TECHNICAL REPORT TR-RD-TE-97-01

ELECTROMAGNETIC ENVIRONMENTAL EFFECTS CRITERIA AND GUIDELINES FOR EMRH, EMRO, LIGHTNING EFFECTS, ESD, EMP, AND EMI TESTING OF US ARMY MISSILE SYSTEMS

31 Jan 97

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This document supersedes Technical Report RD-TE-87-1

DEPARTMENT OF THE ARMY
U. S. ARMY REDSTONE TECHNICAL TEST CENTER
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REPLY TO
ATTENTION OF

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21 February 1997

MEMORANDUM FOR Distribution

SUBJECT: Technical Report RD-TE-97-01, "Electromagnetic Environmental Effects Criteria and Guidelines for EMRH, EMRO, Lightning Effects, ESD, EMP, and EMI Testing of US Army Missile Systems", 31 JAN 1997

1. Enclosed is a copy of the subject document. This document supersedes RD-TE-87-1, "Electromagnetic Environmental Criteria for US Army Missile Systems: EMC, EMR, EMI, EMP, ESD, and Lightning", February 1987.

2. The enclosed document, Report RD-TE-97-01, is a final report. Any comments or recommendations, after consideration, will be incorporated into a later revision. Please submit comments or recommendations to this office by 30 September 1997.

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This report presents the design and test requirements in developing an electromagnetic compatibility missile system. Environmental levels are presented for electromagnetic radiation hazards, electromagnetic radiation operational, electrostatic discharge, lightning, electromagnetic pulse (nuclear), and electromagnetic interference. Testing techniques and facility capabilities are presented for research and development testing of missile systems.

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PART I - INITIAL REVIEW

(Use Only for Unclassified Reports & Publications)

The attached information, Electromagnetic Environmental Effects Criteria and Guidelines for EMRH, EMRO, Lightning Effects, ESD, EMP, and EMI Testing of US Army Missile Systems has been reviewed in E^3 Test Branch by Jeffery D. Craven/Karen C. Compton and determined to be factual and unclassified.

Karen Compton
Jeffery D. Craven

25 Feb 97
25 Feb 97
DATE

PART II - OPSEC REVIEW

(Use Only for Unclassified Reports & Publications)

The attached information, Electromagnetic Environmental Effects Criteria and Guidelines for EMRH, EMRO, Lightning Effects, ESD, EMP, and EMI Testing of US Army Missile Systems has been given an OPSEC review in RTTC by Carl E. Roberts and determined to be unclassified, nonsensitive, and suitable for public release.

Carl E. Roberts

19 March 97
DATE

PART III - PATENT APPLICABILITY REVIEW

(Use Only for Classified & Unclassified Reports & Publications)

The attached information, Electromagnetic Environmental Effects Criteria and Guidelines for EMRH, EMRO, Lightning Effects, ESD, EMP, and EMI Testing of US Army Missile Systems has been reviewed for patent applicability, in E^3 Test Branch by Jeffery D. Craven/Karen C. Compton. The information

(X) appears to contain no patentable material.
( ) appears to contain patentable material.

( ) patent disclosure has been submitted.
( ) patent disclosure should be submitted.

Karen Compton
Jeffery D. Craven

25 Feb 97
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DATE

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The assistance of the ERC/TBE Test Management Support Center in the preparation, editing, publication, and distribution of this document is gratefully appreciated.

This document is a revision/update to the information previously reported in MICOM Technical Report RD-TE-87-1 by Mark Kilpatrick of the Test and Evaluation Directorate, Research, Development, and Engineering Center and Charles D. Ponds, COLSA, Inc., published February 1987.

EXECUTIVE SUMMARY

The Electromagnetic Environmental Effects (E^3) Test Branch, Electro-Mechanical Test Division of Redstone Technical Test Center has for over thirty years supported the development and evaluation of missile systems and components. Toward this end, the E^3 Test Branch has developed tests and test facilities to determine the hazards to and reliability degradation of missile systems caused by Electromagnetic Radiation (EMR) generated effects. The E^3 Test Branch is responsible for planning and conducting these tests as well as analyzing, reporting, and documenting the test results.

Over the past decade, both the test articles and the equipment required to support these tests have become more sophisticated. Similarly, the test methodologies used in the evaluation of the equipment have been revised to account for the evolution of test articles and test equipment. The test fidelity has improved in concert with the need to accurately evaluate systems, subsystems, and components over a broad array of both natural and manmade EM environments, while insuring that the measurement does not in itself alter the observed effects. As a result there is a requirement to document the revised test capabilities, test environment and criteria, and test procedures. This document is an effort to fulfill that requirement. (This document is a revision/update to MICOM Technical Report, TR-RD-TE-87-1 dated Feb 87, which has served as a guide for previous E^3 Tests).

The document describes the background of Army E^3 testing, including both current and projected near term test environment and criteria. It identifies currently available E^3 tests, the test applicability, and test equipment (including measurement probes and calibration required to verify the environment and criteria), test article instrumentation, test philosophy and procedures, data collection, and analysis techniques . This information is followed by an outline of the documentation supporting the tests, including test plans and test reports.

Due to the volume of information provided, the photographs and figures which describe the test facilities are combined in Appendix A. This test facility information includes the transmitters, antennae, and other unique test equipment used in the individual E^3 tests.

SECTION 1.0 INTRODUCTION

1.1 PURPOSE

This report documents the Electromagnetic Environmental Effects (E^3) requirements for US Army Missile Command (MICOM) systems. It also describes the tests performed to determine compliance with these requirements. Systems designed and tested to meet these requirements will be free of operational and safety problems when subjected to the respective electromagnetic (EM) environments described herein. The document provides guidance in: establishing an E^3 evaluation program through the creation of an E^3 Requirements Board (E^3RB); describing the different E^3 tests in detail (including for each test the background, objective, test criteria, test philosophy, test options, instrumentation, test methods and procedures, collection and analysis of test data, and the publication of results). The various facilities required to support these tests are provided in ensemble in Appendix A.

This report will also assist the system developer in documenting system requirements to contractors, subcontractors, and other test and evaluation organizations. Throughout this report, an attempt has been made to clarify the different E^3 tests, their purposes and requirements, by outlining the different test procedures, and, most importantly, to identify the applicability of E^3 tests in the system development cycle. As a whole, the E^3 tests come under the listing of Electromagnetic Compatibility (EMC). EMC is defined as the ability of a system to operate in its intended E^3 environments without suffering or causing unacceptable degradation. A system which operates in all the environments covered in this report will provide an electro-magnetically compatible system.

The EMC environments are briefly identified in the following paragraph in the order in which they are addressed in this document:

A. Electromagnetic Radiation-Hazard (EMRH) is the potential hazard caused by electromagnetic radiation to electro-explosive devices (EEDs), Electronic Safe and Arming Devices (ESADs) and their circuits. The acronym EMRH also includes abortive functioning of the EED, ESAD, and the degradation in the reliability or performance characteristics of the EED or ESAD. There are three types of EED effects: inadvertent initiation, creation of a dud, and thermal stacking (successive pulses that elevate bridgewire temperature).

   Similarly, ESADs failures include: hazards due to inadvertent arming or fuzing of warheads and reliability failures resulting in warheads which fail to arm at the appropriate time.

   In this document, the term EMRH addresses both the design and test criteria for missile system development. Hazards to personnel (HERP) and to fuels (HERF) are not covered. However, EMRH is applicable for all other systems, especially

systems utilizing ordnance items. E^3 criteria are to be used in the design, development, verification and/or certification of firing circuits, and the selection of all EEDs and ESADs to preclude premature detonation during shipping, storage, handling, pre-launch, launch and flight through safe separation distance, and to verify electronic component survivability. Normally, electronic components are not permanently damaged due to the EMRH environment.

B. Electromagnetic Radiation-Operational (EMRO) is the E^3 requirement to be used in the design, development, and verification of non-EED firing circuitry to ensure system reliability. This requirement includes electronic circuitry, especially guidance and control functions. The EMRO criteria apply to training and tactical operations to include pre-launch, launch, and in-flight performance for airborne weapon systems (i.e. missiles).

C. Lightning Effects (LE) is the damage or degradation to systems as a result of direct or near strike lightning. The lightning criteria define an environment to be used in the design, development, and verification of electronic circuitry to ensure safety and reliability. For near strike lightning, the system shall survive without permanent damage and be operational after the strike. For a direct strike, the equipment shall remain safe that is, a direct lightning flash to the weapon system cannot result in hazardous condition. Hazardous conditions would result in premature detonation of hazardous class EEDs and/or ignition of rocket propellant. Normally, the system is not required to operate after exposure to the direct strike lightning environment.

D. Electrostatic Discharge (ESD) is the requirement to be used in the design, development, and verification of the components, subsystems, and systems to prevent the detonation of explosives, the ignition of propellants, or the malfunction of associated electronic circuitry by static electric discharge which could create a hazard or affect system reliability. Both helicopter and personnel-borne charges are specified in these criteria.

E. Electromagnetic Pulse (EMP) is the short burst of electromagnetic radiation associated with a nuclear event. EMP is characterized by pulse duration of less than one second and by a frequency spectrums extending to 100 MHz. It can result in the degradation of electronics as well as EEDs and ESADs.

F. Electromagnetic Interference (EMI) or Radio Frequency Interference (RFI) is the degradation by an unintended electromagnetic signal or an electromagnetic disturbance. EMI/RFI occurs when the unintended signal is coupled into or out of a component, subsystem, and system. EMI is used to describe interference between subsystems as applied to system requirements. These terms (EMI and RFI) are used in reference to screen or shielded room testing per MIL-STD-461 requirements and MIL-STD-462 test methods.

1.2 E^3RB CRITERIA DEVELOPMENT RESPONSIBILITY

The E^3RB is responsible for the development and approval of specific E^3 operating environments (EMRH, EMRO, and EMROH) for each system. This process considers user requirements, intended missions, and both current and evolving threats. The E^3RB criteria are derived from environments caused by EM emitters, both friendly and hostile, that are expected to occur throughout the system life cycle. During this E^3 development process, calculations are performed and E^3 requirements are refined. The EMR criteria generated by this process provide mission critical requirements, which reflect cost and schedule constraints as well as technical issues. When combined with other community endorsed criteria, they establish quantitative E^3 evaluation of the candidate system.

The other E^3 environmental requirements (ESD, Lightning Effects, EMP, and EMI) currently have established criteria. It is the responsibility of the E^3RB to assure that the developer has adequately considered these environments as well.

1.3 FREE SPACE vs SCREEN OR SHIELDED ROOM EM FIELD

E^3 testing is performed under those conditions which replicate the environments which Army materiel will experience over its useful life. Testing is best accomplished by examination of system response when operated under controlled environments. This examination permits the system to be stimulated by the appropriate inputs while observing the resulting response. For those cases where a response is observed, it is in the interest of objective evaluation to determine that the response correlates with the specified input and not a combination of generated and incidental stimuli. In order to ascertain that a response is correlated with a given input, one must be able to recreate the stimuli and repeat the response. This recreation requires that the E^3 tests be performed at a facility which controls the stimuli to those intended specifically for the test. To accomplish the necessary control over the environmental stimuli, testing utilizes both free space and screen room (or shielded room) facilities.

The environmental requirements and test methods for screen (or shielded) room testing are established and included in MIL-STD-461 and MIL-STD-462. Because the environmental requirements and testing methods for free space facilities have not yet been published in a military specification, this report identifies those free space requirements and test methods for Army systems, in particular, missile systems. This document addresses tests performed in both free space, i.e., Open Area Test Site (OATS) and the anechoic chamber.

1.4 HISTORY OF ELECTROMAGNETIC ENVIRONMENTAL REQUIREMENTS

The introduction of high power EMR, radio frequency (RF) emitters, and the development of complex weapon systems (including the use of solid state and/or integrated circuitry, discrete components, and nuclear weapons effects) has created problems due to

exposure of Army systems to free space EM fields. These environments have different meanings and purpose than the EMI environment specified in MIL-STD-461. To ensure that systems can be safely handled and reliably operated in these environments, the Army has establish EMR design and test criteria. The following is a history of that effort.

June 1963: The Office of The Adjutant General (TAG) published a letter, dated 7 Jun 63, subject: "Electromagnetic Radiation (EMR) Objectives and Criteria for Nuclear Weapons", which established EMR criteria for nuclear systems. Because no criteria existed for conventional weapons, the same criteria were used. These criteria were used to test and evaluate weapon systems to determine if the system electro-explosive devices (EEDs) were degraded by nuclear events. Later, these criteria were applied to the evaluation of systems during an operational sequence, thus, system operational reliability was ascertained.

April 1965: Another TAG letter, dated 22 Apr 65, subject: "Program for Weapon Systems - Electromagnetic Radiation (EMR), Analysis and Control", was published in which the 7 Jun 63 letter was rescinded. The responsibility for establishing new criteria for weapon systems was placed on the US Army Combat Development Command (CDC). These criteria were never developed. When Project Managers (PMs) requested EMR criteria, CDC directed the PMs to use the 7 Jun 63 TAG levels.

April 1967: Army Material Command (AMC) Regulation 15-2, dated 27 Apr 67, subject: "AMC Radio Frequency Radiation Effects Committee", enacted this committee. However, the committee failed to establish new EMR criteria before becoming inactive.

January 1970: In January of 1970, a Tri-Service Committee to establish criteria for certifying systems to EM fields was formed. Although some EMR criteria data were gathered by this committee, no military standards were published.

April 1970: MICOM, in a letter to the US Army Material Command, dated 7 Apr 70, established interim EM criteria for missile systems. The intent was to establish criteria that would be used until criteria were formally published.

May 1976: The 7 Apr 70 interim criteria was slightly revised and published in an Internal Technical Note RT-76-61, dated 18 May 76, subject: "Electromagnetic (EM) Environmental Design and Test Criteria for Missile Systems Including EM Radiation Hazards (EMRH), Electromagnetic Radiation Operational (EMRO), Electrostatic Discharge (ESD), and Lightning".

August 1977: Internal Technical Note RT-76-61 was updated by Technical Report ET-77-9, dated Aug 77.

July 1978: A draft MIL STD was published on 25 Jul 78 entitled "Evaluation of Munitions to Electromagnetic Fields, Requirements For". This draft standard was sent to MICOM for review and comments. Comments were sent back stating that the field strengths specified were unrealistically high and would have severe impact on development of MICOM

systems. It was requested that rationale be provided for review to support the proposed field strength levels. No additional information was received.

February 1979: A Military Handbook (MIL-HDBK-235) was published on 5 Feb 79 entitled "Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment, Subsystems, and Systems". This handbook was intended to provide guidance rather than provide detailed EM environments for a specific system. The information in the handbook did not account for reasonable separation distances or the likelihood of encountering certain high powered emitters. Information from this handbook was evaluated and the field strengths were judged to be unrealistically high, severely impacting missile system development. (The environmental requirements herein are for MICOM systems and were established using engineering judgment in defining separation distances and probabilities of encountering high powered emitters.)

March 1981: Technical Report RT-81-5 was issued, adding nuclear EMP (NEMP) requirements, with updates provided Jan 85 (Technical Report RT-85-14) and Feb 87 (Technical Report RD-TE-87-1).

January 1991: A memorandum dated 22 Jan 91 was issued from the Department of the Army, Office of the Assistant Secretary, subject: Army Acquisition Executive (AAE) Policy Memorandum 91-3, Army Electromagnetic Environmental Effects (E^3) Program Implementation. This policy designates the Electromagnetic Environmental Effects Requirements Board (E^3RB) to identify the anticipated electromagnetic environments to be encountered. The board members are required to jointly establish the E^3 design and test criteria necessary to demonstrate the system to be safely and reliably stored and transported in either training or tactical operations, without degradation in these environments.

SECTION 2.0 THE ELECTROMAGNETIC ENVIRONMENTAL EFFECTS PROGRAM

2.1 BACKGROUND

Defense acquisition policy states that systems must neither suffer nor cause unacceptable mission degradation due to E^3. The Army E^3 Program implements the defense acquisition policy by insuring that all acquisitions follow a consistent set of processes: criteria development, assessment, planning, and execution. An E^3RB, consisting of the Material Developer (MATDEV), the Combat Developer (CBTDEV), and matrix support engineer from the AMC Major Subordinate Command (MSC), is responsible for the development and approval of system specific E^3 environments and makes recommendations to the program decision authority. The E^3 Test Branch, Electro-Mechanical Test Division, Redstone Technical Test Center (RTTC), was delegated as the MSC representative for MICOM systems.

The E^3RB criteria are derived from environments caused by electromagnetic emitters, both friendly and hostile, as well as naturally occurring phenomena expected throughout the system life cycle. Through a process that considers user requirements and intended missions, analyses are performed to develop system specific E^3 environments. The E^3RB criteria are combined with other community endorsed criteria to provide quantitative evaluation of system performance. It is the responsibility of the E^3RB to ascertain that the developer adequately considers all these environments. Figure 2.1-1 provides an overview of EM Environmental Tests conducted at RTTC.

2.2 E^3 PROGRAM PURPOSE

The purpose of the E^3 Program is to ensure that Army materiel will accomplish its intended mission in the electromagnetic environment, in both peace and war, in accordance with guidance given in: Department of Defense (DOD) 5000.2, Part 6, Section G, dated 23 Feb 91; Army Regulation (AR) 70-1, "Army Acquisition Policy", dated 31 Mar 93; and Army Acquisition Executive (AAE) Policy Memorandum 91-3, entitled "Army Electromagnetic Environmental Effects Program Implementation", dated 22 Jan 91. This objective will be accomplished by the E^3RB through definition of the electromagnetic environment for all Army equipment and systems during operations, training, transport, and storage.

This process will also include the identification of system degradation caused by the electromagnetic environments, action to correct the identified electromagnetic deficiencies, and incorporation of E^3 monitoring and controls into the life cycle process.

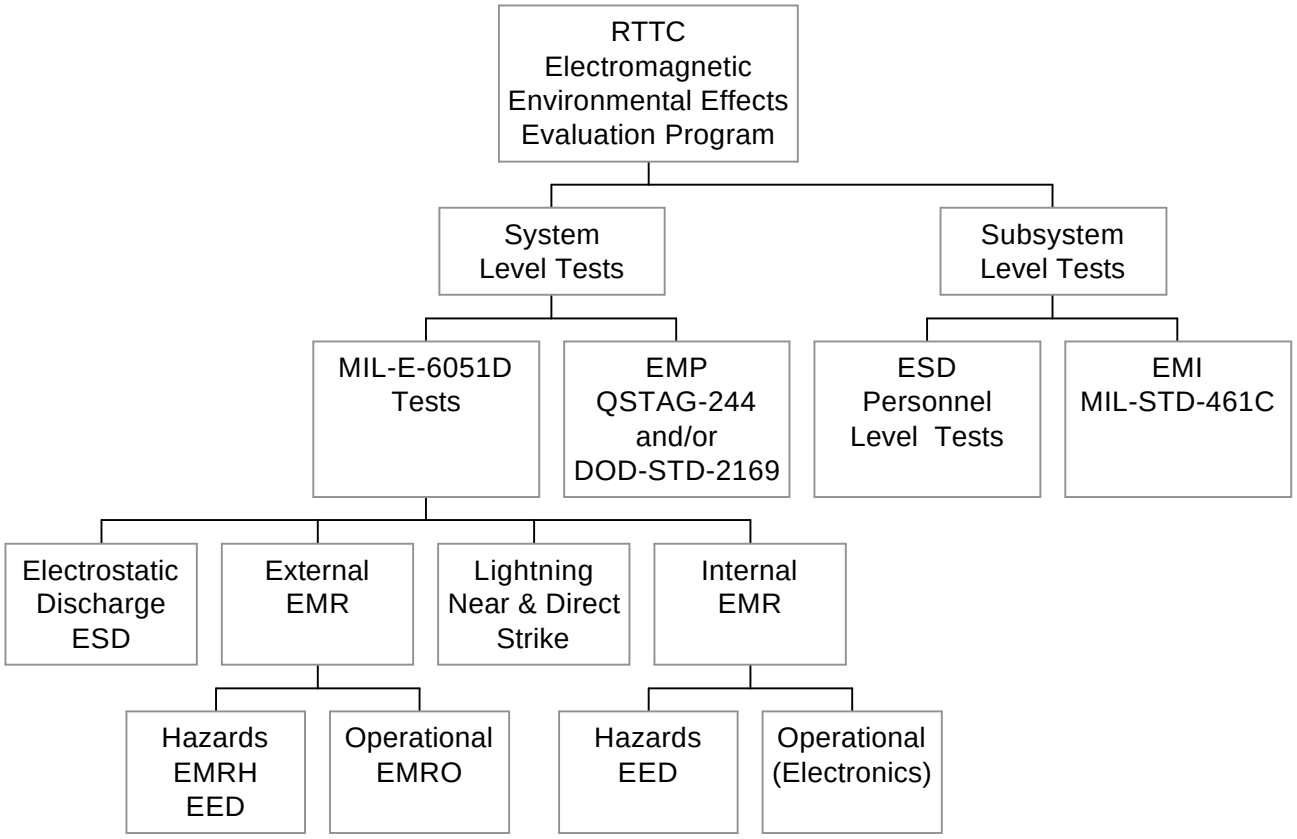


Figure 2.1-1. E^3 Evaluation Program.

2.3 E^3 PROGRAM APPLICABILITY

The E^3 Program process is applicable for all Army systems, subsystems, component parts, and support equipment for all mission areas acquired under any acquisition policy. The E^3 Program requirements shall be considered at all system milestone reviews and shall apply to all materiel procurements.

2.4 PHILOSOPHY

The Army realizes that it is not feasible to make every system or subsystem invulnerable to all forms of electromagnetic effects. Therefore, the E^3RB must assess the risk of E^3 to mission effectiveness of the system in question. Once the risk assessment is accomplished, the E^3RB must determine the degree of protection required to assure mission effectiveness of the system. The most severe electromagnetic environments need to be addressed to identify potential system deficiencies to E^3. Equipment failure or degradation to E^3 resulting in safety issues are the first to be addressed. The equipment failures and degradation need to be mitigated to reduce the potentials hazards to acceptable levels. This mitigation is typically accomplished through hardening.

Equipment failures which do not impact safety, but which affect mission success, need to be corrected such that the risk to degradation of performance is reduced to an acceptable level as determined by the E^3RB. Risk reduction may be accomplished by equipment hardening, change in tactics, system proliferation, mobility, and dispersion.

Safety and reliability fixes are incorporated in ensemble. Once the fixes have been integrated into the system, the system needs to be re-tested to determine that the fixes are not responsible for creating additional unique E^3 susceptibilities. At the conclusion of the tests, the Program Sponsor and user representative must agree the system has demonstrated adequate performance and safety to meet its mission objective within acceptable cost and technical constraints.

2.5 MISSILE SYSTEM CRITERIA PREDICTOR AND DESIGN GUIDE

As stated in sections 3.4, 4.4, 5.4, 6.4, 7.4, and 8.4, the criteria provided in this document are to be taken only as a minimum. It is beneficial to the user/developer to ascertain the actual EM environment to be encountered by his equipment during the execution of its mission. This identification can be made either by observing/measuring EM environments or by analytically calculating the E-fields to be encountered. Toward this end, RTTC has developed a software tool to provide this information analytically.

The software calculates the E-fields generated by the emitters as a function of transmitter output power, antenna gain, and distribution patterns. This calculation is made possible by a data base of emitter output characteristics and weapon system deployments.

The calculations and algorithms developed for this software can be divided into five fundamental categories. These categories consist of:

A. The far-field main-lobe (FFML) electric field.

B. Far-field side-lobe (FFSL) electric field.

C. Near-field main-lobe (NFML) electric field.

D. Near-field side-lobe (NFSL) electric field.

E. Threshold separation distance (TSD).

Given the separation distance between the system of interest and the candidate emitters, the software can estimate the electric field environment (FFML, FFSL, NFML and NFSL) to be encountered. Conversely, if the threshold electric field (which causes upset or damage to the system) is known, either through analysis or operational means , the software can calculate the estimated TSD to various emitters, thereby establishing operational guidelines for use of the system on a safe or non-interference basis with respect to specific emitters. Safety margins, which can reduce the risk to these emitters even further, can be included in these calculations.

As an analysis tool, the software can also identify the potential risk due to specific emitters based on deployment, operating frequency, slant range, duty cycle, and other emitter parameters. The calculations performed in the analysis provide estimates of power density and E-fields based on either near or far field, main or side lobe performance of the emitter. In particular the software can provide the following:

A. Reference plots of E-fields versus frequency at specified ranges from the emitter.

B. Interactive calculations of E-fields as a function of slant range.

C. Adjust E-field strengths which require near field compensation.

D. Adjust E-field strengths depending on side lobe/back lobe considerations.

As a result of these analyses, the E-fields encountered can be documented and will provide a bases for E^3 test requirements. This analysis tool can be used to support the requirements and recommendations provided by the E^3RB.

SECTION 3.0 ELECTROMAGNETIC RADIATION HAZARD (EMRH)

3.1 BACKGROUND

Technological advances have resulted in the development of communications and radar equipment which radiate electromagnetic energy in a directional manner with accompanying high field strengths. These advances coupled with the trend of utilizing more sensitive, low power electronic circuits in the design of weapon systems has increased the hazards to ordnance and electronics from electromagnetic radiation (EMR) or radio frequency (RF) radiation. The most serious of these hazards arises from the utilization of sensitive, electrically initiated explosive devices, or electro-explosive devices (EEDs), and electronic safe and arm devices (ESADs) which can be accidentally initiated by induced RF energy. The resulting hazards to systems include premature activation of explosive trains, abortive functioning of EEDs and ESADs, and the degradation of their electronic performance or reliability characteristics.

3.2 EMRH TEST OBJECTIVE

The objective of the EMRH test is to determine if exposure of any unit under test (UUT) to electromagnetic environment criteria established by the system E^3 Requirement Board (E^3RB) results in a hazardous condition due to premature detonation, or reliability failure due to desensitization of any EEDs or ESADs. The EED, ESADs, and associated electronics, electrical, and electro-mechanical equipment of the specific unit under test (UUT), must be safe and capable of surviving the electromagnetic environment. It should be noted that since each specific system responds differently to the same test environment, the results of each EED and ESAD qualification test can be applied only to the specific system configuration tested. Therefore, EMRH testing is required each time the UUT configuration is modified, whether as a result of either design or material changes.

3.3 EMRH APPLICABILITY

The EMRH requirement is applicable for the determination of hazards caused by EMR on the EEDs and ESADs for frequencies from 14 kHz to 40 GHz. This requirement includes the abortive functioning of the EEDs and ESADs, as well as the degradation in performance or reliability of the EEDs, ESADs, and their associated electronic, electrical, and electromagnetic equipment. The EMRH requirement is applicable for the shipping and storage configurations as well as training and tactical operations including handling, pre-launch, launch, and in-flight (through safe separation) involving the UUT.

3.4 EMRH CRITERIA

The EMRH criteria are different dependent on the deployment and utilization of the UUT. There are separate criteria for ground based systems developed solely for the Army, for systems deployed or utilized on Army helicopters and aircraft, and for systems developed for Army and Navy (Marines) utilization. For the special case in which multiple EMRH

requirements are indicated, the requirements are the composite of the most stressing requirements from all sources combined (i.e., all tables).

The EMRH criteria specified by Tables 3.4-1, MIL STD-1385B, and Table 3.4-2 were developed without specific input from any system E^3RB. Therefore, these EMRH criteria are provided as a minimum Army wide design and test requirement, identifying environments in which Army systems are expected to operate and survive.

3.4.1 Ground Based Army System Criteria.

The root-mean-square (rms) field strength criteria in Table 3.4.1-1, for the frequencies between 100 kHz to 100 MHz, are based upon the highest known power transmitters distributed throughout this frequency band. Systems can be exposed to these fields when transported, stored or deployed. No attempt has been made to identify specific narrow frequency bands which contain only low power transmitters, since the EED and ESAD circuits have broad (wide bandwidth) sensitivity. The rms field strength specified in Table 3.4.1-1 is equivalent to the "average field strength" referenced in the TAG letter, dated 7 Jun 63.

The rms field strength criteria for frequencies above 100 MHz were based on the permissible personnel exposure limit (PEL) of 10 mW/cm^2, specified in TB-MED-523. Using "far field theory", the PEL of 10 mW/cm^2 converts to 194 V/m (which is rounded to 200 V/m). This value was disseminated in the TAG letter, dated 7 Jun 63 and since that date has been used by the Army as the EMRH criteria for ground based Army systems. Detailed PEL requirements are listed in Table 3.4.1-1.

Systems that have been qualified to 100 and 200 V/m have not demonstrated any EMR hazard problems. Therefore, 100 and 200 V/m will continue to be used as the EMRH test criteria for ground based Army systems, even though the new United States Army Environmental Hygiene Agency (USAEHA) Technical Guide No. 153 has lowered the permissible PEL across portions of the 100 kHz to 40 GHz frequency interval.

3.4.2 Airborne Army System Criteria.

If a system under development is intended for use on Army helicopters or aircraft, then the criteria of MIL STD- 1385B is applicable. The criteria of MIL STD-1385B is taken from Aeronautical Design Standard ADS-37, dated 16 Apr 90, entitled: "Electromagnetic Environmental Effects (E^3) Management, Design, and Test Requirements".

EMRH test will demonstrate handling and loading of ordnance. Testing will be conducted at field intensities which are the highest of the combination of MIL-STD-1385 and Army ground based system criteria. ADS-37 is currently being updated, changes will be reflected in MIL STD-1385, and Airborne Army System Test Criteria. Hazards to

Electromagnetic Radiation Operational (HERO) requirements shall be in accordance with MIL-STD 1385. All modes of operation during mission to include loading, unloading, check out, pre-launch, etc., shall be that defined in MIL-STD 1385.

Table 3.4.1-1. Army Ground Based Equipment Criteria.*

Frequency (MHz)	Communication Emitters			RADAR Emitters		
Frequency MHz	Electric Field rms (V/m)	Electric Field Peak (V/m)	Polarization Vert. (V) Horiz. (H)	Electric Field rms (V/m)	Electric Field Peak (V/m) **	Polarization Vert. (V) Horiz. (H)
0.1-2	50	100	V	-	-	-
2-32	100	200	V	-	-	-
32-100	100	200	V&H	-	-	-
100-350	200	400	V&H	-	-	-
350-1000	200	400	V&H	200	6,500	V&H
1000-15000	-	-	-	200	20,000	V&H
15,000-40,000	-	-	-	200	6,500	V&H

* System developed for Army use only.
** This is not a test requirement, intended for design and evaluation only.

3.4.3 Joint Services System Criteria.

If a system under development is intended to be used by the Army and Navy (Marines) or in joint operations, then a combination of Army and Navy environments is applicable. These criteria are provided in Table 3.4.3-1. The Navy environments are taken from MIL STD- 1385B (Navy), dated May 86, entitled: "Preclusion of Ordnance Hazards in Electromagnetic Fields; General Requirements For".

3.4.4 Manhandling EMRH Criteria.

For manhandling configurations, consisting of UUTs which are in containers (for storage or shipping) or exposed (for loading into man portable air defense (MANPAD) launch tubes or onto vehicle launch racks or rails) including mating of all electrical connector(s) in preparation for launch, the EMRH test fields of Tables 3.4.1-1, MIL STD-1385B, and 3.4-3-1 will be used. These values will be limited by the maximum permissible PEL specified in USAEHA Technical Guide No. 153. PEL levels are listed in Tables 3.4.4-1, 3.4.4-2, 3.4.4-3, and 3.4.4-4. The Manhandling Tests will be conducted on inert rounds using instrumentation probes in place of EEDs and ESADs and in the EM environment(s) consistent with the mission(s).

Table 3.4.3-1. Combined Army and Navy Equipment Criteria.

Frequency (MHz)	Electric Field (average) V/m (rms)	Polarization
0.1-0.2	100	V
0.2-0.535	300	V
0.535-32.0	200	V
32.0-100	100	V&H
100-200	200	V&H
200-225	275	V&H
225-790	238	V&H
790-2700	614	V&H
2700-3600	1228	V&H
3600-5400	614	V&H
5400-5900	1228	V&H
5900-7900	614	V&H
7900-8400	812	V&H
8400-11,000	1228	V&H
11,000-18,000	614	V&H
18,000-40,000	200	V&H

Table 3.4.4-1. PEL EMRH Criteria for Manhandled Systems, Part A. Electromagnetic Fields (f in MHz).

Frequency Range (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Power Density (S) (E- Field•H Field) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.003-0.1	614	163	(100,1000000)	6
0.1-3.0	614	16.3/f	($100,10000/f^2$) *	6
3-30	61.4	16.3 f	($900/f^2$, $10000/f^2$) *	6
30-100	61.4	16.3 f	(1.0, $10000/f^2$) *	6
100-300	61.4	0.163	1.0	6
300-3000			f/300	6
3000-15000			10	6
15000-300000			10	$616000/f^{1.2}$

* The plane wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Table 3.4.4-2. PEL EMRH Criteria for Manhandled Systems, Part B.
Induced and Contact Radio Frequency Currents (f in MHz).

Frequency Range	Maximum Current (mA)		
MHz	Both feet	Each foot	Contact
0.003-0.1	2000f	1000f	1000f
0.1-100	200	100	100

Note: Personnel shall not be exposed to EM levels higher than the maximum permissible exposure levels (MPE) specified in Tables 3.4.4-1 through 3.4.4-4. For pulsed fields, additional requirements for 0.1 to 300,000 MHz are as follows:

A. The peak electric fields shall not exceed 100 kV/m for any pulse.
B. For pulse widths less than 100 msec and with pulse repetition periods of at least 100 msec., the peak power density for any single pulse shall not exceed the power density in Tables 3.4.4-1 and Table 3.4.4-2, modified as follows:

Peak MPE =(MPE ◦ Avg. Time)/(5 ◦ Pulse width)

where "Avg. Time" is from tables with the same dimension as pulse width. If the pulse width exceeds 100 msec and the pulse repetition period is less than 100 msec, or there are more than five pulses during the averaging time, then the total energy density (pulse power density integrated over time) during any 100 msec period shall not exceed: MPE ◦ Avg. time/5. These requirements are extracted from ANSI/IEEE C95.1-1991 as implemented in DoDI 6055.11.

Table 3.4.4-3. Maximum Permissible Exposure for Uncontrolled Environments, Part A.

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) E Field ◦ H Field (mW/cm^2)	Averaging Time S (minutes)	
				$\|E\|^2$	$\|H\|^2$
0.003-0.1	614	163	(100,1000000) *	6	6
0.1-1.34	614	16.3/f	$(100,10000/f^2)$ *	6	6
1.34-3.0	823.8/f	16.3 f	$(180/f^2, 10000/f^2)$ *	$f^2/0.3$	6
3.0-30	823.8/f	16.3 f	$(180/f^2, 10000/f^2)$ *	30	6
30-100	27.5	$158.3/f^{1.668}$	$(0.2,940000\ f^{3.336})$ *	30	$0.0636f^{1.337}$
100-300	27.5	0.0729	0.2	30	30
300-3000			f/1500	30	
3000-15000			f/1500	90000/f	
15000-300000			10	$616000/f^{1.2}$	

Note: * The plane wave equivalent power density values, although not appropriate for near field conditions are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Table 3.4.4-4. Maximum Permissible Exposure for Uncontrolled Environments, Part B. Induced and Contact Frequency Currents.

Frequency Range, f	Maximum Current (mA)		
MHz	Both feet	Each foot	Contact
0.003-0.1	900f	450f	450f
0.1-100	90	45	45

3.4.5 Tailoring of EMRH Criteria.

In the opinion of the E^3RB, when the electromagnetic radiation sources associated with the intended mission of the system are capable of producing fields in excess of those specified in Tables 3.4.1-1, MIL STD-1385B, or Table 3.4.3-1, these higher fields shall apply. The EMRH criteria specified by Tables 3.4.1-1, MIL STD-1385B, and Table 3.4.3-1 shall be modified by the system E^3RB to reflect the special electromagnetic environment requirements, as determined by the system's intended mission.

3.4.6 Test Criteria Safety Factors.

The criteria for the associated electronics, electrical, and electromagnetic equipment of the UUT are determined by the survivability of the equipment after exposure to the EMRH criteria environment.

The criteria for the EEDs and ESADs are dependent on the specific UUT. Each EED and ESAD will be designated as potentially either a hazard or reliability problem. A hazard UUT is defined as the premature initiation of an EED or ESAD which results in injury to personnel or destruction of property. A reliability UUT is defined by the premature initiation which results in a dud or desensitization with attendant degradation in performance beyond that which is acceptable, but without hazardous external effects.

3.4.6.1 Hazardous EED and ESADs.

A minimum safety factor of 10 dB shall be exhibited for ground based Army UUTs with respect to the criteria specified in Table 3.4.1-1. A minimum safety factor of 20 dB shall be exhibited for systems intended for use on Army helicopters and aircraft with respect to the criteria specified in MIL STD-1385B. Finally, a minimum safety factor of 16.5 dB shall be exhibited for systems intended for use by the Army and Navy (Marines) or utilized in joint operations with respect to the criteria specified in Table 3.4.1-1. The safety of a system shall be considered adequate when the response of the EED/ESAD device in terms of the measured induced current, voltage, power or energy when subjected to the specified test environment criteria is less than the maximum no fire current, voltage, power or energy by the safety margins identified in Table 3.4.6.1-1.

Table 3.4.6.1-1. Safety Factors.

	Army Ground Systems		Army Air Systems		Tri-Service & Joint Operations	
Parameter	Hazardous	Reliability	Hazardous	Reliability	Hazardous	Reliability
(-)dB	10	6	20	6	16.5	6.9
MNFC/V	.316	.50	.10	.50	.15	.45
MNFP/E	.10	.25	.01	.25	.02	.20

Note: MNFC/V is the maximum no-fire current or voltage and
MNFP/E is the maximum no fire power or energy.

All threshold values are determined by the manufacturer using statistical analysis of a large number of EED or ESAD samples and defined as the 99% probability of no-fire with a confidence level of 95%.

3.4.6.2 Reliability EED and ESADs.

For ground based Army systems, a minimum safety factor of 6 dB shall be exhibited with respect to the criteria specified in Table 3.4.1-1. Similarly a minimum safety factor of 6 dB shall be exhibited for systems intended for use on Army helicopters and aircraft with respect to the criteria specified in MIL STD-1385B. Finally, for those systems used by Tri-Service or Joint operations, a minimum safety factor of 6.9 dB shall be exhibited with respect to the criteria specified in Table 3.4.3-1. Thus, the reliability of a UUT shall be considered adequate when the induced response of the UUT (as defined by the respective NO FIRE parameters) are reduced by the amount defined in Table 3.4.6.1-1 over the specified NO FIRE criteria.

The parameters identified previously: Maximum No Fire Voltage (MNFV), Maximum No Fire Current (MNFC), Maximum No Fire Power (MNFP), or Maximum No Fire Energy (MNFE) are determined by the manufacturer (using statistical analysis of a large sample of EED/ESADs) as a 99% probability of no-fire at a confidence level of 95%.

3.5 E-FIELD CALIBRATIONS

The RTTC test methodology establishes free space field calibration for the E-field sensor probes prior to introducing the UUT into the test site.

3.5.1 Calibration of E-field Sensors.

Periodically, the electric field sensors are calibrated in the laboratory. Electric field sensor systems are normally supplied with tables of calibration factors. These tables identify the dynamic range of the sensor probe, but are insufficient for a complete calibration database. In order to develop a calibration database, the electric field probe should be placed in a known electric field. This electric field is accomplished by using transverse electromagnetic (TEM) transmission cells and matched transmit/receive standard gain horn antennas to obtain electric field sensor calibrations. Below 500 MHz the field sensor probes are calibrated in the TEM transmission cells. Above 500 MHz the field sensor probes are calibrated in the anechoic chamber, utilizing matched transmit/receive standard gain horn antennas. Using a known power for the transmit antenna and a know E-field, the receiving antenna is replaced with the field probe and the probe E-field calibration adjusted accordingly.

3.5.2 Free Space Calibration.

Free space calibrations are performed with E-field sensors in place, but without the UUT installed at the test site. This calibration is done to characterize the E-fields generated by the transmit antenna, without the perturbations that would be created by the presence of the UUT. Monitoring the E-field during the test with the UUT in place may result in erroneous measurements of the test environment due to interference (multipath and reflections) caused by the coexistence of the probe instrumentation and the UUT. The reflections can be constructive or destructive depending on specific location, frequency, polarization, and orientation and could result in invalid field measurements.

For this reason, a free space field calibration is conducted prior to testing at all candidate frequencies and polarizations. The calibrations are accomplished by placing the E-field probe at those locations representative of the future placement of the UUT and recording the E-field observed at those locations. For 10 kHz to 1000 MHz, an Amplifier Research Probe Model Number FP2000 is used. For 80 MHz to 40 GHz, an Amplifier Research Probe Model Number FP 2080 is used. Amplifier Research Model FM 2004 Field Monitor is used to observe the output of either probe.

Calibrations are obtained by measuring the field strengths produced, referenced to the transmitter output power. The results are in the form of a table of transmitter output power versus measured field strength for each test location. These field calibration tables are stored in the data acquisition computer files and are used when the data are processed. During the tests, the computer reads the effective transmitter power (output minus reflected power) and calculates the field strength at the location of the probe during each test run (field strengths can be calculated for transmitter powers other than those at which the calibration was made).

The calibration data is obtained using one of these two approaches:

A. For tests conducted in the 250 MHz to 18 GHz frequency range, standard gain horns with power meters and far field calculations are used to calibrate sensor probes.

B. Below 250 MHz the electric field sensors are calibrated using the transverse electromagnetic (TEM) transmission cell. The sensor probe is then placed in front of the antenna at the future location of the UUT. The E-field environment generated by the test antenna is calibrated prior to each test.

3.5.3 Far Field Testing.

Field uniformity over the volume of the UUT must be considered prior to placing the UUT in the test field. If the UUT is placed too close to the source antenna, the EM field over the UUT may be non-uniform due to the angular dependence of the antenna pattern. This effect is sometimes referred to as the "near field" non-uniformity. To correct this problem, the UUT is placed in the "far field" region of the antenna. The distance to the "far field" region is dependent on the physical size of both the UUT and the antenna as well as the frequencies being used during the test. It is common practice to locate the UUT no closer than the range defined by the relationship:

$$r = (2 \cdot D^2/\lambda)$$

where r is the minimum distance to the antenna,
D is the physical dimension, the larger of the antenna or the UUT, and
λ is the wavelength of the test frequency being used.[1]

3.6 EMRH TEST PHILOSOPHY

EMRH involves testing weapon system EEDs and ESADs to assure that they are compatible with the Electromagnetic Environments defined by the E^3RB, resulting in acceptable hazard and reliability failure levels when exposed to the required E-fields and environments. To this end, the EEDs and ESADs are tested to determine their ability to survive the Electromagnetic Environment. For those cases where the E-fields can be generated, the EEDs and ESADs can be tested outright in either instrumented or go/no-go tests.

The instrumented test requires the EED or ESAD be removed and replaced with an instrument (transducer) capable of measuring the induced voltage, current, power, or energy parameters resulting from the incident E-field at the original location of the EED or ESAD. The effect of the E-field in generating the induced voltage, current, power, or energy is then compared to the Maximum No Fire (MNF) parameter. Ideally, the instrumentation will have a

[1] Skomal , Smith "Measuring The Radio Frequency Environment", 1985, p.212

capability of detecting the MNF parameters. In addition, based on the type of risk involved, i.e., hazard or reliability, the induced parameters are reduced by safety margins (as identified in Table 3.4.6.1-1) which are different for each EED or ESAD. This safety margin reduces the magnitude of the maximum allowable induced MNF Parameter which the EED or ESAD can exhibit when exposed to the E-field and still meet the safety criteria.

Furthermore, if the facility is unable to generate the required E-fields, the induced voltage, current, power, or energy resulting from the test E-fields can be used to extrapolate the data. In this case, the observed effect (namely, the induced voltage, current, power, or energy) is increased in direct proportion to the ratio of the criteria field to the test field. This extrapolation process assumes a linear relationship between the measured response to test E-field versus that response which occurs in the criteria E-field and the response of the EED or ESAD is identical to that of the instrumentation transducer used in the tests.

Alternately, the EED or ESAD can be subjected to go/no-go test. A go/no-go test is best suited for cases in which multiple UUTs are available. This go/no-go test is referred to as Statistical Sampling due to the need to test a number of identical UUT under identical conditions. Testing consists of exposing each UUT to an array of frequencies, waveforms, polarizations, and orientations. Due to the live nature of these tests, an EED or ESAD may fail catastrophically at any time indicating the need for many UUTs in order to conduct the tests across the array of frequencies, waveforms, polarizations, and orientations.

If only a small number of UUTs are available, then additional consideration must be given to the specific test fields used. Under these conditions the test fields are increased by a predetermined amount as defined by safety margins and the test is referred to as a Safety Margin Verification. The safety margins used for the go/no-go tests are identical to those of the instrumented tests and are provided in Table 3.4.6.1-1, differentiated only by the type (i.e., Hazard or Reliability) and mission utilization (i.e., ground, air, etc.). The safety margin is incurred due to the limited number of test assets and the need to provided a predetermined level of confidence that the devices will survive in the mission environment. The Hazard safety margins may demand extraordinary E-fields levels which are beyond the capability of the facility. The inability of the facility to support the required E-fields may prevent the go/no-go test as a viable alternative.

If a go/no-go test is conducted, the EED or ESAD are left in tact. Due to the requirements stated above, the go/no-go test is conducted using either a large number of identical UUTs (Statistical Sampling) or the magnitude of the E-field is increased by the safety margin and the tests is conducted using a smaller number of UUTs (Safety Margin Verification).

In order to make meaningful measurements on the EED or ESAD, it is necessary to understand the operation of these devices. These operations include those mechanisms which contribute to either Hazard or Reliability failures. For EMRH testing, this measurement is best accomplished by understanding the operation of EEDs and ESADs found in missile systems.

3.6.1 EED Device Phenomenology.

The EED requirements stated in this document cover electric initiators and firing devices, i.e., Hot Bridgewire (HBW) EEDs.

3.6.1.1 Hot Bridgewire EEDs.

The most commonly used type of EED in missile systems is the HBW. The HBW is initiated by passing a direct current through the bridgewire from pin-to-pin, heating the bridgewire, and thus initiating the primary explosive charge surrounding the bridgewire. The power to produce this heat may be calculated by squaring the current and then multiplying by the bridgewire resistance (I^2*R). The normal firing mode is a thermal process, therefore the continuous wave (CW) field strengths defined in root mean square (rms) Volts/meter (V/m) and the associated induced EMR current through the bridgewire are of primary concerns.

3.6.1.2 Alternate EED Triggers.

It should be noted that EEDs can also be ignited from peak field strengths resulting in a pin-to-case voltage breakdown and dissipating the power through the chemical mix of the initiator charge. In order for the pin-to-case ignition to occur, the peak field coupling to the EED wiring would have to induce a voltage sufficiently large to breakdown the gap between the bridgewire pin and EED case. The required voltage breakdown would depend upon the separation distance between the EED pin and case and the dielectric properties of the explosive mix. Peak field evaluation is normally conducted during the system's nuclear electromagnetic pulse (EMP) test, electrostatic discharge (ESD) test and lightning effects (LE) test, which provide evaluation over the frequency range of approximately 100 kHz to 300 MHz. If the UUT does not have to perform under these transient requirements, then peak EMRH field testing should be considered. Emerging low-power digital technologies (consisting of solid state electronics which are more susceptible to peak field strengths) will also be candidates to peak EMRH field testing.

3.6.2 ESAD Device Technology.

ESAD requirements cover electric initiators and firing devices consisting of both Exploding Bridgewire (EBW) and Exploding Foil Initiator (EFI) devices.

The ESAD may incorporate any number of simultaneous or serial events which function to provide both a reliable and fail-safe device. The unique sequence of events provides the necessary safeing to prevent unintentional operation while at the same time incorporating the necessary intrinsic energy needed to activate a detonator, once all the necessary thresholds and sequences are met. When the ESAD is properly triggered, the intrinsic energy explodes the EBW or EFI, causing detonation through impact of the EBW or EFI with the primary explosive material. The one critical element required to detonate which is a candidate for EMRH testing is the charge capacitor, wherein an EMR may induce a charge build-up on the charge capacitor resulting in a hazard condition.

3.6.2.1 EBW and EFI Initiator.

ESADs are initiated either by arcing or by shock waves. These include the EBW type and the EFI (or slapper). The EFI operates by exploding a thin metal foil that drives a film of dielectric material across a gap to impact with a high-density explosive. In contrast, the EBW operates by exploding a metal bridgewire into a low-density, compact, secondary explosive which then detonates a primary high-density booster. The particular instrumentation technique required to monitor the initiation process is dependent on the particular type of ESAD being employed by the UUT.

The requirement for igniting ESADs which utilizes EBWs and EFIs is to apply the proper voltage to the charge capacitor. The appearance of the correct voltage on the charge capacitor, when coupled with one or more appropriate digital signals, is responsible for activation of the ESAD.

3.7 TEST METHODOLOGY AND PROCEDURES

Verification that EED and ESAD meet EMRH criteria can be accomplished by two techniques: 1) non-instrumented testing (referred to as go/no-go) and 2) instrumented testing. Due to the necessity of demonstrating a minimum of 10 dB safety margin for hazardous EEDs and a minimum of 6 dB safety margin for reliability EEDs, it is often impractical to verify the EMRH criteria through go/no-go testing. For this reason, instrumented testing techniques at RTTC are preferred to verify the EMRH criteria. The go/no-go test technique is discussed here for two reasons: 1) to provide information on how this technique could be accomplished and 2) to illustrate the impracticality of this technique when verifying that the UUT meets the EMRH criteria due to the extraordinarily high E-field requirements.

Figure 3.7-1 contains a test matrix that identifies all candidate test options. "N/A" indicates those test options which are "Not Applicable" due to the inability to generate the required E-fields, or the inability to determine the success or failure of the UUT. The type of test selected depends on making the test hardware available, generating the required EM environments, and providing the necessary instrumentation.

Due to the potential hazards associated with live systems, EMRH testing is conducted on an inert, but operable, system with the entire UUT exposed to the EM environment. As noted, the test conditions and procedures are conducted in the "as deployed" mission configuration. Test variables and parameters are selected to establish a baseline for evaluation. The sequence for conducting the EMRH test is divided into four distinct phases: 1) test plan development, 2) pretest setup, 3) conduct of test, and 4) data reduction and documentation.

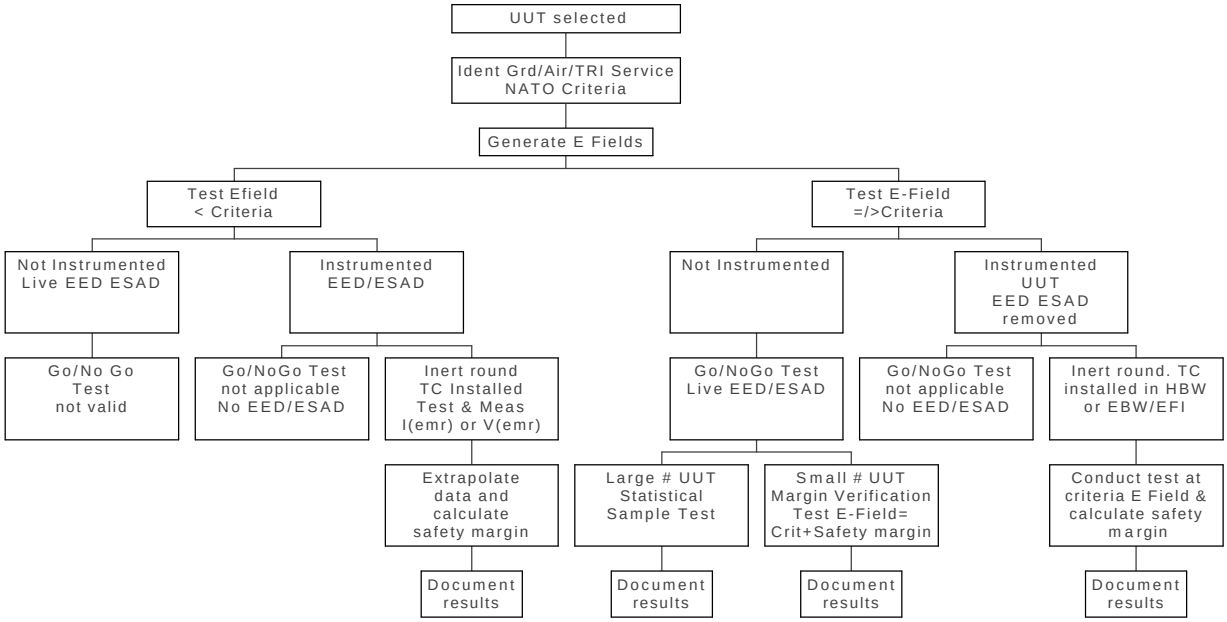


Figure 3.7-1. Matrix of EMRH Test Options.

3.7.1 Go/no-go Testing.

A go/no-go test verification of the EMRH criteria can be accomplished by two methods:

A. Safety Margin Verification test

B. Statistical Sample Size verification test

Both methods require that the test facility has the capability of testing at or above the required criteria field strength levels.

3.7.1.1 Safety Margin Verification.

The safety margin verification method requires testing the UUT with live EEDs or ESADs at field strengths which are higher than the criteria field strengths by the appropriate safety margin (i.e., a 200 V/m rms criteria field strength with a safety margin requirement of 10 dB would require a test field strength of 632 V/m rms). Testing at levels significantly above the required criteria becomes a problem, especially if the UUT has a combination of both hazardous and reliability EEDs and ESADs. The reliability EEDs and ESADs have lower safety margin requirements than the hazardous EEDs and ESADs, resulting in the reliability EEDs and ESADs being subjected to significantly higher E-fields during verification testing of the hazardous EEDs and ESADs. A possible solution to this problem is to subject the UUT to two complete test cycles: 1) to verify the reliability EEDs and ESADs and 2) to verify the hazardous EEDs and ESADs. During the testing of the hazardous EEDs and ESADs with the higher E-fields, the reliability EEDs and ESADs are replaced with impedance matched dummy loads. This replacement prevents ignition of the reliability EEDs and ESADs when exposed to the higher E-fields. In any event, this test method requires that the test facility be capable of generating field strengths 20 dB above the required criteria. For example, qualification of Army airborne systems by this method would require testing at 2000 V/m rms and 274,590 V/m peak. (MIL STD-1385B identifies rms and peak electric field requirements for frequencies from 8 to 10 GHz).

3.7.1.2 Statistical Sample Size Verification.

In order to demonstrate EED and ESAD reliability within the necessary confidence levels, the Statistical Sample Size Verification Method requires testing the UUT with a large number of live EEDs or ESADs at the field levels identified by the test criteria. For ground based Army systems, a minimum of ten sets of EEDs or ESADs are required to demonstrate a reliability of 85 percent with a confidence of 80 percent. Therefore, the UUT would have to be subjected to a minimum of 10 complete test cycles. To demonstrate increased reliability or confidence levels for the UUT, larger sample sizes corresponding to increased numbers of test cycles would be necessary. This test method requires the test facility be capable of generating the criteria E-field levels, preferably testing many samples simultaneously.

3.7.2 UUT Instrumentation.

The basic requirements for instrumenting UUTs for EMRH tests are to minimize both the disturbance to the EM field created by the instrumentation package and the coupling of the EM field to the data channels. These instrumentation requirements are accomplished by keeping the instrumentation package small and internal to the UUT and using optical telemetry techniques to reduce coupling of RF energy into the signal leads. For example, no external hardwire connections and only minor changes in the EED circuit impedance are permitted. The instrumentation package itself should be mounted inside the UUT with power provided through battery packs or air turbine power generators. The UUT is normally non-operating during the EMRH tests, eliminating the need for any additional power requirement.

Instrumented tests consist of removing all explosive/combustible material from the UUT, including any EED and ESAD. The individual EED or ESAD is replaced with a thermocouple which measures the thermal or electrical effects resulting from the incident EM radiation. The thermocouples are electrically matched to the EED or ESAD they replace and are installed at precisely the same location as the original EED or ESAD. This thermocouple replacement is done to emulate the response and duplicate the configuration of the original equipment.

The EMRH instrumentation used is dependent on the type of EED or ESAD being tested. HBW EEDs have three types of instrumentation: thermocouple, vacuum thermocouple, and fluorescence. EFIs and EBWs are not actually instrumented, but the signal leads in the ESADs are monitored, e.g., the voltage on the charge capacitor.

Each EED component in the UUT can be replaced, either with an impedance matched vacuum thermocouple located at precisely the same location as the EED or with a miniature thermocouple, located within 0.001 to 0.003 inches from the exposed bridgewire. This vacuum thermocouple replacement is done to emulate the tactical configuration. Any explosive mixtures in the EED are removed.

EEDs are tested by the manufacturer to establish the maximum no-fire current, voltage, power, and energy (MNFC, MNFV, MNFP, MNFE) which identify the magnitude of the applied or induced parameter at or below which the EED will survive without activating. (Typically, MNFC and MNFV parameters are used for EEDs while MNFP and MNFE are reserved for ESADs). These MNF parameters are used to calibrate the maximum allowable output from the thermocouple or vacuum thermocouple. The thermocouple is calibrated by applying direct current through the bridgewire and recording the output. The vacuum thermocouple is calibrated by observing the thermal power dissipated and recording the output. Vacuum thermocouples are used unless the EED location dictates otherwise. Vacuum thermocouples are placed in proximity to a bridgewire element whose electrical characteristics are identical to that of the EED. The thermocouple and bridgewire combination are placed in a small enclosure which is sealed and evacuated. The electrical signals originating at the thermocouples, represent EED bridgewire temperatures (or control circuit voltages) and provide a measure which is proportional to the change in temperature or voltage due to EMR induced power.

3.7.2.1 HBW Instrumentation.

Installation of the HBW instrumentation is performed to minimize EMR coupling to the UUT. The EMR coupling is minimized by controlling the length of instrumentation signal leads and by placing the HBW instrumentation at locations which utilize the natural shielding of the UUT (i.e., installation of the HBW instrumentation package into the empty flight motor cavity of an inert missile system). Twisted, shielded wires are utilized for instrumentation signal leads and the inputs to the HBW instrumentation package are filtered to minimize induced EMR noise signals into the HBW instrumentation. The HBW instrumentation converts the measured voltages (due to induced EMR currents through the bridgewire) into an infrared (IR) optical signal and then transmits the IR signal via a fiber optic cable from the UUT to a fiber optic receiver in a ground station. The fiber optic receiver then converts the IR signal back into an electrical signal which is then compared to calibration levels, enabling the estimation of the EMR induced power, and eventually the calculation of the safety margin.

The HBW instrumentation can be accomplished through three instrumentation techniques: thermocouple instrumentation, vacuum thermocouple instrumentation, and fluorescence instrumentation.

3.7.2.1.1 Thermocouple Instrumentation.

The thermocouple instrumentation technique involves mounting a thermocouple device within 0.001 to 0.003 inches of the bridgewire of an inert EED. This technique is used to sense the temperature change of the bridgewire. The temperature change at the bridgewire results from the induced EMR current through the bridgewire and provides an output signal which indicates the heating effect. Typically, an access hole is drilled through the base of the EED through which the thermocouple is routed to the bridgewire. The thermocouple is then cemented into place. This technique also requires the use of a second thermocouple device mounted in close proximity to the bridgewire temperature sensing thermocouple in order to negate the effects of changing ambient temperature conditions. The advantage of this technique is that the actual EED and bridgewire are utilized. One disadvantage is that the thermocouple must maintain a small separation distance (approximately 0.001 inch) from the bridgewire. Variations in the separation distance have been shown to occur due to the shock and vibration experienced during thermocouple installation and UUT test setup requiring numerous re-calibrations of the instrumentation. This technique has a sensitivity of approximately 5 to 10 milliamperes (mA), direct current (dc).

3.7.2.1.2 Vacuum Thermocouple Instrumentation.

The vacuum thermocouple instrumentation technique involves replacement of the HBW EED bridgewire with an electrically equivalent vacuum thermocouple. This technique has advantages over the thermocouple instrumentation technique in that the thermocouple is bonded to the resistive element of the vacuum thermocouple and vacuum sealed within a glass bulb The bonding eliminates the problems associated with shock and vibration and the vacuum sealed bulb eliminates the need for a second thermocouple to correct for drifting ambient temperatures.

Normally, the vacuum thermocouple is mounted within the inert EED hardware and connected to the existing EED signal leads. As with the thermocouple, the vacuum thermocouple senses the temperature change of the resistive element (resulting from the induced EMR current through the EED bridgewire) and provides an output voltage which is proportional to the observed bridgewire temperature. This technique has a sensitivity of 0.5 mA dc.

3.7.2.1.3 Fluorescence Instrumentation.

The fluorescence instrumentation technique involves coating the bridgewire of the EED with a fluorescent material and then mounting a fiber optic sensor within close proximity to the bridgewire. An induced EMR current through the bridgewire causes the bridgewire temperature to increase, providing thermal energy to the coating, creating the fluorescence. When the fluorescence occurs, it emits light which is sensed and transmitted by a fiber optic device in much the same manner as above.

Typically, an access hole is drilled through the base of the EED hardware through which the fiber optic cable is routed to the bridgewire and then potted. As with the thermocouple instrumentation technique, the mounting procedure is difficult and requires several inert EEDs. This technique has a sensitivity of approximately 5 to 10 mA dc.

3.7.2.2 EBW and EFI Instrumentation.

As in the case with the HBW instrumentation, the placement of the ESAD instrumentation is done to minimize the generation and coupling of extraneous signals into the data collection/data transfer system. For reasons similar to those addressed on HBW instrumentation, fiber optics are utilized to transfer data from the ESAD instrumentation package, out of the UUT, and to the data acquisition system.

3.7.3 <u>EMRH Signal Conditioning and Telemetry.</u>

Once the thermocouple is located and calibrated, the signals generated during testing are routed to an instrumentation package located in an empty motor or warhead cavity within the UUT. This routing of electrical leads uses wiring techniques that minimize noise generation or energy coupling from the test environment to the signal conditioning and telemetry (TM) package, i.e., short run, twisted, filtered, impedance balanced leads.

The signal conditioning includes multiplexing and modulating a light emitting diode (LED) in either frequency modulated (FM) or pulse code modulated (PCM) modes. The fiber optic link enables transmission of data out of the UUT during exposure of the UUT to the EMRH environments with minimal signal degradation due to cross coupling, noise generation, and pick up.

3.7.3.1 Onboard Signal Conditioning.

The electrical signals from one or more EEDs are conditioned and multiplexed by feeding the detected thermocouple voltages to an amplifier which drives a LED. The LED

utilizes either FM or PCM modulation to provide data transmission out of the UUT using the LED output as an optical carrier. FM and PCM transmitters/modulators are pictured in Figure 3.7.3.1-1 and Figure 3.7.3.1-2 respectively.

The instrumentation TM systems identified above are located in empty cavities on the inert UUT (i.e., the motor cavity or warhead section of a missile) once combustible propellants or explosive mixtures have been removed. The instrumentation package contains standard components for either a PCM or FM telemetry system with output signals going to an LED amplifier-driver and dedicated power supply (battery pack or air turbine generator) for the TM system. The TM system is packaged in a shielded container and located in the UUT. All signals and power inputs are brought into the TM packages through low pass filters. Once signals are collected and conditioned by the onboard monitoring device, the electrical signals are converted to optical signals by an IR data link. This link includes onboard signal conditioning equipment and an IR transmitter consisting of an LED and either FM or PCM modulators which convert the electrical signals to a modulated IR carrier.

3.7.3.2 On Board Telemetry.

The technique used in collection of EMR test data from the UUT consists of a component or circuit monitoring package located within the UUT. This monitoring package collects and conditions signals for transfer out of the UUT for subsequent processing at a remote station. This transfer process is critical due to the fact that the very E-fields which are observed to degrade the UUT can also degrade the integrity of instrumentation signal generation and telemetry. If the instrumentation signals are transferred through electrical conductors, these conductors can act as antenna, creating induced voltages and currents on the same conductors which are needed to transfer the instrumentation signals. Since the induced voltages and currents generated in these conductors cannot be discriminated from those signals created in the UUT by the EMR, the result will be a contamination of UUT signals (internally generated) with conductor signals (externally generated) compromising the integrity of the UUT data.

Various approaches can be employed to reduce the risk of signal contamination during measurement and telemetry. These approaches include the use of: twisted, shielded pairs; short, low impedance, filtered signal leads; and electronic to optical signal conversion and transmission. Collectively these techniques reduce the coupling of EM energy into the data collection/data transfer mechanism.

The on-board instrumentation includes FM or PCM telemetry systems. The FM or PCM carrier is coupled to an IR fiber optic link which transfers the data out of the UUT and into the data acquisition/data processing system. The output of the LED driver is coupled to the ground station via fiber optics. The fiber optic cable is normally brought out through a natural aperture in the UUT or through a hole cut in the UUT skin such that the waveguide cut off frequency associated with the hole is above the frequencies being used in the tests. The fiber optic cable is routed to the IR receiver in the Ground Station. Figure 3.7.3.2-1 depicts a typical Ground Receiving Station. In the Ground Receiving Station the optical signals are converted back to electrical signals and hard wired into the recording equipment.

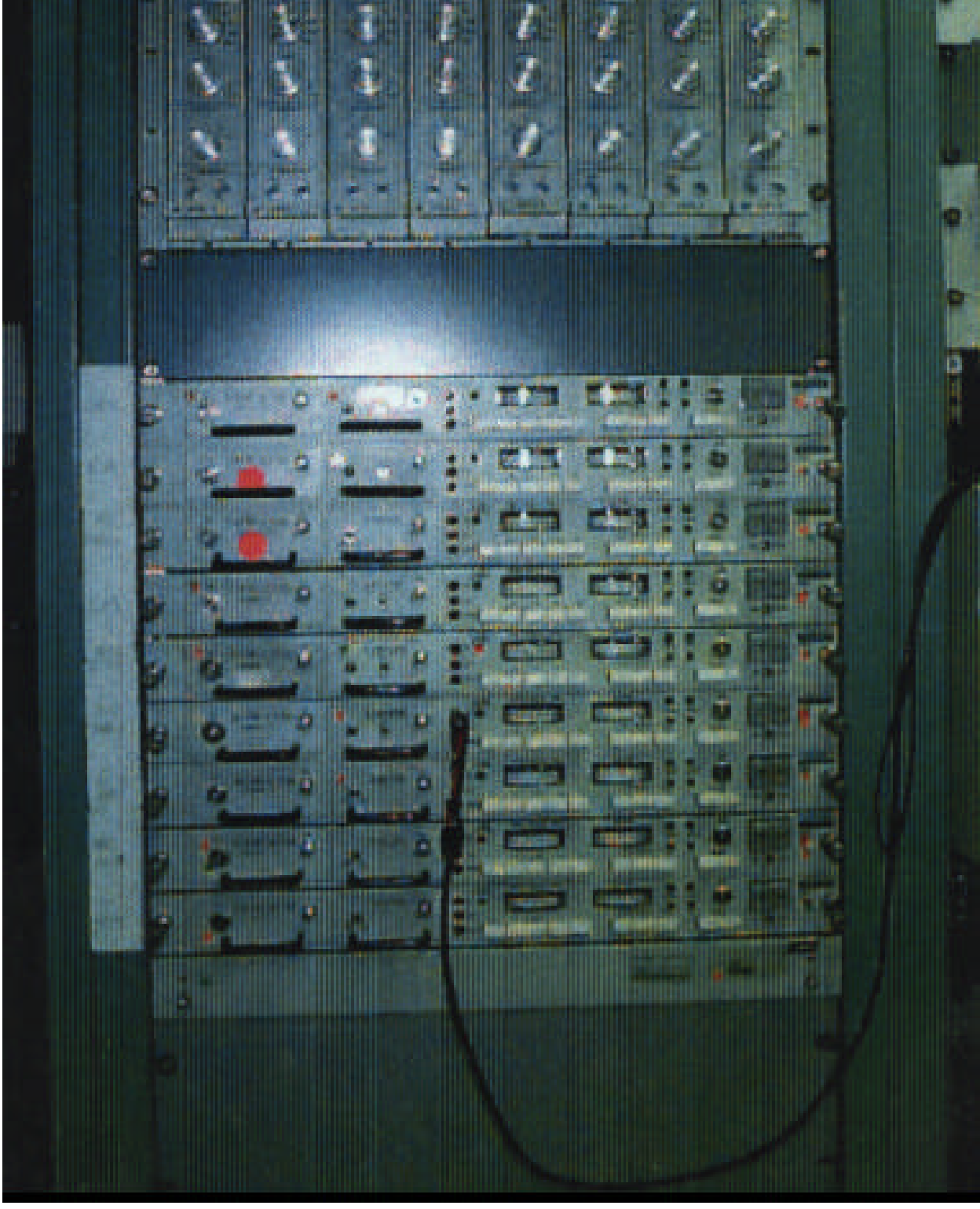


Figure 3.7.3.1-1. FM Modulation.

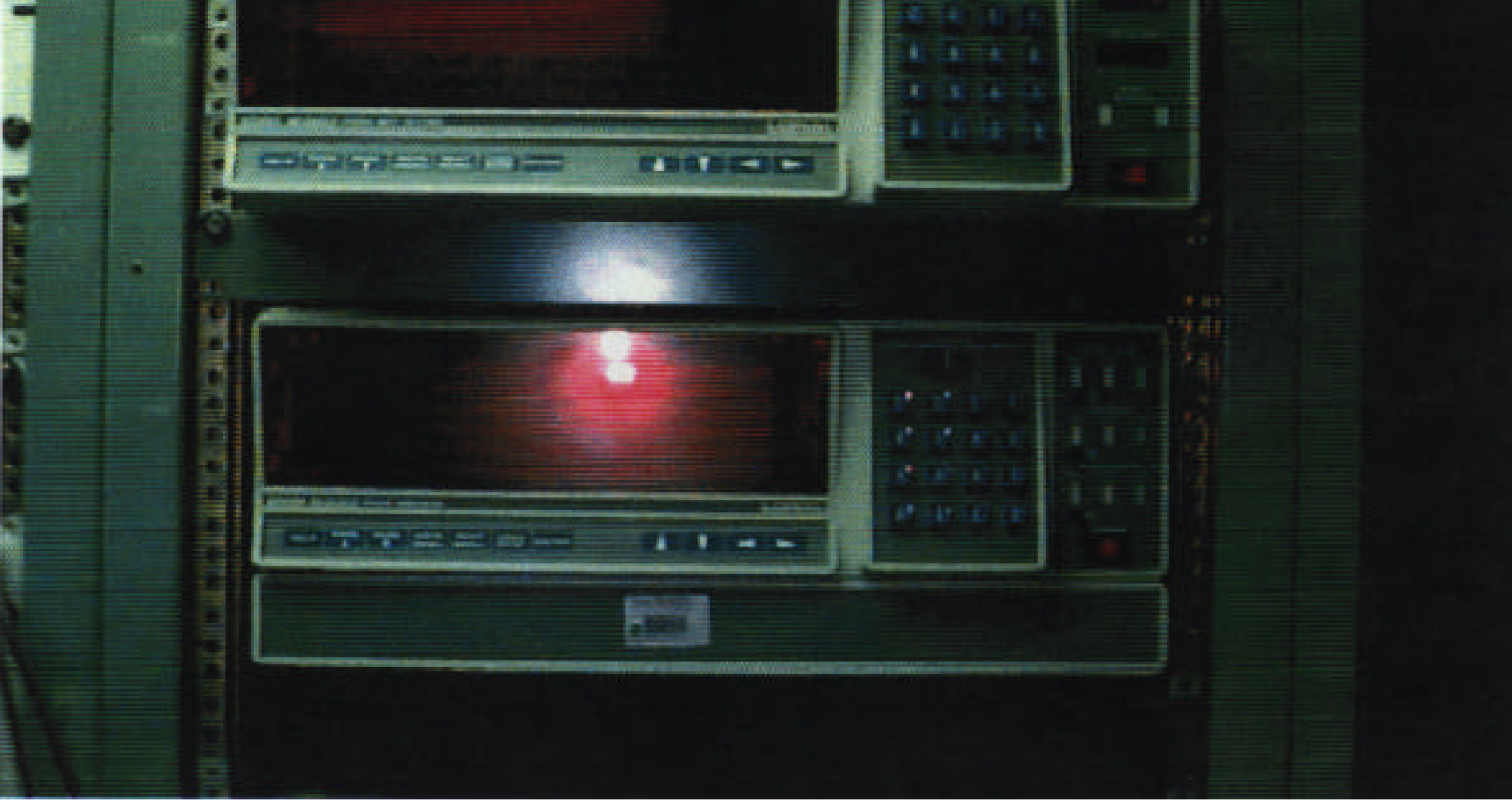


Figure 3.7.3.1-2. Pulse Code Modulation.

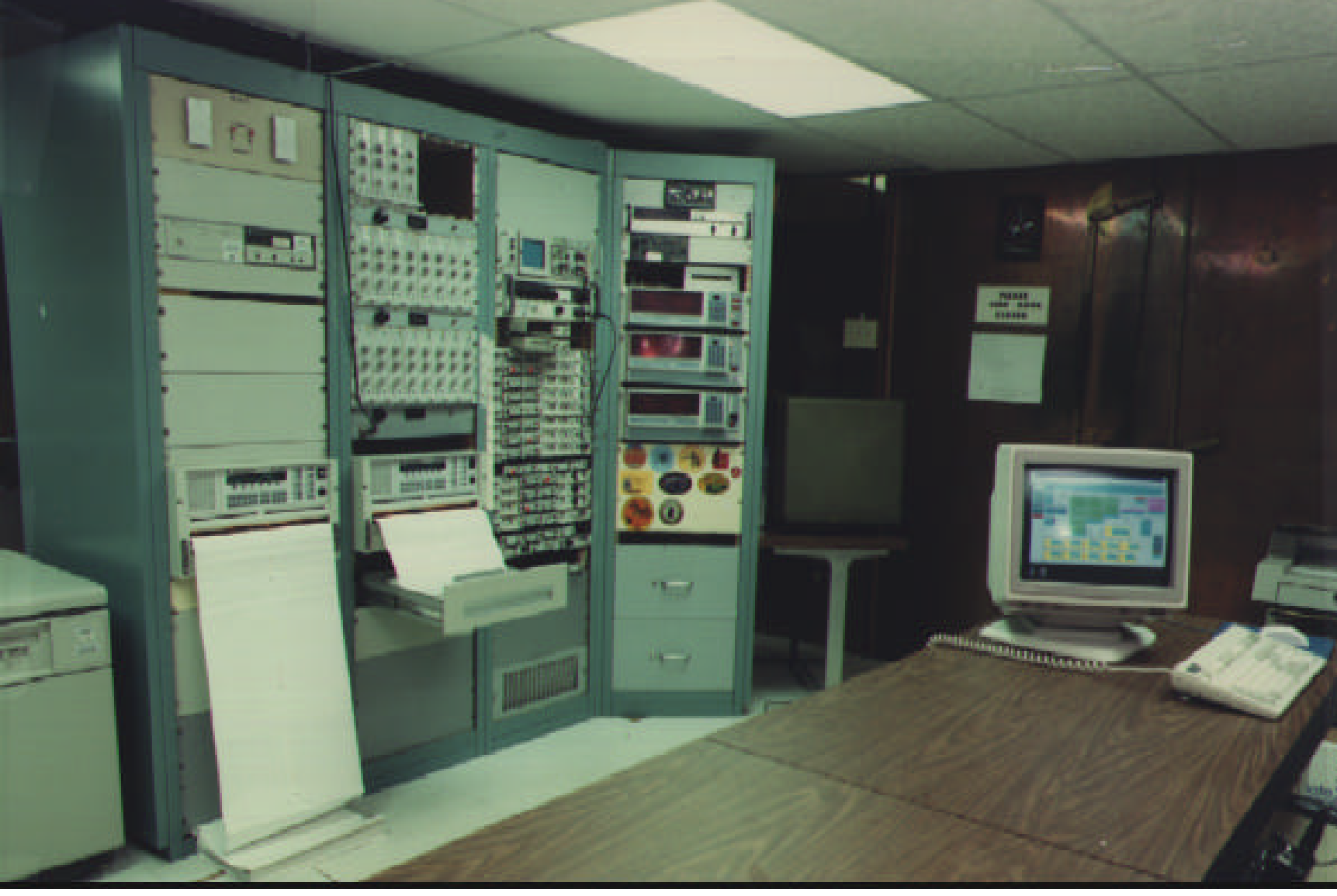


Figure 3.7.3.2-1. Ground Receiving Station.

3.7.4 Test Controller and Data Acquisition.

3.7.4.1 Test Controller.

The data from the UUT are interfaced via personal computer (PC) for real time recording, posttest analysis, and data storage. The PCs are also used to control the UUT, test equipment, and other functions as required, e.g., the Scientific-Atlanta Positioner Systems are PC controlled to automatically position/orient the UUT during the tests.

Three data processing and recording systems are available for receiving and recording data from the UUT for both the open air test site (OATS) and covered test sites. Housed in one of three shielded enclosures, these systems have a full complement of test equipment, including discriminators, oscilloscopes, direct-write oscillograph recorders, tape recorders, computers, power supplies, signal generators, frequency counters, etc.

Figure 3.7.4.1-1 depicts a Test Controller housed in a screen room. The controller uses two to three PCs to record test parameters, calibration data, and test data. These PCs are used to control equipment functions, perform TM demodulation, etc.

3.7.4.2 Data Acquisition.

The FM or PCM IR signal is converted back to electrical signal at the IR receiver in the Ground Receiving Station. The FM analog signal, provided by the IR receiver, is separated by Inter-Range Instrumentation Group (IRIG) discriminators displayed on oscillographs then monitored, recorded, and stored by the computer. The PCM signal is processed, converting the digital signals back to analog, and then displaying the data in a manner similar to that described above.

The Ground Receiving Station, shown in Figure 3.7.3.2-1, houses a PC for real-time recording, analysis, and data storage. All pertinent test conditions and parameters, such as frequency, polarizations, field calibration data, etc., along with monitored data from the UUT, are automatically recorded. In addition, a graphic terminal with hardcopy capability is available for providing data plots for quick-look analysis reports. The computer also controls direct-write oscillographs for recording data from the UUT. All data needed for test reports are stored on disk for subsequent formatting and configuring off line on alternate PCs.

3.7.5 EMRH Data Analysis.

EMRH data analysis can be divided into two categories: 1) those where the applied E-field is compatible with the test criteria, and 2) those where the applied E-fields are less than the criteria.

In the first category, the data reduction task is limited to identifying the magnitudes of the induced voltage, current, power, or energy and determining if the observed parameters are compatible with safe or reliable operation as defined by the calculated safety margin. The results and conclusion are documented as appropriate.

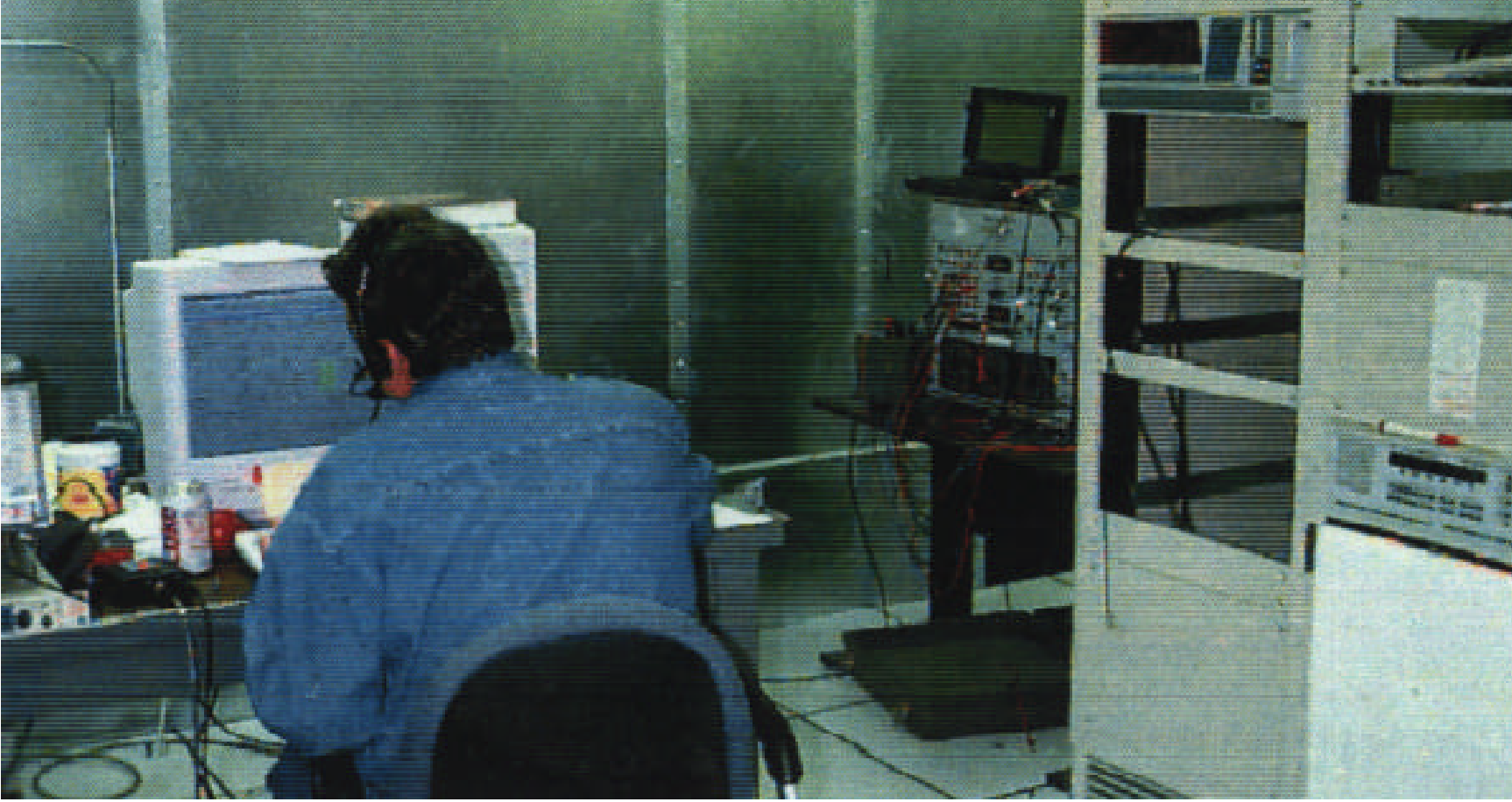


Figure 3.7.4.1-1. Test Controller Installed in Screen Room.

In the second category wherein the applied E-fields are not compatible with the test criteria, two options exist.

A. Option One: used during go/no-go testing, at which time the MNF parameter (current, voltage, power, or energy) is compared to the observed induced parameter, the ratio is used to calculate a safety margin. The calculated safety margin is then compared to a safety margin requirement. The required safety margin is based on mission, deployment, and type of device (hazard or reliability). If the calculated safety margin is equal to or exceeds the safety margin requirement, then the device is determined to be acceptable.

B. Option Two: used when the EED or ESAD is instrumented, the available E-fields are below the test environment, and an induced response is observed. The observed value can be extrapolated to the test environment, with some assumptions. The extrapolated value is then used to estimate the response at the required E-field.

The analytical technique used for each of these options is defined in the following paragraphs.

3.7.5.1 Safety Margin Verification.

The HBW instrumentation is designed to monitor the induced EMR current through the bridgewire in order to determine the safety margin of the EED to the MNFC level while in the test environment. The safety margin is defined as follows:

$$\text{Safety Margin (dB)} = 20 \log(\text{MNFC}/I_{emr})$$

where I_{emr} = the measured induced EMR current or
the minimum detectable current (MDC) of the instrumentation.

Ideally, the MDC of the instrumentation is small such that it can detect I_{emr} at any frequency and criteria. This detection is accomplished when MDC is smaller than I_{emr}, enabling a measurement. In most of the cases, however, I_{emr} is too small to be observed. The estimate for safety margin is based not on I_{emr} , but on the MDC of the instrumentation. Replacing a measurement of I_{emr} with MDC limits the validity of the safety margin calculation, but it errs on the conservative side, calculating a lower safety margin than is actually the case.

The ESAD **(**EBW or EFI **)** instrumentation is designed to monitor the induced EMR voltage on the charge capacitor and determine the safety margin of the ESAD to the MNFV while in the test environment. The safety margin is defined as follows:

Safety Margin (dB) = 20 Log ($MNFV/V_{emr}$)

where V_{emr} = the measured induced EMR voltage, or
the minimum detectable voltage (MDV) of the instrumentation.

Ideally, the MDV of the instrumentation should permit a measurement of V_{emr}. This measurement is accomplished when instrument MDV is smaller than V_{emr} enabling a measurement of V_{emr}. In most of the cases, however, MDV is larger than V_{emr}. In those cases, the estimate for safety margin is based not on V_{emr} , but on the MDV of the instrumentation. This replacement of V_{emr} with MDV limits the validity of the safety margin, erring on the conservative side by calculating a smaller safety margin than is actually the case.

In either case the calculated safety margin is compared to the required safety margin given in Table 3.4.6.1-1 to determine if the device is acceptable.

3.7.5.2 Extrapolation Technique.

During each test, the instrumentation provides a measure of the current or voltage induced in each EED or ESAD. If the E-field available during the test is less than the criteria, then the measured (EMR induced) current or voltage can be extrapolated analytically to the required criteria, assuming a linear relationship between applied E-field and induced current or voltage. The extrapolated value for current or voltage is then used (in place of the empirically observed induced EMR current or voltage value) to calculate the safety margin. The extrapolated level is defined as follows:

$I_{ext} = I_{emr}(E_{crit}/E_{test})$ or

$V_{ext} = V_{emr}(E_{crit}/E_{test})$

where I_{ext} and V_{ext} are the extrapolated values of the induced EMR current or voltage, respectively,

I_{emr} and V_{emr} are the measured values for the induced EMR current (or MDC) and voltage (or MDV), respectively,

E_{crit} is the required (criteria) E-field, and

E_{test} is the E-field available during the test.

Safety margins are calculated using the extrapolated values of I_{ext} and V_{ext} and are compared to those identified in Table 3.4.6.1-1 to determine if the device is acceptable. (If MDC or MDV are used in the extrapolation, the calculated safety margins are on the conservative side depending on the linearity of instrumentation response.)

3.8 TEST DOCUMENTATION

3.8.1 UUT Test Configurations.

The test configurations are determined from "worst case" conditions for the UUT. These configurations include shipping, storage, launch preparation, prelaunch sequence, and in-flight. The worst case conditions throughout these configurations shall include personnel involved in shipping, handling, launch preparation, and launch sequence. Tests are planned to examine those conditions most relevant to the hazard.

3.8.2 Test Plans.

The test plan will be written and approved prior to receiving system hardware. A detailed test procedure will be written after the UUT instrumentation methodology has been determined and the configuration, frequencies, and aspect angles established. A general test procedure for conduct of an EMRH test would be as follows:

A. Perform pretest calibration of the test environment free space E-field.

B. Install the UUT with instrumentation into the test area.

C. Generate the specified E-field on the UUT.

D. Monitor and record the UUT response to the incident E-field.

E. Remove the specified E-field from the UUT.

F. Change polarization and repeat steps “C.” through “E.”

G. Change modulation (if applicable) and repeat steps “C.” through “F.” for all test modulations.

H. Change frequency and repeat steps “C.” through “G.” for all test frequencies.

I. Change orientation of the UUT with respect to the incident E-field and repeat steps “C.” through “H.” for all test orientations of the UUT.

3.8.3 Test Report.

Data processing and recording systems are available for receiving and recording data from the UUT. The data from the UUT are interfaced through a computer with the data processing, recording systems for real-time recording, analysis, and data storage. All pertinent test conditions and parameters, such as frequency, polarizations, field calibration data, etc., along with monitored data from the UUT, are automatically recorded. In addition, a graphic terminal with hardcopy capability is available for providing data plots for quick-look analysis reports. The data processing recording systems also controls direct-write oscillographs for recording data

from the UUTs. All data needed for test reports are stored on disk for subsequent formatting or configuring off line on alternate PCs.

General documentation for the EMRH test includes, but is not limited to, the following:

- Serial numbers of test hardware
- Calibration information
- Non-standard modification of test hardware
- Hardware configuration
- Non-test related problems/failures
- Pretest, posttest, etc. inspection results
- Daily log for test activities
- Facility and instrumentation hardware utilized
- Still photographs of test setup
- Still photographs of test instrumentation

Detailed documentation for each test run shall include, but not be limited to:

- Test sequence number
- Test criteria
- Test environment (to include frequency, polarity and modulation type, orientation of the UUT with respect to the incident E-field, configuration of the UUT)
- Measurement of the induced current or voltage of the EED, power or energy of the ESAD
- Calculation of the safety margin
- Pertinent test observations

SECTION 4.0 ELECTROMAGNETIC RADIATION-OPERATIONAL (EMRO)

4.1 EMRO BACKGROUND

The use of electrical and electromagnetic devices in military systems has become so widespread that most equipment and systems utilized for military purposes depend upon them. The rapid advance of technology has increased not only the number of electrical components and equipment, but also their complexity. The proliferation of solid state and digital electronic equipment has greatly increased the susceptibility to degradation in performance due to interactions with electromagnetic fields.

In a conventional theater battlefield, army operations may employ tens of thousands of emitters of electromagnetic energy. This dense concentration of emitters, as well as the possibility of intentional jamming by enemy forces, increases the likelihood of equipment degradation due to electromagnetic energy. Therefore, testing to verify the operational reliability, namely EMRO of electrical and electronic equipment, is essential to quantify limitations with respect to the electromagnetic radiation (EMR) in the radio frequency (RF) environment.

4.2 EMRO TEST OBJECTIVE

The objective of the EMRO test is to determine if exposure to the representative electromagnetic environment, or that established by the system E^3 Requirements Board (E^3RB), results in degraded operation (malfunctions, undesirable, or unacceptable responses) of the unit under test (UUT) and its associated electronics, electrical, and electromagnetic equipment. It should be noted that since each specific UUT responds differently to the same test environment, the results of each EMRO qualification test can be applied only to the specific UUT configuration tested. Therefore, EMRO testing is required for every different UUT configuration whether as a result of a change in UUT design or material characteristics.

4.3 EMRO APPLICABILITY

The EMRO requirement is applicable for the determination of degraded operation of the UUT and all associated electronics, electrical, and electromagnetic equipment caused by electromagnetic radiation from 14 kHz to 40 GHz. The EMRO requirement is applicable for all configurations and operational phases (i.e., pre-launch, launch, and in flight) of the UUT: for ground based systems, developed for the Army, for systems deployed or utilized on Army rotary and fixed wing aircraft, and for systems developed for both Army and Navy (Marines) including joint operations.

4.4 EMRO CRITERIA

The following EMRO criteria were developed without specific input from any system E^3RB. Thus, the EMRO criteria provided are the minimum Army requirements and describe those environments within which Army systems are expected to operate without degradation.

4.4.1 Army Ground Based System Criteria.

The EMRO criteria, given in Table 4.4.1-1, is generally lower than the EMRH criteria. These low criteria result from the low probability that the system will be deployed and operated near a high power emitter. This condition is even more certain for ground based systems. For the EMRH testing, the UUT is evaluated using worst case conditions, amplifying a potential hazard (e.g., a missile being transported close to high power emitters). Furthermore, EMRO criteria are established using only military emitters while EMRH criteria are established combining both military and civilian emitters.

In calculating field strengths for the EMRO environments, the following emitter-to-UUT separation distances were used:

- Mobile radios, 5 meters
- Fixed and large antenna system, 50 meters
- Aircraft emitters, 150 meters
- "Friendly" countermeasures, 10 meters
- Portable radars, 300 meters
- Permanently installed radar site, 1000 meters

In establishing the modulation to be used, the following criteria were followed:

- Frequency Modulation (FM) - A majority of Army FM emitters are in the 20 to 76 MHz band.
- Amplitude Modulation (AM) - Army AM emitters operate throughout the 0.1 to 1000 MHz band.
- Selected Modulation - Through experience in missile EMRO testing, it has been determined that the most susceptible modulations are related to frequencies inherent to the UUT (e.g., clock frequency, gyro spin rate, etc.).
- Pulse Modulation (PM) - Most radars utilize pulse modulation transmission; representative duty cycles are 0.001 and 0.0001.
- Peak levels up to the capability of broadband emitters are to be verified by test.

Above this capability, the requirements will be verified by either analysis or test, depending on the practicality of performing tests. Usually specific radars will be identified in order to test the system at the appropriate peak E-fields and frequencies.

4.4.2 Airborne Army System Criteria.

If the system under development is intended for use on Army helicopters or aircraft, then the criteria is defined as the greater of 200 V/m (rms), Table 4.4.2-1, or the current shipboard environment specified in MIL-HDBK-235. The criteria of Table 4.4.2-1 was taken from Aeronautical Design Standard ADS-37, dated 16 Apr 90, entitled: "Electromagnetic Environmental Effects (E^3) Management, Design, and Test Requirements". (ADS-37 is currently being revised, and test criteria are likely to change.)

Table 4.4.1-1. Army Ground System EMRO Test Criteria, Pre-launch and Flight.

	Communication Emitters Field (V/m) rms				Radar Emitters (PM)			
Frequency (MHz)	CW	AM	FM	Polarization V/H	Frequency (GHz)	Peak Fields (V/m)	Average Field (V/m) (rms)	Pol
0.1-2.0	25	25		V	0.35-1.2	1500	50	V/H
2.0-20	50	50	-	V	1.2-18	2500	50	V/H
20-30	50	50	50	V	18-26.5	1000	25	V/H
30.0-100	50	50	50	V/H	26.5-40	1500	50	V/H
100-500	25	25	-	V/H	-	-	-	-
500-1000	50	50	-	V/H	-	-	-	-

Note: The above values are the average (rms) field strengths. AM will be tested using a square wave with 80% modulation, at 400 Hz and 1 kHz as a minimum. FM will be tested using ± 50 kHz deviation. Additional frequencies for both AM and FM will be determined from the frequencies encountered by the system during operation. PM is dependent on transmitter limitations and is frequency dependant.

Table 4.4.2-1. Army Airborne System EMRO Criteria.

Frequency	E-field, (V/m) rms
.014 to 350 MHz	Maximum of 200 or shipboard environment *
350-1000 MHz	Maximum of 200 or shipboard environment *
1 - 40 GHz	Maximum of 200 or shipboard environment *

* See Table 4.4.2-2

Table 4.4.2-2 MIL-HNBK-235 Shipboard Environmental Test Criteria.
(The information contained in this table is currently classified and not suitable for inclusion here.)

Frequency	E-field; (V/m), peak/rms

NOTE: For each frequency to be tested, the test manager must review MIL-HNBK-235 and determine the criteria. This determination is based on the greater of 200 V/m, rms, unperturbed field, for frequencies from 14 kHz to 40 GHz plus current (at date of test) shipboard environment, or the value quoted in the MIL-HDBK-235.

4.4.3 Joint Services System Criteria.

If the system under development is intended to be used by the Army and Navy (Marines) or utilized in joint operations, then a worst case combination of Army (Table 4.4.3-1) and Navy (MIL-HNBK 235) environments is applicable. Coordination with the appropriate Navy (Marines) office is needed to ascertain joint service mission requirements.

Table 4.4.3-1. Army, Navy, and Combined Operation Test Criteria.
(The information contained in this table is currently classified and not suitable for inclusion here.)

Frequency	E-field; (V/m), peak/rms

4.4.4 Personnel EMRO Criteria.

When EMRO tests are conducted with personnel involvement in the test area, the EMRO test levels of paragraphs 4.4.1, 4.4.2, and 4.4.3 will be limited to the maximum Personnel Exposure Limit (PEL) specified in USAEHA Technical Guide No. 153. In some instances, due to the reflective characteristics of the article being tested, electric fields may exceed the PEL at positions where personnel are located. This possibility may occur even though the test field is observed to be lower than the PEL during E-field calibration and prior to installation of the UUT. For this reason, the E-field at those positions where personnel will be located, should be measured prior to testing to determine if the observed E-field exceeds the PEL.

4.4.5 Tailoring of EMRO Criteria.

When the EMR sources associated with the intended mission of the system are capable of producing E-fields in excess of those specified in paragraphs 4.3.1-1, 4.3.2-1, and 4.3.3-1, the higher E-fields shall apply as the criteria. The EMRO criteria specified by

paragraphs 4.3.1, 4.3.2, and 4.3.3 shall be tailored by the system E^3RB to meet these special electromagnetic environment requirements as dictated by the system's mission.

4.4.6 Pass/Fail Criteria.

The UUT and all associated electronics, electrical, and electromagnetic equipment shall not exhibit any malfunction nor degradation of performance, which would prevent the UUT from completing its intended mission, when subjected to the radiated electric fields specified in paragraphs 4.3.1, 4.3.2, and 4.3.3 (whichever is applicable). Testing at the criteria level is critical, since extrapolation techniques for interference on signal lines are impractical.

4.5 EMRO FIELD CALIBRATION

The RTTC test methodology establishes free space calibrations for the E-field probes prior to introducing the UUT into the test site.

4.5.1 Calibration of E-field Sensors.

Periodically, the electric field sensors are calibrated in the laboratory. Electric field sensor systems are normally supplied with tables of calibration factors. These tables identify the dynamic range of the sensor probe, but are insufficient for a complete calibration database. In order to develop a calibration database, the E-field probes should be place in known E-fields (intensity). This calibration is accomplished by using TEM transmission cells and matched transmit/receive standard gain horn antennas to obtain the desired E-fields. Below 500 MHz the E-field probes are calibrated in the TEM transmission cells. Above 500 MHz the E-field probes are calibrated in the anechoic chamber, utilizing matched transmit/receive standard gain horn antennas. Using a known power for the transmit antenna and a known E-field, the receive antenna is replaced with the E-field probe and the probe measurement is recorded accordingly.

4.5.2 Free Space Calibration.

Free space calibrations are performed with E-field sensors in place, but without the UUT installed at the test site. This placement is done to characterize the E-fields generated by the transmit antenna, without the perturbations that would be created by the presence of the UUT. Monitoring the E-field during the test with the UUT in the test field could result in erroneous measurements of the test environment due to interference (multipath and reflections) caused by the coexistence of the probe instrumentation and the UUT. The reflections can be constructive or destructive, depending on specific location, frequency, polarization, and orientation, and could result in invalid field measurements.

For this reason, free space field calibration with an E-field probe is conducted prior to the test, for all candidate frequencies and polarization. The calibrations are accomplished by placing the probe at those locations representative of the UUT placement, and recording the probe signals accordingly. For 10 kHz to 1000 MHz, Amplifier Research Probe Model Number FP2000 is used. For 80 MHz to 40 GHz, Amplifier Research Probe Model Number FP 2080 is

used. Amplifier Research Model FM 2004 Field Monitor is used to observe the output of either probe. Power to the antenna is measured with power meters. The E-field calibrations are conducted prior to each test effort.

Field calibrations are obtained by measuring field strengths produced by reference transmitter output power. The results are in the form of a table of transmitter output power versus measured field strength for each test location. These E-field probe calibration tables are stored in the data acquisition computer files and used when the data reduction and data analysis tasks are performed. During the tests, the computer reads the effective transmitter power (output minus reflected power) and calculates the field strength at the location of the UUT. Field strengths can be calculated for transmitter powers other than those at which the calibration was made.

The probe calibration data is obtained using one of two approaches:

A. For tests conducted in the 250 MHz to 18 GHz frequency range, standard gain horns with power meters and far field calculations are used to calibrate sensor probes.

B. Below 250 MHz the electric field sensors are calibrated using the transverse electromagnetic (TEM) transmission cell. The sensor probe is then placed in front of the antenna at the future location of the UUT. The E-field environment generated by the test antenna is calibrated prior to each test.

4.5.3 Far Field Testing.

Field uniformity over the volume of the UUT must be considered prior to placing the UUT in the test field. If the UUT is placed too close to the source antenna, the E-field over the UUT may be non-uniform, due to the antenna spatial distribution pattern. This effect is sometimes referred to as the "near field non-uniformity. In an attempt to correct this problem, the UUT is placed in the "far field" region of the antenna. The distance to the "far field" region is dependent on the physical size of both the UUT and the antenna as well as the frequencies being used during the test. It is common practice to locate the UUT no closer than the range defined by the relationship:

$$r = (2*D^2/\lambda)$$

where r is the minimum distance to the antenna,
D is the physical dimension (larger of the antenna or UUT) and
λ is the wavelength of the test frequency being used.[1]

[1] Skomal , Smith "Measuring The Radio Frequency Environment", 1985, p.212

4.6 EMRO TEST PHILOSOPHY

The RTTC test methodology consists of generating and calibrating free space E-fields with sensor probes prior to introducing the UUT to the test site. This free space calibration is done to prevent (or at least reduce) perturbations due to the presence of UUT during field calibrations and to reduce perturbations due to the probes during the E-field measurement.

4.6.1 Device Technology.

The basic technique used in collecting EMR test data is to use a component or circuit monitoring instrumentation package that collects and conditions signals for telemetry (TM) by an infrared (IR) data link. This data collection can be accomplished by adapting the existing in-flight TM package and combining it with an IR data link. Alternately, custom instrumentation packages can be designed and fabricated to monitor the desired signals. Instrumentation techniques depend on the type of signal to be monitored (analog or digital, simple or multiplexed, continuous or sampled). Critical electronic circuits are identified and instrumented based on the type of signal being monitored and the interface requirements of the UUT.

Since these tests are performed while the system is operational, the UUT must be performing operational functions during the EMRO Tests. For this reason, the electronics of the UUT are energized to permit the initiation and continuation of functional operation throughout the test. The functional operation of the UUT is accomplished by an ancillary system providing both power and cooling for electronics (sometimes through external quick disconnects) since the UUT is stationary during the test. The UUT power supply is replaced with a suitable battery pack or air turbine generator to provide power for the electronics, servos, etc. The TM package is usually powered with a separate battery or air turbine generator.

4.6.2 Test Philosophy.

Due to the potential hazards associated with live UUTs, EMRO testing is conducted on an inert but operable UUT, preferably with the entire UUT exposed to the EM environment. As noted, the test conditions, configurations, and procedures are related to the "as deployed" operational environment.

The UUT is usually considered to be susceptible if degradation occurs which would reduce the effectiveness of the UUT. For example, if the EMR levels prevented a missile guidance system from tracking the target, then the missile would be considered susceptible. The tests can be designed to obtain the necessary input data to support computer simulation, determining the degree of degradation in the UUT as a function of EMR parameters. Test variables and parameters are selected to establish a basis for evaluation. Based on discussions with the development contractor, numerical values are provided for these parameters. The numerical values provide additional test criteria in determining the success or failure of the UUT during EMRO testing. These numerical values refer to analog voltage levels on control circuits and digital logic signals which represent various stages of flight.

The EMRO test is divided into four distinct phases: 1.) test plan development, 2.) pretest setup, 3.) conduct of the test, and 4.) data reduction and test documentation.

The instrumented tests need to be performed at the specified E-field levels (whether according to standard EMRO criteria or to E^3RB) since extrapolation of induced interference on control and digital signals is difficult and estimates of performance based on extrapolated values is always suspect.

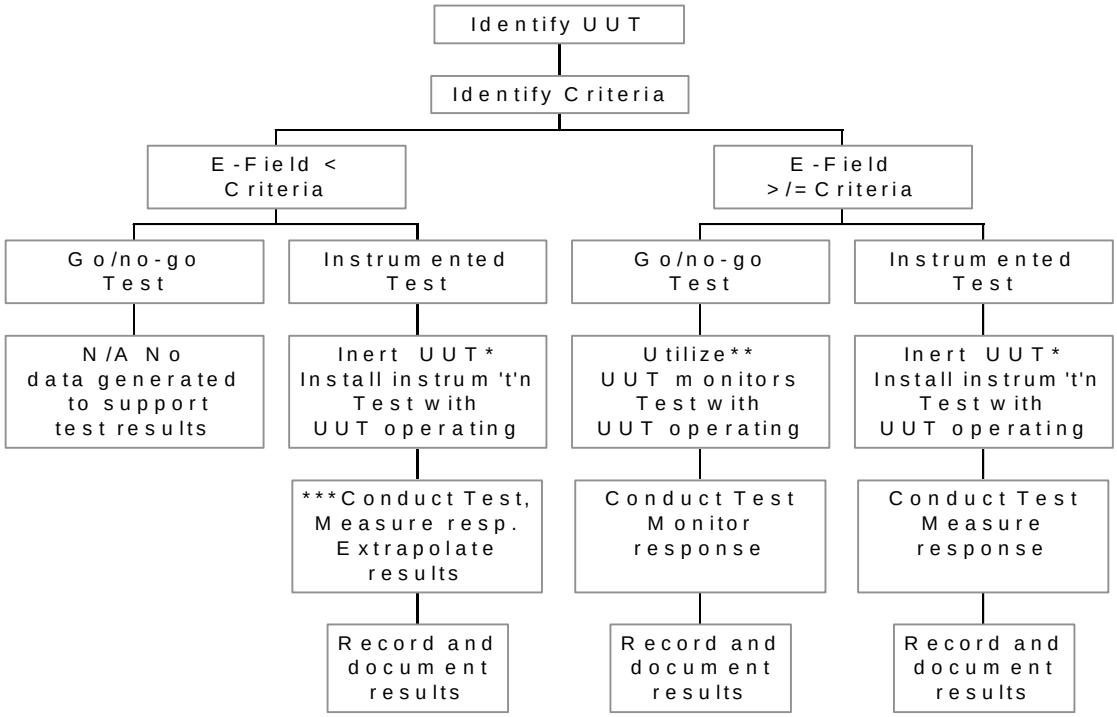
4.7 EMRO TEST PROCEDURES

Verification of the UUT operation in the EMRO environment can be accomplished by two different test techniques: instrumented testing or go/no-go testing. Instrumented testing requires monitoring all signal lines and subsequently obtaining a detailed knowledge of component responses and threshold levels for proper operation. Go/no-go testing involves monitoring the UUT for proper operation. For both test techniques, the UUT should be thoroughly exercised to verify all UUT components and operational modes or functions are satisfactory (e.g., a missile UUT should be exercised from pre-launch through target intercept). For either test technique, it is imperative that a definition for failure (signal interference, UUT reaction or response) be made prior to initiation of test to avoid confusion and indecision. For EMRO testing, it is absolutely necessary that the UUT be tested at E-field levels as specified in the criteria, since go/no-go testing is binary and cannot be extrapolated. It is also critical for the instrumented test since the extrapolation of noise and its effect on control and digital logic signals is nonlinear and conclusions based on extrapolated values are questionable at best.

Figure 4.7-1 contains a test matrix that identifies all candidate test options. Options labeled “N/A” indicate those options which are “not available” due to practical limits (namely, the inability to generate the necessary E-fields) or utility (the inability to determine success or failure of the UUT). The type of test selected depends on the available test hardware, the ability to generate the required EM environments and provide the necessary instrumentation.

4.7.1 Instrumented Testing.

Instrumented testing requires an extensive knowledge of the effects of interference (noise) on the various signals and the threshold level for proper operation of the UUT down to the individual circuit. Utilization of a UUT simulator may be necessary in order to properly determine the interference on the control signals with respect to UUT performance. The effects of various EMR modulations are critical in EMRO testing. Experience indicates that EMR fields should be modulated at the missile carrier frequencies to investigate the possibility of missile upset, e.g., guidance, track maintenance, canard servo controls. By monitoring various system functions and correlating these with test parameters, it is possible to determine the EMR levels (thresholds) which will cause minimum observable perturbations as well as the EMR levels which will give rise to major catastrophic events in the UUT.



* UUT are made inert by system contractor.

** These monitors are UUT specific and may consist of video channel to record panel lights or video monitor of sensor line of sight during track.

*** Due to difficulty in extrapolating test results, this technique is not recommended for EMRO tests.

Figure 4.7-1. EMRO Test Flow Diagram.

If the specified E-fields cannot be achieved, then one method of verifying the system performance is to extrapolate the induced interference signal, assuming linear relationships between the stimulus and response, and injecting the estimated (extrapolated) levels directly into the signal lines. While this approach is physically possible, there is no guarantee that the inserted signals are correctly estimated, nor that the response of the UUT in the real world would be consistent with that observed in the artificially created environment.

4.7.2 Go/no-go Test.

Go/no-go testing requires the UUT be continuously monitored for normal operation while being subjected to specific EMRO criteria. Go/no-go tests are virtual end-to-end tests for the UUT. The go/no-go test is intended to examine UUT performance without extensive additional instrumentation, while observing UUT performance based on intrinsic response. Detailed procedures are followed while UUT responses are monitored and recorded by test personnel. If an upset occurs, the UUT threshold levels are determined by reducing the test field until any abnormal response disappears. In some cases, it may be necessary to record the UUT response with video cameras by viewing through fiber optics and lenses to quantify the interference (i.e., recording the interference effects with a night sight screen or an IR monitor). The go/no-go test requires the facility have the capability to test at the required environment, since a go/no-go response cannot be extrapolated.

4.7.3 EMRO Instrumentation.

The EMRO instrumentation packages are unique for each UUT and signal channel and will vary from one UUT to another. The circuits monitored are usually the same ones observed in flight by the TM system. The EMRO instrumentation packages interface with the critical circuits at the TM connector. If not all of the circuits are available at the TM connector or if a flight TM package is unavailable, then a custom instrumentation package can be designed and installed to monitor these signals. Integration of the EMRO instrumentation is critical to data collection and must minimize EMR-induced noise coupling into the measurement system.

Instrumentation is placed in the UUT to minimize the length of signal leads and to take advantage of the natural shielding of the UUT, for example installing the instrumentation package into an empty flight motor cavity of an inert missile system. Twisted, shielded wires are utilized to mitigate noise sources. Leads are filtered to further minimize EMR-induced noise from getting into and compromising the measurement.

The instrumentation package detects electrical signals representative of the operation of the UUT. The electrical signals are used to modulate (by either FM or PCM) an optical carrier (generated by an IR LED). The modulated IR signal is transferred out of the UUT and test area by a fiber optic cable. The fiber optic cable terminates at an optical receiver located in a shielded ground receiving station (or screen room) where the optical signals are converted back to electrical signals. This method virtually eliminates the possibility of the instrumentation link (fiber optic) affecting the antenna characteristics of the UUT or altering the coupling characteristics of the EMR to the UUT. The fiber optic cable is normally routed through a

natural aperture in the UUT (or if necessary, through a hole cut in the UUT skin) such that the waveguide cut off frequency characteristic of the hole is above that of the EMRO frequencies used in the tests. The size limitation of the hole limits the EMR power entering the UUT through the hole.

The fiber optic receiver located in a ground receiving station converts the IR signal back into an electrical signal, with the latter compared to the calibration levels during data reduction to determine test results. Data processing and recording systems are available for receiving and recording UUT data. The data from the UUT are interfaced with the data processing and recording systems for real-time recording, analysis, and data storage. All pertinent test conditions and parameters, such as frequency, polarization, field calibration data, etc., along with the data monitored by the instrumentation package in the UUT, are automatically recorded.

4.7.3.1 Flight Telemetry Package Adaptation.

For UUTs which include flight TM packages, the most efficient and practical technique is to adapt this TM package for use with an IR data link. Repackaging the TM package into a shielded container may also be necessary to harden the TM package for operation in the EMRO environment. The utilization of the flight TM package has two advantages. First, the signal detection network will not have to be re-engineered, thereby saving design, fabrication, assembly, and integration cost and schedule. The instrumentation package will have minimum impact on the UUT operations, since compatibility of the TM package with the UUT electronics will have been verified during the UUT development program. Secondly, a direct comparison to the data from the development program can be performed since the same signals are being monitored for the EMRO tests.

4.7.3.2 Custom Designed Package.

The custom designed instrumentation package consists of onboard signal conditioning equipment and an IR transmitter which converts each measured electrical signal into a modulated IR signal, using either frequency modulation (FM), as depicted in Figure 3.7.3.1-1, or pulse code modulation (PCM), as depicted in Figure 3.7.3.1-2. This instrumentation design, fabrication, assembly, and integration is usually done with the aid of the system contractor. Provisions are made within the EMRO instrumentation package to turn power on and off and to perform other missile related functions.

4.7.4 Data Acquisition/Test Control.

The data acquisition and test control area, as depicted in Figure 3.7.4.1-1, is housed in a screen room and uses two to three PCs. It has the capability to record test parameters, calibration data, test and equipment control functions, data conditioning, recording, etc.

4.7.4.1 Test Controller.

The PCs are used to control the UUT, test equipment, and other controlling functions as required, i.e., the Scientific-Atlanta Positioner Systems are managed by the test controller and used to position/orient the UUT automatically during test cycles.

4.7.4.2 Data Recording and Display.

The data from the test specimen are interfaced with the computer for real-time recording, analysis, and data storage. All pertinent test conditions and parameters, such as frequency, polarization, field calibration data, etc., along with monitored data from the UUT, are automatically recorded. Additionally, a graphic terminal with hard copy capability is available for providing data plots for quick-look analysis reports. The computer also controls direct-write oscillographs for recording data from UUTs. All data needed for the test report are stored on disk for formatting and configuration off line on alternate PCs.

4.7.5 Data Analysis.

EMRO data are collected from either instrumented or go/no-go tests. In the instrumented tests, the UUT is operated while exposed to the E-fields and the critical circuits (guidance, track, servo control) are monitored for any perceptible change due to the presence of EMR. Comparison of signals before, during, and after EMRO exposure provides indications of susceptibility to degradation or upset due to the EMR. Evaluation is dependent on proper pretest instructions/recommendations by the development contractor/manufacturer as to the appropriate signal levels and waveforms necessary for proper operation of the UUT. This signal comparison is enforced by observations made by E^3 test personnel and their ability to monitor, detect, and record anomalous signals and waveforms unique to both analog and digital signal processing in the UUT. Frequently, the anomalies are subtle. Only through the astute observation by and awareness of the test personnel, in conjunction with the high fidelity test equipment, are the results of UUT exposure to EMRO evident. In the case of the instrumented UUT, the anomalous signals are recorded, as are the EMRO field strengths in existence at the time of the observation. Together these data provide the basis for the developer/manufacturer to analyze, isolate, and modify his equipment in order to reduce or eliminate equipment degradation/upset due to EMRO criteria.

In those cases where the EMRO tests are of the go/no-go variety, the test results are capable of identifying overt perturbations in the UUT. These can take the form of oscillating, stalled or locked canards, or modification in the seeker/gimbal scan sequences/excursions as evidenced by “through the sight viewing” or video signal processing. For a UUT which operates with command input signals, the EMRO tests may demonstrate an inability for command signals to be detected, due to saturation of the receiver channel by excess (in band or out of band) RF background levels. Unfortunately, these go/no-go tests are less likely to detect the subtle modifications in signal characteristics as evidenced by instrumented testing. However it can be used to determine major susceptibilities of equipment to EMRO exposure, prior to conducting instrumented tests. It can also provide rapid examination of equipment performance in and

around missile operational frequencies as a function of UUT orientation, E-field polarization, modulation, amplitude, or frequency.

The benefits of EMRO testing is to provide both quantitative and qualitative testing, to support the examination of UUT to degradation and upset due to EMRO criteria. The data analysis can identify that a problem exists at a certain field strength, frequency (or band of frequencies), polarization and modulations. It may even identify the specific sub-system or subassembly responsible for degraded operation or upset due to signal levels induced on specific components by exposure to specific EMRO frequencies, modulations, and polarization.

As a result, EMRO data analysis is primarily an attempt to identify, isolate, and document the observed anomalous behavior on complex electronic and electromagnetic devices. These observations can be accomplished whether evidenced by overt reduction in performance or more subtle modification in the electrical signals and command logic within the UUT.

4.8 EMRO TEST DOCUMENTATION

4.8.1 Test Configurations.

The test configurations are determined from "worst case" conditions for the UUT. These configurations include UUT checkout, preparation, and operation (i.e., missiles would be configured for launch preparation, launch sequence, and in-flight). The worst case configurations shall include personnel involved in UUT checkout, preparation, and operation. Tests are planned to examine those conditions most relevant to the UUT operation, while controlling the less relevant factors.

4.8.2 Test Plans.

The test plans will be written and approved prior to receiving UUT hardware. A detailed test procedure will be written after the UUT has been instrumented and assembled, with test time limits established for instrumented operation, configuration, frequencies, and aspect angles. A general test procedure for conduct of an EMRO test would be as follows:

A. Perform pretest calibration of the free space E-fields.

B. Install the UUT with instrumentation (if necessary) into the test area.

C. Generate the specified E-field at the UUT.

D. Exercise the UUT through its operational sequence. Monitor and record the UUT response to the incident E-field.

E. Remove the specified E-field from the UUT.

F. Change polarization and repeat steps “C.” through “E”.

G. Change modulation (if applicable) and repeat steps “C.” through “F.” for all test modulations.

H. Change frequency and repeat steps “C.” through “G.” for all test frequencies.

I. Change orientation of the UUT with respect to the incident E-field and repeat steps “C.” through “H.” for all test orientations of the UUT.

4.8.3 Test Report.

General documentation for the EMRO test includes, but is not limited to, the following:

- Serial numbers of test hardware
- Calibration information
- Non-standard modification of test hardware
- Hardware configuration
- Non-test related problems/failures
- Pretest, posttest, etc. inspection results
- Daily log for test activities
- Facility hardware utilized
- Instrumentation hardware utilized
- Still photographs of test setup
- Still photographs of test instrumentation

Detailed documentation for each test run shall include, but is not limited to, test sequence number, test criteria, test environment (to include frequency, amplitude, polarization, modulation, and orientation of the UUT with respect to the incident E-field), configuration of the UUT, measurement of the induced interference signal, and pertinent test observations.

SECTION 5.0 LIGHTNING EFFECTS (LE)

5.1 LE BACKGROUND

Lightning discharges are the result of a build-up of static electrical energy in cloud centers. This buildup is due to air turbulence which typically occurs when cold air fronts meet warm air masses. These frontal storms are large scale events and some fronts may extend over hundreds of miles. The mechanism of cloud electrification is somewhat uncertain. There are at least three theories currently used to explain cloud electrification phenomena: the breaking drop, the influence, and the ionization theory. The last of these three is discussed briefly in the following paragraph.

In the breaking drop theory, the electronic charges are a result of complex hydromechanics in the cloud wherein water droplets alternately rise and fall building in size during the cycle until their weight reaches a point at which they fall from the cloud in the form of rain. Prior to their departure from the cloud, the water droplets contribute to the mechanism of charge separation and buildup. The charge separation progresses so that the lower part of the cloud generally becomes negatively charged (attracted to a positively charged earth), while the top of the cloud becomes positively charged. Cloud tops normally extend to 30,000 feet at which point lightning has been observed to commence. However, some weather heads have been recorded as high as 60,000 feet.

Clouds can demonstrate a tendency toward their electrostatic polarization with charge retention and buildup until a breakdown occurs. This breakdown or discharge can be of two varieties: cloud-to-cloud or cloud-to-ground. However the electromagnetic effects of the breakdown are not the only concern. Even when the cloud is overhead, there is the potential of creating a high intensity electric field between the cloud and the surface of the earth. As the magnitude of the charge on the cloud accumulates, the electrical potential increases until the electric field reaches its breakdown point and discharges, either to another cloud (cloud-to-cloud) or to earth (cloud-to-ground). Damage to systems and components can result from the large fields prior to a strike as well as either a direct strike or a near strike lightning event. Damage can manifest itself as electrical shorts or open circuits in cables, as the destruction of solid state heterostructures or junctions, or as the malfunction of electro-explosive devices (EEDs).

Less traceable but potentially just as critical are the effects of lightning in causing momentary interruption of system power or signals. This effect depends on how well the system is protected. It is important to consider the frequency of occurrence of the system with lightning storms. For example, systems deployed in the polar regions or deserts would have minimal risk from lightning, whereas systems deployed in tropical areas would have a significantly higher risk of thunderstorms. There is currently an international system for recording worldwide the frequency of storm occurrence. This is a binary data record, identifying the number of storms occurring per day without providing a measure of intensity. It enumerates the frequency of electrical storms within geographical limits over the entire surface of the earth. The issue, therefore, is that if a system is to be used in all climates, then the potential risk for damage or

upset resulting from lightning can be investigated and identified. Based on these risk estimates, the designer can determine the necessity of pursuing lightning protection required by the system.

5.2 LE TEST OBJECTIVE

The objective of the LE test is to determine if exposure to the direct strike and near strike lightning defined by minimum Army criteria or the system E^3 Review Board (E^3RB) will result in either a safety hazard or degraded operation of a system. The "system" includes any associated electronics, electrical, and electromagnetic equipment for the unit under test (UUT). Safety hazard is defined as premature activation of an EED or an electronic safe and arm device (ESAD). Degraded operation is defined as a malfunction or as an undesirable or unacceptable response. It should be noted that since each specific system responds differently to the same test environment, the results from any LE test can only be applied to the specific UUT configuration tested. Therefore LE testing is required for each unique UUT configuration, whether by design or material characteristics.

5.3 LE APPLICABILITY

The LE requirement is applicable for the determination of safety hazards or degraded operation of the system and all associated electronics, electrical, and electromagnetic equipment caused by direct or near strike lightning.

5.3.1 Direct Strike Lightning Applicability.

The direct strike lightning requirement is applicable when there is a need to determine safety hazards for systems with ordnance items for all configurations and phases of the system. For systems without ordnance items, the criticality of the system mission will determine the applicability of the direct strike lightning requirement. For ground based systems, the direct strike cloud-to-ground lightning criteria is applicable. For airborne systems, the direct strike cloud-to-ground and cloud-to-cloud lightning criteria, and are applicable for both ordnance safety and flight safety. MICOM requires that Army missile PMs subject live, tactical missile systems to the direct strike lightning environment to determine the safety hazards to warheads and propellants.

The E^3RB has the authority to modify any and all requirements to which systems are subjected. E^3RB mandates take precedence over any documented minimum Army criteria.

5.3.2 Near Strike Lightning Applicability.

The near strike lightning requirement is applicable for Army missile systems in all configurations and all phases of system development to determine safety hazards and (depending on the criticality of the mission) degraded operation of the system, including associated electronics, electrical, and electromagnetic equipment.

5.4 LE CRITERIA

The LE criteria were developed without specific input from any system E^3RB. Thus, the LE criteria are provided as minimum Army system requirements and are environments that Army systems are expected to encounter.

5.4.1 Direct Strike Lightning Criteria.

The direct strike lightning criteria, as given in Table 5.4.1-1 and Figure 5.4.1-1, are derived from the idealized direct strike lightning criteria specified in MIL-STD-1757 and MIL-STD-1795. The total charge parameter, defined as the total integrated charge transferred during the discharge, is calculated by integrating the direct strike current function over time. The action integral, defined as the integral over time of the square of the current, is obtained by squaring the current waveform and integrating over time. For system survivability, UUT performance at levels below the 99th percentile criteria given in Table 5.4.1-1 may be acceptable with the appropriate analysis and approval.

5.4.1.1 Direct Strike Lightning Effects.

The direct effects of lightning are the burning, eroding, blasting, and structural deformation caused by lightning arc attachment, as well as the high pressure shock waves and magnetic forces produced by the associated high currents. For qualification testing, current components (identified as "A" through "D") are utilized to determine the direct strike effects. Each current component (A, B, C, and D) simulates a different characteristic of a lightning event and are shown in Figure 5.4.1-1. For an LE test, these currents can be applied individually or as the composite of two or more components.

5.4.1.1.1 Component A - Initial High Peak Current.

Component A has a peak amplitude of 200 kiloamperes (kA) (±10 percent) and an action integral of $2x10^6$ amperes squared seconds (A^2•sec), ±20 percent, with a maximum time duration not to exceed 500 microseconds (μsec). This component may be oscillatory or unidirectional (e.g., rectangular, exponential, or linearly decaying.)

5.4.1.1.2 Component B - Intermediate Current.

Component B has an average amplitude of 2 kA (±10 percent) flowing for a maximum duration of 5 milliseconds (msec) and a maximum charge transfer of 10 Coulombs (C). The waveform shall be unidirectional.

Table 5.4.1-1. Direct Strike Lightning Criteria.

Parameter	Cloud to Ground Severe *	Cloud to Cloud Severe *
Number of strokes	24 (max.)	3
Time interval between strokes (msec)	60	30
Peak Current of 1st stroke (kA)	200 Component A	20
Time to peak, all strokes (μsec)	6.4 (comp A) 3.2 (comp D)	1.5
Max di/dt (A/sec)	1.4×10^{11}	2×10^{11}
Action Integral $\int i^2 dt$ ($A^2 \bullet sec$)	2×10^{6}	2×10^{4}
Peak current, subsequent strokes (kA)	100 Comp D	10, 2
Action Integral $\int i^2 dt$ ($A^2 \bullet sec$) subsequent strokes	2.5×10^{5}	2.5×10^{3}
Amplitude of continuing current (A) average	400 Comp C	200
Duration of continuing current (msec)	500 Comp C	700
Charge passing in continuing current (coulombs)	200 Comp C	25
Charge per stroke (coulombs)	228	28, 1, 1
Total charge in flash (coulombs)	233	30
Flash duration (sec)	2 (max)	0.90

* Extremely stringent environment, but not worst case.

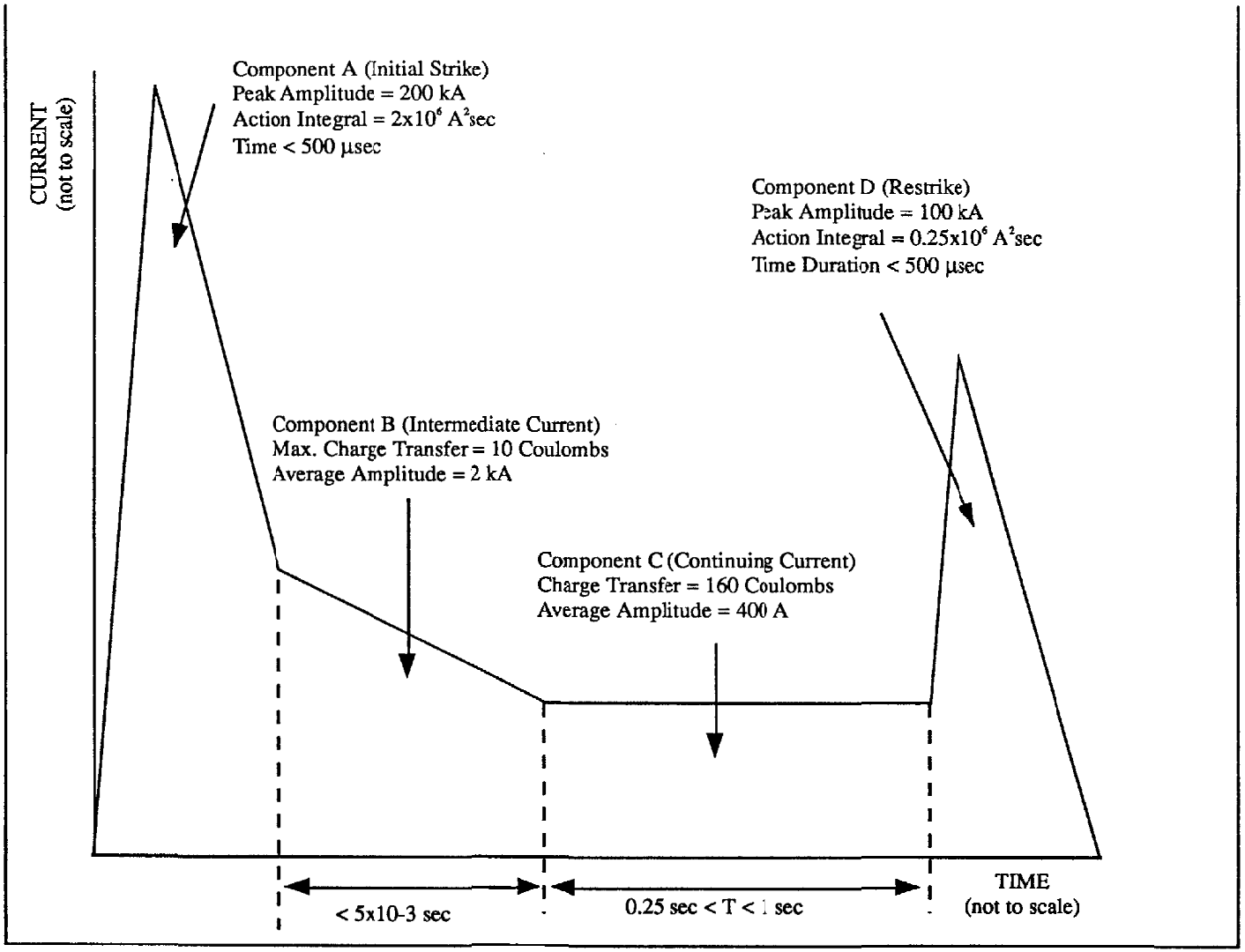


Figure 5.4.1-1. Direct Strike Composite Waveform.

5.4.1.1.3 Component C - Continuing Current.

Component C transfers a charge of 200 C (±20 percent) over a time period of between 0.25 and 1 second. The waveform shall be unidirectional.

5.4.1.1.4 Component D - Restrike Current.

Component D has a peak amplitude of 100 kA (±10 percent) and an action integral of 0.25×10^6 amperes squared seconds ($A^2 \cdot$ sec) (±20 percent). This component may be either unidirectional or oscillatory with a total time duration not exceeding 500 msec.

5.4.1.2 Indirect Effects.

The indirect effects of lightning are predominantly those resulting from the interaction of the electromagnetic fields accompanying lightning with electrical apparatus in the system. Indirect effects are produced by both direct strike and near strike lightning events. For qualification testing, current Components A and D are utilized to determine indirect effects. The indirect effects resulting from Components B and C are insignificant and are described herein for completeness only. The following equations and parameters defining current amplitudes and waveforms are taken from MIL-STD-1795A.

5.4.1.2.1 First Return Stroke Waveform Component A.

For indirect effects, this waveform is a simulation of the initial high peak current represented by Component A of paragraph 5.4.1.1.1 and is expressed by the double exponential:

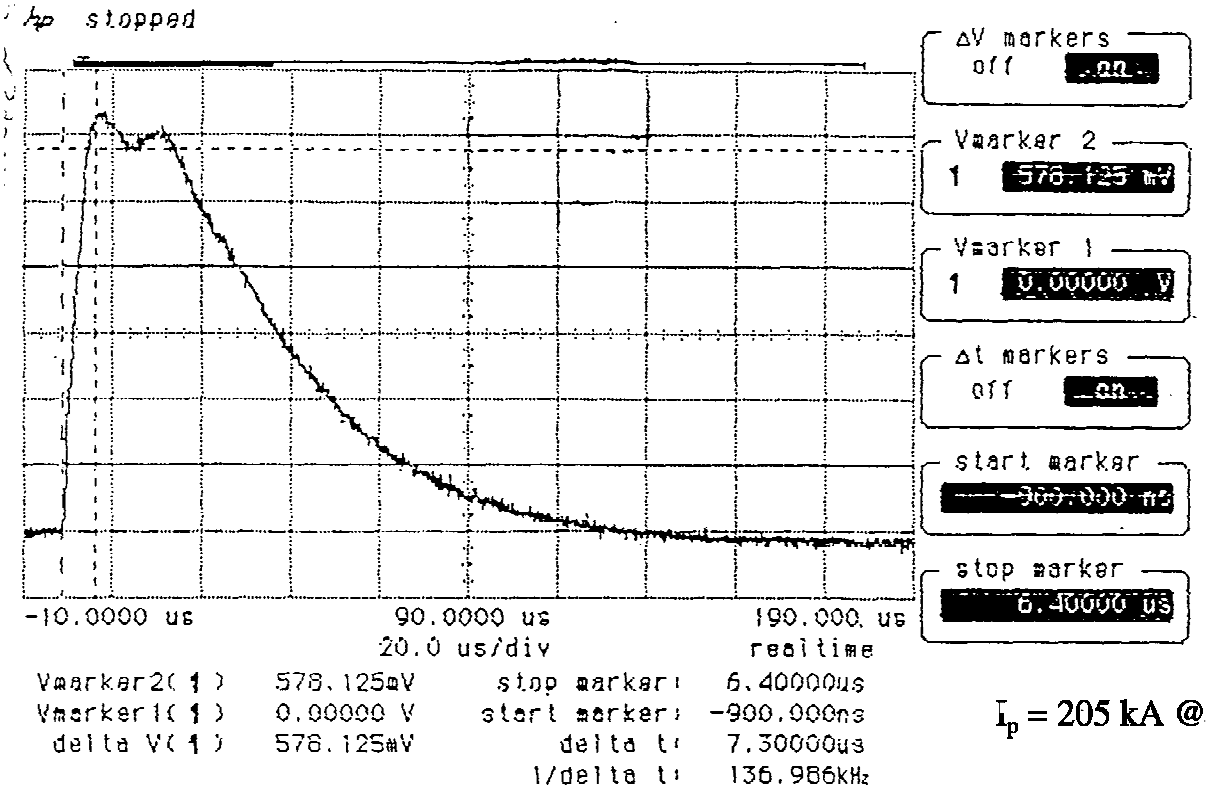
$$i(t) = I_o [e^{-at} - e^{-bt}] \qquad \text{(Equation 5-1)}$$

where $I_o = 218{,}810$ A
$a = 11{,}354$ sec^{-1}
$b = 647{,}265$ sec^{-1}
t = time (sec)

This transient may be of either polarity and the waveform is shown in Figure 5.4.1.2.1-1.

5.4.1.2.2 Intermediate Current (Component B).

Component B has an average amplitude of 2 kA and a charge transfer of 10 Coulombs. For analysis, a double exponential current waveform should be used. This waveform is described mathematically by the double exponential expression:



I_p = 205 kA @ 5.7 µsec

Figure 5.4.1.2.1-1. First Return Stroke Waveform (Component A).

$$i(t) = I_O [e^{-at} - e^{-bt}] \qquad \text{(Equation 5-2)}$$

where $I_O = 11{,}300$ A
$a = 700$ sec^{-1}
$b = 2000$ sec^{-1}
t = time (sec)

This waveform is shown in Figure 5.4.1.2.2-1.

5.4.1.2.3 Continuing Current (Component C).

Component C is a rectangular waveform delivering 200 Coulombs of charge at a rate of between 200 A and 800 A in a time period of between 1 second and 0.25 second, respectively. For analysis purposes, a rectangular waveform of 400 A for a period of 0.5 second should be utilized. This component transfers a charge of 200 Coulombs. The primary purpose of this waveform is charge transfer. This waveform is shown in Figure 5.4.1.2.3-1.

5.4.1.2.4 Restrike Waveform (Component D).

For indirect effects, this waveform is a simulation of the restrike represented by Component D of paragraph 5.4.1.1.4 and is expressed by the double exponential:

$$i(t) = I_O [e^{-at} - e^{-bt}] \qquad \text{(Equation 5-3)}$$

where $I_O = 109{,}405$ A
$a = 22{,}708$ sec^{-1}
$b = 1{,}294{,}530$ sec^{-1}
t = time (sec)

All subsequent strikes are assumed to have this same waveform and may be of either polarity. This waveform is shown in Figure 5.4.1.2.4-1.

5.4.1.2.5 Multiple Stroke Flash.

A typical cloud-to-ground lightning flash contains more than one restrike. A severe version of this phenomenon is represented by Component D. In fact, flashes of up to 24 strokes have been recorded. For protection against direct effects, it is adequate to consider only one return stroke. However, for evaluation of indirect effects it is necessary to consider the multiple-stroke nature of an actual lightning flash, because successive strokes may induce corresponding pulses in data transfer circuits causing either upset or cumulative damage to sensitive systems or components. For indirect effects, this waveform is defined as a “Component A” current followed

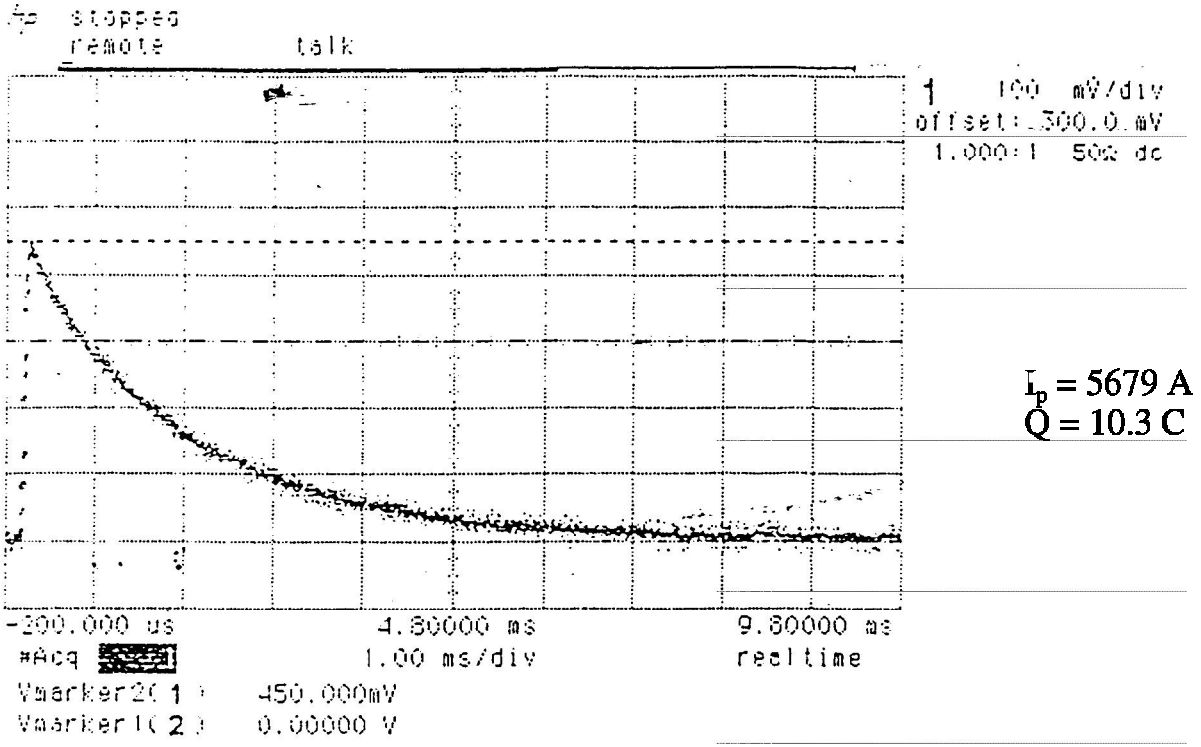


Figure 5.4.1.2.2-1. Intermediate Current (Component B).

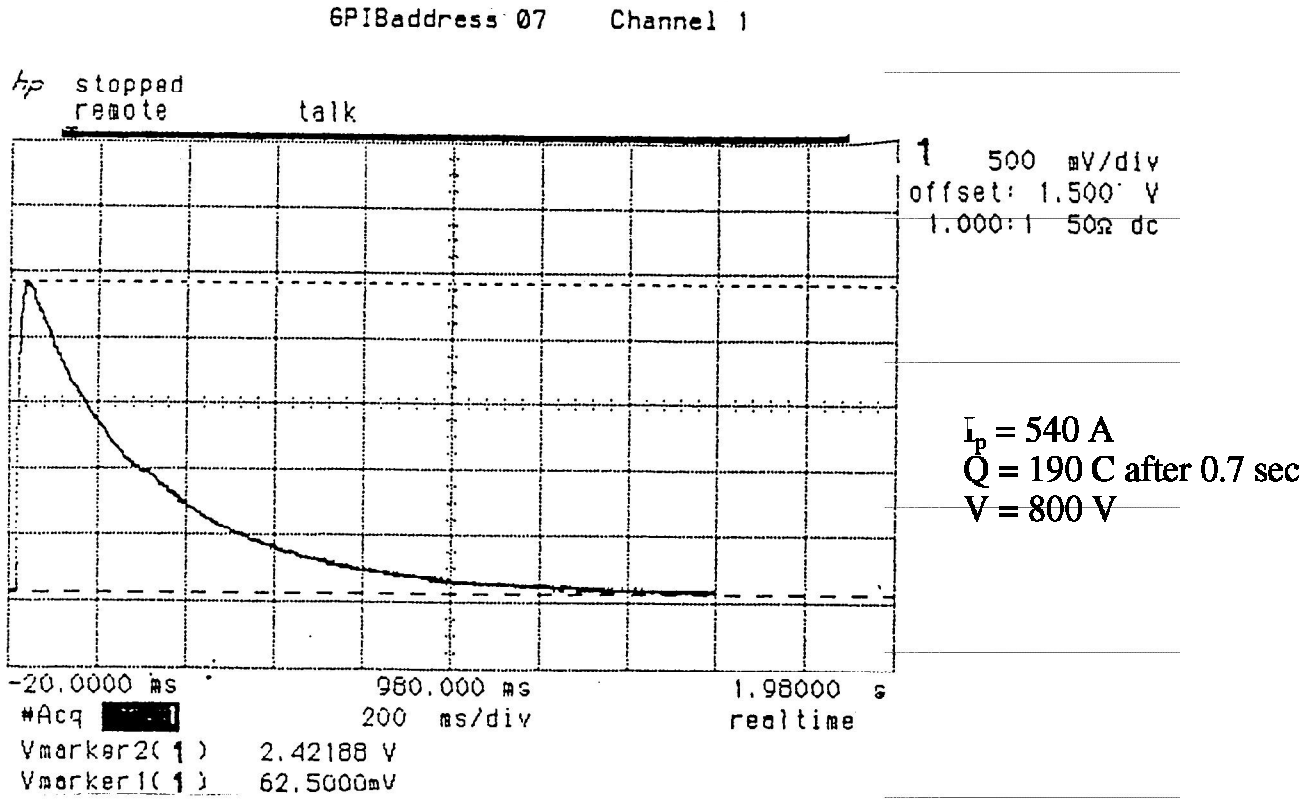


Figure 5.4.1.2.3-1. Continuing Current (Component C).

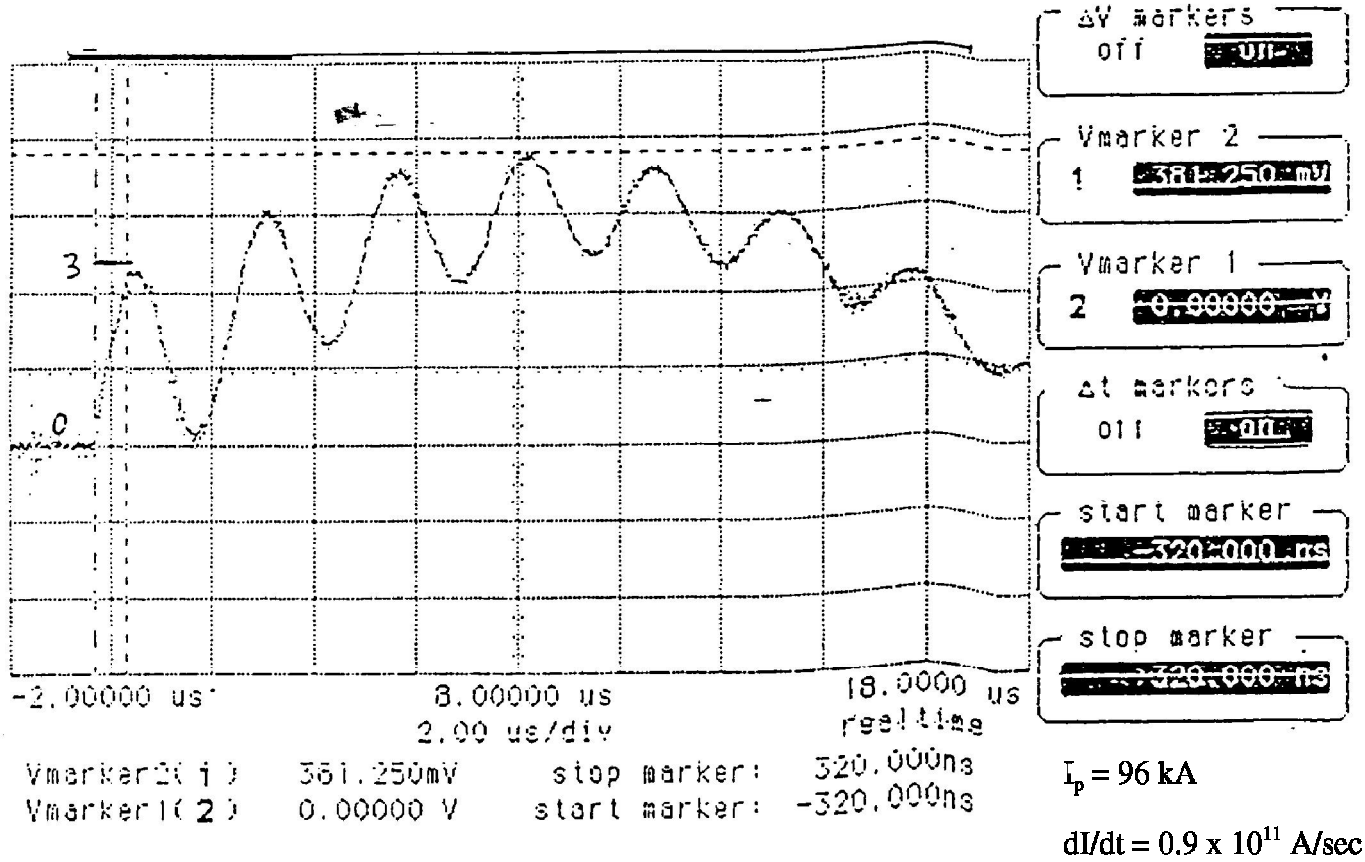


Figure 5.4.1.2.4-1. Restrike Waveform (Component D).

by 23 randomly spaced restrikes, each with a peak amplitude of 50,000 amperes, all occurring within 2 seconds. The multiple stroke flash, (referred to as the "D/2" component), is defined as:

$$i(t) = I_O [e^{-at} - e^{-bt}] \qquad \text{(Equation 5-4)}$$

where $I_O = 54{,}703$ A
$a = 22{,}708\ \text{sec}^{-1}$
$b = 1{,}294{,}530\ \text{sec}^{-1}$
t = time (sec)

5.4.2 Near Strike Lightning Criteria.

The near strike lightning criteria, as given in Table 5.4.2-1, is theoretically derived by modeling the lightning stroke as a vertical line current. The waveform associated with the near-strike lightning is presented in Figure 5.4.2-1.

Table 5.4.2-1. Near Strike Lightning Criteria (Cloud to Ground).

Magnetic Field(H) rate of change @ 10 m	2.2×10^{9} A/m/s
Electric Field (E) rate of change @ 10 m	6.8×10^{11} V/m/s
Maximum Electric Field (E)	3.0×10^{6} V/m

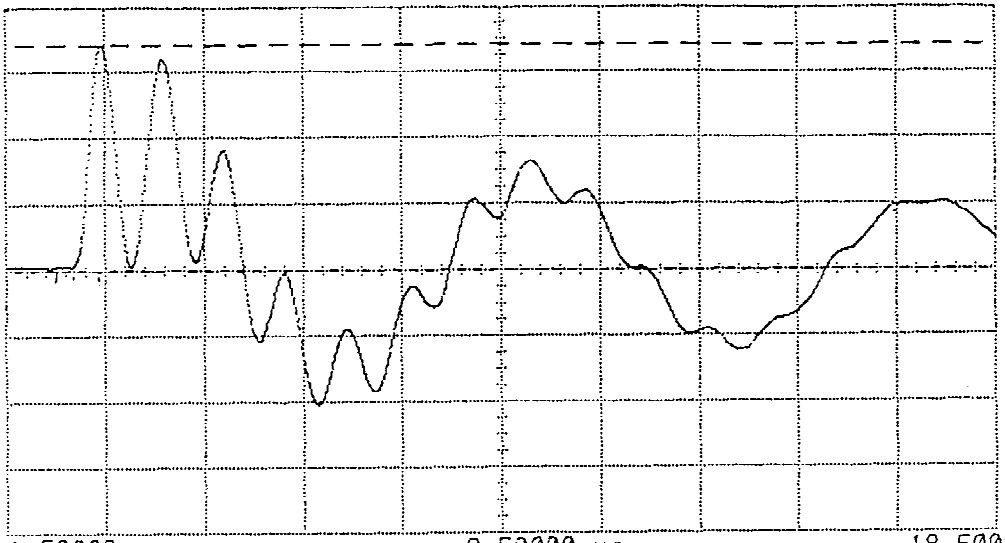
5.4.2.1 Rate Of Change of Magnetic Field.

The time derivative of the magnetic field criteria of Table 5.4.2-1 is theoretically derived first by modeling the lightning strike event as a line charge, as in Equation 5-5 below:

$$H = \frac{I}{2\pi r} \quad \text{A/m} \qquad \text{(Equation 5-5)}$$

where H = magnetic field intensity, in Amperes per meter (A/m),
I = current magnitude in Amperes (A), and
r = separation distance from the lightning channel (line charge) in meters (m).

By differentiating Equation 5-5 with respect to time, the first derivative of magnetic field (dH/dt) can be calculated as indicated in Equation 5-6, since where the maximum rate of change of current, (dI/dt), is specified by MIL-STD-1757 and MIL-STD-1795, and the separation distance (r) are known. For safety hazards, a minimum separation distance of 10 meters is assumed, yielding the rate of change of magnetic field given in Table 5.3.2-1. Smaller separation distances are regarded as a direct strike event. Minimum separation distances for specific systems can be theoretically calculated by utilizing the "cone of protection" or "rolling sphere"



Ch. 1 = 200.0 mVolts/div
Timebase = 2.00 us/div

Offset = 0.000 Volts
Delay = -1.50000 us

Delta V = -680.0 mVolts
Vmarker1 = 680.0 mVolts

Vmarker2 = 0.000 Volts

Trigger mode : Edge
On Pos. Edge on Chan1
Trigger Levels
Chan1 = 100.0 mVolts
Holdoff = 70.000 ns

Figure 5.4.2-1. Near Strike Lightning Waveform.

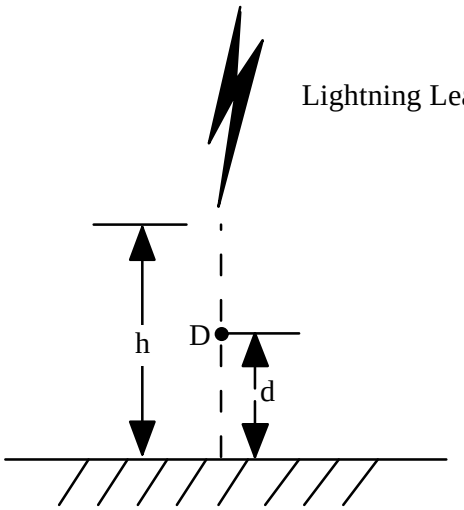
calculation techniques. These techniques tailor the near strike lightning criteria based on specific system configurations and mechanical characteristics. Additionally, for system survivability, separation distances greater than 10 meters may be acceptable when combined with the appropriate analysis and approval.

$$\frac{dH}{dt} = \frac{1}{2\pi r} \times \frac{dI}{dt} \quad A/m/s \qquad \text{(Equation 5-6)}$$

5.4.2.2 Rate of Change of Electric Field.

The maximum electric field and its rate of change is associated with the approach of the stepped leader to the earth or to the system being tested. As the leader approaches, the electric field at the earth can become large, approaching $6x10^5$ volts per meter (V/m), such that a streamer forms (originating on the ground), typically on some pointed objects located on the earth (or system) traveling upward to meet the downward moving leader. This formation occurs at elevations of about 50 meters, with the static electric field limited by air breakdown considerations. Its time derivative at the earth is determined a number of factors: the leader velocity, the charge per unit length on the leader, and the height of the leader tip above the ground (which in turn is determined by the air breakdown limit at that location on the earth).

The electric field below a vertical leader can be determined theoretically by modeling the vertical leader as a uniform line charge and accounting for the influence of the ground by considering a mirror image charge (of opposite sign) located below the ground, as given in Equation 5-7 and illustrated in Figure 5.4.2.2-1. By modeling the leader as a long vertical line charge, ρ_L, Coulombs per meter (C/m), with the lower end at h meters above the ground; one can calculate the electric field, E_d, at a height d, above the ground, immediately below the line charge.



$$E_d = \frac{\rho_L}{2\pi\varepsilon_0 h} \bullet \frac{1}{1-(d/h)^2} \bullet (-\hat{a}_z)$$

Figure 5.4.2.2-1. Electric Field at Point D Directly Below Vertical Leader.

The electric field due to the entire line charge (assumed to be very long compared to the height d) is found by carrying out the integration in Equation 5-7.

$$E_d = \int_{h}^{0} \frac{-L \cdot dz \cdot (-\hat{a}_z)}{4 \cdot \cdot_0 \cdot (z-d)^2} + \int_{-0}^{-h} \frac{-L \cdot dz \cdot (-\hat{a}_z)}{4 \cdot \cdot_0 \cdot (d-z)^2} \quad \text{V/m} \qquad \text{(Equation 5-7)}$$

The term ε_0 is the permittivity of free space, and $(-\hat{a}_z)$ is the unit vector in the z direction.

The integral of Equation 5-7 yields Equation 5-8.

$$E_d = \frac{\rho_L}{4\pi\varepsilon_0} (-\hat{a}_z) \left[\frac{1}{h-d} + \frac{1}{d+h} \right] \text{V/m} \qquad \text{(Equation 5-8)}$$

Algebraic simplification of Equation 5-8, results in the equation for the electric field expressed as Equation 5-9.

$$E_d = \frac{L}{2 \quad_0 h} \bullet \frac{1}{1-(d/h)^2} \bullet (-\hat{a}_z) \quad \text{V/m} \qquad \text{(Equation 5-9)}$$

A solution of Equation 5-9 for the special case of d=0 (ground level) yields Equation 5-10.

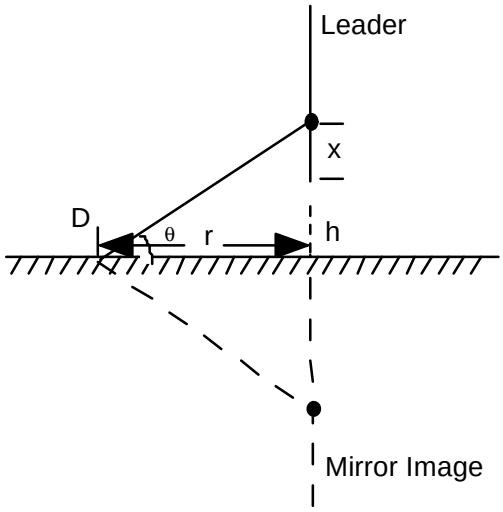
$$E_{(d=0)} = \frac{\rho_L}{2\pi\varepsilon_0 h} (-\hat{a}_z) \quad \text{V/m} \qquad \text{(Equation 5-10)}$$

Moving the point D a horizontal distance, r, as in Figure 5.4.2.2-2, from the lightning channel to account for the rate of change of electric field (dE/dt) for the near strike lightning environment introduces an additional factor of $\sqrt{1+(r/h)^2}$ in the denominator of Equation 5-10, resulting in Equation 5-11.

$$E = \frac{L}{2 \quad_0 h} \bullet \frac{1}{\sqrt{1+(r/h)^2}} \bullet (-\hat{a}_z) \quad \text{V/m} \qquad \text{(Equation 5-11)}$$

Differentiating Equation 5-11 with respect to time, one can calculate the time rate of change of the electric field (dE/dt) as given in Equation 5-12.

$$\frac{dE}{dt} = \frac{{}_{L}h}{2\ {}_{0}\sqrt{(h^2 + r^2)^3}} \bullet \frac{dh}{dt} \bullet (-\hat{a}_z) \quad V/m \qquad \text{(Equation 5-12)}$$



$$E_d = \frac{{}_{L}}{2\ {}_{0}h} \bullet \frac{1}{\sqrt{1 + (r/h)^2}} \bullet (-\hat{a}_z)$$

Figure 5.4.2.2-2. Electric Field at Point D Offset a Distance "r" from Vertical Leader.

Reasonable values for charge per unit length (ρ_L), leader velocity (dh/dt) and distance of the leader above the earth (h) are 10^{-3} Coulombs/meter (C/m), $1x10^{8}$ meters per second (m/s), and 50 meters, respectively. Substitution of these values and the near strike lightning separation distance (r) of 10 meters into Equation 5-12 yields the rate of change of electric field given in Table 5.4.2-1.

5.4.3 Tailoring of LE Criteria.

For systems without ordnance items, the criticality of the system mission will determine the applicability of the direct strike and near strike lightning requirements. The LE criteria specified by Tables 5.4.1-1 and 5.4.2-1 shall be tailored by the system E^3RB to meet the special lightning environment requirements as determined by the system's intended mission and criticality.

5.4.4 Pass/Fail Criteria.

Systems with ordnance items shall not exhibit any hazard to personnel or other material when subjected to the lightning environment specified in Tables 5.4.1-1 and 5.4.2-1. Electrical systems and all associated electronics, electrical, and electromagnetic equipment, depending on the criticality of the system mission, shall not exhibit any malfunction nor degradation of performance which would prevent the system from completing its intended mission when subjected to the near strike lightning environment specified in Table 5.4.2-1.

5.5 LIGHTNING SIMULATOR CALIBRATIONS

Two types of calibrations are utilized in conducting LE Tests. The first is required to monitor the simulated LE environment (current waveforms); the second is required to detect and record the current(s) and voltage(s) induced in the system's (UUTs) circuits.

5.5.1 Instrumentation to Monitor LE Environment.

The instrumentation used to monitor the stimulus (LE) waveforms is required to insure compliance of both the direct and near strike simulated lightning environment with documented test criteria. The specific features monitored by this instrumentation are as follows:

5.5.1.1 Initial Stroke (Component A) Instrumentation.

A Pearson Model 1080, 1049, or 1423 current probe is used to measure and record the initial stroke (current) amplitude and waveform. The current probe is installed on either the center conductor or the ground return conductor of the initial stroke/continuing current discharge path, depending on the physical limitations dictated by the test setup. The initial stroke current waveform measurement is transmitted out of the test area by telemetry via a Nanofast Model OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on a Hewlett-Packard Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible personal computer (PC).

5.5.1.2 Intermediate (Component B) Current Instrumentation.

A Pearson Model 301X Current Probe is utilized as the sensor for the intermediate current waveform measurement. The current probe is installed on the center conductor of the intermediate current discharge path. The intermediate current waveform measurement is transmitted out of the test area by telemetry via a Nanofast Model OP-300 Fiber Optic System to a shielded area for processing. The data are recorded on an HP 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.1.3 Continuing (Component C) Current Instrumentation.

A calibrated resistor, typically a Nichrome ribbon or a stainless steel coil, is utilized as the sensor for the continuing current waveform measurement. The calibrated resistor is installed in-line with the continuing current transmission line. The continuing current waveform measurement is transmitted out of the test area by telemetry either by an in-house frequency modulated (FM) voltage controlled oscillator (VCO) fiber optic system or a Nanofast Model OP-300 DC Fiber Optic System with the P601 differential voltage probe. These data are sent to a shielded area for processing. The data are recorded on an HP 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.1.4 Restrike (Component D) Current Instrumentation.

A Pearson Model 1080 current probe is utilized as the sensor for the restrike current waveform measurement. The current probe is installed on the center conductor of the restrike current discharge. The restrike current waveform measurement is transmitted out of the test area by telemetry via a Nanofast Model OP-300 Fiber Optic System to a shielded area for processing. The data are recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.1.5 Rate of Change of Magnetic Field (B-dot) Sensor.

The rate of change of magnetic field waveform is measured with an EG&G Model MGL-2 B-dot sensor. The sensor is utilized to calibrate the required separation distance between the test article and the restrike current discharge probe (near strike lightning simulation). The rate of change of magnetic field measurement is transmitted out of the test area by telemetry via a Nanofast OP-300 Fiber Optic Systems to a shielded area for processing. The data are recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.1.6 Rate of Change of Electric Field, (D-dot) Sensor.

The rate of change of electric field waveform is measured with an EG&G Model HSD-4 D-dot sensor. The D-dot sensor is utilized to calibrate the required separation distance between the test article and the restrike current discharge probe (near strike lightning simulation). The rate of change of electric field measurement is transmitted out of the test area by telemetry via a Nanofast OP-300 Fiber Optic Systems to a shielded area for processing. The data are recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.1.7 Peak Electric Field Sensor.

The peak electric field waveform is measured with an Nanofast Model EFS-1 peak electric field sensor. The peak electric field sensor is utilized to monitor the peak electric field at either the test article location or within the test article (i.e., empty motor case). The peak electric field measurement is transmitted out of the test area by telemetry via a Nanofast OP-300 Fiber

Optic Systems to a shielded area for processing. The data are recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.2 Instrumentation to Monitor UUT.

Depending on the test data requirements, instrumentation is used to detect and monitor the current and voltage induced in the various system (UUT) circuits.

5.5.2.1 Current Probes.

Depending on size limitations and both sensitivity and signal level requirements, any one of a variety of current probes may be utilized to monitor the induced current transients which occur in a particular UUT circuit. The current probe is installed, depending on data requirements, on either a single circuit (or conductor) , or group of circuits (or conductors) to measure the single (or multiple) induced currents. The induced transient current measurement is transmitted out of the test area by telemetry via a Nanofast Model OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.2.2 Voltage Probes.

A Nanofast Model P601 differential voltage probe is utilized to monitor the induced voltages on particular UUT circuit. The voltage probe is installed between the particular UUT circuits and either the signal return or UUT ground. The induced transient voltage waveform measurement is transmitted out of the test area by telemetry via a Nanofast Model OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.2.3 Surface Current Probes.

The induced surface current on the system is measured with an EG&G Model MGL-S7B B-Dot sensor. The sensor is mounted at specific locations on the UUT body to monitor the induced surface currents. The induced surface current measurement is transmitted out of the test area by telemetry via a Nanofast OP-300 Fiber Optic Systems to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

5.5.3 Instrumentation Calibration.

The measurement oscilloscopes are calibrated on a routine basis by the US Army Test, Measurement, and Diagnostic Equipment (TMDE) Activity located at Redstone Arsenal. Measurement accuracy of Army TMDE equipment is directly traceable to the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS).

The current and voltage probes utilized for system instrumentation are periodically calibrated with a network analyzer to compare the frequency response curves with the manufacturer's frequency response specifications. The network analyzer is calibrated on a routine basis by the US Army TMDE. The Nanofast fiber optic systems are calibrated using a built in calibration signal. Additionally, the Nanofast fiber optic systems are periodically calibrated with a network analyzer to compare the frequency response curves with the manufacturer's frequency response specifications. The stimulus measurement probes are calibrated periodically by comparison of measurement data with other probes of the same model.

5.6 TEST PHILOSOPHY

5.6.1 Direct Strike Lightning Test.

The direct strike lightning test is conducted primarily to determine UUT (missile or ordnance) safety during a direct strike event. Some systems, such as manned aircraft or missile systems with high priority targets, may be required to survive and operate after a direct strike. This is due to their special missions or safety considerations. All UUTs with life cycle configurations that are candidates to direct strike lightning shall be analyzed to establish worst case test configurations as well as lightning current entry and exit points (strike and ground points).

Strike points can be determined by test through high voltage arc testing of the UUT. In most cases the strike points are determined by engineering analysis and judgment. Selected strike points are usually the sharp edges and/or the highest points on the system and the exit points are the natural ground points. The UUT configurations most frequently tested are the system or subsystem "in" or "out" of shipping/storage containers, as well as the configuration used for tactical operation. These configurations encompass both live and inert systems.

5.6.2 Near Strike Lightning Test.

The near strike lightning test is conducted to determine UUT safety and reliability or operability during and after a near strike lightning event. The near strike effects are the results of the interaction of electromagnetic (EM) fields with system electronic circuitry. Thus, the worst case configuration is defined as a fully deployed system, with subsystem and cabling in place and oriented for maximum E-field coupling. Near strike lightning tests are conducted in both “power on" and “power off" states. The “power on" configuration is generally the worst case, since relays and circuits are energized, enabling maximum electrical transmission throughout the UUT.

5.6.3 Test Methodology.

LE test procedures are dependent on the type of test to be performed. The determination of safety hazards or the degradation of system operation, or both, can be accomplished by any of the following three techniques: instrumented tests, go/no-go tests, or their combination.

Instrumented testing requires monitoring signal lines during the tests and combining this data with a detailed knowledge of component responses and threshold levels necessary for activation of EEDs or for proper operation of electrical equipment. Typically, the threshold limits for EEDs are defined in terms of direct current (dc) parameters, but not in terms of transients. For this reason, the go/no-go test is the primary technique for verifying system response to LE criteria. Go/no-go testing involves monitoring the system for safe and proper operation. For either test technique, it is imperative that an absolute definition for failure (signal interference, UUT reaction or response) be defined prior to initiation of the test to avoid confusion and indecision.

5.6.3.1 Instrumented Testing.

Since the threshold limits for EEDs are typically specified in terms of dc parameters and not in terms of transient parameters, instrumented testing is not normally utilized for pass/fail verification of LE criteria. Instrumented testing utilizes worst case test point and UUT configuration for coupling lightning energy to the EEDs. This combination reduces the number of test runs required for the go/no-go test (i.e., testing at only the worst case configurations and test points) as opposed to testing at all available test points).

In some special circumstances, instrumented testing may allow verification of the LE criteria if measured data from a previous test is available for comparison. For testing of EEDs, the maximum no-fire energy (MNFE) needs to be identified in order to evaluate the safety margin and to determine if it meets the specified requirement. Since there is usually only one complete system available for test, it is necessary to further quantify LE susceptibility by obtaining statistical data on many samples of the EEDs of interest. The statistical data are accomplished by obtaining the induced responses on the EEDs during the system level test. Then, testing is performed on a significant number of the EEDs in a laboratory setting by means of a Bruceton test. The MNFE thresholds of the EEDs are compared to the induced energy response observed in the weapon system tests to determine the probability of EED detonation.

EED susceptibilities or safety margins are obtained by the comparison of measured (or extrapolated) responses with data from the sensitivity test of the EEDs. The sensitivity tests often use Bruceton analyses to establish "no fire" energy levels for a given confidence level. The pass/fail performance for the EEDs of each system is determined from the specific EED under test within the system.

Each EED of the system will be designated as either a hazardous or a reliability EED. A hazardous EED is one whose premature initiation, dud creation, or desensitization results in injury to personnel or destruction to property. A reliability EED is defined as an EED whose premature initiation, dud creation, or desensitization results in degradation of the EED performance beyond design tolerances, but without hazardous effects.

For ground based Army systems, hazardous EEDs must exhibit a minimum safety margin of 10 dB, while reliability EEDs must exhibit a minimum safety margin of 6 dB. The

pass/fail performance for the associated electronics, electrical, and electromagnetic equipment of the system is determined by the survivability of the equipment after exposure to the LE environment. Instrumented testing requires monitoring all signal lines and, subsequently, comparing the observations with a detailed knowledge of component and subsystem responses and threshold levels required for proper operation.

5.6.3.1.1 Instrumented Go/No-Go Testing.

This technique is strictly dedicated to verifying safety hazards of EEDs. It utilizes instrumentation to measure the induced transient signal on the EEDs to identify the worst case test point and configuration of the system. Once the worst case test point and configuration is identified, go/no-go testing techniques are utilized to verify that the system meets the LE criteria. For UUTs with several test points and configurations, this test technique will greatly reduce the number of test runs required to verify the system performance since only the worst case test point and configuration will be tested. Examining the UUT at the LE criteria is not necessary for this technique, but is mandatory for the go/no-go verification testing.

5.6.3.1.2 Comparison Analysis.

This technique is strictly limited to verifying safety hazards of EEDs and involves utilization of instrumentation to measure the induced transient signal data on the EEDs and to compare this data with data from previous LE testing. Two requirements must be met in order for this technique to be applicable:

A. the data must be from a previous LE test in which the system's EEDs passed the LE criteria including a go/no-go test, and

B. the EEDs being considered must be exactly the same make and model as the EEDs from the previous LE test.

If the induced transient signal observed is equal to or less than the induced transient signal observed from the previous LE test, then the system is considered to be safe at the LE criteria. If the induced transient signal exceeds that of the previous LE test, then the system is not considered safe and additional tests must be conducted to verify safe performance for the system. Testing at the LE criteria is mandatory for this technique.

5.6.3.1.3 Pin-Injection Testing.

This technique is utilized for testing components and subsystems when it is not feasible to conduct testing of the entire system, as in the case where the LE test is destructive to very expensive components. In those cases one system is instrumented and tested to destruction. The instrumentation is used to record the induced current or voltage waveforms and amplitudes occurring across critical components such as EEDs. Thereafter, the subassemblies are subjected to the sub-criteria, replicating the amplitudes and waveforms they experienced in the full system tests. The sub-criteria define the levels to be provided by the pin-injection waveform; the

subassemblies are instrumented as in the full system test to verify the sub-criteria levels on the subassemblies and components. In this manner, the subassemblies can be subjected to repeated testing to examine their performance, determine the transfer (transient) impedance (from the system to the component), and to monitor the current or voltage induced at the component level.

If it is not feasible to conduct sub-criteria testing of the system, then analysis should be utilized to determine the pin-injection test waveform. Special considerations should be given to determine the coupling, attenuation, and scale factors. Erroneous assumptions or the use of large scale factors can result in unrealistic and often invalid pin-injection levels. For this reason, testing is the preferred means to determine the induced waveform. In either case the induced waveforms observed from the sub-criteria (whether measured or analytically determined) are scaled to arrive at the estimated waveforms and amplitudes which would correspond to the full criteria. These estimated waveforms are applied at the insertion point of the pin injection test to accomplish the same effect as if the entire UUT were to be subjected to the full test criteria. When the proportional pin injection waveforms are applied to the signal lines or the cable shield of the components, the components are monitored for degradation of performance. For components with EEDs, both instrumentation and go/no-go testing techniques are utilized to verify the safety hazard requirement for the EEDs.

5.6.3.2 Go/no-go Testing.

Go/no-go testing requires that the system be monitored for normal operation while being subjected to the specified LE criteria. Detailed procedures are followed and system responses for normal operations have to be monitored and recorded. Threshold levels for abnormal system responses are determined by reducing the test current until any abnormal system response are no longer observed. In some cases, it may be necessary to record the system response with video cameras (employing fiber optic lenses) in order to quantify the interference (i.e., video recording the interference effects with a night sight screen or an IR monitor). This go/no-go test method requires the facility have the capability of testing at the required LE criteria**.** For systems with EEDs, a minimum of 10 EEDs must be tested to establish a statistical level for hazards to safety of 85% reliability with 80% confidence. Additional EEDs must be tested to satisfy higher levels of reliability and confidence.

5.7 LE TEST PROCEDURES

A lightning test sequence should start with the least probable destructive test and end with the most probable destructive test. Near strike lightning testing should be conducted prior to direct strike testing. Non-hazardous testing (testing of inert items) should be conducted prior to hazardous testing (testing of live and explosive items). Hazardous testing is primarily conducted to determine the safety of propellant and explosive material to the lightning event. Conducting the non-hazardous testing first will determine if the EEDs, which initiate these hazardous materials, are safe and if there are any vulnerabilities to lightning which are unrelated to the propellants and explosives. Thereafter additional safety precautions can be taken to prevent ignition of the motors or warheads. “Power on" and “power off" conditions for the

system should also be considered. Figure 5.7-1 “LE Flow Diagram” presents the key options and decision points in structuring an LE Test.

5.7.1 Direct Strike Testing.

A pretest study is conducted to identify the most probable strike points and those which would be most susceptible to damage or likely to cause safety problems (operational problems if system reliability is a requirement). Instrumentation may be necessary to monitor internal test points so that extrapolations can be made and safety margins can be determined.

The test plan will be written and approved prior to receiving system hardware. A detailed test procedure will be written prior to conduct of the test. A general test procedure for conduct of a direct strike LE test would be as follows:

A. Perform pretest calibration of the simulated direct strike lightning generators on a nonfunctional system.

B. Install UUT in the test area for non-hazardous testing (or safety cage for hazardous testing) and secure.

C. Install instrumentation and EEDs and set up Component A (Initial Stroke) simulated direct strike lightning generator and associated test equipment.

D. Secure test area and initiate safety and security test procedures.

E. Verify safety and security requirements; begin lightning generator charging sequence.

F. Initiate video recording sequence (if necessary).

G. Notify safety officer when charging sequence complete and verify permission to conduct lightning attachment.

H. Initiate lightning attachment procedures.

I. After attachment, verify site safety and wait required safety period to enter safety cage.

J. Record test data and inspect EEDs.

K. Repeat steps C. through J. for all test points.

L. Repeat steps C. through K. for Component B (Intermediate Current), Component C (Continuing Current) and Component D (Restrike Current) simulated direct strike lightning generators.

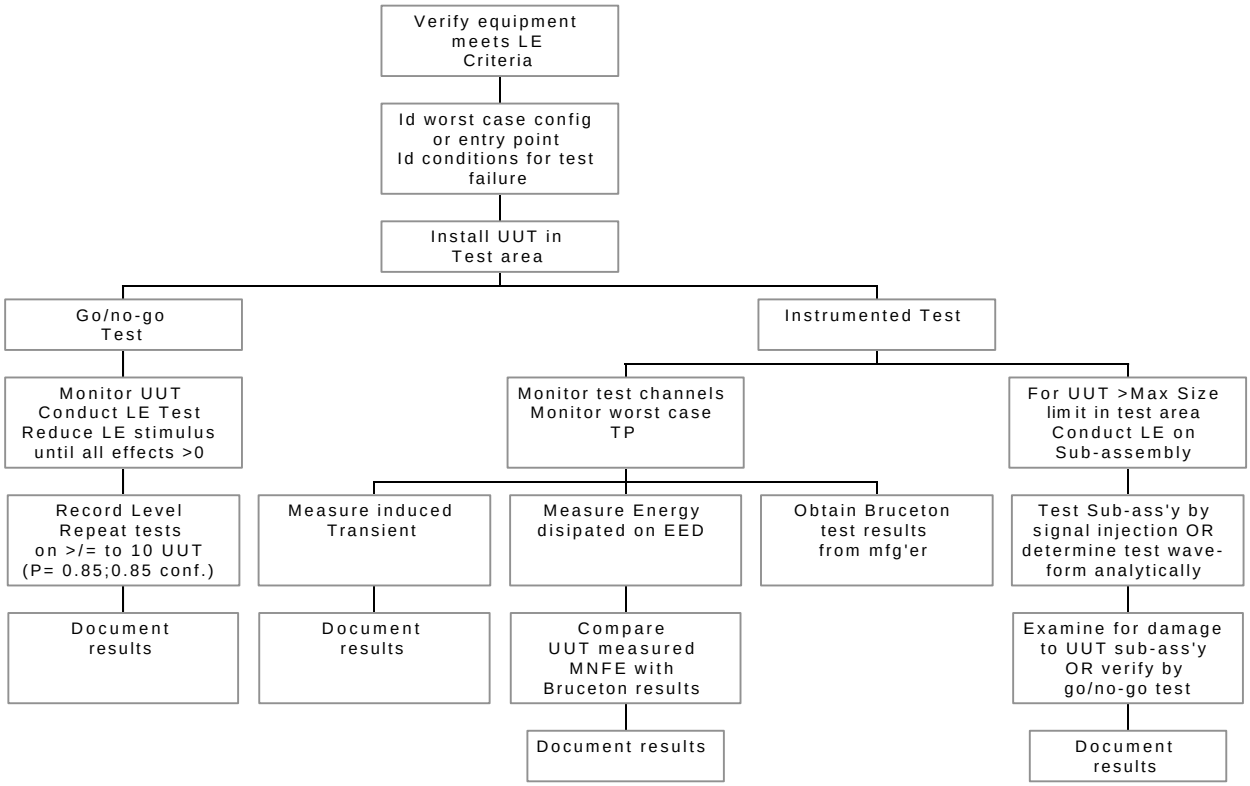


Figure 5.7-1. Lightning Effects Test Flow Diagram.

M. Repeat steps C. through L. for a minimum of 10 sets of EEDs.

5.7.2 Near Strike Lightning Test.

Prior to near strike lightning testing, the magnetic field around the downlink electrode will be mapped using B-dot sensor measurements at several locations to determine a calibrated test position for the system. A pretest study is conducted to identify the test orientation of the system (UUT) with respect to the near strike channel or path (referred to as the downlink) which would be most susceptible to damage or likely to cause safety or operational problems.

Instrumentation may be necessary to monitor internal test points so that extrapolations can be made and safety margins can be determined. The test plan will be written and approved prior to receiving system hardware. A detailed test procedure will be written after the system has been instrumented, assembled, time limits for operation identified, configuration and aspect angles established. A general test procedure for conduct of a near strike LE test would be as follows:

A. Perform pretest calibration of the simulated near strike lightning generator.

B. Install the instrumentation and EEDS and position the system at the predetermined test range and orientation with respect to the lightning strike channel (downlink).

C. Perform pretest operational check of the system.

D. Perform a baseline run.

E. Secure area and initiate safety test procedures.

F. Operate the system.

G. Verify safety and security requirements and begin simulated near strike lightning generator charging sequence.

H. Notify safety officer when charging sequence complete and verify permission to conduct discharge.

I. Initiate discharge procedures.

J. Record test data and inspect EEDs.

K. Verify lightning generator equipment is in a safe configuration.

L. Verify operational capability of the system.

M. If no anomalies are noted, then reposition the system to other orientations with respect to the lightning strike channel and repeat steps C. through L. until all orientations of interest are tested.

N. Repeat steps B. through M. for a minimum of 10 sets of EEDs.

5.7.3 Data Recording and Display.

The data from the test item are interfaced with the computer for real-time recording, analysis, and data storage. All pertinent test conditions and parameters, along with monitored data from the UUT, are automatically recorded. In addition, a graphic terminal with hard copy capability is available for providing data plots for quick-look analysis reports. The computer also controls direct-write oscillographs for recording data from UUT. All data needed for test report writing is stored on disk for report generation, formatting, and editing on alternate PCs.

5.7.4 Double Shielded Instrumentation Van.

The IR signals from the various measurement equipment are converted to electrical signals by the IR receivers in the ground station. The converted electrical signals are displayed on oscillographs and then recorded, monitored and stored by the computer. These test functions are performed in a double shielded instrumentation van as shown in Figure 5.7.4-1.

5.7.5 LE Data Analysis.

LE data is collected from instrumented, go/no-go tests, or both. The instrumented tests are primarily utilized for measuring the induced transient current waveform on the system EEDs and for measuring the stimulus waveforms. The measured, induced, transient current data is compared against known transient energy response levels (response data) for the EEDs to determine a safety margin with respect to the response data. If a sufficient safety margin (typically 20 dB) is not demonstrated with respect to the the response data, then a go/no-go test of ten samples (or more depending on the desired statistical confidence and reliability values) of the EEDs is required to satisfy safety requirements to the lightning environment. In special circumstances, instrumented testing is utilized to monitor the signals of critical circuits. The measured signal data is compared to baseline (normal) circuit signal data to determine the change to the signal due to the lightning environment and its subsequent impact to circuit operation.

Go/no-go testing is utilized to satisfy both safety and operational requirements of the system to the lightning environment. In the case of safety requirements, 10 sets of the EEDs are exposed to the lightning environment and subsequently evaluated to determine the safety status of the EEDs (EED initiation or creation of a dud, or in the case of fuzes whether the fuze "armed"). For operational survivability, the system is monitored through observation for proper operation either during or after exposure to the lightning environment. In either case, the anomalous behavior is evaluated to determine if the anomaly was a one-time event (glitch) or a

catastrophic failure. One-time event anomalies are acceptable, whereas, catastrophic failures are not.

5.8 LE TEST DOCUMENTATION

5.8.1 Test Configurations.

The test configurations are determined from worst case conditions for the system. These configurations include system checkout, preparation, and system operation (i.e., missiles would be configured for launch preparation, during launch sequence, and in flight). Tests are planned to examine those conditions most relevant to the system operation, while controlling the less relevant factors.

5.8.2 Test Plans.

Test plan outlines are identified separately for simulated direct strike and near strike lightning events.

5.8.2.1 Direct Strike.

A pretest study is conducted to identify the most probable strike points, especially those which would be most susceptible to damage or most likely to cause safety problems (or operational problems if system reliability is a requirement). Instrumentation may be necessary to monitor internal test points so that extrapolations can be made and safety margins may be determined. A detailed test plan will be written prior to the initiation of the test. A general test procedure of the direct LE test would be as follows:

A. Perform pretest calibration of the simulated direct strike lightning generators on a dummy system.

B. Install the test system (UUT) into the test area for non-hazardous testing (or into a safety cage for hazardous testing and secure.

C. Install instrumentation and EEDs and set up Component A (Initial Stroke) simulated direct strike lightning generator and associated test equipment.

D. Secure test area and initiate safety and security test procedures.

E. Verify safety and security requirements are being met and begin simulated direct strike lightning generator charging sequence.

F. Initiate video recording sequence (if necessary)

G. Notify safety officer when charging sequence is complete and verify permission to conduct lightning attachment procedures.

Figure 5.7.4-1. Double Shielded Instrumentation Van.

H. Initiate lightning attachment procedures on UUT.

I. After attachment, verify site safety and wait required safety period to enter safety cage.

J. Record test data and inspect EEDs of UUT.

K. Repeat steps C. through J. for all test points on UUT.

L. Repeat steps C. through K. for Component B (Intermediate Current), Component C (Continuing Current), and Component D (Restrike Current) simulated direct strike lightning generators.

M. Repeat steps C. through L. for a minimum of 10 sets of EEDs

5.8.2.2 Near Strike Lightning Tests.

Prior to near strike lightning tests, the magnetic field around the downlink electrode will be mapped using a B-dot sensor measurement at several locations to determine a calibrated test position for the system (UUT). A pretest study is conducted to identify the test orientation of the system with respect to the near strike channel or path, referred to as the downlink, which would be most susceptible to damage or likely to cause safety and operational problems. Instrumentation may be necessary to monitor internal test points so that extrapolations can be made and safety margins can be determined. The test plan will be written and approved prior to receiving system hardware. A detailed test procedure will be written after the system has been instrumented and assembled, time limits for operation identified, configuration and aspect angles established. A general test procedure for the conduct of a near strike LE test would be as follows:

A. Perform pretest calibration of the simulated near-field lightning generator.

B. Install the instrumentation and EEDs and position the system at the predetermined test range and orientation with respect to the lightning strike channel (downlink).

C. Perform pretest operational check of the system (UUT).

D. Perform baseline run.

E. Secure area and initiate safety test procedures.

F. Operate the system.

G. Verify safety and security requirements are being met, and begin simulated near strike lightning generator charging sequence.

H. Notify safety officer when charging sequence is complete and verify permission to conduct discharge procedures.

I. Initiate discharge procedures on UUT.

J. Record test data.

K. Verify lightning generator equipment is in a safe configuration.

L. Inspect EEDs for effects of near strike.

M. Verify operational capability of UUT.

N. If no anomalies are noted, then reposition the UUT to next orientation with respect to lightning strike channel and repeat steps B. through M. until all required orientations are tested.

O. Repeat steps C. through N. for a minimum of 10 sets of EEDs.

5.8.3 Test Reports.

General documentation for the LE test includes, but is not limited to the following:

- Serial numbers of test hardware
- Calibration information
- Nonstandard modification of test hardware
- Hardware configuration
- Nontest related problems/failures
- Pretest, posttest, etc. inspection results
- Daily log for test activities
- Facility hardware utilized
- Instrumentation hardware utilized
- Still photographs of test setup
- Still photographs of test instrumentation

Detailed documentation for each test run shall include, but is not limited to, test sequence number, test criteria, test environment (to include, orientation of the UUT with respect to the LE simulator, configuration of the UUT), measurement of the induced effects and any other significant test observations.

SECTION 6.0 ELECTROSTATIC DISCHARGE (ESD)

6.1 ESD BACKGROUND

The electrostatic discharge (ESD) event can be described as a high voltage, low current breakdown phenomenon. The breakdown is characterized as a capacitor discharge pulse and the damage to components is very similar to the damage associated with high frequency radar pulses. The critical parameter is the direct current (dc) resistance rather than the complex impedance as in the case of radio frequency (RF). Electric charges are transferred whenever two objects make contact, especially if the objects are non-conductors. Multiple contact, such as rubbing or particle impact, can greatly increase the magnitude of the charge transferred.

Additionally, a charged object can cause the charge on a second adjacent object to redistribute by merely approaching (not contacting) the second object. If a momentary ground connection is then provided to the second object, charge is removed or added to the second object resulting in a residual electrostatic charge on the second object. Electrostatic charging of systems is common. A projectile passing through rain or dust, a plastic cover removed suddenly from a weapon or component, or the presence of a highly charged thunderhead can all provide methods of producing an electrostatic charge on a system or its components. Any contact or insulation rupture between a charged object and an EED or circuit component can result in an electric discharge through the component, resulting in either a potential safety hazard or performance degradation in the system.

6.2 ESD TEST OBJECTIVE

The objective of the ESD test is to determine if exposure to the personnel borne or helicopter generated ESD environments can result in a safety hazard or degraded performance (malfunctions, undesirable and unacceptable responses) of the system including associated electronics, electrical, and electromagnetic equipment under test (normally referred to as Unit Under Test, UUT). It should be noted that since each specific system responds differently to the same test environment, the results of each ESD qualification test can be applied only to the specific configuration (of the UUT) tested. Therefore, additional ESD testing is required for each UUT configuration whether due to modifications in design or material.

6.3 ESD APPLICABILITY

The ESD requirement is applicable for the determination of safety hazards and degraded operation of the UUT caused by personnel-borne or helicopter-borne electrostatic discharge.

6.3.1 Personnel-Borne ESD (PESD) Applicability.

The PESD requirement is applicable in determining safety hazards for systems with ordnance for all manhandling configurations and phases. For non-ordnance items, the PESD requirement is applicable for all manhandling configurations and phases of the system to

determine reliability and survivability. Special manhandling configurations for some systems may require the system have “power on" during the PESD test. It may also be necessary to subject live, tactical ordnance systems to the PESD environment to determine if any safety hazards exist for a warhead, propellant, or other explosive material.

6.3.2 Helicopter-Borne ESD (HESD) Applicability.

The HESD requirement is applicable for all systems to be transported via helicopter to determine safety hazards and degraded operation of the system and all associated electronics, electrical, and electromagnetic equipment. The system will be configured for helicopter transportation. It may also be necessary to subject systems with live, tactical ordnance to the HESD environment to determine the safety hazards for warhead, propellant, and explosive material.

6.4 ESD CRITERIA

The standard for testing fuzes to evaluate their safety and reliability under ESD conditions is MIL-STD-331B, "Electrostatic Discharge Test". This standard is used as a guide in establishing ESD test criteria for systems. The ESD test criteria is developed without specific inputs from any system E^3RB. Thus, the ESD criteria provided here are minimum Army requirements and define the ESD environment that Army systems are expected to encounter. There are four electrostatic discharge environmental conditions that are of interest when dealing with the handling and operation of systems: Personnel, or PESD, helicopter, or HESD, Triboelectrification, and precipitation, or P-static.

6.4.1 PESD Criteria.

The personnel environment or PESD is the electrostatic voltage (potential build-up of static charge) developed on a system when personnel directly handle, disassemble, transport, etc., systems and/or components. This electrostatic environment is sometimes identified as "human build-up" or "personnel-borne" electrostatic charge. The PESD criteria, given in Table 6.4.1-1**,** is taken from MIL-STD-331B and MIL-I-23659. However, Lightning and Transients Research Institute suggests changing the capacitance from 500 picofarads (pF) to 250 pF and the resistance from 5000 ohm (Ω) to 500 Ω. Their studies indicate this equivalent circuit is a better representation of a static discharge from a person. For a UUT with hazard related EEDs, the 250 pF capacitance shall be utilized for a "go/no-go" test with no less than 50 test samples.

Table 6.4.1-1. Personnel Handling Electro-Static Discharge.

Discharge Path	Voltage (kV)	Capacitance (pf)	Series Resistance (ohms)
Personnel	25 ± 0.500	250 ± 5 %	500 ± 5%

This Table reflects the change in effective capacitance from 500 pf to 250 pf per recommendation by the Lightning and Transient Research Institute.

6.4.2 HESD Criteria.

The helicopter environment or HESD is the voltage (potential build-up of static charge) developed on a system when transported by a helicopter, a person carrying a system or component inside the helicopter, slung on a pallet from a helicopter, or fired from a launcher mounted on a helicopter. Another configuration is loading a system or component into a hovering helicopter. This latter configuration includes a person in series with the discharge path. The US Army Transportation Research Center, Fort Eustis, VA performed measurements on the H-37, H-34, H-19, HV-1, and H-21 helicopters. From this data, criteria have been established and are presented in Table 6.4.2-1 as helicopter-generated ESD.

Table 6.4.2-1. Helicopter Borne Electro-Static Discharge.

Discharge Path	Voltage (kV)	Capacitance (pf)	Series Resistance (ohms)
Personnel Carry On/Off	300 ± 0.500	1000 ± 5 %	500 ± 5%
Sling	300 ± 0.500	1000 ± 5 %	1 ± 5%

Note that the effective series resistance value for personnel carry-on/carry-off equipment is different from that of sling borne equipment.

6.4.3 Triboelectrification.

The triboelectrification environment is the voltage (potential build-up of static charge) developed by friction between two objects such as the static charge accumulated on a missile motor due to the lifting, separating, or the rubbing of a Kevlar motor case or a similar surface or materials. This process is normally referred to as triboelectrification and has the potential for ignition of the propellant when the static charging process is combined with several factors such as low temperature, low humidity, and possible mechanical stress in the propellant grain. The most critical factors in propellant ignition are electric field stress and energy.

The probability of propellant ignition is extremely low as evidenced by the failure of ESD testing to demonstrate any premature ignition. Extensive mechanical stress tests have also been performed without incident. Therefore, propellant ignition resulting from ESD is a rare occurrence and depends upon a unique combination of conditions to occur. There is no test criteria for this requirement. The system developer shall be aware of these risks and assure that all proper materials and designs are considered and that the necessary precautionary (corrective) actions have been taken.

6.4.4 Precipitation Static (P-Static).

Systems in motion encounter dust, rain, snow, and ice from which a voltage can develop on the structure. This voltage is due to p-static charging, since there is no other

mechanism for the electrical charges to accumulate. This buildup of static electricity causes significant voltage differentials, which can result in electronic interference in the equipment and shock hazards to personnel. The system designer shall control p-static induced interference resulting from receivers connected to antennas or flown onboard host platforms, such that system operational requirements are met.

6.4.5 Tailoring of ESD Criteria.

The ESD criteria specified by Table 6.4.1-1 and Table 6.4.2-1 shall be tailored by the system E^3RB to meet any unique electrostatic requirements as determined from the system's intended mission and criticality.

6.4.6 Pass/Fail Criteria.

Systems with ordnance items shall be safe, survivable and reliable when subjected to the ESD environment specified in Tables 6.4.1-1 and 6.4.2-1. Electrical systems and all associated electronics, electrical, and electromagnetic equipment shall not exhibit any malfunction nor degraded performance which would prevent the system from completing its intended mission when subjected to the ESD environment specified in Tables 6.4.1-1 and 6.4.2-1. The decision that the system has met or failed to meet the criteria shall be based on posttest inspection, appropriate testing of the system, or engineering judgment and analysis. A go/no-go test is considered a failure if the EED ignites, is visually damaged, or the electronics fail to operate.

An instrumented EED test requires additional bench testing and analysis to determine ignition thresholds and safety factors, i.e., using transient digitizing scopes to measure and record currents and waveforms. These tests need to be performed on a number of EED samples to establish maximum no-fire energy for each type of EED. Electronic components and circuits will not be instrumented unless it is determined that their failure might lead to a hazardous condition. Electronic Safe and Arm Device (ESAD) are instrumented to determine all possible failure modes with further evaluation performed by analysis or bench tests. Generally, each system using ESADs requires a unique evaluation plan in order to make a pass-fail decision.

6.5 ESD CALIBRATION AND INSTRUMENTATION

Two types of instrumentation are utilized at the ESD facilities. One type is used to monitor the facility, viz., the ESD simulated waveforms and amplitudes. The other type of instrumentation monitors the current and voltage waveforms induced on the UUT circuits. The following paragraphs discuss the instrumentation in greater detail.

6.5.1 Facility Instrumentation.

The ESD facility instrumentation monitors the ESD waveforms to insure compliance with the ESD environment criteria. Instrumentation monitors for both PESD and HESD tests are discussed below.

6.5.1.1 PESD Current Instrumentation.

An Ailtech Model 91550-2 current probe is utilized as the sensor for the PESD current waveform measurement. The current probe is installed around the ground return conductor of the discharge path. The PESD current waveform measurement is transferred out of the UUT with telemetry using a Nanofast Model OP-50 or OP-300 Fiber Optic System to a shielded area for processing. In the shielded area the signal is recorded on a Hewlett-Packard Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC. The magnitude of the test voltage is monitored by the voltage meter on the ION Physics 0-30 kV ESD simulator.

6.5.1.2 HESD Current Instrumentation.

A Pearson Model 3025 Current Probe is utilized as the sensor for the HESD current waveform measurement. The current probe is installed around the ground return conductor of the discharge path. The HESD current waveform measurement is passed out of the UUT by telemetry using a Nanofast Model OP-50 or OP-300 Fiber Optic System to a shielded area for processing. In the shielded area, the signal is recorded on an HP 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC. The magnitude of the test voltage level is monitored by the voltage meter on the Hipotronics Model 8300, 360 kV power supply.

6.5.2 System (UUT) Instrumentation.

Depending on the data collection requirements, system (UUT) instrumentation may be required to monitor the induced current and voltage signals on the various UUT circuits.

6.5.2.1 Current Probes.

Depending on size limitations as well as sensor sensitivity and signal level requirements, a variety of current probes are available to monitor the induced transient current of a particular UUT circuit. Depending on data requirements, the current probe is installed on either a specific UUT circuit lead or conductor (or on a group of circuit conductors) to measure the induced individual (or ensemble) current(s). The transient current measurement is passed out of the UUT with telemetry using a Nanofast Model OP-50 or OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

6.5.2.2 Voltage Probes.

A Nanofast Model P601 differential voltage probe is utilized to monitor the induced voltage transient on a particular UUT circuit. The voltage probe is installed between the particular UUT circuit lead or conductor and the signal return (or system ground). The induced transient voltage waveform measurement is passed out of the UUT with telemetry using a Nanofast Model OP-50 or OP-300 Fiber Optic System to a shielded area for processing. The

signal is recorded on an HP 54510 A/D Digital Oscilloscope and reduced on an IBM compatible PC.

6.5.2.3 Surface Current Probes.

The induced surface current on the UUT is measured with an EG&G Model MGL-S7B B-Dot sensor. The sensor is mounted at specific locations on the system body to monitor the induced surface currents. The induced surface current measurement is passed out of the UUT with telemetry using a Nanofast OP-50 or OP-300 Fiber Optic Systems to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

6.5.2.4 Electrostatic Field Sensors.

Depending on size limitations, sensor sensitivity, or signal level requirements, a variety of electrostatic field sensors are available to monitor the electrostatic field on the UUT. Simco Model M400 and Monroe Models 145, 171, 175, 244, and 245 are candidate sensor instruments for the measurement of the electrostatic fields. The sensor probe is typically located at a specified distance (per calibration) from the UUT to monitor the electrostatic field.

6.5.3 Test Equipment Calibration.

The measurement equipment, including oscilloscopes, is calibrated by the US Army Test, Measurement, and Diagnostic Equipment (TMDE) Activity located at Redstone Arsenal. These calibrations occur on a schedule, determined by TMDE. The accuracy for Army TMDE calibrations is traceable to the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS). The current and voltage probes utilized for the system (UUT) instrumentation are periodically checked with a network analyzer to compare the frequency response curves of the probes with the manufacturer's specifications. The network analyzer is calibrated on a regular schedule as governed by US Army TMDE. The Nanofast fiber optic systems are calibrated by utilization of a built-in test.

Additionally, the Nanofast fiber optic systems are periodically calibrated with a network analyzer to compare the frequency response curves with the manufacturer's specifications. The stimulus measurement probes are calibrated periodically by comparison of measured data with that of other probes of the same model.

6.6 ESD TEST PHILOSOPHY

6.6.1 PESD Test.

The PESD test is conducted to determine system safety and survivability to the PESD environment. All system life cycle configurations (shipping, storage, preflight, deployment) that are conducive for PESD exposure shall be analyzed to establish worst case test configurations. The strike points are determined by engineering analysis and judgment based on personnel

handling points (i.e., connectors, switches, etc.). The PESD test is usually a go/no-go or one-shot live EED (or component) test which is performed on a significant number of samples, using statistical test methods.

A Bruceton statistical method is used along with MIL-STD-331 as a guide in designing the PESD test. In general, it takes up to 50 samples (EEDs or components) to perform each test configuration and sequence. For RTTC tests, the number of samples used is usually 10, due to the prohibitively large cost of the test sample. The 10 sample requirement was established by committee in the early 1970's and results in 85% reliability with 80% confidence. The 10 sample requirement has been utilized throughout the years without any identifiable adverse effects. The ESD test is conducted through all normal and abnormal firing modes of the EED, such as the pin-to-case, pin-to-pin, etc., as well as the most susceptible discharge points on the components.

Occasionally, the PESD requires an instrumented test, due to the limited number of available test samples. An instrumented test requires prior transient data on the EED (or the component) in question, otherwise, live EEDs (or components) will be needed to establish this data. Measurements are made on the ESD transient currents induced in the bridgewire of each EED or the signal conductor of the component. The induced current is measured by current probes and these measurements are transferred out of the test area using fiber optic data links. These data links permit high voltage isolation of the sending unit and prevent EM coupling which would otherwise result from the use of conventional hardwire data transfer. Typically, a Nanofast Model OP-50 or OP-300 fiber optic data transmission system is used, similar to those described above.

If favorable weather conditions exist, there is a high probability that personnel generated static charges, with electrical potentials approaching 25 kV, will be created. Any EED or component, which can be shown to malfunction at or below 25 kV, will suggest that a problem exists. For the purposes of the PESD test, the UUT is grounded at an appropriate location as determined by the test engineer. The test technique involves charging the PESD generator probe to 25 kV and discharging it to a point on the UUT.

6.6.2 HESD Test.

The HESD test is conducted to determine system safety and survivability after an HESD event. All system life cycle configurations (shipping, storage, preflight, and deployment), that are candidate to an HESD exposure, shall be analyzed to establish worst case test configurations. The strike points are determined by engineering analysis and judgment based on helicopter transportation configurations. For sling loaded equipment, the test points will be those on the shipping container which are most likely to make first contact with the ground. For personnel transported equipment and equipment affixed to the helicopter (i.e., missiles in launchers) the test points will be those most likely to be discharge points. Some tests may require the equipment be active (i.e., power on). The test for EEDs (and other safety related items) is conducted in either of two ways; a go/no-go test, or an instrumented test. The go/no-go test requires a large sample size. The larger the sample size, the more confidence there is in the

test results. Ideally, the sample size should be 50; for RTTC testing, the minimum number of test samples utilized is 10. Usually one sample is used to determine the survivability of all components other than EEDs. However, when EEDs are at issue, the same component is used throughout the EED testing.

For the instrumented test, measurements are made of the transient currents induced in the bridgewires of each EED or in the signal lead of a component. These measurements are made using current probes, a high frequency fiber optic data link, digitizing scopes and a computer. The fiber optic instrumentation link permits isolation of the test equipment from the high voltages. The fiber optic instrumentation also eliminates nonrepresentative electromagnetic signal generation and coupling which would result from the use of conventional hardwire conductors in tactical configuration. The instrumentation is placed inside UUT cavities, such as an empty motor case or a warhead section of a missile. The transient currents are sensed by the wide bandwidth shielded current probes placed around any one or more of the conductors in each EED.

The signal from each current probe is linked to the fiber optic transmitter via a short length of double shielded coaxial cable. Once transmitted out of the UUT, the optical signals are detected, demodulated and converted back to electrical signals. The electrical signals are monitored by transient digitizers and scopes and analyzed by a computer.

A system safety margin can be determined by using the technique described herein for an instrumented EED, identifying those levels (above the PESD criteria) at which the EED or component can be shown to operate successfully. Safety margins are not determined by go/no-go testing. However high confidence levels can be achieved with go/no-go testing and larger sample sizes. The high confidence levels are desired to assure the system can meet the criteria.

6.6.3 Test Configurations.

The test configurations are determined from "worst case" conditions for the system. For PESD, all manhandling configurations will be tested. For HESD, those configurations representative of helicopter transport will be tested. Helicopter sling loaded equipment will be tested in its shipping configuration. Equipment transported by personnel onto or off of helicopters will be tested in the manhandling configuration while equipment mounted on the exterior of the helicopter (i.e., missile launchers with missiles loaded) will be tested in its tactical configuration and may need to be tested in its active (power on) mode.

6.7 ESD TEST PROCEDURES

An ESD test sequence should start with the least probable destructive test and end with the most probable destructive test. Testing of containerized equipment should be conducted prior to testing of bare equipment. Testing of passive states (power off) for equipment should be performed prior to testing of active (power on) equipment. Figure 6.7-1 provides a schematic of ESD testing, indicating test options and decision points.

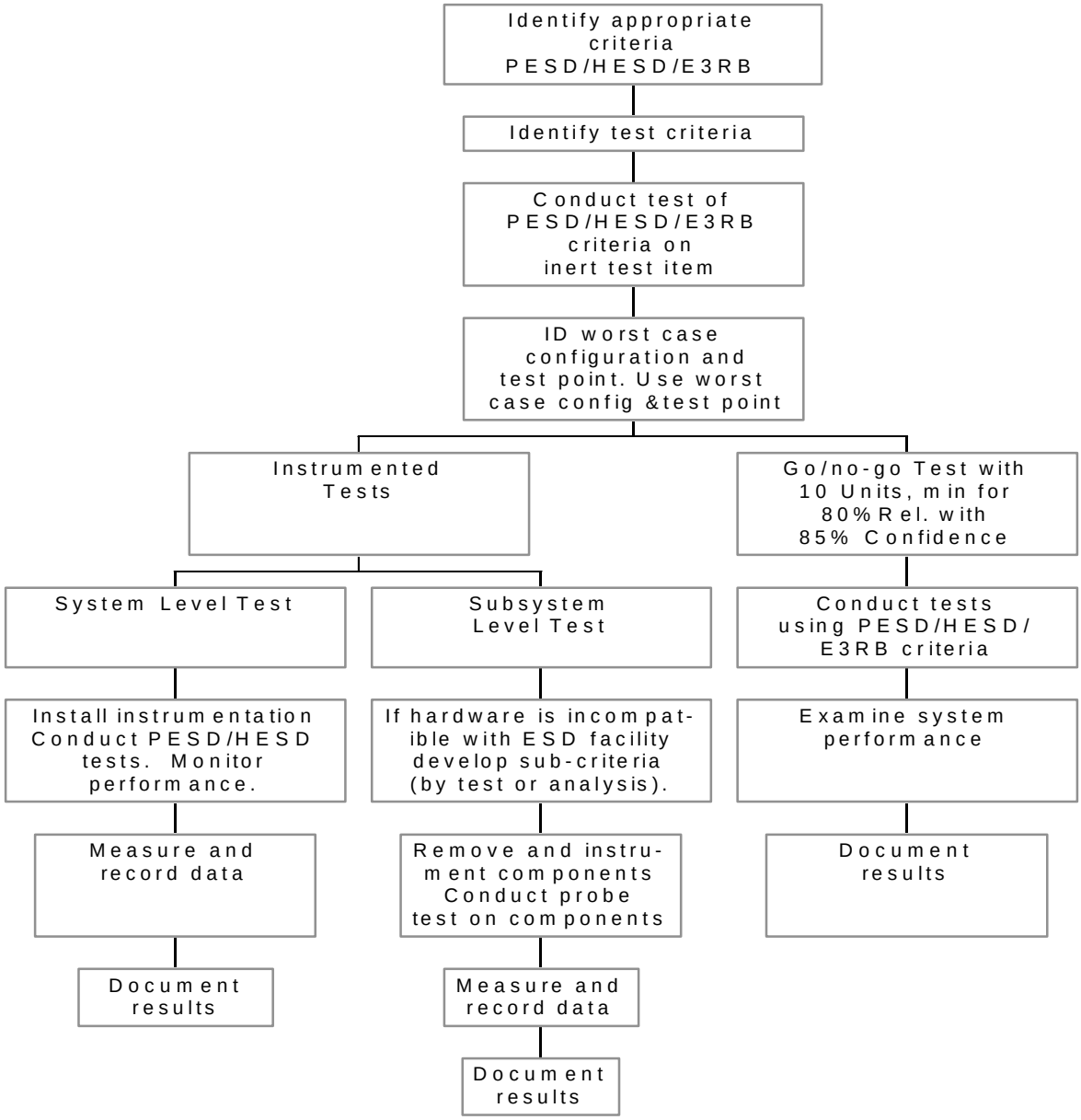


Figure 6.7-1. ESD Test Flow Diagram.

Verification that UUT performs under ESD criteria is dependent on whether the test objective is to determine safety hazards or degradation of system operation, or both, and can be accomplished by the following three techniques: instrumented testing, go/no-go testing, or their combination. Instrumented testing requires monitoring signal lines and, subsequently, having detailed knowledge of component responses and threshold levels for activation of EEDs or proper operation of electrical equipment. Typically, threshold limits for EEDs are defined in terms of dc parameters and not in terms of transient parameters. For this reason, the go/no-go test is the primary technique for verifying system performance under ESD. Go/no-go testing involves monitoring the system for safe and proper operation. For either test technique, an absolute definition for failure (signal interference, system reaction or response) is required prior to initiation of the tests to avoid confusion and indecision during the tests.

6.7.1 Instrumented Testing.

Since the threshold limits for EEDs are typically specified in terms of dc parameters and not in terms of transient parameters, instrumented testing is not normally utilized for verification of equipment performance under ESD. Instrumented testing is used primarily to determine the worst case test point and worst case configuration of the system for coupling ESD energy to the EEDs. Identification of worst case test point and configuration is done to reduce the number of test runs for the go/no-go test (i.e., testing only those test points demonstrating worst case coupling as opposed to all candidate test points). In some circumstances, instrumented testing may allow for verification of UUT performance under ESD criteria if measured data from a previous test is available for comparison.

For testing of EEDs, the maximum no fire energy (MNFE) needs to be determined in order to establish the required safety margin requirement. Since there is usually only one complete system available for test, it is necessary to further quantify susceptibility margins by obtaining statistical data on many samples of the EEDs of interest. This data is accomplished by obtaining induced responses on the EEDs during the system level test, and then testing a statistically significant number of identical, stand alone EEDs under laboratory conditions by means of Bruceton tests. The thresholds for noncompliance of the stand alone EEDs are then related to the response of the EEDs in the weapon system to obtain a statistical statement of EED activation thresholds. Susceptibility or safety margins of EEDs are obtained by comparison of measured or extrapolated responses with data from the sensitivity test of the EEDs. The sensitivity tests often use Bruceton analyses to establish a "no fire" energy levels for a given confidence level. The performance criteria for the EEDs of each system is determined from the specific EED under test within the system.

Each EED of the system will be designated as either a hazard EED (an EED whose premature initiation, dud creation, or desensitization results in injury to personnel or destruction of property) or a reliability EED (an EED whose premature initiation, dud creation or desensitization results in degradation of the EED performance beyond design tolerances, but without hazardous external effects). For ground based Army systems, hazardous EEDs must exhibit a minimum safety factor of 10 dB, while reliability EEDs must exhibit a minimum safety factor of 6 dB. The criteria for the associated electronics, electrical, and electromagnetic equipment of the system is determined by the survivability of the equipment after exposure to the ESD environment. Instrumented testing requires monitoring all signal channels, and subsequently comparing the data collected during the tests to previously documented component responses and threshold levels required for proper operation.

6.7.1.1 Instrumented Go/No-Go Testing.

This technique is used specifically for verifying safety hazards of EEDs and involves observing and measuring (with the appropriate instrumentation) the induced transient signals on the EEDs. These observation are needed to identify the worst case test point and configuration of the system. Once the worst case test point and configuration are identified, then go/no-go testing is utilized to verify the UUT performance under ESD criteria. For systems with several test points and configurations, this test technique greatly reduces the number of test runs required to verify the system performance, since only one combination of test point and configuration is examined in detail. Testing at the levels identified in the ESD criteria is not necessary for this technique, but is mandatory for the go/no-go verification.

6.7.1.2 Comparison Analysis.

This technique is used strictly for verifying safety hazards of EEDs and involves observing UUTs with instrumentation capable of monitoring and measuring induced transients, and comparing the data collected during the ESD test with previously collected ESD data. Two requirements must be met in order for this technique to be applicable:

A. The previous EED test data must be from an ESD test in which the system's EEDs passed the ESD criteria and which included a go/no-go test.

B. The EED being tested must be the exact same make and model as the EEDs from the previous ESD test.

If the measured induced transient signal is equal to or less than the measured induced transient signal from the previous ESD test, then the system is considered to be safe under the ESD criteria. If the measured induced transient signal exceeds that measured from the previous test, then the system cannot be considered safe and other test techniques must be conducted to verify the UUT performance under the ESD criteria. Testing at the ESD criteria is mandatory for this technique.

6.7.1.3 Pin-Injection Testing.

This technique is utilized for testing UUT components and subsystems when it is neither possible nor feasible to test the entire system. Typically, the level of the pin-injection waveform is determined by a sub-criteria level test on the system. This test is conducted with the various UUT components instrumented after which the entire UUT is subjected to the ESD criteria. The instrumentation provides a means of determining the transfer impedance, i.e., the identification of the ESD induced current or voltage waveform and amplitudes coupled from the system (UUT) to the individual components. This approach enables subsequent tests performed on individual components, using the sub-criteria determined from instrumented system tests. If testing at the system level (to empirically determine the correct sub-criteria that would occur at the component level) is not possible or feasible, then the only other alternative is to perform analyses to estimate the appropriate pin-injection waveform.

Special considerations should be given to the determination of the coupling, attenuation, and scale factors. Erroneous assumptions or large scaling factors can result in unrealistic, if not invalid, pin-injection levels. For this reason, the preferred approach for the determination of the induced waveforms is through empirical tests. The induced waveform (whether measured or determined analytically) is scaled numerically to represent the waveform and amplitude (sub-criteria level) which would appear at the component in question. This simulated sub-criteria is generated and then injected into the corresponding circuits, conductors, or shields of the component. The component is monitored for degradation of performance. For components with EEDs, both instrumented and go/no-go test techniques are utilized to verify the safety hazards for the EEDs.

6.7.2 Go/No-Go Testing.

Go/no-go testing requires the system be monitored for normal operation while being subjected to the ESD criteria. Detailed procedures are followed and system responses for normal operations are monitored and recorded by test personnel. If anomalous performance due to ESD is observed, the stimulus levels are reduced until the abnormal system response is no longer observed. The ESD level arrived at by this method is the threshold level for acceptable system response.

In some cases, it may be necessary to record the system response in order to quantify the interference. This recording might utilize video cameras with fiber optic cables and lenses, i.e., video recording the interference to a night sight screen or an IR monitor. The go/no-go test method requires the facility have the capability of testing at the criteria levels. For systems with EEDs, a minimum of 10 EEDs must be tested to establish a statistical level for safety hazards. This provides a reliability of 85% with a confidence of 80%. Additional EEDs would need to be tested to guarantee higher levels of reliability and confidence.

6.7.3 Data Recording and Display.

The data from the UUT are interfaced with the computer for real-time recording, analysis, and data storage. All pertinent test conditions and parameters along with data from the UUT being monitored are automatically recorded. In addition, a graphic terminal with hard copy capability is available for providing data plots needed for quick-look analyses and reports. The computer also controls direct-write oscillographs for recording data from UUT. All data needed for test report writing is stored on disk for formatting and editing off line on alternate PCs.

6.7.4 Double Shielded Instrumentation Van.

The IR signals generated for transferring data out of the UUT from the various measurement equipment through the fiber optics are converted to electrical signals by the IR receivers in the ground station. The converted electrical signals are displayed on oscillographs and then recorded, monitored and stored by the computer. These test functions are performed in a double shielded instrumentation van as shown in Figure 6.7.4-1.

6.8 ESD TEST DOCUMENTATION

6.8.1 Test Configuration.

The data recorded is appropriate for a particular UUT configuration and a particular test criteria. Because of this uniqueness, the test configurations for each UUT are recorded for traceability of test data to particular configurations. Some tests are conducted only for worst case configurations of the UUT. Worst case configuration is dependent on both configuration and mission, i.e. shipping, storage, and deployment, whether ground or air, etc.

For PESD test, all manhandling configurations will be tested. While for HESD, only those configurations representative of helicopter transport will be tested. This consist of sling loaded equipment which will be tested in its “as shipped” configuration.

Equipment that is carried on or carried off helicopters will be tested in the manhandling configuration, while equipment externally mounted on the helicopter will be tested in its tactical configuration, possible in an active mode, i.e. with power on.

6.8.2 Test Plans.

The following provides an outline for ESD Test Plan. Information is provided separately for PESD and HESD test plans.

Figure 6.7.4-1. Double Shielded Instrumentation Van.

6.8.2.1 PESD Test Plan.

A pretest study is conducted to identify the manhandling points and those which would be more susceptible to damage or likely to cause safety problems or operational problems. Instrumentation may be necessary to monitor internal test points so that safety margins may be determined, and extrapolations can be made. The test plan will be written and approved prior to receiving system hardware. A detailed test procedure will be written prior to test conduct. A general test procedure for conduct of a PESD test would be as follows:

A. Perform pretest calibration of the PESD generators on a dummy system and perform pretest operational check of the system.

B. Install instrumentation and EEDs.

C. Suspend the system from an insulated fixture and ground system.

D. Secure test area and initiate safety and security test procedures.

E. Verify safety and security requirements are met and begin charging the PESD simulator to +25 kV.

F. Initiate video recording sequence (if necessary).

G. Notify safety officer when charging sequence is complete and verify permission to discharge probe on UUT.

H. Discharge the ESD Simulator by contacting the system with the probe at the selected test point.

I. Record test data.

J. Repeat steps E. through I. for all test points.

K. Repeat steps E. through J. for -25 kV.

L. Check the system electronics for operational integrity.

M. Visually and electrically check the EEDs. Replace EEDs and repeat steps B. through L. until a minimum of 10 sets of EEDs are tested

6.8.2.2 HESD Test Plan.

A pretest study is conducted to identify the most probable HESD discharge points and those which would be more susceptible to damage or likely to cause safety or operational problems. Instrumentation may be necessary to monitor internal test points so that safety

margins may be determined and extrapolations can be made. The test plan will be written and approved prior to receiving system hardware. A detailed test procedure will be written prior to test conduct. A general test procedure for conduct of an HESD test would be as follows:

A. Perform pretest calibration of the HESD generators on a dummy system and perform pretest operational check of the system.

B. Install instrumentation and EEDs.

C. Suspend the system from an insulated fixture and place it against the high voltage probe or toroid.

D. Secure test area and initiate safety and security test procedures.

E. Verify safety and security requirements are being met and begin charging the PESD simulator to +300 kV.

F. Initiate video recording sequence (if necessary).

G. Notify safety officer when charging sequence is complete and verify permission to conduct attachment.

H. Discharge the probe to the system at the selected test point.

I. Record test data.

J. Repeat steps E. through I. for all test points.

K. Repeat steps E. through J. for at -300 kV.

L. Check the system electronics for operational integrity.

M. Visually and electrically check the EEDs. Replace EEDs and repeat steps B. through L. until a minimum of 10 sets of EEDs are tested.

6.8.3 Test Report.

General documentation for the ESD test includes, but is not limited to, the following:

- Serial numbers of test hardware
- Calibration information
- Non-standard modification of test hardware
- Hardware configuration
- Non-test related problems/failures
- Pretest, posttest, etc. inspection results
- Daily log for test activities

- Facility hardware utilized
- Instrumentation hardware utilized
- Still photographs of test setup
- Still photographs of test instrumentation

Detailed documentation for each test run shall include, but is not limited to: test sequence number, test criteria, test environment (to include charge voltage, peak current and power in the ESD waveform), configuration of the test item, measurement of the induced current and voltage signals and pertinent test observations.

SECTION 7.0 ELECTROMAGNETIC PULSE (EMP)

7.1 EMP BACKGROUND

Electromagnetic Pulse (EMP) is a short duration (less than one second) burst of electromagnetic radiation associated with a nuclear event. A nuclear event can produce radiation that ionizes surrounding material, e.g., weapon debris, air, soil, etc. The resulting currents can create large electric and magnetic fields. EMP is a potential threat to virtually all sophisticated systems, including missile systems. Army materiel are required to meet the EMP criteria for system safety and reliability per Army Regulation (AR) 70-60. The specific criteria used in EMP testing is classified and can be found in the following documents: Quadripartite Standardization Agreement (QSTAG), "Nuclear Survivability Criteria for Military Equipment (Classified)", dated Oct. 80, and in DOD-STD-2169 (Classified).

The criteria are based on a high altitude (exoatmospheric), nuclear events (detonations) which give rise to E-fields of 10,000 to 100,000 V/m at ranges of 3,000 miles from the event. This high altitude event is called High Altitude Burst Electromagnetic Pulse (HABEMP). The spectrum and waveform of HABEMP differ from those of other natural or commonly used man-made EMP sources. The spectrum is broad and extends from extremely low frequencies to approximately 100 MHz. The temporal waveforms have faster rise times and higher amplitudes than fields generated by near strike lightning. When used in the context of component reliability, this criteria is specified in terms of recovery time. A missile system with its components must meet the specified operational criteria after exposure to an EMP event.

EMP radiation represents electrical energy at frequencies identical with currently deployed missile systems. The most critical part of the EMP spectrum for missile systems occurs between 300 kHz and 3 MHz. However, the upper and lower frequencies should not be ignored. EMP will couple to varying degrees into EEDs and electronic devices. Solid state components are the most susceptible, particularly where they interface with electric conductors that are oriented so as to permit maximum coupling of EMP energy into the conductor. Exposed apertures, unshielded cables, and antennas are prime candidates for EMP coupling into the internal electronics, due to their efficiency in transferring the large voltage and current transients. Digital equipment is potentially the most vulnerable to EMP because of their inherent low threshold for electronic upset and damage. Component damage, loss of logic circuits and their function, and transient induced malfunction are candidate failure modes.

The effects of EMP on a system depend not only upon the energy collected by a system, but also upon the type of circuits and components in the system. Unless proper EMP protection is employed, these transients can cause upset of digital logic systems and damage electronic components. Candidate approaches to protect missile systems from EMP effects include protective circuits and devices, cable filters, proper grounding, electromagnetic shielding, and isolation.

For the purposes of conducting EMP tests, the environments are free field. The exact EMP environments used during the tests will depend on such variables as ground conductivity, angle of incidence and equipment height above ground.

7.2 EMP TEST OBJECTIVE

The objective of the EMP testing is to obtain data to support an EMP hardness evaluation of the system. An additional objective is to determine if exposure to the exoatmospheric EMP environments as characterized by HABEMP and specified in QSTAG-244 (Classified) and DOD-STD-2169 (Classified) will result in a safety hazard or degraded operation (malfunctions, undesirable and unacceptable responses) of the unit under test (UUT). As used here, UUT includes all associated electronics, electrical, and electromagnetic components in the system. Thus, testing is to verify that the protective measures currently incorporated in the system design are adequate.

Testing can provide for verification of analysis performed during conceptual and early design phases, as well as verification of extended analysis on a more complex system that is not adequately defined. Testing is the only known method that can be used to locate unexpected susceptibilities. Qualification tests are intended to provide assurance that the system meets established criteria. It should be noted that since each specific system responds differently to the same test environment, the results of each EMP qualification test can be applied to only the specific system configuration tested. Therefore, EMP testing is required for each component or subsystem with differing design, material, or configuration characteristics.

7.3 EMP APPLICABILITY

The EMP test requirement is applicable for the determination of safety hazards and degraded operation of the UUT (with all associated electronics, electrical and electromagnetic equipment) which are caused by a nuclear event resulting in EMP per AR 70-60.

7.4 EMP CRITERIA

The EMP criteria are developed specifically for each system based upon the approach outlined in QSTAG-244 (Classified), Defense Nuclear Agency (DNA) EMP Handbook, DNA 211, Volume IV and in DOD-STD-2169 (Classified).

7.5 EMP SIMULATOR INSTRUMENTATION AND CALIBRATION

Two types of instrumentation are utilized at the EMP facilities: 1) facility instrumentation which is necessary to monitor the simulated EMP waveforms, and 2) system instrumentation which is necessary to monitor both current and voltage amplitudes and their waveforms induced on the UUT circuits.

Calibrations of test equipment are provided by US Army test support agencies, occurs on a predetermined schedule to ensure measurement accuracy, and are traceable to national standards.

7.5.1 Facility Instrumentation.

The facility instrumentation is necessary to monitor the EMP waveforms to insure compliance of the test environment with EMP criteria. The test monitors are discussed in detail as follows.

7.5.1.1 Rate of Change of Magnetic Field (B-dot) Sensor.

The rate of change of magnetic field waveform is measured with an EG&G Model MGL-2 B-Dot sensor. This sensor is used to calibrate the magnetic field at the location of the UUT. The rate of change of magnetic field measurement is transferred by telemetry via a Nanofast OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

7.5.1.2 The Rate of Change of Electric Field (D-dot) Sensor.

The rate of change of electric field waveform is measured with an EG&G Model HSD-4 D-Dot sensor. This sensor is utilized to detect D-dot at the location of the UUT. The measurement of the rate of change of electric field is transferred by telemetry via a Nanofast OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

7.5.1.3 Peak Electric Field Sensor.

The peak electric field is measured with an Nanofast Model EFS-1 peak electric field sensor. This sensor is utilized to monitor the peak electric field at the location of the UUT. The peak electric field measurement is transferred by telemetry via a Nanofast OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

7.5.2 System Instrumentation.

System (UUT) instrumentation is necessary to monitor both current and voltage amplitudes and their waveforms on the various UUT circuits. These are necessary to define coupling of EMP energy into the UUT during the sub-criteria tests, enabling identification of UUT response and extrapolation of the measured response when needed.

7.5.2.1 Current Probes.

Depending on physical limitations as well as sensitivity and dynamic range (amplitude) requirements, a variety of current probes are available to monitor the current

transients which appear on a particular UUT circuit. The current probe is installed around a circuit conductor or cable (or on a group of conductors, depending on data requirements), to measure the induced current, (either individual or ensemble). The transient current measurement is transferred out of the UUT by telemetry via a Nanofast Model OP-50 or OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

7.5.2.2 Voltage Probes.

A Nanofast Model P601 differential voltage probe is utilized to monitor the induced voltage transient on a particular UUT circuit. The voltage probe is installed between the particular UUT circuit conductor and return or UUT ground. The induced voltage waveform measurement is transferred out of the UUT by telemetry via a Nanofast Model OP-50 or OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

7.5.2.3 Surface Current Probes.

The induced surface current on the system is measured with an EG&G Model MGL-S7B B-Dot sensor. The current sensor is mounted at specific locations on the UUT body to monitor the induced surface currents. The induced surface current measurement is transferred out of the UUT by telemetry via a Nanofast OP-50 or OP-300 Fiber Optic System to a shielded area for processing. The signal is recorded on an HP Model 54510 A/D Digital Oscilloscope and processed on an IBM compatible PC.

7.5.2.4 Shielded Boxes.

Special shielded boxes are fabricated to access individual circuits and electrical conductors. The shielded boxes are specially designed for each system to minimize extraordinary EMP coupling. These shielded boxes utilize identical connectors (both male and female) employed on the UUT and are installed in-line with existing UUT conductors to permit the monitoring of specific electronic circuits of interest.

7.5.3 Calibration.

The measurement equipment, including oscilloscopes, is calibrated by the US Army Test, Measurement, and Diagnostic Equipment (TMDE) Activity located at Redstone Arsenal. These calibrations occur on a schedule which is determined and maintained by TMDE. The accuracy for Army TMDE equipment calibrations is traceable to the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS). The current and voltage probes utilized for system (UUT) instrumentation are periodically calibrated with a network analyzer to compare the frequency response curves of the probes with the manufacturer's specifications. The network analyzer is also calibrated by US Army TMDE Activity. The Nanofast fiber optic systems are calibrated by utilization of built-in tests.

Additionally, the Nanofast fiber optic systems are periodically calibrated with a network analyzer to compare the frequency response curves with the manufacturer's specifications. The current and voltage probes used in measurement of the EMP simulator are verified periodically by comparison of measurement data with other probes of the same model.

7.6 EMP TEST PHILOSOPHY

Systems with ordnance items shall be safe, survivable, and reliable when subjected to the EMP environment specified in QSTAG-244 and DOD-STD-2169. Electrical systems and all associated electronics, electrical, and electromagnetic equipment shall meet specified operational criteria. When addressing component reliability, this criteria is stated in terms of recovery time.

For high priority UUTs, resources are made available so that an EMP hardness assessment can be obtained with a high degree of confidence. This assessment is accomplished by a thorough pretest analysis and test planning, followed by a combination of sub-criteria threat and CW measurements. A posttest evaluation of the sub-criteria threat and CW measurements results in the identification of system functional responses and vulnerability assessment. These measurements provide data to support further exploratory-type threat level tests.

For systems that are minimally complex in terms of potential electromagnetic coupling paths, the CW and sub-criteria threat pulse evaluation techniques may be used exclusively, negating the need for threat level testing. In order to gain confidence in the evaluation of UUT response to EMP, a very simple threat level test will be conducted. These threat level tests may involve single conductor current injection, simultaneous multiple conductor current injection, subsystem exposure, or full system exposure. The optimum approach for EMP testing is different for each system and should be developed by EMP test and evaluation specialists, with the assistance of those system (UUT) experts familiar with the design, normal functioning, and performance of the UUT.

When the resources are not available for a high confidence EMP hardness assessment, the specific approach adopted should be structured to yield the maximum amount of useful information. The information should be relevant to both system hardness and the uncertainty in the overall assessment.

7.7 EMP TEST PROCEDURE

There are four test techniques used to determine UUT hardness to EMP. These techniques are: 1) threat-level simulation, 2) sub-threat simulation, 3) frequency domain testing and 4) scale modeling. Figure 7.7-1 provides a flow diagram of EMP test options and decision points.

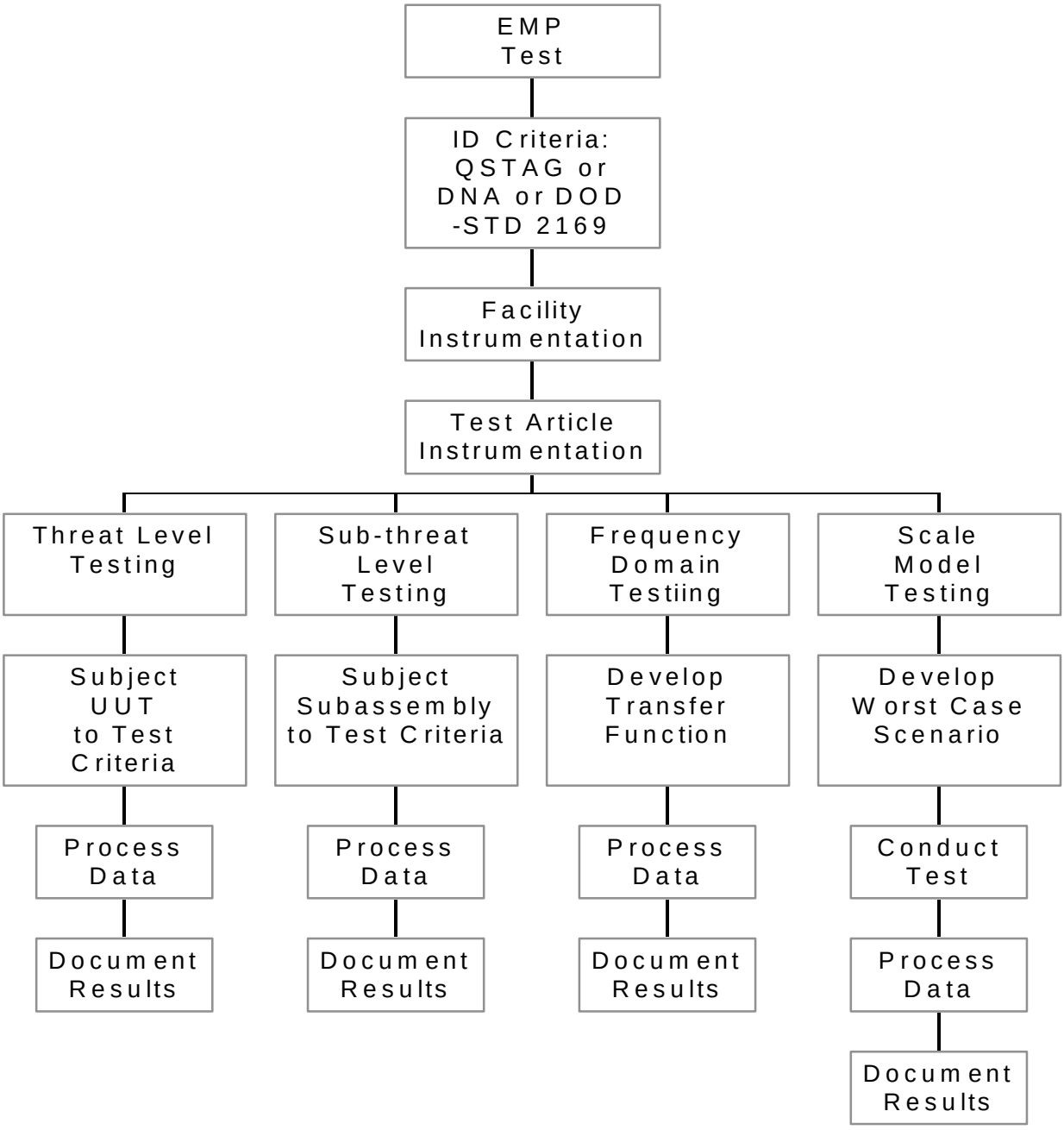


Figure 7.7-1. EMP Test Flow Diagram.

7.7.1 Threat-Level Simulation.

Threat-level simulation in the time domain determines transient responses of the system and components. Threat level simulation is the testing of a UUT under the full EMP criteria as defined in paragraph 7.4. Threat level simulation permits go/no-go testing of systems and components. A minimum of 10 samples of the test item are required to establish 85% reliability with 80% confidence. Higher levels of reliability and confidence require additional test items. If a sufficient number of samples (UUT) are not available, then data from instrumented tests, exposing a single UUT to the threat levels, will enable the evaluation of the EMP hardness for a UUT or its components.

7.7.2 Sub-Threat Level Simulation.

Sub-threat level simulation refers to the testing of UUT under the EMP environment generated by Transportable Electromagnetic Pulse Simulator (TEMPS). These levels are lower than the threat levels identified by paragraph 7.4. Sub-threat level simulation in the time domain is utilized to determine system and component transient responses. These transient responses are extrapolated analytically to the threat levels to determine system response. Go/no-go test methods using sub-threat level simulation cannot be utilized as a means to verify UUT compliance with EMP criteria. Data from instrumented tests of UUT must be extrapolated to threat levels to evaluate the EMP hardness for the UUT and components. It must be pointed out that a linear extrapolation may be invalid in estimating the actual coupling of the threat level to the UUT. For test parameters other than amplitudes (e.g., rise time, etc.), extrapolation is also invalid.

7.7.3 Frequency Domain Testing.

This technique utilizes a series of CW frequency measurements to determine transfer functions for the system and components. Several requirements must be satisfied to successfully conduct transfer function measurements:

A. The transfer functions require measurements of phase and amplitude of each frequency used.

B. The sampling rate is a function of (pulse) bandwidth and is determined by the pulse rise time and duration (pulse width).

C. Test time is determined by the number of frequencies used in generating the data base.

D. Data has to be computer processed to interpret the effects at threat level.

E. The threat level extrapolation assumes EMP effects are linear (an assumption which may be invalid for some components and systems).

Instrumentation is necessary to monitor data for frequency domain testing. Frequency domain testing does not permit the utilization of go/no-go test techniques for verification.

7.7.4 Scale Modeling.

This technique determines system responses in the time-domain for either worst case scenarios or system test configurations. Generally scale modeling utilizes test articles (UUT "replicas") that are smaller than the actual UUT but which retain certain desirable electrical/ mechanical features of the UUT. Scale modeling is a useful technique for test planning and for developing "ball park" estimates of the system responses. It rarely precludes the necessity of conducting full scale testing on the actual UUT. This technique is limited to certain special and limited conditions and is not applicable for all systems or components.

7.7.5 Data Recording and Display.

The data from the test articles (UUT) are processed via computer interface for real-time recording, analysis, and data storage. All pertinent test conditions and parameters along with data from the UUT being monitored are automatically recorded. In addition, a graphics terminal with hard copy capability is available for generating data plots for quick-look analyses and reports. The computer also controls direct-write oscillographs for recording data from UUT. All data needed for test report writing is stored on disk for formatting and editing off line on alternate PCs.

7.7.6 Double Shielded Instrumentation Van.

The IR signals, used for transferring data (generated by the measuring equipment) out of the UUT through the fiber optics links, are converted to electrical signals at the IR receivers in the ground station. The converted electrical signals are displayed on oscillographs and then recorded, monitored and stored by the computer. The double shielded instrumentation van is shown in Figure 7.7.6-1.

7.7.7 Data Analysis.

Data analysis for EMP investigations consists of instrumenting and recording UUT response to EMP stimulus, identifying component degradation/upset based upon observed performance during testing. Due to the fact that EMP testing is usually conducted either at sub-criteria threat levels or over frequency domains, it is mandatory that both the stimulus and response functions are recorded. This enables posttest analysis, identifying equipment shortfall and the stimulus which was responsible for the effect. It also provides the opportunity to estimate UUT degradation/upset under full EMP environment.

While this empirical approach depends on assumptions on data collection and extrapolation procedures similar to those made under other E^3 tests, it is significant to note that few facilities have the ability to test at full EMP environments. The tests results then are used as a guide in determining the critical components, circuits, and entry points which are candidate for

Figure 7.7.6-1. Double Shielded Instrumentation Van.

upset by EMP stimulus. Once these components, locations, and responses are identified, they can be analyzed for sensitivity to EMP stimulus, and equipment designers can pursue the alternatives as necessary, i.e., either hardening the current design or redesigning.

7.8 EMP TEST DOCUMENTATION

7.8.1 Test Configurations.

Depending on the specific EMP requirements, the test configurations include all conditions for the system from stockpile storage to shipping, tactical deployment, and operation (including flight). Some equipment will only require testing in the passive state (power off) while other systems will require testing in both passive and active (power on) states.

7.8.2 Test Procedure.

RTTC capabilities are currently limited to two basic types of test techniques: 1.) sub-criteria threat repetitive pulse simulator and 2.) CW measurements of transfer functions of critical subsystems and components. These two techniques can be used separately and then combined analytically to establish system hardness. The repetitive pulse testing is intended to use simulation of the threat field waveform with simple linear extrapolation to determine EMP effects at threat level. However, it cannot be determined with certainty that a system will be upset by a threat level environment unless a full threat level test is conducted. Before performing costly, cumbersome, and time consuming full threat test, a combination of low level and CW tests coupled with “in depth analyses” are used to design the full threat level test. The advantages of repetitive pulse testing are: ease of data collection, validity of data collected can be easily verified, continuous probing can be accomplished and, low cost.

The disadvantages of repetitive pulse testing are: sensitivity, the ability to detect responses on a very small system is limited; extrapolation, the assumption that responses are linear may be invalid; and threat simulation validity, extrapolation is invalid for any EMP field parameter other than amplitude.

Similarly, there are several CW testing requirements that must be satisfied to successfully conduct transfer function measurements:

- Transfer functions require accurate measurements of phase and amplitude.
- The number of frequency samples required is a function of EMP spectrum bandwidth, which is determined by the pulse rise time and duration.
- Extensive range time is required to obtain data at many frequencies.
- Data has to be processed by computer to interpret the effects at threat level.
- Extrapolation of results to full threat level is assumed to be linear.

7.8.2.1 Sub-Threat Repetitive Pulse Testing.

A pretest study is conducted to identify the instrumentation points and test exposure angles. The UUT is tested in either an active (power on) or passive (power off) mode, depending upon the operational requirements of the system. When testing to determine EMP effects on EEDs, the system electronics will be inactive if EMP requirements are only to prevent a hazard and/or component burn out during storage and prelaunch configurations. Most Army missile system EMP criteria do not require an active or operational system during an EMP event. An exception to this rule occurs when a missile system is either positioned on a launcher in a "ready" or "energized" state for an extended period of time (pre-launch), or when the system is considered strategic.

The number of test shots (or pulses) made on a system (UUT) depends upon the required number of instrumented components, the availability of instrumentation channels, fiber optic TM systems, and the ability to produce the EMP wave shape. The test plan will be written and approved prior to receiving system (UUT) hardware. A detailed test procedure will be written prior to conduct of the test. A general test procedure for conduct of a sub-criteria threat repetitive pulse test would be as follows:

A. Raise TEPS antenna and pulser to test position.

B. Place field measuring probes (B-dot or E-field) at desired test location (typically 50 meters from center of antenna).

C. Install data recording equipment in appropriately shielded enclosures.

D. Power up pulser and measure field level at test location. Move probe as necessary to locate exact test location.

E. Place UUT at calibrated test location and install current probes or other instrumentation as required.

F. Record data from current probes or other instrumentation and field probes.

G. Lower antenna and pulser to ground level after completing tests.

7.8.2.2 Frequency Domain CW Measurements.

A pretest study is conducted to identify instrumentation points and test exposure angles. The UUT is tested in either an active (power on) or passive (power off) mode, depending upon the operational requirements of the system. Frequency domain CW measurements establish damage and/or upset thresholds of components, depending upon system requirements. When measurements are performed to determine damage and upset thresholds of electronic components, then measurements must be made of both amplitude and phase (complex impedance) at each frequency of interest. Frequencies of interest are usually determined in sub-

threat time domain pulse tests. The test plan will be written and approved prior to receiving system hardware. A detailed test procedure will be written prior to test conduct. A general test procedure for conduct of a frequency domain CW test would be as follows, (E-field is an rms value):

A. Perform pretest calibration of the E-field.

B. Install the UUT with instrumentation into the test area.

C. Generate the specified E-field on the UUT.

D. Monitor and record the system response to the incident E-field.

E. Remove the specified E-field from the UUT.

F. Change frequency and repeat steps C. through E. for all test frequencies.

G. Change orientation of the UUT with respect to the incident E-field and repeat steps C. through F. for all test orientations of the UUT.

H. Repeat steps C. through G. for all test configurations.

I. Repeat steps B. through H. for all instrumentation points.

7.8.3 Test Documentation.

General documentation for the EMP test includes, but is not limited to, the following:

- Serial numbers of test hardware
- Calibration information
- Non-standard modification of test hardware
- Hardware configuration
- Non-test related problems/failures
- Pretest, posttest, etc. inspection results
- Daily log for test activities
- Facility hardware utilized
- Instrumentation hardware utilized
- Still photographs of test setup
- Still photographs of test instrumentation

Detailed documentation for each test run shall include, but is not limited to, the following:

- Sequence number
- Criteria

- Environment, include charge voltage, peak E-field (repetitive pulse testing)
- Frequency (frequency domain CW measurement)
- Item (UUT) configuration
- Measurement of the induced current and voltage waveforms
- Pertinent observations

SECTION 8.0 ELECTROMAGNETIC INTERFERENCE (EMI)

8.1 EMI BACKGROUND

Electromagnetic Interference (EMI) or Radio Frequency Interference (RFI) is defined as degradation by an unwanted electromagnetic signal or an electromagnetic disturbance. An electromagnetic or radio frequency interference is when this unwanted signal is coupled in or out of a component, subsystem, and system. EMI is usually in reference to interference between subsystems or components as applied to the system requirements. The term EMI is usually used in reference to screen or shielded room testing per MIL-STD-461 requirements and MIL-STD-462 test methods.

Subsystem level tests should be considered early in the development of components and subsystems before a complete assembly is made into a final system. Those components and subsystems that fail to meet the requirements can be modified and then retested. With this technique there is a high probability that, when assembled, the overall system electromagnetic environmental effects (E^3) requirements will be met. Testing should be in accordance with the most recent versions of MIL-STD-461 and MIL-STD-462. Presently MIL-STD-461D and MIL-STD-462D are the applicable versions. Both of these standards were approved for use on 11 Jan. 93. MIL-STD-461D superseded MIL-STD-461C (4 Aug 86) and MIL-STD-462D superseded MIL-STD-462 (31 Jul. 67).

8.2 EMI TEST OBJECTIVE

The objective of the EMI test is to obtain data to evaluate the ability of the electronic, electrical, and electromagnetic equipment and subsystems to meet the design requirements for the control of the electromagnetic emission and susceptibility characteristics specified in MIL-STD-461.

8.3 EMI APPLICABILITY

The applicability of the emission and susceptibility requirements is dependent upon the types of equipment or subsystems and their intended installations as specified in MIL-STD-461.

8.4 EMI CRITERIA

Electronic, electrical, and electromagnetic equipment and subsystems shall comply with the applicable requirements and limits specified in MIL-STD-461.

8.5 EMI CALIBRATION

The measurement equipment are calibrated on a scheduled basis by the US Army Test, Measurement, and Diagnostic Equipment (TMDE) Activity located at Redstone Arsenal.

Accuracy for Army TMDE is established directly by traceability to the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS).

8.6 EMI TEST PHILOSOPHY

The components and subsystems are tested to the EMI requirements, thus adding to the assurance that when assembled into the system there are no electromagnetic radiation (EMR) problems. It should be noted that MIL-STD-461 does specify system level testing. However, since Army systems require EMRH, EMRO and EMP system level testing and the MIL-STD-462 test procedures are not good test practices for a system test, it is RTTC's test philosophy not to perform system level MIL-STD-461 tests. Also, this test provides base-line performance data for subsystems whenever the need arises for second source production.

There are three basic types of effects:

- Effects between subsystems
- Effects of subsystems upon external systems
- Effects of external systems upon the subsystems

These effects are further divided into the following test methods:

- Radiated Emissions (RE)
- Conducted Emissions (CE)
- Radiated Susceptibilities (RS)
- Conducted Susceptibilities (CS)

Normally, the tests are conducted in an electromagnetically quiet room and the test methods followed are in accordance with MIL-STD-462.

8.7 EMI TEST PROCEDURES

Compliance with the requirements and limits specified in MIL-STD-461 are verified by the test procedures specified in MIL-STD-462.

8.8 EMI TEST DOCUMENTATION

8.8.1 Configuration.

Depending on the specific EMI requirements, the test configurations include all conditions for the system from stockpile storage, to shipping, tactical deployment, and operation (including flight). Some equipment will only be required to be tested in the passive state (power off) while other systems will be required to be tested in both passive and active (power on) states.

8.8.2 Test Plans.

Test Plans are written and approved by all agencies involved before testing begins. As a minimum, test plans must be reviewed and signed by the Program Manager, the prime contractors and sub-contractors involved, and the E^3 Test Branch.

8.8.3 Test Reports.

General documentation for the EMI test includes, but is not limited to, the following:

- Serial numbers of test hardware
- Calibration information
- Non-standard modification of test hardware
- Hardware configuration
- Non-test related problems/failures
- Pretest, posttest, etc. inspection results
- Daily log for test activities
- Facility hardware utilized
- Measurement hardware utilized
- Still photographs of test setup

Detailed documentation for each test shall be in accordance with the documentation and data requirements specified in MIL-STD-462.

APPENDIX A
E^3 TEST AREA FACILITIES

Note: The Figures for Appendix A are accessible by selecting links to their reference in the document or through the Table of Contents. The figures are contained in separate files.

A. E^3 TEST AREA FACILITIES

The RTTC E^3 Test Facility has been configured specifically for testing missile systems during their development cycle. It was designed to provide rapid test, evaluation, and analysis of test results, so that system designs can be evaluated. If EM Compatibility problems were discovered during the tests, the designs could be modified early in development cycle. The flexibility of this facility permits rapid response to test requirements, conduct of unique and special investigations, collection of high fidelity test data, quick response to data reduction and analysis, and documentation of results.

Data reduction and analysis are available in real-time to provide for timely evaluation of E^3 consisting of EMRH, EMRO, LE, ESD, EMP and EMI. The facilities needed to support these tests are addressed in this section, Appendix A. The following text describes in varying detail the enclosures, transmitters, and antennas, the UUT mounting, orientation, and rotation pedestals. These items are unique to each of the E^3 Test Areas. An aerial view of the E^3 Test Area is shown in Figure A-1. Instrumentation, which is intended specifically for the UUT, is addressed in that portion of the main text which describe those tests, i.e., Sections 3 through 8.

A.1 ELECTROMAGNETIC RADIATION (EMRH AND EMRO) TEST FACILITY

One element of the E^3 Test Area is the EMR Facility. The EMR Test Facility has assembled an array of transmitters and antennas to generate the necessary EM environments needed to evaluate the various UUTs. The following is a description of the individual transmitters and antennas, auxiliary equipment, and test chambers used in EMR testing.

A.1.1 Transmitters.

The available transmitters provide EM environments from 100 kHz to 40 GHz. Details are presented in Table A.1.1-1. All transmitters are capable of operation in continuous wave (CW), Amplitude Modulation (AM), Frequency Modulation (FM), and Pulse Modulation (PM) operation.

Transmitters capable of operation between 100 kHz and 350 MHz, or 350 MHz and 10 GHz, are shown in Figures A.1.1-1 and A.1.1-2, respectively. These transmitters are located in the Bounded Wave test areas.

The Radar Electromagnetic Environment Simulator (REES) is a high power pulsed microwave transmitter system designed for testing from 100 MHz to 40 GHz, however present transmitter assets limit its performance to frequencies between 750 MHz and 40 GHz. The combined transmitter and antennas performance of the REES system is presented in Table A.1.1-2. The REES transmitter is shown in Figure A.1.1-3.

Table A.1.1-1. OATS Transmitter Capabilities.

Frequency Band (Megahertz, MHz)	Transmitter Average Power Kilowatts (kW)	Configuration S = Stationary P = Portable
2-30	10	S
30-350	5	S
350-500	1	S
500-1000	1.5	S
1000-2500	1.5	S
2500-4000	1.5	S
4000-8000	1.5	S
8000-10000	1.5	S
0.1-30	0.200	P
350-450	0.200	P
450-650	0.200	P
500-1000	0.300	P
1000-2300	0.200	P
2300-4000	0.200	P
4000-8000	0.200	P
8000-10000	0.200	P
10000-18000	0.200	P

Table A.1.1-2. REES System Transmitter Capabilities (750 MHz To 40 GHz).

Band Designation.	Frequency Band (MHz)	Max. Power (kW)	Max. Pulsewidth (microsec)	PRF (Hz)	Max. Duty Factor (-dB)	Max. E-field (V/m)
UHF	750-1000	206	2	500	30	1709
L Band/ L	1200-1310	207	2	500	30	3606
L Band/ H	TBD	1600	1	500	30	5880
S Band/L	2900-3100	900	1	1000	31	3625
S Band/H	2900-100	2113	1	1000	31	6165
C Band/L	5450-5825	260	1	1000	30	2450
C Band/H	5450-5825	932	1	1000	30	4300
X Band	8500-9600	372	1	1000	30	2834
KU Band	14800-15200	225	0.4	2000	30	1873
K Band	24250	42.3	0.12	2000	31.5	908
Ka Band	35050	200	0.04	2000	34.4	1414

A.1.2 Antennas.

The antennas available for use with the transmitters identified above include the following:

- Bounded Wave antenna for frequencies of 100 kHz to 30 MHz
- Log Periodic antenna for frequencies from 30 MHz to 350 MHz
- Standard Gain horns for frequencies from 100 MHz to 350 MHz
- Standard Gain horns for frequencies of 350 MHz to 1000 MHz
- Standard Gain horns for frequencies of 1 GHz to 10 GHz
- Whip or Monopole antenna for frequencies from 2 to 30 MHz
- REES antennas for 750 MHz to 40 GHz

A.1.2.1 Bounded Wave Antenna.

Testing from 100 kHz to 30 MHz is conducted at the bounded wave antenna test site. It consists of two parallel, 150 ft (l) by 132 ft (w) wire grids with a 30 ft (h) separation. The Bounded Wave antenna is vertically polarized. A 2 kW transmitter is used to power the 100 kHz to 2 MHz antenna, while a 10 kW transmitter system powers the 2 MHz to 30 MHz antenna. Figure A.1.2.1-1 depicts the physical features of this antenna.

A.1.2.2 Log Periodic Antenna.

Testing from 30 MHz to 350 MHz is conducted at the Log Periodic antenna test site. The Log Periodic antenna is capable of either vertical or horizontal polarization. It has a gain of 6 dB to 10 dB, depending on frequency. The Log Periodic antenna test site is an OATS, but the test volume is covered by a portamod structure which is 40 ft (w) by 60 ft (l) by 25 ft (h). The portamod structure isolates the UUT from various weather conditions such as wind, snow, and rain, and provides visual security for the UUT. A 5 kW transmitter system powers the Log Periodic antenna. Figure A.1.2.2-1 provides the physical features of this antenna.

A.1.2.3 Very High Frequency Standard Gain Horns.

Testing from 100 MHz to 350 MHz can be conducted at the Very High Frequency (VHF) Standard Gain Horn test site consisting of three standard gain horns. These horn antennas can be rotated to transmit either a vertically or horizontally polarized field and have gains of 14 dB to 16 dB, depending on frequency. A 5 kW transmitter system powers the VHF standard gain horn antennas. Figure A.1.2.3-1 provides the physical features of this antenna.

A.1.2.4 Very High Frequency to Super High Frequency Standard Gain Horns.

Testing from 350 MHz to 10 GHz is conducted at the VHF to Super High Frequency (SHF) test site. The SHF test site consists of fifteen standard gain horns. Three of the standard

gain horn antennas, operating from 350 MHz to 1 GHz, can be rotated to transmit either a vertically or horizontally polarized field with gains of 15 to 18 dB, depending on frequency. The remaining twelve horn antennas are matched sets, with each pair providing either horizontal or vertical polarized fields, and gains from 18 to 22 dB, depending on frequency. Figures A.1.2.4-1 and A.1.2.4 -2 depict the physical features of the VHF to SHF antennas.

The VHF to SHF standard gain horn test site is an OATS, including a portamod structure, 40 ft (w), 60 ft (l), 25 ft (h) to cover the test volume. The portamod structure isolates the UUT from various weather conditions, such as wind, snow and rain, and provides visual security for the UUT. A 1 kW transmitter system powers the VHF to SHF standard gain horn antennas.

A.1.2.5 Whip Antenna.

Testing from 2 MHz to 30 MHz can be conducted at the Whip, or monopole, antenna test site. The whip antenna is an OATS and consists of a ground plane, 180 ft (l) by 135 ft (w), covered by asphalt. The Whip or monopole antenna site, provides a ground plane test area which permits simulation of shipboard environments. The Whip antenna is vertically polarized. A 10 kW transmitter system is available for use with the Whip antenna. Figure A.1.2.5-1 provides the physical features of this antenna.

A.1.2.6 REES Antennas.

The REES antennas operate in conjunction with the REES transmitters. The output of REES is from 750 MHz to 40 GHz. with variable polarization. Output power varies from 200 to 1600 kW depending on frequency, and peak E-field up to 6000 V/m. REES antennas are shown in Figure A.1.2.6-1.

A.1.3 Ancillary Transmitter Equipment.

There is an assortment of equipment available to support transmitter operations (i.e., frequency synthesizers, signal generators, functional generators, amplifiers, frequency counters, power meters, dummy loads, etc.).

A.1.3.1 Portable Amplifiers.

Portable antennas and transmitters are available from 1 MHz to 18 GHz. A billboard antenna is used from 100 kHz to 200 MHz with a 200 watt transmitter. A small Log Periodic antenna is used from 250 to 1000 MHz with a 300 watt transmitter. Standard gain antennas are collocated with 200 watt transmitters and mounted on wheeled cabinets, and used from 1 to 18 GHz.

A.1.3.2 UUT Turntable.

A turntable is available to provide a convenient means of rotating the UUT. Rotating the UUT enables measurements of the angular dependence of system susceptibility with respect to the transmitting antenna. The turntable is shown in Figure A.1.3.2-1. It has a maximum load capacity of 55,000 lb and a maximum excursion of ±360° azimuth (yaw). The UUT Turntable is available for supporting test articles in the Anechoic Chamber.

A.1.3.3 Test Fixtures.

Two Scientific Atlanta Positioner Systems are available for supporting and positioning test specimens, as indicated in Figure A.1.3.3-1. These systems consist of an azimuth Positioner, with 360° excursion, a model tower (upright fiber glass pole), a programmable digital controller. One of the Positioners has both roll and pitch positioning capability. The systems are capable of supporting a maximum vertical load of 20,000 lbs, without the use of the fiberglass poles and provide angular excursions of up to 360 ° in azimuth, and ± 45° in elevation.

A.1.4 Anechoic Chamber.

The Anechoic Chamber is located in Building 8935. Its purpose is to provide an electromagnetically quiet environment from outside emitters as well as to reduce errors due to internal reflections. The interior walls of the chamber is lined with pyramid shaped energy absorbers capable of attenuating electromagnetic energy by approximately 40 dB for frequencies from 100 MHz to 20 GHz. The exterior of the chamber is constructed of welded steel and has a measured shielding effectiveness of 100 dB for frequencies from 100 MHz to 20 GHz.

The effective test volume of the chamber is 46 ft(l) by 28 ft(w) by 17 ft (h). At the center of the chamber is a large 18 ft (diameter) turntable capable of supporting large test articles such as the MLRS Launcher, or the Bradley Fighting Vehicle. These test articles have weights in excess of 54,500 lb The turntable provides 360° rotation in azimuth. A smaller two axis pitch and roll (± 90°) stage, referred to as a Positioner/Controller and developed by Scientific Atlanta, is available for smaller test articles, such as antenna and missiles. When used in conjunction with the large diameter azimuth turntable, they provide three axis orientation and rotation of the test article.

One of the main purposes of the Anechoic Chamber is to house REES system. REES operates over the frequency interval of 750 MHz to 35 GHz, and can evaluate the susceptibility of Army weapon system to radar environments encountered during training and military deployment. See Figures A.1.4-1 and A.1.4-2.

In addition to REES, test capabilities include radar cross section (RCS) measurement of small items, measurement of antenna patterns, emission testing, and specialized target generation. Supporting the measurement of RCS and antenna patterns is an HP 8530 Network Analyzer. An HP Frequency Agile Signal Simulator, FASS, enables the generation of complex waveforms and has been used to evaluate the effectiveness of target recognition systems.

Classified signal generation and testing are also possible due to the high degree of shielding of the chamber.

Located adjacent to the main Anechoic Chamber are four ante rooms. These rooms have direct access to the chamber and are used to house transmitters, data acquisition systems, and other measurement apparatus. Each room is equipped with a sealed door and provides shielding effectiveness of 100 dB. The upstairs rooms are currently being modified for MIL-STD-461/462 testing. The Anechoic Chamber incorporates PCM and FM modulated fiber optic instrumentation and data transfer system, which has been developed in house. This data transfer system enables custom installation of instrumentation inside the test article, for transmission to a remote data collection/data processing ground station with minimal effect on the fidelity or validity of the data stream.

A.2 LIGHTNING EFFECTS, LE

A.2.1 LE Facilities.

Three distinct LE test facilities are utilized at RTTC. The High Energy Lightning Simulator (HELS) test facility is specifically designed to conduct direct strike lightning testing of live, explosive systems. The HELS test facility is especially unique in that it is the only facility in the free world capable of testing live, tactical missile systems and ordnance items to the direct strike lightning environment. The HELS test facility has two test sites; one for conducting direct strike lightning testing of small and man-portable systems and a second for conducting direct strike lightning testing of large systems. The Simulated Lightning Effects Test (SLET) facility is designed for conducting both direct strike and near strike lightning testing of inert, except for Class 1.4 explosives, systems. The Transportable Lightning Effects Simulator (TLES) is transportable and is specifically designed to conduct direct strike lightning testing at locations other than the HELS and SLET facilities.

The LE testing methods used at RTTC are based upon the LE test experience. These facilities were designed to provide rapid test results so that a system (UUT) design can be changed early in development cycle if problems associated with lightning phenomenon are uncovered. The flexibility of these facilities permit interactive testing such that observed anomalies can be investigated and candidate design modifications can be evaluated in a timely manner. Test data are reduced and results made available in near real-time to facilitate rapid resolution of problem areas. Aerial views of the HELS and SLET Test Facilities are shown in Figures A.2.1-1 and A.2.1-2 respectively.

A.2.1.1 High Energy Lightning Simulator Test Facility (HELS).

The HELS test facility is specifically designed to conduct direct strike lightning testing of live, explosive missile systems and ordnance items. For small systems, the near strike lightning environment requirement can be accomplished at the small system test site. The explosive limits for the HELS test facility at the large system test site are 100 pounds of Class 1.1 explosive, 5000 pounds of Class 1.2 explosive, 15,000 pounds of Class 1.3 explosive

and unlimited Class 1.4 explosive. The small system test site has an explosive limitation of 40 pounds of either Class 1.1 or Class 1.2 explosives. The HELS test facility is comprised of five discrete capacitor banks for simulating the cloud-to-ground direct strike lightning environment; one capacitor bank is available for simulating the initial stroke (component A) current waveform, one capacitor bank for simulating the intermediate (component B) current waveform, one capacitor bank for simulating the continuing (component C) current waveform, and two capacitor banks for simulating the restrike (component D) current waveform (one each for the small system test site and large system test site, respectively).

A.2.1.1.1 Initial Stroke (Component A) Capacitor Bank.

The HELS initial stroke current capacitor bank consists of 480 capacitors (120 capacitors in parallel in each of four banks, with the four banks connected in series). Each capacitor is rated at 60 kV and 1.875 microfarads (μF). It is configured as a two-stage Marx bank with a total calculated capacitance of 56.25 μF and an output voltage of 220 kV. A 2.25 μF, 300 kV peaking capacitor circuit is utilized, in conjunction with the initial stroke capacitor bank. This peaking capacitor is used to increase the current rate-of-rise, resulting in a discharge time of 6.5 μsec. The initial stroke capacitor bank can generate a simulated direct strike lightning (Component A) waveform with a peak current of 200 kA ± 10% and an action integral of 2.0×10^6 ampere squared seconds (A^2 sec) ± 20%. A Hipotronics Model No. 8300-165 High Voltage DC Power Supply, rated for 300 kV and 165 mA, is utilized to charge the HELS initial stroke capacitor bank. The HELS initial stroke capacitor bank is shown in Figure A.2.1.1.1-1.

A.2.1.1.2 Intermediate Current (Component B) Capacitor Bank.

The HELS intermediate current capacitor bank consists of five layers of electrolytic capacitors connected in series. Each layer contains eight capacitors, each rated at 450 volts (V) and 3000 mF, in parallel. The total calculated capacitance is 4800 mF. The charge voltage is 2100 V. The intermediate current capacitor bank can generate a simulated direct strike waveform (Component B) with an average amplitude of 2000 ampere (A) ± 10%, a peak current of approximately 5800 A and a charge transfer of 10 coulombs (C). A Hipotronics Model No. 850/50/100 High Voltage DC Power Supply, rated for 50 or 100 kV and 100 mA, is utilized to charge the HELS intermediate current capacitor bank. The HELS intermediate current capacitor bank is shown in Figure A.2.1.1.2-1.

A.2.1.1.3 Continuing Current (Component C) Capacitor Bank.

The HELS continuing current capacitor bank consists of two layers of electrolytic capacitors connected in series. Each layer contains 196 capacitors, each rated at 450 volts (V) and 3000 mF, in parallel. The total measured capacitance is 0.37 F and is charged to a nominal value of 750 V. The continuing current capacitor bank can generate a simulated component C waveform with 200 C ± 20% of charge transfer. A Hipotronics Model No. 801-5A High Voltage DC Power Supply, rated for 1 kV and 5 A, is utilized to charge the HELS continuing current capacitor bank. The HELS continuing current capacitor bank is shown in Figure A.2.1.1.3-1.

A.2.1.1.4 Large System Restrike (Component D) Marx Capacitor Bank.

The HELS large system restrike Marx capacitor bank is an 18-stage Marx bank with a calculated total capacitance of 0.9375 mF. Each stage, consisting of nine capacitors, rated at 60 kV and 1.875 mF, wired in parallel, is normally charged to 42 kV to provide a total output voltage of 756 kV. Energy from the Marx bank is delivered to the peaking capacitor/spark gap assembly via a one-inch diameter insulated conductor. The peaking capacitor bank has a total capacitance of 0.027 mF and a maximum voltage capability of 2.2 megavolts (MV). The peaking capacitor bank consists of two parallel stacks of Maxwell capacitors. Each stack contains 22 capacitors, with each rated at 0.3 mF and 100 kV, wired in series. The large system restrike Marx capacitor bank can generate a 100 kA ± 10% peak current simulated component D waveform with an average current rate-of-rise of 1.0×10^{11} amperes per second (A/sec) and a maximum current rate- of-rise of 1.4×10^{11} A/sec ± 20%. A Hipotronics Model No. 8100-250 High Voltage DC Power Supply, rated 100 kV and 250 mA, is utilized to charge the HELS large system restrike current capacitor bank. The HELS large system restrike Marx capacitor bank is shown in Figure A.2.1.1.4-1.

A.2.1.1.5 Small System Restrike (Component D) Marx Capacitor Bank.

The HELS small system restrike Marx capacitor bank is an 18-stage (series configuration) Marx bank with a calculated total capacitance of 0.0556 μF. Each stage, consisting of two capacitors, each rated at 100 kV and 0.5 μF in parallel, is charged to 80 kV to provide a total output voltage of 1.44 MV. Energy from the Marx bank is delivered to the peaking capacitor grid/spark gap assembly via bus wires. The peaking capacitor grid consists of two parallel, 50-foot diameter wire grids with a 20-foot (high) separation. Equation A2-1 can be used to calculate the capacitance (C) of the small system peaking capacitor grid

$$C = \frac{\varepsilon S}{d} \quad \text{(in Farads)} \qquad \text{(Equation A2-1)}$$

where S is the area of each grid, ε is the total permittivity and d is the separation distance between the parallel grids. Solving Equation 5-9 (Section 5) for the above noted parameters (and converting to metric units) yields a calculated capacitance for the small system peaking capacitor grid of 265 picofarads (pF). The small system restrike Marx capacitor bank can generate a 50 kA ± 10% peak current simulated component D waveform with an average current rate-of-rise of 1.0×10^{11} A/sec and a maximum current rate-of-rise of 1.4×10^{11} A/sec ± 20%. A Hipotronics Model No. 850/50/100 High Voltage DC Power Supply, rated for 50 or 100 kV and 100 mA, is utilized to charge the HELS small system restrike current capacitor bank. The HELS small system restrike capacitor bank is shown in Figure A.2.1.1.5-1.

A.2.1.1.6 Safety Cage.

The HELS test site utilizes a large safety cage to contain the live, explosive system. Armor plating and a fire wall are built into the south and west walls of the safety cage to protect the capacitor banks. A water deluge system is mounted in the ceiling of the safety cage to extinguish fires within the safety cage. A portable environmental conditioning unit is also

available which can be assembled around the missile system to conduct lightning tests at hot and cold temperature extremes. The primary safety cage is designed to contain a Pershing missile while the secondary safety cage, utilized for test articles smaller than a Pershing missile, is designed to contain an MLRS rocket. The secondary cage consists of a lattice structure of rectangular tubular steel (3 x 3 x 5/16; 3 x 6 x 5/16; 6 x 6 x 5/16 in.) with maximum openings limited to less than 7 in. Approximately 80% of the structure is covered by ½ in steel plate. The southern door of the secondary safety cage does not have steel plates attached thus allowing the venting of any over-pressure. The approximate dimensions of the secondary safety cage is 28 ft (l) by 10 ft (w) by 7 ft (h). The secondary safety cage is anchored to the concrete pad at the test site. Figures A.2.1.1.6-1 and A.2.1.1.6-2 provide photos of the HELS Secondary Safety Cage as viewed from the south and north, respectively.

A.2.1.2 Simulated Lightning Effects Test Facility (SLET).

The SLET facility is comprised of a restrike (component D) Marx capacitor bank for conducting near strike and direct strike lightning tests (component D, only) of inert systems. The SLET capacitor bank consists of a 36-stage Marx bank enclosed within a non-conductive fiberglass structure with a total calculated capacitance of 20.8 nanofarads (nF). Each stage, consisting of a 150 kV, 0.75 μF capacitor, is normally charged to 75 kV to provide a total output voltage of 2.7 MV. Energy from the Marx bank is delivered to the peaking capacitor grid/spark gap assembly via bus wires. The peaking capacitor grid consists of two parallel, 150 ft (l) by 132 ft (w) wire grids with a 30 ft (h) separation. Solving Equation 5-9 (Section 5) for these parameters (and converting to metric units) yields a calculated capacitance for the SLET peaking capacitor grid of 1.78 nF. The SLET restrike Marx capacitor bank can generate a 70 kA ± 10% peak current simulated component D waveform with an average current rate-of-rise of 1.0×10^{11} A/sec and a maximum current rate-of-rise of 1.4×10^{11} A/sec ± 20%. A Hipotronics Model No. 8100-250 High Voltage DC Power Supply, rated for 100 kV and 250 mA, is utilized to charge the SLET restrike current capacitor bank. The SLET restrike capacitor bank is shown in Figure A.2.1.2-1.

A.2.1.3 Transportable Lightning Effects Simulator (TLES).

The TLES is specifically designed to conduct direct strike lightning testing at locations other than the HELS and SLET facilities. The TLES is comprised of two distinct capacitor banks for simulating the cloud-to-ground direct strike lightning environment: 1) an initial stroke (component A) current generator and 2) a continuing (component C) current generator. The TLES is shown in Figure A.2.1.3-1.

A.2.1.3.1 Initial Stroke (Component A) Capacitor Bank.

The TLES initial stroke current capacitor bank consists of 40 capacitors, each rated at 30 kV and 111 mF, configured as a two-stage Marx bank with a total calculated capacitance of 69.375 mF and an output voltage of 240 kV. A 2.25 mF, 252 kV peaking capacitor circuit is utilized in conjunction with the initial stroke capacitor bank to increase the current rate-of-rise resulting in a discharge time of 6.5 msec. The initial stroke capacitor bank can generate a

simulated direct strike lightning waveform (Component A) with a peak current of 200 kA ± 10% and an action integral of 2.0×10^6 A^2 sec ± 20%. A Hipotronics Model No. 8150-100 High Voltage DC Power Supply, rated for 150 kV and 100 mA, is utilized to charge the TLES initial stroke capacitor bank. The TLES initial stroke capacitor bank is shown in Figure A.2.1.3.1-1.

A.2.1.3.2 Continuing Current (Component C) Capacitor Bank.

The TLES continuing current capacitor bank is identical to the HELS continuing current capacitor bank and consists of two layers of electrolytic capacitors connected in series. Each layer contains 196 capacitors, each rated at a minimum 450 V and 3000 mF, in parallel. The total measured capacitance is 0.37 F and is charged to a nominal value of 750 V. The continuing current capacitor bank can generate a simulated component C waveform with 200 C ± 20% of charge transfer. A Hipotronics Model No. 801-5A High Voltage DC Power Supply, rated for 1 kV and 5 A, is utilized to charge the TLES continuing current capacitor bank. The TLES continuing current capacitor bank is shown in Figure A.2.1.3.2-1.

A.3 ELECTROSTATIC DISCHARGE TEST FACILITIES

Two distinct ESD test facilities are utilized at RTTC. The nonhazardous ESD test facility is specifically designed to conduct PESD and HESD testing of inert systems (limited to Class 1.4 Explosives). The nonhazardous ESD test facility is located in Building 8979. This building is environmentally controlled to maintain low humidity levels. The nonhazardous ESD generator and test equipment is portable and can be located at other test locations when necessary. The hazardous ESD test facility utilizes the safety cage at the HELS facility and is specifically designed to conduct PESD and HESD testing of live, explosive systems. The ESD testing methods used are based upon test techniques specified in MIL-STD-331B and upon RTTC test experience. These facilities were designed to provide rapid generation and analysis of test results so that system design can be modified early in the development cycle if necessary. The flexibility of these facilities allow interactions with system design and modification for meaningful system evaluation. Test data are available in real time to facilitate timely data analysis.

A.3.1 Nonhazardous ESD Test Facility.

The nonhazardous ESD test facility is comprised of the PESD simulator and a HESD simulator. This facility is specifically designed for testing of inert systems limited to Class 1.4 explosives. These simulators are portable and can be moved to other locations for ESD testing as necessary.

A.3.1.1 PESD Simulator.

The PESD simulator utilizes an ION Physics Model 0-30 kV high voltage power supply, generating a ± 25 kV PESD waveform. The discharge circuit can be configured with either a 5000 Ω, as per MIL-STD-331, or a 500 Ω, series resistor which provides both a more realistic and severe test environment. The PESD simulator is shown in Figure A.3.1.1-1.

A.3.1.2 HESD Simulator.

The HESD simulator consists of three 3000 pF, 100 kV Maxwell capacitors connected in series and discharged through a series resistor. A Hipotronics Model 8300, 360 kV power supply is used to charge the Maxwell capacitors. The HESD simulator can generate a ± 300 kV HESD waveform. The discharge circuit can be configured with either a 1 Ω or a 500 Ω series resistor. The HESD simulator is shown in Figure A.3.1.2-1.

A.3.2 Hazardous PESD Simulator.

The hazardous ESD test facility is comprised of a PESD simulator and a HESD simulator. As stated above this facility is specifically designed for testing of live, explosive systems and utilizes the safety cage of the HELS facility. The explosive limits for the HELS test facility are 100 lb of Class 1.1 explosive, 5000 lb of Class 1.2 explosives, 15000 lb of Class 1.3 explosive and an unlimited Class 1.4 explosive. The simulators are portable and can be moved to other locations for ESD testing, as necessary.

A.3.2.1 Hazardous PESD Simulator.

The hazardous PESD simulator consists of one 25 kV, 250 pF capacitor discharge through a 500 Ω series resistor. A Hipotronics Model 8300, 60 kV power supply is utilized to charge the capacitor. The hazardous PESD simulator can generate a simulated ± 25 kV personnel borne ESD waveform. An air actuated piston is utilized to remotely control the discharge probe. The hazardous PESD simulator is shown in Figure A.3.2.1-1.

A.3.2.2 Hazardous HESD Simulator.

The hazardous HESD simulator consists of three 3000 pF, 100 kV Maxwell capacitors connected in series and discharged through a series resistor. A Hipotronics Model 8300360 kV power supply is utilized to charge the Maxwell capacitors. The HESD simulator can generate a simulated ± 300 kV helicopter borne ESD waveform. The discharge circuit can be configured with either a 1 Ω or a 500 Ω series resistor. An air actuated piston is utilized to remotely control the discharge probe. The hazardous HESD simulator is shown in Figure A.3.2.2-1.

A.3.2.3 Safety Cage.

The HESD test site utilizes a large safety cage to contain the live explosive system. Armor plating and a fire wall are built into the south and west walls of the safety cage to protect the capacitor banks. A water deluge system is mounted in the ceiling of the safety cage to extinguish fires within the cage. A portable environmental conditioning unit is also available which can be assembled around the missile system to conduct discharge testing at hot and cold temperature extremes. The primary safety cage is designed to contain a Pershing missile while the secondary safety cage, utilized for UUT smaller than the Pershing, is designed to contain a MLRS rocket. The secondary cage consists of a lattice structure of rectangular tube steel

(3 x 3 x 5/16; 3 x 6 x 5/16; 6 x 6 x 5/16 in) with maximum openings limited to less than 7 in. Approximately 80% of the structure is covered by 1/2 in thick steel plates. The access door located in the southern end of the safety cage does not have a steel plate, thereby permitting pressure relief. The approximate dimensions of the secondary cage are 28 ft(l) by 10 ft (w) by 7 ft (h). The secondary safety cage is anchored to the concrete pad at the test site. Figures A.3.2.3-1 and A.3.2.3-2 provide photos of the Safety Cage with views form the south and east, respectively.

A.4 ELECTROMAGNETIC PULSE TEST FACILITIES

A.4.1 Transportable Electromagnetic Pulse Simulator.

A Transportable Electromagnetic Pulse Simulator (TEMPS), previously used by DNA for EMP testing was obtained by RTTC, but without the threat-level Marx generator. The RTTC TEMPS is a horizontal dipole simulator consisting of a 9 ft diameter dipole driven with a 100 kV repetitive pulse generator, which produces a peak E-field of approximately 1000 V/m at a distance of 50 meters (Figure A.4.1-1). RTTC uses the low level TEMPS for EMP tests.

Systems are first tested at RTTC to perform an initial screening of susceptibilities to EMP. Under certain conditions, systems are taken to threat-level simulators at other locations, i.e., White Sands Missile Range (WSMR) or Air Force Phillips Laboratory (AFPL). This approach has been shown to be cost effective because tests conducted at RTTC TEMPS sub-criteria threat simulator are low cost preliminary tests compared to the full threat level simulators. The results of the preliminary low level tests can provide significant low level diagnostics, reducing both the test time, measurement and data reduction, as well as the posttest analysis needed to identify the necessary improvements prior to conduct of the threat level tests. For electromagnetically simple systems or subsystems (i.e., shoulder-fired missile systems), which are designed and built to have a very large EMP safety margin, RTTC's low level TEMPS may be sufficient for determination of EMP hardness. CW transfer functions are used in conjunction with system (UUT) sub-criteria threat responses to compute system EMP responses.

A.4.2 Bounded Wave Antenna.

The frequency domain CW measurements from 100 kHz to 3 MHz are conducted in the Bounded Wave antenna facility. The Bounded Wave antenna consists of two parallel, 150 ft (l) by 132 ft (w) wire grids with a 30 ft (h) separation. The Bounded Wave antenna is vertically polarized. A 2 kW transmitter system is utilized from 100 kHz to 2 MHz. A 10 kW transmitter system is utilized from 2 MHz to 30 MHz.

A.4.3 Log Periodic Antenna.

The frequency domain CW measurements from 30 MHz to 350 MHz can be conducted at the Log Periodic antenna facility. The Log Periodic antenna is polarized in two orthogonal axes (vertical and horizontal) and has a gain of 6 dB to 10 dB, depending on frequency. A 5 kW transmitter system is utilized with the Log Periodic antenna.

A.4.4 Very High Frequency Standard Gain Horns.

The frequency domain CW measurements from 100 MHz to 1100 MHz can be conducted at the very high frequency (VHF) standard gain horn facility consisting of three standard gain horns. These horn antennas can be rotated to transmit either a vertically or horizontally polarized field and have gains of 14 dB to 16 dB, depending on frequency. A 5 kW transmitter system is utilized with the VHF standard gain horn antennas.

A.5 ELECTROMAGNETIC INTERFERENCE TEST FACILITY

A.5.1 Shielded Screen Room.

The shielded screen room is located in Building 8975 and is a double room structure with copper screen as the shielding material. The test area of the screen room measures 13.5 ft (w) by 16.7 ft (l) by 7.7 ft (h). The shielded screen room is used for conducting procedures in accordance with MIL-STD-462, including both emission and susceptibility procedures in accordance with MIL-STD-462D. The control room which is adjacent to the screen room measures 13.5 ft(w) by 13.33 ft(l) by 7.66 ft(h).

A.5.2 Shielded Rooms.

Two solid shielded rooms are located in Building 8935. The test control room measures 14 ft (w) by 14 ft (l) by 8 ft (h), whereas, the test area room measures 14 ft (w) by 26 ft (l) by 8 ft(h). Each room provides 100 dB of shielding from incident electric fields. The shielded rooms enable both conducted emission and conducted susceptibility test procedures in accordance with MIL-STD-462D.

A.5.3 Anechoic Chamber.

The anechoic chamber is located in Building 8935. The chamber is constructed of solid metal providing 100 dB of shielding from incident electric fields and has absorber material which provides 40 dB of attenuation of incident electric fields from 100 MHz to 40 GHz. The available test volume of the anechoic chamber is 28 ft(w) by 46 ft(l) by 17 ft (h). The anechoic chamber enables conducting both radiated emission and radiated susceptibility test procedures in accordance with MIL-STD-462D.

A.5.4 Test Equipment.

Equipment is available to support all the requirements of MIL-STD-461 and the test procedures of MIL-STD-462. Some of the major items available to provide rapid quantitative testing of components and subsystems include spectrum analyzers, frequency synthesizers, computer controller, and other equipment for computer controlled testing. Table A.5.4-1 is a listing of the EMI test equipment utilized at RTTC.

Table A.5.4-1. List of EMI Test Equipment.

Antennas: Set of EMCO antennas 100 kHz - 12.4 GHz Set of Narda Horns 1.1 - 18.0 GHz IFI EFG-3 10-220 MHz MGL-2A B-Dot Probe B-Dot Probe Set National Bureau of Standards Set Standard Gain Dipoles Set Nonofast EFS-1 E Field Sensor Set Nonofast EFS-2 E Field Sensor Set Narda 8633 H-Field Sensor System Narda 8700 E-field Sensor System EMCO 7120 E-field Sensor System Signal Generators: HP 8660C HP 8690 Marconi 2022 10 kHz-1 GHz Singer 6201 50 kHz - GHz HP 8640 0.5 MHz - 1.1 GHZ HP 8340B, 8341B, 8642 A HP 3314 HP 3325 Computer Equipment: HP Computers:	Oscilloscopes & Digitizers: Tektronix 454, 454A, 485 Tektronix 7612D, R7912 A/D Tektronix 7104, 7904 Tektronix 2215A HP 54111D HP 54200 HP 54510D Amplifiers: Amplifier Research 10W100 Amplifier Research 300HB Hughes 1177 H Hughes 1277 H ENI 240L ENI 500L ENI 503L Solar 6552-1 RF Power Labs M102L IFI 404 Microwave Power Devices PWA 45 65-22/3320 Microwave Power Devices PWA 3542-22/3320 Microwave Power Devices ELWA 3012-52 Miscellaneous: Spectrum Analyzers: HP 8566A HP 8568 HP 3583A

Table A.5.4-1. List of EMI Test Equipment (Continued).

Computer Equipment (Cont.): A400 1000, E-series A900 A900 (UNIX) IBM PC Compatibles: Dell System 310 Compaq System 386/33 Unisys System PW20C Plotters: HP 7550A HP 7585B Telemetry Systems: Pulse Code Modulated: EMR 8320, 8330, 8350 Frequency Modulated Amplifiers Preston 8300 XWB Discriminators: EMR 287A Schlumberger 287 Loral Tunable 8340 Frequency Counters: HP 5324B HP 5328A HP 5340A	Miscellaneous (Cont.): Sweep Generators: Solar 6550-1 Interstate F77 Spike Generators: Solar 8282-1 Solar 7054-1 Oscillographs: Astro-Med 9500 Astro-Med 95000 Audio Transformer: Solar 6220-1 Injection Network Solar 7415-1 TEM Transmission Cells: Narda 8801, DC-500 MHz Narda 8802, DC-250 MHz HP 4204 Oscillator Counter Timer Cinadex CF-200R Data Acq/Control Unit HP 3852 RF Impedance Analyzer: HP 4191A Network Analyzer: HP 3577A Programmable Pulse Generator: HP 8160A Programmable Signal Source: HP 8165A Waveform Analyzer Autek 505

Figure A.1.2.4-2. VHF to SHF Standard Gain Horn Antennas, beyond 1 GHz.

Figure A.1.2.5-1. Whip/Monopole Antenna 2 to 30 MHz.

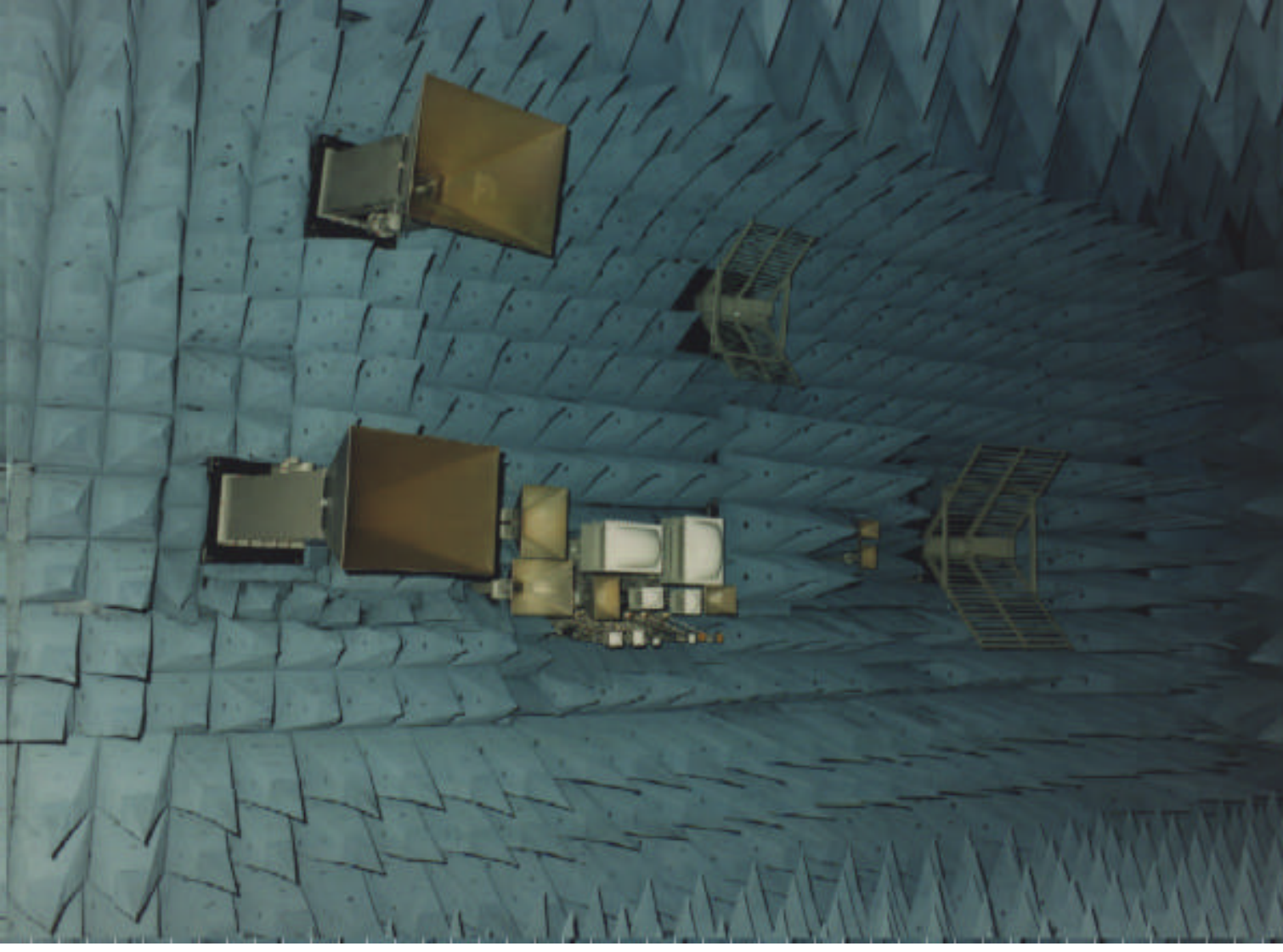


Figure A.1.2.6-1. REES System Antennas, 750 MHz to 40 GHz.

Figure A.1.3.2-1. UUT Turntable.

Figure A.1.3.3-1. Scientific Atlanta Positioner System.

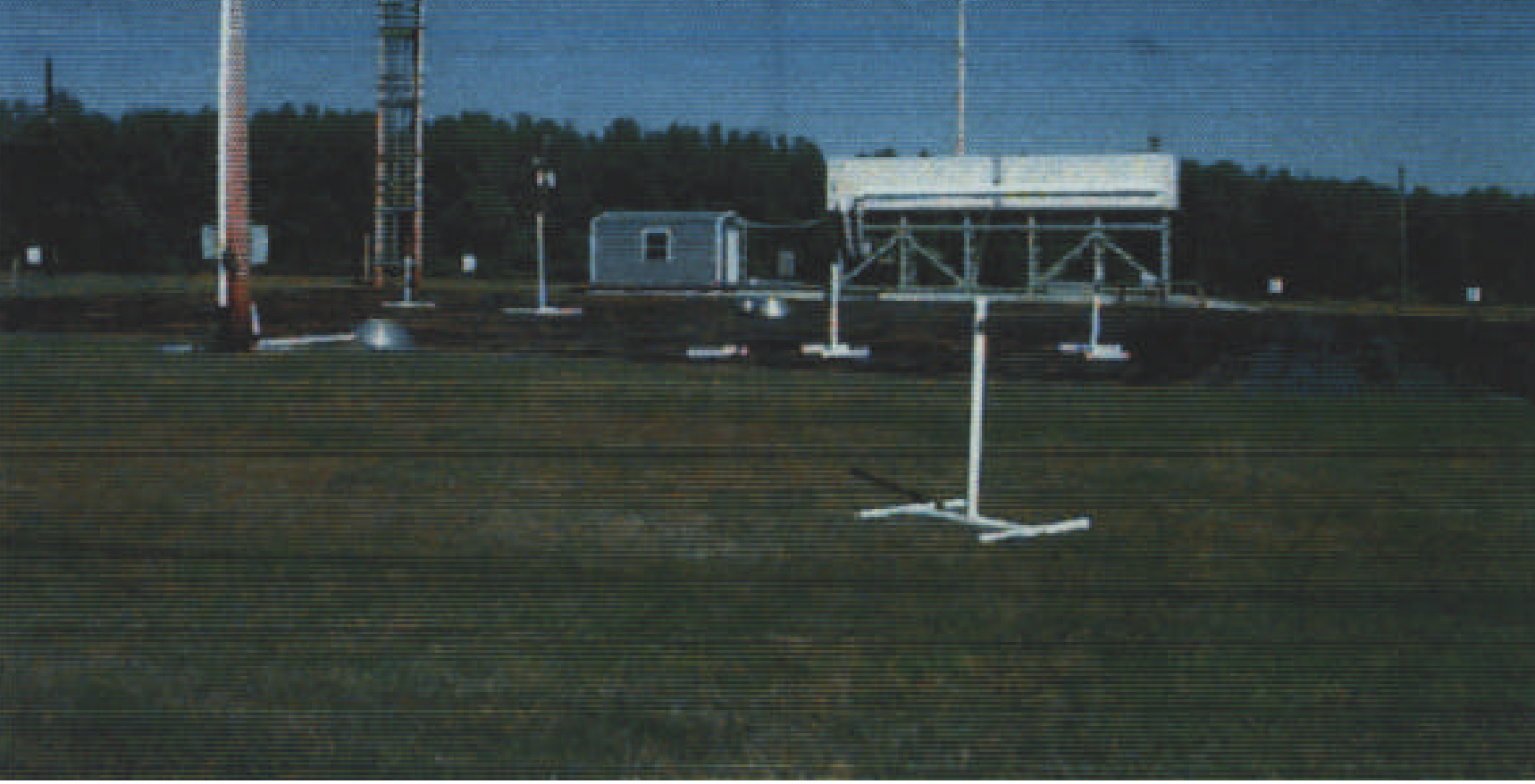


Figure A.2.1.2-1. SLET Restrike Current Capacitor Bank.

Figure A.2.1.3-1. TLES “A” and “C” Current Generator.

Figure A.3.1.1-1. Nonhazardous PESD Simulator.

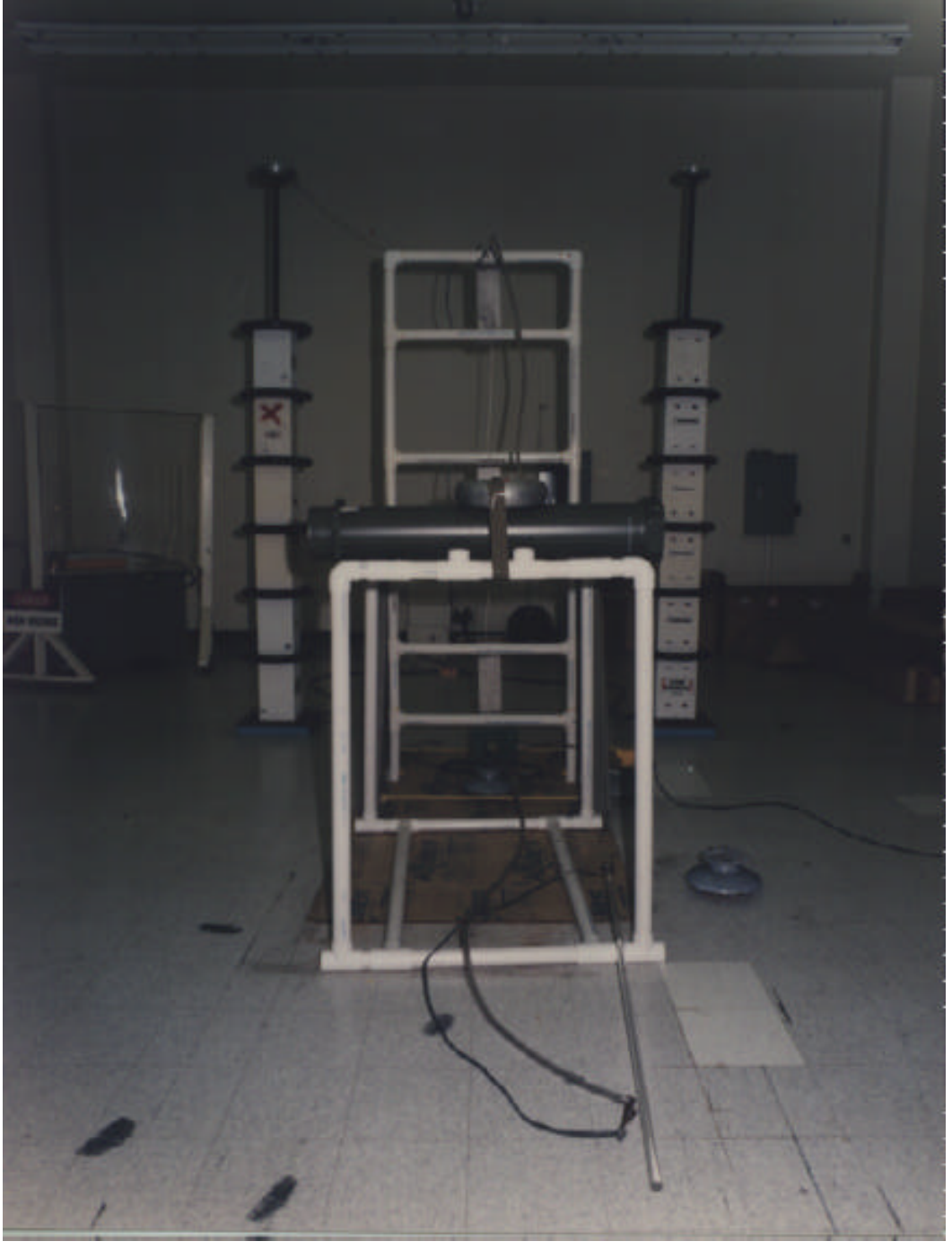


Figure A.3.1.2-1. Nonhazardous HESD Simulator.

Figure A.3.2.1-1. Hazardous PESD Simulator.

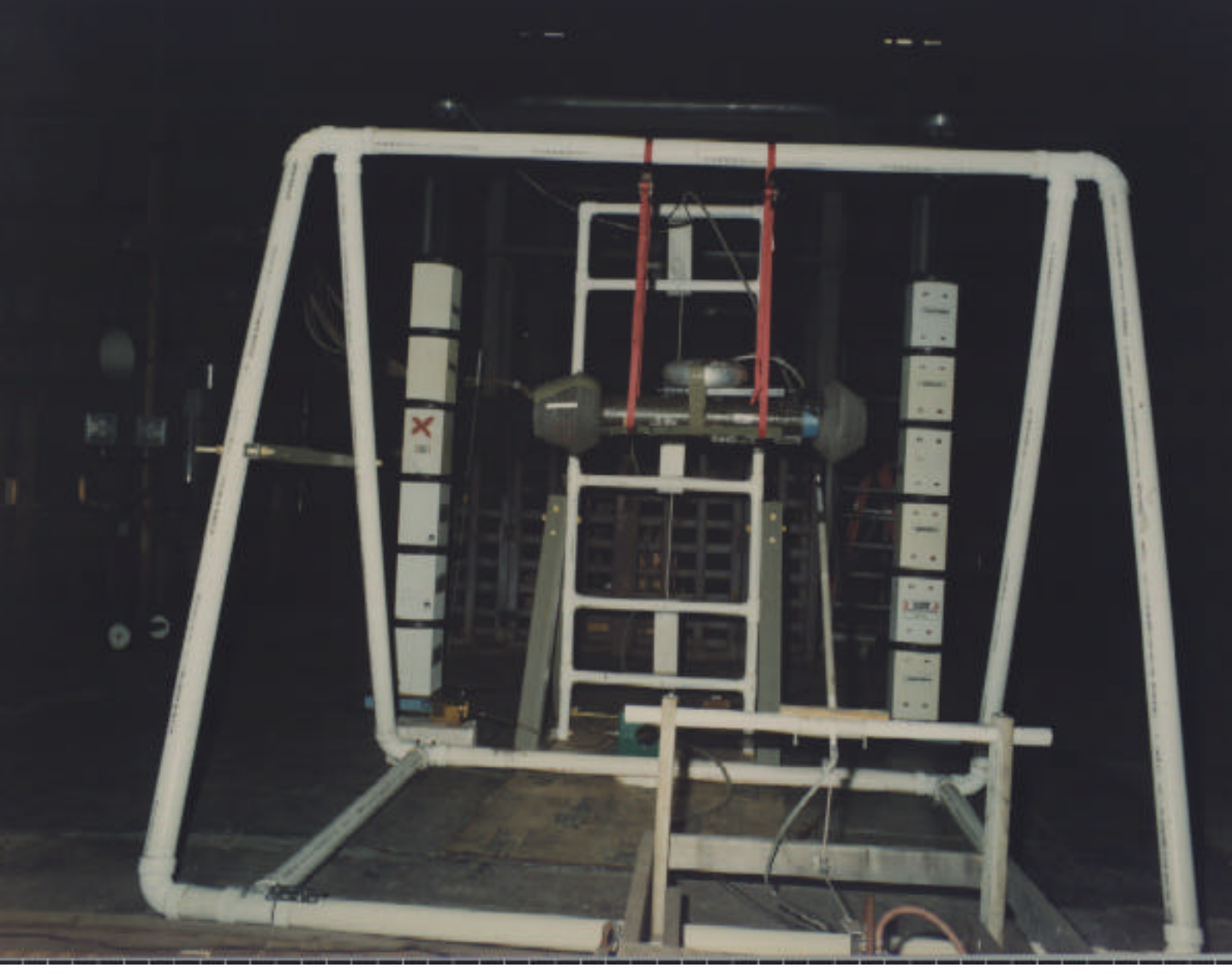


Figure A.3.2.2-1. Hazardous HESD Simulator.

Figure A.3.2.3-1. Safety Cage, South End View.

Figure A.3.2.3-2. Safety Cage, East End View.

Figure A.2.1.1.1-1. HELS Initial Stroke Capacitor Bank.

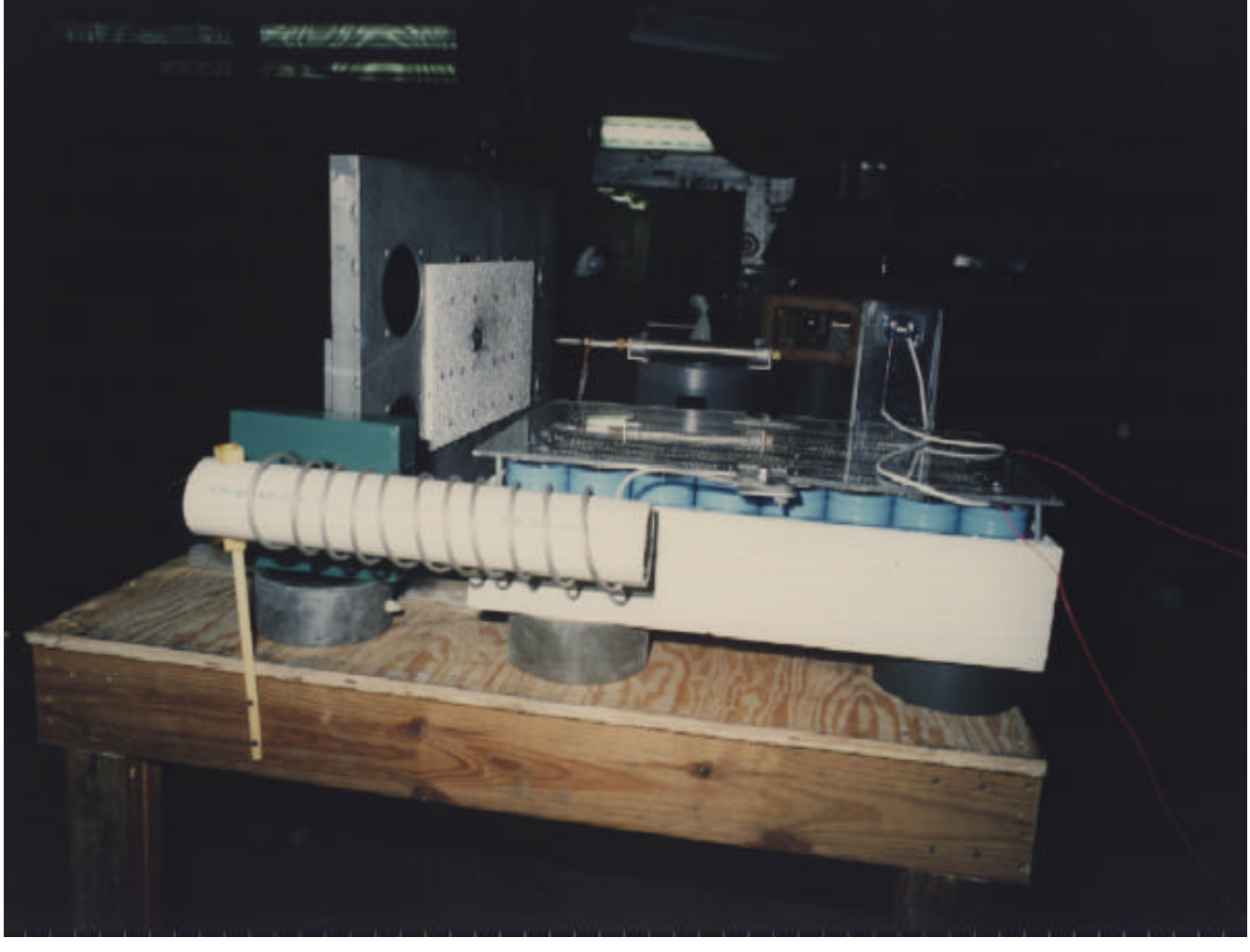


Figure A.2.1.1.2-1. HELS Intermediate Capacitor Bank.

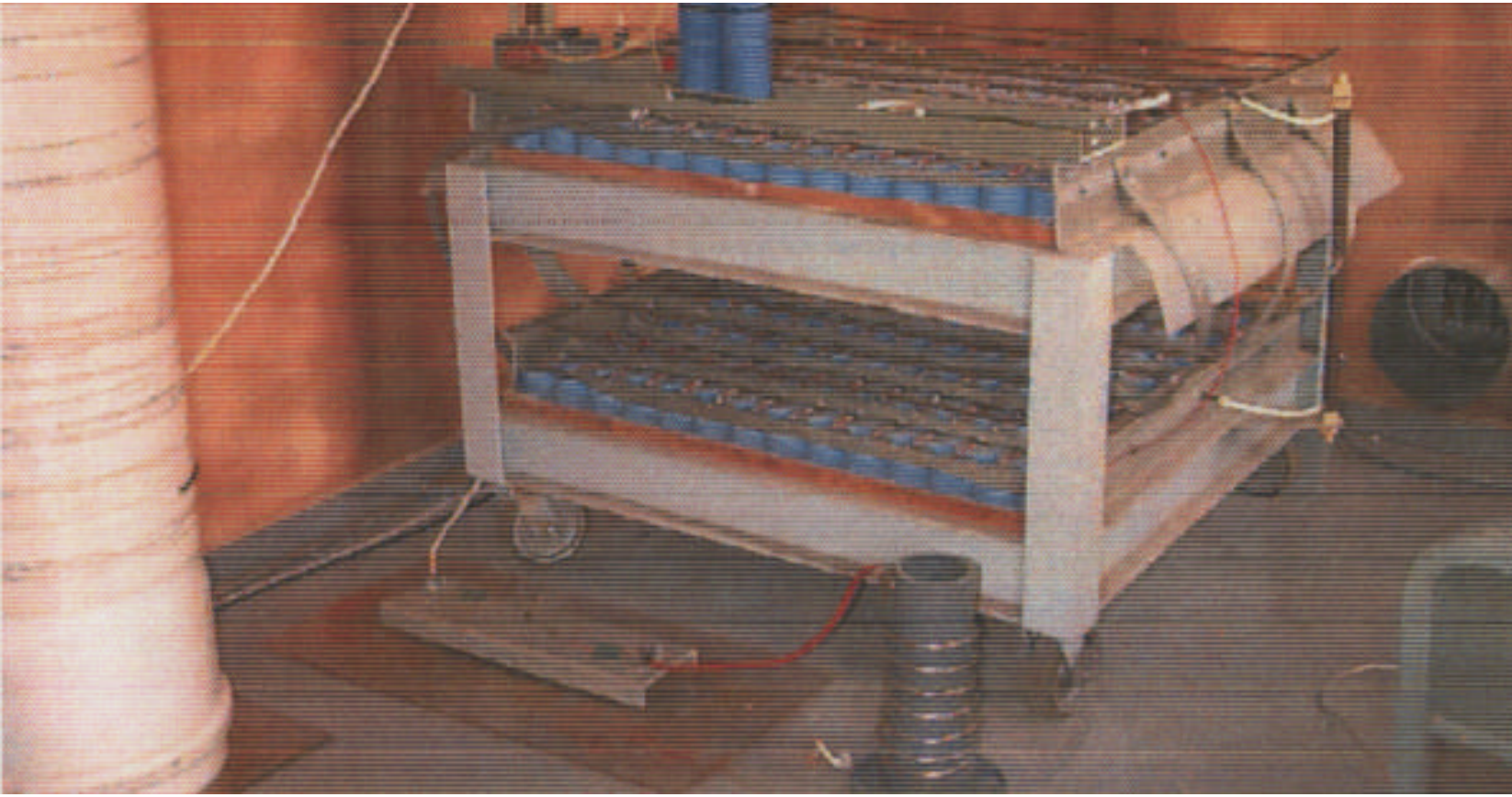


Figure A.2.1.1.3-1. HELS Continuing Current Capacitor Bank.

Figure A.2.1.1.4-1. HELS Large System Restrike Marx Capacitor Bank.

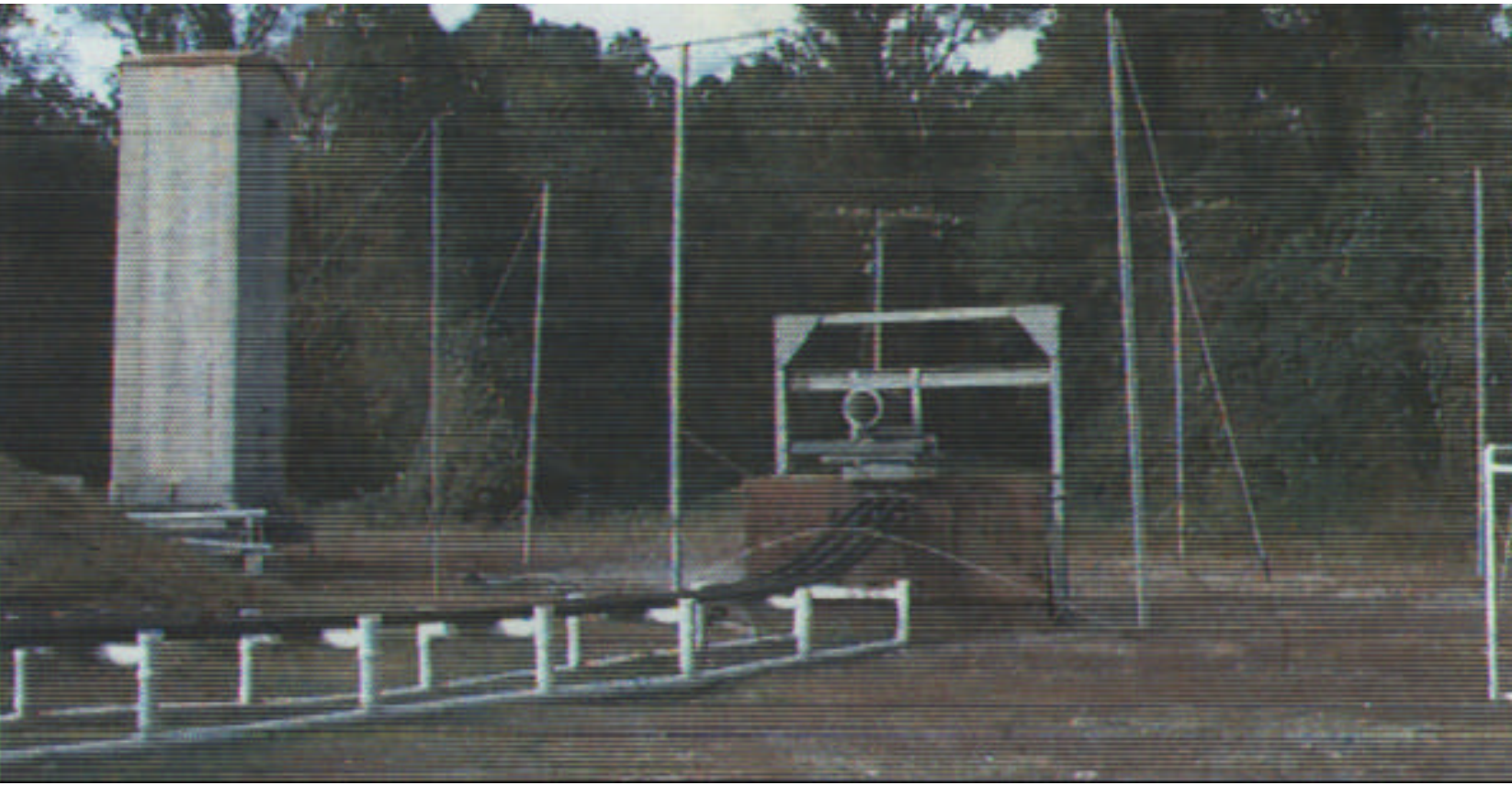


Figure A.2.1.1.5-1. HELS Small System Restrike Capacitor Bank.

Figure A.2.1.1.6-1. Southern View of HELS Secondary Safety Cage.

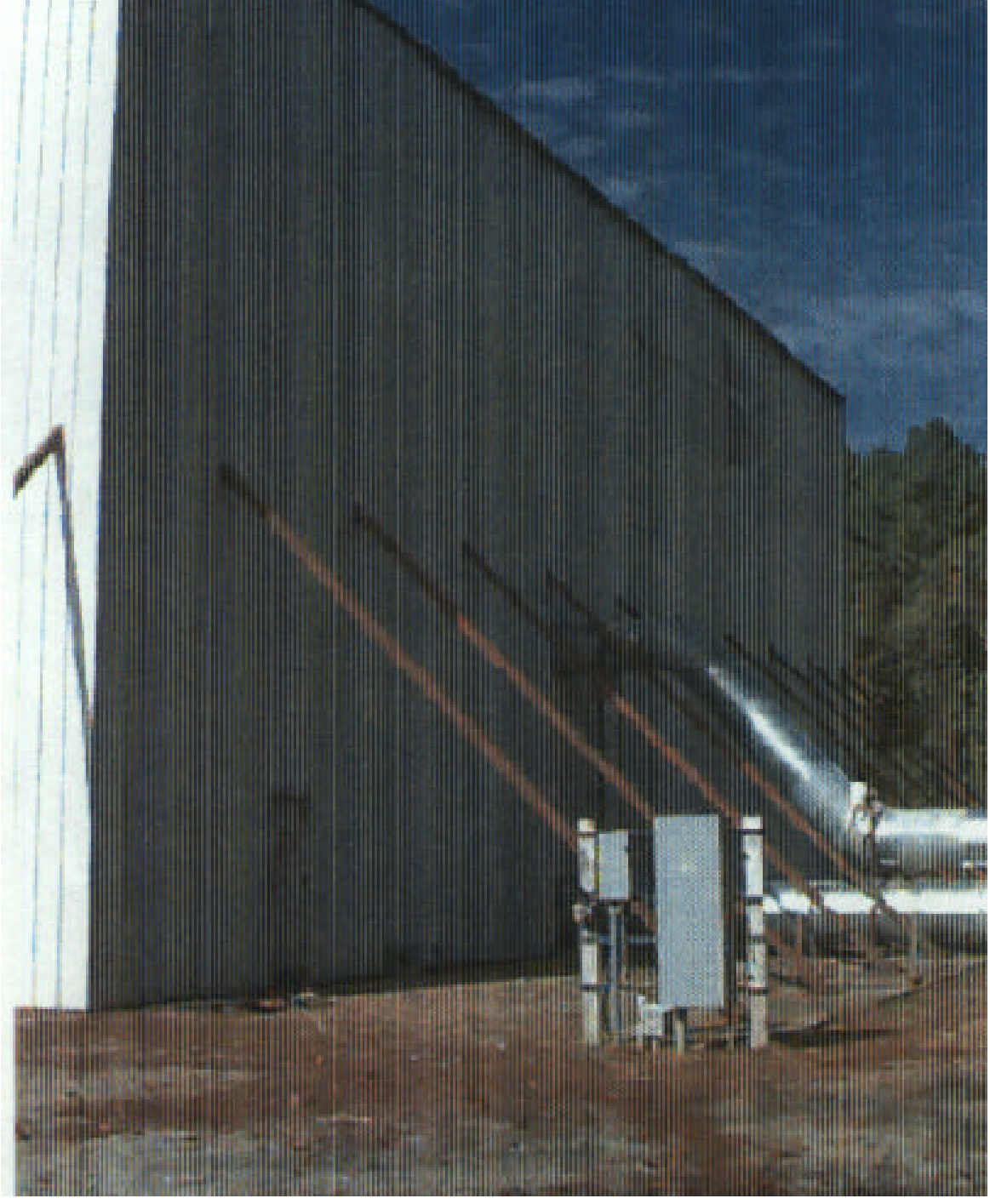


Figure A.2.1.1.6-2. Northern View of HELS Secondary Safety Cage.

Figure A.2.1.3.1-1. TLES Initial Stroke Capacitor Bank.

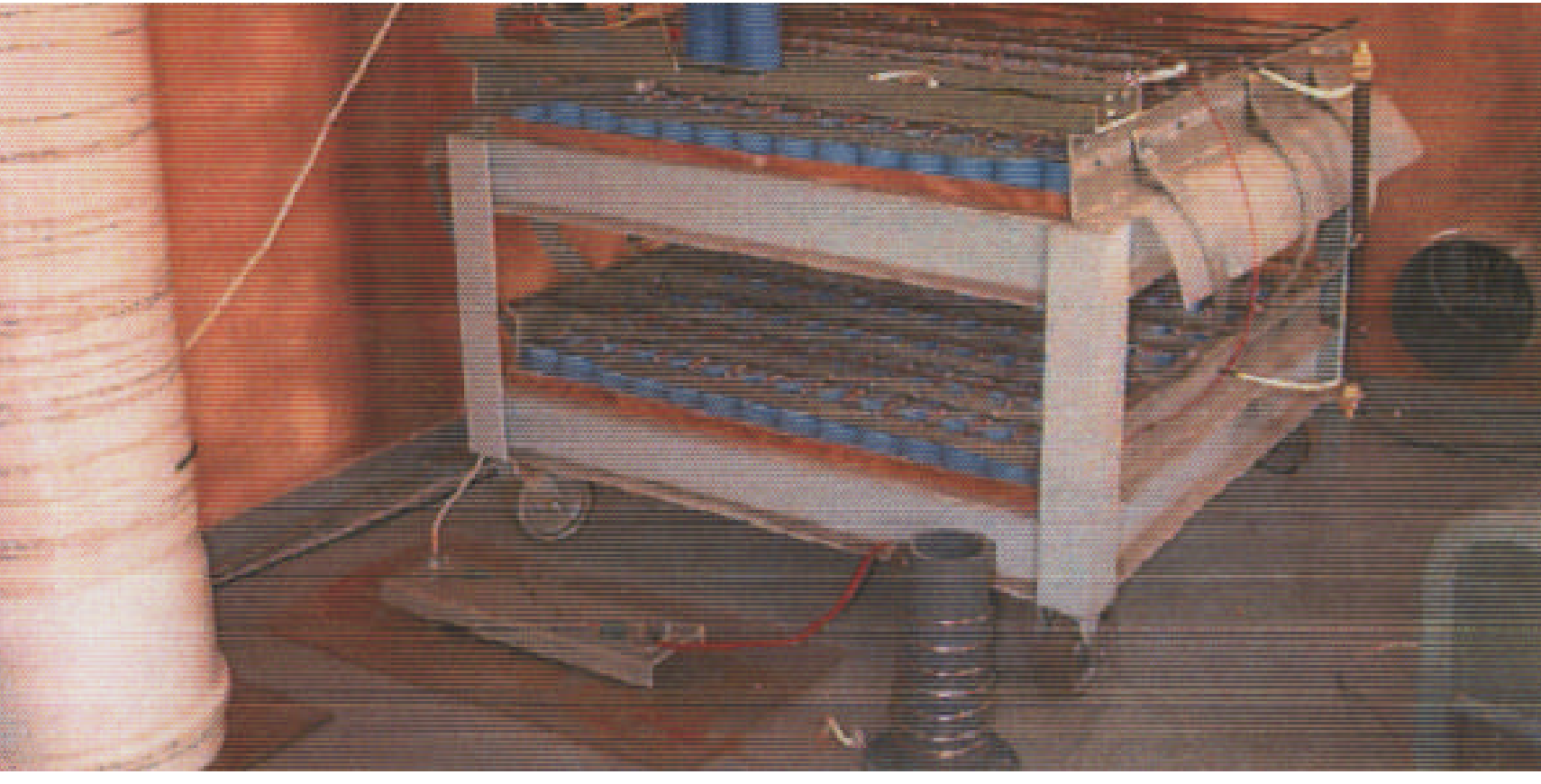


Figure A.2.1.3.2-1. TLES Continuing Current Capacitor Bank.

APPENDIX B
LEXICON OF E^3 TERMS

LEXICON OF E^3 TERMS

Continuous Wave (CW) - An unmodulated electromagnetic wave whose oscillations are identical under steady state conditions.

Electro-explosive Device (EED) - An EED is an electric initiator or other component, i.e., Hot Bridgewire (HBW), Exploding Bridgewire (EBW), carbon bridgewire, or electronic firing ignitor, in which electrical energy is used to cause initiation of explosives contained in a system. Inadvertent initiation of an EED can occur as a result of electromagnetic (EM) energy unintentionally conducted to the EED.

Electromagnetic Compatibility (EMC) - EMC is defined as the ability of a system to operate in its intended E3 environments without suffering or causing unacceptable degradation. A system which operates in all the environments covered in this report will provide an electromagnetically compatible system.

Electromagnetic Environment (EME) - The electromagnetic field(s) and/or signals existing with or radiated on a system.

Electromagnetic Environmental Effects (E^3) - The electromagnetic environmental impact on the performance of systems and subsystems containing electro-explosive devices (EEDs) and electronic components. The electromagnetic disciplines include EMI, EMRO, ESD, LE, EMRH and EMP.

Electromagnetic Interference (EMI) - EMI or Radio Frequency Interference (RFI) is the degradation by an unintended electromagnetic signal or an electromagnetic disturbance. EMI/RFI occurs when the unintended signal is coupled into or out of a component, subsystem, and system. EMI is used to describe interference between subsystems as applied to system requirements. These terms (EMI and RFI) are used in reference to screen or shielded room testing per MIL-STD-461 requirements and MIL-STD-462 test methods.

Electromagnetic Pulse (EMP) - EMP is the short burst of electromagnetic radiation associated with a nuclear event. EMP is characterized by pulse duration of less than one second and by a frequency spectrum extending to 100 MHz. It can result in the degradation of electronics as well as EEDs and ESADs.

Electromagnetic Radiation (EMR) - The propagation of energy in the form of varying electric and magnetic fields through free space at the speed of light.

Electromagnetic Radiation Hazard (EMRH) - EMRH is the potential hazard caused by electromagnetic radiation to electro-explosive devices (EEDs), Electronic Safe and Arming Devices (ESADs) and their circuits. The acronym EMRH also includes abortive functioning of the EED, ESAD, and the degradation in the reliability or performance characteristics of the EED or ESAD. There are three types of EED effects: inadvertent initiation, creation of a dud, and thermal stacking (successive pulses that elevate bridgewire temperature). Similarly, ESADs

failures include: hazards due to inadvertent arming or fuzing of warheads and reliability failures resulting in warheads which fail to arm at the appropriate time.

In this document, the term EMRH addresses both the design and test criteria for missile system development. Hazards to personnel (HERP) and to fuels (HERF) are not covered. However, EMRH is applicable for all other systems, especially systems utilizing ordnance items. E^3 criteria are to be used in the design, development, verification and/or certification of firing circuits, and the selection of all EEDs and ESADs to preclude premature detonation during shipping, storage, handling, pre-launch, launch and flight through safe separation distance, and to verify electronic component survivability. Electronic components shall not be permanently damaged due to the EMRH environment.

Electromagnetic Radiation Operation (EMRO) - EMRO is the E^3 requirement to be used in the design, development, and verification of non-EED firing circuitry to ensure system reliability. This requirement includes electronic circuitry, especially guidance and control functions. The EMRO criteria apply to training and tactical operations to include pre-launch and launch performance for airborne systems (i.e. missiles).

Electromagnetic Vulnerability (EMV) - A Navy term. EMV is the evaluation of the effect a Navy EM environment has upon the operation of a system. The EMV requirement is the same for Navy systems as the EMRO requirement is for Army missile systems.

Electrostatic Discharge (ESD) - ESD is the requirement to be used in the design, development, and verification of the components, subsystems, and systems to prevent the detonation of explosives, the ignition of propellants, or the malfunction of associated electronic circuitry by static electric discharge which could create a hazard or affect system reliability. Both helicopter and personnel-borne charges are specified in these criteria.

Field Intensity (FI) - A measure of electric (E) or magnetic (H) field intensity in an electromagnetic field, usually expressed in volts per meter (V/m) and amperes per meter (A/m), respectively.

Free Space Field Intensity - The electromagnetic field intensity that exist at a point in a uniform medium in the absence of waves reflected from other objects. For the purpose of this report, a free space field, is a field from either the radiator or antenna, in an open area or anechoic chamber with a minimum of material substances from which waves may be reflected.

Hazards of Electromagnetic Radiation to Ordnance (HERO) - HERO is a Navy requirement and has essentially the same meaning as the EMRH requirements (See EMRH). MIL-STD-1385B provides the HERO criteria. Army systems that are to be transported on Navy ships are required to use a combination of the EMRH and HERO requirements.

High Power Microwave (HPM) - A very intense pulsed EMR environment. A future HPM tactical weapon is a possibility for both Red and Blue forces which would provide an environment for missile systems. The HPM environment has not been defined at this time. The efficacy of future HPM weapons will depend upon the feasibility of deploying portable systems

with antennas to achieve coupling efficiencies that will be effective against other weapon systems.

Intersystem Compatibility - This condition is when the system is compatible to the EM environment generated outside the system. In general, an intersystem test consists of EMRH, EMRO, LE and ESD tests.

Intra-System Compatibility - This condition is when the system is compatible to the EM environment generated within the system. Generally, an intra-system compatibility test consists of a system test set-up simulating a deployed configuration, where each subsystem can be sequenced as the system is monitored for degradation. Monitoring can be done visually or with instrumentation.

Leader- A leader is the preliminary breakdown that forms an ionized path for the charge to be channeled towards the opposite charge center. The "stepped" leader advances in a series of short, luminous steps prior to the first return stroke. The "dart" leader re-ionizes the return stroke path in one luminous step prior to each subsequent return stroke in the lightning flash.

Lightning Effects (LE) - LE is the damage or degradation to systems as a result of direct or near strike lightning. The lightning criteria define an environment to be used in the design, development, and verification of electronic circuitry to ensure safety and reliability. For near strike lightning, the system shall survive without permanent damage and be operational after the strike. For a direct strike, the equipment shall remain safe that is, a direct lightning flash to the weapon system cannot result in hazardous condition. Hazardous conditions would result in premature detonation of hazardous class EEDs and/or ignition of rocket propellant. Normally, the system is not required to operate after exposure to the direct strike lightning environment.

Log - All logarithms are base 10.

Power Density (P_d) - Value of the Poynting vector at a point in space. P_d is the rms E-field intensity squared divided by free space impedance (377 ohms) or $P_d = E^2/377$ Watts/meter^2 (W/m^2).

Streamer - The preliminary breakdown path originating from the ground, which develops toward the atmospheric charge center. It operates in conjunction with the leader to establish the discharge path prior to the first return stroke.

Special Electromagnetic Interference (SEMI) - This is an in-depth electromagnetic assessment to determine system vulnerability in a battlefield scenario and in support of electronic warfare evaluations. SEMI is essentially the same as EMRO except SEMI is more of an in-depth evaluation compared to EMRO. SEMI supports the electronic warfare assessment program by investigating and quantifying the effects (electronic upset) of out-of-band EM countermeasures of weapon/communication electronic systems. Systems are subjected to complex electromagnetic environments to determine system performance degradation as a function of many parameters. If a system is found vulnerable, electronic countermeasure options are investigated to reduce or eliminate the problem.

Subsystem - A subsystem is a major functional component or element of a system, usually consisting of several equipment that are essential to the operational completeness of a system. Examples are airframe, seeker, propulsion, guidance, launch platform, night sight, warhead, launch control, etc. Usually, E^3 testing on a subsystem is limited to EMI (MIL-STD-461) and personnel ESD requirements.

Susceptibility - The failure of a system to pass a test and /or analysis based on system pass-failure criteria and the E^3 environment requirements in this report.

System - A composite of equipment, subsystems and operating personnel capable of performing and supporting an operational role. A complete system includes related support equipment, material and support personnel required for its operation to the degree that it can be considered a self-sufficient unit in its exposed E^3 environments. As related to E^3 testing, tests are performed on complete systems, including all launch platforms, all system electronics, instrumentation, controls, fluids, and mechanical subsystems required under normal or simulated operational conditions. E^3 evaluation requires that special attention be given to the assembly of the system which would provide true deployment configurations, especially the inter-connecting cabling.

UUT- The unit being tested or Unit Under Test, consisting of system, subsystem or component in a particular configuration. Efforts are made to assure the test including location, orientation, instrumentation, or operation do not unnecessarily alter the UUT and that the data recorded are consistent with deployed configuration. If any one component is modified, altered or removed the configuration changes and the system, subsystem or component must be retested to confirm its performance in an E^3 scenario.

Vulnerability - The determination of unfavorable probabilities of failure when known susceptibilities, as found in testing and/or analysis, are matched to actual scenarios containing known and projected threats.

APPENDIX C
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REFERENCES

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APPENDIX D
ABBREVIATIONS AND ACRONYMS

ABBREVIATIONS AND ACRONYMS

AAE	Army Acquisition Executive
ADS	Aeronautical Design Standard
AFPL	Air Force Phillips Laboratory
AM	Amplitude Modulation
AMC	Army Material Command
AR	Army Regulation
A/s	Ampere/sec
CBTDEV	Combat Developer
CDC	Combat Development Command
dB	Decibel
dBm	Decibel millivolt
dc	Direct Current
DNA	Defense Nuclear Agency
DOD	Department of Defense
EBW	Exploding Bridgewire
EED	Electro-explosive Device
E^3	Electromagnetic Environmental Effects
E^3RB	Electromagnetic Environmental Effects Review Board
EFI	Exploding Foil Initiators
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EMR	Electromagnetic Radiation
EMRH	Electromagnetic Radiation Hazard
EMRO	Electromagnetic Radiation Operational
EMV	Electromagnetic Vulnerability
ESAD	Electromagnetic Safe and Arm Device
ESD	Electro-Static Discharge
F	Farads
FFML	Far Field Main Lobe
FFSL	Far Field Side Lobe
FM	Frequency Modulation
ft	Feet
GHz	Gigahertz
Hz	Hertz
h	high
HBW	Hot Bridgewire
HEBEMP	High Energy Burst Electromagnetic Pulse
HERP	Hazard of Electromagnetic Radiation to Personnel
HERF	Hazard of Electromagnetic Radiation to Fuels
HERO	Hazard of Electromagnetic Radiation to Ordnance
HELS	High Energy Lightning Simulator

HP FASS	Hewlett Packard Frequency Agile Simulator System
HPM	High Power Microwave
IRIG	Inter-Range Instrumentation Group
kA	Kiloamps
kHz	Kilohertz
km	kilometer
kV	Kilovolts
kW	Kilowatts
l	long
LE	Lightning Effects
LED	Light Emitting Diode
m	meter
ma, mA	milliampere
MATDEV	Material Developer
MDC	Minimum Detectable Current
MDV	Minimum Detectable Voltage
MHz	Megahertz
MICOM	(US Army) Missile Command
MIL-I	Military Instruction
MIL-STD	Military Standard
MLRS	Multiple Launch Rocket System
MNFC	Maximum No Fire Current
MNFE	Maximum No Fire Energy
MNFP	Maximum No Fire Power
MNFV	Maximum No Fire Voltage
MSC	Major Subordinate Command
MV	megavolts
µF	microfarads
NBS	National Bureau of Standards
nF	nanofarads
NFML	Near Field Main Lobe
NFSL	Near Field Side Lobe
NIST	National Institute for Standards and Technology
OATS	Open Air Test Site
PC	Personal Computer
PCM	Pulse Code Modulation
PEL	Personnel Exposure Limit
pf	picofarads
PM	Project Managers, Pulse Modulation
REES	Radar Electromagnetic Environment Simulator
RF	Radio Frequency
RFI	Radio Frequency Interference

rms	root mean square
RTTC	Redstone Technical Test Center
SEMI	Special EM Interference
SLET	Simulated Lightning Effects Test (Facility)
TAG	Office of Adjutant General
TEM	Transverse Electromagnetic
TEMP	Test and Evaluation Master Plan
TEMPS	Transportable Electromagnetic Pulse Simulator
TLES	Transportable Lightning Effects Simulator
TM	Telemetry
TMDE	Test Measurement and Diagnostic Equipment
TSD	Threshold Separation Distance
USAEHA	United States Army Environmental Hygiene Agency
USATA	US Army Test Activity
UUT	Unit Under Test
V/m	volts per meter
V/m/s	volts per meter per second
w	wide
WSMR	White Sands Missile Range

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