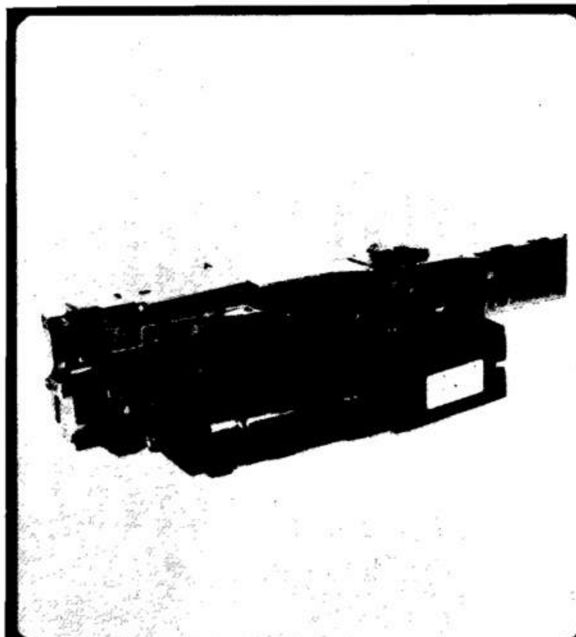
Charging a weapon requires a linear actuator and therefore may be accomplished with an electrical motor driving a ball screw mechanism or a chain drive. In chain drive mechanisms, the chain is driven between two sprockets, and the linear motion is provided by a pawl attached to one link of the chain. This type of system is used to charge the M139 weapon on the M27 weapon station.

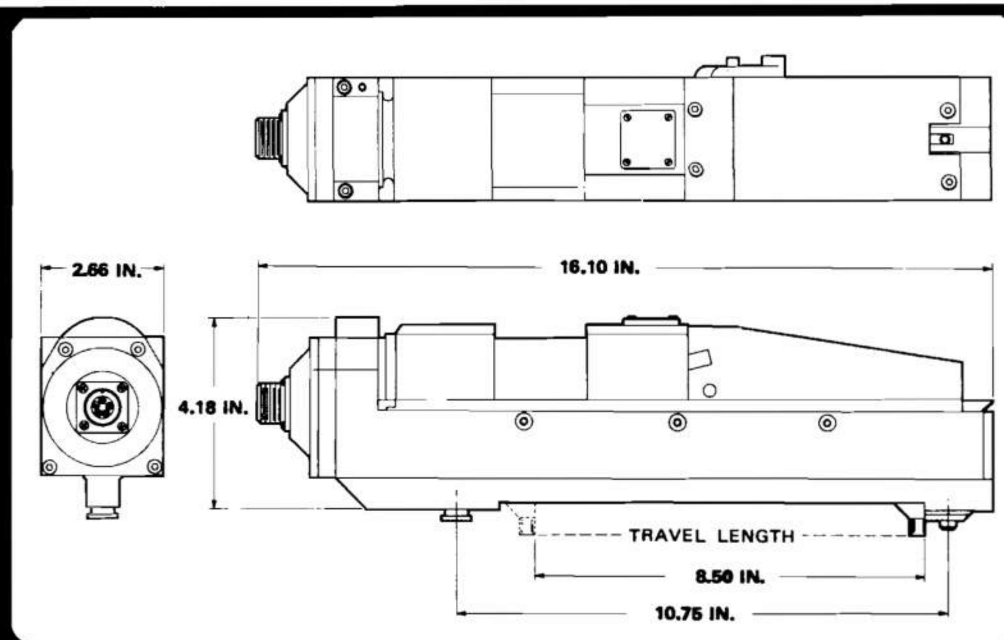
Figs. 17-59, 17-60, 17-61, and 17-62 present the specifications and illustrations of electric chargers produced by Standard Armaments of Glendale, California.

17-14 FIRING CIRCUITS

The weapon firing circuit provides for remote firing of the weapon. In addition, it may control such functions as length of burst and rate of fire. The design of the firing circuit is dependent on the weapon firing mechanism and the type of primer used in the ammunition.

The M139 weapon in the M27 weapon station is fired by a solenoid that activates a sear. The sear releases the bolt, allowing it to slide forward and fire the round. In the M27 station, the current for the firing solenoid passes directly from the 24 ± 6 VDC supply, through a switching transistor to the solenoid. A relay has been placed in series between the transistor and the solenoid solely as a safety measure on the possibility that the transistor might fail in a shorted mode (which has





DESCRIPTION

Designed for the M85 - 50 Caliber machine gun. This unit provides the high velocity charging RATE WHICH IS MANDATORY FOR EJECTION of unfired rounds or empty cases. No mounting bolts are required as there is provided built-in mounting capability.

SPECIFICATIONS

DESIGN DATA

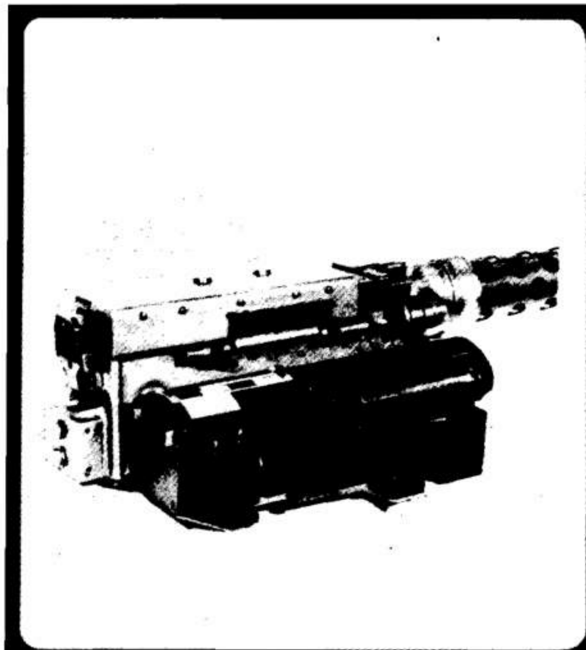
CHARGING TIME	2 SEC
CURRENT PEAK	11 A
DUTY CYCLE	INTERMITTENT
LIFE	10,000 CYCLES
AMBIENT OPERATING TEMPERATURE	-65° TO $+165^{\circ}$ F
WEIGHT	11 LB

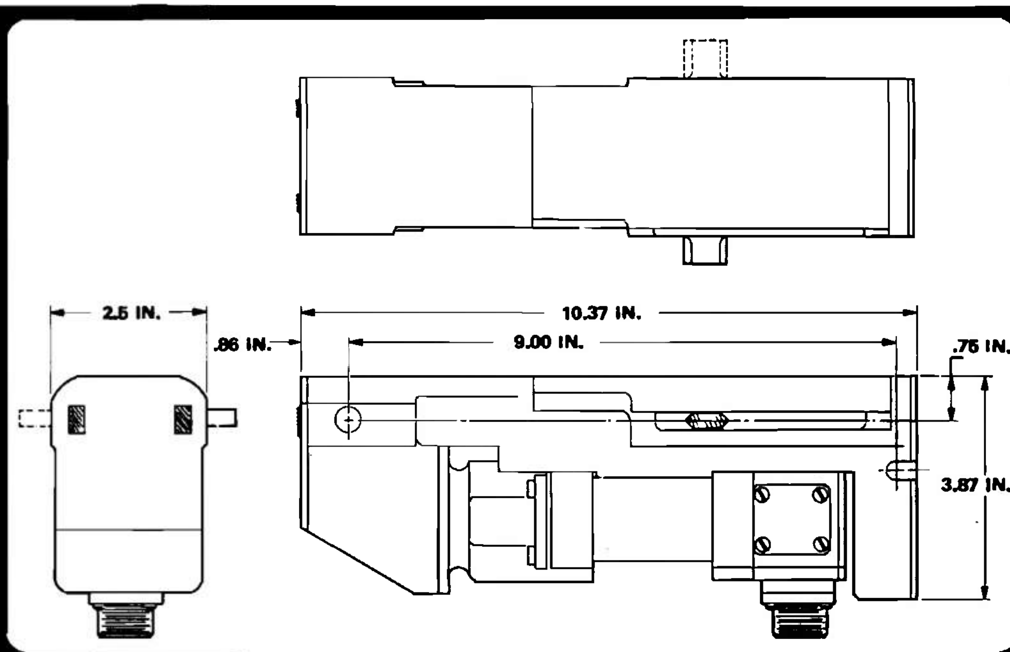
MOTOR DATA

VOLTAGE	24 V DC
RPM	10,000
CURRENT	11 A
TORQUE	3.78 LB-IN.
PINION	8 TOOTH–32 D.P.
TYPE WINDING	SERIES

PERFORMANCE VALUES ARE NOMINAL AT 77°F AMBIENT TEMPERATURE WITH 24 V DC

Figure 17-59. M85 (Cal .50) Electric Charger





DESCRIPTION

Designed for the M73-7.62 mmmachine gun. This unit delivers instant power to meet the high charging force curve. Installation can be made on either side of the weapon. No mounting bolts are required as there is provided built-in mounting capability.

SPECIFICATIONS

DESIGN DATA

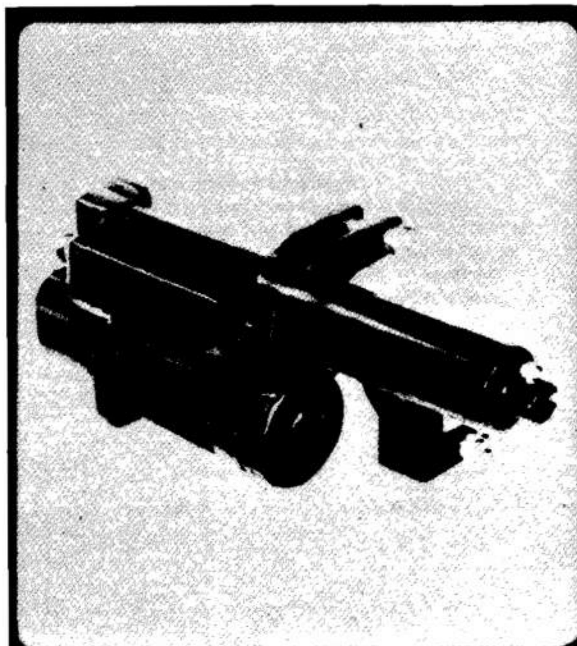
CHARGING TIME	.5 SEC
CURRENT PEAK	11 A
DUTY CYCLE	INTERMITTENT
LIFE	10,000 CYCLES
AMBIENT OPERATING TEMPERATURE	-65° TO $+165^{\circ}$ F
WEIGHT	8.7 LB

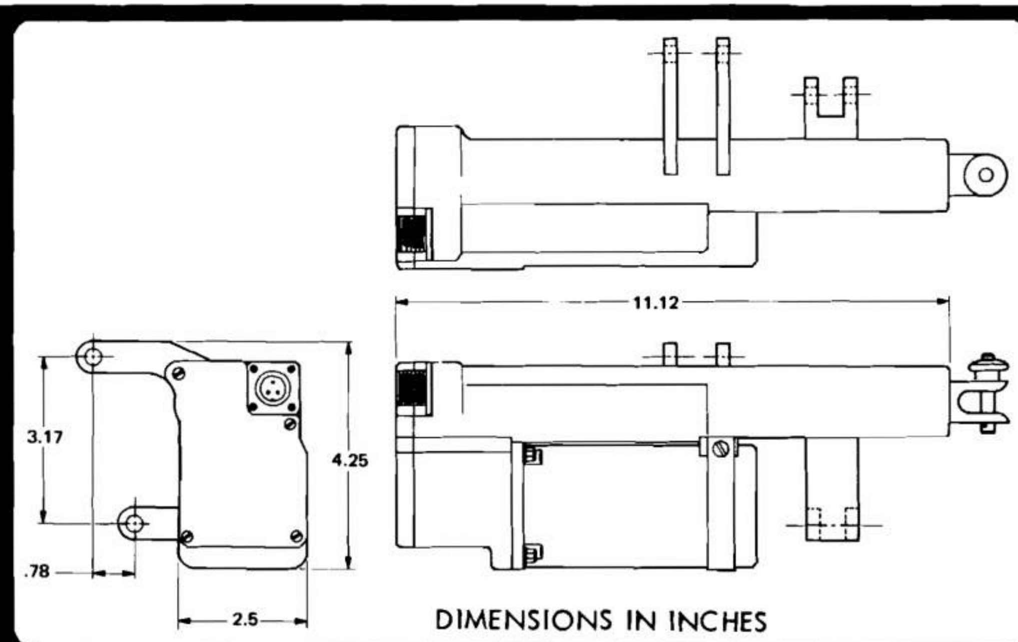
MOTOR DATA

VOLTAGE	24 V DC
RPM	10,000
CURRENT	11 A
TORQUE	3.78 LB-IN.
PINION	8 TOOTH–32 D.P.
TYPE WINDING	SERIES

PERFORMANCE VALUES ARE NOMINAL AT 77°F AMBIENT TEMPERATURE WITH 24 V DC

Figure 17-60. M73 (7.62 mm) Electric Charger





DESCRIPTION

Mounted directly on the M60-7.62 mm machine gun. This unit provides electro-mechanical remote charging capability. Used as a safety this item prevents accidental firing of weapon.

SPECIFICATIONS

DESIGN DATA

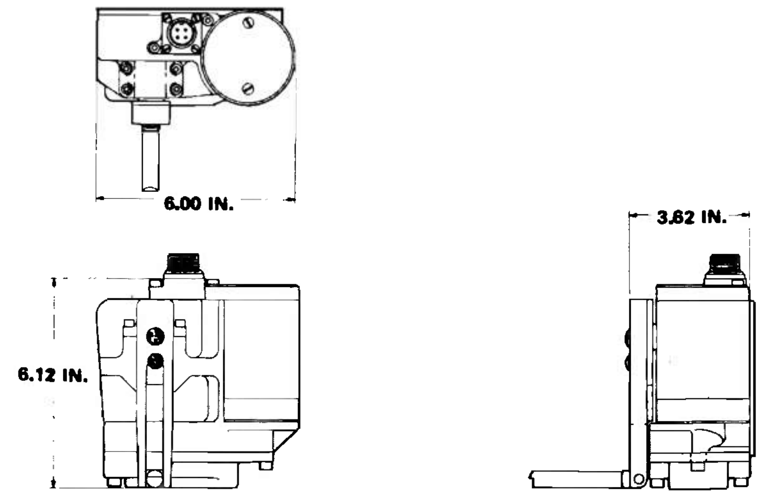
CHARGING TIME	1.75 SEC
DUTY CYCLE	INTERMITTENT
LIFE	10,000 CYCLES
AMBIENT OPERATING TEMPERATURE	-65° TO $+165^{\circ}$ F
WEIGHT	5 LB

MOTOR DATA

VOLTAGE	24 V DC
RPM	9000
PINION	8 TOOTH–32 D.P.

PERFORMANCE VALUES ARE NOMINAL AT 77°F AMBIENT TEMPERATURE WITH 24 V DC

Figure 17-61. M60 (7.62 mm) Electric Charger



DESCRIPTION

Electro-mechanical as well as manual charging capability for the HS820-20 mm cannon is provided for by this unit. Manual charging is accomplished by means of a built-in handle. Unit is mounted to weapon cradle by means of mounting bolts.

SPECIFICATIONS

DESIGN DATA

CHARGING TIME	3 SEC
CURRENT PEAK	11 A
DUTY CYCLE	INTERMITTENT
LIFE	10,000 CYCLES
AMBIENT OPERATING TEMPERATURE	−65° TO +165° F
WEIGHT	10 LB

MOTOR DATA

VOLTAGE	24 V DC
RPM	10,000
CURRENT	11 A
TORQUE	3.78 LB-IN.
PINION	8 TOOTH−32 D.P.
TYPE WINDING	SERIES

PERFORMANCE VALUES ARE NOMINAL AT 77° AMBIENT TEMPERATURE WITH 24 (V DC)

Figure 17-62. HS820, M139 (20 mm) Electric Charger occurred a number of times). In addition, timing circuitry is used to provide the following functions:

1. Fast rate
2. Slow rate
3. Single shot
4. Slow burst
5. Fast burst.

For the fast rate, the solenoid remains in the activated position until the trigger is released. In the slow rate, the solenoid is activated at a rate of 200 times/min until the trigger is released. In the single shot mode, the solenoid is activated once when the trigger is pulled, and the weapon will not fire again until the trigger has been released. In the slow burst mode, the solenoid is pulsed five times at a rate of 200 rounds/min each time the trigger is pulled. In the fast burst mode, the solenoid is activated long enough for the weapon to fire five ± 1 rounds at its full cyclic rate each time the trigger is depressed. Regardless of the firing mode, the safety relay is energized as long as the trigger is depressed.

Weapons utilizing electric primed ammunition require a pulse of electrical energy to fire the round. Those weapons using electrical primed ammunition include the M162 and M81 (152 mm) combination Gun/Missile Launcher, the M68 (105 mm) Tank Gun, and the XM168 (20 mm) Cannon.

The primer detonation is initiated by sending a small current through a resistance wire imbedded in an explosive or through a conductive primer mixture. Fig. 17-63 shows the M52A3B1 Electric Primer used in 20 mm ammunition. This primer uses a conductive primer mixture.

To design an electric firing circuit, the electrical characteristics of the primer must be known. In addition, consideration must be given to the resistance between the firing probe and the primer. In the XM168, 330 VDC is applied to the firing probe. Since this firing voltage is well above the 24-VDC vehicle system voltage, an inverter and transformer are required in vehicle applications.

Electrically primed ammunition is liable to accidental firing in the presence of radio frequency (RF) fields such as those produced by high powered radar and communication equipment. The M81 Primer with the M63 Initiator will fire every time if a 1.25-A current is applied for 0.1 sec. This same initiator will not fire if a 0.19-A current is applied for 1 sec. The resistive path is 0.8 to 1.8 ohms.

The RF hazard to ordnance depends on the probability of primer leads acting as an antenna. This particular hazard therefore can be removed by one or more techniques which destroy the normal antenna characteristics (e.g., shielding, twisting leads). This subject is thoroughly covered in Refs. 23 and 25.

17-15 SAFETY INTERLOCKS

Safety interlocks prevent firing of the weapon in other than safe conditions. Interlocks are required on large-caliber weapons to insure that the breech is locked before firing.

In some vehicle applications, interlocks may be required on hatches to prevent firing when a crew member opens a hatch in front of the muzzle. Alternately, this type of interlock may incorporate a weapon position

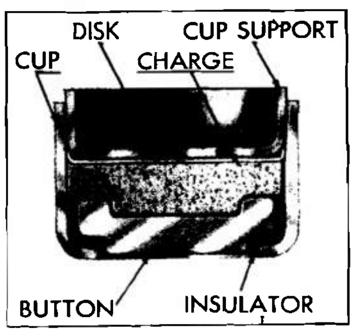


Figure 17-63. M52A3B1 Electric Primer

sensing mechanism so that the weapon is prevented from firing when it is in the region of a hatch.

Maximum weapon depression normally is provided in front of combat vehicles. As the weapon station is rotated away from the front sector, it must be elevated to prevent physical interference with the vehicle. In addition, the weapon may have to be elevated to clear obstructions such as hatches or head lights.

The deck clearance system provides signals to the weapon elevation drive to automatically elevate the weapon in these forbidden zones. Potentiometers can be used to provide a voltage proportional to the position of the weapon. Since the elevation velocity of the weapon is finite, however, the forbidden zone of the weapon will be unnecessarily large unless a tachometer is used to sense the rotational velocity of the weapon station. If the voltage from the position sensor is summed with the voltage from the tachometer, logic circuitry can determine the optimum point where the elevation drive must be actuated.

SECTION IV

MISSILE SYSTEMS

17-16 INTRODUCTION

The development of surface-to-surface antitank missile systems has provided armored fighting vehicles with substantially improved firepower and hit capability against opposing armor, troops, or fortifications. The successful performance of such systems as SHILLELAGH and TOW will undoubtedly lead to wider application of these, or similar systems, on future military vehicles.

17-17 MISSILES FOR VEHICLES

The SHILLELAGH Guided Missile System has been designed to permit its integration into any combat vehicle without imposing any unusual vehicular characteristics except that power line transients must not exceed those shown in Fig. 17-64, and—with the possible exception of sight, sight mount, and guidance and control cable sets—no modification of system components should be required. These components have, to the extent possible, been designed to be compatible with proposed combat vehicles. However, integration with new or existing vehicles may require sights and/or mounts peculiar to the individual installation.

The TOW (Tube-launched, Optically-tracked, Wire-command-link-guided) missile has been deployed by U.S. Army NATO forces in Europe as the primary antitank weapon at battalion level. The new guided missile is being assigned to antitank platoons in the infantry, light infantry, mechanized infantry, airborne, and airmobile battalions. It is fired as a tripod-mounted, crew-portable weapon, or it can be mounted on wheeled and tracked vehicles or helicopters.

17-17.1 SHILLELAGH MISSILE

The SHILLELAGH Guided Missile System consists of the SHILLELAGH guided missile, the guidance and control (G&C) system, and the related test equipment. Since the test

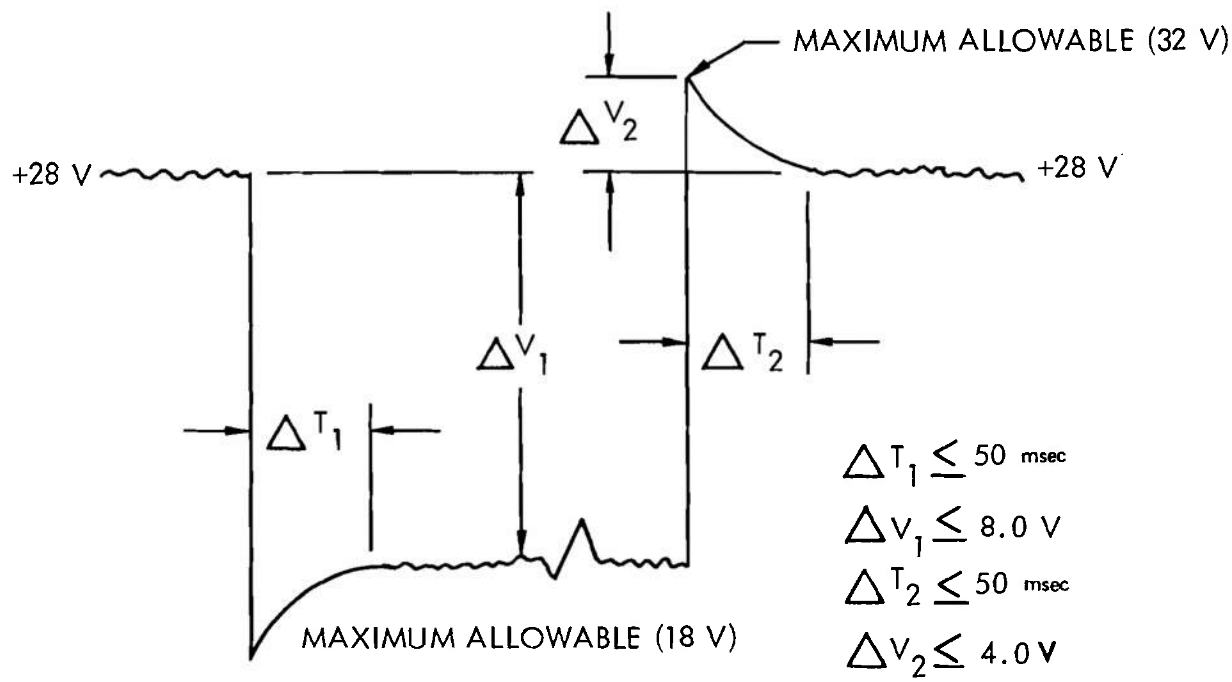


Figure 17-64. Allowable Prime Power Line Transients (SHILLELAGH Missile)[19]

equipment is not combat vehicle mounted, only the first two will be discussed.

The SHILLELAGH missile is a fin-stabilized guided missile which is electrically fired from a 152-mm gun/launcher. The missile is stabilized in a roll attitude and capable of maneuvering in pitch and yaw in response to commands received from the G&C system mounted on and in the combat vehicle.

The basic function of the G&C system is to constrain the missile to fly along the gunner-generated line of sight (LOS) between the launching vehicle and the target until impact.

To accomplish this, the G&C system measures the missile deviation from the LOS and the LOS rates, determines the required correction, transmits the correction to the missile, and thereby commands missile control forces to reduce the deviation. Measurements of missile deviation and transmission of command signals are continuous, and both are accomplished by infrared data links.

From the instant the missile launch is initiated, the sole human function involved in the operation of the weapon system is that of maintaining the LOS on the target until target damage is assessed and the need for a second shot is evaluated. The gunner's role with SHILLELAGH is less demanding as compared to firing a conventional round, in that the gunner need not superelevate or apply a lead correction.

Preparation for firing requires the normal human action of activation of the turret control system, target acquisition, and loading. On vehicles where dual ammunition is provided, the gunner must, in addition, select "missile" on the gun control selector panel.

The gunner also must determine that the weapon system is ready and operating properly by observing the system status lights (go-no-go) on the test set panel (TSP) during the system self-test and by performing operation checks and boresight procedures.

17-17.2 TOW MISSILE

The secret of the success of TOW is its simple, foolproof, automatic guidance system. The gunner simply trains the telescopic sight on the target, then presses the trigger to lanuch the missile. As TOW flies toward the target it unreels two hair-thin wires from internal bobbins. As the gunner continues to hold the crosshairs on the target, steering signals transmitted over the wires keep TOW on course.

According to the U.S. Army, TOW can defeat any known enemy armor. It can also be used against field fortifications. TOW has a minimum range of 65 m, a maximum range of 3,000 m. Its velocity is in the transonic range. It leaves no smoke trail because of smokeless propellants and because both the launch motor, which boosts the missile out of the launch tube, and the flight motor burn for a very short time.

17-18 MISSILE INSTALLATION (SHILLELAGH)

The electrical requirements imposed on a vehicle by the SHILLELAGH system are described in the paragraphs that follow.

The G&C system components carried by the combat vehicle require a variety of operating potentials of sufficiently diverse types to warrant the inclusion of a power supply unit as part of the system. The use of this unit makes it unnecessary to require unusually precise regulation and control of the vehicle prime power supply. Fifty amperes at a potential maintained within an 18 to 30 VDC range, at the point of application to the G&C power supply, will permit full operation of the G&C system. Allowable prime power transients are depicted in Fig. 17-64. The maximum allowable line ripple is 5 V peak to peak.

The three optical elements of the G&C system (the sight, the tracker, and the transmitter) are related functionally in that the axes of the sight and transmitter must be aligned with the tracker axis. The tracker and the transmitter must be in visual contact with the missile immediately after launch, and the sight must be in visual contact with the target prior to and throughout missile flight. Each installation must be examined as to the physical location of the transmitter, tracker-gun tube to verify their capability to operate within the SHILLELAGH parameter.

The remainder of the system components, while functionally dependent, are physically independent except for electrical cabling. These components can be located so as to take maximum advantage of the space available within the vehicle but with a view to minimizing the length and complexity of the interconnecting cabling. A schematic of the components and cabling is shown on Fig. 17-65. To facilitate organizational maintenance of the G&C system, all connectors should be unobstructed to allow for removal and replacement of test cables provided with the Test Set, Guided Missile System.

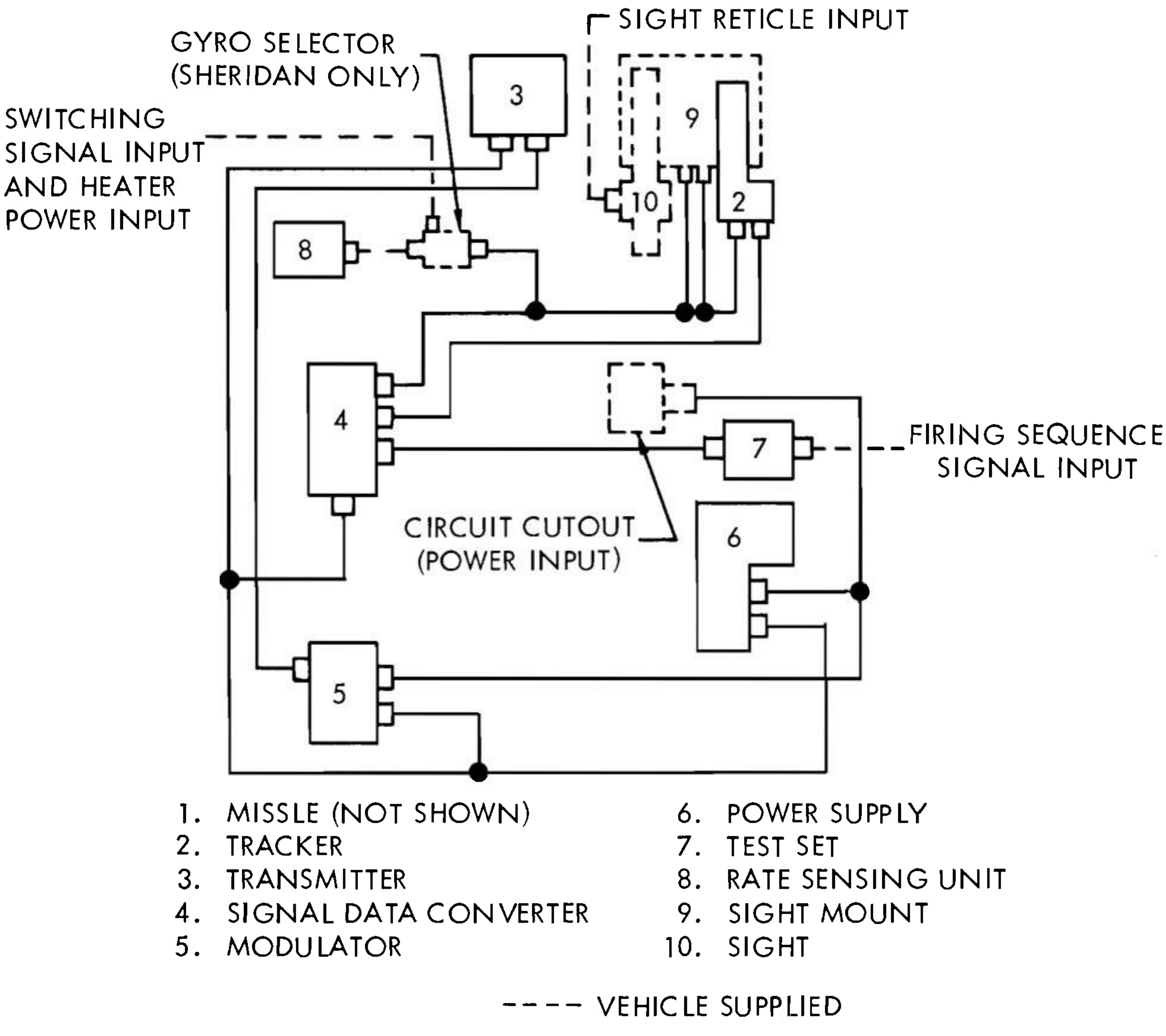


Figure 17-65. Typical SHILLELAGH Missile Installation[19]

The cabling required by the system can be separated into two categories:

1. Cabling within the system, or the intraconnecting cables. These cables are supplied as a part of the G&C system.

2. Cabling connecting the vehicle and system, or interconnecting cables. These cables are supplied by the vehicle manufacturer. In addition, the main weapon firing circuit, while not peculiar to the missile system, must have characteristics determined in part by the requirements for missile ignition. In particular, the impedance of the firing circuit—from a loaded 18-VDC minimum source to the receptacle in the missile—may not exceed 0.570 ohm under any condition. The receptacle in the missile is designed so the contact resistance between the receptacle contacts and the breech probe will not exceed 0.070 ohm.

17-18.1 INTRACONNECTING CABLE

The electrical cabling that intraconnects the components of the G&C system will be furnished as an integral part of the system.

Since the conductor lengths are a function of component placement within the vehicle, the cable set will be peculiar to a vehicle type. The cable set will be designed in conjunction with the vehicle installation from information furnished by the vehicle manufacturer.

All G&C system electronic components must be electrically bonded to the vehicle turret structure. A design goal of 10 mohm between the unit and turret has been established for the tracker. The maximum bonding resistance for the remaining units should not exceed 80 mohm. A bonding strap between the gun mount and turret structure should be used to eliminate the need for reliance on the trunnion bearings as a ground path where found necessary. Case bonding terminals for strap attachment are provided on the tracker, signal data converter, modulator, power supply, and test set. Bonding straps should be used where corrosion resulting from dissimilar metals in contact may adversely affect the bond obtained in the unit mounting.

17-18.2 INTERCONNECTING CABLING

The G&C system is connected to the vehicle electrical system at four points:

1. Prime power is fed through the vehicle circuit cutout to the power supply and modulator assemblies.

2. Vehicle sequencing signals are applied to the TSP.

3. The rate sensing unit is supplied operating power by the G&C system power supply and heater power by the vehicular prime power. These power inputs and the signal outputs are routed through the vehicle-supplied gyro selector, which also switches the rate signals to the G&C or turret control system as required. To minimize G&C system warmup time, the rate sensing unit heater is regulated thermostatically from vehicle prime power.

4. The three operating signals which the G&C system supplies to the mount have the following characteristics:

a. The checksight source motor driver input is 115 ± 6 V rms, 400 Hz.

b. The checksight source lamp excite signal is 80± 2 mA DC.

c. The solenoid release pulse is at prime voltage potential with minimum duration of 20 msec and maximum duration of 150 msec. Maximum allowable current is 1.0 A DC for the duration of the pulse.

Only four interconnecting cables are required to complete these connections, since the cable attachment for prime power is through intraconnecting cable. The lengths of the individual cables should be kept to the minimum practical in order to minimize line impedance while holding wire size to the minimum. It should also be noted that the rate sensing unit is attached to the gun and hence moves in elevation, requiring that the cables connected to these components be flexible.

It should be noted that the system may be installed in a vehicle not equipped for stabilized turret operation. In such an application, the rate sensing unit will be installed without the gyro selector. To facilitate this installation, the receptacle on the rate sensing unit must be compatible with the connector on the interconnecting cable, which otherwise mates with the vehicle-supplied gyro selector.

17-18.3 CONCLUSION

In order to establish design criteria for the SHILLELAGH system, it has been necessary to determine, quantitatively and qualitatively, those characteristics which are generally representative of combat vehicles as a class and which affect the system performance. These vehicular characteristics, which have become determining factors in the SHILLELAGH Guided Missile System performance and reliability, must be observed in any vehicular installation of the system. Furthermore, the installation of any other missile system in a military vehicle application will require similar consideration and must be coordinated closely with the U.S. Army Missile Command[19].

SECTION V

SUPPORTING SYSTEMS

17-19 INTRODUCTION

Weapon station support systems include the necessary heating, lighting, ventilating, power distribution, and control equipment required to implement and facilitate the operation of a weapon system on a military vehicle. These systems must be integrated with the basic vehicle electrical system so that sufficient power is available when needed and electromagnetic interference or compatibility problems are avoided. A typical weapon station schematic diagram, as shown in Fig. 17-66, illustrates the scope of such systems.

17-20 POWER REQUIREMENTS

Weapon station power consumption requirements vary as a function of the type of elevation and traversing mechanism used, the mode of operation (i.e., stabilized, unstabilized, or standby), the performance requirements of the turret, and the electrical requirements of the weapon system. The major power demands are experienced when traversing the turret. Such loads for systems now in the inventory are compared in Table 17-6.

System efficiency characteristics are such that the average electrical current required to traverse an electrohydraulically powered turret will be higher than that required to traverse the same turret powered with electric motors. On the other hand, the average electrical current required to stabilize a weapon on the same turret will be higher for an electric motor driven system than for an electrohydraulic system because incremental weapon position adjustments demand high electric motor breakaway current pulses. The same adjustments can be made more efficiently by an electrohydraulic system with short pulses of stored energy from the hydraulic system accumulator that is then periodically recharged. Both electrical and electrohydraulic stabilization systems require an average continuous current from the vehicle power supply during stabilized operation. Furthermore the actual current required when traveling over a bumpy cross country course may be five times higher than that required to control the weapon in a stabilized mode with the vehicle stationary.

Other heavy power demands occur simultaneously with traverse, elevation, and stabilization loads when the weapon is fired. These include weapon firing solenoids, weapon charging motors, smoke scavenger fans, and searchlights. While these additional loads are intermittent, their effects must be considered carefully. For example, the simultaneous application of these loads at the instant an electrohydraulic pump motor switches on can produce instantaneous loads two or three times greater than the total vehicle generating system capacity. This will reduce instantaneously the system voltage to levels that could cause other systems to malfunction; unless they have been designed to tolerate the condition.

Power connections to a weapon station are made through power rings in a slip ring assembly. The distribution of power for turret lighting and control functions necessitates distribution boxes and interconnecting cabling unique to each turret. Signal rings are also required in the slip ring assembly to connect turret-mounted communications, land navigation, and stabilization systems with hull-mounted components of these systems (Fig. 17-67). Part numbers and electrical characteristics of slip ring assemblies in the present inventory are given in Table 8-19.

17-21 TURRET LIGHTING

A dual lighting system—supplying at each crew position white light for daylight operation and red light for night operation, and both controllable as to intensity throughout the proper range—is required to provide the amount and type of illumination necessary

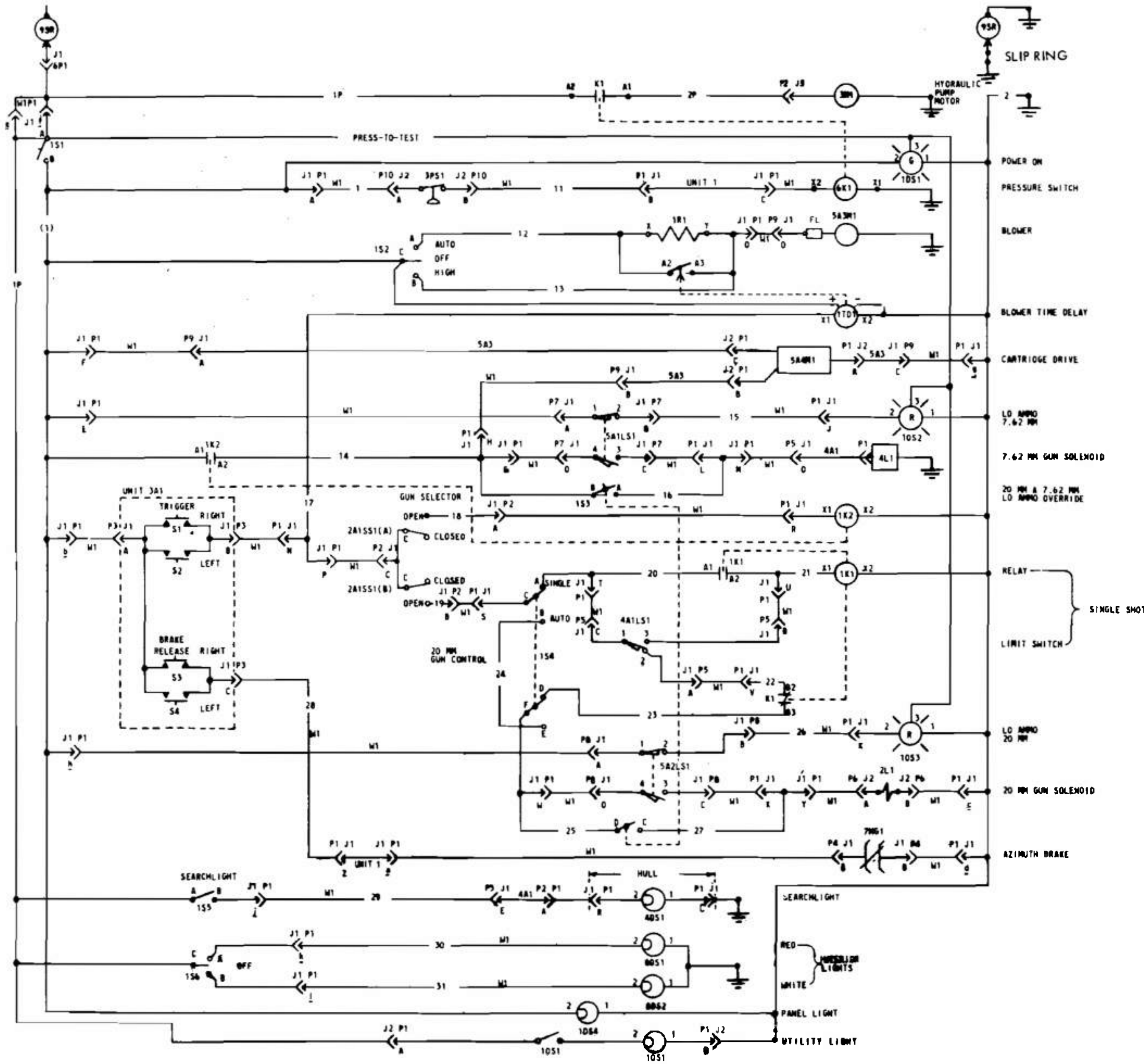


Figure 17-66. Weapon Station Power and Control Circuit Schematic

TABLE 17-6. TYPICAL WEAPON STATION POWER DEMANDS, 28-V SYSTEM

Weapon System	Turret Weight, lb	Standby Current, A	Slewing Rate, deg/sec	Average Traverse Current, A	Peak Traverse Current, A	Average Current Stabilized Moving, A	Average Current Stabilized Stationary, A	Remarks
M60A2 Electro-hydraulic	37,750	–	45	200	600	87.3	17.7	
M60A2 Electric	37,750	–	45	90	660	130	22	Experi-mental
M551 Electric	8,332	4.5	24	60	170	–	–	
LVTP7 Electro-hydraulic	1,520	3	60	120	180	–	–	
XM741 VULCAN	4,688	12	60	45	220	–	–	

for efficient vision during day and night operations.

A 6-cp bulb in an efficient reflecting fixture provides adequate illumination (up to 100 foot-candles) to meet the maximum demands for daytime illumination at any selected position, insuring a reasonably short glare recovery time after eye exposure through a periscope or other vision device to bright outside light.

At night, in contrast to daytime operations, only the minimum illumination is required for efficient performance of the necessary tasks, since there are no disturbing sources of outside glare and the eyes are adapted to low light levels. Furthermore, in order to preserve dark adaptation during night operations, illumination should be by red rather than white light. The use of red light and low levels of illumination at night have the added advantage of minimizing enemy detection of the vehicle by light leakage through periscopes and other apertures. A 6-cp bulb in an efficient reflecting fixture, fitted with a red filter, provides usable illumination up to 1 foot-candle, which is ample light for all night operations. When supplied with a rheostat or other control device, the intensity of illumination can be set for the task at hand and thus insure optimum preservation of dark adaptation. The distribution of light provided by 6-cp bulbs in the fixtures now employed in tanks is satisfactory.

The location of light fixtures should fit the requirements of the visual tasks at each crew position and the relative amount of light required for the efficient performance of each task. Light fixtures should be so located that they do not, themselves, constitute sources of glare or produce disturbing glare by shining directly into periscope windows or onto other reflecting surfaces. Light fixtures and controls should be located for accessibility and convenient operation.

Design indicator systems so that indicator power is not available in any part of the weapon system unless it is intentionally turned on by the operator of the system. Provide a minimum number of indicators in the turret to show the armed or safe condi-

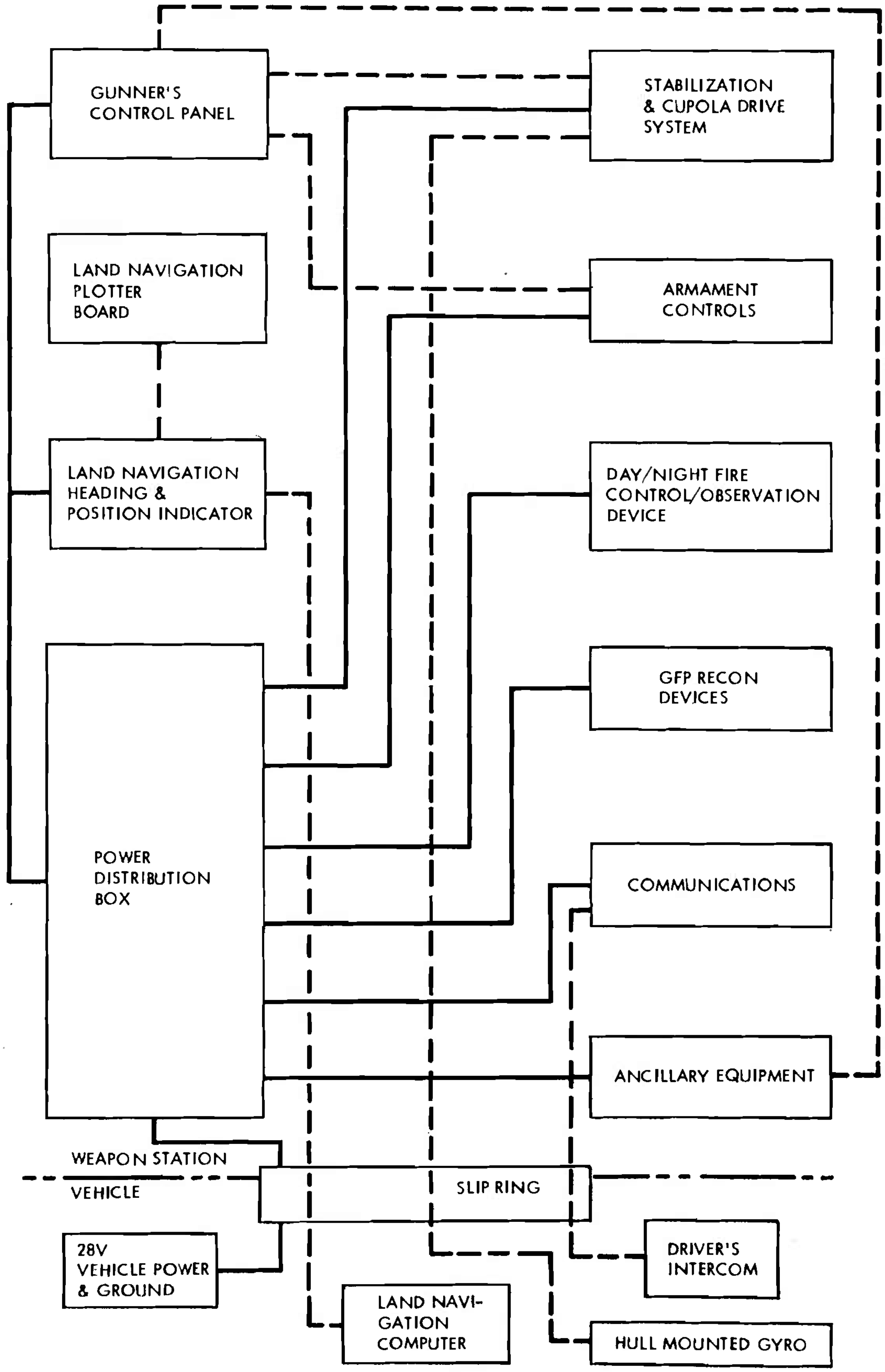


Figure 17-67. Weapon Station Power and Signal Distribution

tion of critical weapon components, and design the arming and fuzing indicators to be automatic with no manual operation required except the power-on function, and the press-to-test feature of the monitor test function. For multiple carriage, each weapon should be monitored individually.

Refer to Chapter 13 for additional interior lighting design and component information.

17-22 VENTILATION

The noxious fumes created during weapon firing must be removed from the turret and crew compartment before they build up to intolerable levels. Usually a blower is provided for this purpose. Turret ventilating systems may require anywhere from 2 A to 55 A at 28 VDC depending upon fan size. One system provides an automatic mode wherein the fan runs at half speed except during weapon firing at which time the blower speed is increased to the maximum. A time-delay relay holds the blower at high speed for a few seconds after firing has stopped in order to clear all fumes from the turret.

The M81E1 Gun Launcher incorporates a closed breech scavenge system. This is used when firing to scavenge automatically the breech and gun tube of debris and gases.

The system consists of a four-stage air compressor, two air cylinders, a solenoid and manual discharge valve, on/off switch, regulator and shutoff valves, pressure gage, weapon-mounted telescoping unit, and attaching hoses and fittings.

Compressor operation is controlled by a pressure control switch on the compressor which energizes the compressor motor when pressure in the system drops to 2800 psi and de-energizes the motor when pressure reaches 3100 psi. Air is discharged into the closed breech cavity when the gun returns to battery and contacts the in-battery limit switch. A pressure gage indicates both the total psi retained in the air cylinders and the total remaining number of discharges available at any given stage of firing. The compressor is locked in an off position when firing in the missile mode to prevent compressor starting transients from interfering with the missile guidance system. Additional information with regard to ventilation systems and components may be found in Chapter 14.

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CHAPTER 18

ELECTROMAGNETIC INTERFERENCE AND COMPATIBILITY

SECTION I

ELECTROMAGNETIC INTERFERENCE (EMI)

18-1 INTRODUCTION

Undesired electromagnetic energy that is propagated by conduction or radiation can produce many interference problems in sensitive electronic equipment. These problems can vary from trivial annoyance to loss of mission capability.

Initial recognition of EMI as a problem came with the advent of radio communications. In order to maintain good radio reception it was necessary to control emanations from electric motors, electronic equipment, and other noise generating sources. As electronic devices with greater power and sensitivity proliferated, the need for controls increased in scope until the present equipment compatibility specifications evolved. These specifications set maximum allowable limits on the interference-producing emanations from a system and also established a minimum allowable level of EMI susceptibility for systems and components.

It is now the policy of the Department of the Army, as expressed in AR 11-13, that measures for the reduction of electromagnetic interference and susceptibility shall be incorporated to the maximum extent compatible with the state of the art in all Army electronic and electrical equipment capable of producing or responding to such interference. Such measures shall be considered at all stages of the procurement cycle from the earliest planning stages through research, development, production, and maintenance. Furthermore, the DOD RF Compatibility Program requires that data be compiled on the spectrum occupancy characteristics of transmitters and receivers used by the Army.

MIL-E-6051[1], *Electromagnetic Compatibility Requirements, Systems,* is mandatory for use by all departments and agencies of the Department of Defense. This Specification should be used as a direct reference in establishing overall requirements for system electromagnetic compatibility and control management responsibility.

MIL-STD-461[2] establishes the acceptable emission and susceptibility levels of EMI for various categories of systems and subsystems, and MIL-STD-462[3] establishes techniques to be used for measurement of the emission and susceptibility characteristics as specified by MIL-STD-461[2].

In order to prevent the unnecessary expense and time delays caused by last minute electromagnetic suppression design modifications on otherwise completed systems, it is imperative that EMI suppression be treated as a system design problem at the inception of a project.

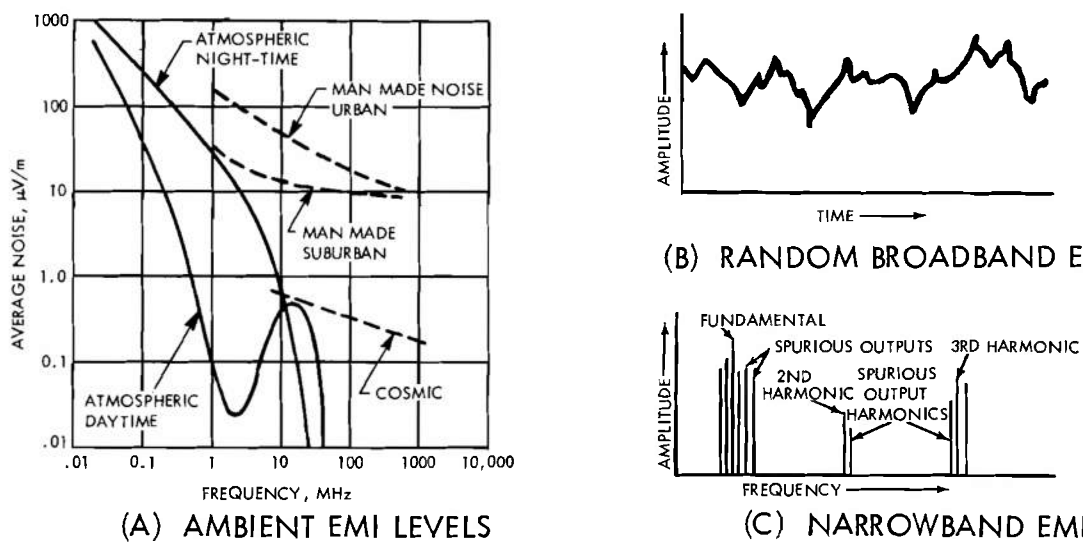
Military publications that provide detailed information regarding EMI control—such as Refs. 4 and 5—are readily available to the system designer, therefore, the contents of this handbook are limited to describing EMI and how it affects military vehicle electrical system design.

18-2 SOURCES OF EMI

There are both natural and man-made sources of EMI. Natural sources include galactic noise from the sun and other stars, precipitation static, and corona discharge from atmospheric electrical disturbances. The amplitudes and various frequency components that constitute natural noise are random with time and vary in overall level from day to night, year to year, and with geographical location (Fig. 18-1(A)).

The EMI produced by man-made devices may be broadband or narrowband in nature. Spectra generated by switching commutation, sparks, and barrage noise jamming techniques usually fall in the broadband category (Fig. 18-1(B)). CW and modulated or pulsed CW, produced by spot jamming or friendly interference, usually fall in the narrowband category. A radar transmitter is an example of a narrowband interference producer. Note that spurious outputs and harmonics may occur over a wide frequency range (Fig. 18-1(C)).

All sources of EMI produce time varying electric or magnetic fields that are of sufficient magnitude to interfere with susceptible equipment.



(A) AMBIENT EMI LEVELS

(B) RANDOM BROADBAND EMI

(C) NARROWBAND EMI

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Figure 18-1. Types of Electromagnetic Interference [7]

SECTION II

ELECTROMAGNETIC COMPATIBILITY (EMC)

18-3 INTRODUCTION

Electromagnetic compatibility is defined as the ability of communication electronic equipment, subsystems, and systems, together with electromechanical devices (i.e., vehicles, engine generators, and electrical tools) to operate in their intended operational environments without suffering or causing unacceptable degradation because of unwanted electromagnetic radiation or response.

Hardening weapon systems against the accidental firing of electroexplosive devices, which are inherently susceptible to radio frequence (RF) energy, is a critical facet of some electromagnetic compatibility control programs (see Ref. 8).

18-4 EMC SPECIFICATION CONSIDERATIONS

MIL-E-6051[1] requires that a system be operated with a safety margin of 6 dB (20 dB for explosives) or better in its intended worst case environment without degradation due to interference. The Specification also includes controls for lightning protection, static electricity, bonding, and grounding. In addition, it requires that the system and all associated subsystem equipment, both airborne and ground, shall be designed to achieve system compatibility. Every effort should be made to meet these requirements during initial design rather than on an after-the-fact basis. Since each system has its own unique requirements and characteristics, which general EMC design criteria documents may not cover satisfactorily, system and subsystems equipment control plans should be used to define supplementary requirements as necessary. As a minimum, the system design program should cover the following areas:

1. Subsystem/equipment criticality categories

2. Degradation criteria

3. Interference and susceptibility control

4. Wiring and cable coupling considerations

5. Electrical power source characteristics

6. Bonding and grounding

7. Lightning protection

9. Static electricity

9. Personnel hazards

10. Electromagnetic hazards to explosives and ordnance

11. External environment

12. Suppression components.

18-5 APPLICATIONS

Various vehicles have been and will be used as operation platforms for complex electronic systems. For example, many basic armored vehicles have been modified as communication centers containing several transmitters and receivers that could easily interfere with each other. Complex weapon systems, such as the M61 VULCAN 20 mm Antiaircraft System, have been mounted on M113 Armored Personnel Carriers. The VULCAN system employs electrical drive servos and complete radar fire control that could be affected by vehicle-generated EMI.

When missiles are mounted on vehicles, the possibility of inadvertent launching due to EMI becomes a serious factor because missile launching is usually done with an electric initiator-electroexplosve device (EED). In addition, EMI could upset the missile control systems that are dependent on radio, radar, and computer circuits.

MIL-STD-461[2], Notice 4, clearly stipulates that a control plan must be made for EMI system control. This interference control plan should be a detailed plan specifying the interference reduction program and the engineering design procedures and techniques that will be used to achieve conformance with the requirements of the standard and that will enable the equipment, subsystem, or system to perform its operational function within its specified design parameters without adversely affecting or being affected by equipments, subsystems, or systems collocated.

When establishing system compatibility requirements, it is advisable to to make two lists. One list includes anticipated EMI sources with their probable frequencies and dB levels. The second list should include sensitive receptors with identification of susceptibility modes, frequencies, and dB levels. After the development of accurate lists, problem areas—where emitted frequencies could affect susceptible circuits—can be anticipated and suppressed. Often selection of a suitable physical location for equipment and cable routings will improve or prevent EMC problems.

SECTION III

ELECTROMAGNETIC INTERFERENCE REDUCTION

18-6 INTRODUCTION

The first step in solving an EMI problem involves determining the magnitude of the interference and comparing it with the allowable specification limits. The surest method is to measure the interference levels with appropriate equipment. Interference levels may also be determined by predictive analysis and corroborated with later measurements. The required measuring equipment includes antennas, attenuators, signal generators, coupling networks, frequency selective voltmeters and receivers, radio interference field intensity meters, and spectrum analyzers. The latter two are the most widely used.

After interference producers have been identified through analytical or test methods, the various suppression methods can be considered and applied to each source to the degree necessary for achieving conformance with EMI specifications.

18-7 EMI SPECIFICATION CONSIDERATIONS

Before 1 August 1968, MIL-S-10379 was the controlling specification for EMI requirements for military vehicles. When MIL-STD-461[2] became the applicable specification the EMI requirements became more restrictive. Notice 4 of MIL-STD-461 has eased some of the original requirements for vehicles. The most important changes include revisions to the conducted emission requirements adding a new conducted emissions test category (CEO7) and some switching transient exemptions.

18-8 INTERFERENCE PRODUCERS

As noted, electromagnetic energy is produced by time varying changes in electrical current and voltage. A more rapid rate of change produces greater electromagnetic energy and increases the possibility of producing EMI (Fig. 18-2). Power switching transients therefore can produce excessive EMI. Typical examples are the switching of lights, solenoids, relays, heaters, and motors. The EMI generated by such switching devices almost always will exceed the allowable limits of MIL-STD-461. Most short duration automatic, or recurring control, or switching functions therefore must be considered and suppressed as necessary. However, those vehicle equipment or switching functions that are required to start or shutdown equipment for a mission are exempted by MIL-STD-461.

DC motors and generators, alternators, voltage regulators, rectifiers, fluorescent lamps, vibrators, horns, and ignition systems also produce rapid changes in current and voltage which require suppression.

Extremely rapid changes in voltage and current are produced by a spark. A typical vehicle contains several spark producing devices. The foremost of these is the ignition system followed by the commutator brushes of motors and generators. In addition, static charge buildup followed by an arc discharge can occur on poorly grounded subassemblies and produce EMI transients.

Intentionally generated electromagnetic energy—such as that produced by communication transmitters, radar transmitters, and local oscillators in receivers—becomes EMI sources when their emission appears at undersired places as a result of capacitive or inductive coupling.

18-9 INTERFERENCE SUPPRESSION

The most obvious basic approach to interference control is to choose or design equipment that is inherently interference free. This often pays dividends in increased reliability, reduced maintenance, and elimination of the costs for suppression or shielding. The most common example is that of using induction or other noncommutating motors instead of

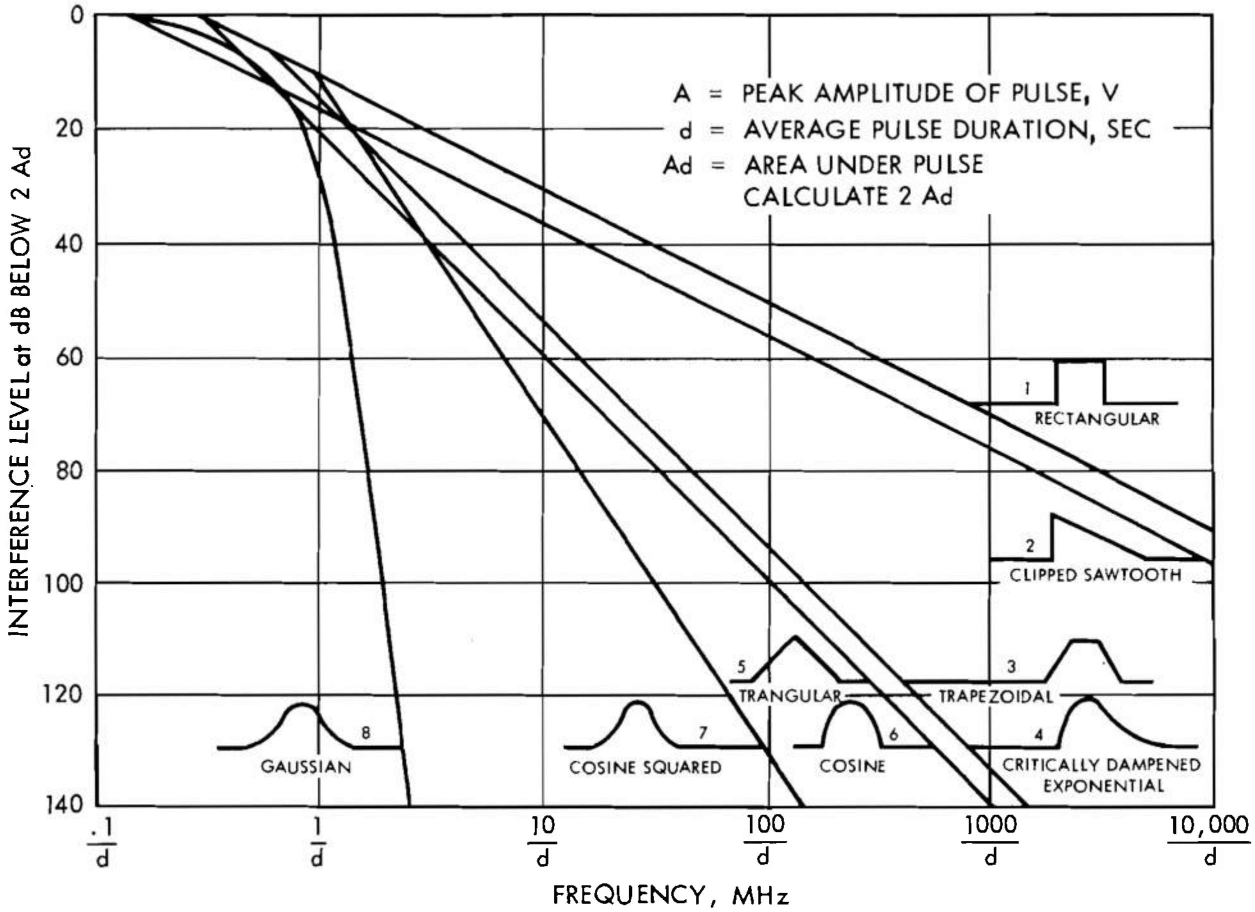

Figure 18-2. Interference Levels for Various Pulse Shapes[4]

commutating types. Other examples include permanent magnet AC generators that eliminate slip rings, replacement of commutation DC generators with diode rectified AC generators, and the use of carbon pile of analog voltage regulating systems instead of vibrating contact or switching types.

Suppression of an interference source consists of confining and dissipating the interference energy that has been generated so that it cannot reach susceptible circuits or equipment by conduction or radiation. The conduction mode occurs through a common electrical conducting path from the EMI source to an undesired receptor. The radiation mode is similar to and obeys the basic laws of transmitted radio signals. Chapter 1, Section IV, *Interference Reduction Guide for Design Engineers-Volume 1*[4]. presents a concise explanation of the 2 modes of transmission. Inductive and capacitive coupling are submodes of radiated transmission. In some cases conduction and radiation combine to transmit the EMI. In other words, the EMI source may radiate to a wire that has a common electrical conducting path to the receptor, or a conducting path from the EMI source may couple to the receptor wiring (Table 18-1).

TABLE 18-1. EMI SOURCES AND SUPPRESSION METHODS[7]

Sources	Transfer Mechanism	Suppression Methods
Antennas	Orientation or proximity to receivers that should not receive transmissions.	Reorient antenna or relocate antenna or receiver; use antenna with better directivity; filter receiver input.
	Poorly bonded stays, dirty insulators, or corroded connectors produce broadband radio frequency interference (RFI).	Preventive maintenance and proper installation.
Components	Underrating passive components (resistors, capacitors, inductors, transformers) and active devices (tubes and transistors).	Operate conservatively. This will prevent RFI from causes such as arcing in the dielectric of an underrated capacitor.
Converters: Frequency and DC to AC Inverters	Conduct and radiate broadband RFI due to internal switching.	Weigh merits of rotary converters against electronic converters. Use shielding and filtering. Use pulse shaping to reduce RFI in electronic converters.
Generators and Motors	Send broadband RFI into power lines and radiate RFI; AC generators also produce harmonics.	Avoid use of brushes, commutators, or slip-rings, but use brush (or conductive grease) on shaft bearings to prevent charge build-up in armature; machines should have good concentricity. Shield ventilation ports and filter output/input leads. In DC machines, use preventive maintenance; a large number of commutator segments reduces RFI.
Ignition Systems	Radiated broadband RFI is due to inherent arcing.	Shield the ignition system parts; shape (round out) the ignition pulse.
Power Supplies (DC)	Conductive RFI. Transients produce broadband RFI; also AC ripple, which is usually negligible.	Suppress transients and filter out the AC ripple.
Relays	Produce conducted and radiated RFI.	Place R-C circuit across protected contact or across the load. Shield.
Air Conditioners	Motor-driven compressors produce conducted and radiated RFI.	Use appropriate motor suppression.
Switches	Produce conducted and radiated broadband RFI.	Place R-C circuit across switch, if possible.
Thermostats	Produce conducted and radiated broadband RFI.	Connect thermostat to ground side and place R-C across it. Shield.

SECTION IV

INTERFERENCE REDUCTION TECHNIQUES

18-10 INTRODUCTION

Certain radio-interference suppression techniques are used so frequently and are common to so many different equipments that much repetition would result if they were treated in relationship to each individual application. Therefore, techniques are described and discussed generally, without reference to specific equipments.

18-11 AVAILABLE TECHNIQUES

Proper bonding and the installation of by-pass capacitors account for more than two-thirds of all corrective measures applied to equipment that fails to meet the requirements of the radio-interference suppression specifications. This fact alone shows the importance of paying close attention to those two items in the design and installation of radio-interference suppression systems. The components and materials required for proper bonding and by-passing are also the ones most commonly available and therefore easiest to procure.

The remaining suppression measures common to many installations—and treated in this chapter—are filtering, shielding, use of resistor suppressors, and significance of the physical layout.

Filters by-pass the radio-interference currents in much the same way as capacitors. Since in most cases capacitors are sufficient to satisfy the requirements of the specifications, filters are not recommended except in special instances. Resistor-suppressors are important and effective in those applications for which they are recommended; however, their field of application is limited mainly to ignition systems. Finally, shielding, though cumbersome and expensive, is always necessary to attenuate high-frequency interference from strong sources such as distributors and other ignition-system components, and from effective radiators such as interconnecting leads in ignition systems and radar installations. Efficient use of existing shielding—such as afforded by housings, dust covers, or partitions (see par. 18-11.4) – is an excellent means of augmenting a suppression system. Furthermore, for many severe interference sources, other suppression means of equal effectiveness are not available hence shields must be used.

The basic suppression principles to consider in the design of the physical layout suggest that the source, or circuits in which interference is present, should be separated as far as practicable from susceptible parts of the same equipment and from external antenna circuits of any kind. Reduction of undesired coupling (by separation) greatly reduces the necessary degree of shielding and may reduce undesired feedback problems.

18-11.1 CAPACITORS AND FILTERS

By-pass capacitors and filters are used to prevent radiated and conducted interference from reaching sensitive receivers. They accomplish this either by introducing a high impedance into the path of the interference currents or by shunting them to ground through a low impedance. Since the circuits into which the capacitors or filters are inserted are designed to carry power, control, or signal currents, the suppression elements must be designed so as to affect as little as possible the normal operation of the circuits.

The effectiveness of the suppression elements can be measured in terms of their impedance. However, the effect of the other impedances in the circuit is important also, and another type of measurement is found to be more practical—that of insertion loss. The insertion loss ratio is defined as:

$$\text{Insertion Loss} = 20 \log \frac{E_2}{E_1}, \text{dB} \qquad (18\text{-}1)$$

where

E_2 = potential across load impedance Z_L with filter in circuit, V

E_1 = potential across load impedance Z_L without filter in circuit, V

The insertion loss is a function not only of the impedances of the suppression elements, but also of the load impedance Z_L and the source impedance Z_s; if, however, the suppression system is a single shunt element of impedance Z, and if Z is very small as compared to Z_s and Z_L—as is usually the case at the frequencies of the interference currents—then the insertion loss ratio is very nearly inversely proportional to the impedance Z, and either impedance or insertion loss may be taken as a measure of effectiveness. For test purposes, the impedances Z_s and Z_L are standardized, usually at 50 ohms resistance each, so that the effectiveness of different systems may be compared.

An ideal capacitor is an element that contains nothing but pure capacitative reactance. Its impedance is inversely proportional to the frequency at all frequencies. For a general purpose suppression capacitor, this is an ideal characteristic since normally the interference frequencies are much higher than those of the power or control currents for which the system was designed. Thus, the presence of a high-impedance element in shunt does not affect the normal operation of the equipment, while at radio frequencies the low impedance shunts the interference currents to ground.

All practical capacitors must of necessity contain resistance and inductance in addition to their capacitance, which causes their characteristics to deviate from those of the ideal capacitor. The degree to which the ideal is approached depends on the details of construction and on the installation.

The inductance of a practical capacitor causes its impedance to decrease with frequency until a minimum is reached, and then to rise again. The frequency at which the minimum occurs is called the resonant frequency, and the impedance at the resonant frequency is the resistance of the capacitor. Correspondingly, the insertion loss reaches a maximum at the resonant frequency and then decreases. Thus a capacitor ceases to be an effective by-pass element at frequencies much above its resonant frequency.

If capacitors were ideal, their effectiveness as shunt elements would be greater the larger their capacitance. In actual capacitors, one of the factors that limits the value of capacitance that can be used in a suppression element is the inherent inductance, which usually increases with the size of the capacitor. Since the resonant frequency is raised by decreasing the inductance, the use of a smaller capacitance increases the high-frequency effectiveness. Thus it comes about that, though an ideal capacitor of 1 μF (microfarad) capacitance would be ten times as effective in by-passing radio-interference currents as one of 0.1 μF, in practice the smaller one is likely to be more effective at higher frequencies.

Filters are more complicated and more expensive, and combine the by-passing action of capacitors with the impeding action of inductors. Properly chosen filters provide greater insertion loss than by-pass capacitors over the frequency range for which they are designed. The most frequently used filters are low-pass filters with cut-off frequencies in the region from 1 to 10 kHz. They will then have very small insertion loss for DC and ordinary power-frequency currents, and will attenuate strongly all radio-interference currents.

Since filters contain capacitances as elements, the inherent inductance of a capacitor is a limiting factor here also. Moreover, filters also contain inductance coils, whose distributed capacitances impose further limitations on the design. However, it is possible to take these stray elements into consideration during the design, and a well designed and carefully constructed low-pass filter will remain effective as a suppression element up to frequencies well above 100 MHz.

Special filters are sometimes useful in the solution of specific radio-interference problems. Band-pass filters, which allow a certain band of frequencies to pass and suppress all others, are sometimes used in the antenna circuit of receivers in order to increase their selectivity and improve their interference rejection. They also may be used in the output circuits of transmitters or oscillators in order to suppress harmonics and other spurious frequencies. Band-elimination filters, which suppress a certain band of frequencies and pass all others, find applications when the interference to be suppressed contains only a narrow band of frequencies, such as that from a radar modulator.

The principles to be followed in the installation of suppression components are the same for filters and capacitors. They follow directly from a consideration of two basic facts: (1) that the lead from the interference source to the suppression element carrier interference currents, and (2) and that the impedances of the connections to the element and from the element to ground are in series with the by-passing portion of the element. It follows that the suppression component must be installed as close to the source as possible and that good bonding, as discussed in par. 18-11.3, is extremely important in the installation of filters and capacitors. Improper connection can reduce the effectiveness of any filter as illustrated in Fig. 18-3.

18-11.2 RESISTOR-SUPPRESSORS

Resistor-suppressors are series impedances inserted in a line to reduce the interference currents. Since their impedance is resistive, it is independent of frequency, and therefore the currents for which the system was designed are affected by them in the same way as the interference currents. This restricts the use of resistor-suppressors to those systems whose operation is not affected adversely by the insertion of additional resistance. By far the most important example of the effective use of resistor-suppressors is the ignition system of internal combustion engines.

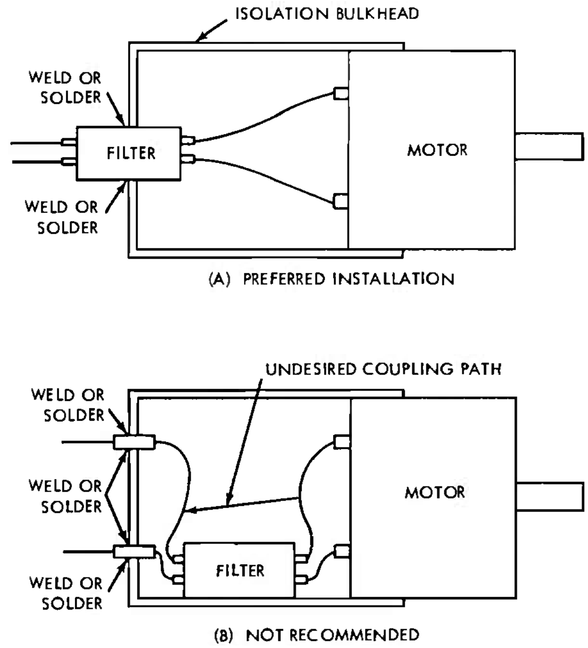

Figure 18-3. Filter Installation[5]

18-11.3 BONDING

As far as radio interference is concerned, bonding serves one main purpose i.e., to provide a path of low impedance for the radio-interference currents. It has been found in practice that a necessary condition for the existence of a good bond is very low DC resistance. On the other hand, because of the importance of inductance and capacitance at radio frequencies, low DC resistance does not assure a good bond. A very low inductance and proper installation, in which care is taken lest the system capacitance combine with the bond inductance to produce a very high impedance, are also of great importance. Yet, because of the difficulties in measuring radio-frequency impedances of bonds, the DC resistance is used as a measure of the effectiveness of the bond.

Two general types of bonding are used—direct bonding and bonding by means of straps. The direct bonding method is preferred because at best a bond strap is no more than a poor substitute for a direct bond. Direct bonding is simply bare metal to bare metal contact, the metal being previously cleaned of all protective coatings. This usually is accomplished by the use of tooth type lockwashers which by their milling action during application remove paint and other foreign material from the mating surfaces thus providing a satisfactory bond. This is an economical and practical compromise although a permanent bond made by welding or brazing is, of course, the most satisfactory. Bond straps are used whenever equipment is shock mounted or when clearance between the bonded members must be maintained for mechanical reasons. Bond straps are fabricated of flat tinned copper braid, terminated at each end in either a soldered or a properly crimped lug. The most important considerations are assuring that the bond strap is of minimum permissible length, that it is securely grounded with tooth type lockwashers, and that the solder has not affected its flexibility. Other types of specialized bonding occasionally used are conductive rubber belts and brush bonds. Conductive rubber belts frequently are required to prevent the accumulation of electric charges which develop as a result of friction between the belt and pulley. MIL-B-11040 details the requirements for these belts. Brush bonds are used to provide a path of low impedance for two surfaces in continuous relative motion by having a brush ride on a specially grounded slip ring or directly on a shaft.

When two members are connected through a bond strap, the length of the strap introduces an inductance into the circuit which is much larger than that of a direct bond. The inductance is small enough to be of no importance at power frequencies, but an inductance as low as 0.01 μH (microhenry) has an impedance of about 6 ohms at 100 MHz, which cannot be neglected in many applications; and most bond straps have inductances larger than this.

An additional difficulty is introduced by the ever-present capacitance between the bonded members—which is in parallel with the inductance of the strap. The impedance of a parallel combination of inductance and capacitance is very high at certain frequencies, and in many applications these frequencies lie in the region between 50 and 500 MHz, i.e., well in the region of radio-interference considerations. These effects are reduced by keeping the inductance as low as possible, which in turn requires the use of straps of minimum length and high ratio of width to thickness. The most important considerations are to make the bonding straps as short as possible and to ensure good direct bonding between the straps and the members to be bonded. Examples of bonding techniques are shown in Fig. 18-4 and Fig. 18-5. Additional information may be found in Section III, page 2-19 of Ref. 4.

18-11.4 SHIELDS

The purpose of a shield is to keep all radio-interference energy confined within a specified region, or to prevent all radio-interference energy from entering a specified region. The first type is used for ignition systems, motors, and other sources of radio interference. The second type is used for receivers or leads leading to receivers. Because power or control energy always must be supplied or removed from the region within the shield—and because the techniques of construction as well as the necessity for accessibility and serviceability demand that shields be made of more than one part—openings, seams, joints, or other discontinuities must always be present. The problem of constructing an effective shield has therefore two separate phases: (1) the prevention of the penetration of electromagnetic energy through the shielding wall itself, and (2) the prevention of leakage through the discontinuities in the shield. The second of these two problems—the proper design of the necessary discontinuities so that effectiveness of the entire shield is not impaired—requires the greater consideration and attention. Just as a chain is no stronger than its weakest link, a shield is no more effective than its poorest joint.

When properly employed, shielding is one of the most effective ways to protect susceptible components and prevent radiation from

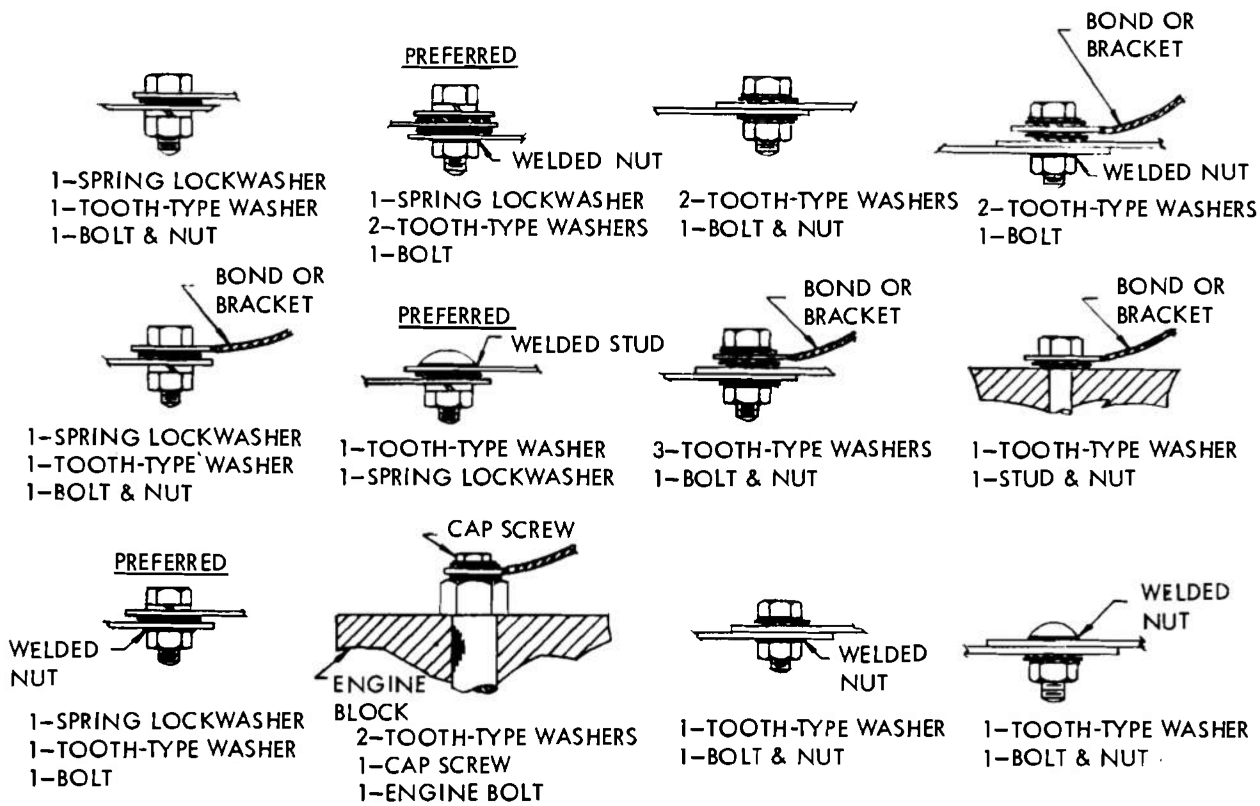

Figure 18-4. Typical Tooth Type Lockwasher Applications

EMI sources. However, there are some definite mistakes to avoid when using shields. The greatest danger is the introduction of ground loop currents. The termination and grounding of shields must be done properly in order to yield effective and reproducible results. The effectiveness of the shielding often is disappointing at short separation distances and lower frequencies. Chapter 2, Section IV, Ref. 4, presents comprehensive guidance regarding shield applications.

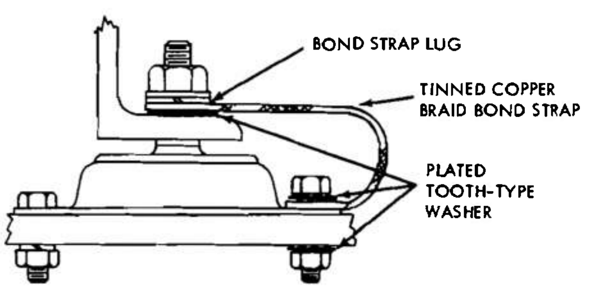

Figure 18-5. Typical Shock-mount Bond

18-12 CONCLUSIONS

As the communication and fire control systems on vehicles have become more complex, the probable occurrence of EMI and EMC problems has increased. These problems can be very difficult to resolve if they have not been anticipated in the system design phase.

This chapter has only touched on potential EMI problems and cures. Specific requirements and more detailed information should be obtained from the referenced material. System control requirements are in MIL-E-6051[1]. Actual EMI limitations are specified in MIL-STD-461[2]. Measurement procedures are specified in MIL-STD-462[3]. Volume 1[4] and Volume 2[5] of *The Interference Reduction Guide for Design Engineers* serve as good basic reference manuals. The Air Force Command Design Handbook No. DH 1-4, *Electromagnetic Compatibility*[6] is another good reference.

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CHAPTER 19

SPECIAL PURPOSE EQUIPMENT

19-1 INTRODUCTION

Aside from the ordinary vehicle electrical equipment discussed in the preceding chapters, the electrical system design engineer will occasionally encounter special purpose equipment applications involving electrical requirements and considerations. Such equipment is briefly described in this chapter.

19-2 AUXILIARY ELECTRIC POWER SYSTEMS

A vehicle auxiliary power unit (APU) is a self-contained unit capable of delivering electric power in addition to that provided by the vehicle charging system. An APU may be required to provide DC power as a substitute, or supplement, for power furnished by the vehicle generating system; or, it may be required to provide the AC power necessary to operate welding equipment, hand tools, or certain communication-electronic equipment. The most common configuration employs an electrical generator driven by a reciprocating rope-started gasoline engine.

Two Military Standards published within the last few years describe the majority of electrical characteristics for mobile electric power units to be in the inventory in the next 10- to 20-yr period. These are: MIL-STD-1332, *Definitions of Tactical, Prime, Precise, and Utility Terminologies for Classification of the DOD Mobile Electric Power Engine Generator Set Family*[1], and MIL-STD-633, *Mobile Electric Power Engine Generator Standard Family Characteristics Data Sheets*[2]. MIL-STD-633 is the catalog of equipment available to the user, and it will be revised periodically to reflect the inclusion and deletion of electrical power sources as the technology advances. Inclusions in this family will be screened against all service requirements and, in order to meet the criteria for inclusion, must be accepted by all military services.

Although it is not prescribed in MIL-STD-633, a 4.2-kW, 28-VDC gasoline engine-driven APU, described by MIL-G-62120[3], is presently used on the USA M577A1 Carrier, Command Post, and the USMC LVTC7, Landing Vehicle, Tracked, Command. This APU features a starter-generator and therefore may be started from vehicle battery power.

Under the subactivity "Electric Power Sources", the Army conducts a majority of its generator R&D. In-house laboratory work is performed at the USA Mobility Equipment R&D Center (MERDC). Research and development efforts are currently focused on short- and middle-range projects. The major midrange project is to field a second generation DOD standard family of turbine-engine-driven generator sets, and special purpose fuel cells and thermoelectric devices.

The recent development of small, lightweight, thermoelectric generators for vehicle application may provide the means to eliminate deep battery discharge resulting from standby operation of engine coolant heaters in the arctic or from vehicle silent watch loads[4]. Thermoelectric-generators of this type (Fig. 19-1) could be installed in parallel with the vehicle batteries to provide 10, 20, or 30 A at 28 VDC. Energy is supplied by heating a thermopile with any variety of vehicle fuels including diesel fuel. Twenty-five of these lightweight generators were delivered to the Army in 1972. The generators are extremely quiet, being inaudible at a distance of 100 ft. It is probable that a 20-A unit, provided in kit form, would allow vehicles to remain in unattended arctic standby with coolant heaters operating continuously as long as vehicle fuel is available. Furthermore, the same kit could extend the capability of the crew by allowing use of the personnel heater during low temperature silent watch missions, or by allowing full-time use of sensor and vision devices during silent watch without fear of battery discharge. At the present time, two type units have been manufactured. These units are designated PP-6074( )/U and PP-6095( )/U. A third type unit PP-6128( )/U with a 30-A output is in the development stage. Physical and electrical characteristics for these units are given in Table 19-1.

Most military vehicles have a slave receptacle to which a 28-VDC APU can be connected to supply power for battery charging, or for operating 28-V vehicle equipment.

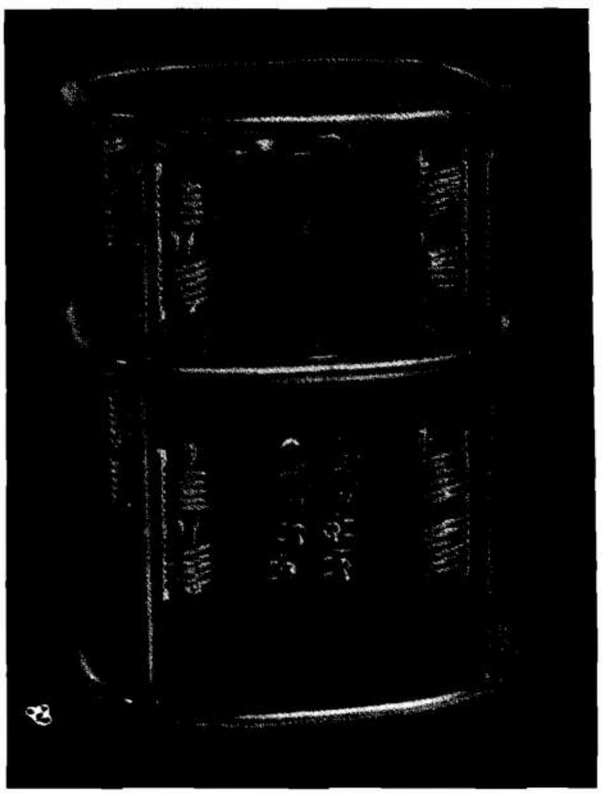

Figure 19-1. Thermoelectric Power Source Model PP-6075( )/U

TABLE 19-1. THERMOELECTRIC APU CHARACTERISTICS

	Capacity, A	Wt, lb	Height, in.	Diameter, in.
PP-6074 ( )/U	10	25	21	13.25
PP-6075 ( )/U	20	35	23	14
PP-6128 ( )/U	30	50	23	15.5

For voltages in excess of 28 V, either AC or DC, a separate connector must be installed in the vehicle. This connector must be isolated from the chassis, and must be wired so as to prevent shocks to personnel.

19-3 ELECTRIC WINCHES AND CAPSTANS

Winches and capstans generally are designed to handle specific loads for specific lengths of time.

Winches normally are mounted on the front of a vehicle, and may be used for recovery of the vehicle to which they are attached. A winch also may be used to recover another vehicle or to move cargo.

An electric winch incorporates a drum to store the towing cable. This drum is driven by an electric motor through a set of reduction gears. The mechanism has a levelwind device to insure even layering of the cable on the drum.

Fig. 19-2 shows a typical winch installations.

A capstan is a relatively inexpensive mechanism, used in lieu of a winch for loading cargo or equipment into a vehicle. The pulling force of a capstan does not reach that of a winch.

A capstan is versatile in that any tow line may be used. The operator wraps the line around the drum, maintaining tension on the free end of the line. This creates friction

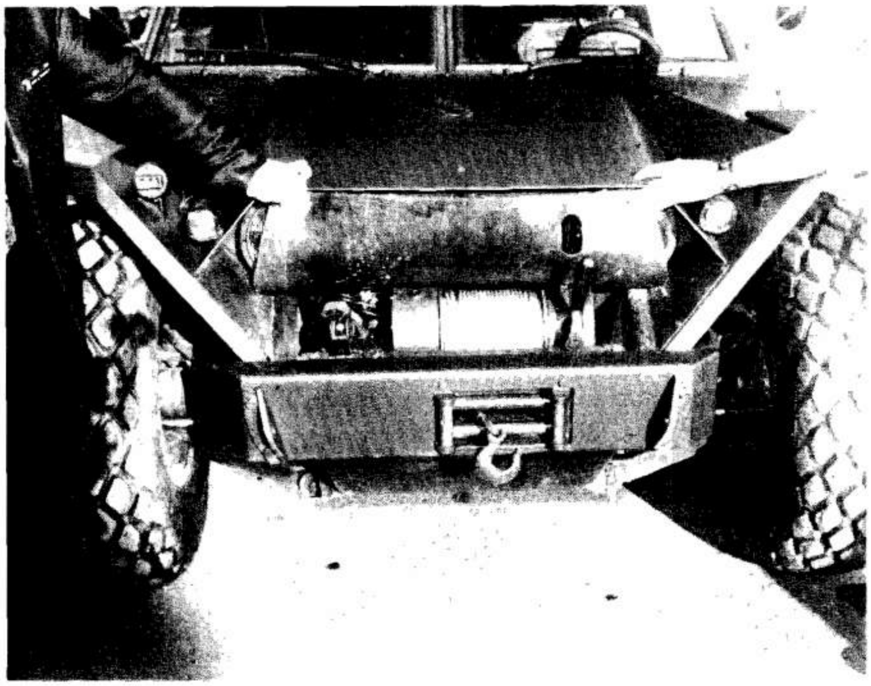

Figure 19-2. Winch Installation

between the line and the surface of the drum allowing the line to transmit drum force to the load. The line is not wound up as the drum reels it in; instead the free end, which becomes ever longer, must be disposed of by the operator. Fig. 19-3 illustrates a typical electrically driven capstan.

Some of the electrical design considerations involved in both capstan and winch installations are:

1. Motor

a. The motor can be either shunt wound, series wound, or compound wound.

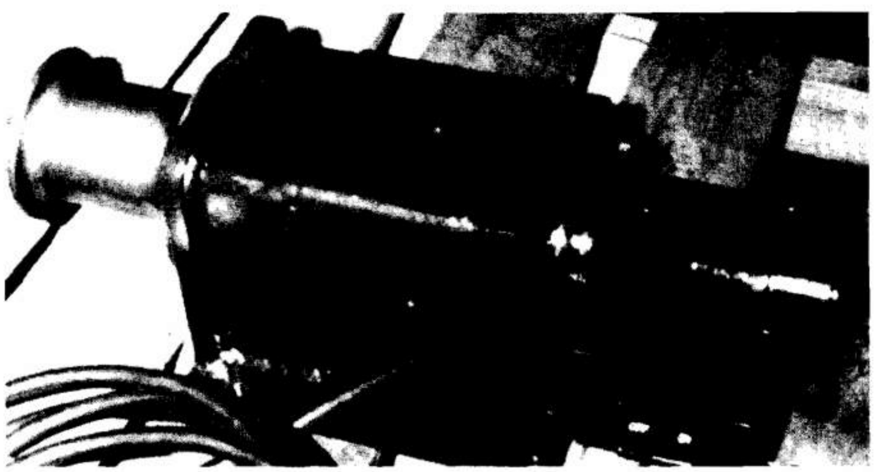

Figure 19-3. Capstan

b. The shunt wound motor has good speed regulation over a broad load range and, because the field has a fixed strength, this type of motor has a relatively low breakdown torque. However, a compound wound motor of the same frame size has approximately 50 percent lower inrush current, and increased torque capability.

c. A compound wound motor, gear-mounted to a winch or capstan to pull a load between 3,000 and 5,000 lb, will require a current of 100 to 150 A.

2. Motor Control:

a. Switch. The switch contacts must be capable of withstanding the inrush and maximum continuous current required by the motor. The design must also allow opening of the contacts under full load current.

b. Circuit Breaker. Selection of a circuit breaker that will provide circuit protection and yet allow the required current for motor operation under maximum torque conditions for short periods of time is difficult to optimize. In the process, the designer must consider ambient temperature variations, duty cycles, and motor characteristics. This is best accomplished in a test setup simulating actual load conditions.

3. Specifications. There are several generalized specifications covering the design and construction of winches. Some of these specifications are listed:

a. MIL-W-15802(SHIPS), *Winch, Gypsy, Power Operated, Electric*[5].

b. MIL-W-15808(SHIPS), *Winch, Drum, Power Operated, Electric*[6].

c. MIL-W-17265(USAF), *Winch, Drum, Power Operated, 4,000 lb Capacity, 28 VDC, Portable*[7]

d. MIL-W-38018(USAF), *Winch, Drum, Power Operated*[8].

19-4 DEEP-WATER FORDING KITS

The majority of overland military vehicles are not amphibious; therefore, they require a bridge, raft, barge, or other supplementary means of traversing small bodies of water.

The addition of a deep-water fording kit, similar to that designed for the M60A1 Tank, provides a vehicle with limited capability to crawl along the bottom of waterways over short distances.

Dependent upon the depth of the waterway, total submergence capability may be required. The crew compartment must be sealed, the engine exhausted, the electrical system waterproofed, and seepage into the crew compartment expelled.

All external wiring must be made waterproof. The method shall be determined by the type of connection encountered. Wires through the hull must be fed through a stuffing tube if a connector is not used.

Penetrator-type connectors must be made waterproof by the use of gaskets under the flange to prevent leakage around the barrel, and under the protective cap to prevent leakage through the connector and protect the connectors from corrosion.

Even with a deep-water fording kit properly installed, some seepage may enter into the crew compartment. This necessitates the use of a bilge pump located in the compartment. The size of the pump is determined by the area to be pumped and the method used to exhaust the water.

19-5 WELDERS

Metal-Inert-Gas (MIG) welding and metallic arc (stick) welding are both required capabilities for military recovery type vehicles. MIG is the more versatile of the two methods because it is used for welding both aluminum and steel. This system uses an inert gas such as helium, argon, or carbon dioxide, separately or in combination, to protect the weld from contamination. The welding head contains a spool that continuously feeds welding wire through the head during the welding operation. To change the type of wire, the whole spool must be changed. This system requires relatively complicated controls for gas control and wire feed control, as well as arc adjustment. A MIG welding set that is in the Army supply system is listed under Federal Stock Number FSN 3431-691-1415. This set includes either a Linde model SWM-9C or a Westinghouse model SA-135 (optional) control and torch. 115 VDC or 115 VAC, 60 Hz, 200 A is the required power input at the weatherproofed control unit, and this power usually is provided by an auxiliary power unit (APU). The welder is shown in Fig. 19-4.

Another MIG welding set is specified on drawing 80064-2625083. This unit, available in the Navy system, uses power supply 90064-2624193. As presently used, it is powered by a vehicle engine-driven alternator supplying 12 kVA, 208 V at 60 Hz. The metallic arc current requirements from the power supply are about the same as for the MIG welder.

The electrical designer must be fully aware of the electromagnetic interferences created by welders in operation and the difficulty entailed in suppressing such interferences.

19-6 HAND TOOLS

Some ancillary vehicles carry electrically operated hand tools for making emergency repairs in the field. These tools are powered either by the vehicle generating system or from auxiliary power supplied through a receptacle on the vehicle. The major tools available in the military system are shown in Table 19-2.

19-7 LAND NAVIGATION SYSTEMS

Recent developments in land navigation systems are particularly useful for off-the-road military vehicles. Because these vehicles are not traversing marked thoroughfares, the crew has no rapid means of ascertaining their exact position. In modern warfare, dead reckoning is not acceptable.

Two promising land navigation systems have been introduced. These are the Magnetic Automatic Navigation (MAN) system, and the Gyrocompass Automatic Navigation (GAN) system. These systems are being tested by the Army at Fort Carson, Colorado.

The MAN system employs a magnetic header for a north-seeking sensor which feeds the vehicle heading into a computer. At the same time, the speed and distance traveled are fed into the computer from the vehicle speedometer and odometer. The computer contains a means of compensating for wheel or track slippage.

Figure 19-4. MIG Welding Set

TABLE 19-2. VEHICLE HAND TOOLS[9]

Part no.	V	A	Component
2624744	115/120AC	15	Grinder, portable
2624807		90 to 600	Torch, cutting
8898482	115 AC/DC	10	Soldering iron
Fed. Spec W-D-661, Type IV (FSN 5130-473-6228)	115 AC/DC	7.5	Drill, portable, 3/4-in.
Fed. Spec W-D-661, Type III, CLA (FSN 5130-889-9000)	115 AC/DC	3.5	Drill, portable, 3/8-in.
Fed. Spec W-W-650, Size 2 (FSN 5130-221-0607)	115/120 AC/DC	1.2	Wrench, impact, 1-in.
Fed. Spec W-W-650, Size 5 (FSN 5130-317-8058)	115/120 AC/DC	10	Wrench, impact 1-in.
Fed. Spec GGG-S-51, Type II Size 10 (FSN 5130-239-5795)	115 AC/DC	12	Saw, circular, portable

The computer also determines the vehicle position in relation to a preset reference and feeds the information to a readout in the crew compartment. At the same time, the information is fed to a lighted map board, also located in the crew compartment, which displays the information in terms of vehicle position and heading.

Fig. 19-5 shows the MAN system interconnection diagram.

The GAN system is the same as the MAN system, except it employs a gyrocompass as the north-seeking sensor.

The MAN systems appears to be the better and less costly of the two systems, but it is not adaptable to all vehicles. It cannot be used in a vehicle with large masses of ferrous material such as encountered in a heavily armored tank. The rotation of a gun in a turret also affects the accuracy of the MAN system.

The GAN system is not affected by any material and is, therefore, suitable for use on all military vehicles. Fig. 19-6 shows the GAN system interconnection diagram.

The MAN header assembly has the advantage of being field repairable, while the GAN header assembly must be sent to a maintenance depot for repair.

The MAN system has a slight accuracy advantage over the GAN system. Characteristics of the two systems are compared in Table 19-3.

An additional system based on the Loran principle as used for aircraft navigation has been considered. Because this system relies on external signals for its operation, it is not as adaptable as are MAN and GAN, which are completely contained units independent of external signals.

TABLE 19-3. LAND NAVIGATION SYSTEM CHARACTERISTICS

	V	A	Weight (incl. cables), lb
MAN	24 DC	4 max	50
GAN	24 DC	5-12*	120

*Depending upon the gyrocompass used.

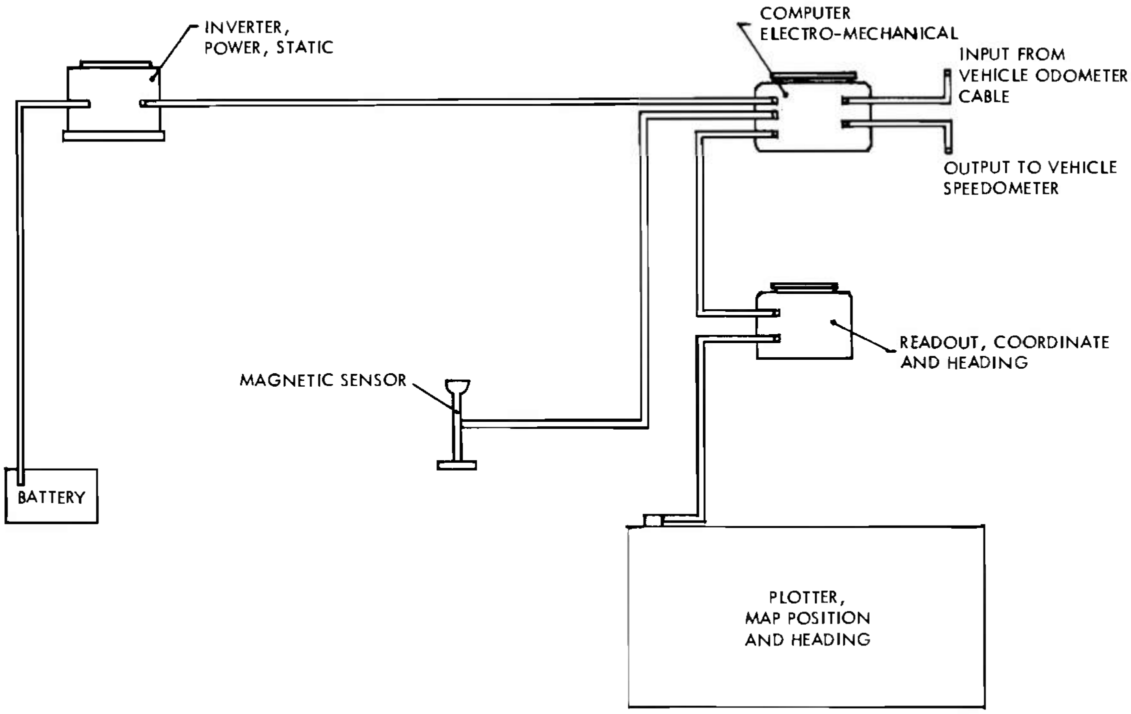

Figure 19-5. MAN Land Navigation System, Interconnection Diagram

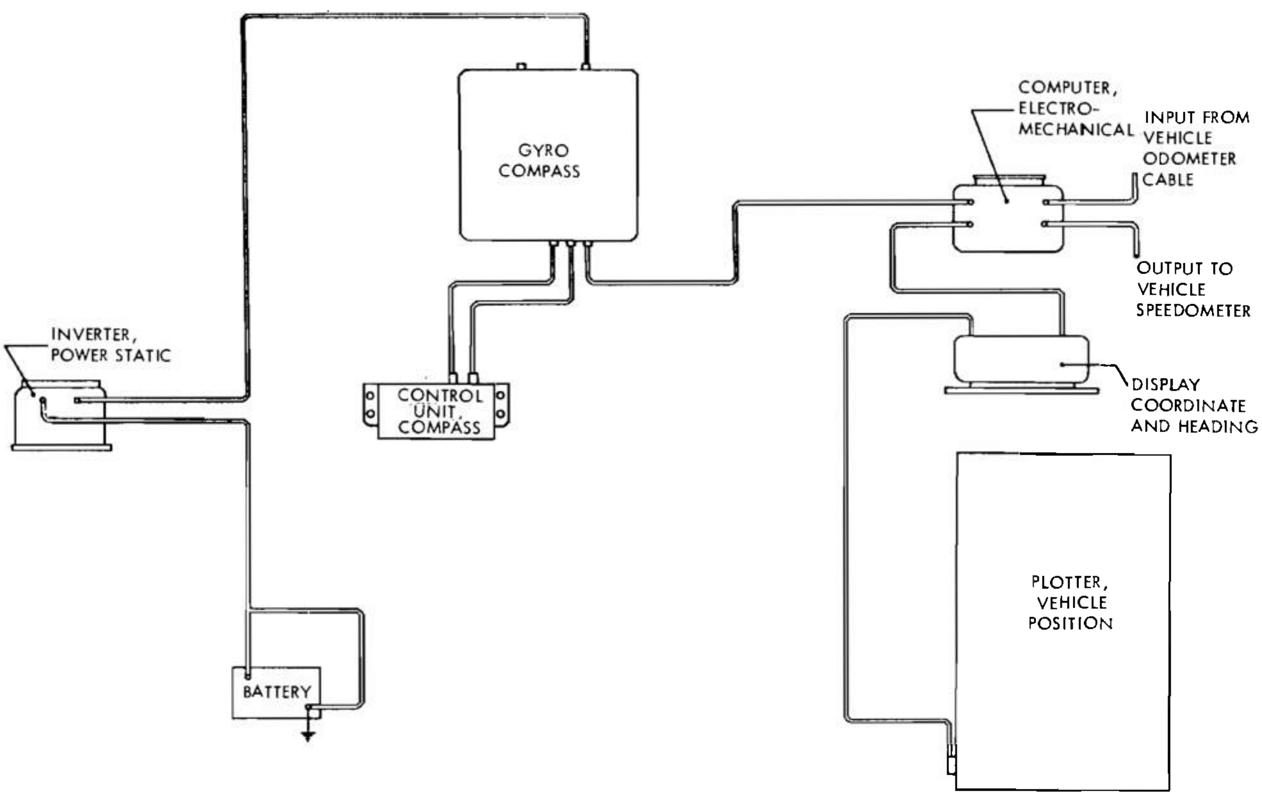

Figure 19-6. GAN Land Navigation System, Interconnection Diagram

19-8 NAVIGATION LIGHTS

Amphibious military vehicles are required to carry running lights as specified by the United States Coast Guard *Rules of the Road*[10].

These rules are minimal as applicable to small craft. Four lights are required: white on the fore and aft, red on the port, and green on the starboard. The lights must be screened so that an approaching vessel will not see the wrong color light. "Lights, Navigation, for small boats" per MS-17847 have been used successfully for this application. Four of these lights would require 1 A current at 28 VDC.

The lights must be capable of being switched from the running configuration to the anchored configuration. Usually the lights are designed as portable add-on fixtures that may be fitted to a vehicle as the need arises.

Because the rules are international in scope, and are subject to constant revision, the height of the lights, and the range and arc of visibility should be determined from the current issue of *Rules of the Road*. Particular attention is called to rule 13(b), which states that if a government so determines that a military vessel of special construction cannot comply with provisions of these rules without interfering with its military function, the government may determine and use an arrangement that is in the closest possible compliance with the rules.

19-9 FIRE SUPPRESSION SYSTEMS

Automatic fire suppression systems for military vehicles interface directly with the vehicle electrical system and utilize electrical components to detect fires and actuate suppressant valves.

These systems are intended to detect explosive fuel fires and snuff them out within fractions of a second after they begin so as to permit the safe egress of personnel. In order to meet such system requirements, the suppressant valves must operate rapidly, and the suppressant must be dispersed completely and evenly within 200 msec after the detector senses a fire. Optical, thermal, and wire grid fire detectors have been employed to sense the presence of fire or fuel cell penetrations, and explosive squib or solenoid action has been used to actuate fire suppressant cylinder valves. Usually an amplifier is required to convert the signal received from the detector to one of sufficient strength to activate the valves. Monobromotrifluormethane (Halon 1301), contained in high pressure gas cylinders, is commonly used as the suppressant.

An interim USATACOM Research and Development Requirement[11] specifies that future systems must operate when supplied with power in accordance with the requirements of MIL-STD-1275. A continuous standby current of not more than 10 mA is expected, and 18 A or more may be required for a period of at least 3 sec to power devices associated with activating the release valves.

Research continues in an effort to develop optical detectors that will not false fire, detection systems with delayed response to the penetration of a vehicle by a HEAT round, and solenoid valves with fast response so that resetting of an automatic system is not complicated by the necessity for supplying and replacing explosive squibs.

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GLOSSARY

Air Gap. Generally used to define contact separation or magnetic pole separation.

Amplidyne. A motor-generator.

Attitude. The relative orientation of a vehicle or object represented by its angles of inclination to three orthogonal reference axes.

Availability. The fraction of the total desired operating time that equipment actually is operable.

Boresight. To align the sight of a weapon with the bore.

Bourdon Tube. A pressure-sensing element consisting of a twisted or curved tube of noncircular cross section which tends to be straightened by the application of internal pressure.

Break-before-make Contacts . Break-before make contacts are contacts which interrupt one circuit before establishing another.

Capacitive Transduction. Conversion of the measurand into a change of capacitance.

Cell Capacity. The quantity of electric charge which a cell can store, expressed in ampere-hours.

Centrifugal Advance. The mechanism in an ignition distributor by which the spark is advanced or retarded as the engine speed varies.

Chatter. A sustained rapid opening and closing of contacts caused by variations in the coil current, mechanical vibration, shock, or other causes.

Confidence Level. The probability that a given statement is correct, or the chance that the value lies between two confidence limits (the confidence interval).

Contacts. Current-carrying parts of a relay or switch which engage or disengage to make or break electrical circuits.

Contact Arrangement. The combination of the different basic contact forms to make up the entire switch or relay switching structure.

Contact Bounce. The uncontrolled making and breaking of contact as contacts are moved to the closed position.

Cycle. In battery terminology, a single sequence of charge and discharge. In switch terminology, an off-on sequence.

Dark Adaptation. The process by which the eyes become more light sensitive in dim light.

dB(A). The noise sound pressure level, in decibels, registered by a standard sound level meter set on the *A* weighting scale.

Definite-purpose Relay. A readily available relay which has some electrical or mechanical feature which distinguishes it from a general-purpose relay. Types of definite-purpose relays are interlock, selector, stepping, sequence, latch-in, and time-delay.

Differential Relay. A relay having multiple windings that function when the voltage current or power difference between the windings reaches a predetermined value.

Distribution. A statistical arrangement showing the frequency of occurrence of the members of a group over a given area or throughout a space or unit of time.

Dual Ignition. Engine ignition system using two spark plugs for each cylinder so that a dual spark effect takes place during each power stroke.

Electromagnetic Transduction. Conversion of the measurand into an output induced in a conductor by a change in magnetic flux, in the absence of excitation.

Excitation. The external electrical voltage and/or current applied to a transducer for its proper operation.

General-purpose Relay. A readily available relay that has design, construction, operational characteristics, and rating such that it is adaptable to a wide variety of uses.

Human Factors Engineering. The application of scientific principles concerning human physical and psychological characteristics to the design of equipment, so as to increase speed and precision of operations, provide maximum maintenance efficiency, reduce fatigue, and simplify operations.

Ignition Advance. Refers to the spark timing advance produced by the distributor in accordance with engine speed and intake manifold vacuum.

Impulse Noise. Nonperiodic variation in atmospheric pressure which may be described completely by its pressure vs time history. It has a positive pressure envelope duration of less than 1 sec and a peak to root-mean-square value greater than 10 dB.

Inductive Transduction. Conversion of the measurand into a change of the self-inductance of a single coil.

Interlock Relay. An interlock relay is a relay composed of two or more coils with their armatures and associated contacts so arranged that the freedom of one armature to move or its coil to be energized is dependent upon the position of the other armature.

Latch-in Relay. A relay having contacts that lock in either the energized or de-energized position until reset either manually or electrically.

Maintainability. The probability of completing a maintenance action within a specified period of time.

Make-before-break Contacts. Make-before-break contacts are double-throw contacts so arranged that the moving contact establishes a new circuit before disrupting the old one.

Measurand. A physical quantity, property, or condition which is measured.

Mil. A unit of angular measurement used in artillery and equal to 1/6400 of 360 deg.

Mutual Induction. Induction associated with more than one circuit, as two coils, one of which induces current in the other as the current in the first changes.

Normal Position. The normal position is the usual de-energized position, open or closed, of contacts due to spring tension or gravity.

Octave Band Sound Pressure Levels. The noise sound pressure level, in decibels, at the center frequencies of a continuous series of octave bands across the sound spectrum. The American National Standards (ANSI S1.6 1960) preferred center frequencies are 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 Hz.

Particulate Radiation. Emission of small particles of matter from the unstable nucleus or unstable extranuclear electronic area.

Percentile Value. A measurement indicating the percentage of people falling at or below a particular value of measurement.

Photoconductive Transduction. Conversion of the measurand into a change in the resistance or conductivity of a semi-conductor material as a result of a change in the amount of illumination incident upon the material.

Photoemissive Transduction. Conversion of the measurand into a change in the emission of electrons due to a change in the incidence of photons on a photocathode.

Photovoltaic Transduction. Conversion of the measurand into a change in the voltage generated when a junction between certain dissimilar materials is illuminated.

Piezoelectric Transduction. Conversion of the measurand into a change in the electrostatic charge or voltage generated by certain materials when mechanically stressed.

Plunger Relay. A relay operated by energizing an electromagnetic coil that in turn operates a movable core or plunger by solenoid action.

Polarized Relay. A relay in which the operation is dependent upon the polarity of the energizing current.

Potentiometric Transduction. Conversion of the measurand into a voltage ratio by a change in the position of a movable contact on a resistance element across which excitation is applied.

Probability. The relative frequency of events in a very long series of trials or the relative distribution of a very large collection of data.

Rated Coil Current. The steady-state coil current at which a relay or solenoid is designed to operate.

Rated Coil Voltage. The coil voltage at which a relay or solenoid is designed to operate.

Rated Contact Current. The current which switch or relay contacts are designed to carry for their rated life.

Rem. A measure of the dose of any ionizing radiation to the body tissues in terms of its estimated biological effect relative to a dose of 1 roentgen of X rays.

Resistive Transduction. Conversion of the measurand into a change of resistance.

Roentgen. A unit of particulate radiation equal to the amount of radiation that produces in 1 cubic centimeter of dry air under standard conditions temperature and pressure ionization equal to 1 electrostatic unit of charge.

Secondary Cell. A cell which can be recharged hundreds to many thousands of times.

Sensing Element. That part of transducer which responds directly to the measurand.

Servo-type Transducer. A transducer in which the output of the transduction element is amplified and fed back so as to balance the forces applied to the sensing element or its displacements. The output is a function of the feedback signal.

Strain-gage Transduction. Conversion of the measurand into a change of resistance due to strain usually in two or four arms of a Wheatstone bridge (strain-gage bridge).

Thermal Relay. A thermal relay is a relay which is operated by the heating effect caused by electric current flow.

Thermoelectric Transduction. Conversion of the measurand into a change in the emf generated by a temperature difference between the junctions of two selected dissimilar materials.

Time-delay Relay. A relay in which a delayed action is purposely introduced.

Transducer. A device which provides a usable output in response to a specified measurand.

Transduction Element. The (electrical) portion of transducer in which the output originates.

Voltage Ratio. For potentiometers, the ratio of output voltage to excitation voltage, usually expressed in percent.

INDEX

D

E

F

M

N-O

P

Q

R

S

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