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XM-1 Tank EMP Susceptibility and Survivability Test Program and Plan

by Andrew A. Cuneo, Jr.

U.S. Army Electronics Research
and Development Command
Harry Diamond Laboratories
Adelphi, MD 20783

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This document describes in detail the test approach, functional tests, support requirements, safety procedures, instrumentation, simulators, and specific test procedures necessary to determine susceptibility and survivability of the XM-1 tank to a simulated nuclear electromagnetic pulse environment. The approach is designed to give high confidence level results with a test sample of one. It incorporates simulator illumination, electromagnetic scale modeling, and cable driving technology.

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1. INTRODUCTION

1.1 Scope

This document describes in detail the test approach, functional tests, support requirements, safety procedures, instrumentation, simulators, and specific procedures for the XM-1 tank susceptibility and survivability test. The approach is designed to give high confidence level results with a test sample of one. It incorporates simulator illuminations, electromagnetic scale modeling, and cable driving technology.

1.2 Test Program Purpose and Objectives

Purpose. — The purpose of this test program is to determine the susceptibility and the survivability of the full scale engineering development (FSED) model of the XM-1 to an exoatmospheric electromagnetic pulse (EMP) environment. This program is part of the XM-1 Development Testing, Phase II (DT-II), Integrated Test Program.

Objectives. — The objectives of this DT-II EMP test of the XM-1 are as follows.

a. To assure, by judicious combination of field testing and electromagnetic scale modeling, that all aspects of the exoatmospheric EMP threat have been considered.

b. To perform adequate checks on the tank subsystems to ascertain any failure occurring as a result of the EMP testing.

c. To take sufficient diagnostic data to validate Chrysler's design criteria at the box and subassembly levels.

1.3 Susceptibility and Survivability Criteria

Performance criteria for this environment can be summarized as follows:

a. The XM-1 system will incur no catastrophic component failure to any of the test EMP simulation methods.

b. No irreversible transient upset responses will occur.

c. The amount of test time devoted to a particular subsystem will be related to the Chrysler confidence improvement factor (CIF) assigned to that subsystem. Subsystems with the highest CIF's will receive the largest amount of time.

d. The performance characteristics of all critical subsystems in the tank will be determined prior to and immediately after both Army EMP Simulator Operations (AESOP) (one-half "threat" and full "threat") illuminations and the current injection of selected cables. The tank's automatic checking system will be used as well as engineering judgment of experienced personnel. The diagnostic test sets will be used if it is believed that a permanent failure has occurred.

1.4 Background

During May and June 1977, the PV-31 version of the XM-1 was tested by Chrysler at the Harry Diamond Laboratories (HDL) Woodbridge Research Facility (WRF). The results of that test have been reported.[1] Those results have been reviewed with respect to technical accuracy and adequacy to meet the stated conclusions.

In addition, the results of the Chrysler test on the PV-31 have been evaluated in the light of its being integrated into the test of the FV-4 version of the XM-1. Every effort has been made to minimize new test data requirements by using the results of the 1977 DT-I test.

[1] *EMP Test Data Reduction and Analysis for the PV-31 Vehicle, Chrysler Sterling Defense Division, Sterling Heights, MI (July 1977).*

1.5 System Description

The XM-1 system is a main battle tank weapon operated by a four-person crew consisting of the commander, the gunner, the loader, and the driver The main weapon is a 105-mm cannon mounted on a 360-deg rotational turret A caliber 0.50 machinegun is mounted coaxially with the main gun The commander's weapon station also is equipped with a caliber 0.50 machinegun mounted externally on the turret roof. The loader's weapon station is equipped with three pintle mounts to accommodate a 7.62-mm machinegun.

The XM-1 system weighs 58 tons and is powered by an electronically controlled AGT-1500 turbine engine with an X1100-3 hydrokinetic transmission

Primary electrical power is provided by four 12-V batteries arranged in a series parallel network to provide 24 V for the system The battery-charging network consists of an oil-cooled alternator and a solid state regulator

Electrical power is distributed through a two-wire-isolated return, electrical system A separate power bus is maintained for isolation of sensitive control circuits The power ground wire is routed with the corresponding hot wire in a twisted pair for electromagnetic compatibility (EMC) control. Electromagnetic interference (EMI) shielding is used on cable harnesses and electrical equipment enclosures

Communication is provided by a Government-furnished AN/VRC 12 radio and an AN/VIC-1 intercommunication set with provisions for a voice security unit

The fire control network comprises a solid state ballistic computer, a crosswind sensor, line-of-sight data link transfer, a laser rangefinder, main gun and turret drive stabilization, thermal night vision, and gunner's primary sights

The XM-1 to be tested is designated the FV-4. Eighty percent of the electronics in this tank are the same as in the PV-31 tested at WRF for Chrysler by HDL in May and June 1977 Some physical changes have been made with regard to locations of certain subsystems and associated electronics. These have necessitated the rearrangement of certain cable routings In addition, the following subsystems have been added to the FV-4:

a. Night vision system
b. Fuel management system
c. Grenade launcher system
d. Radio communication using external wire

2. TEST APPROACH

2.1 General

The AESOP and Repetitive Electromagnetic Pulse Simulator (REPS) at WRF can achieve uniform peak threat level fields only over a relatively small test volume, for a very limited range of angles of incidence, and for principally horizontal polarization of the electric field vector. The Vertical EMP Simulator (VEMPS) produces a non-threat-related vertically polarized waveform.

The concept of using cable driving technology to drive above threat level currents on the outer sheaths of interior cables allows a high confidence level test to be performed. The overstressing of the system allows one to account for the statistical variations in semiconductor component damage parameters as well as for the illumination limitations of the simulators.

The approach to be used is basically the following

a Scale modeling will be used to help determine worst case coupling orientations

b The FV-4 will be illuminated with sub-threat-level horizontally polarized fields in the REPS or the AESOP and vertically polarized fields in the VEMPS to determine bulk current waveforms on interior cabling

c Critical circuits, harnessing, and wiring will be identified, and their responses will be recorded

d The FV 4 will be subjected to peak threat level fields at the AESOP for the worst case horizontal polarization coupling orientation at one angle of incidence.

e Selected cables will be injected with threat-level and above-threat-level current waveforms by using cable driving technology to validate the design criteria at the box and subassembly levels. The waveforms will replicate the external field induced waveforms.

f System upset and damage will be determined.

2.2 Test Data Requirements

Requirements for test data are these

a To provide sufficient diagnostic data (current and voltage time domain waveforms) so that (1) if upset or damage occurs, it can be determined what happened and why it happened with respect to the design of the system, (2) a system response data base is available for performing any subsequent hardening analysis in a cost-effective manner, and (3) a basis is available for evaluating any future design changes in a cost-effective manner.

b To assure, by judicious combination of field testing, analytical calculations, and electromagnetic scale modeling that all aspects of the exoatmospheric EMP threat have been considered.

c To perform adequate checks on the XM-1 subsystems to ascertain any failure occurring as a result of the EMP testing

2.3 Overall Program Activity Flow

Figure 1 (p. 8) expresses the relationship between the essential activities required to determine the susceptibility and the survivability of the FSED model of the XM-1 to an exoatmospheric EMP environment. This procedure in general uses existing EMP test facilities and state-of-the-art experimental tools to provide a high confidence level assessment of system vulnerability.

2.3.1 Review of Previous Work

As a result of the PV-31 test at WRF, Chrysler generated Revised EMP Protection Guidelines for FSED XM-1 Tanks.[2] These new guidelines were expected to allow more exact protection design and also to reduce hardening cost. Chrysler stated that the results of the EMP test indicated that a number of the PV-31 assumptions for hardening were too pessimistic, but that the results of the test could be used with other data to define new, more realistic guidelines.

The data include input impedance measurements for PV-31 electronic subsystems and also actual EMP test data for semiconductor devices. The unknown factors listed by Chrysler were the following:

a Not all wires or cable sheath currents have been measured for EMP induced currents.

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[2] *V. Formanek, Design Data Sheet, Chrysler Sterling Defense Division, Sterling Heights, MI (8 July 1977).*

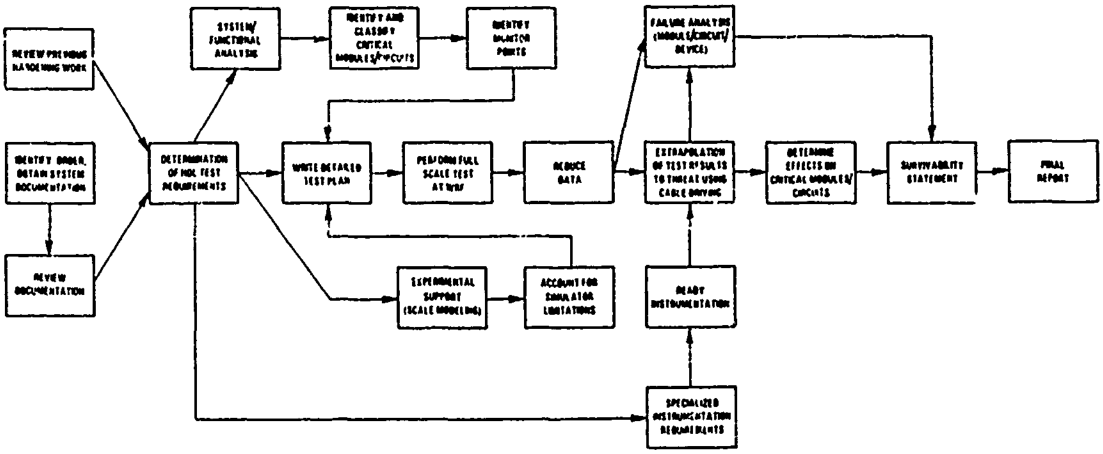

Figure 1. Method to determine susceptibility of XM-1 tank to EMP.

b. The EMP test data have not been obtained for all angles of incidence of the EMP.

c. The systems and the cable routing for the FV-4 will not be identical to those of the PV-31, the tank used for the EMP tests.

d. No EMP damage data exist for many of the interface semiconductor devices to be used in the FV-4 systems.

Chrysler makes the following simplifying assumptions:

a. Although complete information is not available for the exact systems to be used in the FV-4, it may be assumed that (1) the peak cable sheath currents will not be greater for the FV-4 than for the PV-31, but will just occur on different cables, (2) the worst case cable shielding will be the same for the FV-4 as for the PV-31, and (3) in the worst case, variation of angle of incidence will not change the peak induced currents, but will merely move those peaks to other wires or cables.

b. Although specific EMP damage data are not available for all subsystems, there are enough data to formulate worst case EMP failure levels for all devices by using either data for that device type or worst case data for the family of which the device is a member.

c. The EMP ring frequency and ring down time will remain the same for the FV-4 as for the PV-31.

The data resulting from the May and June 1977 EMP test on the PV-31 were reduced by Chrysler and the IIT Research Institute (IITRI) and presented in a test report.[1] Presented in table 1 are worst case values from the data obtained and not necessarily the absolute worst case coupling conditions for the tank.

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[1] *EMP Test Data Reduction and Analysis for the PV-31 Vehicle, Chrysler Sterling Defense Division, Sterling Heights, MI (July 1977).*

TABLE 1. EMP DESIGN GUIDELINES FOR FV-4 TANK

Parameter	Worst case measured value
Cable sheath current	10.46 A
Tank attenuation	40 dB
Cable shielding (sheath/bulk)	−17 8 dB
Worst case division of bulk current	1/2 96
Wire currents	0 242 A
Decay time of current pulses	0.5 μs
Ring frequency	20 MHz

Note: Values to be used for FV-4 EMP design

$(I_{sc})_{max} = (10\ 46)(1/2\ 96)(-17\ 8\ dB) = 0\ 455\ A$,

$(V_{oc})_{max} = (0\ 455)(2.96)(16\ \Omega) = 21.8\ V$,

where cable $Z_o = 16\ \Omega$,

$E_{max} = \left[(I_{sc})(V_{oc})/2\right]\ (0\ 5\ \mu s) = 2\ 48\ \mu J$.

These values are obtained in the following manner. To find the worst case wire currents (I_{SC}), the worst case bulk core current is found by multiplying the worst case cable sheath current (10 46 A) by the worst case cable shielding (−17 8 dB) as found by the EMP tests. The worst case wire current is found by multiplying the bulk core current by 1/2 96, which is the worst case ratio between the bulk core current and an individual wire current measured during the EMP tests The Z_0 (characteristic impedance) of 16 for the cable is an estimate for multiconductor cables of the type used in the PV-31. The worst case open circuit voltage $(V_{oc})_{max}$ is obtained by multiplying the worst case bulk core current by the Z_0 of the cable The maximum available energy is found by multiplying V_{OC} and I_{SC} together, dividing this result by two, and multiplying by a representative time for the current pulse as measured. The ring frequency of 20 MHz was chosen since this frequency appeared in approximately 80 percent of the measurements and was the frequency of the highest values of induced current in the tests.

Chrysler modified the design guidelines presented in table 1 to account for the fact that the experimental data were obtained for only a limited number of cables and angles of incidence. Chrysler believed that the best way to ensure the EMP hardness of the XM-1 would be to increase the design hardness level of each system within the tank as a function of the importance of each to the tank's mission.

Table 2 ranks the XM-1 system as a function of importance to the mission The class I system is the most critical to mission performance, and the class IV system is the least important. Each of the systems ranked in table 2 is assigned a CIF that will increase the hardness of the system. The CIF is applied to the energy delivered to the interface semiconductor device and not to the total energy available. The choice of the magnitude of the CIF's is based on the DNA EMP Awareness Course Notes.[3] A CIF of 20 dB was chosen for class I systems to account for various factors that may not be calculated accurately and to allow for the large variation of device damage constants from vendor to vendor and lot to lot This 20-dB CIF is reduced by Chrysler for the class II through IV systems for the following reasons:

a The EMP coupling data used in system design are based on real system data so that some of the unknown factors have been reduced.

b. The analysis depends upon estimates of EMP coupling that tend to be pessimistic in most instances considered

[3]*DNA EMP Awareness Course Notes, IIT Research Institute, Chicago, IL, Contract with Defense Nuclear Agency, Washington, DC, DNA 2772T (1971), 98.*

c. Not all the systems are required to be functional after exposure to EMP threats.

TABLE 2. RANKING OF XM-1 MISSION CRITICAL SYSTEMS

Class	System
I	Personnel safety
	Fire extinguisher
II	Requirement for minimum combat performances
	Engine controls
	Primary weapons
	Night vision
	Computer electronics
	Laser rangefinder
	Line-of-sight stabilization
	Gunner's primary sight
	Alternator and regulator
III	Secondary weapons
	Commander's weapon station
IV	Non-mission-critical
	Crosswind sensor
	Cant sensor
	Fuel sensor
	Malfunction indicator

Table 3 gives the CIF's for all classifications Chrysler adds a caution. It is envisioned that cables that penetrate the tank may be routed in cable harnesses that carry signals between systems When this routing exists, the protected inputs from those cables must be protected with the next highest CIF. This protection is required because of cross coupling between the wires of the bundle that connect to the sensitive system and the cable that penetrates the hull of the tank

TABLE 3. CONFIDENCE IMPROVEMENT FACTORS FOR XM-1 TANK SYSTEMS

Class	Confidence improvement factor (dB)
I	20
II	16
III	10
IV	6

Although susceptibility data for all the semiconductors used in the XM-1 do not exist, enough data on similar devices and devices of the genera are available so that device susceptibility can be estimated according to Chrysler.

Table 4 presents EMP damage data that will be used for FV-4 EMP design These data[4] represent the worst case damage for each of the generic device types for a pulse with a width of 0.5 μs, which represents the pulse width of the EMP induced waveforms within the tank.

2.3.2 Electromagnetic Scale Modeling

Objectives of modeling.—The objectives of the scale modeling effort were to determine how both the exterior surface currents and the interior cable currents of the XM-1 changed as a function of angle of incidence of the EMP and to investigate the ~20 MHz ringing in both specific surface current measurements and most of the interior cable current measurements on the PV-31.

Experimental results.—A 20.1 scale model of the XM-1 was built of brass. The model has a removable turret and easily allows for cutting slots in its skin for monitoring surface current using a Tektronix CT-1 current probe (fig. 2)

[4]*SUPER SAP 2 Experimental Data Bank, Air Force Weapons Laboratory, Kirtland Air Force Base, NM [n.d.].*

TABLE 4. EMP ENERGY LIMITS FOR VARIOUS INTERFACE DEVICES

Device	Input (receiver)	Output (driver)
Line receiver or driver	50 W peak (0.5 μs), 25 μJ	50 W peak (0.5 μs), 25 μJ
Transistor transistor logic	1.53 W peak (0.5 μs), 0.763 μJ	0.42 W peak (0.5 μs), 0.21 μJ
Bipolar operational amplifier	3 W peak (0.5 μs), 1.5 μJ	12 W peak (0.5 μs), 6.0 μJ
Complementary metal oxide semiconductor	Always protect to overvoltage	0.7 W peak (0.5 μs), 0.35 μJ
Discrete	To be determined for each device from relevant data	To be determined for each device from relevant data

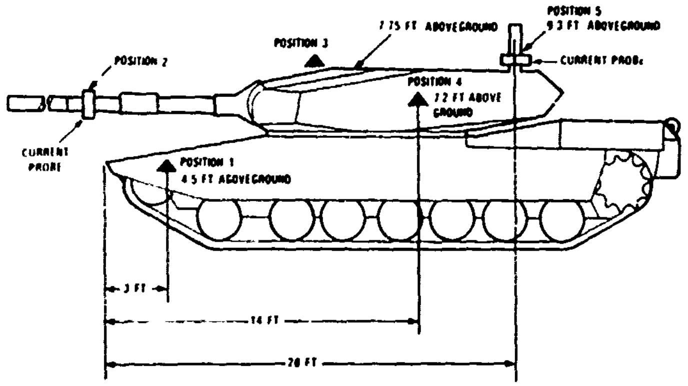


Figure 2. Surface current monitor points on FV-4 version of XM-1 tank.

Shown in figures 3 and 4 are peak turret surface current (refer to fig 2, position 4) plotted as a function of the angle of incidence for broadside illumination In figure 3, the turret was electrically isolated from the hull by masking tape; in figure 4, the turret and the hull were making electrical contact. Comparison is made to a sine wave functional dependence with elevation angle

Figure 5 shows the hull surface current (refer to fig 1, position 1) as a function of angle of incidence with a comparison to a sine wave dependence Figure 6 shows the current on a wire in the hull parallel to the width dimension of the tank. The wire is soldered to the walls Again, a comparison to a sine wave dependence is shown.

In the PV-31 test, a ring frequency of ~20 MHz was seen in some of the surface current measurements This frequency was seen also in the data taken on the hull harnesses and associated individual wires. It was deemed important to (1) verify that indeed this frequency was actually due to a tank resonance and not to perhaps some instrumentation problem and (2) understand its nature

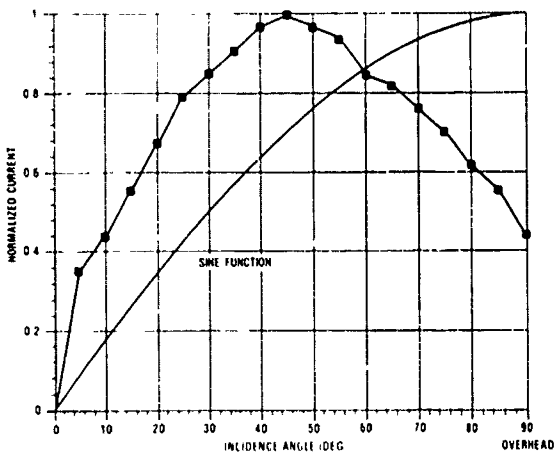


Figure 3. FV-4 turret surface current (position 4) with turret isolated electrically from hull.

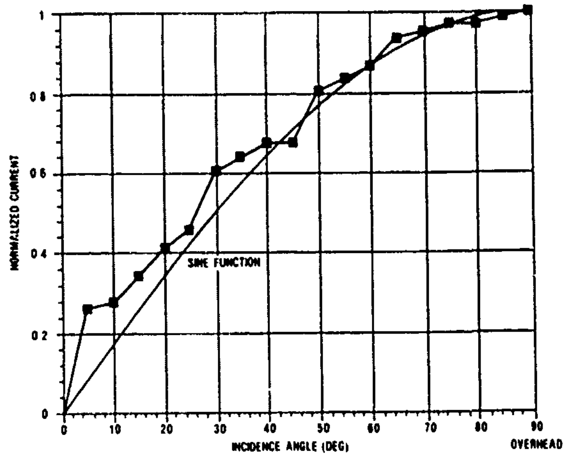


Figure 5. FV-4 hull surface current (position 1).

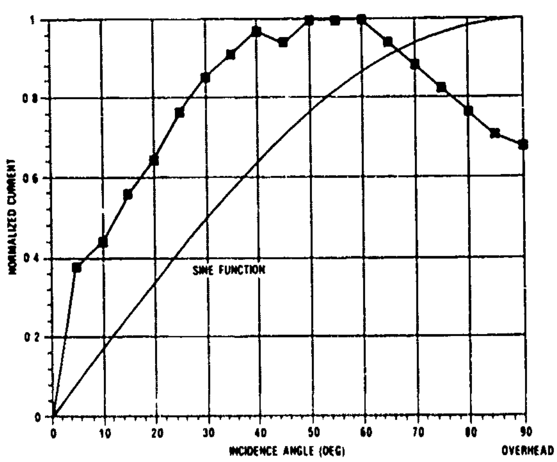


Figure 4. FV-4 turret surface current (position 4) with turret making electrical contact with hull.

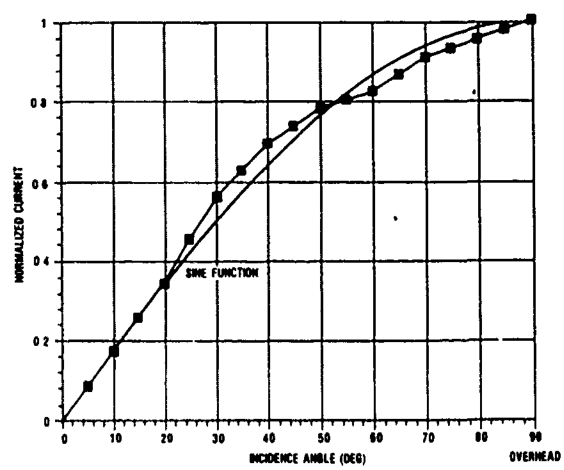


Figure 6. Current on wire in FV-4 hull (parallel to tank width); data points are every 10 deg, and other points are extrapolated.

Shown in figure 7 is the effect of electrically connecting the turret to the hull on the turret current. The ringing is eliminated when the turret and the hull become one metallic body Figure 8 shows the current with the turret isolated from the hull.

Figures 9 to 11 show the effect of the gun barrel on the hull surface current. The presence of the gun barrel overhead causes the ringing to be seen.

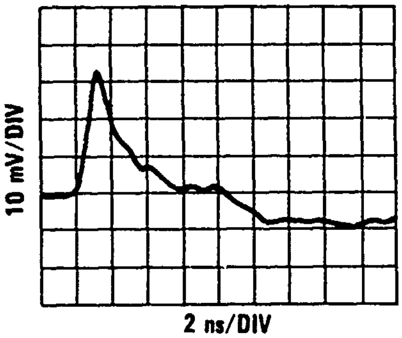


Figure 7. FV-4 turret skin current with turret electrically connected to hull; angle of incidence is 45 deg.

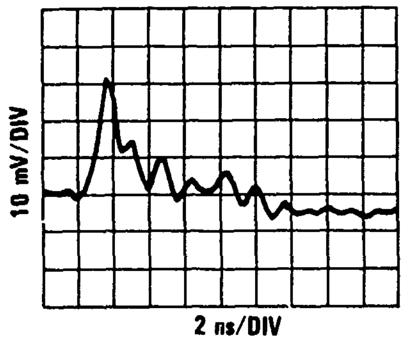


Figure 8. FV-4 turret skin current with turret electrically isolated from hull; angle of incidence is 45 deg.

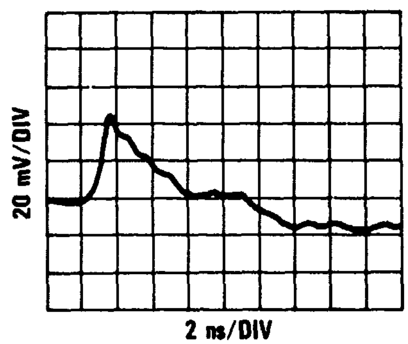


Figure 9. FV-4 hull current with turret not isolated from hull; angle of incidence is 45 deg; gun barrel is not overhead of slot.

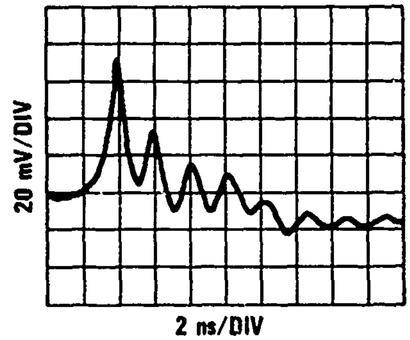


Figure 10. FV-4 hull current with turret not isolated from hull; angle of incidence is 45 deg; gun barrel is overhead of slot.

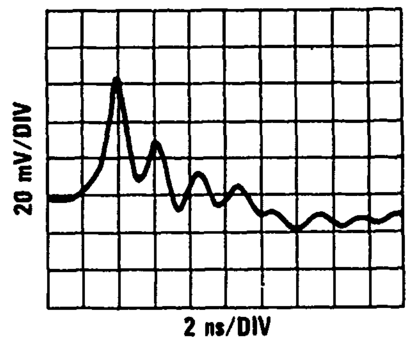


Figure 11. FV-4 hull current with turret isolated from hull; angle of incidence is 45 deg; gun barrel is overhead of slot

Conclusions.—These conclusions can be drawn from the FV-4 scale model current measurements:

a. The response of the hull surface current (position 1) is essentially sinusoidal with the angle of elevation.

b. The response of the turret surface current (position 4) peaks at 45 deg when the turret is isolated from the hull. This response is somewhat distorted when the turret and the hull make electrical contact.

c. The response of the wire (simulated cable) in the hull is essentially sinusoidal with the angle of elevation.

d. The ringing seen in the turret surface current can be eliminated by electrically connecting the turret to the hull at the turret-hull interface

e. The ringing seen in the hull surface current appears to be due to the proximity of position 1 to the gun barrel. No ringing is seen in the hull data for other positions.

2.3.3 Full Scale Testing

Full scale testing of the XM-1 will take place at WRF. Use will be made of the horizontally polarized REPS to obtain low level diagnostic data. Specifically, the outer sheath currents flowing on the harnesses will be measured. The vertically polarized VEMPS will be used to measure harness sheath currents.

The AESOP will be used for bulk core current and circuit level voltage and current measurements. It will be used for functional testing at one-half threat and full threat *

2.3.4 Measurements

The following kinds of measurements using state-of-the-art instrumentation (see app A) will be made at several levels of the system including critical subsystems, harnessing, and communication system interfaces (app B diagrams specific measurement locations):

a. Electric and magnetic field components where necessary to adequately define the incident, scattered, and penetrating electromagnetic fields.

b. Bulk shield current on cables entering subsystems

c. Total wire currents (cores) on cables entering subsystems

d. Selected individual wire currents

e. Selected differential voltage measurements

2.3.5 Extrapolation of Test Results to Threat

Because of the complex interaction of an incident transient electromagnetic wave with a metal object resting on or near the ground, it is not readily obvious how the currents on the surface vary as a function of the angle of incidence Of even more complexity is the coupling through apertures on the body as a function of angle of incidence.

These questions are of practical interest in EMP testing since all angles of incidence are not available for illuminating the test object because of inherent simulator limitations. Consequently, a knowledge of how the induced currents vary with incidence angle is important so that the measured data can be extrapolated to worst case threat with reasonable confidence For this knowledge, the scale modeling technology is useful. The formula for computing the worst case threat is

$$I_T(t) = KI(t)$$

where

$I_T(t)$ = the current at the same point scaled up to the worst case threat,

*Because of the inability to achieve all angles of incidence, full threat cannot be obtained.

K = a number determined from the scale modeling results (the ratio of the peak current at the worst case angle to the peak current at the test angle),

I(t) = a current induced in the system, from a simulator illumination at 50 kV/m, at the test angle

For the XM-1, the extrapolation to and above threat will be attained by using cable driving technology. Specifically, replicas of the field measured waveforms will be inductively induced onto the outer shield of selected internal harnesses.

In effect, the system will be stressed one or more subsystems at a time. Conceptually, if one is able to drive all input cable sheaths to a particular subsystem with replicas of waveforms (the same current and charge distribution) as seen by those cables when illuminated by an EMP, then as far as this subsystem is concerned it cannot distinguish between an EMP and an artifically induced current situation Then one can think of testing a complex system by inducing a threat or an above-threat situation on an individual subsystem while the total system remains functionally intact. Functional integrity can easily be checked before and after testing.

Subsystems connected to the same harness as the subsystem under test can potentially see the threat or above-threat waveforms due to direct coupling. These subsystems should be monitored during testing. Subsystems connected to other harnesses will be loosely coupled to the drivers Consequently, they will see sub-threat-level pulses for all but perhaps the highest driver levels. A more detailed discussion of in-situ harness injection is beyond the scope of this report This subject will be covered in some length in the final report.

2.3.6 Survivability Statement

In cooperation with the U.S. Army Test and Evaluation Command (TECOM), HDL will prepare an EMP survivability statement for the XM-1 This statement will be based on the ability of the system to meet all of its operational requirements after being subjected to a simulated EMP.

Should the system fail to meet all operational requirements, the specific vulnerabilities, reaction times, and losses of system capability will be identified. All functional test results, pertinent simulation data, and test diagnostic data will be provided to facilitate EMP hardening program decisions by the appropriate Government agencies.

2.3.7 Analysis

Failure analysis.—If during the conduct of the test a failure occurs, it will be Chrysler's responsibility to isolate the problem so that the test may be continued with a minimum of delay. When the failed components have been identified, HDL will analyze them to determine if the failure is related to EMP.

EMP data analysis.—Using diagnostic data from the FV-4 or the PV-31 test, HDL will isolate the cause of the failure

2.3.8 Final Report

The final test report will contain the following items:

a Pertinent diagnostic test data scaled up to threat

b Documentation of all upsets and failures

c. Failure analysis if required

d EMP data analysis if required to isolate causes of failure

e. Field monitor hard copies of EMP waveforms

f Detailed description of each test setup

g. Detailed description of all checks on the XM-1 system and its subsystems

h Recordings of all inspections and significant check data

3. SYSTEM FUNCTIONAL TESTS

System functional integrity will be tested during the following phases of the overall test:

a. Illumination of the tank to one-half and full threat level fields at the AESOP

b Bulk sheath current injection of selected cables in the tank, minimum level of excitation one-half threat level (bulk sheath current as determined from simulator illumination), maximum level of excitation 10 times threat, overstressing levels to be determined by the ranking of the mission critical system

The tank will be in a fully operational mode

Critical subsystems will be checked for performance both before and after stressing to determine if performance degraded permanently. For these tests, degradation is defined as the failure of any subsystem to meet minimum operational specifications. At each level (for both AESOP illumination and current injection), the XM-1 will be subjected to a minimum of 10 pulses before the system is checked out This subjection is to establish confidence in the system hardness. If no degradation in performance is observed, the XM-1 will be subjected to the next highest level, and the above procedures will be repeated If performance degradation is observed for any subsystem, the fault will be isolated to individual circuit boards. The defective circuit board will be replaced with known good boards if these are available, and checkout procedures will be followed for the subsystem that failed. When the subsystem in question is functioning properly, the XM-1 will be subjected to another 10 pulses, after which checkout procedures must be repeated. If a failure occurs again, it will be isolated to an individual circuit board. Whether failure recurs or not, the XM-1 will be subjected to the next highest level to determine the survivability of the remaining subsystems. These procedures will be followed all the way up to the maximum level. All upsets and failures will be documented appropriately.

4. TEST SUPPORT REQUIRED BY HDL

The following support is required by HDL to conduct the EMP test on the XM-1:

a Engineering support from Chrysler to isolate malfunctions

b Trained technicians to test functioning

c Driver-mechanics

5. SAFETY

5.1 General

The XM-1 Tank Program FSED/PEP Phase, Safety Statement[5] will be in effect throughout EMP testing.

[5]*XM-1 Tank Program FSED/PEP Phase, Safety Statement, Chrysler Sterling Defense Division, Sterling Heights, MI, X-COOF-1 (12 January 1978).*

5.2 Test Safety Responsibility

One Chrysler engineer and one HDL engineer will be designated as the responsible safety representatives throughout the EMP tests It will be the joint responsibility of the two safety representatives to do as follows.

a Inspect the test vehicle, its instrumentation, and the test facility to determine readiness for testing

b During operation of the tank, let no one enter the tank caution area or mount the tank without consent of the tank crew. During EMP tests, keep this area clear of personnel at all times.

c "Safe" the laser rangefinder during all testing, except when conducting laser rangefinder system upset mode tests. Limit laser rangefinder firings to only those required for upset mode tests. Enforce all laser rangefinder range safety procedures* during any laser firings Ensure that protective goggles are worn by all test participants (except those in the tank) and observers during laser firings.

d See that no live ammunition is on or in the tank during EMP testing

e. Ensure that Chrysler and other personnel not required in the tank during EMP tests vacate the immediate area

f Brief all test participants on safety regulations and precautions before the testing begins and also at the beginning of each subtest.

g. Ensure that appropriate communication channels are established between key test operators (at least among the overall test director, the vehicle operator, and the facility operator) before testing begins. Establish an emergency backup communication system

h. Monitor the safety aspect of all EMP testing, and strictly enforce both the HDL Safety Procedures for Simulator Site Users and the XM-1 Automotive Test Rig and Pilot Vehicle (PV-31) Operating Instructions

i Critique each subtest to identify any unexpected problem areas or safety violations, and include any necessary remedial actions in the briefing for the next subtest.

5.3 Test Operations

Over and above the safety precautions and the requirements described, the following additional safety precautions will be enforced throughout the conduct of all EMP testing

a. The perimeter of the operating tank, described as 3 ft (0.9 m) beyond the end of the main gun tube throughout its 360-deg excursion, will be roped off to define the operating tank caution area

b During operation of the tank, no one will enter the tank caution area or mount the tank without consent of the tank crew. During EMP tests, this area will be kept clear of personnel at all times.

c The laser rangefinder will be safed during all testing, except when the laser rangefinder system upset mode is being tested Laser rangefinder firings will be limited only to those required for upset mode tests All laser rangefinder range safety procedures (XM-1 Automotive Test Rig and Pilot

*XM-1 Automotive Test Rig and Pilot Vehicle (PV-31) Operating Instructions—Appendix A, Electromagnetic Pulse Test Plan (PV-31), Chrysler Corp., Sterling Heights, MI, Report XP7411-2 (5 April 1977).

Vehicle (PV-31) Operating Instructions*) will be enforced during any laser firings Protective goggles will be worn by all test participants (except those in the tank) and observers during laser firings.

d. No live ammunition will be on or in the tank during EMP testing

e. Chrysler and other personnel not required in the tank during EMP tests will vacate the immediate area.

**XM-1 Automotive Test Rig and Pilot Vehicle (PV-31) Operating Instructions—Appendix A, Electromagnetic Pulse Test Plan (PV-31), Chrysler Corp., Sterling Heights, MI, Report XP7411-2 (5 April 1977)*

APPENDIX A.—INSTRUMENTATION FOR MEASURING ELECTROMAGNETIC PULSE

CONTENTS

FIGURE

TABLE

The basic schematic block diagram (fig A-1) describes the elements in any standard electromagnetic pulse (EMP) instrumentation system.

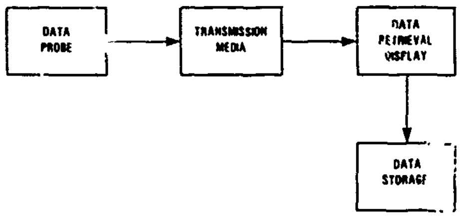


Figure A-1. Instrumentation for measuring EMP related signals.

In the conventional measurement, a single wire current probe might represent the data acquision element; a coaxial cable, the transmission media; and a single channel oscilloscope and camera, the data display Data storage would be the project engineer's notebook.

The XM-1 tank Development Test, Phase II (DT-II), test will call upon a state-of-the-art instrumentation system, but the same basic block diagram still applies.

A-1. DATA PROBE

A wide range of probes is available for EMP measurements, and probe selection depends on the measurement type to be performed. These are the basic probe types.

a. Single ended voltage
b Differential voltage
c Single wire current
d Bulk cable current
e Electric field
f Magnetic field
g Surface current

A-2. TRANSMISSION MEDIA

The present state of the art provides three different types of transmission media for EMP applications:

a Multiple shielded cable
b. Optical data links
c Dielectric waveguide links

Each of the three types can transmit signals over distances to about 100 m ranging from 100 kHz to 200 MHz. Optical data links and dielectric waveguide links provide dielectric isolation between the sensor and the display systems This provision is advantageous for the simulated hostile EMP environment. Included are descriptions of the transmission systems.

A 150-MHz fiber optic link has been developed by the Harry Diamond Laboratories (HDL) to transmit wide bandwidth EMP response data over a nonconducting path This link consists of a self-contained battery-operated transmitter, a low-loss low-dispersion 100-m fiber optic cable, and a receiver

This fiber optic system has been designed so that the transmitter responds to commands from the receiver. Power on, power off, remote attenuator commands, and internal calibration commands are selected from the receiver end and are transmitted to the remote transmitter via a separate fiber optic cable. Transmitter electrical status (power on and off, attenuator state, and calibrator) may be interrogated from the receiver.

The overall system has the electrical characteristics identified in table A-1. Tests are made with a 3-m fiber optic cable. Rise time and bandwidth are slightly reduced with longer fiber optic runs.

TABLE A-1. TEST DATA FOR LIGHT EMITTING DIODE SIGNAL LINK

Parameter	Data
System No	21
Peak pulse (20-ns width) for 1-dB output compression	±34 mV
Output for ±34 mVp-p sine input, 100 MHz ± 350 mV	
Detector voltage	285 V
Detector current	150 mA
Rise time (10 to 90%) at −2 dB from 1-dB compression level	2.4 ns
Bandwidth upper limit (3 dB down) for sine or peak to peak value 3 dB below 1 dB compression level for pulses	155 MHz
Dynamic range for 100-MHz sine	33 dB
Light emitting diode bias	1.08 V across 20 Ω emitter resistor
Calibrator level	±10 mV referenced to 50-Ω unbalanced input

A-3. DATA ACQUISITION

The modern replacement for the oscilloscope and camera arrangement is the transient digitizer. The signal arriving from the transmission media is routed to one or more Tektronix R7912 transient digitizers. Multiple digitizers are required since the input signal for analysis must be digitized into more coordinate pairs than any one digitizer can handle. What is conventionally done is to allow transient digitizer No. 1 to digitize at the faster sweep speed, such as 20 ns/division. The second digitizer is set for a slower speed, usually five times the previous sweep, or 100 ns/division. The digital outputs from each transient digitizer can be merged via computer software in the Tektronix CP-4165 controller to form a composite waveform. As each data shot is processed in the CP-4165 controller, the merged waveform may be displayed on the computer display terminal. A hard copy is available on request. Continuous data records that represent each data shot are stored on the CP-112 floppy disc for off-line analysis.

A-4. CALIBRATION

All test equipment that requires periodic calibration will be calibrated at the factory. The functioning of other equipment such as probes and optical data links will be checked at the beginning of each day. The primary items to be checked are gain, band-width, and common mode rejection ratio (for different voltage probes).

APPENDIX B.—TEST PROCEDURES AND MONITOR POINTS FOR SUSCEPTIBILITY ANALYSIS OF XM-1 TANK

CONTENTS

FIGURES

FIGURES (Cont'd)

TABLE

B-1. GENERAL TEST PROCEDURES

(1) For the XM-1 tank, upon starting a new set of measurements with a particular probe and fiber optic system, measure the noise Disconnect the probe from the monitor point. (If a breakout box is used, leave the probe in the box with the top fastened) Measure any pickup on the probe or the data link.

(2) Unless otherwise directed, reverse the probe for all measurements (both current and voltage).

(3) On the fastest sweep speed oscillograph, ensure that at least one division of flat baseline precedes the leading edge of the waveform

(4) Use sweep speeds of 10 and 100 ns/division to start Adjust them afterwards as necessary.

(5) Document all upsets and failures

(6) Describe each test setup in detail.

(7) Provide field monitor data to describe EMP waveforms and show repeatability

(8) Describe in detail all checks of the XM-1 system and its subsystems

(9) Record all inspections and check significant data

(10) Photograph each test configuration

B-2. HARNESS LAYOUTS AND MONITOR POINTS

The harness layout diagrams (fig. B-1 to B-19) show all critical subsystems associated with particular harnesses of interest. These diagrams are used for EMP testing to show the subsystems that will be artificially current injected Those subsystems are indicated by diagonal lines A circle with a "D" indicates a particular harness branch to be current injected The arrow indicates the orientation of a reference current probe that is used to measure the actual response to a simulated EMP

The multiport current injector can drive up to six cables simultaneously with a damped sine wave of approximately 20 MHz The output amplitude current coupled to a cable is adjustable in the approximate range of 1 to 100 A

B-3. BREAKOUT BOX PREPARATION

(1) Using the information contained in section P-2, place current and voltage probes on the proper terminals.

(2) Where there is more than one breakout box per harness, always have a box ready so that when one box is finished being used you can immediately replace it.

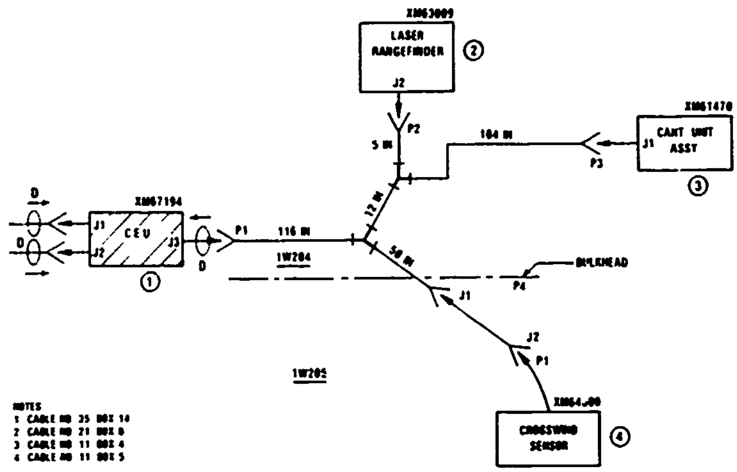


Figure B-1. Current injection of computer electronics unit (C.E.U.) of primary weapons system showing harnesses 1W204 and 1W205.

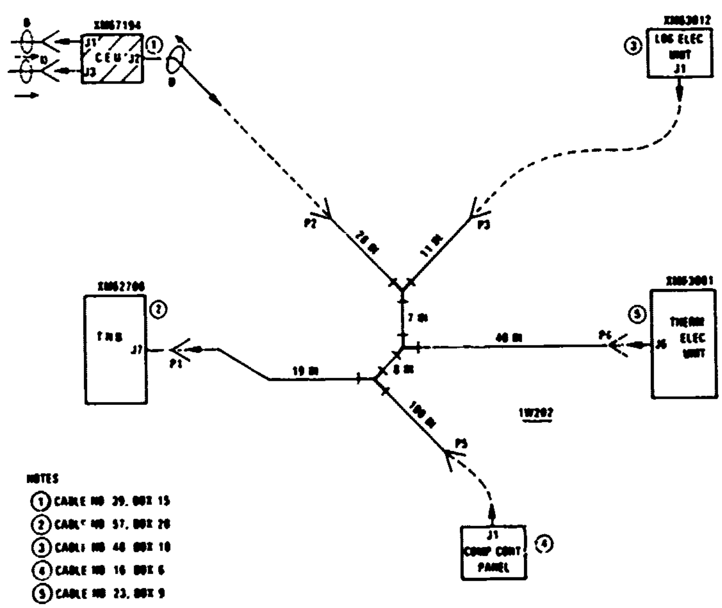


Figure B-2. Current injection of computer electronics unit (C.E.U.) of primary weapons system showing harness 1W202.

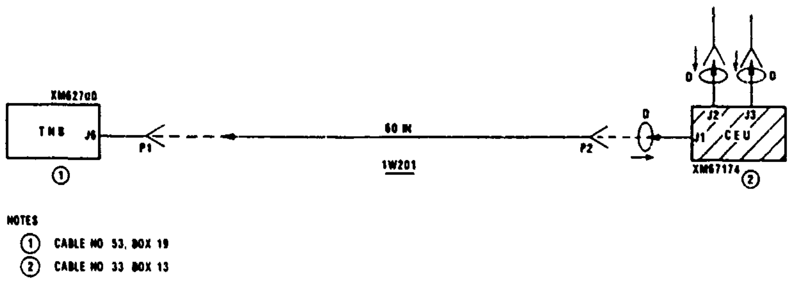


Figure B-3. Current injection of computer electronics unit (C.E.U.) of primary weapons system showing harness 1W201.

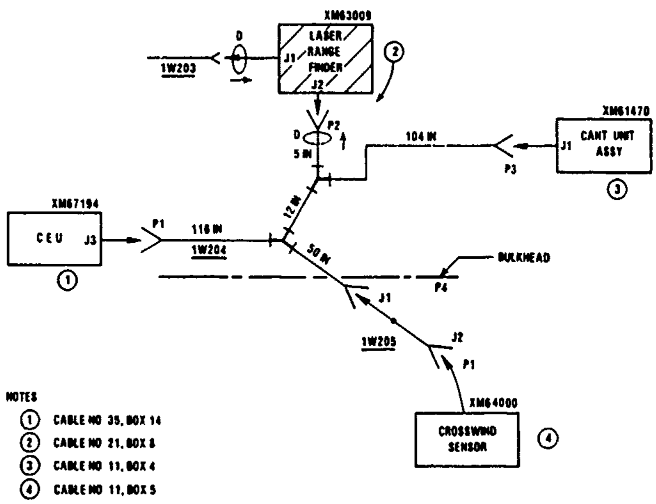


Figure B-4. Current injection of laser rangefinder of primary weapons system showing harnesses 1W204 and 1W205.

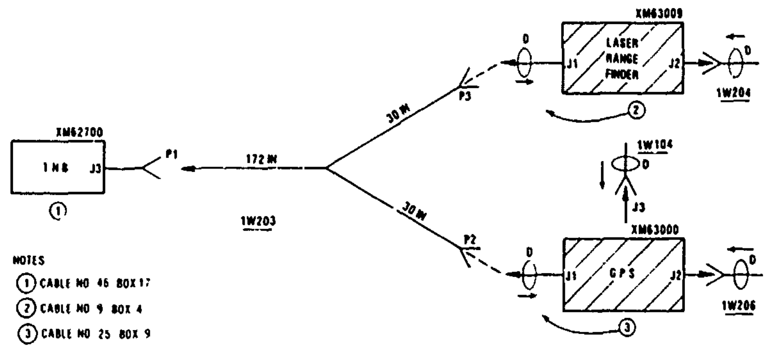


Figure B-5. Current injection of laser rangefinder of primary weapons system showing harness 1W203.

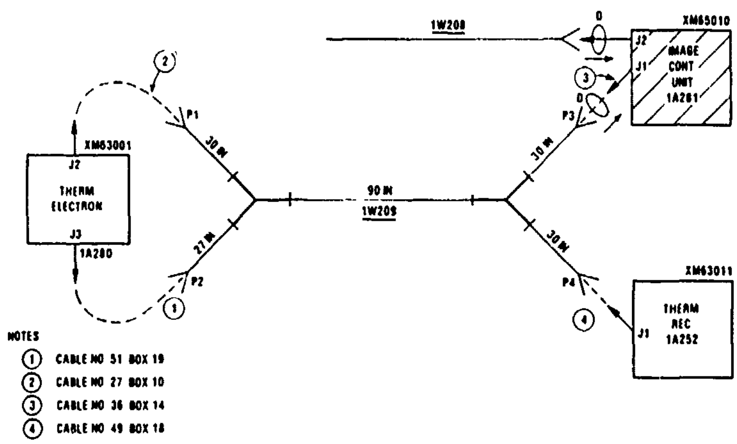


Figure B-6. Current injection of image control unit of night vision system showing harness 1W209.

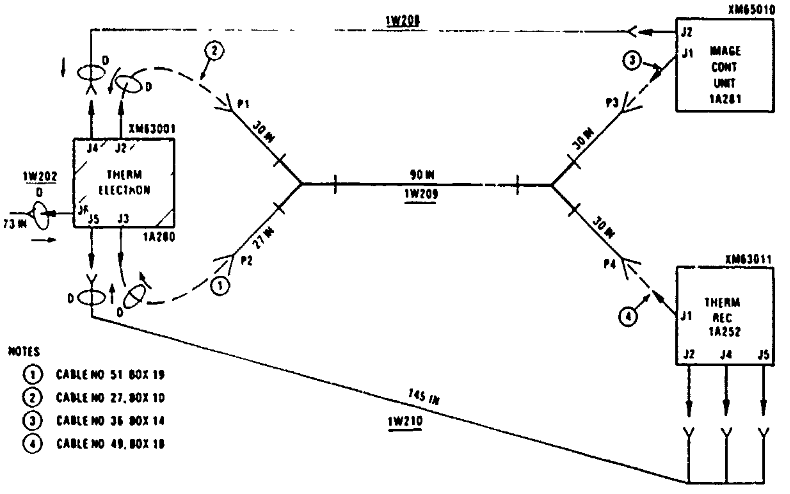


Figure B-7. Current injection of thermal electronics unit of night vision system showing harnesses 1W208, 1W209, and 1W210.

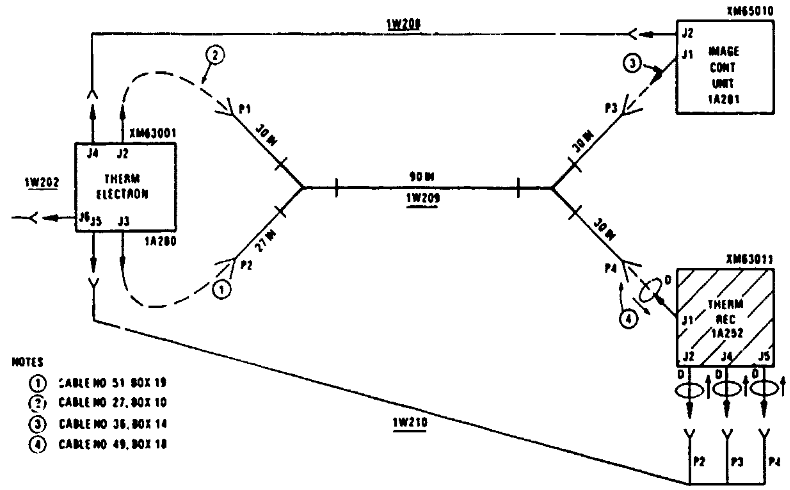


Figure B-8. Current injection of thermal receiver unit of night vision system showing harnesses 1W208, 1W209, and 1W210.

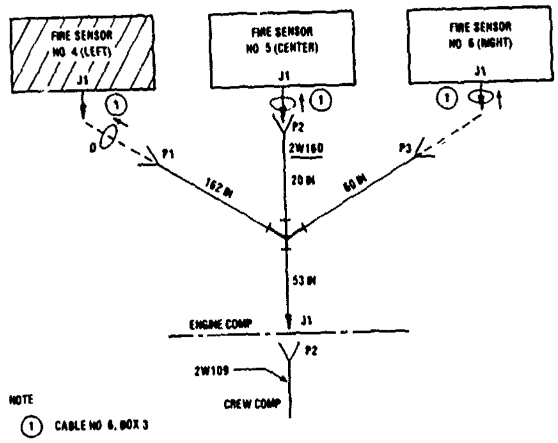


Figure B-9. Current injection of fire sensor of fire extinguisher system showing harness 2W160.

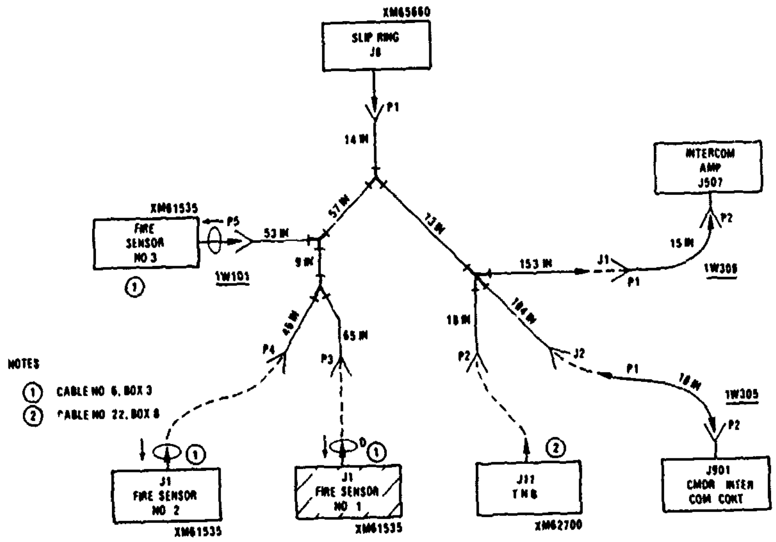


Figure B-10. Current injection of fire sensor of fire extinguisher system showing harnesses 1W101, 1W305, and 1W308.

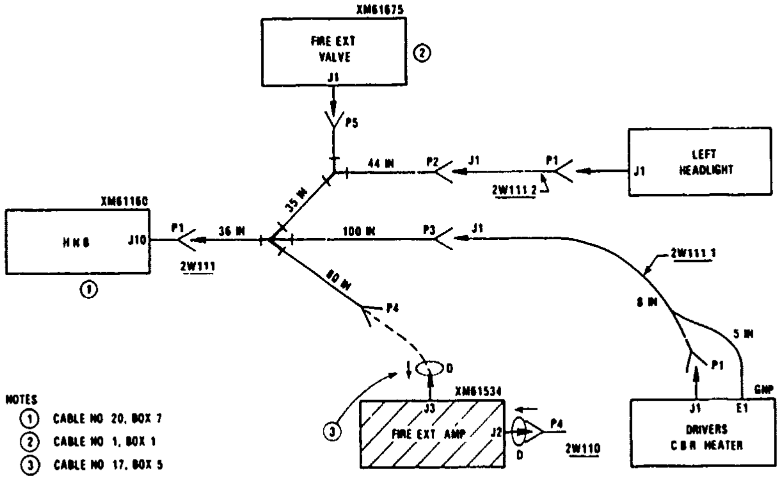


Figure B-11. Current injection of fire extinguisher amplifier of fire extinguisher system showing harness 2W111.

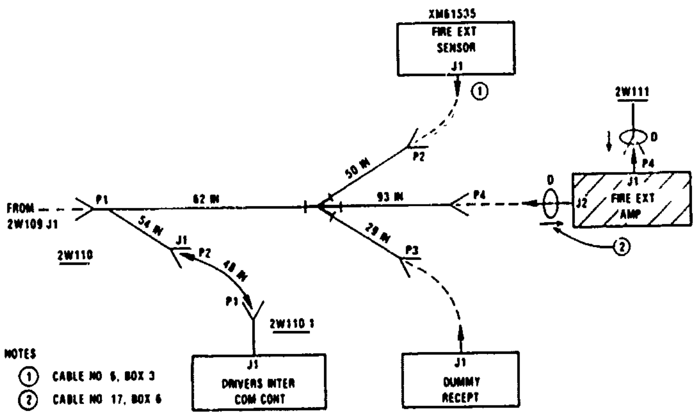


Figure B-12. Current injection of fire extinguisher amplifier of fire extinguisher system showing harness 2W110.

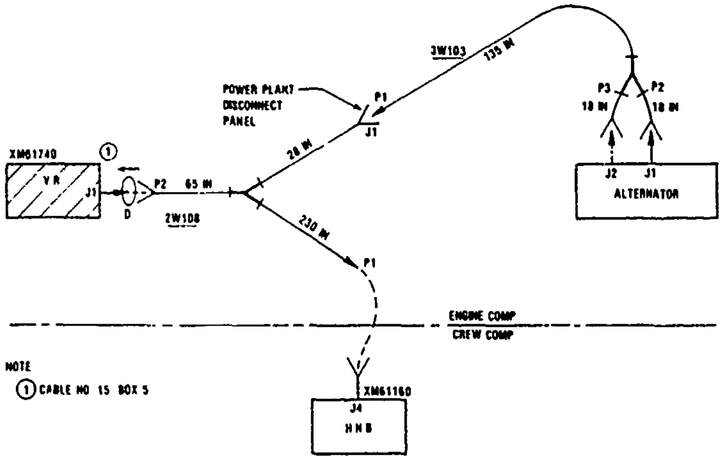


Figure B-13. Current injection of voltage rectifier (V.R.) of tank's primary power system showing harness 2W108.

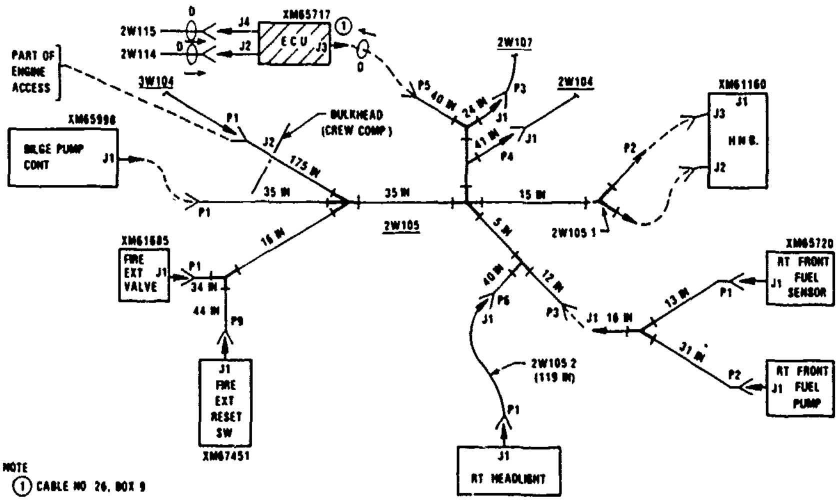


Figure B-14. Current injection of engine control unit (E.C.U.) showing harness 2W105.

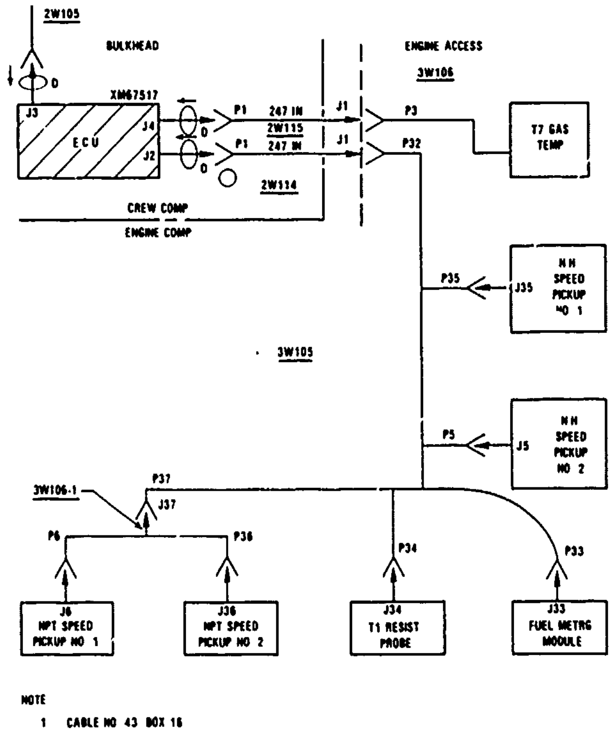


Figure B-15. Current injection of engine control unit (E.C.U.) showing harnesses 3W105 and 3W106.

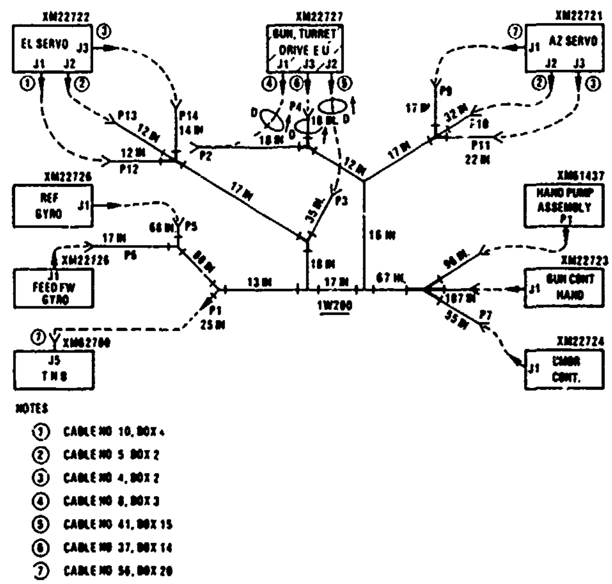
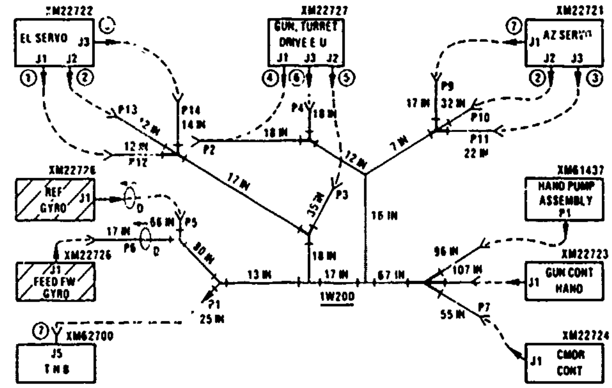


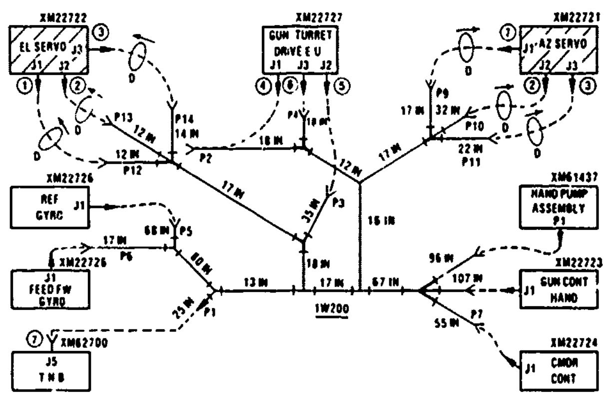
Figure B-16. Current injection of gun turret drive of primary weapons system showing harness 1W200.



NOTES

1. CABLE NO 10 BOX 4
2. CABLE NO 5 BOX 2
3. CABLE NO 4 BOX 2
4. CABLE NO 8 BOX 3
5. CABLE NO 41 BOX 15
6. CABLE NO 37, BOX 14
7. CABLE NO 56 BOX 20

Figure B-17. Current injection of reference and feed forward gyroscopes of primary weapons system showing harness 1W200.



NOTES

1. CABLE NO 10 BOX 4
2. CABLE NO 5 BOX 2
3. CABLE NO 4 BOX 2
4. CABLE NO 8 BOX 3
5. CABLE NO 41 BOX 15
6. CABLE NO 37, BOX 14
7. CABLE NO 56 BOX 20

Figure B-18. Current injection of elevation and azimuth servos of primary weapons system showing harness 1W200.

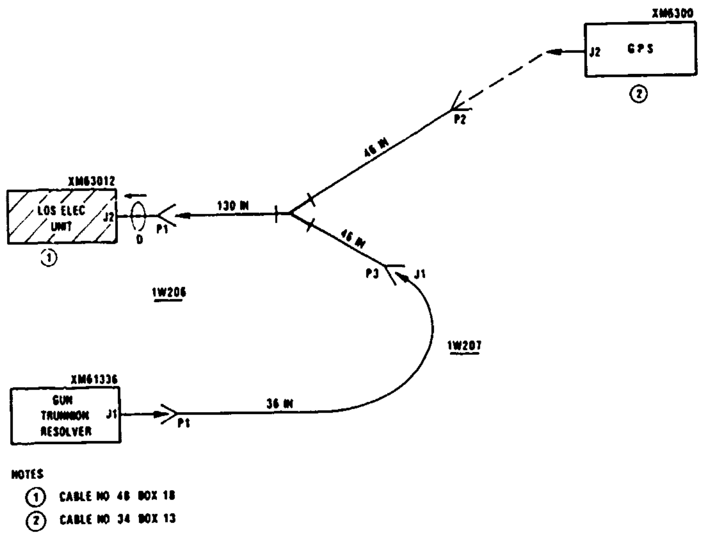


Figure B-19. Current injection of line of sight (LOS) electronics unit of primary weapons system showing harnesses 1W206 and 1W207.

B-4. FIELD ILLUMINATION USING REPS

(1) Using the Repetitive Electromagnetic Pulse Simulator (REPS), measure all components of the field from a point on the center line at a ground range of 25 m from the pulser. Repeat measurements of the horizontal component of the magnetic field (H_y) every 20 min to assure adequate repeatability.

(2) Place the tank (center) on the center line of the simulator, 25 m from the base of the pulser, with the long axis parallel to the wire cage of the antenna.

(3) Take diagnostic measurements in sequence according to the monitor point list to be provided. Measure bulk sheath current, vehicle surface (fig B-1) current, and breakout box bulk core and individual wire current and differential voltage.

B-5. FIELD ILLUMINATION USING VEMPS

(1) Monitor the vertical component of the electric field (E_V) and the azimuthal component of the magnetic field (H_ϕ) at a radial distance of 25 m from the Vertical Electromagnetic Pulse Simulator (VEMPS). Repeat measurements of E_V every 20 min to assure adequate repeatability.

(2) Place the tank (center) 25 m from the VEMPS with the long axis and the gun barrel along the radial coordinate. The barrel should face the VEMPS.

(3) Take diagnostic measurements in sequence according to the monitor point list. Measure bulk sheath current.

B-6. FIELD ILLUMINATION USING AESOP

(1) Use the B-dot sensor setup on the center line of the Army EMP Simulator Operations (AESOP) at approximately 25 m to monitor every shot

(2) Place the tank (center) on the center line of the AESOP 50 m from the base of the pulser with the long axis parallel to the wire cage. During all illuminations at the AESOP, ensure that the system is in the silent watch mode

(3) Check preillumination and postillumination functioning, and take data according to the monitor point list Allow 10 pulses before checking postillumination functioning Move the probes from point to point during the 10 pulses. Measure individual wire currents and differential voltage.

(4) Keeping the tank center located at 50 m, rotate the tank 180 deg. Check preillumination and postillumination functioning, and take data according to the monitor point list. Allow 10 pulses before checking postillumination functioning Move the probes from point to point during the 10 pulses Measure individual wire currents and differential voltage

(5) Keeping the tank in the same orientation, trail out 50 ft (15 m) of communication cable from the tank parallel to the antenna. Repeat direction (4)

(6) Place the tank (center) on the center line of the simulator, 22 m from the base of the pulser, with the long axis parallel to the wire cage

(7) Check preillumination and postillumination functioning, and take data according to the monitor point list. Allow 10 pulses before checking postillumination functioning Move the probes from point to point during the 10 pulses Measure individual wire currents and differential voltage

(8) Keeping the tank center located at 22 m, rotate the tank 180 deg. Check preillumination and postillumination functioning, and take data according to the monitor point list. Allow 10 pulses before checking postillumination functioning Move the probes from point to point during the 10 pulses. Measure individual wire currents and differential voltage.

(9) Keeping the tank in the same orientation, trail out 50 ft (15 m) of communication cable from the tank parallel to the antenna Repeat direction (8).

B-7. DETERMINATION OF CURRENT INJECTION STRESS LEVELS

The stress levels (sheath current—I_{ST}) to be used during the current injection testing are obtained by using the sheath current diagnostic data obtained from simulator illumination of the tank, electromagnetic scale modeling, and confidence factors The formula used for computing the stress levels is

$$I_{ST} = C_F K_1 K_2 I_{3\sigma} ,$$

where

C_f = confidence factor (table B-1),

K_1 = peak amplitude scale factor (e.g., 50 kV/m/5 kV/m),

K_2 = angle of incidence extrapolation factor (from scale modeling),

$I_{3\sigma}$ = current obtained by taking upper three-standard-deviation point of distribution of all measured sheath currents.

Time would not allow the sheath currents on all the harnesses to be measured in sufficient detail to ascertain the current as a function of position on a complex harness Even if this information were available, its value would be mostly academic since the array of current injector sources needed to reproduce this current distribution would be prohibitively large. Consequently, we are defining $K_1K_2I_{3\sigma}$ to be the threat current for the ensemble of tank harnesses. For all tests, it should represent a reasonable worst case, but should not include data points that are far out on the skirt of the distribution. These points will be handled, if necessary, as special cases

B-8. CURRENT INJECTION TEST PROCEDURES

During current injection testing, the system will be operated in both the static and the silent watch modes

(1) Set up current injectors and current probes on the harness as shown on the appropriate harness sheet

(2) Functionally check all subsystems associated with the harness to be tested

(3) Inject a current level (peak to peak amplitude) on the harness of approximately 1 × threat level. This is a single shot from the driver.

(4) Move to other wire current and differential voltage monitor points in the breakout box before pulsing again at the same level.* Use 10 single shots at each level so that all monitor points will be attained in the period of 10 shots

**If after attempting to make six voltage or current measurements you find the signals still buried in the noise, the test engineer may decide to wait for the next stress level before attempting to make more diagnostic measurements.*

(5) Move to the next stress level, and repeat the monitor point measurements over the period of 10 shots. The stress levels are given in table B-1 for the various classes of systems

(6) After each stress level is completed (10 shots at each level), repeat the functional check.

TABLE B-1. SHEATH CURRENT STRESS LEVELS

Class I (CIF = 20 dB)	Class II (CIF = 16 dB)	Class III (CIF = 10 dB)	Class IV (CIF = 6 dB)
1 × threat	1 × threat	1 × threat	1 × threat
2 × threat	2 × threat	2 × threat	2 × threat
4 × threat	4 × threat	3 × threat	
10 × threat	6 × threat		

Note CIF = confidence improvement factor

B-9. UPSET CONTINGENCY PLAN

Check the functioning on all subsystems associated with the harness If any performance degradation is observed for any subsystem, isolate the fault to individual circuit boards. Replace the defective board with known good units if these are available, and follow checkout procedures for the subsystem that failed. When the subsystem in question is functioning properly, subject the harness (if during AESOP testing, the whole vehicle) to another 10 pulses. After them, repeat the checkout procedures If failures occur again, isolate them to individual circuit boards, and terminate the test on that subsystem Initiate a full failure and EMP analysis

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