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METRIC

MIL-STD-188-125
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MILITARY STANDARD

HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) PROTECTION FOR GROUND-BASED C^4I FACILITIES PERFORMING CRITICAL, TIME-URGENT MISSIONS

for Common
Long-Haul/Tactical Communication Systems

AMSC N/A

FSC SLHC

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DEPARTMENT OF DEFENSE
Washington, DC 20301

HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) PROTECTION FOR GROUND-BASED C⁴I FACILITIES PERFORMING CRITICAL, TIME-URGENT MISSIONS

1. This military standard is approved and mandatory for use by all Departments and Agencies of the Department of Defense, in accordance with Department of Defense Directive 4640.11, 21 December 1987.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: TIC/TIS, Scott AFB, IL 62225-6000, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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FOREWORD

1. Originally, Military Standard 188 (MIL-STD-188) covered technical standards for tactical and long-haul communications, but later evolved through revisions (MIL-STD-188A, MIL-STD-188B) into a document applicable to tactical communications only (MIL-STD-188C).

2. The Defense Communications Agency (DCA) published DCA circulars (DCAC) promulgating standards and engineering criteria applicable to the long-haul Defense Communications System (DCS) and to the technical support of the National Military Command System (NMCS).

3. As a result of a Joint Chiefs of Staff (JCS) action, standards for all military communications are now being published in a MIL-STD-188 series of documents. The MIL-STD-188 series is subdivided into a MIL-STD-188-100 series covering common standards for tactical and long-haul communications, a MIL-STD-188-200 series covering standards for tactical communications only, and a MIL-STD-188-300 series covering standards for long-haul communications only. Emphasis is being placed on developing common standards for tactical and long-haul communications published in the MIL-STD-188-100 series.

4. This document contains technical standards and design objectives for high-altitude electromagnetic pulse (HEMP) protection of ground-based facilities which are nodes in a HEMP-hardened network for performing critical and time-urgent command, control, communications, computer, and intelligence (C^4I) missions. The requirements are stringent in order to avoid both damage and functional upsets which prevent mission accomplishment within operationally prescribed timelines. The standards apply uniformly to all facilities in the end-to-end chain, since disruption of a single node may result in network failure.

5. This initial version of MIL-STD-188-125 addresses HEMP hardening for fixed ground-based facilities which perform critical, time-urgent C^4I missions. Studies are currently in progress to demonstrate sound and practical measures for protection of transportable systems. The standard will be amended to include requirements and design objectives for HEMP hardening of transportable, critical, time-urgent C^4I systems when these studies are completed.

6. Use of the standard for HEMP protection of other ground-based communications-electronics facilities that require hardening is encouraged to the extent permitted by cost constraints.

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7. Performance, acceptance, and verification requirements are contained in the body of the standard. HEMP-unique acceptance and verification test techniques are temporarily included as appendices A, B, and C; it is intended that these procedures will ultimately be promulgated as separate standards.

8. Implementation of MIL-STD-188-125 is supported by MIL-HDBK-423 (in preparation), "High-Altitude Electromagnetic Pulse (HEMP) Protection for Fixed and Transportable Ground-Based Facilities." The handbook also includes planning, management, logistics, and data requirements for HEMP protection acquisition programs and hardness maintenance and hardness surveillance requirements for operational facilities.

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1. SCOPE

1.1 Purpose. This standard establishes minimum requirements and design objectives for high-altitude electromagnetic pulse (HEMP) hardening of fixed and transportable[1] ground-based facilities which perform critical, time-urgent command, control, communications, computer, and intelligence (C^4I) missions. Facilities required to fully comply with the provisions of the standard will be designated by the Joint Chiefs of Staff, a Military Department Headquarters, or a Major Command.

1.2 Scope. This standard prescribes minimum performance requirements for low-risk protection from mission-aborting damage or upset due to HEMP threat environments of DoD-STD-2169. The standard also addresses minimum testing requirements for demonstrating that prescribed performance has been achieved and for verifying that the installed protection subsystem provides the operationally required hardness for the completed facility.

1.3 Applications. This standard shall be used in the design, engineering, fabrication, installation, and testing of specifically designated fixed and transportable ground-based facilities in a HEMP-hardened, critical, time-urgent C^4I network. Such nodes include subscriber terminals and data processing centers, transmitting and receiving communications stations, and relay facilities. The standard applies to both new construction and retrofit of existing facilities. Although only local portions of facility interconnects are addressed, it is assumed that survivable long-haul communications paths, fiber optic links, or other hardened interconnects between facilities will be provided as required for mission accomplishment. Use of the standard for HEMP protection of other ground-based communications-electronics facilities that require hardening is also encouraged.

1.4 Objectives. Survivable C^4I capabilities are essential to a credible military deterrent. This standard supports nuclear survivability objectives by providing a standardized, low-risk protection approach for fixed and transportable ground-based facilities in a HEMP-hardened C^4I network. These uniform requirements ensure balanced HEMP hardening for all critical facilities in the network.

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[1]This initial version of the standard addresses fixed facilities only. It will be amended to include transportable facilities when current studies to demonstrate sound and practical hardening measures for transportable systems are completed.

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2. REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation form a part of this standard to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-Q-9858 – Quality Program Requirements.

STANDARDS

FEDERAL

FED-STD-368 – Quality Control System Requirements.
FED-STD-1037 – Glossary of Telecommunication Terms.

MILITARY

DoD-STD-100 – Engineering Drawing Practices.
MIL-STD-188-124 – Grounding, Bonding and Shielding.
MIL-STD-248 – Welding and Brazing Procedure and Performance Qualification.
MIL-STD-470 – Maintainability Program Requirements.
MIL-STD-785 – Reliability Program for Systems and Equipment Development and Production.
MIL-STD-1472 – Human Engineering Design Criteria for Military Systems, Equipment and Facilities.
MIL-STD-2165 – Testability Program for Electronic Systems and Equipments.
DoD-STD-2169 – High-Altitude Electromagnetic Pulse (HEMP) Environment (U) (document is classified Secret).

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HANDBOOKS

MILITARY

MIL-HDBK-419	-	Grounding, Bonding, and Shielding.
MIL-HDBK-423	-	High-Altitude Electromagnetic Pulse (HEMP) Protection for Fixed and Transportable Ground-Based Facilities. (in preparation)
MIL-HDBK-729	-	Corrosion and Corrosion Prevention Metals.

2.1.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this standard to the extent specified herein.

DoD Directive 4245.4	-	Acquisition of Nuclear-Survivable Systems.
JCS Pub. 1	-	Joint Chiefs of Staff: DoD Dictionary of Military and Associated Terms.
DNA-H-86-60	-	DNA EMP Engineering Handbook for Ground Based Facilities.

(Copies of specifications, standards, handbooks, drawings, and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this standard to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted shall be those listed in the issue of the DoDISS specified in the solicitation. The issues of documents which have not been adopted shall be those in effect on the date of the cited DoDISS.

NFPA 101 - Life Safety Code.

(Applications for copies should be addressed to the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.)

2.3 Order of precedence. In the event of a conflict between the text of this standard and the references cited herein, the text of this standard shall take precedence.

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3. DEFINITIONS

3.1 Acronyms used in this standard. The acronyms used in this standard are defined as follows:

a. C^4I – Command, Control, Communications, Computer, and Intelligence

b. CW – Continuous Wave

c. DoDISS – Department of Defense Index of Specifications and Standards

d. FWHM – Full Width at Half Maximum Amplitude

e. HEMP – High-Altitude Electromagnetic Pulse

f. MEE – Mission-Essential Equipment

g. PCI – Pulsed Current Injection

h. POE – Point-of-Entry

i. RF – Radio Frequency

j. SELDS – Shielded Enclosure Leak Detection System

3.2 Sources for definitions. Sources for definitions of terms used in MIL-STD-188-125, in order of decreasing priority, are as follows:

a. FED-STD-1037, "Glossary of Telecommunication Terms"

b. JCS Pub. 1, "Dictionary of Military and Associated Terms"

c. DNA-H-86-60, "DNA EMP Engineering Handbook for Gound Based Facilities"

3.3 Additional definitions.

3.3.1 Aperture point-of-entry. Aperture points-of-entry are intentional or inadvertent holes, cracks, openings, or other discontinuities in the facility HEMP shield surface. Intentional aperture points of entry are provided for personnel and equipment entry and egress and for fluid flow (ventilation and piped utilities) through the electromagnetic barrier.

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3.3.2 Conductive point-of-entry. An electrical wire or cable or other conductive object, such as a metal rod, which passes through the electromagnetic barrier is a conductive point-of-entry. Conductive points-of-entry are also called penetrating conductors.

3.3.3 Electromagnetic barrier. The HEMP electromagnetic barrier is the topologically closed surface created to prevent or limit HEMP fields and conducted transients from entering the enclosed space. The barrier consists of the facility HEMP shield and point-of-entry treatments, and it encloses the protected volume.

3.3.4 Electromagnetic stress. An electromagnetic stress is a voltage, current, charge, or electromagnetic field which acts on an equipment. If the electromagnetic stress exceeds the vulnerability threshold of the equipment, mission-aborting damage or upset may occur.

3.3.5 Facility HEMP shield. The facility HEMP shield is the continuous metallic housing that substantially reduces the coupling of HEMP electric and magnetic fields into the protected volume. The facility HEMP shield is part of the electromagnetic barrier.

3.3.6 HEMP acceptance test. An acceptance test of a system, subsystem, or component is performed to ensure that specified performance characteristics have been met. HEMP acceptance tests, conducted near the conclusion of a hardening construction or installation contract, are tests for the purpose of demonstrating that at least minimum performance requirements of the HEMP protection subsystem have been achieved before the subsystem will be accepted by the Government from the contractor.

3.3.7 HEMP hardness. HEMP hardness is the ability of the facility to withstand exposure to a HEMP environment without mission-aborting damage or upset. Shielding effectiveness and performance of point-of-entry treatments and special protective measures are factors in determining HEMP hardness.

3.3.8 HEMP hardness critical item. A hardness critical item is an item at any assembly level having performance requirements for the purpose of providing protection from an explosion or natural disaster. Nuclear hardness critical items provide protection from environments produced by a nuclear event or are specially designed to operate under nuclear stresses. HEMP hardness critical items are the elements of the HEMP protection subsystem.

3.3.9 HEMP hardness critical process. A HEMP hardness critical process is a process, specification, or procedure which must be followed exactly to ensure that the associated hardness critical item attains its required performance.

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3.3.10 HEMP hardness maintenance and hardness surveillance. HEMP hardness maintenance and hardness surveillance are the combined preventive maintenance, inspection, test, and repair activities accomplished on a HEMP-protected operational facility to ensure that HEMP hardness is retained throughout the system life cycle.

3.3.11 HEMP protection subsystem. The HEMP protection subsystem includes the electromagnetic barrier and all special protective measures installed for the purpose of hardening the mission-essential equipment against the HEMP environment.

3.3.12 Low-risk HEMP hardening. Low-risk HEMP hardening is a hardening technique that features a high-quality electromagnetic barrier with minimized and protected points-of-entry. Virtually all mission-essential communications-electronics and support equipment are placed in the protected volume enclosed by the barrier and operate in a relatively benign electromagnetic environment, isolated from the external HEMP stresses. The low-risk approach results in a well-defined HEMP protection subsystem configuration with inherent testability.

3.3.13 Mission-essential equipment (MEE). Mission-essential equipment includes all communications-electronics and support equipment required to perform specified missions. In the context of this standard, MEE refers to equipment required to perform missions specified to be hardened against the HEMP environment.

3.3.14 Penetrating conductor. Any electrical wire or cable or other conductive object, such as a metallic rod, which passes through the electromagnetic barrier is a penetrating conductor. Penetrating conductors are also called conductive points-of-entry.

3.3.15 Penetration entry area. The penetration entry area is that area of the electromagnetic barrier where long penetrating conductors (such as an electrical power feeder) and piping points-of-entry are to be concentrated.

3.3.16 Point-of-entry (POE). A point-of-entry is a location on the electromagnetic barrier where the shield is penetrated and HEMP energy may enter the protected volume unless an adequate POE protective device is provided. POEs are classified as aperture POEs or penetrating conductors according to the type of penetration. They are also classified as architectural, mechanical, structural, or electrical POEs according to the architectural-engineering discipline in which they are usually encountered.

3.3.17 POE protective device or POE treatment. A POE protective device or treatment is the protective measure used to prevent or limit HEMP energy from entering the protected volume at a POE. Common POE protective devices include waveguides-below-cutoff and

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closure plates for aperture POEs, and filters and electrical surge arresters on penetrating conductors.

3.3.18 Protected volume. The protected volume is the three-dimensional space enclosed by the electromagnetic barrier, except for those spaces which are also within special protective volumes.

3.3.19 Pulsed current injection (PCI). Pulsed current injection is a test method for measuring performance of a POE protective device on a penetrating conductor. A HEMP threat-relatable transient is injected on the penetrating conductor at a point outside the electromagnetic barrier and the residual internal transient stress is measured inside the barrier.

3.3.20 Residual internal stress. Residual internal stresses are the electromagnetic fields, voltages, currents, or charges which originate from the HEMP environment and penetrate into the protected volume after attenuation by elements of the electromagnetic barrier.

3.3.21 Retrofit HEMP hardening. A retrofit action is an action taken to modify in-service equipment. Retrofit HEMP hardening is the installation or substantial upgrade of the HEMP protection subsystem for an existing facility or equipment.

3.3.22 Shielded enclosure leak detection system (SELDS). Any of a class of commercially available instruments designed for checking shielding effectiveness in the magnetic field test regime is called a SELDS. Most of these instruments operate at one or more discrete frequencies, often of the order of 100 kHz.

3.3.23 Special protective measures. Special protective measures include all HEMP hardening measures required in addition to implementation of the electromagnetic barrier. Special protective measures are necessary for mission-essential equipment outside the barrier, for mission-essential equipment which is within the protected volume and experiences damage or upset during verification testing, and in cases requiring a special protective volume.

3.3.24 Special protective volume. A special protective volume, enclosed within a special protective barrier (see illustration in 5.1.8.3), is a region within the electromagnetic barrier where electromagnetic stresses due to HEMP may exceed the residual internal stress limits for the protected volume. The special protective barrier may be a separate shield with protected penetrations; more commonly, shielded cables or conduits and equipment cabinets and closed piping systems are used to provide the needed electromagnetic isolation from the protected volume.

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3.3.25 Verification testing. Verification tests are conducted for demonstrating that the installed HEMP protection subsystem provides the required HEMP hardness. They are performed after the construction and acceptance testing are complete and after the equipment is installed and functioning, to determine if the operational system suffers mission-aborting damage or upset due to simulated HEMP excitations. Verification is normally a Government-conducted test, and is not part of a facility construction contract.

3.3.26 Vulnerability threshold. The vulnerability threshold of an equipment is the minimum stress level which causes the equipment to suffer definite degradation. In the context of this standard, the vulnerability threshold is the minimum electromagnetic stress which causes mission-aborting damage or upset.

3.3.27 Waveguide-below-cutoff. A waveguide-below-cutoff is a metallic waveguide whose primary purpose is to attenuate electromagnetic waves at frequencies below the cutoff frequency (rather than propagating waves at frequencies above cutoff). The cutoff frequency is determined by the transverse dimensions and geometry of the waveguide and properties of the dielectric material in the waveguide.

3.3.28 Waveguide-below-cutoff array. A waveguide-below-cutoff array is an assembly of parallel waveguides-below-cutoff, with adjacent cells usually sharing common cell walls (see illustration in 5.1.5.2). A waveguide-below-cutoff array is used when the area of the shield aperture required to obtain adequate fluid flow within pressure drop limitations is larger than the permissible area of a single waveguide-below-cutoff.

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4. GENERAL REQUIREMENTS

4.1 General.

4.1.1 HEMP protection overview. The need exists for uniform and effective hardening, verification, hardness maintenance, and hardness surveillance of fixed and transportable ground-based C⁴I facilities, which require network interoperability during and after exposure to HEMP environments. In critical time-urgent applications where some momentary upsets, as well as damage, are mission-aborting, the hardening requirements include stringent shielding, POE protection, and special protective measures. Because normal operational experience may not indicate the condition of the HEMP protection subsystem, thorough verification testing, hardness maintenance, and hardness surveillance after deployment are necessary. For additional information, refer to supporting handbook MIL-HDBK-423.

4.1.2 Integration with related requirements. Elements of the HEMP protection subsystem can serve multiple purposes. For example, the electromagnetic barrier can also be used to meet emanations security requirements. HEMP hardening measures should be integrated with those of electromagnetic disciplines, such as electromagnetic interference, electromagnetic compatibility, lightning protection, and TEMPEST, and with treatments for other hardening requirements.

4.2 Hardness program management.

Hardness program management[2] for fixed and transportable ground-based facilities being HEMP hardened in accordance with requirements of this standard shall implement the policy and procedures of Department of Defense Directive 4245.4. Design and engineering, fabrication, installation, and testing activities shall be managed to accomplish the following objectives:

a. To provide a HEMP-protected facility design based upon verifiable performance specifications

b. To verify hardness levels through a cost-effective program of testing and analysis

c. During the acquisition process, to develop a maintenance and surveillance program which supports the operational phase of life-cycle HEMP hardness

[2] HEMP planning, analysis, design, test procedures, and test reporting documentation, and requirements for hardness maintenance and hardness surveillance program development and execution are described in MIL-HDBK-423.

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4.3 HEMP hardening design. Facility protection against the HEMP threat environment specified in DoD-STD-2169 shall be achieved with an electromagnetic barrier and with additional special protective measures as required. The electromagnetic barrier shall consist of the facility HEMP shield and protective devices for all POEs. Special protective measures shall be implemented for hardening mission-essential equipment which must be placed outside the barrier and for other special cases to be defined. Reliability (MIL-STD-785), maintainability (MIL-STD-470), safety and human engineering (MIL-STD-1472), testability (MIL-STD-2165), and corrosion control (MIL-HDBK-729) shall be incorporated into the HEMP protection subsystem design.

4.3.1 Facility shield. The facility HEMP shield shall be a continuously welded or brazed metallic enclosure which meets or exceeds shielding effectiveness requirements of this standard (see 5.1.3.1).

4.3.2 Points-of-entry. The number of shield POEs shall be limited to the minimum required for operational, life-safety, and habitability purposes. Each POE shall be HEMP protected with POE protective devices which satisfy performance requirements of this standard (see 5.1.4 through 5.1.7).

4.3.3 Mission-essential equipment. All equipment required to perform trans- and post-attack missions shall be designated as mission-essential equipment. MEE includes such items as communications-electronic equipment, data processing subsystems, command and control equipment, local portions of hardened interconnects,[3] and critical support subsystems such as power generation, power distribution, and environmental control.

4.3.3.1 Mission-essential equipment within the electromagnetic barrier. All MEE which will operate satisfactorily and compatibly within the facility HEMP shield shall be installed inside the electromagnetic barrier. No HEMP-unique performance characteristics are required in design and selection of mission-essential equipment which will be housed within the barrier.

4.3.3.2 Mission-essential equipment outside the electromagnetic barrier. MEE, such as a radio antenna or evaporative heat exchanger, which must be placed outside the electromagnetic barrier, shall be provided with special protective measures (see 5.1.8) as required to ensure HEMP hardness in the HEMP threat environment.

[3]Although they are not included within the scope of this document, HEMP-hardened interconnects and survivable long-haul communication circuits to other hardened facilities in the network must be provided as required for mission accomplishment.

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4.3.3.3 HEMP-hardened electrical power. The facility shall be provided with HEMP-hardened electrical power generation and distribution capability sufficient to perform trans- and post-attack missions, without reliance upon commercial electrical power sources.

4.3.4 Special protective measures. Special protective measures shall be implemented in special cases where HEMP hardness cannot be achieved with the electromagnetic barrier alone. Additional shielding, transient suppression/attenuation devices, and equipment-level protection shall be provided as required to achieve HEMP hardness. The three categories of cases requiring special protective measures are as follows:

a. MEE which must be located outside the electromagnetic barrier and, therefore, is not protected by the barrier (see 5.1.8.1)

b. MEE which is enclosed within the electromagnetic barrier and experiences mission-aborting damage or upset during verification testing, even though the barrier elements satisfy all performance requirements (see 5.1.8.2)

c. Special protective volumes and barriers to provide supplementary isolation, when POE protective devices cannot satisfy the barrier requirements without interfering with facility operation (see 5.1.8.3)

4.4 HEMP testing. The HEMP testing program shall demonstrate that hardness performance requirements have been satisfied and that the required HEMP hardness has been achieved. This program shall include quality assurance testing during facility construction and equipment installation, acceptance testing for the electromagnetic barrier and special protective measures, and verification testing of the completed and operational facility.

4.4.1 Quality assurance program. A quality assurance program in accordance with FED-STD-368 and MIL-Q-9858 shall be implemented during facility construction and installation to demonstrate that the HEMP protection subsystem materials and components comply with performance requirements of this standard. The quality assurance test procedures and results shall be documented for use as baseline configuration and performance data for the hardness maintenance and surveillance program.

4.4.2 Acceptance testing. Acceptance of the HEMP protection subsystem shall be based upon successful demonstrations of compliance with hardness performance requirements of this standard. HEMP acceptance tests of the electromagnetic barrier and special protective measures shall be conducted after all related construction work has been completed. Acceptance test procedures and results shall be documented for use as baseline configuration and performance data.

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4.4.3 Verification testing. After completion of the HEMP protection subsystem and installation and operational checks of the facility equipment, HEMP hardness of the facility shall be verified through a program of tests and supporting analysis. The verification program shall provide a definitive statement on the HEMP hardness of critical, time-urgent mission functions at the facility under test. Verification test procedures and results shall be documented for use as baseline configuration and performance data.

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5. DETAILED REQUIREMENTS

5.1 Fixed facilities.

5.1.1 HEMP protection subsystem topology.

5.1.1.1 Electromagnetic barrier topology. The electromagnetic barrier, consisting of the facility HEMP shield and POE protective devices, shall be configured to accomplish the following technical requirements:

a. To enclose all mission-essential equipment except those equipments such as radio antennas, evaporative heat exchangers, or external security sensors, which will not function properly if placed within the protected volume

b. To minimize the number of POEs

c. To avoid requirements for special protective measures internal to the barrier

d. To facilitate HEMP acceptance and verification testing

e. To minimize requirements for scheduled hardness maintenance

5.1.1.2 Penetration entry area. As a design objective, there should be a single penetration entry area on the electromagnetic barrier for all piping and electrical POEs except those connected to external conductors less than 10 m (32.8 ft) in length. The penetration entry area shall be located as far from normal and emergency personnel and equipment accesses and ventilation POEs as is permitted by the facility floor plan.

5.1.2 Facility grounding.

5.1.2.1 Equipotential ground plane. Fixed ground-based C^4I facilities shall be grounded using the equipotential ground plane method in accordance with MIL-STD-188-124 and guidance in MIL-HDBK-419. The facility HEMP shield shall form a major portion of the equipotential ground plane.

5.1.2.2 Grounding to the facility HEMP shield. Grounds for equipment and structures enclosed within the protected volume shall be electrically bonded to the inside surface of the shield by the shortest practical paths, including via the raised floor structure. Grounds for equipment and structures outside the electromagnetic barrier shall be electrically bonded to the outside surface of the shield or to the earth electrode subsystem. Ground cables

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used to connect the facility shield (equipotential ground plane) to the earth electrode subsystem shall be electrically bonded to the outside surface of the shield, and at least one such ground cable shall be located at the penetration entry area. All grounding connections to the facility HEMP shield shall be made in a manner which does not create POEs.

5.1.3 Facility HEMP shield.

5.1.3.1 Shielding effectiveness. The facility HEMP shield, with all POE protective devices installed, shall provide at least the minimum shielding effectiveness shown in figure 1.

5.1.3.2 Shield construction. The facility HEMP shield, exclusive of its POEs, shall be a continuous steel or copper enclosure, closed on all wall, ceiling, and floor surfaces. All seams and joints between adjacent panels shall be continuously welded (for steel shields) or continuously brazed (for copper shields). Welding and brazing shall be performed using procedures and personnel qualified in accordance with MIL-STD-248.

5.1.3.3 Shield monitoring capability. A built-in test capability to at least qualitatively monitor for electromagnetic shield leakage shall be provided (see 5.1.11).

5.1.3.4 Shield construction quality assurance.

5.1.3.4.1 In-progress inspection of welded and brazed seams. In-progress inspection of welded and brazed seams and joints shall proceed continuously in parallel with the shield fabrication and assembly activity. The quality of all shield seams and joints, including those used for installation of POE protective devices, shall be monitored with visual and magnetic particle inspection, SELDS measurements, or dye penetrant testing.

5.1.3.4.2 Shielding effectiveness survey. After the shield is closed but before interior equipments and finishes are installed, a shielding effectiveness survey shall be performed. SELDS testing and plane wave shielding effectiveness tests shall be employed. Shield defects found during the survey must be corrected, retested, and shown to provide the required performance before the interior equipment and finishes are installed.

5.1.3.5 Shield acceptance testing. After completion of the shield and after installation of the POE protective devices, internal equipments, and finish work provided under the construction contract, the shield acceptance test shall be conducted to determine if the facility shield performs in accordance with minimum requirements of figure 1. The test shall be conducted with POEs and their protective devices in a normal operating configuration, using shielding effectiveness test procedures of appendix A. All defects found during

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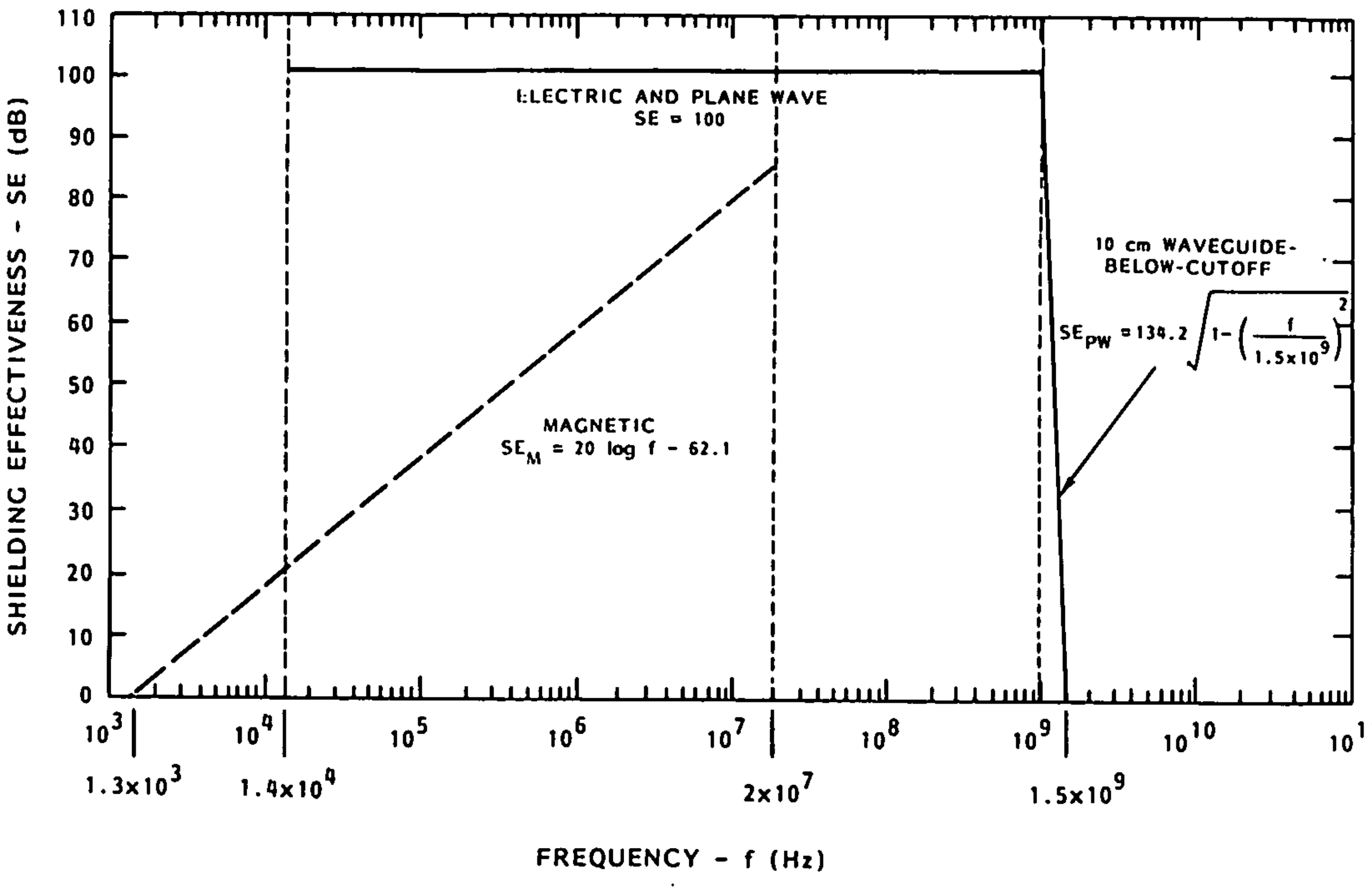

FIGURE 1. Minimum HEMP shielding effectiveness requirements (measured in accordance with procedures of appendix A).

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the acceptance testing shall be corrected, retested, and shown to provide the required performance before the installation of communications-electronics equipment.

5.1.3.5.1 Facility shield modifications. If POEs are added or the facility HEMP shield is breached and repaired after acceptance, shield acceptance testing in the affected area shall be repeated.

5.1.4 Architectural points-of-entry.

5.1.4.1 HEMP protection for architectural POEs. HEMP protection for architectural POEs, including personnel entryways and exits and equipment accesses through the facility shield, shall be provided with electromagnetic closure, waveguide-below-cutoff techniques, or combinations of closure and waveguides-below-cutoff.

5.1.4.1.1 Quality assurance for architectural POE protective devices. All welded or brazed seams and joints required for installation of architectural POE protective devices shall be monitored under the program of in-progress inspection of welded and brazed seams (see 5.1.3.4.1). Shielded doors and other closure or access covers shall be subjected to electromagnetic and mechanical quality assurance tests to demonstrate acceptable performance.

5.1.4.1.2 Acceptance testing for architectural POE protective devices. Acceptance testing for architectural POE protective devices shall be conducted using shielding effectiveness test procedures of appendix A.

5.1.4.2 Personnel entryways and exits. HEMP protection for all normal and emergency personnel entryways and exits shall be provided with a two-door shielded waveguide-below-cutoff entryway or with a two-door shielded vestibule (figure 2). As design objectives, the number of personnel entryways and exits should be constrained to the minimum requirements of NFPA 101 and the main personnel entryway should be a waveguide-below-cutoff.

5.1.4.2.1 Waveguide entryway dimensions. When a waveguide-below-cutoff entryway is used, height and width of the waveguide shall each not exceed 2.44 m (8 ft), and the length of the waveguide along its shortest path shall be at least five times the diagonal dimension of the cross-section. As a design objective, no electrical wiring, piping, or other conductors should run longitudinally inside the waveguide entryway. Where electrical wiring cannot be eliminated from the entryway, it shall be run in metal conduit. All conduits and other groundable conductors such as pipes or handrails in the waveguide entryway shall be electrically bonded to the entryway shield at intervals not exceeding 1 m (3.3 ft).

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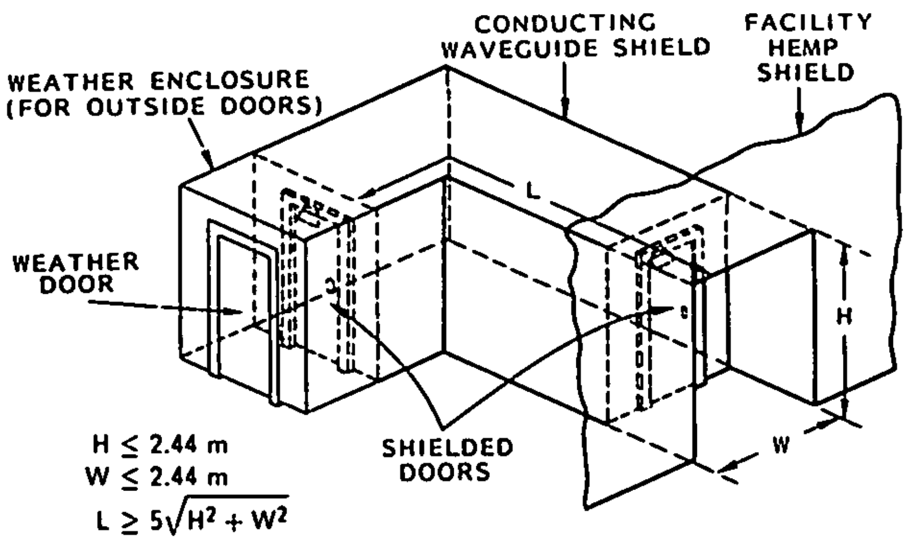
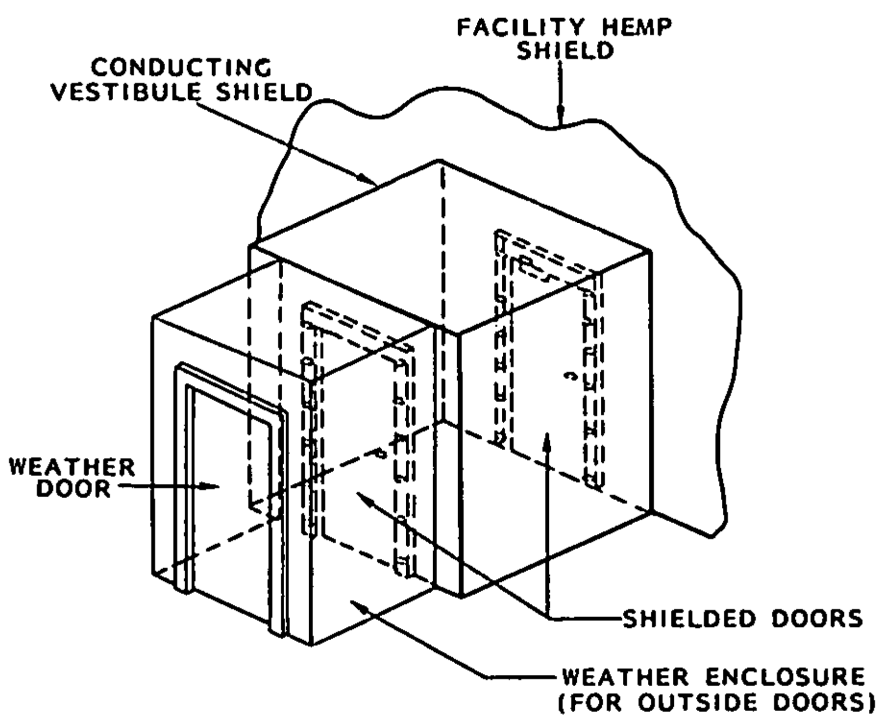


a. Waveguide entryway.



b. Vestibule entryway.

FIGURE 2. Typical waveguide and vestibule entryways.

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5.1.4.2.2 Entryway shield. The entryway shield shall comply with the same requirements applicable to the facility HEMP shield (see 5.1.3). All entryway POEs, either into the facility protected volume or to the outside, shall comply with the same requirements applicable to other POEs through the electromagnetic barrier (see 5.1.5 through 5.1.7).

5.1.4.2.3 Entryway shield doors. Entryway shield door frames shall be welded or brazed into the entryway shield. When installed, vestibule shield doors shall provide at least the minimum shielding effectiveness shown in figure 1. Waveguide entryway doors shall provide at least the minimum electric and plane wave shielding effectiveness shown in figure 1, but are not required to satisfy the magnetic shielding effectiveness criteria. A weather enclosure with appropriate environmental controls shall be provided to protect exterior shield doors from corrosion and exposure to blown dust and other natural elements.

5.1.4.2.4 Entryway interlocks and alarms. The entryway shield doors shall be provided with interlocks to ensure that at least one of the shield doors remains closed except during emergency evacuations. The entryway shield doors shall be provided with an alarm to indicate that the interlock has been overridden or that both shield doors are open.

5.1.4.3 Equipment accesses. A protected equipment access POE shall be provided only when movement of the equipment through a personnel entryway is not practical. HEMP protection for equipment accesses through the facility HEMP shield shall be provided with electromagnetic closure. The metal access cover shall be continuously seam welded in place, if anticipated usage is less than once per 3 years, and shall be radio frequency gasketed and secured by a closure mechanism which ensures a proper gasket seal, when expected usage is more frequent. When closed, the equipment access covers shall provide at least the minimum shielding effectiveness shown in figure 1. A weather enclosure shall be provided to protect exterior gasketed access covers from corrosion and exposure to blown dust and other natural elements.

5.1.5 Mechanical points-of-entry.

5.1.5.1 HEMP protection for mechanical POEs. HEMP protection for mechanical POEs, including piping and ventilation penetrations through the facility HEMP shield, shall be provided with waveguide-below-cutoff techniques. As a design objective, the number of piping POEs should be constrained to fewer than 20 and the number of ventilation POEs should be constrained to fewer than 10.

5.1.5.1.1 Quality assurance for mechanical POE protective devices. All welded and brazed seams and joints required for installation of mechanical POE protective devices,

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including those for piping and ventilation penetrations, shall be monitored under the program of in-progress inspection of welded and brazed seams and joints (see 5.1.3.4.1).

5.1.5.1.2 Acceptance testing for mechanical POE protective devices. Acceptance testing for mechanical POE protective devices, including those for piping and ventilation penetrations, shall be conducted using shielding effectiveness test procedures of appendix A.

5.1.5.2 Metallic piping POEs. Metallic piping shall penetrate the facility HEMP shield as a pipe section which is configured as a single waveguide-below-cutoff or a waveguide-below-cutoff array (figure 3). Dielectric hoses or pipes shall be converted to metal piping before penetrating the shield. The presence of the protected piping POE shall not degrade shielding effectiveness of the facility HEMP shield below the minimum requirements of figure 1.

5.1.5.2.1 Metallic piping waveguide dimensions. The inside diameter of a single waveguide-below-cutoff and each of the transverse cell dimensions in a waveguide-below-cutoff array shall not exceed 10 cm (4 in), except where a special protective volume will be established (see 5.1.8.3.1). The length of the waveguide section shall be at least five times the inside diameter of a single waveguide-below-cutoff or at least five times the transverse cell diagonal dimension in a waveguide-below-cutoff array.

5.1.5.2.2 Metallic piping waveguide construction. All joints and couplings in the waveguide section shall be circumferentially welded or brazed, and the waveguide-below-cutoff shall be circumferentially welded or brazed to the facility HEMP shield at the POE. Cell walls of a waveguide-below-cutoff array shall be metallic, and there shall be continuous electrical bonds at all intersections and between the cell walls and the waveguide wall. No dielectric (glass, plastic, etc.) pipe lining shall be permitted in the waveguide section. External and internal piping shall be connected at the ends of the waveguide section; no HEMP-unique requirements apply to these couplings.

5.1.5.3 Ventilation POEs. Ventilation ducts shall penetrate the facility HEMP shield in a section of metallic ducting which is configured as a waveguide-below-cutoff array panel (figure 4). The presence of the protected ventilation POE shall not degrade shielding effectiveness of the facility HEMP shield below the minimum requirements of figure 1.

5.1.5.3.1 Waveguide array dimensions. Each of the transverse cell dimensions of the waveguide-below-cutoff array shall not exceed 10 cm (4 in). The length of the waveguide shall be at least five times the transverse cell diagonal dimension.

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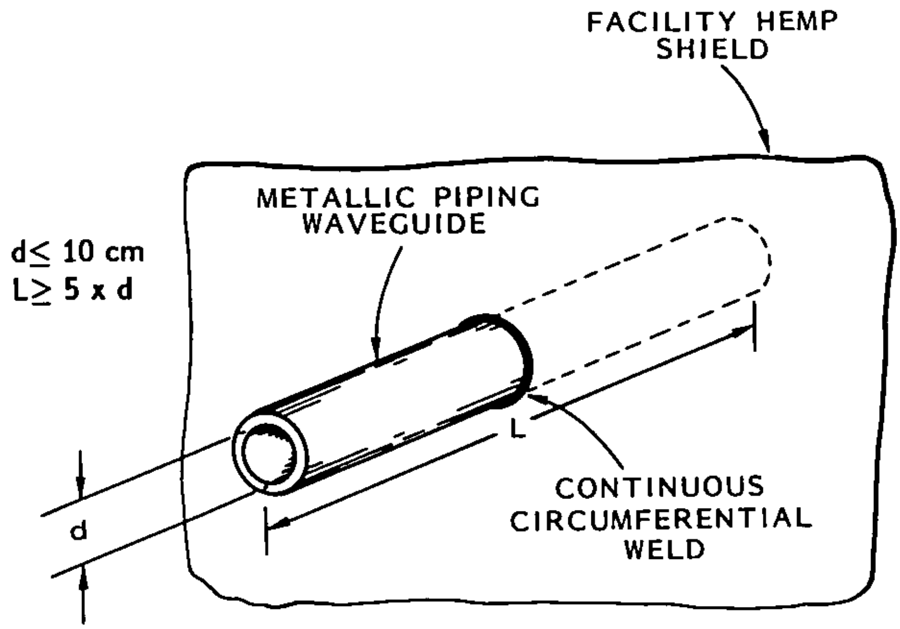
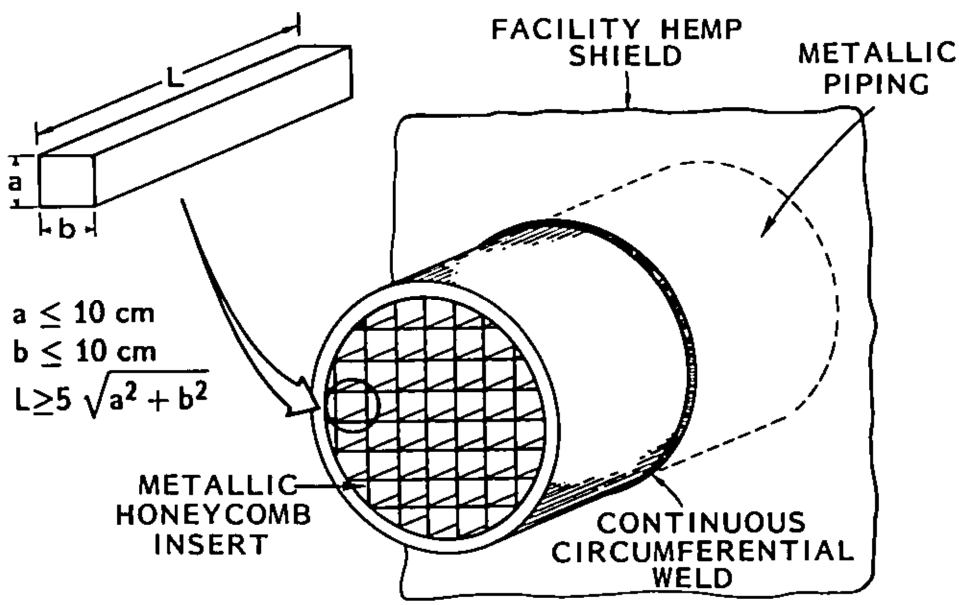


a. Single waveguide-below-cutoff.



b. Waveguide-below-cutoff array.

FIGURE 3. Typical waveguide-below-cutoff piping POE protective devices.

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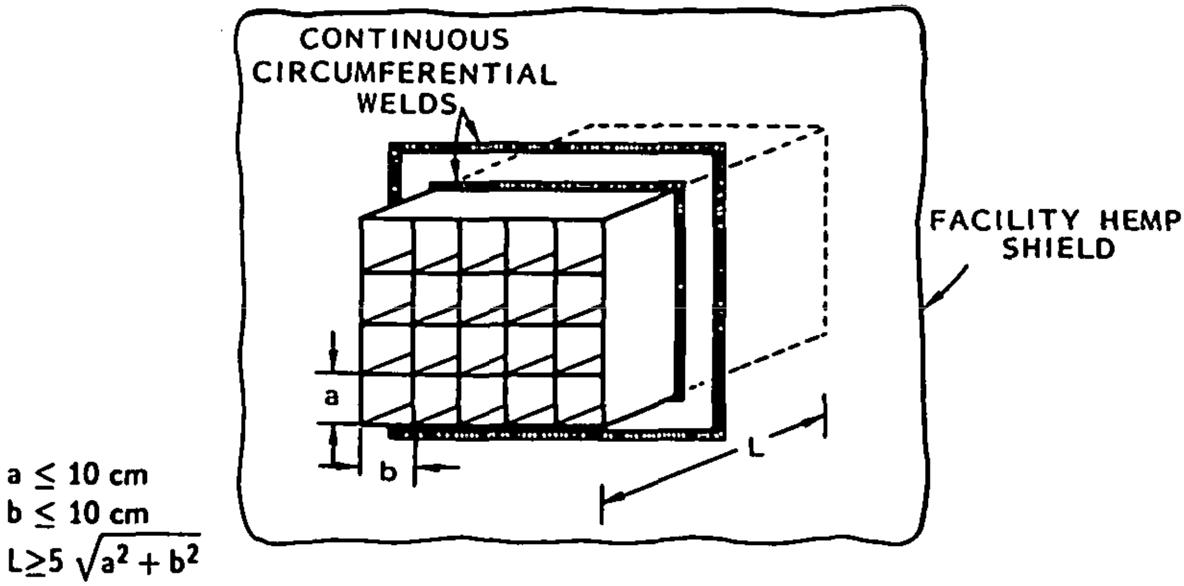

FIGURE 4. Typical waveguide-below-cutoff array ventilation POE protective device.

5.1.5.3.2 Waveguide array construction. The waveguide-below-cutoff array panel frame shall be circumferentially welded or brazed to the facility HEMP shield at the POE. Cell walls shall be metallic and there shall be continuous electrical bonds at all intersections and between the cell walls and the duct wall. No conductors shall be permitted to pass through the waveguide.

5.1.6 Structural points-of-entry.

5.1.6.1 HEMP protection for structural POEs. HEMP protection for structural POEs, including beams, columns, and other metallic structural elements which must penetrate the electromagnetic barrier, shall be provided with continuously welded or brazed seams and joints between the penetrating element and the facility shield. As a design objective, the facility should be configured to minimize the number of metallic structural elements required to penetrate the barrier. Nonmetallic structural elements shall not penetrate the electromagnetic barrier.

5.1.6.2 Quality assurance for structural POE protective treatments. All welded and brazed seams and joints required for structural POE treatments shall be monitored under the program of in-progress inspection of welded and brazed seams (see 5.1.3.4.1).

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5.1.6.3 Acceptance testing for structural POE protective treatments. Acceptance testing for structural POE protective treatments shall be conducted using shielding effectiveness test procedures of appendix A.

5.1.7 Electrical points-of-entry.

5.1.7.1 HEMP protection for electrical POEs. HEMP protection for electrical POEs, including all power, communications and control penetrating conductors whether shielded or unshielded, shall be provided with transient suppression/attenuation devices (except under conditions identified in 5.1.7.9).

5.1.7.1.1 Electrical POE protective device requirements. A transient suppression/attenuation device shall consist of an electrical surge arrester and additional linear and nonlinear elements as required. The varistor voltage at 1 mA direct current d.c. (for a metal oxide varistor) or the d.c. breakdown voltage (for a spark gap) shall be 150 to 250 percent of the peak operating voltage on the line. The protective device shall limit the residual internal transient stress to a maximum prescribed for each class of electrical POE, when prescribed pulses are injected at its external terminal (see table I). Additionally, the protective device shall be rated to withstand at least 2000 short pulses at the prescribed peak injection current without damage or performance degradation, as defined in test procedures of appendix B.

5.1.7.1.2 Electrical POE protective device installation. Electrical POE protective devices shall be installed in the configuration shown in figure 5. The external and internal conduits and compartment covers do not have shielding requirements as part of the electromagnetic barrier, but shielding may be necessary as a special protective measure (see 5.1.8) or to satisfy other electromagnetic requirements. The presence of the protected electrical POE shall not degrade shielding effectiveness of the facility HEMP shield below minimum requirements of figure 1.

5.1.7.2 Quality assurance for electrical POE protective devices. All welded and brazed seams and joints required for installation of electrical POE protective devices shall be monitored under the program of in-progress inspection of welded and brazed seams (see 5.1.3.4.1). Transient suppression/attenuation devices shall be subjected to electrical and mechanical quality assurance tests to demonstrate acceptable performance.

5.1.7.3 Acceptance testing for electrical POE protective devices. Acceptance testing for electrical POE protective devices shall be conducted using the pulsed current injection test procedures of appendix B.

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TABLE I. Residual internal stress limits and injected pulse characteristics for classes of electrical POEs.[1]

a. Double exponential waveform injections.

Class of Electrical POE	Residual Internal Stress Limits[1]			Pulsed Current Injection Requirements[1]			
	Type of Measurement	Peak Response Current (A)	Peak Rate of Rise (A/s)	Type of Injection	Peak Injected Current (A)	Risetime (s)	FWHM[1] (s)
Commercial Power Lines (Intersite)							
Short Pulse	Bulk current	10	1×10^{6}	Common mode	8000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Short Pulse	Wire current	10	1×10^{6}	Wire-to-ground	4000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Intermediate Pulse	No damage or performance degradation			Common mode	500	$\le1\times10^{-6}$	$\ge5\times10^{-3}$
Intermediate Pulse	No damage or performance degradation			Wire-to-ground	500	$\le1\times10^{-6}$	$\ge5\times10^{-3}$
Long Pulse	No damage or performance degradation			Common mode	200	≤0.5	≥100
Long Pulse	No damage or performance degradation			Wire-to-ground	200	≤0.5	≥100
Other Power Lines (Intrasite)							
Short Pulse	Bulk current	10	1×10^{6}	Common mode	8000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Short Pulse	Wire current	10	1×10^{6}	Wire-to-ground	4000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Audio/Data Lines (Intersite)							
Short Pulse	Bulk current	0.1	1×10^{6}	Common mode	8000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Short Pulse	Wire current	0.1	1×10^{6}	Wire-to-ground	[3] $8000/\sqrt{N}$ or 500	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Intermediate Pulse	No damage or performance degradation			Common mode	500	$\le1\times10^{-6}$	$\ge5\times10^{-3}$
Intermediate Pulse	No damage or performance degradation			Wire-to-ground	500	$\le1\times10^{-6}$	$\ge5\times10^{-3}$
Long Pulse	No damage or performance degradation			Common mode	200	≤0.5	≥100
Long Pulse	No damage or performance degradation			Wire-to-ground	200	≤0.5	≥100
Control/Signal Lines (Intrasite)							
Short Pulse	Bulk current	[4] 1.0 or 0.1	1×10^{6}	Common mode	8000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Short Pulse	Wire current	[4] 1.0 or 0.1	1×10^{6}	Wire-to-ground	[3] $8000/\sqrt{N}$ or 500	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
RF Antenna Lines--Signal Conductors							
[5] $f\le2$ MHz	Wire current	[6] 1.0 or 0.1	—	Wire-to-shield	8000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
RF Antenna Lines--Shields							
Buried[7]	Shield current	0.1	1×10^{6}	Shield-to-ground	1000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Nonburied	Shield current	0.1	1×10^{6}	Shield-to-ground	8000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Conduit Shields							
Buried[7]	Bulk current	[8] 10, 1.0, or 0.1	1×10^{6}	Conduit-to-ground	1000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}
Nonburied	Bulk current	[8] 10, 1.0, or 0.1	1×10^{6}	Conduit-to-ground	8000	[2] $\le1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}

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TABLE I. Residual internal stress limits and injected pulse characteristics for classes of electrical POEs (concluded).

b. Damped sinusoidal waveform injections.

Class of Electrical POE	Residual Internal Stress Limits[1]			Pulsed Current Injection Requirements[1]			
	Type of Measurement	Peak Response Current (A)	Peak Rate of Rise (A/s)	Type of Injection	Peak Injected Current (A)	Center Frequency (MHz)	Decay Factor (Dimensionless)
RF Antenna Lines–Signal Conductors							
[5] 2 MHz < $f \le$ 30 MHz	Wire current	[6] 1.0 or 0.1	—	Wire-to-shield	[2] 2500	[2] 2 ± 10%	[2] 10 ± 3
[5] 30 MHz < $f \le$ 200 MHz	Wire current	[6] 1.0 or 0.1	—	Wire-to-shield	[2] 900	[2] 30 ± 10%	[2] 10 ± 3
[5] 200 MHz < f	Wire current	[6] 1.0 or 0.1	—	Wire-to-shield	[2] 250	[2] 200 ± 10%	[2] 10 ± 3

[1] Additional limits on the residual internal stress, other pass/fail criteria, details of the injected pulse waveforms, and circuit test configuration information are contained in the PCI test procedures of appendix B. FWHM is pulse full width at half maximum amplitude.

[2] These parameters of the injected current pulse are design objectives. Minimum injection requirements are contained in appendix B.

[3] Whichever is larger. N is the number of penetrating conductors in the cable.

[4] 1 A is the limit for control/signal lines with a maximum operating voltage ≥90 V. 0.1 A is the limit for control/signal lines with maximum operating voltage <90 V.

[5] f = 600/L MHz, where L is the largest dimension of the associated antenna in meters.

[6] 1 A is the limit for transmit or transceive antenna signal conductors. 0.1 A is the limit for receive-only antenna signal conductors.

[7] An antenna shield is considered buried when it terminates at a buried antenna and less than 1 m (3.3 ft) of its total length is not covered by earth or concrete fill. A conduit is considered buried when it connects two protected volumes and less than 1 m (3.3 ft) of its total length is not covered by earth or concrete fill.

[8] 10 A is the limit for power lines with a maximum operating current ≥10 A. 1 A is the limit for power lines with maximum operating current between 1 A and 10 A. 0.1 A is the limit for control/signal lines and power lines with maximum operating current ≤1 A.

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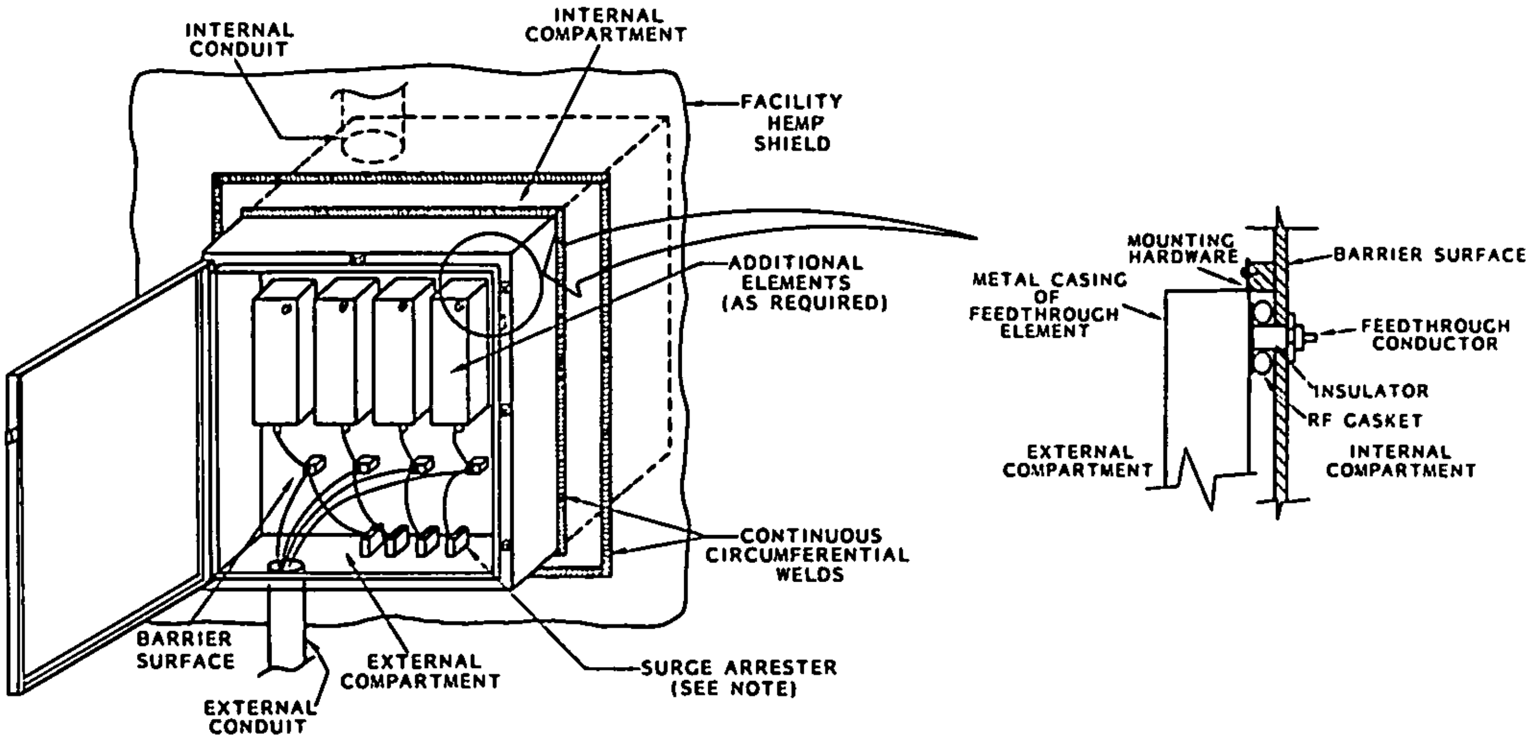

NOTE: USE SHORT ELECTRICAL LEADS; CASE OF THE SURGE ARRESTER TO BE GROUNDED TO THE EXTERNAL ENCLOSURE

FIGURE 5. Typical electrical POE protective device.

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5.1.7.4 Commercial electrical power feeder POEs. A transient suppression/attenuation device shall be provided on each penetrating conductor of a commercial electrical power feeder POE. The section of the commercial power feeder immediately outside the electromagnetic barrier shall be buried for a length of at least 15.2 m (50 ft). As a design objective, a maximum of two commercial electrical power feeders should penetrate the facility HEMP shield.

5.1.7.4.1 Commercial power POE protective device requirements. A 4000 A pulse with 10 ns risetime and 500 ns full width at half maximum amplitude (FWHM), occurring on a penetrating conductor at the POE protective device external terminal, shall produce a residual internal transient stress no greater than 10 A and shall not cause device damage or performance degradation.[4] A pulse of 500 A with 1 μs risetime and 5 ms FWHM and a pulse of 200 A with 0.5 s risetime and 100 s FWHM, at the POE protective device external terminal, shall not cause device damage or performance degradation.[4] If a POE protective device cannot be designed to satisfy the residual internal transient stress limits without interfering with operational signals which it is required to pass, a special protective volume shall be established (see 5.1.8.3.2). As a design objective, each commercial power feeder should be provided with a device to disconnect the incoming lines automatically if a HEMP event occurs or manually for alert conditions.

5.1.7.5 Other electrical power feeder POEs. A transient suppression/attenuation device shall be provided on each penetrating conductor of electrical power feeder POEs which supply internal power to equipment outside the electromagnetic barrier. As a design objective, internal power should be supplied only to MEE outside the electromagnetic barrier. Nonessential equipment outside the barrier should be powered from an external source.

5.1.7.5.1 Electrical power POE protective device requirements. A 4000 A pulse with 10 ns risetime and 500 ns FWHM, occurring on a penetrating conductor at the POE protective device external terminal, shall produce a residual internal transient stress no greater than 10 A and shall not cause device damage or performance degradation.[4] If a POE protective device cannot be designed to satisfy the residual internal transient stress limits without interfering with operational signals which it is required to pass, a special protective volume shall be established (see 5.1.8.3.2).

[4]Common mode pulse withstanding requirements, waveform details of the injected pulses, additional constraints on the residual internal transient stress, and circuit test configuration information are contained in PCI test procedures of appendix B.

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5.1.7.6 Audio and data line POEs.

5.1.7.6.1 Standard audio and data lines. All standard voice and data lines, whether shielded or unshielded, shall be converted to fiber optics outside the electromagnetic barrier and shall penetrate the facility HEMP shield on all-dielectric fiber optic cables. Electro-optic equipment outside the electromagnetic barrier shall be protected using special protective measures (see 5.1.8.1), if the associated audio or data line is mission essential. The fiber optic cable POE shall be protected with a waveguide-below-cutoff protective device.

5.1.7.6.1.1 Fiber optic waveguide dimensions. The inside diameter of a fiber optic waveguide-below-cutoff shall not exceed 10 cm (4 in). The length of the waveguide shall be at least five times the inside diameter of the waveguide-below-cutoff.

5.1.7.6.1.2 Fiber optic waveguide construction. All joints and couplings in the waveguide shall be circumferentially welded or brazed, and the waveguide-below-cutoff shall be circumferentially welded or brazed to the facility HEMP shield at the POE. No conductors or conducting fluids shall be permitted to pass through the waveguide; the waveguide shall be filled or its ends shall be capped to prevent inadvertent insertion of conductors.

5.1.7.6.2 Nonstandard audio and data lines. A transient suppression/attenuation device shall be provided on each penetrating conductor of shielded or unshielded nonstandard audio or data lines which cannot be practically converted to fiber optics. As a design objective, a maximum of 20 such nonstandard audio or data lines should penetrate the facility HEMP shield.

5.1.7.6.2.1 Nonstandard audio and data POE protective device requirements. An $8000/\sqrt{N}$ A or 500 A pulse with 10 ns risetime and 500 ns FWHM (where N is the number of penetrating conductors in the audio or data cable and the larger amplitude is chosen), occurring on a penetrating conductor at the POE protective device external terminal, shall produce a residual internal transient stress no greater than 0.1 A and shall not cause device damage or performance degradation.[4] A pulse of 500 A with 1 μs risetime and 5 ms FWHM and a pulse of 200 A with 0.5 s risetime and 100 s FWHM, at the POE protective device external terminal, shall not cause device damage or performance degradation.[4] If a POE protective device cannot be designed to satisfy the residual internal transient stress limits without interfering with operational signals it is required to pass, a special protective volume shall be established (see 5.1.8.3.2).

5.1.7.7 Electrical control and signal line POEs. A transient suppression/attenuation device shall be provided on each penetrating conductor of electrical control and signal lines, whether shielded or unshielded. As a design objective, the number of control and signal

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lines penetrating the facility HEMP shield should be minimized by use of alternate control techniques.

5.1.7.7.1 POE protective device requirements for control and signal lines operating at voltages less than 90 V. An $8000/\sqrt{N}$ A or 500 A pulse with 10 ns risetime and 500 ns FWHM (where N is the number of penetrating conductors in the control or signal cable and the larger amplitude is chosen), occurring on a penetrating conductor at the POE protective device external terminal, shall produce a residual internal transient stress no greater than 0.1 A and shall not cause device damage or performance degradation.[4] If a POE protective device cannot be designed to satisfy the residual internal transient stress limits without interfering with operational signals it is required to pass, a special protective volume shall be established (see 5.1.8.3.2).

5.1.7.7.2 POE protective device requirements for control and signal lines operating at 90 V and higher. An $8000/\sqrt{N}$ A or 500 A pulse with 10 ns risetime and 500 ns FWHM (where N is the number of penetrating conductors in the control or signal cable and the larger amplitude is chosen), occurring on a penetrating conductor at the POE protective device external terminal, shall produce a residual internal transient stress no greater than 1 A and shall not cause device damage or performance degradation.[4] If a POE protective device cannot be designed to satisfy the residual internal transient stress limits without interfering with operational signals it is required to pass, a special protective volume shall be established (see 5.1.8.3.2).

5.1.7.8 Radio frequency antenna line POEs. A transient suppression/attenuation device shall be provided on signal-carrying conductors of all penetrating radio frequency antenna lines. The antenna cable shields shall be circumferentially bonded to the facility HEMP shield at the POE.

5.1.7.8.1 Antenna line POE protective device requirements.

5.1.7.8.1.1 Signal conductor injection for receive-only antennas. A pulse of the prescribed waveform and amplitude, occurring on the signal-carrying conductor at the external terminal of a receive-only antenna line POE protective device, shall produce residual internal transient stresses no greater than 0.1 A on the signal-carrying conductor and shield and shall not cause device damage or performance degradation.[4] The pulse waveform and amplitude are determined by the lowest characteristic response frequency, f, which is $600/L$ MHz (where L is the largest dimension of the associated antenna in meters). The prescribed pulse is an 8000 A double exponential with 10 ns risetime and 500 ns FWHM, where the lowest characteristic response frequency is less than 2 MHz.[4] The prescribed pulse is a 2 MHz damped sinusoid with 2500 A peak current, where the lowest response

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frequency is 2 MHz to 30 MHz.[4] The prescribed pulse is a 30 MHz damped sinusoid with 900 A peak current, where the lowest response frequency is 30 MHz to 200 MHz, and a 200 MHz damped sinusoid with 250 A peak current, when the lowest response frequency is greater than 200 MHz.[4] If a POE protective device cannot be designed to satisfy the residual internal transient stress limits without interfering with operational signals it is required to pass, a special protective volume shall be established (see 5.1.8.3.2).

5.1.7.8.1.2 Signal conductor injection for transmit antennas. A pulse of the prescribed waveform and amplitude, occurring on the signal-carrying conductor at the external terminal of a transmit-only or transceive antenna line POE protective device, shall produce residual internal transient stresses no greater than 1 A on the signal-carrying conductor and 0.1 A on the shield and shall not cause device damage or performance degradation.[4] The pulse waveform and amplitude are determined by the lowest characteristic response frequency, f, which is $600/L$ MHz (where L is the largest dimension of the associated antenna in meters). The prescribed pulse is an 8000 A double exponential with 10 ns risetime and 500 ns FWHM, where the lowest characteristic response frequency is less than 2 MHz.[4] The prescribed pulse is a 2 MHz damped sinusoid with 2500 A peak current, where the lowest response frequency is 2 MHz to 30 MHz.[4] The prescribed pulse is a 30 MHz damped sinusoid with 900 A peak current, where the lowest response frequency is 30 MHz to 200 MHz, and a 200 MHz damped sinusoid with 250 A peak current, when the lowest response frequency is greater than 200 MHz.[4] If a POE protective device cannot be designed to satisfy the residual internal transient stress limits without interfering with operational signals it is required to pass, a special protective volume shall be established (see 5.1.8.3.2).

5.1.7.8.1.3 Shield injection. A 1000 A pulse with 10 ns risetime and 500 ns FWHM, occurring on the shield of a buried antenna cable at a point outside the electromagnetic barrier, shall produce residual internal transient stresses no greater than 0.1 A on the signal-carrying conductor and shield and shall not cause POE protective device damage or performance degradation.[4] For a nonburied antenna cable, an 8000 A pulse with 10 ns risetime and 500 ns FWHM on the shield at a point outside the barrier shall produce residual internal transient stresses no greater than 0.1 A on the signal-carrying conductor and shield and shall not cause POE protective device damage or performance degradation.[4] An antenna cable is considered buried when less than 1 m (3.3 ft) of its total length is not covered by earth or concrete fill and it terminates at a buried antenna. The cable is considered nonburied if at least 1 m (3.3 ft) of its total length is not covered.

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5.1.7.9 Conduit shielding.

5.1.7.9.1 Buried control and signal line conduits. A control and signal cable run between two protected volumes may be HEMP-protected using a buried metal conduit, when the length of the run is less than 25 m (82 ft). A cable containing one (or more) control or signal lines or one (or more) power lines with maximum operating current below 1.0 A is considered to be a control and signal cable. A conduit is considered buried when less than 1 m (3.3 ft) of its total length is not covered by earth or concrete fill. Transient suppression/attenuation devices are not required on the penetrating conductors under these conditions.

5.1.7.9.2 Nonburied control and signal line conduits. A control and signal cable run between two protected volumes may be HEMP-protected using a nonburied metal conduit when the length of the run is less than 3.1 m (10.2 ft). A conduit is considered nonburied when 1 m (3.3 ft) or more of its total length is not covered by earth or concrete fill. Transient suppression/attenuation devices are not required on the penetrating conductors under these conditions.

5.1.7.9.3 Power line conduits. A cable run between two protected volumes and containing only power lines with operating currents above 10 A may be HEMP-protected using a buried metal conduit, when the length of the run is less than 2500 m (8200 ft). A cable run between two protected volumes and containing only power lines with operating currents above 10 A may be HEMP-protected using a nonburied metal conduit, when the length of the run is less than 312 m (1025 ft). For a cable run of power lines with operating currents between 1.0 A and 10 A, the maximum conduit length is 250 m (820 ft) for a buried conduit and 31.2 m (102 ft) for a nonburied conduit. Transient suppression/attenuation devices are not required on the penetrating conductors under these conditions.

5.1.7.9.4 Conduit requirements. HEMP protection conduits shall be rigid metal conduit, circumferentially welded or brazed at all joints and couplings, and circumferentially welded or brazed to the facility HEMP shields at POEs on both ends. Pull boxes in the conduit run shall be welded or brazed metal enclosures and shall be electromagnetically closed with welded, brazed, or radio frequency gasketed and bolted covers. A 1000 A pulse on a buried control and signal line conduit and an 8000 A pulse on a nonburied control and signal line conduit, with 10 ns risetime and 500 ns FWHM, shall produce a residual internal transient stress no greater than 0.1 A on the wire bundle inside the conduit.[4] The same pulses occurring on the outer surface of a power line conduit shall produce a residual internal transient stress no greater than 10 A, when the operating current on the lowest rated conductor in the wire bundle inside the conduit is above 10 A, and no greater than 1.0 A when the operating current is between 1.0 A and 10 A.[4]

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5.1.8 Special protective measures. In special cases where HEMP hardness cannot be achieved with the electromagnetic barrier alone (see 4.3.4), special protective measures shall be implemented. Special protective measures shall not be used as a substitute for an electromagnetic barrier which satisfies the performance requirements of this standard.

5.1.8.1 Mission-essential equipment outside the electromagnetic barrier. Special protective measures shall be implemented to HEMP harden mission-essential equipment which is placed outside the electromagnetic barrier in accordance with provisions of this standard (see 5.1.1.1). Special protective measures for MEE outside the barrier may include:

a. Cable, conduit, and local volume shielding

b. Linear and nonlinear transient suppression/attenuation devices

c. Equipment-level hardening (reduced coupling cross-section, dielectric means of signal and power transport, use of inherently robust components)

d. Remoting sensitive circuits to locations within the protected volume

e. Automatic recycling features or operator intervention schemes, when the mission timeline permits

f. Other hardening measures appropriate for the particular equipment to be protected

Performance requirements for the special protective measures shall ensure that HEMP-induced peak time-domain current stresses at the equipment level are at least 20 dB less than the vulnerability thresholds of the equipment.[5]

5.1.8.2 Mission-essential equipment inside the electromagnetic barrier. Special protective measures shall be implemented to HEMP harden mission-essential equipment which is within the electromagnetic barrier, but experiences mission-aborting damage or upset during verification testing. Special protective measures for MEE inside the barrier may include cable, conduit, and volume shielding, transient suppression/attenuation devices, equipment-level hardening, automatic recycling, operator intervention features, and other hardening measures appropriate for the particular equipment to be protected. Performance requirements for the special protective measures shall ensure that HEMP-induced peak time-domain current stresses at the equipment level are at least 20 dB less than the vulnerability thresholds of the equipment.[5]

[5]See MIL-HDBK-423 for methods to determine vulnerability thresholds and guidance in applying the 20 dB margin.

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5.1.8.3 Special protective volumes.

5.1.8.3.1 Special protective volumes for piping POEs. When a piping POE waveguide-below-cutoff must be larger than 10 cm (4 in) to provide adequate fluid flow and a waveguide-below-cutoff array insert cannot be used, a special protective volume shall be established inside the electromagnetic barrier (figure 6).

5.1.8.3.1.1 Special waveguide requirements. A waveguide-below-cutoff which must be larger than 10 cm shall be of the minimum inside diameter consistent with its functional requirements. The length of the waveguide section shall be at least five times the inside diameter. All joints and couplings in the waveguide section shall be circumferentially welded or brazed and the waveguide shall be circumferentially welded or brazed to the facility HEMP shield at the POE. No dielectric lining shall be permitted in the waveguide section.

5.1.8.3.1.2 Special protective barrier for piping POEs. A special protective barrier shall completely enclose piping which is protected at its POE with a waveguide-below-cutoff larger than 10 cm in inside diameter. The special protective barrier may be a separate shield with protected penetrations or it may be implemented using the metal walls of the piping system itself. Performance requirements for the special protective barrier shall ensure that the total shielding effectiveness, measured through the primary electromagnetic barrier and special protective barrier, satisfies at least the minimum requirements shown in figure 1.

5.1.8.3.2 Special protective volumes for electrical POEs. When an electrical POE protective device cannot be designed to achieve the transient suppression/attenuation performance prescribed for the class of electrical POE (see 5.1.7) without interfering with operational signals it is required to pass, a special protective volume shall be established inside the electromagnetic barrier (figure 6).

5.1.8.3.2.1 Special electrical POE protective device requirements. An electrical POE protective device which cannot achieve the prescribed transient suppression/attenuation performance shall be designed to provide the maximum transient suppression/attenuation consistent with its functional requirements. When the pulse prescribed for the class of electrical POE occurs at the external terminal, the POE protective device shall perform in accordance with its design and the device shall not be damaged or degraded.

5.1.8.3.2.2 Special protective barrier for electrical POEs. A special protective barrier shall completely enclose wiring and equipment directly connected to an electrical POE protective device which cannot achieve the transient suppression/attenuation performance

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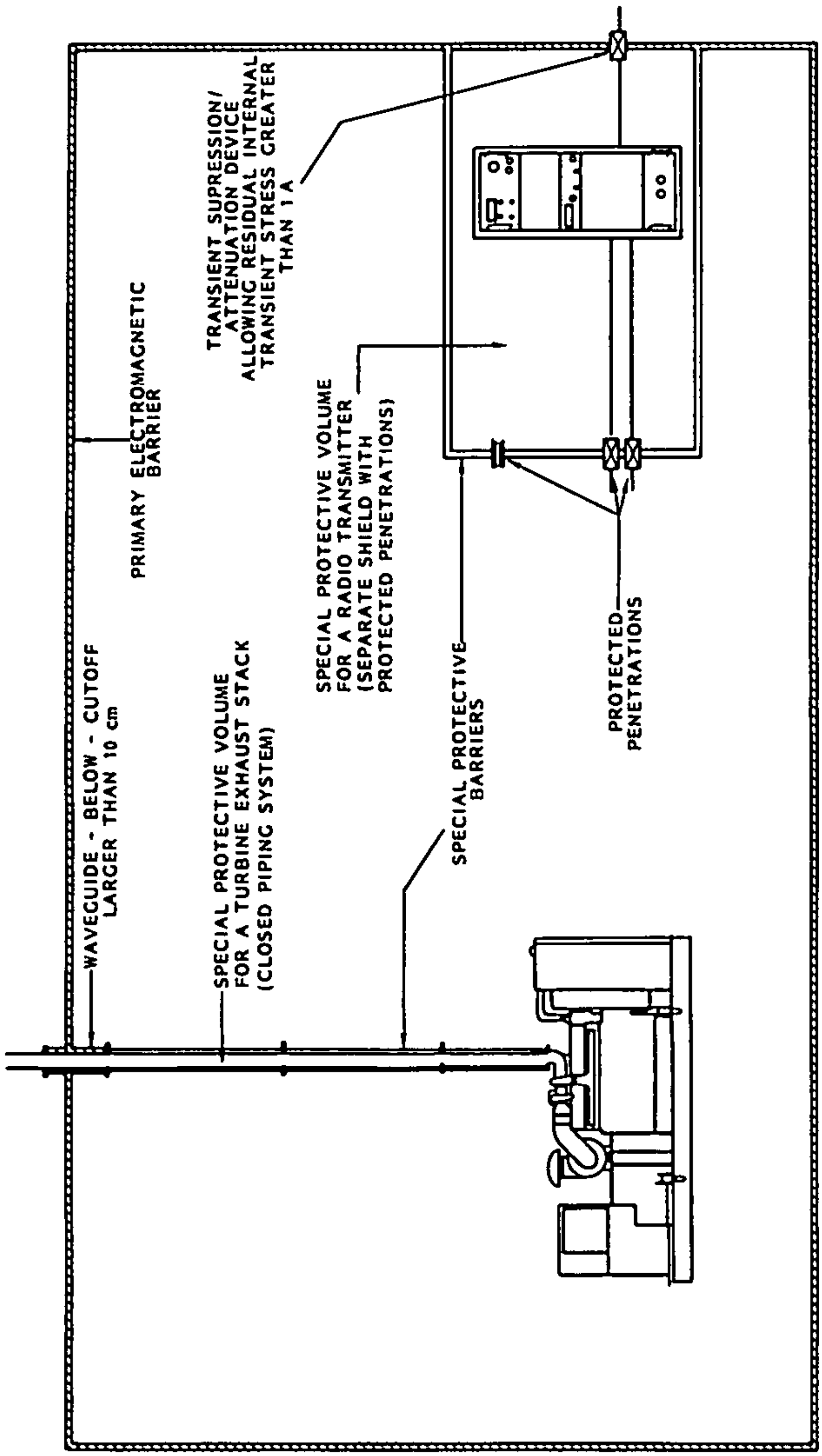

FIGURE 6. Typical special protective volumes.

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required by 5.1.7. The special protective barrier may be a separate shield with protected penetrations or it may be implemented using cable and conduit shields and equipment cabinets. Performance requirements for the special protective barrier shall ensure the following:

a. That the total shielding effectiveness, measured through the primary electromagnetic barrier and special protective barrier, satisfies at least the minimum requirements of figure 1.

b. That the total transient suppression/attenuation, measured through the primary electromagnetic barrier and special protective barrier, satisfies at least the minimum requirements of 5.1.7.

5.1.8.3.2.3 Mission-essential equipment in a special protective volume. Special protective measures shall be implemented as necessary to harden mission-essential equipment in a special protective volume to the HEMP-induced signals which will occur in that volume. Special protective measures for MEE in a special protective volume may include cable, conduit, and volume shielding, transient suppression/attenuation devices, equipment-level hardening, remoting sensitive circuits, automatic recycling, operator intervention features, and other hardening measures appropriate for the particular equipment to be protected. Performance requirements for the special protective measures shall ensure that HEMP-induced peak time-domain current stresses at the equipment level are at least 20 dB less than the vulnerability thresholds for the equipment.[5]

5.1.8.4 Quality assurance for special protective measures. Quality assurance tests shall be conducted to ensure that special protective measures comply with performance requirements for the particular installation.

5.1.8.5 Acceptance testing for special protective measures.

5.1.8.5.1 Special protective measures for mission-essential equipment. Acceptance testing is not required for equipment-level special protective measures installed on MEE in accordance with 5.1.8.1, 5.1.8.2, and 5.1.8.3.2.3. HEMP hardness provided by these special protective measures shall be demonstrated during the verification test program.

5.1.8.5.2 Special protective barriers. Acceptance testing for all special protective barriers shall be conducted using shielding effectiveness test procedures of appendix A. Additionally, acceptance testing for all special protective barriers required because of an electrical POE protective device shall include pulsed current injection in accordance with test procedures of appendix B.

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5.1.9 Reliability and maintainability. The HEMP protection subsystem shall be designed and constructed to be rugged, reliable, and maintainable. Reliability and maintainability program tasks and requirements shall be included in the facility acquisition specifications to assure that reliability is considered in component selections, to reduce the frequency, complexity, and costs of design-dictated maintenance, and to provide adequate provisioning with spare hardness critical items and maintenance tools and supplies.

5.1.10 Safety and human engineering. Safety and human engineering criteria, principles, and practices shall be applied in the design, selection, and placement of HEMP protection subsystem elements. Entryways shall be designed to accommodate expected traffic and shield doors shall operate simply with operating forces within limits imposed by MIL-STD-1472. Inspection covers shall be designed for safety and ease of removal and proper reinstallation. Electrical POE protective devices shall provide fail-safe features, such as capacitor discharge resistors, for protection of personnel during installation, operation, maintenance, and repair.

5.1.11 Testability. The HEMP protection subsystem shall be designed and constructed to accommodate quality assurance, acceptance, and verification testing and hardness maintenance and hardness surveillance. The facility shield shall be accessible for visual inspection at all POEs. Access for periodic shielding effectiveness measurements shall be provided except on the floor shield of a bottom floor and on buried facilities. The built-in shield monitoring capability shall consist of a permanently installed large loop or a permanently installed shield injection point system, as described in MIL-HDBK-423, or other exciter and sensor elements which will detect significant changes in the electromagnetic barrier performance. Electrical POE protective devices shall be installed with accessible pulsed current injection drive points and measurement points.

5.1.12 Corrosion control. Corrosion protection measures shall be implemented in the design and construction of the HEMP protection subsystem. The facility shield and POE protective devices shall be constructed with inherently corrosion-resistant materials or metals shall be coated or metallurgically processed to resist corrosion. Pockets where water or condensation can collect shall be avoided and a crawl space shall be provided above the ceiling shield to allow inspection for roof leakage. Buried conduits or cables shall be coated with asphalt compound, plastic sheaths, or equivalent corrosion protection, and a means for detecting leakage shall be provided. Joints between dissimilar metals shall be avoided and, where required, shall be provided with corrosion preventive measures. Cathodic protection shall be provided, where required by environmental conditions.

5.1.13 Configuration management. A hardness configuration management program shall be implemented during design and construction of the HEMP protection subsystem.

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Hardness critical items and hardness critical processes shall be identified in the facility drawings in accordance with DoD-STD-100, and installed hardness critical items shall be distinctively marked. Facility design and installation changes shall be assessed for potential HEMP hardness impacts prior to approval. The affected portions of the HEMP protection subsystem shall be retested when configuration changes occur after acceptance testing.

5.1.14 Verification testing. After the HEMP protection system has been accepted and facility equipment is installed and operational, a verification test program shall be conducted. As a minimum, verification testing shall include continuous wave (CW) immersion testing of the electromagnetic barrier, PCI tests at electrical POEs, and additional site-specific tests as needed to demonstrate effectiveness of special protective measures. All deficiencies identified by the verification test program shall be corrected, retested, and shown to provide the required hardness.

5.1.14.1 CW immersion testing. CW immersion testing shall be performed in accordance with procedures of appendix C. At frequencies where the measurement dynamic range exceeds the attenuation required by figure 1, ratios of illuminating field strength to the internal field measurements shall be equal to or greater than the minimum shielding effectiveness requirement. Internal field measurements shall be below the instrumentation noise or operating signal level in frequency bands where measurement dynamic range is less than attenuation requirements of figure 1. Internal current measurements, when extrapolated to threat using equations defined in appendix C, shall be less than 0.1 A. No interference with mission-essential communications-electronics or support equipment shall occur.

When approved by the sponsoring agency for the verification test, a thorough program of shielding effectiveness measurements using procedures of appendix A and a thorough SELDS survey in accordance with MIL-HDBK-423 guidance may be performed in lieu of the CW immersion test.

5.1.14.2 Pulsed current injection verification testing. PCI verification testing shall be performed in accordance with procedures of appendix B. Residual internal transient stress measurements shall not exceed maximum limits for the applicable class of electrical POE. POE protective devices shall not be damaged or degraded by the PCI excitations. No time-urgent, mission-aborting damage or upsets of MEE shall occur.[6]

5.1.14.3 Verification for special protective measures. Site-specific procedures for verification of special protective measures shall be developed based upon test approaches of

[6]The determination whether an observed interruption or upset is mission-aborting is the responsibility of the operational authority for the facility.

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5.1.14.3.1 and 5.1.14.3.2. The verification testing shall demonstrate that HEMP-induced electromagnetic stresses resulting from facility exposure to the threat environment of DOD-STD-2169 will not cause time-urgent, mission-aborting damage or upsets.[6]

5.1.14.3.1 Verification of special protective measures for mission-essential equipment. Verification testing for MEE hardened with special protective measures shall generally include coupling measurements and pulsed current injection procedures. The coupling test shall be threat-level illumination, threat-level skin current injection, or threat-relatable testing such as CW immersion (see appendix C). MEE cable currents shall be measured and shall be extrapolated to threat when required.

Long conductors, which connect to the MEE and are directly exposed to the HEMP environment, shall be PCI tested with injected pulses of the amplitudes and waveforms prescribed in appendix B.

Cables, which connect or are internal to the MEE and are not directly exposed, shall also be PCI tested. The injected pulse characteristics shall comply with one of the following requirements:

a. Amplitudes equal to 10 times the (measured or extrapolated) threat responses and waveforms similar to the measured data

b. Amplitudes and waveforms prescribed in appendix B for the applicable class of electrical circuit

These verification test excitations shall not cause time-urgent, mission-aborting damage or upset of MEE.[6]

5.1.14.3.2 Verification of special protective barriers. Verification of special protective barriers shall include PCI testing of all electrical POEs which penetrate into the special protective volume from outside the protective volume. Amplitudes and waveforms of the injected pulses shall be as prescribed in appendix B. In addition to functional observations and measurements required by 5.1.14.3.1, residual internal stresses shall be measured on conductors which penetrate from the special protective volume into the protected volume. Responses measured at test points within the protected volume shall not exceed maximum allowable limits, and the test excitations shall not cause time-urgent, mission-aborting damage or upset of MEE.[6]

5.2 Transportable facilities. HEMP protection requirements for transportable ground-based facilities performing critical, time-urgent missions will be provided in a future amendment to MIL-STD-188-125.

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6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. The standard contains minimum requirements and design objectives for HEMP protection of ground-based facilities which perform critical, time-urgent C^4I missions. The purpose is to standardize design, construction, and test of HEMP protection subsystems for these facilities and to thereby assure the quality and durability of the protection.

6.2 Subject term (key word) listing.

Continuous wave (CW) immersion
Electrical surge arrester
Electromagnetic barrier
Facility HEMP shield
Hardening
Hardness verification
Low risk HEMP protection
Mission-essential equipment
Nuclear survivability
Point-of-entry
Protection device, point-of-entry
Pulsed current injection
Shielding effectiveness
Special protective measures
Survivability/vulnerability
Transient suppression/attenuation device
Waveguide-below-cutoff

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APPENDIX A

SHIELDING EFFECTIVENESS TEST PROCEDURES[7]

10. GENERAL

10.1 Scope. This appendix establishes procedures for measuring shielding effectiveness of the electromagnetic barrier required for low-risk high-altitude electromagnetic pulse (HEMP) protection of critical ground-based facilities with time-urgent missions. The procedures are applicable for testing other HEMP-hardened facilities, when specified by the procurement documentation.

10.2 Applications. These procedures shall be used for shielding effectiveness acceptance testing of the facility HEMP shield and aperture point-of-entry (POE) protective treatments, as required by DETAILED REQUIREMENTS of MIL-STD-188-125. The procedures shall also be performed for acceptance of repairs or installations of new POE protective devices after construction acceptance, except that only areas affected by the repair or installation shall be tested. Shielding effectiveness measurements may also be conducted as part of the verification test program.

20. REFERENCED DOCUMENTS

20.1 Government documents. The following documents form a part of this appendix to the extent specified:

MIL-STD-285 – Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Method of.

NSA 65-6 – National Security Agency Specification for RF Shielded Enclosures for Communications Equipment: General Specification.

DNA-EMP-1 – Electromagnetic Pulse (EMP) Security Classification Guide (U) (document is classified S–RD).

[7] HEMP-unique test procedures are temporarily included as appendices to MIL-STD-188-125; it is intended that these procedures will ultimately be promulgated as separate standards outside of the MIL-STD-188- series.

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30. DEFINITIONS

30.1 Shielding effectiveness. Shielding effectiveness at a test area for the purposes of this procedure is the ratio, expressed in decibels (dB), of the received signal when the receiving antenna is illuminated by electromagnetic radiation in the test calibration configuration (no shield present) to the received signal through the electromagnetic barrier in the test measurement configuration. Assuming that antenna voltage is detected

$$SE = 20 \log \left(\frac{V_c}{V_m} \right)$$

where V_m is the measured signal at the test area and V_c is the calibration signal at the same frequency and transmitting antenna polarization. Shielding effectiveness values are test method-dependent and different values may be obtained when time-domain or other frequency-domain measurement techniques are used.

40. GENERAL REQUIREMENTS

40.1 General. This HEMP shielding effectiveness test method is a modified MIL-STD-285 or NSA 65-6 procedure. A transmitting antenna is placed on one side of the electromagnetic barrier in the center of each test area. The receiving antenna is centered on the test area at the opposite side of the barrier to obtain a stationary measurement. Additionally, the receiving antenna is swept over the entire test area and rotated in orientation until the maximum received signal strength is detected. Selection of test areas, test frequencies, and polarizations of the transmitting antennas are defined in the appendix.

40.2 Purpose. These procedures define shielding effectiveness, as used in MIL-STD-188-125. The purpose of the measurements is to obtain shielding effectiveness data for demonstrating compliance with facility shield and aperture POE treatment performance requirements established by MIL-STD-188-125.

40.3 HEMP protection subsystem test configuration. The shielding effectiveness acceptance test should be conducted near the conclusion of the construction contract, when the following prerequisite conditions are met. The facility shield assembly shall be fully complete. All POEs and their POE protective devices, required as part of the construction work, shall be installed and in a normal operating condition. Internal and external wiring to conductive POE protective devices, if provided under the construction contract, shall be in place and connected. Penetrating fiber optic cables, if provided under the construction contract, shall be installed. All interior equipment and finish work under the construction contract shall be completed. Installed equipment may be either operating or nonoperating.

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A visual shield inspection shall be performed before starting the measurements to assure that these configuration requirements have been met.

When these shielding effectiveness measurements are conducted as part of the verification test program, the facility shall be in a normal operating configuration and shall be performing actual or simulated mission functions. The HEMP protection subsystem shall be intact.

40.4 Analysis requirements. There are no pretest or post-test analyses required for these procedures.

40.5 Test equipment requirements. Test equipment required for shielding effectiveness measurements is identified in table II.

40.6 Operational impact analysis and risk. Since the electromagnetic barrier must remain intact during conduct of the shielding effectiveness measurement sequence and use of electrically noisy equipment must be restricted, construction activity or unusual operations (facility modification, maintenance) may be affected. Radiated signal levels are low and present no hazard to equipment, but frequency adjustments may be required to avoid self-interference or interference with nearby facilities. Normal electrical safety precautions apply.

40.7 Test plan and procedures. A shielding effectiveness test plan and detailed test procedures shall be prepared. These may be combined in a single document or two separate documents may be used. As a minimum, the documentation shall contain the following information:

a. A statement of test objectives

b. Facility identification and description

c. Plane wave test area identification—The entire surface (including the floor when both sides of the shield are accessible) of the electromagnetic barrier shall be divided into numbered plane areas not greater than 2.5 m × 2.5 m (8.2 ft × 8.2 ft), as illustrated by the example in figure 7. A plane wave transmitting antenna location exists at the center of each area. A list of POEs, by test area, shall be included.

d. Low frequency magnetic field test area identification—Each 2.5 m × 2.5 m plane wave test area which contains a POE shall also be designated as a magnetic field test area. Additional magnetic field test areas shall be chosen to survey the entire surface of the electromagnetic barrier in sections not greater than 7.5 m × 7.5 m (24.6 ft ×

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TABLE II. Shielding effectiveness test equipment requirements.

Equipment	Characteristics
Oscillator(s)	15–30 kHz, 300–500 kHz, 1–20 MHz, 100–400 MHz, 900–1000 MHz
Power Amplifier(s)	15–30 kHz, 300–500 kHz, 1–20 MHz, 100–400 MHz, 900–1000 MHz, power output as required for dynamic range
Preamplifier(s)	15–30 kHz, 300–500 kHz, 1–20 MHz, 100–400 MHz, 900–1000 MHz, amplification and noise figure as required for dynamic range
Receiver(s)/ Spectrum Analyzer(s)	15–30 kHz, 300–500 kHz, 1–20 MHz, 100–400 MHz, 900–1000 MHz
Antenna Kit[1]	15–30 kHz, 300–500 kHz, 1–20 MHz, 100–400 MHz, 900–1000 MHz
Miscellaneous Cables and Attenuators	As required

[1]Any antennas which radiate at the prescribed frequencies, with adequate field strength for compliance with dynamic range requirements, may be used. The procedures are written assuming use of dipole or aperture antennas for plane wave measurements and loop antennas for magnetic field measurements.

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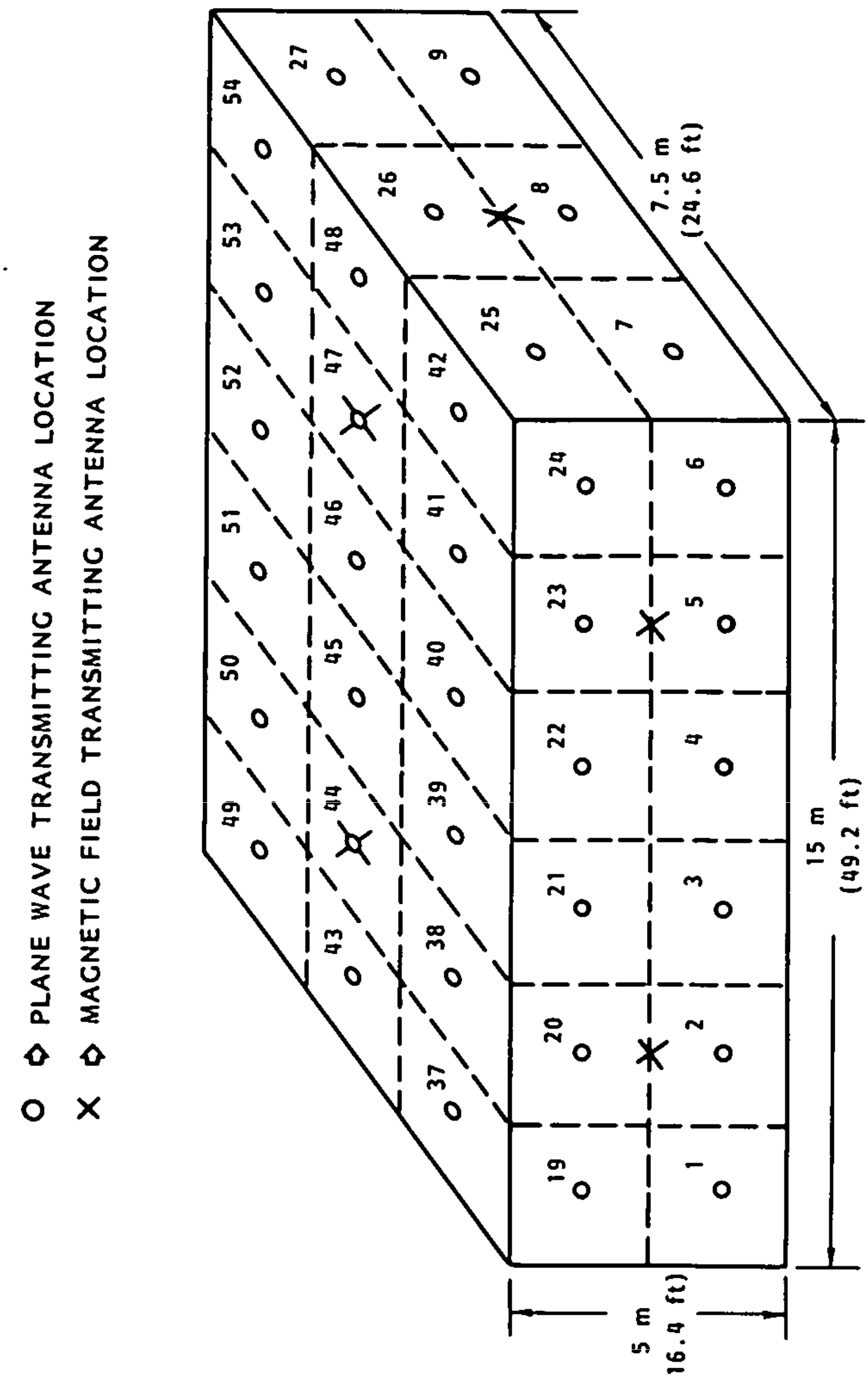

FIGURE 7. Sample test area assignments.

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24.6 ft). A magnetic field transmitting antenna location exists at the center of each test area.

e. Electric field transmitting antenna and test point locations, when required by the procurement documentation

f. Identification of test frequencies

g. Test equipment identification by manufacturer, model, and serial number

h. Any deviations from requirements of this appendix

i. Procedures for marking, repair, and retest of defects

j. Data management—including calibration and measurement data quality control procedures, data acceptability criteria, preservation of data records, and pass/fail criteria

k. Safety

l. Security (see A.40.9)

m. Test schedule—including priority of measurements

Data item description DI-R-1759A, "Nuclear Weapons Effects Test Plan," should be used.

40.8 Test report requirements. A shielding effectiveness test report shall be prepared. As a minimum, the report shall contain the following information:

a. Facility identification and test plan reference

b. A discussion of any deviations from the test plan and requirements of this appendix

c. Test calibration and measurement data—figure 8 illustrates a typical data sheet.

d. Pass/fail conclusions

Data item description DI-R-1760A, "Nuclear Weapons Effects Test Report," should be used.

40.9 Data classification. Test data may be classified. DNA-EMP-1 and the classification guide for the specific facility or system should be consulted for guidance.

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SHIELDING EFFECTIVENESS
DATA SHEET

Facility: ______________________

Test Date: ______________________

Inspector: ______________________

Test Area Number	Type of Test (Plane Wave or Magnetic)	Frequency	Polarization	Type of Measurement (Stationary or Swept)	Calibration Signal (V_c) (V or dBV)	Measured Signal (V_m) (V or dBV)	Shielding Effectiveness 20 log(V_c/V_m) or $dBV_c - dBV_m$	Shielding Effectiveness Requirement (dB)	Pass/Fail

Comments: ____

____

____

____

____

____
Signature

____
Title and Organization

FIGURE 8. Sample shielding effectiveness data sheet.

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50. DETAILED REQUIREMENTS

50.1 Plane wave shielding effectiveness measurements.

50.1.1 Plane wave data requirements. For each plane wave test area (see A.40.7.c), eight shielding effectiveness measurements shall be made. Stationary and swept measurements shall be made at two frequencies for each of two transmitting antenna polarizations, as follows:

a. Frequencies—One frequency in the range of 100–400 MHz and one frequency in the range of 900–1000 MHz

b. *Antenna polarizations*—Dipole (or antenna aperture) parallel to the test area surface in two orientations at 90 degrees to each other and parallel to the principal weld seams in the shield

50.1.2 Plane wave calibration procedure. Plane wave calibration for each frequency and transmitting antenna polarization shall be performed in accordance with figure 9. The transmitting and receiving dipole antennas shall be parallel to each other (or aperture antenna planes parallel to each other). The distance between antennas shall be as large as possible, within dynamic range constraints, but shall be at least 2.5 m (8.2 ft). The receiving antenna position shall be varied by ±30 cm (1 ft) from its nominal location to ensure that it is not located at a minimum of the radiation pattern. Test equipment shall be chosen to provide a dynamic range at least 20 dB in excess of the shielding effectiveness requirement at the test frequency.

During calibration, no equipment or other electromagnetic reflectors (except ground) shall be closer than three times the antenna separation. The antennas shall be at least 2 m (6.6 ft) above ground.

The received signal strength for each frequency and transmitting antenna polarization shall be recorded as the calibration signal (V_c) for that configuration.

50.1.3 Plane wave measurement procedure. Plane wave shielding effectiveness measurements for each test area and at each required frequency and transmitting antenna polarization shall be performed as shown in figure 9. Identical equipment, antennas, cables, and equipment settings (except attenuator settings) shall be used in the calibration and measurement sequences.

The transmitting antenna shall normally be placed outside the electromagnetic barrier and it shall be centered on the test area. The transmitting dipole axis (or aperture antenna

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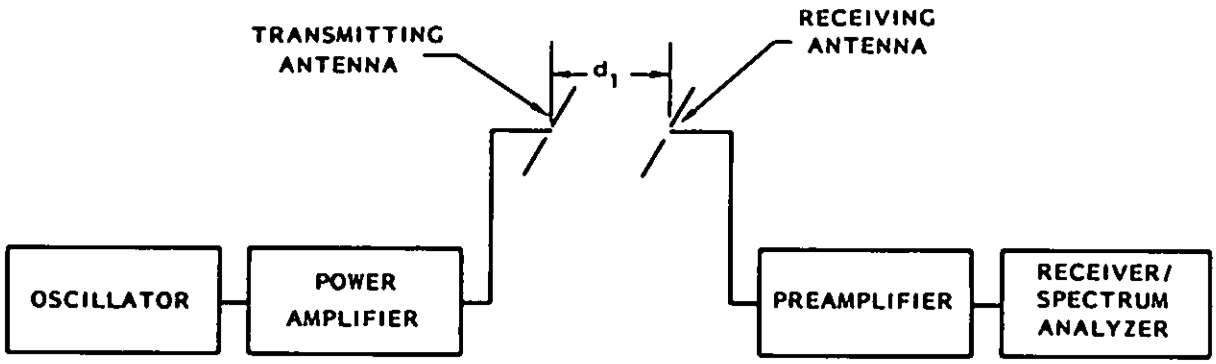
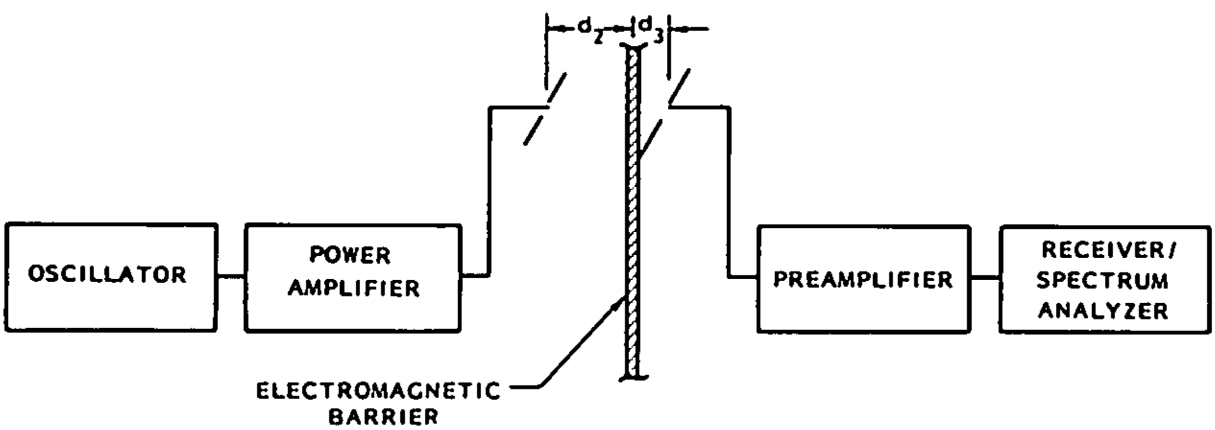


a. Calibration.



b. Measurement.

d_1 – AS LARGE AS POSSIBLE. WITHIN DYNAMIC RANGE CONSTRAINTS. AND AT LEAST 2.5 m (8.2 ft)

d_2 = d_1 – 30 cm (1 ft)

d_3 = 30 cm (1 ft) (STATIONARY MEASUREMENT)

= 5 cm (2 in) to 60 cm (2 ft) (SWEPT MEASUREMENT)

FIGURE 9. Plane wave test configurations.

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plane) shall be parallel to the test area surface and parallel to one of the two principal weld seam directions. The distance from the transmitting antenna to the test area surface shall be 30 cm (1 ft) less than the separation at which calibration was performed.

The receiving antenna shall normally be inside the barrier. To obtain the stationary measurement, the receiving antenna shall be centered on the test area and the dipole axis (or aperture antenna plane) shall be parallel to the transmitting antenna axis (or plane). Distance from the receiving antenna to the test area surface shall be 30 cm (1 ft). The received signal strength shall be recorded as the stationary measured signal (V_m) for that test area, frequency, and transmitting antenna polarization.

To perform the swept measurement, the receiving antenna shall be swept over the entire test area at distances from approximately 5 cm (2 in) to 60 cm (2 ft) from the test area surface and shall be rotated in orientation until a maximum received signal is obtained. The maximum received signal strength shall be recorded as the swept measured signal (V_m) for that test area, frequency, and transmitting antenna polarization.[8]

50.1.4 Plane wave pass/fail criteria. The pass/fail criteria for plane wave shielding effectiveness are shown as a function of frequency by figure 10.

50.2 Low frequency magnetic field shielding effectiveness measurements.

50.2.1 Magnetic field data requirements. For each 2.5 m × 2.5 m magnetic field test area (see A.40.7.d), twelve shielding effectiveness measurements shall be made. Stationary and swept measurements shall be made at three frequencies for each of two transmitting antenna polarizations, as follows:

a. Frequencies—One frequency in the range of 15–30 kHz, one frequency in the range of 300–500 kHz, and one frequency in the range of 1–20 MHz

b. Antenna polarizations–Plane of the loop antenna normal to the test area surface in two orientations at 90 degrees to each other and parallel to the principal weld seams in the shield

[8] When the test area contains an aperture or conductive POE which requires a special protective volume inside the electromagnetic barrier, the receiving antenna shall also be swept over the entire outer surface of the special protective barrier, at distances from approximately 5 cm to 60 cm from the barrier surface, and rotated in orientation. Pass/fail criteria for these readings are the same as the pass/fail criteria for other shielding effectiveness measurements.

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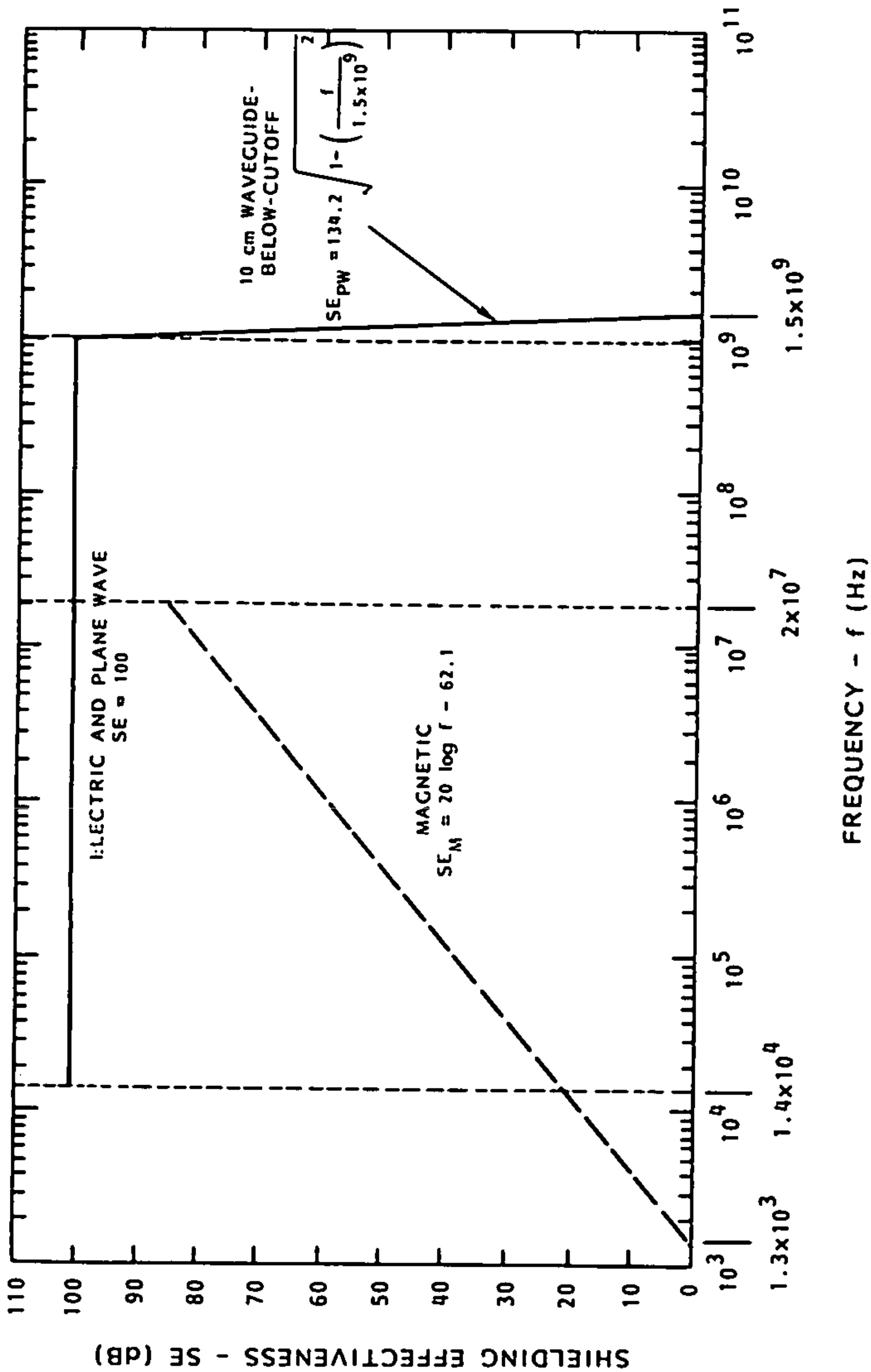

FIGURE 10. Minimum HEMP shielding effectiveness requirements (per MIL-STD-188-125).

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For each 7.5 m × 7.5 m magnetic field test area, six shielding effectiveness measurements shall be made. Stationary measurements shall be made at three frequencies for each of two transmitting antenna polarizations, as described above.

50.2.2 Magnetic field calibration procedure. Magnetic field calibration for each frequency and transmitting antenna polarization shall be performed in accordance with figure 11. The loops of the transmitting and receiving antennas shall be in the same plane. The distance between antennas shall be as large as possible, within dynamic range constraints, but shall be at least two loop diameters and at least 1.25 m (4.1 ft). The receiving antenna position shall be varied by ±30 cm (1 ft) from its nominal location to ensure that it is not located at a minimum of the radiation pattern. Test equipment shall be chosen to provide a dynamic range at least 20 dB in excess of the shielding effectiveness requirement at the test frequency.

During calibration, no equipment or other electromagnetic reflectors (except ground) shall be closer than three times the antenna separation. The antennas shall be at least 2 m (6.6 ft) above ground.

The received signal strength for each frequency and transmitting antenna polarization shall be recorded as the calibration signal (V_c) for that configuration.

50.2.3 Magnetic field measurement procedure. Magnetic field shielding effectiveness measurements for each test area and at each required frequency and transmitting antenna polarization shall be performed as shown in figure 11. Identical equipment, antennas, cables, and equipment settings (except attenuator settings) shall be used in the calibration and measurement sequences.

The transmitting antenna shall normally be placed outside the electromagnetic barrier, and it shall be centered on the test area. The plane of the transmitting loop antenna shall be normal to the test area surface and parallel to one of the two principal weld seam directions. The distance from the transmitting antenna to the test area surface shall be 30 cm (1 ft) less than the separation at which calibration was performed.

The receiving antenna shall normally be inside the barrier. To obtain the stationary measurement, the receiving antenna shall be centered on the test area and its loop shall be in the same plane as that of the transmitting antenna. Distance from the receiving antenna to the test area surface shall be 30 cm (1 ft). The received signal strength shall be recorded as the stationary measured signal (V_m) for that test area, frequency, and transmitting antenna polarization.

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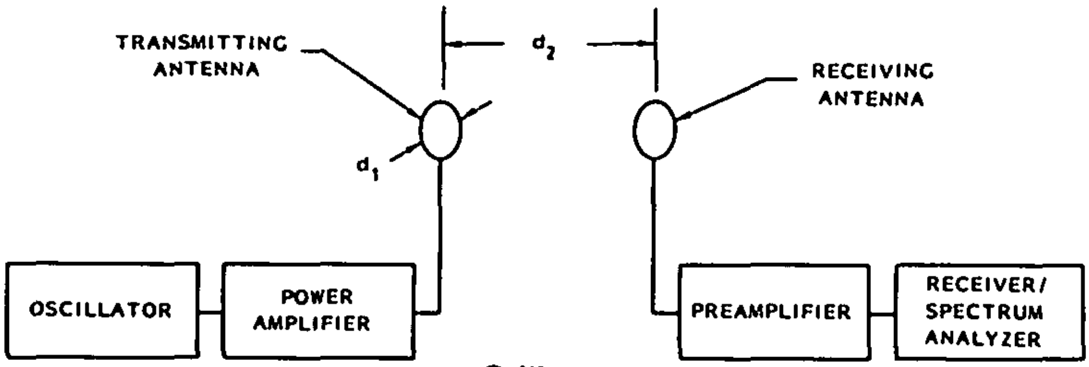
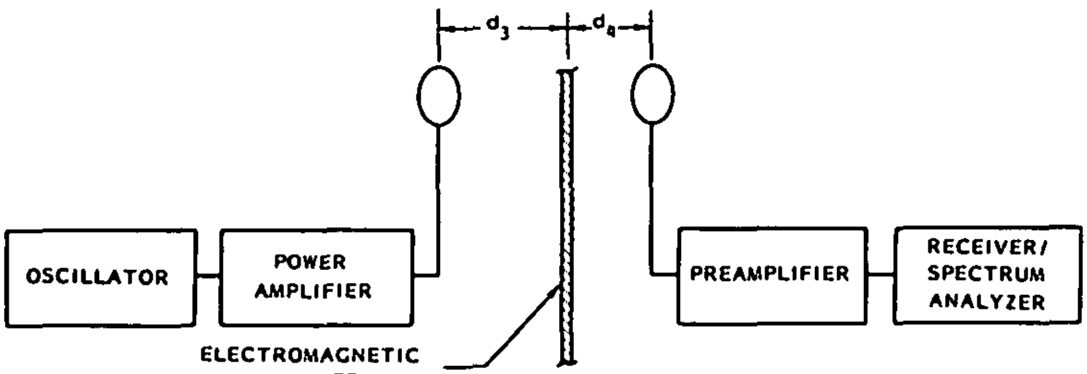


a. Calibration.



b. Measurement.

d_1 - LOOP DIAMETER

d_2 - AS LARGE AS POSSIBLE, WITHIN DYNAMIC RANGE CONSTRAINTS, AND AT LEAST 2 x d1 OR 1.25 m (4.1 ft), WHICHEVER IS LARGER

d_3 = d_2 – 30 cm (1 ft)

d_4 = 30 cm (1 ft) (STATIONARY MEASUREMENT)

= 5 cm (2 in) to 60 cm (2 ft) (SWEPT MEASUREMENT)

FIGURE 11. Magnetic field test configurations.

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To perform the swept measurement, when required, the receiving antenna shall be swept over the entire test area at distances from approximately 5 cm (2 in) to 60 cm (2 ft) from the test area surface and shall be rotated in orientation until a maximum received signal is obtained. The maximum received signal strength shall be recorded as the swept measured signal (V_m) for that test area, frequency, and transmitting antenna polarization.[8]

50.2.4 Magnetic field pass/fail criteria. The pass/fail criteria for magnetic field shielding effectiveness are shown as a function of frequency by figure 10.

50.3 Electric field shielding effectiveness measurements. Electric field shielding effectiveness measurements are not required unless such tests are explicitly prescribed by the procurement documentation. When required, electric field test point locations, frequencies, and calibration and measurement procedures shall be in accordance with MIL-STD-285 and additional instructions contained in the requiring document. The pass/fail criteria for electric field shielding effectiveness are shown as a function of frequency by figure 10.

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APPENDIX B

PULSED CURRENT INJECTION TEST PROCEDURES[9]

10. GENERAL

10.1 Scope. This appendix establishes pulsed current injection (PCI) test procedures for electrical point-of-entry (POE) protective devices required for low-risk high-altitude electromagnetic pulse (HEMP) protection of critical ground-based facilities with time-urgent missions. The procedures are applicable for testing other HEMP-hardened facilities, when specified by the procurement documentation.

10.2 Applications. These procedures shall be used for acceptance testing after construction of the HEMP protection subsystem and for verification testing of electrical POE protective treatments after the facility is completed and operational, as required by DETAILED REQUIREMENTS of MIL-STD-188-125.

20. REFERENCED DOCUMENTS

20.1 Government documents. The following document forms a part of this appendix to the extent specified:

DNA-EMP-1 – Electromagnetic Pulse (EMP) Security Classification Guide (U) (document is classified S–RD).

30. DEFINITIONS

30.1 Norms. Norms are scalar quantities which characterize the features of a complicated waveform. Norms used as pass/fail criteria for PCI test residual internal stresses are peak current, peak rate of rise, rectified impulse, and root action.

30.2 Peak current. The peak current norm of a current waveform $I(t)$, in units of amperes, is the maximum absolute value of $I(t)$ over times from $t = 0$ to $t = 5 \times 10^{-3}$s. At the start of the PCI drive pulse, $t = 0$.

[9]HEMP-unique test procedures are temporarily included as appendices to MIL-STD-188-125; it is intended that these procedures will ultimately be promulgated as separate standards outside of the MIL-STD-188- series.

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30.3 Peak rate of rise. The peak rate of rise norm of a current waveform $I(t)$, in units of amperes per second, is the maximum absolute value of dI/dt over times from $t = 0$ to $t = 5 \times 10^{-3}$s. At the start of the PCI drive pulse, $t = 0$.

30.4 Rectified impulse. The rectified impulse norm of a current waveform $I(t)$, in units of ampere-seconds, is defined by the equation

$$\text{Rectified impulse} = \int_0^{5\times 10^{-3}\text{s}} |I(t)|\, dt$$

where $t = 0$ at the start of the PCI drive pulse.

30.5 Root Action. The root action norm of a current waveform $I(t)$, in units of amperes-$\sqrt{\text{seconds}}$, is defined by the equation

$$\text{Root action} = \sqrt{\int_0^{5\times 10^{-3}\text{s}} I^2(t)\, dt}$$

where $t = 0$ at the start of the PCI drive pulse.

40. GENERAL REQUIREMENTS

40.1 General. Pulsed current injection acceptance testing is used to demonstrate that electrical POE protective devices, as-installed, perform in accordance with MIL-STD-188-125 transient suppression/attenuation requirements. PCI verification testing confirms the transient suppression/attenuation performance in operational circuit configurations and demonstrates that mission-essential equipment (MEE) are not damaged or upset by residual internal transient stresses.

The test method couples threat-relatable transients to penetrating conductors at injection points outside the electromagnetic barrier. Injections in both common mode (all penetrating conductors of a cable simultaneously driven with respect to ground) and individual wire-to-ground configurations are required. For purposes of this procedure, ground is a point on the facility HEMP shield in the vicinity of the POE protective device under test. Residual internal responses are measured, and operation of the MEE is monitored during the verification test to determine if mission-aborting damage or upsets occur.

The required tests are performed on each penetrating conductor and cable, radio frequency (RF) antenna shield, and conduit shield. Simultaneous injection of all electrical POE protective devices, if practicable, is desirable for verification testing.

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40.2 Purpose.

40.2.1 Purposes of PCI acceptance testing. The purposes of PCI testing, as an acceptance test procedure, are as follows:

a. To measure the performance of as-installed conductive POE protective devices

b. To demonstrate through post-test inspection, surge arrester performance checks, and response data analysis that the protective devices will not be damaged or degraded by threat-relatable transients

c. To identify defective devices or faulty installation practices, so that repairs or replacements can be made

40.2.2 Purposes of PCI verification testing. The purposes of PCI testing, as part of a verification test program, are as follows:

a. To measure the performance of conductive POE protective devices in operational circuit configurations

b. To demonstrate, through post-test inspection, surge arrester performance checks, and response data analysis, that the protective devices will not be damaged or degraded by threat-relatable transients

c. To identify defective devices or faulty installation practices, so that repairs or replacements can be made

d. To characterize the residual internal transient stresses

e. To demonstrate that residual internal transient stresses will not cause mission-aborting damage or upsets of the MEE in its various operating states

f. To provide data for HEMP hardness assessment of the facility and baseline data for the hardness maintenance/hardness surveillance program

40.3 HEMP protection subsystem test configuration.

40.3.1 Acceptance test facility configuration. PCI testing for acceptance is performed after the POE protective devices have installed at the facility. The electromagnetic barrier is not required to be complete, but it must be recognized that an incomplete barrier may result in degradations of the POE protective device performance and the instrumentation signal-to-noise ratio. Equipment which, in the facility operation, will electrically connect to the POE protective device under test is not required to be powered or installed.

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40.3.2 Verification test facility configuration. When PCI verification testing is conducted, the facility shall be in a normal operating configuration and shall be performing actual or simulated missions. The HEMP protection subsystem shall be intact. Equipment which electrically connects to the POE protective device under test shall be powered and operating, except as otherwise specified in this procedure.

40.4 Pretest analysis requirements. There are no pretest analyses required for PCI acceptance testing. Pretest analysis for PCI verification testing shall be performed to determine operating states in which the MEE will be tested. An equipment should be tested in multiple states when the switching produces significantly different propagation paths for the residual internal transient, significant changes in the equipment vulnerability threshold, or significant changes in the function being performed. A mission-essential transceiver, for example should be tested in at least two states—transmitting and receiving—and a digital interface should be tested in both the low and high signal states.

40.5 Test equipment requirements. Test equipment required for pulsed current injection testing is identified in table III.

40.6 Operational impact analysis and risk.

40.6.1 Acceptance testing impact. When PCI testing is performed as an acceptance test procedure, the electromagnetic barrier must remain reasonably intact, such that POE protective device performance and instrumentation signal-to-noise ratio are not excessively degraded, and use of electrically noisy equipment must be restricted in order to achieve the required measurement sensitivity. Construction activity may, therefore, be affected.

40.6.2 Verification testing impact. During PCI verification testing, the barrier must remain intact and use of electrically noisy equipment which is not part of the normal site equipment complement must be restricted; unusual operations (facility modification, maintenance) may be affected. Mission operations can continue normally, except as follows:

a. The circuit and POE protective device under test may be unavailable for normal use; it may be necessary to disconnect unprotected equipment outside the barrier, and the circuit may be periodically deenergized.

b. A special sequence of activities may be required so that the circuit and facility can be tested in their various operating states.

40.6.3 Risk. PCI testing requires application of high voltages and large currents. Special high-voltage electrical safety precautions apply. Because of the high injection levels, risk of

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TABLE III. PCI test equipment requirements.

Equipment	Characteristics		
	Short Pulse[1]	Intermediate Pulse[1]	Long Pulse[1]
Pulse Generators[2]	Up to 8000 A, double exponential waveform and damped sinusoidal waveform	Up to 500 A, double exponential waveform	Up to 200 A, double exponential waveform
Current Sensors (Injected Transient)	10 kHz–750 MHz, 0–8000 A	d.c. – 10 MHz, 0–500 A	d.c. – 10 kHz, 0–200 A
Current Sensors (Residual Internal Transient)	100 Hz–750 MHz, 0–100 A, transfer impedance as required for measurement sensitivity	d.c. – 10 MHz, 0–500 A	d.c. – 10 kHz, 0–200 A
Oscilloscopes or Transient Digitizers[3]	100 Hz–750 MHz, minimum sensitivity as required for measurement sensitivity	d.c. – 10 MHz	d.c. – 10 kHz
Data Recorder[3]	0–5 ms	0–50 ms	0–100 s
Preamplifier(s)	100 Hz–750 MHz, amplification and noise figure as required for measurement sensitivity	—	—
Instrumentation Shield and Power Supplies	As required for isolation from pulse generator	As required for isolation from pulse generator	As required for isolation from pulse generator
Miscellaneous Cables, Attenuators, and Dummy Load Resistors	As required	As required	As required

[1]See B.50.2.1 for characteristics of the short, intermediate, and long pulses.

[2]Pulse generator current output requirements are stated in terms of current delivered at the external terminal of the POE protective device. The method of coupling the pulse generator output to the penetrating conductor and the pulse generator source impedance are not specified. However, connection of the pulse generator into the circuit under test must not interfere with normal circuit operation and pulse generator source impedance must normally be much greater than the effective load impedance.

[3]Use of a personal computer with an IEEE-488 general purpose interface bus (GPIB) to control instrumentation and store test data on magnetic disk is strongly recommended.

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POE protective device or equipment damage cannot be completely eliminated. However, the procedures are designed to minimize this risk.

40.7 Test plan and procedures.

40.7.1 Acceptance test plan. A comprehensive, site-specific test plan and detailed test procedures for PCI acceptance testing shall be prepared. These may be combined in a single document or two separate documents may be used. As a minimum, the documentation shall contain the following information:

a. A statement of the test objectives

b. Facility identification and description—including a site plan, floor plan of the shielded volume, list of shield POEs, and a description of the HEMP protection subsystem

c. Identification of circuits and POE protective devices to be tested—including circuit functions and manufacturers' data sheets and specifications for the protective devices

d. Identification of test points and injection levels (see table IV)

e. HEMP simulation and data acquisition equipment description—including manufacturer, model and serial numbers, characteristics, and detailed calibration procedures

f. Any deviations from the requirements of this appendix

g. Data management—including data quality control procedures, data acceptability criteria, data processing requirements, annotation and presentation of data records, and pass/fail criteria

h. Safety

i. Security (see B.40.10)

j. Test schedule—including priority of measurements

Data item description DI-R-1759A, "Nuclear Weapons Effects Tests Plan," should be used.

40.7.2 Verification test plan. A comprehensive, site-specific test plan and detailed test procedures for PCI verification testing shall be prepared. These may be combined in a single document or two separate documents may be used. As a minimum, the documentation shall contain the following information:

a. A statement of the test objectives

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TABLE IV. PCI amplitudes and waveforms.

a. Double exponential waveforms (fig. 12).

Class of Electrical POE	Type of Injection	Peak Current - I (A)	Risetime - τ_R (s)	FWHM (s)	Acceptance Test Load Impedance (Ω)
Commercial Power Lines (Intersite)					
Short Pulse	Common mode[1]	8000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	Not applicable[1]
Short Pulse	Wire-to-ground[3]	4000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[4] 2 or V_{rated}/I_{rated}
Intermediate Pulse	Common mode[1]	500	$\leq 1\times10^{-6}$	$\geq 5\times10^{-3}$	Not applicable[1]
Intermediate Pulse	Wire-to-ground[3]	500	$\leq 1\times10^{-6}$	$\geq 5\times10^{-3}$	50
Long Pulse	Common mode[1]	200	≤ 0.5	≥ 100	Not applicable[1]
Long Pulse	Wire-to-ground[3]	200	≤ 0.5	≥ 100	50
Other Power Lines (Intrasite)					
Short Pulse	Common mode[1]	8000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	Not applicable[1]
Short Pulse	Wire-to-ground[3]	4000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[4] 2 or V_{rated}/I_{rated}
Audio/Data Lines (Intersite)					
Short Pulse	Common mode[1]	8000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	Not applicable[1]
Short Pulse	Wire-to-ground[3]	[5] $8000/\sqrt{N}$ or 500	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	50
Intermediate Pulse	Common mode[1]	500	$\leq 1\times10^{-6}$	$\geq 5\times10^{-3}$	Not applicable[1]
Intermediate Pulse	Wire-to-ground[3,6]	500	$\leq 1\times10^{-6}$	$\geq 5\times10^{-3}$	50
Long Pulse	Common mode[1]	200	≤ 0.5	≥ 100	Not applicable[1]
Long Pulse	Wire-to-ground[3,6]	200	≤ 0.5	≥ 100	50
Control/Signal Lines (Intrasite)					
Short Pulse	Common mode[1]	8000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	Not applicable[1]
Short Pulse	Wire-to-ground[3]	[5] $8000/\sqrt{N}$ or 500	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[4] 2 or V_{rated}/I_{rated}
RF Antenna Lines–Signal Conductors [7] $f \leq 2$ MHz	Wire-to-shield	8000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[8] 50
RF Antenna Lines–Shield					
Buried[9]	Shield-to-ground[10]	1000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[8] 50
Nonburied	Shield-to-ground[10]	8000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[8] 50
Conduit Shields					
Buried[9]	Conduit-to-ground[11]	1000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[12] 2
Nonburied	Conduit-to-ground[11]	8000	[2] $\leq 1\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	[12] 2

b. Damped sinusoidal waveforms (fig. 13).

Class of Electrical POE	Type of Injection	Peak Current - I (A)	Center Frequency - f_c (MHz)	Decay Factor - Q (Dimensionless)	Acceptance Test Load Impedance (Ω)
RF Antenna Lines–Signal Conductor					
[7] 2 MHz < $f \leq$ 30 MHz	Wire-to-shield	[13] 2500	[13] 2 ± 10%	[13] 10 ± 3	[8] 50
[7] 30 MHz < $f \leq$ 200 MHz	Wire-to-shield	[13] 900	[13] 30 ± 10%	[13] 10 ± 3	[8] 50
[7] 200 MHz < f	Wire-to-shield	[13] 250	[13] 200 ± 10%	[13] 10 ± 3	[8] 50

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TABLE IV. PCI amplitudes and waveforms (concluded).

c. Notes to table IV.

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[1]For a common mode test, all penetrating conductors in the cable are simultaneously driven with respect to ground, where ground is a point on the facility HEMP shield in the vicinity of the POE protective device. Common mode tests are required for verification, but they are not required for acceptance.

[2] $\tau_R \leq 1 \times 10^{-8}$ s is a design objective. The minimum requirement is $\tau_R \leq 5 \times 10^{-8}$ s.

[3]For a wire-to-ground test, each penetrating conductor in the cable is driven with respect to ground, where ground is a point on the facility HEMP shield in the vicinity of the POE protective device.

[4]Whichever is smaller. V_{rated} and I_{rated} are the maximum voltage and current ratings of the POE protective device, respectively.

[5]Whichever is larger. N is the number of penetrating conductors in the cable.

[6]Intermediate and long pulse wire-to-ground tests of audio/data lines are required for acceptance, but they are not required for verification.

[7] $f = 600/L$ MHz, where L is the largest dimension of the associated antenna in meters. When $f \leq 2$ MHz, a double exponential pulse is required. When $f > 2$ MHz, a damped sinusoidal waveform is specified.

[8]Signal conductor terminated to the shield with 50 Ω. The shield conductor is electrically bonded to the facility HEMP shield.

[9]An antenna shield is considered buried when it terminates at a buried antenna and less then 1 m (3.3 ft) of its total length is not covered by an earth or concrete fill. A conduit is considered buried when it connects two protected volumes and less than 1 m (3.3 ft) of its total length is not covered by earth or concrete fill.

[10]For a shield-to-ground test, maximum feasible length of the antenna line shield is driven with respect to ground, where ground is a point on the facility HEMP shield in the vicinity of the POE protective device.

[11]For a conduit-to-ground test, maximum feasible length of the conduit is driven with respect to ground, where ground is a point on the facility HEMP shield in the vicinity of the conduit penetration.

[12]Wiring internal to the conduit is terminated at the installed equipment, if present. Other internal wiring is bundled together and terminated in common 2 Ω resistors at each end. The conduit is welded to the facility HEMP shields at both ends.

[13]The damped sinusoidal waveform is a design objective. The minimum requirement is to inject the current output from a PCI source which delivers the following current pulse $[I(t)]$ with an unspecified waveform into a 50 Ω calibration load:

a. $$\int_0^T I(t)\, dt \geq \frac{0.3\hat{I}}{f_c}$$

b. $$|I(t)| \leq K_{DS}\, \hat{I} e^{-\frac{\pi f_c t}{10}} \quad \text{for all } t > T$$

where t is time in seconds, $\hat{I}$ is the prescribed peak current in amperes, f_c is the prescribed center frequency, K_{DS} is a scaling constant (see fig. 13), and T is the time of the first zero crossing or $1/f_c$ whichever occurs earlier.

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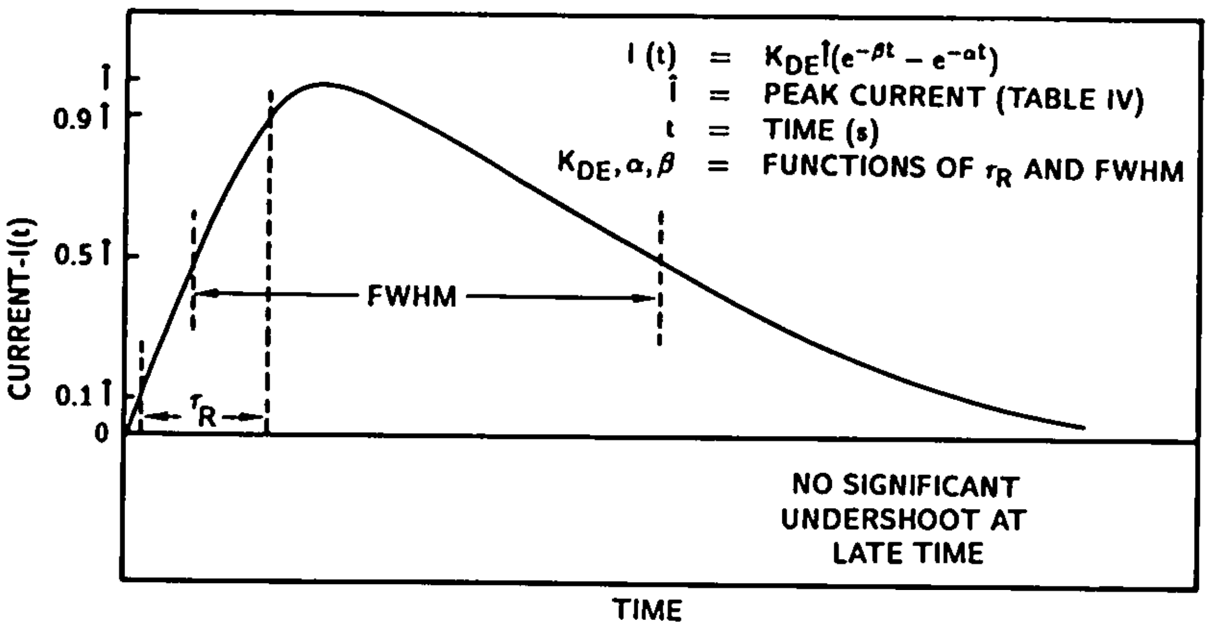

FIGURE 12. Double exponential waveform.

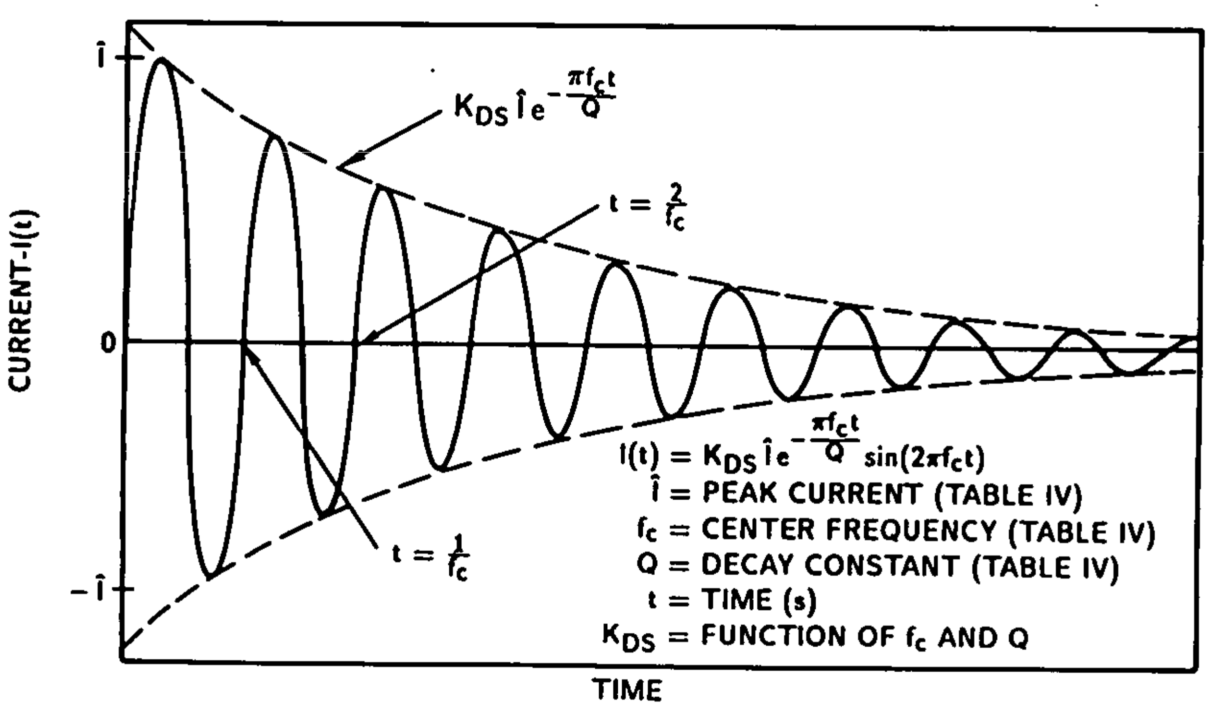

FIGURE 13. Damped sinusoidal waveform.

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b. Facility identification and description—including a site plan, floor plan of the shielded volume, list of shield POEs, list of mission-essential equipment inside and outside the electromagnetic barrier, and a description of the HEMP protection subsystem

c. Identification of circuits and POE protective devices to be tested—including circuit functions and manufacturers' data sheets and specifications for the protective devices

d. Identification of test points

e. HEMP simulation and data acquisition equipment description—including manufacturer, model and serial numbers, characteristics, and detailed calibration procedures

f. Detailed test procedures—including facility and circuit configuration requirements, equipment operating states, diagrams of the data acquisition system, injection levels (see table IV), data requirements, and step-by-step procedures

g. Data management—including data quality control procedures, data acceptability criteria, data processing requirements, annotation and preservation of data records, and pass/fail criteria

h. Safety

i. Security (see B.40.10)

j. Test schedule—including priority of measurements

Data item description DI-R-1759A, "Nuclear Weapons Effects Tests Plan," should be used.

40.8 Test report requirements.

40.8.1 Acceptance test report. A PCI acceptance test report shall be prepared. As a minimum, the test report shall contain the following information:

a. Facility identification and test plan reference

b. A discussion of any deviations from the test plan and requirements of this appendix

c. Copies of the measured results, along with sensor calibrations and instrumentation settings required to convert the data to engineering units

d. A summary table of the norms of the measured internal responses and comparison to the maximum allowable residual internal response characteristics (see table V)

e. Pass/fail conclusions

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TABLE V. Maximum allowable residual internal response characteristics for electrical POEs.

Class of Electrical POB	Type of Injection	Type of Measurement	Peak Current (A)	Peak Rate of Rise (A/s)	Rectified Impulse (A-s)	Root Action ($A\sqrt{s}$)
Commercial Power Lines (Intersite)						
Short Pulse	Common mode	Bulk current	10	1×10^{6}	1×10^{-2}	1.6×10^{-1}
Short Pulse	Wire-to-ground	Wire current	10	1×10^{6}	1×10^{-2}	1.6×10^{-1}
Intermediate Pulse	Common mode	Bulk current		No damage or performance degradation[1]		
Intermediate Pulse	Wire-to-ground	Wire current		No damage or performance degradation[1]		
Long Pulse	Common mode	Bulk current		No damage or performance degradation[1]		
Long Pulse	Wire-to-ground	Wire current		No damage or performance degradation[1]		
Other Power Lines (Intrasite)						
Short Pulse	Common mode	Bulk current	10	1×10^{6}	1×10^{-2}	1.6×10^{-1}
Short Pulse	Wire-to-ground	Wire current	10	1×10^{6}	1×10^{-2}	1.6×10^{-1}
Audio/Data Lines (Intersite)						
Short Pulse	Common mode	Bulk current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Short Pulse	Wire-to-ground	Wire current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Intermediate Pulse	Common mode	Bulk current		No damage or performance degradation[1]		
Intermediate Pulse	Wire-to-ground	Wire current		No damage or performance degradation[1]		
Long Pulse	Common mode	Bulk current		No damage or performance degradation[1]		
Long Pulse	Wire-to-ground	Wire current		No damage or performance degradation[1]		
Control/Signal Lines (Intrasite)						
Low-Voltage Lines[2]						
Short Pulse	Common mode	Bulk current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Short Pulse	Wire-to-ground	Wire current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
High-Voltage Lines[2]						
Short Pulse	Common mode	Bulk current	1.0	1×10^{6}	1×10^{-3}	1.6×10^{-2}
Short Pulse	Wire-to-ground	Wire current	1.0	1×10^{6}	1×10^{-3}	1.6×10^{-2}

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TABLE V. Maximum allowable residual internal response characteristics for electrical POEs (concluded).

Class of Electrical POE	Type of Injection	Type of Measurement	Peak Current (A)	Peak Rate of Rise (A/s)	Rectified Impulse (A-s)	Root Action ($A\sqrt{s}$)
RF Antenna Lines Receive Only Signal Conductor Drive	Wire-to-shield	Wire current	0.1	No damage or performance degradation[1]		
		Shield current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Receive Only Shield Drive	Shield-to-ground	Wire current	0.1	No damage or performance degradation[1]		
		Shield current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Transmit and Transceive Signal Conductor Drive	Wire-to-shield	Wire current	1.0	No damage or performance degradation[1]		
		Shield current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Transmit and Transceive Shield Drive	Shield-to-ground	Wire current	0.1	No damage or performance degradation[1]		
		Shield current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Conduit Shields Signal and Low Current Power[3] Buried or Nonburied	Conduit-to-ground	Bulk current	0.1	1×10^{6}	1×10^{-4}	1.6×10^{-3}
Intermediate Current Power[3] Buried or Nonburied	Conduit-to-ground	Bulk current	1.0	1×10^{6}	1×10^{-3}	1.6×10^{-2}
High Current Power[3] Buried or Nonburied	Conduit-to-ground	Bulk current	10	1×10^{6}	1×10^{-2}	1.6×10^{-1}

[1]Pass/fail criteria on internal response waveform norms are not specified for intermediate or long pulse current injection test sequences. Pass/fail criteria on the peak rate of rise, rectified impulse, and action norms are not specified for RF antenna line signal conductors. The pass/fail criteria of no POE protective device damage or performance degradation also applies to PCI test sequences where this note does not appear in the table.

[2]Low voltage control/signal lines are those with a maximum operating voltage <90 V. High voltage control/signal lines are those with maximum operating voltage ≥90 V.

[3]Low current power lines are those with a maximum operating current ≤1 A. Intermediate current power lines are those with maximum operating current between 1 A and 10 A. High current power lines are those with maximum operating current ≥10 A.

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Data item description DI-R-1760A, "Nuclear Weapons Effects Test Report," should be used.

40.8.2 Verification test report. A PCI verification test report shall be prepared. As a minimum, the test report shall contain the following information:

a. Facility identification and test plan reference

b. A discussion of any deviations from the test plan and requirements of this appendix

c. Copies of the measured results, along with sensor calibrations and instrumentation settings required to convert the data to engineering units

d. A summary table of the norms of the measured internal responses and comparison to the maximum allowable residual internal response characteristics (see table V)

e. Test conclusions—including a definitive statement of HEMP hardness of mission functions, based on continuous wave (CW) immersion (see appendix C) and PCI test results and supporting analysis

f. Test chronology—including a sequence of events and identification of failures, upsets, or interference observed and the conditions under which they occurred

Data item description DI-R-1760A, "Nuclear Weapons Effects Test Report," should be used.

40.9 Post-test analysis requirements.

40.9.1 Analysis of acceptance test data. Post-test analysis of PCI acceptance measured data is required for data corrections for probe and instrumentation response characteristics and conversion of results into norms in engineering units.

40.9.2 Analysis of verification test data. Post-test analysis of PCI verification measured data is required for data corrections for probe and instrumentation response characteristics and conversion of results into norms in engineering units. Additional analysis of measured data shall be performed to assist in developing a definitive statement of facility HEMP hardness. Detailed requirements for post-test analysis of PCI verification test results shall be established by the sponsoring agency for the test. They will generally include calculations of threat responses from CW immersion and PCI test data, analysis of verification test adequacy, development of hardness conclusions, and recommendations for corrective actions, if required.

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40.10 Data classification. Test data may be classified. DNA-EMP-1 and the classification guide for the specific facility or system should be consulted for guidance.

40.11 Alternative test methods. When approved by the sponsoring agency, cable shield injection may be used for verification testing on shielded intrasite control or signal lines in lieu of the common mode PCI requirement. Maximum required current amplitude and the prescribed waveform for cable shield injection shall be as shown in table VI. Intrasite cable shields shall be driven over their entire length by removing intermediate grounds and other low-impedance paths to ground along the cable run. Internal response measurements shall be made on the bulk cable. Pass/fail criteria of table V apply.

TABLE VI. Cable shield PCI amplitudes and waveforms.

Class of Electrical POE	Double Exponential Waveform (Fig. 12)		
	Peak Current - $\hat{I}$ (A)	Risetime - τ_R (s)	FWHM (s)
Control/Signal Lines (Intrasite)	8000	[1] $\leq 1 \times 10^{-8}$	$5 \times 10^{-7} - 5.5 \times 10^{-7}$

[1] $\tau_R \leq 1 \times 10^{-8}$ s is a design objective. The minimum requirement is $\tau_R \leq 5 \times 10^{-8}$ s.

50. DETAILED REQUIREMENTS

50.1 Test configuration. Typical PCI test configurations are illustrated in figure 14, and a typical data recording system is illustrated in figure 15. The pulse generator output may be directly coupled to the circuit under test, or it may be capacitively or inductively coupled. All injection current amplitude and waveform requirements refer to the signal observed on the external current sensor. The external current sensor shall be within 15 cm (6 in) of the external terminal of the POE protective device, and there shall be no branches in the wiring between the sensor location and the external terminal. The internal current sensor shall be within 15 cm (6 in) of the internal terminal of the POE protective device, and there shall be no branches in the wiring between the sensor location and the internal terminal.

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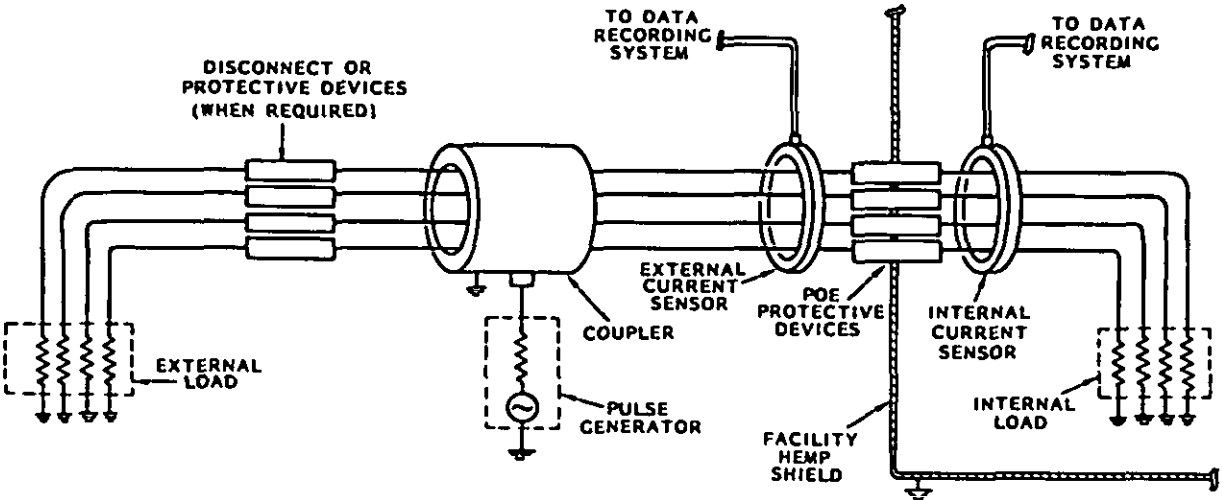
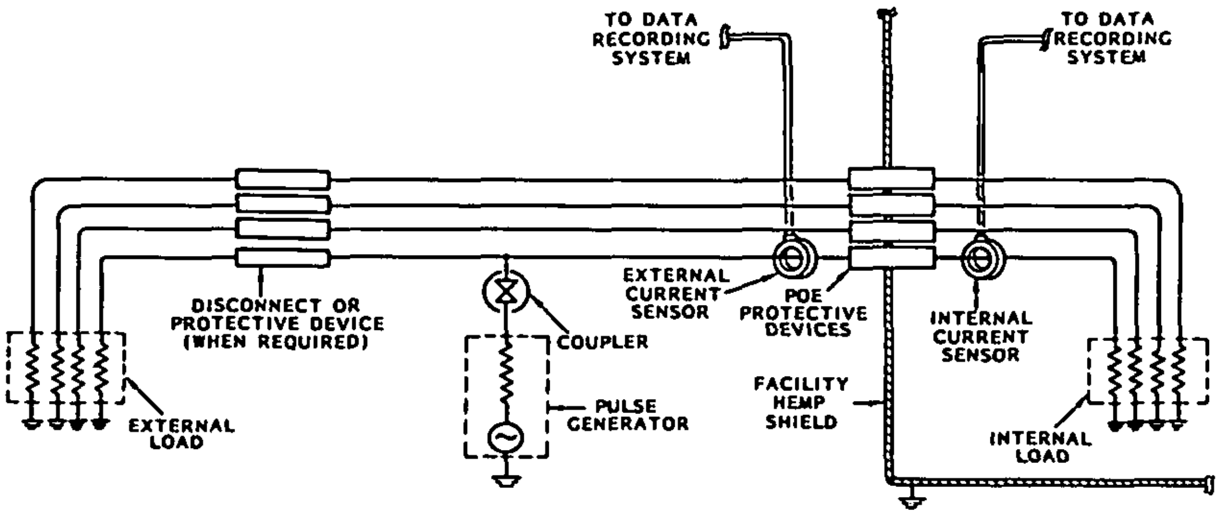


a. Common mode test configuration.



b. Wire-to-ground test configuration.

FIGURE 14. Typical PCI test configurations.

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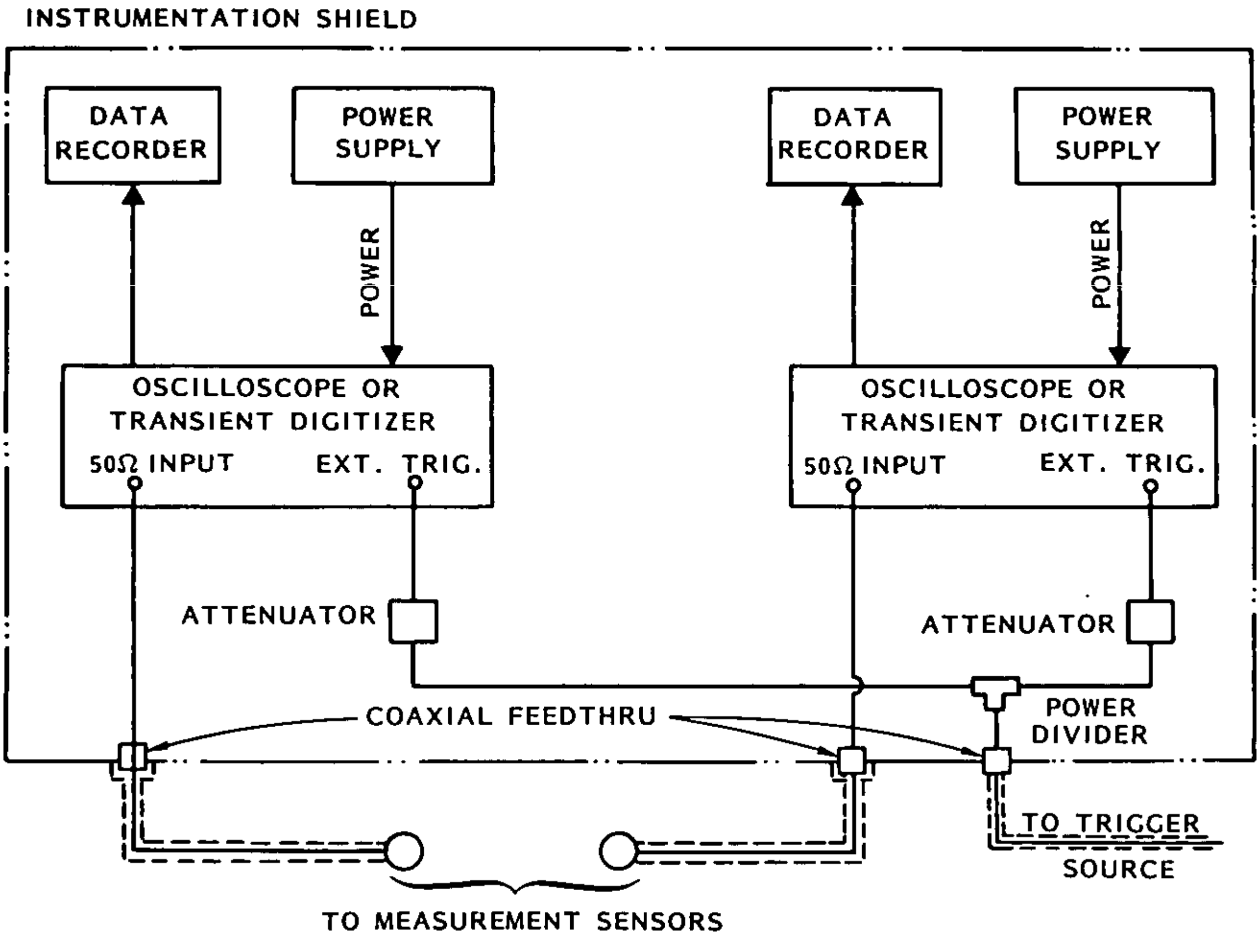

FIGURE 15. Typical PCI data recording system.

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50.1.1 Acceptance test configuration. For PCI performed as acceptance testing, the external load shall be an open-circuit termination and the internal load shall be a dummy resistor (see B.50.2.3).

50.1.2 Verification test configuration. For PCI verification testing, the external load shall be the installed site equipment or an equivalent dummy load impedance,[10] which permits the circuit under test to be energized and performing actual or simulated functions. The internal load for PCI verification testing shall be the installed site equipment, which shall be energized[11] and performing actual or simulated functions.

50.2 Current injection requirements.

50.2.1 Maximum injection levels. Maximum required current amplitudes and prescribed waveforms for acceptance and verification PCI testing for all classes of electrical POEs shall be as shown in table IV and figures 12 and 13. These requirements apply to the signal observed at the external current sensor, shown in figure 14. Note that common mode PCI injections are required only during verification testing, and that intermediate and long pulse wire-to-ground tests on intersite audio or data lines are required only for acceptance testing.

50.2.2 Testing sequence. To minimize the possibility of POE protective device or equipment damage, a series of pulses at increasing amplitudes shall be applied as follows:

a. Pulse at the lowest available current output from the pulse generator; this level shall be less than 10 percent of the maximum amplitude in table IV or less than that amplitude which activates any nonlinear components in the POE protective device, whichever is greater.

b. Perform a series of pulses, increasing the amplitude by a factor of approximately two at each step; when testing several circuits with identical POE protective devices, this series of intermediate pulses may be abbreviated after the first two samples.

c. Pulse at the maximum required amplitude for the circuit under test. Peak current should not exceed 110 percent of the levels listed in table IV.

[10]When the external equipment is not designed to withstand the test transients, temporary protection should be provided or a dummy load should be used in place of the external equipment.

[11]When the circuit under test operates at voltages greater than 600 V a.c. or 600 V d.c. and cannot safely be tested with power on, PCI verification testing may be performed in a deenergized condition. Switches, relay contacts, and other circuit interrupters shall be placed in the operating state to simulate the power-on condition.

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CAUTION: Surge arresters in electrical POE protective devices have limited pulse lives. The number of test pulses delivered to each device should be recorded for inclusion in maintenance records. If the total number of previous pulses on the device exceeds 90 percent of the rated life, surge arresters should be replaced before starting the test.

This sequence shall be used for both acceptance and verification testing.

50.2.3 Acceptance test load resistance. Ohmic values of the PCI acceptance test internal load resistors for all classes of electrical POEs shall be as listed in table IV. For wire-to-ground tests, only the penetrating conductor under test requires the specified termination. For conduit shield tests, internal wiring shall be terminated on normal equipment, if present, and other conductors shall be bundled together and terminated with a common 2 Ω resistor at each end. Wiring which connects the load resistor between the internal terminal of the POE protective device and its enclosure shall be less than 30 cm (12 in) in length.

50.3 Measurements and functional observations.

50.3.1 Data requirements. At each step in the testing sequence, for both acceptance and verification testing, the external pulse amplitude and waveform and the internal pulse amplitude and waveform shall be recorded.[12] The internal pulse waveform shall be recorded to time of 5 ms after the start of the PCI short drive pulse, with recording instrument sweep speeds which allow resolution of the early, intermediate, and late time response.

50.3.2 Verification test functional observations. Operation of facility mission-essential equipment shall be monitored during and immediately after the pulse for indications of damage or upset. A detailed description of any abnormal occurrences shall be prepared for inclusion in the test chronology.

50.4 Measurement procedures. PCI test procedures for acceptance and verification testing shall be as follows:

a. Set up the pulse generator source and data acquisition equipment in the desired configuration and perform calibrations.

[12]When the POE protective device leads into a special protective volume inside the electromagnetic barrier, amplitudes and waveforms shall also be recorded on all electrical POEs through the special protective barrier into the protected volume. The measurements shall be made in the protected volume. Pass/fail criteria for these data are the same as the pass/fail criteria for other internal response measurements.

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b. Deenergize the circuit to be tested, for acceptance testing or when required by safety considerations, and install sensors. Reenergize the circuit after sensor installation is complete (verification test only).

c. Perform a noise check of the data recording system to ensure a satisfactory signal-to-noise ratio.

d. Establish the required facility, equipment state, and test configurations.

e. Inject a pulse into the circuit under test at the lowest available current output from the pulse generator (see B.50.2.2).

f. Record measurement point responses.

g. Record results from the functional monitoring of the mission-essential equipment (verification test only).

h. Compare measured and observed results to the pass/fail criteria (see B.50.5). If the results are not satisfactory, halt the test and effect repairs or replacement of the POE protective device. Repeat the PCI test procedure after the corrective action has been completed.

i. Repeat steps e through h at increasing injection levels until the maximum required transient has been injected.

j. Continue to the next state to be tested and repeat steps d through i (verification test only).

k. Deenergize the circuit under test, when required, and remove the sensors and pulse generator output connection.

l. Disconnect the electrical surge arrester from the circuit. Measure the voltage at 1 mA direct current (d.c.) of a metal oxide varistor or the d.c. breakdown voltage of a spark gap. Compare the measured results to the device specifications. If the results are not satisfactory, effect repairs or replacement of the POE protective device. Repeat the PCI test procedure after the corrective action has been completed.

m. Reconnect the electrical surge arrester, and restore the circuit to its operational configuration.

n. Continue to the next circuit to be tested and repeat steps b through m.

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50.5 Pass/fail criteria.

50.5.1 Internal response pass/fail criteria. The POE protective device shall be considered satisfactory when both of the following criteria are met:

a. Norms of the measured internal response waveforms, at all short pulse injection levels, do not exceed the maximum allowable norm values of table V for the applicable class of electrical POE.[13]

   If internal responses measured in the PCI verification test cannot be discriminated from circuit operating and noise signals, the test shall be repeated in a power-off (acceptance) configuration. The pass/fail determination for internal response norms shall then be made using the resulting power-off data.

b. Post-test physical inspection of the POE protective device, surge arrester measurement of voltage at 1 mA d.c. current (for a metal oxide varistor) or d.c. breakdown voltage (for a spark gap), and response data analysis indicate that the device has not been damaged or degraded by the test pulses.

The internal response pass/fail criteria apply for both acceptance and verification testing.

50.5.2 Verification test functional pass/fail criteria. Hardening of equipment within the electromagnetic barrier shall be considered satisfactory when both of the following criteria are met:

a. No damage to mission-essential equipment occurred during the PCI verification testing.

b. No mission-aborting interruption of mission-essential functions or upsets of mission-essential equipment occurred during the PCI verification testing.[14]

50.5.3 Test failures. Any failure to satisfy the internal response or functional success criteria shall be considered a HEMP vulnerability. An investigation into the cause of the possible vulnerability shall be conducted. The condition shall be corrected, if possible, and the PCI verification test sequence shall be repeated.

[13]When the protected side of the POE protective device is contained within a special protective volume, norms of the measured internal responses must not exceed design values for that special protective volume.

[14]The determination of whether an observed interruption or upset is mission-aborting is the responsibility of the operational authority for the facility.

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APPENDIX C

CW IMMERSION TEST PROCEDURES[15]

10. GENERAL

10.1 Scope. This appendix establishes procedures for continuous-wave (CW) immersion testing of the electromagnetic barrier required for low-risk high-altitude electromagnetic pulse (HEMP) protection of critical ground-based facilities with time-urgent missions. The procedures are applicable for testing other HEMP-hardened facilities, when specified by the procurement documentation.

10.2 Applications. These procedures shall be used for verification testing of the facility HEMP shield and aperture point-of-entry (POE) protective treatments, as required by DETAILED REQUIREMENTS of MIL-STD-188-125.

20. REFERENCED DOCUMENTS

20.1 Government documents. The following documents form a part of this appendix to the extent specified:

DoD-STD-2169 – High-Altitude Electromagnetic Pulse (HEMP) Environment (U) (document is classified Secret).

DNA-EMP-1 – Electromagnetic Pulse (EMP) Security Classification Guide (U) (document is classified S–RD).

30. DEFINITIONS

30.1 Illuminating field. The illuminating field at a location with respect to the transmitting antenna is the total electromagnetic field, including ground effects, which would be measured at that point if the facility or system under test was not present. Thus, the illuminating field does not include reflections from the facility under test.

30.2 Principal component of the illuminating field. A principal component of the illuminating field is a magnetic or electric field component which is maximized by the antenna geometry and ground effects. For example, azimuthal magnetic field and vertical electric

[15]HEMP-unique test procedures are temporarily included as appendices to MIL-STD-188-125; it is intended that these procedures will ultimately be promulgated as separate standards outside of the MIL-STD-188- series.

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field are principal components of the illuminating field of a vertical monopole antenna over a ground plane.

30.3 Reference field. The reference field in a CW immersion test is a measured field for monitoring the output from the transmitting antenna. The reference sensor may be placed at any location with respect to the antenna and facility, where the measurement has a known relationship to the illuminating field at all frequencies of interest. This requirement implies that reflections from the facility under test are negligible at the reference sensor, or that they can be analytically subtracted from the measured data. When corrected for facility reflections and location with respect to the transmitting antenna, the reference field measurement provides the illuminating field data.

40. GENERAL REQUIREMENTS

40.1 General. The CW immersion test procedure is an element of verification testing, performed as soon as practical after the HEMP-protected facility is completed and operational. The test method illuminates the exterior surface of the electromagnetic barrier with radiated CW fields and surveys the interior protected volume to identify shield defects and inadequately protected aperture POEs and to provide data for hardness assessment. Because coupling to exposed external portions of penetrating conductors may not be efficient, CW immersion has limited effectiveness for evaluating conductive POE protection. Therefore, protection provided for penetrating conductors is also evaluated with pulsed current injection (PCI) testing (see appendix B).

40.2 Purpose. The purposes of CW immersion testing are as follows:

a. To measure attenuation of electromagnetic fields in the HEMP portion of the spectrum by linear elements of the as-built electromagnetic barrier

b. To identify HEMP shield and aperture POE protective device defects, faulty installation practices, and inadvertent POEs, so that repairs can be made

c. To characterize residual internal field and conducted electromagnetic stresses, within limitations of the linearity and planarity assumptions, through post-test analysis

d. To observe operation of the facility for interference or upset (interference which occurs as the result of the low-level CW excitation may indicate a circuit which is particularly vulnerable to HEMP effects)

e. To provide data for HEMP hardness assessment of the facility and baseline data for the hardness maintenance and hardness surveillance program

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40.3 HEMP protection subsystem test configuration. During conduct of the CW immersion test, the facility shall be in a normal operating configuration and shall be performing actual or simulated mission functions. The HEMP protection subsystem shall be intact.

40.4 Pretest analysis requirement. Pretest analysis shall be performed to select transmitting antenna locations, reference sensor locations, and measurement points. Transmitting antenna locations shall be chosen to obtain the required illuminating field strength and efficient coupling to all areas on the electromagnetic barrier surface. Reference sensor locations shall be chosen to monitor the transmitting antenna output and determine the illuminating field. Measurement points shall be chosen to provide representative mappings of field responses within the protected volume and special protective volumes and current responses within the internal cable plant.

40.5 Test equipment requirements. Test equipment required for CW immersion testing is identified in table VII.

40.6 Operational impact analysis and risk. Since the electromagnetic barrier must remain intact during conduct of the CW immersion test and use of electrically noisy equipment which is not part of the normal site equipment complement must be restricted, unusual operations (facility modification, maintenance) may be affected. Mission operations can continue normally, except that a special sequence of activities may be required so that the facility can be tested in its various operating states (transmitting, receive-only, etc.). Radiated signal levels are low and present no hazard to equipment, but frequency clearance and bands in which transmissions must be suppressed may be required to avoid self-interference or interference with nearby facilities. Normal electrical safety precautions apply.

40.7 Test plan and procedures. A comprehensive, site-specific test plan and detailed test procedures for CW immersion testing shall be prepared. These may be combined into a single document or two separate documents may be used. As a minimum, the test documentation shall contain the following information:

a. A statement of the test objectives

b. Facility identification and description—including a site plan, floor plan of the protected volume, list of shield POEs, list of mission-essential equipment inside and outside the electromagnetic barrier, and a description of the HEMP protection subsystem

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TABLE VII. CW immersion test equipment requirements.

Equipment	Characteristics
Network Analyzer(s)[1]	100 kHz–1 GHz, minimum sensitivity as required for measurement sensitivity
Power Amplifier(s)	100 kHz–1 GHz, amplification as required for measurement sensitivity
Antenna(s)	100 kHz–1 GHz
Sensors	Free-field, surface current (or charge) density, current, voltage, 100 kHz–1 GHz
Preamplifiers	100 kHz–1 GHz, amplification and noise figure as required for measurement sensitivity
Data Recorder[1]	Dual channel
Fiber Optic Links	100 kHz–1 GHz, up to several hundred meters in length
Miscellaneous Cables and Attenuators	As required

[1]Use of a personal computer with an IEEE-488 general purpose interface bus (GPIB) to control instrumentation and store test data on magnetic disk is strongly recommended.

c. Transmitting antenna locations, reference sensor locations, and expected measurement sensitivity of the illumination and instrumentation system

d. CW illumination and data acquisition equipment identification—including manufacturer, model and serial numbers, characteristics, and detailed calibration procedures

e. Detailed test procedures—including facility configuration requirements, equipment operating states, diagrams of the test configuration, step-by-step procedures, and measurement point locations

f. Data management—including data quality control procedures, data acceptability criteria, data processing requirements, annotation and preservation of data records, and pass/fail criteria

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g. Safety

h. Security (see C.40.10)

i. Test schedule—including priority of measurements

Data item description DI-R-1759A, "Nuclear Weapons Effects Test Plan," should be used.

40.8 Test report requirements. A CW immersion test report shall be prepared. As a minimum, the test report shall contain the following information:

a. Facility identification and test plan reference

b. A discussion of any deviations from the test plan and requirements of this appendix

c. Copies of the measured results, along with sensor calibrations and instrumentation settings required to convert the data to engineering units

d. Test results and conclusions—including a definitive statement of HEMP hardness of mission functions, based on CW immersion and PCI test results and supporting analyses

e. Test chronology—including a sequence of events and identification of failures, upsets, or interference observed and the conditions under which they occurred

Data item description DI-R-1760A, "Nuclear Weapons Effects Test Report," should be used.

40.9 Post-test analysis requirements. A post-test analysis of the measured data shall be performed to assist in developing a definitive statement of facility HEMP hardness. Detailed requirements for post-test analyses of verification test results shall be established by the sponsoring agency for the test. They will generally include calculations of threat responses from CW immersion and PCI test data, analysis of verification test adequacy, development of hardness conclusions, and recommendations for corrective actions, if required.

40.10 Data classification. Test data may be classified. DNA-EMP-1 and the classification guide for the specific facility or system should be consulted for guidance.

40.11 Alternative test methods. When CW illumination of a facility is not practical because of physical interference with other facilities in the vicinity, the CW immersion test may be performed using CW current injection on the outer surface of the electromagnetic

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barrier. A site-specific CW shield current injection test plan and detailed procedures shall define the shield excitation technique, source strength, injection points, and predicted shield current density distributions. Minimum data acquisition system sensitivity required for verifying the HEMP protection subsystem effectiveness and pass/fail criteria shall be determined.

When approved by the sponsoring agency, a thorough program of shielding effectiveness measurements (see appendix A) and a thorough shielding effectiveness leak detection system (SELDS) survey in accordance with MIL-HDBK-423 guidance may be used for verification testing in lieu of the CW immersion test.

50. DETAILED REQUIREMENTS

50.1 Test configuration. The CW immersion test configuration is illustrated in figure 16. Swept or stepped CW excitation, generated by the network analyzer source, is propagated to the transmitting antenna location via a hardwired or fiber optic link. The signal is amplified and radiated from the antenna—a vertical monopole, horizontal dipole, log periodic, rhombic or other antenna—to illuminate the facility. The reference sensor, located in a clear area where the measured field has a known relationship to the total field illuminating the facility, monitors the source output. Free-field, surface current or charge density, current and voltage sensors monitor the response at measurement points inside (and outside, if desired) the electromagnetic barrier. Preamplifiers and fiber optic links are used, as required, in the measurement channels. Reference and measurement point data are monitored on the network analyzer and recorded. Figure 17 illustrates a sample 1 MHz to 100 MHz data record, where identical $\dot{B}$ (time rate of change of the magnetic induction field) sensors are employed in both channels and the reference channel is a direct measurement of the illuminating field.

50.2 Transmitting antenna locations. Transmitting antenna locations shall be chosen to illuminate all areas on the barrier surface with the radiated field excitation. Three or four locations around the periphery of the facility will normally be required. The antenna shall be placed as far from the facility as possible, within physical and measurement sensitivity constraints.[16]

[16]When $R > \lambda_{MAX}$ and $R > 2D^2/\lambda_{MIN}$—where R is the distance from the antenna to the barrier, λ_{MAX} is the wavelength of the lowest radiated frequency, λ_{MIN} is the wavelength of the highest radiated frequency, and D is the antenna characteristic length or largest barrier dimension transverse to the propagation direction of the illuminating field—results can be interpreted as plane wave responses. When these inequalities are not satisfied, near-field and wave curvature effects may be significant.

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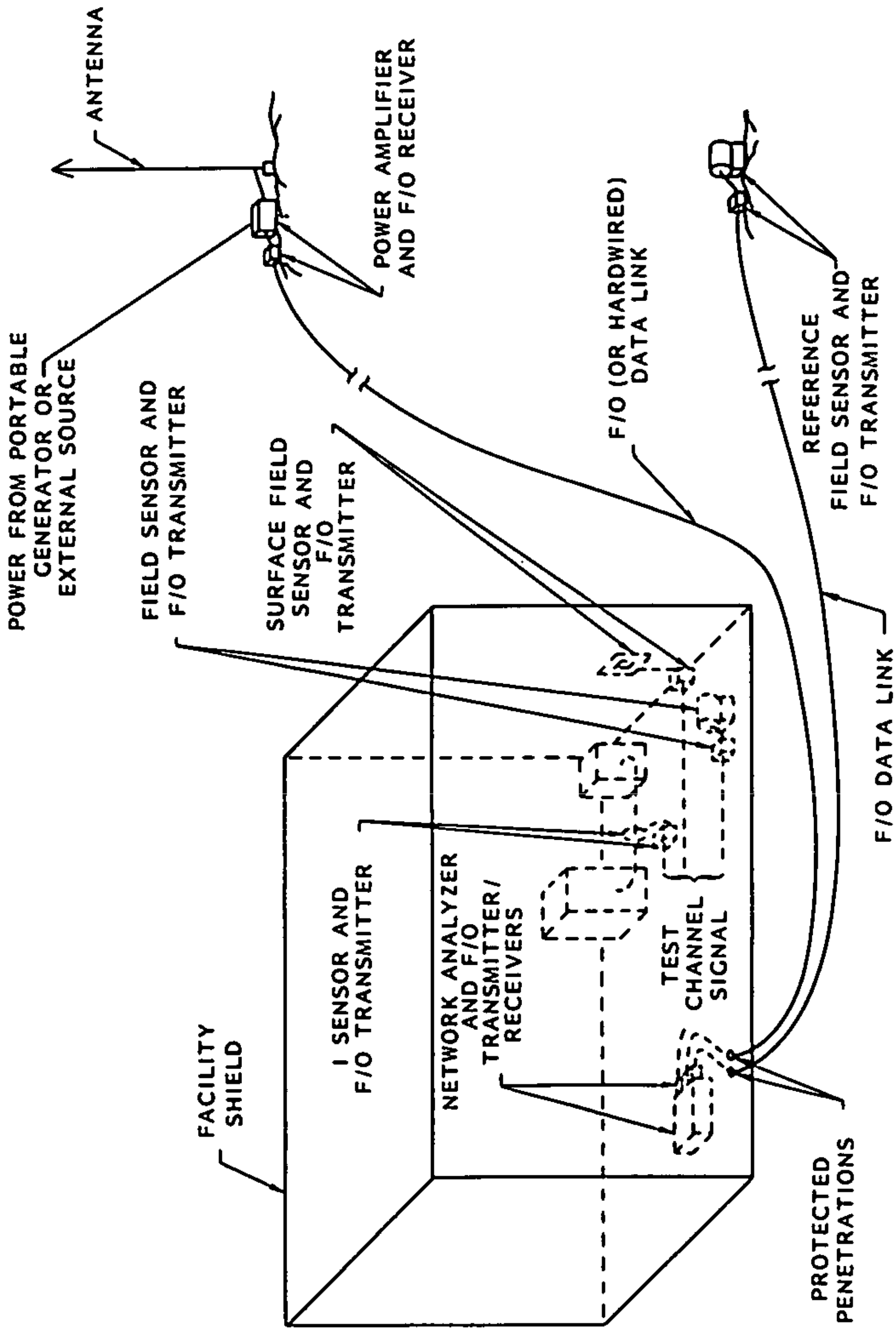

FIGURE 16. CW immersion testing.

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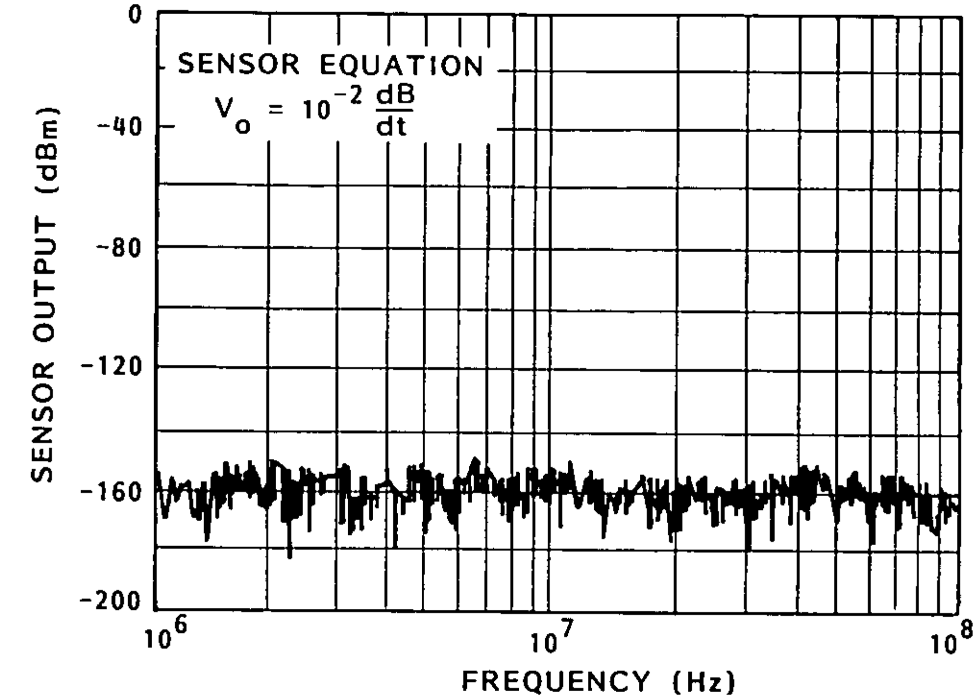
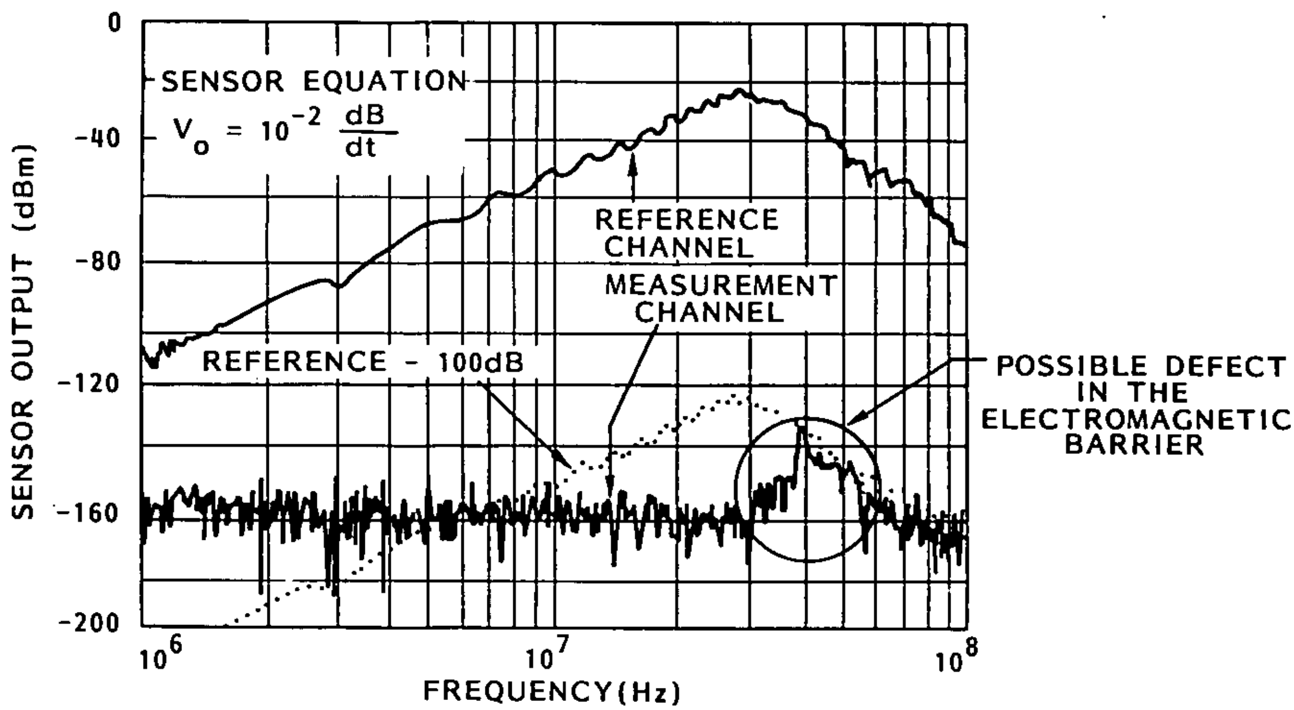


a. Noise/operating signal response.



b. Reference and measurement point responses.

FIGURE 17. CW immersion test record.

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50.3 Measurement locations. For facilities less than 900 m^2 (10,000 ft^2) in shielded floor area, a minimum of 5 (×3 components) electric or magnetic free-field measurement locations, 3 (×2 components) surface current or charge density measurement locations, and 20 current measurement locations throughout the shielded volume shall be chosen for each transmitting antenna location. For larger facilities, the number of measurement locations shall be increased in proportion to the total shielded floor area.

Measurement points for each transmitting antenna location should be concentrated in the 40 to 50 percent of the protected volume and in special protective volumes physically closest to electromagnetic barrier surfaces which are directly illuminated.

Internal free-field measurement points shall be chosen to provide a representative mapping of field responses within the electromagnetic barrier. The free-field measurements shall be made in areas which are relatively clear of equipment. The three orthogonal components of the field response shall be recorded. Internal magnetic free-field measurements should normally be emphasized.

Internal surface current or charge density measurements shall principally be made at penetration areas on the electromagnetic barrier. Internal surface current density measurements should normally be emphasized. When measuring surface current density, the two orthogonal components of the response shall be recorded.

Internal current measurement points shall be chosen to provide a representative mapping of current responses in the internal cable plant. Current measurements shall be made on selected penetrating cables near their POE protective devices, on selected cables with long interior runs or layouts producing efficient coupling geometries, and on input cables to selected mission-essential equipment.

An interior electromagnetic survey, with CW excitation applied from each transmitting antenna location, shall be performed to locate areas of maximum response. Particular attention should be given to barrier penetration areas. Additional free-field and current measurement points shall be chosen where the largest signals are detected during the survey.

50.4 Test frequencies. Test data are desired at frequencies from 100 kHz to 1 GHz. It is usually necessary to divide the frequencies into several bands, selecting different antennas to maximize the radiation efficiency in the different bands.

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50.5 Measurement procedures. CW immersion test procedures shall be as follows:

a. Set up the data acquisition equipment in the desired configuration and perform calibrations. Minimum sensitivity of the data acquisition system should be −147 dBm or lower.

b. Set up the transmitting antenna and map its fields. The principal component of the illuminating field:

[speed of light (c) × magnetic induction field ($B_{\text{illuminating}}$)] or electric field ($E_{\text{illuminating}}$)

should be at least 1 V/m from 1 MHz to 50 MHz and at least 0.1 V/m from 50 MHz to 100 MHz at the point on the electromagnetic barrier closest to the transmitting antenna. As a design objective, the principal component of the illuminating field should be at least 0.1 V/m from 100 kHz to 1 MHz and 0.01 V/m from 100 MHz to 1 GHz. Choose a reference sensor location.

c. Perform a check of each data acquisition channel to verify link noise immunity. Disconnect the sensor and terminate the sensor cable in its characteristic impedance. Energize the radiating source, and record the received signal strength as a function of frequency.

d. With the radiating source energized, perform a survey of the area to be monitored and select the additional measurement locations.

e. Place the sensor and use preamplifiers as required to obtain the desired measurement sensitivity.

f. With the source and data acquisition equipment in a normal configuration, except that the power amplifier is turned off, record the noise and operating signal response at the measurement point as a function of frequency. Narrow band filter and long sweep time settings of the network analyzer are necessary.

g. Turn the power amplifier on and record the reference and measurement point responses as a function of frequency, using the same filter and sweep time settings employed for the noise and operating signal measurement.

h. Perform data quality control. Annotate and preserve the data records.

i. Record any interference with the operation of facility equipment observed during the CW immersion test. Also record test and operational conditions which existed at the time the interference was noted.

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j. Continue to the next measurement location and repeat steps e through i.

k. When measurements for one transmitting antenna location are completed, continue to the next transmitting antenna location and repeat steps b through j.

50.6 Pass/fail criteria[16].

50.6.1 Internal field measurements. In frequency bands where the measurement dynamic range is less than the required attenuation, internal CW immersion free-field and surface current or charge density measurements shall be considered satisfactory when there is no observable test point response above the noise and operating signal level.

In the frequency band where the measurement dynamic range is greater than the required attenuation, expected to be at least 5 MHz to 100 MHz, internal CW immersion field measurements shall be considered satisfactory when the test point responses are below the principal component of the illuminating field by at least the required attenuation. This success criterion is expressed by the following equations:

50.6.1.1 For internal magnetic induction field measurements.

$$B_{\text{internal}} \leq \frac{8000}{\omega} \times B_{\text{illuminating}} \quad \omega < 8 \times 10^8$$

$$\leq 10^{-5} \times B_{\text{illuminating}} \quad \omega \geq 8 \times 10^8$$

where

B_{internal} = measured component of the magnetic induction field at a test point inside the electromagnetic barrier (Wb/m^2)

$B_{\text{illuminating}}$ = principal component of the illuminating magnetic induction field at the point on the electromagnetic barrier closest to the transmitting antenna (Wb/m^2)

ω = angular frequency (s^{-1})

[16]These pass/fail criteria apply to all measurements made in the protected volume. Responses measured in a special protective volume must not exceed design values for that special protective volume.

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50.6.1.2 For internal electric field measurements.

$$E_{\text{internal}} \leq 10^{-5} \times E_{\text{illuminating}}$$

where

E_{internal} = measured component of the electric field at a test point inside the electromagnetic barrier (V/m)

$E_{\text{illuminating}}$ = principal component of the illuminating electric field at the point on the electromagnetic barrier closest to the transmitting antenna (V/m)

50.6.1.3 For internal surface current density measurements.

$$J_{S_{\text{internal}}} \leq \frac{6.4 \times 10^{9}}{\omega} \times B_{\text{illuminating}} \qquad \omega < 8 \times 10^{8}$$

$$\leq 8 \times B_{\text{illuminating}} \qquad \omega \geq 8 \times 10^{8}$$

where

$J_{S_{\text{internal}}}$ = measured component of surface current density at a test point inside the electromagnetic barrier (A/m)

50.6.1.4 For internal charge density measurements.

$$Q_{S_{\text{internal}}} \leq 8.9 \times 10^{-17} \times E_{\text{illuminating}}$$

where

$Q_{S_{\text{internal}}}$ = measured surface charge density at a test point inside the electromagnetic barrier (C/m^2)

50.6.2 Internal current measurements. Internal CW immersion current measurements shall be considered satisfactory when the peak value of the threat-extrapolated response, transformed into the time domain, does not exceed 0.1 amperes. This success criteria is

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expressed by the following equation:

$$\frac{1}{2\pi}\int_{2\pi f_\ell}^{2\pi f_u}\left[I_{\text{threat}}(\omega)e^{-i\omega t}+I^{*}_{\text{threat}}(\omega)e^{i\omega t}\right]d\omega \le 0.1$$

for all time t, where

f_ℓ = the lowest CW immersion test frequency (Hz)

f_u = the highest CW immersion test frequency (Hz)

$I_{\text{threat}}(\omega)$ = threat-extrapolated current in the frequency domain (A/Hz)

$$= \frac{I_{\text{internal}}(\omega)}{[c \times B_{\text{illuminating}}(\omega)] \text{ or } E_{\text{illuminating}}} \times E_{\text{threat}}(\omega)$$

$I_{\text{internal}}(\omega)$ = measured current at a test point inside the electromagnetic barrier (A)

$E_{\text{threat}}(\omega)$ = early-time threat HEMP field in the frequency domain (V/m-Hz) (see DoD-STD-2169)

$I^{*}_{\text{threat}}(\omega)$ = complex conjugate of $I_{\text{threat}}(\omega)$

50.6.3 Interference. Functional monitoring of facility operation shall be considered satisfactory when no interference with mission-essential communication-electronics or support equipment is observed.

50.6.4 Test failures. Any failure to satisfy the internal field measurement, internal current measurement, or interference success criteria shall be considered a HEMP vulnerability. An investigation into the cause of the possible vulnerability shall be conducted. The condition shall be corrected, if possible, and the CW immersion test sequence shall be repeated.

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Navy—MC,NC,NM,OM,TD
Air Force—01,02,13,14,15,17,19,89,91,92,93
DLA—DH
DNA—DS
DCA—DC
NSA—NS
JTC^3A—JT
DoD/ECAC—EM
DMA—MP

User activities:
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MIL-STD-188-125	See Section 6. REMARKS

3a. NAME OF SUBMITTING ORGANIZATION

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6. REMARKS

High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C^4I Facilities Performing Critical, Time-Urgent Missions for Common Long-Haul/Tactical Communication Systems

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional

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