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SENSITIVE

MIL-STD-464D
24 December 2020

SUPERSEDING
MIL-STD-464C
1 December 2010

DEPARTMENT OF DEFENSE
INTERFACE STANDARD

ELECTROMAGNETIC ENVIRONMENTAL EFFECTS REQUIREMENTS FOR SYSTEMS

AMSC 9159 AREA EMCS

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

FOREWORD

1. This standard is approved for use by all Departments and Agencies of the Department of Defense.

2. This standard contains two sections, the main body and an appendix. The main body of the standard specifies a baseline set of requirements. The appendix provides rationale, guidance, and lessons learned for each requirement to enable the procuring activity to tailor the baseline requirements for a particular application. The appendix also permits Government and Industry personnel to understand the purpose of the requirements and potential verification methodology for a design. The appendix is not a mandatory part of this document. However, the term "shall" is used in the appendix as a means to reiterate points of emphasis (*in italics*) that the main section of this standard presents.

3. A joint committee consisting of representatives of the Army, Navy, Air Force, other DoD Agencies, and Industry participated in the preparation of the basic version of this standard.

4. Comments, suggestions, or questions on this document should be addressed to AFLCMC/EZSS, Bldg. 28, 2145 Monahan Way, Wright-Patterson AFB, OH 45433-7017, or emailed to Engineering.Standards@us.af.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil/.

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TABLES

1. SCOPE

1.1 Purpose.

This standard establishes electromagnetic environmental effects (E3) interface requirements and verification criteria for airborne, sea, space, and ground systems, including associated ordnance.

1.2 Application.

This standard is applicable for complete systems, both new and modified.

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed in this section are specified in sections 3, 4, or 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3, 4, or 5 of this standard, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
DOD-STD-1399-070-1	Interface Standard for Shipboard Systems Section 070 – Part 1 D.C. Magnetic Field Environment (Metric)
MIL-STD-2169	High Altitude Electromagnetic Pulse Environment (U)

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-240	Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide

(Copies of these documents are available online at https://quicksearch.dla.mil/. Application for copies of MIL-STD-2169 should be addressed with a need-to-know to: Defense Threat Reduction Agency, ATTN: RD-NTSA, 8725 John J Kingman RD STOP 6201, Fort Belvoir VA 22060-6201).

2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTEL REPORTS

Information Operations Capstone Threat Assessment Report (Latest Edition)

(Copies of this document are available via SIPRNET at http://www.intelink.sgov.gov/wiki/PROGRAM_THREAT_SUPPORT/.)

PUBLICATIONS

CNSS TEMPEST 01-02	Advisory Memorandum, NONSTOP Evaluation Standard
DoDI 4650.01	Policy and Procedures for Management and Use of the Electromagnetic Spectrum
DoDI 6055.11	Protecting Personnel from Electromagnetic Fields
NSTISSAM TEMPEST/1-92	Compromising Emanations Laboratory Test Requirements, Electromagnetics
NTIA	Manual of Regulations and Procedures for Federal Radio Frequency Management

(Copies of CNSS and NSTISSAM documents are available only through the procuring activity.)

(Copies of DoD Instructions are available online at https://www.esd.whs.mil/dd.)

(Copies of the NTIA Manual are available from the U.S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.)

(Copies of the NTIA Manual are available online at http://www.ntia.doc.gov/publications/.)

2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI/IEEE C63.14	Dictionary of Electromagnetic Compatibility (EMC) Including Electromagnetic Environmental Effects (E3)

(Copies of this document are available online at http://www.ieee.org/.)

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

ISO 46	Aircraft – Fuel Nozzle Grounding Plugs and Sockets

(Copies of this document are available from the International Organization for Standardization, 3 rue de Varembe, 1211 Geneve 20, Geneve, Switzerland or online at https://www.iso.org/store.html.)

JOINT SERVICES MUNITION SAFETY TEST WORKING GROUP

JOTP-062	Joint Ordnance Test Procedure (JOTP) Personnel-borne ElectroStatic Discharge (PESD) Helicopter-borne ElectroStatic Discharge (HESD)

(Copies of this document are available online at https://quicksearch.dla.mil.)

2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

The terms used in this standard are defined in ANSI Standard C63.14. In addition, the following definitions are applicable for the purpose of this standard.

3.1 All-up-round (AUR).

The completely assembled munition as intended for delivery to a target or configured to accomplish its intended mission. This term is identical to the term all-up-weapon.

3.2 Bare devices.

Bare electrically initiated devices (EIDs) such as electrical initiators, exploding foil initiators, detonators, etc., in an all-up round that have either one or both pins accessible on an external connector.

3.3 Below deck.

An area on ships that is surrounded by a metallic structure such as the hull or superstructure of metallic surface ships, the hull of a submarine, the screened areas or rooms of non-metallic ships, the screened areas of ships utilizing a combination of metallic/non-metallic material for hull and superstructure or a deck mounted metallic shelter. This also includes inside the pressure hull of submarines.

3.4 Compromising emanations.

Unintentional intelligence-bearing signals which, if intercepted and analyzed, disclose the national security information transmitted, received, handled, or otherwise processed by any classified information processing system.

3.5 Electrically initiated device (EID).

An EID is a single unit, device, or subassembly that uses electrical energy to produce an explosive, pyrotechnic, thermal, or mechanical output. Examples include: electroexplosive devices (such as hot bridgewire, semiconductor bridge, carbon bridge, and conductive composition), exploding foil initiators, laser initiators, burn wires, and fusible links.

3.6 Electromagnetic environmental effects (E3).

The impact of the electromagnetic environment (EME) upon the operational capability of military forces, equipment, systems, and platforms. E3 encompasses the electromagnetic effects addressed by the disciplines of electromagnetic compatibility (EMC), electromagnetic interference (EMI), electromagnetic vulnerability (EMV), electromagnetic pulse (EMP), electronic protection (EP), electrostatic discharge (ESD), and hazards of electromagnetic radiation to personnel (HERP), ordnance (HERO), and volatile materials (HERF). E3 includes the electromagnetic effects generated by all EME contributors including radio frequency (RF) systems, ultra-wideband devices, high-power microwave (HPM) systems, lightning, precipitation static, etc.

3.7 Energetics.

A substance or mixture of substances that, through chemical reaction, is capable of rapidly releasing energy. A few examples of energetics are: liquid and solid propellants such as in rockets and air bags, gun propellants, Polymer Bonded Explosives (PBX) for warheads, pyrotechnics for flares and ignition systems.

3.8 Flight Deck.

The upper deck of an aircraft carrier that serves as a runway. The deck of an air-capable ship, amphibious aviation assault ship, or aviation ship used to launch and recover aircraft.

3.9 HERO SAFE ordnance.

Any ordnance item containing an EID that is sufficiently shielded or otherwise so protected that all EIDs contained by the item are immune to adverse effects (safety or reliability) when the item is employed in the radio frequency environment delineated in this standard. The general hazards of electromagnetic radiation to ordnance requirements defined in the hazards from electromagnetic radiation manuals must still be observed. Note: Percussion-initiated ordnance have no HERO requirements.

3.10 HERO SUSCEPTIBLE ordnance.

Any ordnance item containing EIDs proven by test or analysis to be adversely affected by radio frequency energy to the point that the safety and/or reliability of the system is in jeopardy when the system is employed in the radio frequency environment delineated in this standard.

3.11 HERO UNSAFE ordnance.

Any ordnance item containing EIDs that have not been classified as HERO SAFE or HERO SUSCEPTIBLE ordnance as a result of a hazards of electromagnetic radiation to ordnance (HERO) analysis or test. Additionally, any ordnance item containing EIDs (including those previously classified as HERO SAFE or HERO SUSCEPTIBLE ordnance) that has its internal wiring exposed; when tests are being conducted on that item that result in additional electrical connections to the item; when EIDs having exposed wire leads are present and handled or loaded in any but the tested condition; when the item is being assembled or disassembled; or when such ordnance items are damaged causing exposure of internal wiring or components or destroying engineered HERO protective devices.

3.12 Helicopter-borne electrostatic discharge (HESD).

The sudden flow of electric charge between a helicopter or rotary winged aircraft and an object of different electrical potential. A buildup of static electricity can be caused by triboelectric charging or electrostatic induction generated from operating rotary wings.

3.13 High power microwave (HPM).

A radio frequency environment produced by microwave sources (weapon) capable of emitting high power or high energy densities. The source may produce microwaves in the form of a single pulse, repetitive pulses, pulses of more complex modulation, or continuous wave (CW) emissions.

3.14 Launch vehicle.

A composite of the initial stages, injection stages, space vehicle adapter, and fairing having the capability of launching and injecting a space vehicle or vehicles into orbit.

3.15 Lightning direct effects.

Any physical damage to the system structure and electrical or electronic equipment due to the direct attachment of the lightning channel and current flow. These effects include puncture, tearing, bending, burning, vaporization, or blasting of hardware.

3.16 Lightning indirect effects.

Electrical transients induced by lightning due to coupling of electromagnetic fields. These effects include malfunction or damage to electrical/electronic equipment.

3.17 Margins.

The difference between the subsystem and equipment electromagnetic strength level, and the subsystem and equipment stress level caused by electromagnetic coupling at the system level. Margins are normally expressed as a ratio in decibels (dB).

3.18 Maximum no-fire stimulus.

The greatest firing stimulus that will not cause initiation or degrade an EID of more than 0.1 % of all electric initiators of a given design at a confidence level of 95%. Stimulus refers to electrical parameters such as current, rate of change of current (di/dt), power, voltage, or energy, which are most critical in defining the no-fire performance of the EID.

3.19 Mission critical.

Unless otherwise defined in the procurement specification, a term applied to a condition, event, operation, process, or item which if performed improperly, may: 1) prohibit execution of a mission, 2) significantly reduce the operational capability, or 3) significantly increase system vulnerability.

3.20 Multipaction.

Multipaction is a radio frequency (RF) resonance effect that occurs only in a high vacuum, where RF field accelerates free electrons resulting in collisions with surfaces creating secondary electrons that are accelerated, resulting in more electrons and ultimately a major discharge and possible equipment damage.

3.21 Non-developmental item.

Non-developmental item is a broad, generic term that covers material, both hardware and software, available from a wide variety of sources with little or no development effort required by the Government.

3.22 Ordnance.

All up rounds or components with explosives, chemicals pyrotechnics or similar stores such as: missiles, torpedoes, bombs, ammunition, cartridge actuated devices, flares, smoke or napalm.

3.23 Personnel-borne electrostatic discharge (PESD).

The sudden flow of electric charge between personnel and an object of different electrical potential. A buildup of static electricity can be caused by triboelectric charging or electrostatic induction generated by the movement of the person's body.

3.24 Platform.

A mobile or fixed installation such as a ship, aircraft, ground vehicles and shelters, personnel, launch-space vehicles, shore or ground station. For the purposes of this standard, a platform is considered a system.

3.25 Safety critical.

Unless otherwise defined in the procurement specification, a term applied to a condition, event, operation, process, or item whose proper recognition, control, performance or tolerance is essential to safe system operation or use; for example, safety critical function, safety critical path, or safety critical component. A term also used when a failure or malfunction of a system or subsystem can cause death or serious injury to personnel.

3.26 Shielded area.

An area not directly exposed to EM energy. This includes shielded spaces, compartments and rooms; areas inside the hull and superstructure of metallic hull ships; areas inside metallic shelters, a metallic enclosure or a metallic mast; and areas in screen rooms on nonmetallic hull ships.

3.27 Spectrum-dependent systems.

All electronic systems, subsystems, devices, and/or equipment that depend on the use of the spectrum to properly accomplish their function(s) without regard to how they were acquired (full acquisition, rapid acquisition, Joint Concept Technology Demonstration, etc.) or procured (commercial off-the-shelf, government off-the-shelf, non-developmental items, etc.). This includes transmitters, transceivers, and receive-only systems.

3.28 Space vehicle.

A complete, integrated set of subsystems and components capable of supporting an operational role in space. A space vehicle may be an orbiting vehicle, a major portion of an orbiting vehicle, or a payload of an orbiting vehicle which performs its mission while attached to a recoverable launch vehicle. The airborne support equipment, which is peculiar to programs utilizing a recoverable launch vehicle, is considered a part of the space vehicle being carried by the launch vehicle.

3.29 Subsystem.

A portion of a system containing two or more integrated components that, while not completely performing the specific function of a system, may be isolated for design, test, or maintenance. Either of the following are considered subsystems for the purpose of establishing EMC requirements. In either case, the devices or equipment may be physically separated when in operation and will be installed in fixed or mobile stations, vehicles, or systems.

a. A collection of devices or equipment designed and integrated to function as a single entity but wherein no device or equipment is required to function as an individual device or equipment.

b. A collection of equipment and subsystems designed and integrated to function as a major subdivision of a system and to perform an operational function or functions. Some activities consider these collections as systems; however, as noted above, they will be considered as subsystems.

3.30 System.

A composite of equipment, subsystems, skilled personnel, and techniques capable of performing or supporting a defined operational role. A complete system includes related facilities, equipment, subsystems, materials, services, and personnel required for its operation to the degree that it can be considered self-sufficient within its operational or support environment (see 3.24).

3.31 System operational performance.

A set of minimal acceptable parameters tailored to the platform and reflecting top level capabilities such as range, probability of kill, probability of survival, operational availability, and so forth. A primary aspect of acquisition related to this definition are key performance parameters (KPPs), which are used in acquisition to specify system characteristics that are considered most essential for successful mission accomplishment and that are tracked during development to evaluate the effectiveness of the system. For the purposes of this document, the set of parameters under consideration would normally extend beyond this limited set of parameters to address other details of system performance that may be less critical but still have a substantial impact on system effectiveness.

3.32 TEMPEST.

An unclassified, short name referring to the investigation and study of compromising emanations.

3.33 Topside areas.

All shipboard areas continuously exposed to the external electromagnetic environment, such as the main deck and above, catwalks, and those exposed portions of gallery decks.

3.34 Vertical replenishment (VERTREP).

The transfer of ordnance and cargo using rotary winged aircraft.

3.35 Weather Deck.

The topside of the ship that is exposed to the weather. The weather deck does not include the flight deck, hangar, well deck, man-aloft areas, or the ship's mast.

4. GENERAL REQUIREMENTS

4.1 General.

Each system shall be electromagnetically compatible in its operational electromagnetic environment such that the operational performance requirements are met. This standard identifies baseline design requirements and verification to address E3 issues. Requirements and verification approaches may be tailored based on engineering justification derived from the system's operational requirements and engineering analysis. Design techniques used to achieve electromagnetic compatibility shall be verifiable, maintainable, and effective over the rated life cycle of the system. Design margins shall be established based on system criticality, hardware tolerances, and uncertainties involved in verification of system-level design requirements. Verification shall address all life cycle aspects of the system, including (as applicable) normal in-service operation, checkout, storage, transportation, handling, packaging, loading, unloading, launch, and the normal operating procedures associated with each aspect. The Data Item Description (DID) called out in the standard provide a means for establishing an overall integrated E3 design and verification approach to identify areas of concern early in the program, mitigate risk, and document test results.

5. DETAILED REQUIREMENTS

5.1 Margins.

Margins shall be established for safety and mission critical subsystems/equipment within the system. Margins shall be no less than 6 dB for safety critical subsystems/equipment, unless otherwise stated in the detailed requirements of this standard. Compliance shall be verified by test, analysis, or a combination thereof.

5.2 Intra-system electromagnetic compatibility (EMC).

The system shall be electromagnetically compatible within itself such that system operational performance requirements are met. Compliance shall be verified by system-level test, analysis, or a combination thereof. This includes permanent, temporary, and portable electronic equipment.

5.2.1 Hull generated intermodulation interference (IMI).

For surface ship applications, the intra-system EMC requirement is considered to be met for hull generated IMI when IMI product orders higher than 19th order produced by High Frequency (HF) transmitters installed onboard ship are not detectable by antenna-connected receivers onboard ship. Compliance shall be verified by test, analysis, or a combination thereof, through measurement of received levels at system antennas and evaluation of the potential of these levels to degrade receivers.

5.2.2 Shipboard internal electromagnetic environment (EME).

For ship and submarine applications, electric fields (peak V/m-rms) below deck from intentional onboard transmitters shall not exceed the following levels:

a. Surface ships.

1) Metallic: 10 V/m from 10 kHz to 18 GHz.

Intentional transmitters used below deck shall be limited to a maximum output of 100 milliwatts (mW) effective isotropic radiated power (EIRP). The total combined power radiated within a compartment and within the operating frequency band shall be limited to 550 mW total radiated power (TRP). Additionally, no device shall be permanently installed within 1 meter of safety or mission critical electronic equipment.

2) Non-metallic: 50 V/m from 2 MHz to 1 GHz;
Metallic limits apply for all other frequency bands

Intentional transmitters used below deck shall be limited to a maximum output of 100 milliwatts (mW) effective isotropic radiated power (EIRP). The total combined power radiated within a compartment and within the operating frequency band shall be limited to 13.75 W total radiated power (TRP). Additionally, no device shall be permanently installed within 1 meter of safety or mission critical electronic equipment.

b. Submarines. 5 V/m from 10 kHz to 30 MHz and
10 V/m from 30 MHz to 18 GHz.

Intentional transmitters used below deck shall be limited to a maximum output of 25 milliwatts (mW) effective isotropic radiated power (EIRP). The total combined power radiated within a compartment and within the operating frequency band shall be limited to 250 mW total radiated power (TRP).

For surface ships, compliance shall be verified by test of electric fields generated below deck with all antennas (topside and below decks) radiating and adherence to the total radiated power limits indicated. For submarines, compliance shall be verified by test or by analysis of the TRP of below deck transmitters.

5.2.3 Multipaction.

For space applications, equipment and subsystems shall be free of multipaction effects. Compliance shall be verified by test and analysis.

5.2.4 Induced levels at antenna ports of antenna-connected receivers.

Induced levels appearing at antenna ports of antenna-connected receivers caused by unintentional radio frequency (RF) emissions from equipment and subsystems shall not exceed critical receiver design thresholds such that system operational performance requirements are met. Compliance shall be verified by measurements at antenna ports of receivers over their entire operating frequency band at the system level.

5.3 External RF EME.

The system shall be electromagnetically compatible with its defined external RF EME such that its system operational performance requirements are met. TABLE I shall be used for deck operations on Navy ships, and TABLE II shall be used for ships operations in the main beam of transmitters for Navy ships. For space and launch vehicle systems applications, TABLE III shall be used. For ground systems, TABLE IV shall be used. For rotary wing aircraft, where shipboard operations are excluded, TABLE V shall be used. For fixed wing aircraft applications, where shipboard operations are excluded, TABLE VI shall be used. Unmanned vehicles shall meet the above requirements for their respective application. It should be noted that for some of the frequency ranges, limiting the exposure of personnel will be needed to meet the requirements of 5.9.1 for personnel safety.

TABLE I. Maximum external EME for deck operations on Navy ships.

Frequency Range		Shipboard Flight Decks		Shipboard Weather Decks	
		Electric Field (V/m – rms)		Electric Field (V/m – rms)	
(MHz)	(MHz)	Peak	Average	Peak	Average
0.01	2	*	*	*	*
2	30	164	164	189	189
30	150	61	61	61	61
150	225	61	61	61	61
225	400	61	61	61	61
400	700	196	71	445	71
700	790	94	94	94	94
790	1000	491	100	744	141
1000	2000	212	112	212	112
2000	2700	159	159	159	159
2700	3600	4700	595	4700	595
3600	4000	1225	200	1859	200
4000	5400	200	200	200	200
5400	5900	361	213	711	235
5900	6000	213	213	235	235
6000	7900	213	213	235	235
7900	8000	200	200	200	200
8000	8400	200	200	200	200
8400	8500	200	200	200	200
8500	11000	913	200	913	200
11000	14000	745	200	833	200
14000	18000	745	200	833	200
18000	50000	200	200	267	200

NOTE: *denotes no emitters in that frequency range.

TABLE II. Maximum external EME for ship operations in the main beam of transmitters.

Frequency Range (MHz)		**Main Beam** (distances vary with ship class and antenna configuration) **Electric Field (V/m – rms)**	
		Peak	**Average**
0.01	2	*	*
2	30	200	200
30	150	15	15
150	225	17	17
225	400	43	43
400	700	2036	268
700	790	20	20
790	1000	2615	489
1000	2000	930	156
2000	2700	21	21
2700	3600	27460‡	7500‡
3600	4000	8553	272
4000	5400	1357	198
5400	5900	3234	637
5900	6000	637	637
6000	7900	667	667
7900	8000	667	667
8000	8400	449	449
8400	8500	400	400
8500	11000	6900	6900
11000	14000	3329	642
14000	18000	3329	642
18000	50000	2862	576

NOTE: * denotes no emitters in that frequency range.

‡ The EME levels in the table apply to shipboard operations in the main beam of systems in the 2700 to 3600 MHz frequency range on surface combatants. For all other operations, the unrestricted peak EME level is 12667 V/m and the unrestricted average level is 5350 V/m.

TABLE III. Maximum external EME for space and launch vehicle systems.

Frequency Range (MHz)		Electric Field (V/m – rms)	
		Peak	Average
0.01	2	1	1
2	30	73	73
30	150	17	17
150	225	4	1
225	400	*	*
400	700	47	6
700	790	1	1
790	1000	7	7
1000	2000	63	63
2000	2700	187	187
2700	3600	23	8
3600	4000	2	2
4000	5400	3	3
5400	5900	164	164
5900	6000	164	164
6000	7900	6	6
7900	8000	3	1
8000	8400	1	1
8400	8500	3	1
8500	11000	140	116
11000	14000	114	114
14000	18000	16	9
18000	50000	23	23

NOTE: *denotes no emitters in that frequency range.

TABLE IV. Maximum external EME for ground systems.

Frequency Range (MHz)		Electric Field (V/m – rms)	
		Peak	Average
0.01	2	54	54
2	30	103	103
30	150	74	74
150	225	41	41
225	400	92	92
400	700	98	98
700	790	58	58
790	1000	58	58
1000	2000	232	94
2000	2700	638	42
2700	3600	1148	219
3600	4000	320	25
4000	5400	645	173
5400	5900	5183	129
5900	6000	40	40
6000	7900	3190	292
7900	8000	2471	296
8000	8400	2471	296
8400	8500	82	82
8500	11000	810	139
11000	14000	3454	102
14000	18000	7897	243
18000	50000	2793	48

TABLE V. Maximum external EME for rotary-wing aircraft excluding shipboard operations.

Frequency Range (MHz)		Electric Field (V/m – rms)	
		Peak	Average
0.01	2	200	200
2	30	200	200
30	150	200	200
150	225	200	200
225	400	200	200
400	700	1311	402
700	790	700	183
790	1000	700	215
1000	2000	6057	232
2000	2700	3351	200
2700	3600	4220	455
3600	4000	3351	200
4000	5400	9179	657
5400	5900	9179	657
5900	6000	9179	200
6000	7900	400	200
7900	8000	400	200
8000	8400	7430	266
8400	8500	7430	266
8500	11000	7430	266
11000	14000	7430	558
14000	18000	730	558
18000	50000	1008	200

TABLE VI. Maximum external EME for fixed-wing aircraft excluding shipboard operations.

Frequency Range (MHz)		Electric Field (V/m – rms)	
		Peak	Average
0.01	2	88	27
2	30	64	64
30	150	67	13
150	225	67	36
225	400	58	3
400	700	2143	159
700	790	554	81
790	1000	289	105
1000	2000	3363	420
2000	2700	957	209
2700	3600	4220	455
3600	4000	148	11
4000	5400	3551	657
5400	5900	3551	657
5900	6000	148	4
6000	7900	344	14
7900	8000	148	4
8000	8400	187	70
8400	8500	187	70
8500	11000	6299	238
11000	14000	2211	94
14000	18000	1796	655
18000	50000	533	38

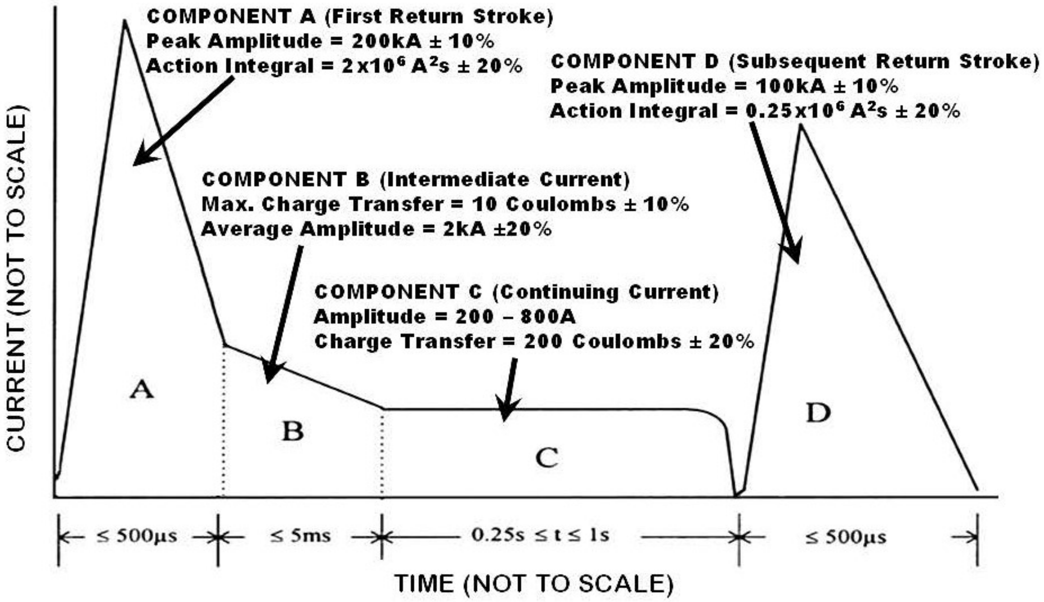
Systems exposed to more than one of the defined EMEs shall use the worst case composite of the applicable EMEs. External RF EME covers compatibility with, but is not limited to, EME's from like platforms (such as aircraft in formation flying, ship with escort ships, and shelter-to-shelter in ground systems) and friendly emitters. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.

5.4 High-power microwave (HPM) sources.

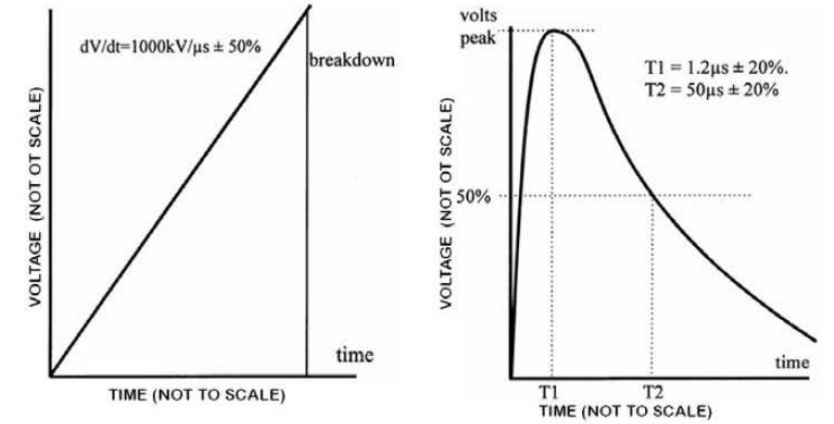
The system shall meet its operational performance requirements after being subjected to the narrowband and wideband HPM environments. Applicable field levels and HPM pulse characteristics for a particular system shall be determined by the procuring activity based on operational scenarios, tactics, and mission profiles using authenticated threat and source data, such as the Capstone Threat Assessment Report. This requirement is applicable only if specifically invoked by the procuring activity. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.

5.5 Lightning.

The system shall meet its operational performance requirements when subjected to direct, indirect, and near strike lightning effects. Ordnance shall meet its operational performance requirements after experiencing a near strike in an exposed condition and a direct strike in a stored condition. Ordnance shall remain safe during and after experiencing a direct strike in an exposed condition. FIGURE 1 provides aspects of the lightning environment that are relevant for protection against direct effects. TABLE VII defines the waveform parameters applicable at the platform for lightning direct and indirect effects evaluations. Waveforms appropriate for direct effects include voltage Waveforms A, B, C, D, and current Components A, Ah, B, C, and D. Waveforms appropriate for indirect effects evaluations include current components A, D, and H which are individual components of the single stroke, multiple stroke and multiple burst waveform sets. FIGURE 2 provides the timing sequence and number of pulses required to replicate the multiple stroke and multiple burst environments. TABLE VIII shall be used for the near strike lightning environment. Compliance shall be verified by system, subsystem, equipment, and component level tests, analysis, or a combination thereof.

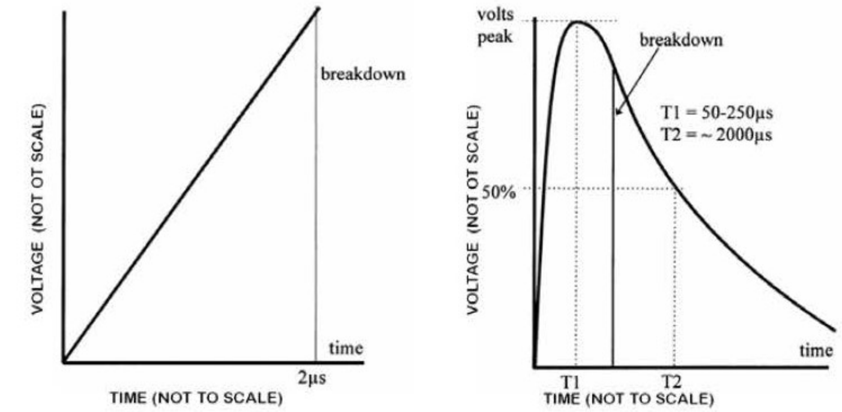


Electrical Current Waveforms



VOLTAGE WAVEFORM COMPONENT A

VOLTAGE WAVEFORM COMPONENT B



VOLTAGE WAVEFORM COMPONENT C

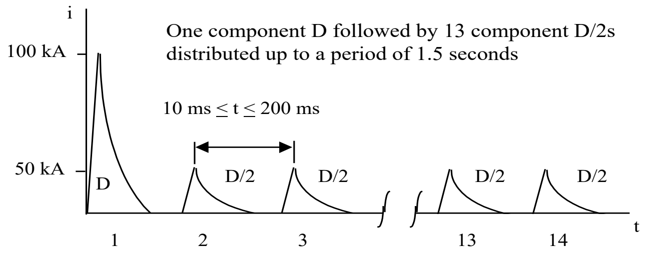
VOLTAGE WAVEFORM COMPONENT D

FIGURE 1. Lightning direct effects environment.

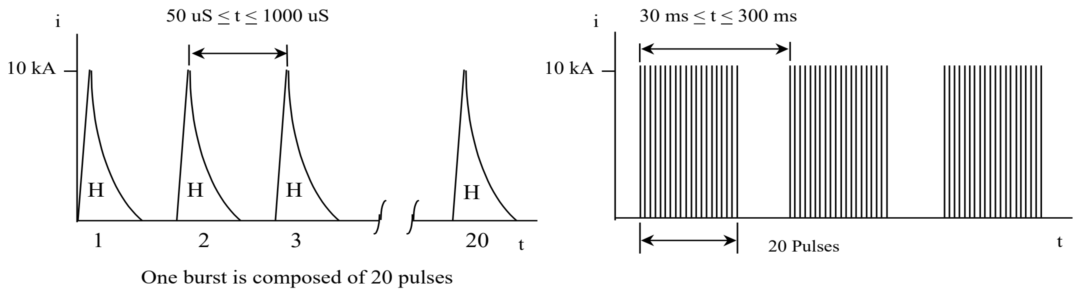
TABLE VII. Lightning direct and indirect effects waveform parameters.

Current Component	Description	$i(t) = I_o\left(e^{-\alpha t} - e^{-\beta t}\right)$ t is time in seconds (s)		
		I_o (Amperes)	$\alpha(s^{-1})$	$\beta(s^{-1})$
A	Severe stroke	218,810	11,354	647,265
A_h	Transition zone first return stroke	164,903	16,065	858,888
B	Intermediate current	11,300	700	2,000
C	Continuing current	400 for 0.5 s	Not applicable	Not applicable
D	Subsequent Stroke Current	109,405	22,708	1,294,530
D/2	Multiple stroke	54,703	22,708	1,294,530
H	Multiple burst	10,572	187,191	19,105,100

NOTE: Current Component A_h is applicable in the Transition Zone 1C and represents the estimated shape of the first return stroke (Component A) at higher altitudes.



Multiple Stroke Flash



Multiple Burst Waveform

FIGURE 2. Lightning indirect effects environment.

TABLE VIII. Electromagnetic fields from near strike lightning (cloud-to-ground).

Magnetic field rate of change @ 10 meters	2.2×10^{9} A/m/s
Electric field rate of change @ 10 meters	6.8×10^{11} V/m/s

5.6 Electromagnetic pulse (EMP).

The system shall meet its operational performance requirements after being subjected to the EMP environment. This environment is classified and is currently defined in MIL-STD-2169. This requirement is applicable only if invoked by the procuring activity. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.

5.7 Subsystems and equipment electromagnetic interference (EMI).

Individual subsystems and equipment shall meet interference control requirements (such as the conducted emissions, radiated emissions, conducted susceptibility, and radiated susceptibility requirements of MIL-STD-461) so that the overall system complies with all applicable requirements of this standard. This includes permanent, temporary, and portable electronic equipment. Compliance shall be verified by tests that are consistent with the individual requirement (such as testing in accordance with MIL-STD-461).

5.7.1 Portable Electronic Devices and Carry-On Equipment Requirements.

Portable electronic devices and carry-on equipment containing electronics which are not permanently installed or integrated into platforms and require airworthiness certification shall meet, as a minimum, the following EMI interface control requirements:

> Safety Critical: All platform emissions and susceptibility requirements (such as those defined in MIL-STD-461) that are defined for safety critical equipment.
>
> Non-Safety Critical: All platform emissions requirements (such as those defined in MIL-STD-461).

If any part of the portable electronic device/carry-on equipment contains radio frequency transmission capability, then transmitter emissions characteristics shall be measured (such as in MIL-STD-461 Test Method CE106), in addition to the applicable requirements stated above. An aircraft EMC evaluation per 5.2 shall also be required to demonstrate platform compatibility of the portable electronic devices/carry-on equipment which have radio frequency transmitting capability.

If any part of the portable electronic device/carry-on equipment contains ordnance or is integrated into an ordnance system, then the HERO requirements stated within this standard shall also be met. Compliance shall be verified by test per the applicable requirements.

5.7.2 Non-developmental items (NDI) and commercial items.

NDI and commercial items shall meet EMI interface control requirements suitable for ensuring that system operational performance requirements are met. Compliance shall be verified by test, analysis, or a combination thereof.

5.7.3 Shipboard DC magnetic field environment.

Subsystems and equipment used aboard ships shall not be degraded when exposed to its operational DC magnetic environment (such as DOD-STD-1399-070-1 (NAVY)). Compliance shall be verified by test, analysis, or a combination thereof.

5.8 Electrostatic environments.

The system shall safely control and dissipate the build-up of electrostatic charges caused by precipitation static (p-static) effects, fluid flow, air flow, exhaust gas flow, personnel charging, charging of launch vehicles (including pre-launch conditions) and space vehicles (post deployment), and other charge generating mechanisms to avoid fuel ignition, inadvertent detonation or dudding of ordnance hazards, to protect personnel from shock hazards, and to prevent performance degradation or damage to electronics. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

5.8.1 Vertical lift and in-flight refueling.

The system shall meet its operational performance requirements when subjected to a 300 kilovolt discharge from a simulated aircraft capacitance of 1000 picofarads, through a maximum of one (1) ohm resistance with a circuit inductance not to exceed 20 microhenry as delineated in joint documentation such as the JOTP-062. This requirement is applicable to vertical lift aircraft, in-flight refueling of any aircraft, any systems operated or transported externally by vertical lift aircraft. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

5.8.2 Precipitation static (p-static).

The system shall control p-static interference to antenna-connected receivers onboard the system or on the host platform such that system operational performance requirements are met. The system shall protect against puncture of structural materials and finishes and shock hazards from charge density of 30 $\mu A/ft^2$ (326 $\mu A/m^2$). Compliance shall be verified by test, analysis, inspections, or a combination thereof.

5.8.3 Ordnance subsystems.

Ordnance shall meet their safety and system operational performance requirements for personnel-borne electrostatic discharge (PESD) and helicopter-borne electrostatic discharge (HESD) from stockpile to safe separation. Compliance shall be verified by test, analysis, inspection, or a combination thereof.

5.8.3.1 Personnel-borne ESD (PESD) for Ordnance and Ordnance Systems.

Ordnance, ordnance subsystems and components shall meet their safety requirements when subjected to PESD environment and meet their system operational performance requirements after being subjected to PESD environment. The PESD environment is characterized by discharges up to 25 kV through 500 ohm and 5000 ohm resistors, from a 500 pF capacitance with a circuit inductance not to exceed 5 microhenry as delineated in joint documentation such as the JOTP-062. Compliance shall be verified by test, analysis or a combination thereof.

5.8.3.2 Helicopter-borne ESD (HESD) for Ordnance and Ordnance Systems.

Ordnance, ordnance subsystems and components shall meet their safety requirements when subjected to HESD environment and meet their system operational performance requirements after being subjected to HESD environment. The HESD environment is characterized by a discharge up to 300 kV with circuit resistance not to exceed 1 ohm and circuit inductance not to exceed 20 microhenry as delineated in joint documentation such as the JOTP-062. The ordnance systems fielded configuration in the intended operating environment is the basis of the assessment in the HESD evaluation. Compliance shall be verified by test, analysis or combination thereof.

5.8.4 Electrical and electronic subsystems.

Systems shall assure that all electrical and electronic subsystems that do not interface or control ordnance subsystems shall meet their operational performance requirements during and after exposure to electrostatic discharges. This requirement is applicable to electrical, electronic, and electromechanical subsystems and equipment that have a man-machine interface. The ESD environment is defined as an 8 kV (contact discharge) or 15 kV (air discharge), discharged from a 150 picofarad capacitor through a 330 ohm resistor with a circuit inductance not to exceed 5 microhenry. Compliance shall be verified by test in accordance with MIL-STD-461.

5.9 Radiation hazards (RADHAZ).

The system design shall protect personnel, fuels, and ordnance from hazardous effects of electromagnetic radiation. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

5.9.1 Hazards of electromagnetic radiation to personnel (HERP).

The system shall comply with current DoD criteria for the protection of personnel against the effect of electromagnetic radiation. DoD policy is currently found in DoDI 6055.11. Compliance shall be verified by test, analysis, or combination thereof.

5.9.2 Hazards of electromagnetic radiation to fuel (HERF).

Fuels shall not be inadvertently ignited by radiated EMEs. The EME includes onboard emitters and the external EME (see 5.3). Compliance shall be verified by test, analysis, inspection, or a combination thereof.

5.9.3 Hazards of electromagnetic radiation to ordnance (HERO).

Ordnance that contain EIDs shall remain safe and operational during and after exposure to the external EME levels of TABLE IX for both direct RF induced actuation of the EID and inadvertent activation of an electrically powered firing circuit. Relevant ordnance phases involving unrestricted and restricted levels in TABLE IX are listed in TABLE X. In order to be assigned a HERO classification of "HERO SAFE ORDNANCE" at the all-up round or appropriate assembly level, the ordnance or system under test (SUT) must be evaluated against, and be in compliance with, TABLE IX. Compliance shall be verified by test (see MIL-HDBK-240), analysis, or a combination thereof. EIDs shall have a margin of at least 16.5 dB of maximum no-fire stimulus (MNFS) for safety assurances and 6 dB of MNFS for other applications. Instrumentation installed in system components during testing for margins shall capture the maximum system response and shall not adversely affect the normal response characteristics of the component. When environment simulations below specified levels are used, instrumentation responses may be extrapolated to the full environment for components with linear responses (such as hot bridgewire EIDs). When the response is below instrumentation sensitivity, the instrumentation sensitivity shall be used as the basis for extrapolation. For components with non-linear responses (such as semiconductor bridge EIDs), no extrapolation is permitted.

TABLE IX. Maximum external EME levels for ordnance.

Frequency Range		Field Intensity (V/m – rms)			
(MHz)	(MHz)	Unrestricted*		Restricted **	
		Peak	Average	Peak	Average
0.01	2	200	200	80	80
2	30	200	200	100	100
30	150	200	200	80	80
150	225	200	200	70	70
225	400	200	200	100	100
400	700	2200	410	450	100
700	790	700	190	270	270
790	1000	2700	490	1400	270
1000	2000	6100	420	2500	160
2000	2700	6000	500	490	160
2700	3600	27460	5350	2500	220
3600	4000	8600	280	1900	200
4000	5400	9200	660	650	200
5400	5900	9200	660	6200	240
5900	6000	9200	640	550	240
6000	7900	3190	670	3190	240
7900	8000	2500	670	550	200
8000	8400	7500	450	1100	200
8400	8500	7500	400	1100	200
8500	11000	7500	3450	2000	300
11000	14000	7500	650	3500	220
14000	18000	7900	660	7900	250
18000	50000	2900	580	2800	200

NOTES:

* It must be noted that on certain naval platforms, there are radar systems (and unique modes of operation) that may produce fields in excess of those in Table IX, and MIL-HDBK-235 must be consulted to identify specific EME test requirements.

** In some of the frequency ranges for the "Restricted Average" column, limiting the exposure of personnel through time averaging will be required to meet the requirements of 5.9.1 for personnel safety.

TABLE X. Ordnance phases and associated environments.

Stockpile-to-Safe Separation Phase	Environment
Transportation/storage	Unrestricted
Assembly/disassembly	Restricted
Staged	Unrestricted
Loading/unloading	Restricted
Platform-loaded	Unrestricted
Immediate post-launch	Unrestricted

5.10 Life cycle, E3 hardness.

The system operational performance and E3 requirements of this standard shall be met throughout the rated life cycle of the system and shall include, but not be limited to, the following: maintenance, repair, surveillance, and corrosion control. Compliance shall be verified by test, analysis, inspections, or a combination thereof. Maintainability, accessibility, and testability, and the ability to detect degradations shall be demonstrated.

5.11 Electrical bonding.

The system, subsystems, and equipment shall include the necessary electrical bonding to meet the E3 requirements of this standard. Compliance shall be verified by test, analysis, inspections, or a combination thereof, for the particular bonding provision.

5.11.1 Power current return path.

For systems using structure for power return currents, bonding provisions shall be provided for current return paths for the electrical power sources such that the total voltage drops between the point of regulation for the power system and the electrical loads are within the tolerances of the applicable power quality standard. Compliance shall be verified by test or analysis of electrical current paths, electrical current levels, and bonding impedance control levels.

5.11.2 Antenna installations.

Antennas shall be bonded to obtain required antenna patterns and meet the performance requirements for the antenna. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

5.11.3 Mechanical interfaces.

The system electrical bonding shall provide electrical continuity across external mechanical interfaces on electrical and electronic equipment, both within the equipment and between the equipment and other system elements, for control of E3 such that the system operational performance requirements are met. For instances where specific controls have not been established for a system and approved by the procuring activity, the following direct current (DC) bonding levels shall apply throughout the life of the system.

a. 10 milliohms or less from the equipment enclosure to system structure, including the cumulative effect of all faying surface interfaces.

b. 15 milliohms or less from cable shields to the equipment enclosure, including the cumulative effect of all connector and accessory interfaces.

c. 2.5 milliohms or less across individual faying interfaces within the equipment, such as between subassemblies or sections.

Compliance shall be verified by test, analysis, inspections, or a combination thereof.

5.11.4 Shock, fault, and ignitable vapor protection.

Bonding of all electrically conductive items subject to electrical fault currents shall be provided to control shock hazard voltages and allow proper operation of circuit protection devices. For interfaces located in fuel or other flammable vapor areas, bonding shall be adequate to prevent ignition from flow of fault currents. Compliance shall be verified by test, analysis, or a combination thereof.

5.12 External grounds.

The system and associated subsystems shall provide external grounding provisions to control electrical current flow and static charging for protection of personnel from shock, prevention of inadvertent ignition of ordnance, fuel and flammable vapors, and protection of hardware from damage. External grounds compliance shall be verified by test, analysis, inspections, or a combination thereof.

5.12.1 Aircraft grounding jacks.

Grounding jacks shall be attached to the system to permit connection of grounding cables for fueling, stores management, servicing, maintenance operations and while parked. ISO 46 contains requirements for interface compatibility. Grounding jacks shall be attached to the system ground reference so that the resistance between the mating plug and the system ground reference does not exceed 1.0 ohm DC. The following grounding jacks are required:

a. Fuel nozzle ground. A ground jack shall be installed at each fuel inlet. To satisfy international agreements for interfacing with refueling hardware, the jack shall be located within 1.0 meter of the center of the fuel inlet for fuel nozzle grounding.

b. Servicing grounds. Ground jacks shall be installed at locations convenient for servicing and maintenance.

c. Weapon grounds. Grounding jacks shall be installed at locations convenient for use in handling of weapons or other explosive devices.

Compliance shall be verified by test and inspections.

5.12.2 Servicing and maintenance equipment grounds.

Servicing and maintenance equipment shall have a permanently attached grounding wire suitable for connection to earth ground. All servicing equipment that handles or processes flammable fuels, fluids, explosives, oxygen, or other potentially hazardous materials shall have a permanently attached grounding wire for connection to the system. Compliance shall be verified by inspection.

5.13 TEMPEST.

National security information shall not be compromised by emanations from classified information processing equipment. Compliance shall be verified by test, analysis, inspections or a combination thereof. (NSTISSAM TEMPEST/1-92 and CNSS Advisory Memorandum TEMPEST 01-02 provide testing methodology for verifying compliance with TEMPEST requirements.)

5.14 System radiated emissions.

The system shall control radiated fields necessary to operate with the other co-located systems and to limit threat capability to detect and track the system commensurate with its operational requirements.

5.14.1 Emission control (EMCON).

When tactical EMCON conditions are imposed, surface ships, submarines and airborne systems electromagnetic radiated emissions shall not exceed -110 dBm/m^2 (5.8 dBµV/m) at one nautical mile or -105 dBm/m^2 (10.8 dBµV/m) at one kilometer in any direction from the system over the frequency range of 500 kHz to 40 GHz, when using the resolution bandwidths listed in TABLE XI. Compliance shall be verified by test and inspection.

TABLE XI. EMCON bandwidths.

Frequency Range (MHz)	6 dB Bandwidth (kHz)
0.5 – 1	1
1 – 30	10
30 – 1000	30
1000 – 40000	100

NOTES

1. Video filtering shall not be used to bandwidth limit the receiver response.
2. Larger bandwidths may be used, but no correction factors are permissible.

5.14.2 Platform radiated emissions.

Unintentional radiated emissions from Army tactical ground vehicles shall be controlled such that antenna-connected receivers located in the operational vicinity of the vehicle are not adversely impacted. Key parameters (such as frequency range, emission limit, ambient conditions) shall be defined by the procuring activity and shall be based upon the expected operational scenarios of the vehicle and the nearby receiver characteristics. Compliance shall be verified by test and analysis.

5.15 EM spectrum supportability.

Spectrum-dependent systems shall comply with the DoD, national, and international spectrum regulations for the use of the electromagnetic spectrum (see National Telecommunications and Information Administration (NTIA) "Manual of Regulations and Procedures for Radio Frequency Management" and DoDI 4650.01). Compliance shall be verified by test, analysis, or a combination thereof, as appropriate for the development stage of the system.

6. NOTES

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

6.1 Intended use.

This standard contains E3 requirements for systems.

6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of this standard.

6.3 Associated Data Item Descriptions (DIDs).

This standard has been assigned an Acquisition Management Systems Control (AMSC) number authorizing it as the source document for the following DIDs. When it is necessary to obtain the data, the applicable DIDs must be listed on the Contract Data Requirements List (DD Form 1423).

DID Number	DID Title
DI-EMCS-81540B	Electromagnetic Environmental Effects (E3) Integration and Analysis Report
DI-EMCS-81541B	Electromagnetic Environmental Effects (E3) Verification Procedures
DI-EMCS-81542B	Electromagnetic Environmental Effects (E3) Verification Report
DI-EMCS-81827	Spectrum Certification Spectral Characteristics Data

The above DIDs were current as of the date of this standard. The ASSIST database should be researched at https://quicksearch.dla.mil/ to ensure that only current and approved DIDs are cited on the DD Form 1423.

6.4 Tailoring guidance for contractual application.

Application specific criteria may be derived from operational and engineering analyses on the system being procured for use in specific environments. When analyses reveal that a requirement in this standard is not appropriate or adequate for that procurement, the requirement should be tailored and incorporated into the appropriate documentation. The appendix of this standard provides guidance for tailoring.

6.5 Subject term (key word) listing.

E3
Electrical bonding
Electromagnetic compatibility (EMC)
Electromagnetic environment
Electromagnetic emission
Electromagnetic interference (EMI)
Electromagnetic radiation hazards (RADHAZ)
Electromagnetic susceptibility
Electrostatic
EMCON
EMP
ESD
Grounding
HERF
HERO
HERP
HPM
IMI
Inter-system electromagnetic compatibility
Intra-system electromagnetic compatibility
Lightning
Multipaction
P-static
TEMPEST

6.6 International standardization agreement implementation.

This standard implements NATO STANAG 4370, “Electromagnetic Environmental Effects Tests and Verification which covers Air, Land and Sea Platforms and E3 Ordnance Assessments”. When changes to, revision, or cancellation of this standard are proposed, the preparing activity must coordinate the action with the U.S National Point of Contact for the international standardization agreement, as identified in the ASSIST database at https://assist.dla.mil/.

6.7 Acronyms used in this standard.

The acronyms used in this standard are defined as follows.

CTTA	certified TEMPEST technical authority

E3	electromagnetic environmental effects
EID	electrically initiated device
EMC	electromagnetic compatibility
EMCON	emission control
EME	electromagnetic environment
EMI	electromagnetic interference
EMP	electromagnetic pulse
EPS	engineering practice study
ESD	electrostatic discharge
HERF	hazards of electromagnetic radiation to fuel
HERO	hazards of electromagnetic radiation to ordnance
HERP	hazards of electromagnetic radiation to personnel
HESD	helicopter-borne electrostatic discharge
HPM	high power microwave
IMI	intermodulation interference
ISO	International Organization for Standardization
ISR	intelligence, surveillance, and reconnaissance
KPP	key performance parameter
MNFS	maximum no-fire stimulus
NDI	non-developmental item
PESD	personnel-borne electrostatic discharge
p-static	precipitation static
RADHAZ	Radiation hazards
RF	radio frequency
rms	root-mean-square

6.8 Technical points of contact.

Requests for additional information or assistance on this standard can be obtained from the following:

Air Force
AFLCMC/EZAC, Bldg. 28
2145 Monahan Way
Wright Patterson AFB, OH 45433-7101
DSN 785-7676, Commercial (937) 255-7676

Army
Department of the Army
Combat Capabilities Development Command
Building 4488
FCDD-AMA-S
Redstone Arsenal, AL 35898
DSN 897-8447, Commercial (256) 313-8447

Navy
NAVAIRSYSCOM
E3 Division (Code 41M)
48110 Shaw Road
Bldg 2187 Room 3256
Patuxent River, MD 20670
DSN 342-1660, Commercial (301) 342-1660

Any information relating to Government contracts must be obtained through contracting officers.

6.9 Changes from previous issue.

Marginal notations are not used in the revision to identify changes with respect to the previous issue due to the extent of the changes.

APPLICATION GUIDE

A.1 SCOPE

A.1.1 Scope.

This appendix provides background information for each requirement in the main body of the standard. The information includes rationale for each requirement, guidance on applying the requirement, and lessons learned related to the requirement. This information should help users understand the intent behind the requirements and adapt them as necessary for a particular application. This appendix is not a mandatory part of the standard. The information contained herein is intended for guidance only.

A.2 APPLICABLE DOCUMENTS

A.2.1 Government documents.

A.2.1.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

AECTP-500	Electromagnetic Environmental Effects Test and Verification

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-23659	Initiators, Electric, General Design Specification for
MIL-DTL-83413	Connectors and Assemblies, Electrical, Aircraft Grounding, General Specification for

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-188-124	Grounding, Bonding and Shielding for Common Long Haul/Tactical Communications Systems Including Ground Based Communication-Electronics Facilities and Equipments
MIL-STD-188-125-1	High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C^4I Facilities Performing Critical, Time-Urgent Missions, Part 1 Fixed Facilities

MIL-STD-188-125-2	High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C^4I Facilities Performing Critical, Time-Urgent Missions, Part 2 Transportable Systems
MIL-STD-331	Fuze and Fuze Components, Environmental and Performance Tests for
MIL-STD-449	Radio Frequency Spectrum Characteristics, Measurement of
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-1310	Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility, Electromagnetic Pulse (EMP) Mitigation, and Safety
DOD-STD-1399-070-1	Interface Standard for Shipboard Systems Section 070 – Part 1 D.C. Magnetic Field Environment (Metric)
MIL-STD-1399-300-1	Electric Power, Alternating Current
MIL-STD-1542	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities
MIL-STD-1605(SH)	Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships)
MIL-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
MIL-STD-2169	High Altitude Electromagnetic Pulse Environment (U)
MIL-STD-3023	HEMP Protection for Military Aircraft
MIL-STD-3053	Satellite Systems Natural and Nuclear Environment Standard
MIL-STD-3054	Comprehensive Endo-/Exo-Atmospheric Nuclear Environment Standard (Canes)
MIL-STD-4023	HEMP Protection for Maritime Assets

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-235-1	Military Operational Electromagnetic Environment Profiles, General Guidance
MIL-HDBK-235-2	External Electromagnetic Environment Levels for U.S. Navy Surface Ship Operations (U)
MIL-HDBK-235-3	External Electromagnetic Environment Levels for Space and Launch Vehicle Systems (U)
MIL-HDBK-235-4	External Electromagnetic Environment Levels for Ground Systems (U)
MIL-HDBK-235-5	External Electromagnetic Environment Levels for Rotary-Wing Aircraft, Including UAVs, Except During Shipboard Operations (U)
MIL-HDBK-235-6	External Electromagnetic Environment Levels for Fixed-Wing Aircraft, Including UAVs, Except During Shipboard Operations (U)
MIL-HDBK-235-7	External Electromagnetic Environment Levels for Ordnance (U)
MIL-HDBK-235-8	External Electromagnetic Environment Levels from High Power Microwave (HPM) Systems (U)
MIL-HDBK-235-9	External Electromagnetic Environment Levels for Other U.S. Ships (Coast Guard, Military Sealift Command and Army Ships) (U)
MIL-HDBK-235-10	External Electromagnetic Environment Levels for Submarine Operations (U)
MIL-HDBK-237	Electromagnetic Environmental Effects and Spectrum Supportability Guidance for the Acquisition Process
MIL-HDBK-240	Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide
MIL-HDBK-274	Electrical Grounding for Aircraft Safety
MIL-HDBK-419	Grounding, Bonding, and Shielding for Electronic Equipments and Facilities, Volume 1 of 2 Volumes Basic Theory
MIL-HDBK-423	High-Altitude Electromagnetic Pulse (HEMP) Protection for Fixed and Transportable Ground-Based C^4I Facilities, Volume 1, Fixed Facilities
MIL-HDBK-454	General Guidelines for Electronic Equipment

MIL-HDBK-83575	General Handbook for Space Vehicle Wiring Harness Design and Testing

(Copies of these documents are available online at https://quicksearch.dla.mil/.)

(Application for copies of MIL-STD-2169 should be addressed with a need-to-know to: Defense Threat Reduction Agency, ATTN: RD-NTSA, 8725 John J Kingman RD STOP 6201, Fort Belvoir VA 22060-6201)

(Procedures for obtaining MIL-HDBK-235-2 through 10 are specified in MIL-HDBK-235-1.)

A.2.1.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

AIR FORCE

AFWL-TR-85-113	Guidelines for Reducing EMP Induced Stresses in Aircraft
R-3046-AF	Techniques for the Analysis of Spectral and Orbital Congestion in Space Systems (DTIC No. ADA140841)
TO 00-25-172	Ground Servicing of Aircraft and Static Grounding/Bonding
TO 31Z-10-4	Electromagnetic Radiation Hazards

(Copies of these documents are available from National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161 or the Defense Technical Information Center, Attn: DTIC-R, 8725 John J. Kingman Rd. Suite 0944, Fort Belvoir, VA 22060-6218 or online at http://www.dtic.mil/dtic/. Air Force Technical Orders are available from Oklahoma City Air Logistics Center (OC-ALC/MMEDT), Tinker AFB, OK 73145-5990.)

ARMY

ADS-37A-PRF	Electromagnetic Environmental Effects (E3) Performance and Verification Requirements
ATPD-2407	Electromagnetic Environmental Effects (E3) for US Army Tank and Automotive Vehicle Systems Tailored from MIL-STD-464C
TOP 01-2-511A	US Army Test and Evaluation Command Test Operations Procedure

TR-RD-TE-97-01	Electromagnetic Effects Criteria and Guidelines for EMRH, EMRO, Lightning Effects, ESD, EMP, and EMI Testing of US Army Missile Systems
TB MED 523	Control of Hazards to Health from Microwave and Radio Frequency Radiation and Ultrasound

(Copies of these documents are available from National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161 or the Defense Technical Information Center (DTIC), Bldg. 5, Cameron Station, Alexandria, VA 22304-6145 or online at http://www.dtic.mil/dtic/.)

DEPARTMENT OF DEFENSE (DOD)

DoDD C-5200.19	Control of Compromising Emanations (U)
DoDI 4650.01	Policy and Procedures for Management and Use of the Electromagnetic Spectrum
DoDI 6055.11	Protecting Personnel from Electromagnetic Fields
EPS-MIL-STD-461	Engineering Practice Study - Results of Detailed Comparisons of Individual EMC Requirements and Test Procedures Delineated In Major National and International Commercial Standards with Military Standard MIL-STD-461E

(Copies of these documents are available online at https://www.esd.whs.mil/dd/ . Copies of the EPS-MIL-STD-461 are available online at https://acc.dau.mil/CommunityBrowser.aspx?id=122797.)

FEDERAL AVIATION ADMINISTRATION (FAA)

AC 20-53	Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning
AC 20-136	Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning
DOT/FAA/CT-89/22	Aircraft Lightning Handbook
DOT/FAA/CT-86/40	Aircraft Electromagnetic Compatibility

(Copies of these documents are available online at http://www.dtic.mil/dtic/ or from Defense Technical Information Center (DTIC), Bldg. 5, Cameron Station, Alexandria, VA 22304-6145 or the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.)

GOVERNMENT ACCOUNTING OFFICE (GAO)

GAO-03-617R	Defense Spectrum Management

(Copies of this document are available online at http://www.gao.gov/index.html.)

PRECIPITATION STATIC (P-STATIC)

NASA

TP2361	Design Guidelines for Assessing and Controlling Spacecraft Charging Effects
TR 32-1500	Final Report on RF Voltage Breakdown in Coaxial Transmission Lines

(Copies of these documents are available from NASA Industrial Application Center/USC, 3716 South Hope St. #200, Los Angeles, CA 90007.)

NAVY

IA PUB-5239-31	Information Assurance Shipboard Red/Black Installation Publication
NAVSEA OP 3565	Electromagnetic Radiation Hazards (Hazards to Ordnance)

(Copies of these documents are available from Commanding Officer, Naval Surface Warfare Center, Port Hueneme Division, Naval Sea Data Support Activity (Code 5700), Department of the Navy, Port Hueneme, CA 93043.)

NATIONAL SECURITY AGENCY (NSA)

CNSS TEMPEST 01-02	Advisory Memorandum, NONSTOP Evaluation Standard
NSTISSAM TEMPEST/1-92	Compromising Emanations Laboratory Test Requirements, Electromagnetics
NSTISSAM TEMPEST/1-93	Compromising Emanations Field Test Evaluations
NSTISSAM TEMPEST/2-95	Red/Black Installation Guidance

(Copies of these documents are available only through the procuring activity.)

PUBLICATIONS

47 CFR Part 300	Manual of Regulations and Procedures for Federal Radio Frequency Management
47 U.S.C. Section 305	Government Owned Stations
47 U.S.C. Chapter 8	National Telecommunications and Information Administration
NTIA	Manual of Regulations and Procedures for Federal Radio Frequency Management
OMB Circular No. A-11	Preparation, Submission and Execution of the Budget

(Copies of Code of Federal Regulations are available online at http://www.ecfr.gov/. Copies of United States Codes are available online at http://uscode.house.gov/. Copies of OMB Circulars are available online at http://www.whitehouse.gov/OMB/circulars/.)

A.2.2 Non-Government publications.

The following non-Government documents form a part of this standard to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS (AIAA)

AIAA-S-121	Electromagnetic Compatibility Requirements for Space Equipment and Systems

(Copies of this document are available online at http://www.aiaa.org/.)

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI/ESD S20.20	ESD Association Standard for the Development of an Electrostatic Control Program for - Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices)

ELECTROSTATIC DISCHARGE ASSOCIATION (ESDA)

ESD TR 20.20	Handbook for the Development of an Electrostatic Control Program for - Protection of Electrical and Electronic Parts, Assemblies, and Equipment

(Copies of this document are available online at http://www.esda.org/.)

INTERNATIONAL ELECTROTECHNICAL COMMISSION

IEC 61000-2-9	Description of HEMP Environment - Radiated Disturbance

(Copies of this document are available online at http://www.iec.ch/.)

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

ISO 46	Aircraft - Fuel Nozzle Grounding Plugs and Sockets

(Copies of this document are available online at http://www.iso.org/iso/home/store.htm.)

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 70	National Electrical Code
NFPA 780	Standard for the Installation of Lightning Protection Systems

(Copies of these documents are available online at http://catalog.nfpa.org/.)

NORTH ATLANTIC TREATY ORGANIZATION (NATO)

ANEP 45	Electro-Magnetic Compatibility (EMC) in Composite Vessels

(Copies of this document are available from Central US Registry, The Pentagon, Room 1B889, Washington, DC 20310-3072.)

RADIO TECHNICAL COMMISSION FOR AERONAUTICS (RTCA), INC.

DO-160	Environmental Conditions and Test Procedures for Airborne Equipment

(Copies of this document are available online at http://www.rtca.org.)

SPACE AND MISSILE SYSTEMS CENTER (SMC)

SMC-S-008	Electromagnetic Compatibility Requirements for Space Equipment and Systems

(Copies of this document are available online at http://www.dtic.mil/.)

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)

ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP4242	Electromagnetic Compatibility Control Requirements, Systems
ARP5412	Aircraft Lightning Environment and Related Test Waveforms
ARP5414	Aircraft Lightning Zoning
ARP5415	User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
ARP5416	Aircraft Lightning Test Methods
ARP5577	Aircraft Lightning Direct Effects Certification

(Copies of this document are available online at http://www.sae.org/.)

A.3 ACRONYMS

The acronyms used in this appendix are defined as follows.

AAPG	antenna inter-antenna propagation with graphics
AGC	automatic gain control
AM	amplitude modulation
ASEMICAP	air systems EMI corrective action program
BIT	built-in test
C^3I	command, control, communications, and intelligence
C^4I	command, control, communications, computers, and intelligence
CCF	cavity calibration factor
CTTA	certified TEMPEST technical authority
CW	continuous wave
DID	Data Item Description
E3	electromagnetic environmental effects
ECCM	electronic counter counter-measures
ECM	electronic counter-measures
EID	electrically initiated device
ELV	expendable launch vehicle
EM	electromagnetic
EMC	electromagnetic compatibility

EMCON	emission control
EME	electromagnetic environment
EMI	electromagnetic interference
EMP	electromagnetic pulse
EMV	electromagnetic vulnerability
ESD	electrostatic discharge
GPS	global positioning system
GTD	geometric theory of diffraction
HEMP	high altitude electromagnetic pulse
HERF	hazards of electromagnetic radiation to fuel
HERO	hazards of electromagnetic radiation to ordnance
HERP	hazards of electromagnetic radiation to personnel
HESD	helicopter-borne electrostatic discharge
HIRF	high intensity radiated fields
HPM	high power microwave
IEC	International Electrotechnical Commission
IMI	intermodulation interference
ISR	intelligence, surveillance, and reconnaissance
I/CC	induced/contact current
MHD	magnetohydrodynamic
MNFS	maximum no-fire stimulus
MoM	method of moments
NDI	non-developmental item
NTIA	National Telecommunications and Information Administration
pbw	percentage bandwidth
PCS	personal communication system
PESD	personnel-borne electrostatic discharge
POR	point of regulation
PEL	permissible exposure limit
p-static	precipitation static
RADHAZ	Radiation hazards
RF	radio frequency
SE	shielding effectiveness
SEMCIP	shipboard EMC improvement program

SNR	signal to noise ratio
TWT	traveling wave tube
SS	spectrum supportability

A.4 GENERAL REQUIREMENTS AND VERIFICATION

In this section, the requirements from the main body are repeated (*printed in italics*) and are then followed by rationale, guidance, and lessons learned for each interface requirement and rationale, guidance, and lessons learned for each verification requirement. Interface and verification requirement discussions are treated separately because they address different issues. Tables and figures associated with the requirements from the main body are not repeated in this appendix.

A.4.1 General.

Each system shall be electromagnetically compatible in its operational electromagnetic environment such that the operational performance requirements are met. This standard identifies baseline design requirements and verification to address E3 issues. Requirements and verification approaches may be tailored based on engineering justification derived from the system's operational requirements and engineering analysis. Design techniques used to achieve electromagnetic compatibility shall be verifiable, maintainable, and effective over the rated lifecycle of the system. Design margins shall be established based on system criticality, hardware tolerances, and uncertainties involved in verification of system-level design requirements. Verification shall address all life cycle aspects of the system, including (as applicable) normal in-service operation, checkout, storage, transportation, handling, packaging, loading, unloading, launch, and the normal operating procedures associated with each aspect. The Data Item Description (DID) called out in the standard provide a means for establishing an overall integrated E3 design and verification approach to identify areas of concern early in the program, mitigate risk, and document test results.

Requirement Rationale (A.4.1):

The E3 area addresses a number of interfacing issues with environments both external to the system and within the system. External to the system are electromagnetic effects such as lightning, EMP and man-made RF transmissions. Internal to the system are electromagnetic effects such as electronic noise emissions, self-generated RF transmissions from antennas, and cross-coupling of electrical currents. Systems today are complex from a materials usage and electronics standpoint. Many materials being used are non-metallic and have unique electromagnetic properties which require careful consideration. Electronics performing critical functions are common. Wide use of RF transmitters, sensitive receivers, other sensors, and additional electronics creates a potential for problems within the system and from external influences. Increasing use of commercial equipment in unique military operational environments poses special interface considerations. Each system must be compatible with itself, other systems, and external environments to ensure required performance and to prevent costly redesigns for resolution of problems.

Requirement Guidance (A.4.1):
The system and all associated subsystems and equipment, including ordnance, need to achieve system compatibility. Every effort needs to be made to meet these requirements during initial design rather than on an after-the-fact basis. System E3 Integration and Analysis Reports are used to aid in technical management of programs. These reports describe requirement flowdown from this standard and specific design measures being implemented to meet the requirements of this standard. The other requirements of this standard address specific aspects of the E3 control area. Additional guidance on EMC can be found in MIL-HDBK-237, DOT/FAA/CT-86/40, SAE ARP4242, Army ADS-37A-PRF, Army ATPD-2407, and NATO ANEP 45. For Army systems, the test procedures are defined in TOP 01-2-511. TOP 01-2-511A is the overarching document that covers Army E3 testing.

An overall integrated EMC design and verification approach for the system must be established. Based on system-level architecture, appropriate hardening requirements are allocated between system design features and subsystems and equipment hardness. Transfer functions from system-level environments to stresses at the subsystem and equipment-level are determined and appropriate electromagnetic interference controls are imposed.

An E3 integration approach can be organized into five activities:

a. Establish the external threat environment against which the system is required to demonstrate compliance of immunity. The external environments (EME, lightning and EMP) to which the system should be designed and verified are addressed in other sections of this appendix.

b. Identify the system electrical and electronic equipment performing functions required for operation during application of the external threat. Normally all functions essential for completing the missions are protected against the external threats.

c. Establish the internal environment caused by external electromagnetic effects for each installed equipment. All of the environments external to the system specified in this standard cause related environments internal to the system. The level of this internal environment will be the result of many factors such as structural details, penetration of apertures and seams, and system and cable resonances. The internal environment for each threat should be established by analysis, similarity to previously tested systems, or testing. The internal environment is usually expressed as the level of electrical current stresses appearing at the interface to the equipment or electromagnetic field quantities. These internal stresses are typically associated with standardized requirements for equipment (for example, MIL-STD-461). Trade-offs need to be made of the degree of hardening to be implemented at the system-level (such as shielded volumes or overbraiding on interconnecting wiring) versus equipment-level (more stringent electromagnetic interference requirements) to establish the most effective approach from performance and cost standpoints.

d. Design the system and equipment protection. System features are then designed as necessary to control the internal environment (including margin considerations) to levels determined from the trade-off studies and appropriate requirements are imposed on the electrical and electronic equipment. The equipment immunity levels must be above the internal environments by necessary margins to account for criticality of the equipment, manufacturing tolerances, and uncertainties in verification. Normally there are design and test requirements in MIL-STD-461 applicable for each of the external environments, but they may need modification for the particular system application. For example, external environment may result in internal environments above the susceptibility level specified in MIL-STD-461. If so, the limit must be tailored for the particular system, alternative requirements must be imposed or the internal environment must be reduced to an acceptable level. The system E3 design must be viable throughout the system life cycle. This aspect requires an awareness of proper application of corrosion control provisions and issues related to maintenance actions that may affect EMC. Examples are ensuring that electrical bonding provisions are not degraded, maintaining surface treatments in place for E3 control, and considering exposure of electronics to EMEs when access panels are open. Maintaining a viable system E3 design also requires an effective configuration management program for tracking and evaluating engineering changes to the system to ensure that the E3 design is not compromised.

e. Verify the protection adequacy. The system and equipment E3 protection design must be verified as meeting contractual requirements. Verification of the adequacy of the protection design includes demonstrating that the actual levels of the internal environments appearing at the equipment interfaces and enclosures do not exceed the qualification test levels of the equipment for each environment by required margins. This may be accomplished by test and/or analysis with testing normally being required to minimize the required-margin demonstration. System level testing at the full external threat environment has historically been employed. However, due to increasing environments this is not always feasible. An alternative method is to decompose the testing into multiple lower power tests and statistically determine the probability-of-effect. The distribution of the maximum fields within the system enclosure is first measured using complex cavity test techniques. This can be scaled to the external threat environment by the frequency-dependent shielding effectiveness transfer function of the system enclosure. Then, the internal equipment threshold can be directly measured through susceptibility testing (at levels representative of internal fields). Finally, the probability-of-effect is determined from the system hardness margin (i.e. the ratio of equipment threshold to the maximum environment).

These verification activities need to be documented in detail in verification procedures and verification reports, as applicable. Section 6.3 of the main body provides DIDs for documents that are suitable for this purpose.

Requirement Lessons Learned (A.4.1):

The early implementations of E3 requirements have been instrumental in preventing problems on previous programs. Evolving system designs regarding changing materials and increasing criticality of electronics demand that effective electromagnetic effects controls be implemented.

It is important that all external environments be treated in a single unified approach. Duplication of efforts in different disciplines has occurred in the past. For example, hardening to EMP and lightning-induced transients has been addressed independently rather than as a common threat with different protection measures being implemented for each. This situation is apparently due in part to organizational structures at contractor facilities which place responsibility in different offices for each of the threats.

Verification Rationale (A.4.1):

Each separate requirement must be verified in accordance with the contractual system requirements and statement of work. The developing activity should flow down elements of verification responsibility to associate contractors as appropriate for their supplied systems and subsystems.

Verification Guidance (A.4.1):

Most of the requirements in this standard are verified at the system-level. Compliance for some requirements is verified at the subsystem, equipment, or component level, such as EMI requirements on a subsystem or lightning certification of an airframe component.

The selection of test, analysis, or inspection or some combination to demonstrate a particular requirement is generally dependent on the degree of confidence in the results of the particular method, technical appropriateness, associated costs, and availability of assets. Some of the requirements included in this standard specify the method to be used. For example, verification of subsystem and equipment-level electromagnetic interference requirements must be demonstrated by test, because analysis tools are not available which will produce credible results.

Analysis and testing often supplement each other. Prior to the availability of hardware, analysis will often be the primary tool being used to ensure that the design incorporates adequate provisions. Testing may then be oriented toward validating the accuracy and appropriateness of the models used. The level of confidence in a model with respect to a particular application determines the balance between analysis and testing. Testing is often essential to completing a convincing verification argument.

E3 requirements need to be verified through an incremental verification process. "Incremental" implies that verification of compliance with E3 requirements is a continuing process of building an argument (audit trail) throughout development that the design satisfies the imposed performance requirements. Initial engineering design must be based on analysis and models. As hardware becomes available, testing of components of the subsystem can be used to validate and supplement the analysis and models. The design evolves as better information is generated. When the system is actually produced, inspection, final testing, and follow-on analysis complete the incremental verification process. It is important to note that testing is often necessary to obtain information that may not be amenable to determination by analysis. However, testing also is often used to determine a few data points with respect to a particular interface requirement with analysis (and associated simulations) filling in the total picture. It should be noted that the guidance sections for individual E3 requirements specified in other sections below generally treat the predominant methods for final verification rather than dealing with the overall philosophy described in this section.

The following list provides guidance on issues which should be addressed for E3 verification:

a. Systems used for verification should be production configuration, preferably the first article.

b. The system should be up-to-date with respect to all approved engineering change proposals (both hardware and software).

c. EMI qualification should be completed on subsystems and equipment.

d. Subsystems and equipment should be placed in modes of operation that will maximize potential indication of interference or susceptibility, consistent with system operational performance requirements.

e. Any external electrical power used for system operation should conform to the power quality standard of the system.

f. Any anomalies found should be evaluated to determine whether they are truly an E3 issue or some other type of malfunction or response.

g. Any system modifications resulting from verification efforts should be validated for effectiveness after they have been engineered.

h. Margins need to be demonstrated wherever they are applicable.

Verification Lessons Learned (A.4.1):
Historically, failure to adequately verify system performance in an operational EME has resulted in costly delays during system development, mission aborts, and reduced system and equipment

operational effectiveness. It is important that assets required for verification of E3 requirements be identified early in the program to ensure their availability when needed.

A.5 DETAILED REQUIREMENTS

A.5.1 Margins.

Margins shall be established for safety and mission critical subsystems/equipment within the system. Margins shall be no less than 6 dB for safety critical subsystems/equipment, unless otherwise stated in the detailed requirements of this standard. Compliance shall be verified by test, analysis, or a combination thereof.

Requirement Rationale (A.5.1):
Variability exists in system hardware from factors such as differences in cable harness routing and makeup, adequacy of shield terminations, conductivity of finishes on surfaces for electrical bonding, component differences in electronics boxes, and degradation with aging and maintenance. Margins must be included in the design to account for these types of variability. In addition, uncertainties are present in the verification process due to the verification method employed, limitations in environment simulation, and accuracy of measured data. The proper application of margins in system and subsystem design provides confidence that all production systems will perform satisfactorily in the operational E3 environments.

Requirement Guidance (A.5.1):
Margins are generally applied for particular environments external to the system, including lightning (only indirect effects), inter-system EMC, EMP, HERO, and aspects of intra-system EMC associated with any type of coupling to ordnance circuits.

Margins need to be viewed from the proper perspective. The use of margins simply recognizes that there is variability in manufacturing and that requirement verification has uncertainties. The margin ensures that every produced system will meet requirements, not just the particular one undergoing a selected verification technique. Smaller margins are appropriate for situations where production processes are under tighter controls or more accurate and thorough verification techniques are used. Smaller margins are also appropriate if many production systems undergo the same verification process, since the production variability issue is being addressed. Margins are not an increase in the basic defined levels for the various electromagnetic environments. The most common technique is to verify that electromagnetic and electrical stresses induced internal to the system by external environments are below equipment strength by at least the margin. This approach is similar to the test methodology described in A.4.1 (e). While margins can sometimes be demonstrated by performing verification at a level in excess of the defined requirement, the intent of the margin is not to increase the requirement.

The 16.5 dB margin specified for safety assurance for EIDs in ordnance is derived from the criterion in MIL-STD-1385 (which has been canceled and superseded by MIL-STD-464) that the maximum allowable induced level for EIDs in required environments is 15% of the maximum no-fire current. The ratio of no-fire to allowable currents in decibels is 20 log (0.15) or a 16.5 dB margin. The requirement is expressed in decibels in this standard so that the requirement can be applied to designs which do not use conventional hot bridgewire EIDs, where the term “no-fire current” may be meaningless. MIL-STD-1385 also specified a criterion of 45% of no-fire current (7 dB margin) for EIDs when there are consequences other than safety. The equivalent criterion in this standard is specified as 6 dB.

Hot bridgewire EIDs with a one amp/one watt MNFS are often used in ordnance applications to help in meeting safety requirements. As an alternative to using large sample sizes to demonstrate that the statistical criteria contained in the definition of MNFS (no more than 0.1% firing with a confidence level of 95%) is met, the methods of MIL-DTL-23659 can be used to establish a one amp/one watt MNFS.

Margins are closely linked to both design and verification since the planned verification methodology influences the size of the margin and the resulting impact on the required robustness of the design. The specific margin assigned for a particular design and environment is an engineering judgment. If the margin is too large, then penalties in weight and cost can be inflicted on the design. If the margin is too small, then the likelihood of an undesirable system response becomes unacceptably high.

The size of the margin assigned is inversely proportional to the inherent accuracy of the verification method employed. One method of verifying lightning protection is to expose an operational aircraft to a simulated severe lightning encounter (most severe flashes with worst case attachment points). With this relatively accurate method of verification, a smaller overall margin should be required. Another method of verifying lightning protection is the use of low-level pulsed or continuous-wave (CW) testing with extrapolation of measured induced levels on electrical cabling to a full scale strike. These levels are then either applied to the cables at the system level or compared to laboratory data. This type of approach would typically require an overall margin of 6 dB. Similar margins may be appropriate for purely analytical approaches which produce results that have been shown by previous testing to be consistently conservative for the particular type of system being evaluated.

The least accurate verification method is the use of an analysis which has not been previously verified as yielding “accurate” results for the system type of interest. The term “previously verified" in this case means that the analysis is based on accepted principles (such as previously documented in E3 handbooks) but the particular system configuration presented for certification has not been previously tested to verify the accuracy of the analysis. For this case, margins as large as 30 dB are not unrealistic.

For most approaches, margins typically fall in the range of 6 to 20 dB. For equipment that is not classified as safety critical, mission critical, or ordnance, it may be desirable to use a reduced (possibly zero) margin to conserve program resources.

Requirement Lessons Learned (A.5.1):

The use of margins in verifying intra-system EMC requirements among subsystems by test has been attempted in the past; however, this practice has largely been abandoned except for electroexplosive circuits. A basic difficulty existed in the lack of available techniques to evaluate how close a circuit is to being upset or degraded. With the numerous circuits on most platforms, it can be a formidable task to evaluate all circuits. One technique that has been used is to identify the circuits through analysis which are potentially the most susceptible. The intentional signal being transmitted across the electrical interface is reduced in amplitude by the required number of dB to decrease the relative level of the intentional signal to whatever interference is present. However, there is some controversy in this type of testing since the receiving circuit does not see its normal operating level. Margins for EIDs have been commonly demonstrated using techniques such as electro-optics, infrared, current probes, thermocouples, RF detectors, and temperature sensitive waxes.

Verification Rationale (A.5.1):

To obtain confidence that the system will perform effectively in the various environments, margins must be verified. In addition to variability in system hardware, test and analysis involve uncertainties which must be taken into account when establishing whether a system has met its design requirements. These uncertainties include instrumentation tolerances, measurement errors, and simulator deficiencies (such as inadequate spectral coverage).

Verification of margins for space and launch vehicles is essential since these items are costly and must meet performance the first and only time. For expendable launch vehicles (ELVs), there are no on-orbit repairs.

Verification Guidance (A.5.1):

Some uncertainties, such as system hardware variations or instrumentation errors, may be known prior to the verification effort. Other uncertainties must be evaluated at the time of a test or as information becomes available to substantiate an analysis. Margins must be considered early in the program so that they may be included in the design. It is apparent that better verification techniques can result in leaner designs, since uncertainties are smaller. Caution must be exercised in establishing margins so that the possible lack of reliable or accurate verification techniques does not unduly burden the design.

During an E3 test, the contribution to uncertainties from the test is either errors or variations. The errors fall into categories of measurement, extrapolation (simulation), and repeatability. Variations are caused by various issues such as system orientation with respect to the incident field, polarization of the incident field, and different system configurations (such as power on/off, refuel, ground alert). The contributions of errors and variations are combined for margin determination. They can be directly added; however, this approach will tend to produce an overly conservative answer. The more common approach is to combine them using the root-sum-square.

Verification Lessons Learned (A.5.1):
An example of margin assessment used during verification of lightning indirect effects and electromagnetic pulse protection is the demonstration that the electrical current levels induced in system electrical cables by the particular environment are less than the demonstrated equipment hardness at least by the margin. This verification is generally accomplished by a combination of tests and analyses. The equipment hardness level is generally demonstrated in the laboratory during testing in accordance with MIL-STD-461. Testing can also be performed on individual equipment items at the system-level. There are some concerns with induced transient waveforms determined at the system-level being different than those used during equipment-level testing. Analysis techniques are available for waveform comparison such as the use of norm attributes to assess various parameters in the waveform. Test techniques are available to inject measured current waveforms into electrical cables at amplified levels during a system-level test.

A.5.2 Intra-system electromagnetic compatibility (EMC).

The system shall be electromagnetically compatible within itself such that system operational performance requirements are met. Compliance shall be verified by system-level test, analysis, or a combination thereof. This includes permanent, temporary, and portable electronic equipment.

Requirement Rationale (A.5.2):
It is essential within a system that the subsystems and equipment be capable of providing full performance in conjunction with other subsystems and equipment which are required to operate concurrently. EMI generated by a subsystem or other subsystems and equipment must not degrade the overall system effectiveness. Shipboard topside and below-deck areas have very complex electromagnetic environments with significant amount of equipment and systems integrated and/or co-located. The Navy has been integrating equipment qualified to MIL-STD-461 but also to commercial standards such as IEEE and IEC standards to reduce costs. For surface ships, MIL-STD-1605(SH) provides test methods used to verify compliance with the requirements of this standard for intra- and inter-system EMC, hull generated intermodulation interference, and electrical bonding.

EMC among antenna-connected subsystems (termed RF compatibility on some programs) is an essential element of system performance. Inability of an antenna-connected subsystem to properly receive intentional signals can significantly affect mission effectiveness. Achieving compatibility requires careful, strategic planning for the placement of receiver and transmitter antennas on the system and on the interoperability of the subsystems.

Requirement Guidance (A.5.2):
Intra-system EMC is the most basic element of E3 concerns. The various equipment and subsystems need to be designed and integrated to coexist and to provide the operational performance required by the user. However, varying degrees of functionality are necessary depending upon the operational requirements of individual items during particular missions. Certain equipment may not need to be exercised at the time of operation of other equipment. For this situation, intra-system compatibility requirements do not necessarily apply. The procuring activity and system user should be consulted to determine the required functionality. An example of these circumstances is that it is unlikely that an aircraft instrument landing system needs to be compatible with a radiating electronic warfare jamming subsystem during precision approaches. However, they need to be compatible during other operations such as when built-in test (BIT) is exercised.

Requirement Lessons Learned (A.5.2):
When appropriate measures are included in system design, such as E3 hardening at the system level, EMI requirements on subsystems and equipment, and good grounding and bonding practices, there are relatively few intra-system EMC problems found. Most problems that are found involve antenna-connected transmitters and receivers. Receiver performance has been degraded by broadband thermal noise, harmonics, and spurious outputs coupled antenna-to-antenna from transmitters. Microprocessor clock harmonics radiating from system cabling and degrading receivers have been another common problem. Electromagnetic fields radiated from onboard antennas have affected a variety of subsystems on platforms. Typical non-antenna-related problems have been transients coupled cable-to-cable from unsuppressed inductive devices and power frequencies coupling into audio interphone and video signal lines. Problems due to cable-to-cable coupling of steady state noise and direct conduction of transient or steady state noise are usually identified and resolved early in the development of a system.

Generation of broadband EMI on ships from electrical arcing has been a common source of degradation of antenna-connected receivers and must be controlled. Sources of the arcing have been brush noise from electrical machinery and induced voltages and currents between metallic items from antenna transmissions. Intermittent contact of the metallic items due to wind or ship motion is a contributor. MIL-STD-1605(SH) provides guidance on controlling and locating sources of broadband EMI.

Predictive antenna-to-antenna software modeling is recommended to reduce risk early in a system development program. Common software modeling techniques include Method of Moments (MoM), Geometric Theory of Diffraction (GTD), and geometrical optics (ray-tracing). Software programs can use one of these techniques or a hybrid of multiple techniques to predict antenna-to-antenna coupling, and ultimately an EMI margin between coupled levels versus receiver sensitivity. Software modeling is extremely useful when actual hardware is not available for testing. Limitations of any analysis program must be considered when using the results to draw conclusions.

A common problem in systems occur when the system uses both electronic countermeasures (ECM) and radar equipment operating at overlapping frequencies. The following measures may be helpful to provide RF compatibility between these types of subsystems: blanking, pulse tagging, utilization of coherent processing dead time, band splitting, and digital feature extraction. A blanking matrix is commonly used to depict the relationship between source and victim pairs.

Intermodulation products (sometimes termed passive intermodulation) are caused by the mixing of two signals in non-linear junction (such as a corroded bond) and occur at predictable frequencies: intermodulation frequency = $mf_1 \pm nf_2$ where m and n are integers and f_1 and f_2 are two signal frequencies. These products may degrade antenna-connected receivers that are tuned to the intermodulation frequency. In some installations where there is flexibility on selecting the operating frequencies of equipment, potential problems can be handled through frequency management by avoiding predictable combinations. Where very sensitive receivers are involved, even higher order products may affect the receivers. Space applications have special concerns with intermodulation issues.

Verification Rationale (A.5.2):
Verification of intra-system EMC through testing supported by analysis is the most basic element of demonstrating that E3 design efforts have been successful.

Verification of EMC by test is essential to ensure an adequate design which is free from the degradation caused by antenna-to-antenna coupled interference. Prior analysis and equipment-level testing are necessary to assess potential problems and to allow sufficient time for fixing subsystem problems.

Verification Guidance (A.5.2):
Although analysis is an essential part of the early stages of designing or modifying a system, testing is the only truly accurate way of knowing that a design meets intra-system EMC requirements. An anechoic chamber is often required for system-level testing, to minimize reflections and ambient interference that can degrade the accuracy of the testing, and to evaluate modes of operation that are reserved for war or are classified.

The following list provides guidance on issues which should be addressed for intra-system EMC testing:

a. Potential interference between source/victim pairs should be systematically evaluated by exercising the subsystems and equipment onboard the system through their various modes and functions while monitoring the remaining items for degradation. Both one source versus a victim and multiple sources versus a victim conditions need to be considered.

b. A frequency selection plan should be developed for exercising antenna-connected transmitters and receivers. This plan should include:

   1) Predictable interactions between transmitters and receivers such as transmitter harmonics, intermodulation products, other spurious responses (such as image frequencies), and cross modulation. The acceptability of certain types of responses will be system dependent.

   2) Evaluation of transmitters and receivers across their entire operating frequency range, including emergency frequencies.

   3) Evaluation of known EMI emission and susceptibility issues with individual subsystems.

c. Margins should be demonstrated for ordnance subsystems and other relevant subsystems.

d. Operational field evaluation of system responses found in the laboratory environment should be performed (such as flight testing of an aircraft to assess responses found during testing on the ground).

e. Testing should be conducted in an area where the electromagnetic environment does not affect the validity of the test results. The most troublesome aspect of the environment is usually dense utilization of the frequency spectrum, which can hamper efforts to evaluate the performance of antenna-connected receivers with respect to noise emissions of other equipment installed in the system.

f. Testing should include all relevant external system hardware such as weapons, stores, provisioned equipment (items installed in the system by the user), and support equipment.

g. It should be verified that any external electrical power used for system operation conforms to the power quality standard of the system.

h. For portable electronic devices and carry-on equipment, EMI requirements are defined in 5.7.1.

Operational testing of systems often begins before a thorough intra-system EMC test is performed. Also, the system used for initial testing is rarely in a production configuration. The system typically will contain test instrumentation and will be lacking some production electronics. This testing must include the exercising and evaluation of all functions that can affect safety. It is essential that aircraft safety-of-flight testing be done to satisfy safety concerns prior to first flight and any flight thereafter where major electrical and electronic changes are introduced.

A common issue in intra-system EMC verification is whether to use instrumentation during the test to evaluate the performance of subsystems and equipment. The most common approach is to monitor subsystem performance through visual and aural displays and outputs. It is usually undesirable to modify cabling and electronics boxes to add instrumentation, since these modifications may change subsystem responses and introduce additional coupling paths. However, there are some areas where instrumentation is important. Demonstration of margins for critical areas normally requires some type of monitoring. For example, EIDs require monitoring for assessment of margins.

Some antenna-connected receivers, such as airborne instrument landing systems and identification of friend or foe, require a baseline input signal (set at required performance levels) for degradation to be effectively evaluated. Other equipment which transmits energy and evaluates the return signal, such as radars or radar altimeters, need an actual or simulated return signal to be thoroughly assessed for potential effects. The instrumentation required for these types of operations work thorough antenna coupling and don’t require the onboard equipment to be modified.

Attempts are sometimes made to perform intra-system EMC testing of space systems with on-board transmitters being simulated. It is essential that the actual transmitters be used and operated in their mission modes to ensure that equipment is exposed to realistic electromagnetic fields and resulting currents and voltages and to adequately evaluate intermodulation concerns. Without the actual RF emitters being used, there is no assurance that a 100% functional system is being provided.

Output characteristics of spread spectrum transmitters present unique technical issues which need to be addressed to achieve EMC.

RF compatibility between antenna-connected subsystems is an element of intra-system EMC and demonstration of compliance with that requirement needs to be integrated with these efforts. Any blanking techniques implemented for EMC performance should be evaluated during the testing.

Both MIL-STD-461 as well as some commercial standards reduces the risk of EMI due to case and cable conducted and radiation emissions and susceptibility. Compliance with these standards still leave system level risks due to the large amount of co-located systems being integrated in ships. The shipboard EME is dynamic and varies by compartment as well as between ships in a class due to modernizations and equipment variations due to the long period for ship construction. Therefore, conducting MIL-STD-1605(SH) tests to evaluate EMC is highly recommended where feasible.

Verification Lessons Learned (A.5.2):
Performance degradation of antenna-connected communication receivers cannot be effectively assessed by simply listening to open channels as has been done commonly in the past. Squelch break has often been used as the criteria for failure. There are number of problems with this technique.

Other than for EIDs, margin assessment is practical in several areas. Margins can be assessed for antenna-connected receivers using the spectrum analyzer technique described at the end of A.5.2.4. Another area where margin evaluation is practical is potential degradation of subsystems due to electrical cable coupling from electromagnetic fields generated by on-board antenna-connected transmitters. Intra-system compatibility problems due to communication transmitters, particularly HF (2-30 MHz), are fairly common. The induced levels present in critical interface cables can be measured and compared to demonstrated hardness levels from laboratory testing in the same manner as described in the appendix under A.5.3 for inter-system EMC.

System-level testing should be a final demonstration that RF compatibility has been obtained. It should not be a starting point to identify areas requiring fixes. Previous analysis and bench testing should resolve compatibility questions beforehand. To evaluate E3 system hardness the Navy utilizes MIL-STD-1605(SH). An EMI survey is required for new construction ships and ships receiving overhauls or other major repair work that changes the ships electromagnetic configuration.

Active signal cancellation techniques present a risky approach to EMC and should be rigorously tested before being implemented. This approach is most sensitive to signal phase error and may actually worsen an interference problem by injecting phase noise resulting from a changing multi-path situation (due to aircraft stores load, release, and so forth).

A.5.2.1 Hull generated intermodulation interference (IMI).

For surface ship applications, the intra-system EMC requirement is considered to be met for hull generated IMI when IMI product orders higher than 19th order produced by High Frequency (HF) transmitters installed onboard ship are not detectable by antenna-connected receivers onboard ship. Compliance shall be verified by test, analysis, or a combination thereof, through measurement of received levels at system antennas and evaluation of the potential of these levels to degrade receivers.

Requirement Rationale (A.5.2.1):
In general, control of IMI in systems is covered by the requirements of 5.2 addressing intra-system EMC. Because of difficulty on ships with limiting IMI produced by HF transmitters, only

higher order intermodulation products must be controlled to permit effective use of the spectrum. Issues with lower order products are addressed through frequency management.

Requirement Guidance (A.5.2.1):
The large number of HF transmitters, output power of the transmitters, and construction materials and techniques used on ships make the presence of IMI a reality. Electromagnetic fields from HF transmissions induce current flow in the ship's hull. The various currents from different transmitters mix in non-linearities within the hull (termed the "rusty bolt effect") to produce signals at sum and difference frequencies of the fundamental and harmonic frequencies of the incident signals ($F_3 = \pm n_1F_1 \pm n_2F_2 \pm \ldots$; n_1, n_2, ... are integers). The order of the IMI is the sum of the n terms. The mixing of a fundamental with a fourth harmonic produces a fifth order IMI.

Requirement Lessons Learned (A.5.2.1):
Experience has shown that controlling higher than the 19th order IMI provides frequency management personnel with sufficient flexibility to effectively manage the spectrum.

Verification Rationale (A.5.2.1):
Test and associated analysis are the only effective means to verify IMI requirements.

Verification Guidance (A.5.2.1):
Guidance on evaluating IMI is available through the Shipboard EMC Improvement Program (SEMCIP) technical assistance network. Access to the data base can be obtained by emailing SEMCIP@navy.mil.

Verification Lessons Learned (A.5.2.1):
Testing, supported by analysis, has proven to be an effective tool in evaluating IMI.

A.5.2.2 Shipboard internal electromagnetic environment (EME).

For ship applications, electric fields (peak V/m-rms) below deck from intentional onboard transmitters shall not exceed the following levels:

a. Surface ships.

1) *Metallic: 10 V/m from 10 kHz to 18 GHz.*

   Intentional transmitters used below deck shall be limited to a maximum output of 100 milliwatt (mW) effective isotropic radiated power (EIRP). The total combined power radiated within a compartment and within the operating frequency band shall be limited.

2) *Non-metallic: 50 V/m from 2 MHz to 1 GHz;*
   Metallic limits apply for all other frequency bands.

Intentional transmitters used below deck shall be limited to a maximum output of 100 milliwatt (mW) effective isotropic radiated power (EIRP). The total combined power radiated within a compartment and within the operating frequency band shall be limited to 13.75 W total radiated power (TRP). Additionally, no device shall be permanently installed within 1 meter of safety or mission critical electronic equipment.

b. *Submarines. 5 V/m from 10 kHz to 30 MHz and*
10 V/m from 30 MHz to 18 GHz.

Intentional transmitters used below deck shall be limited to a maximum output of 25 milliwatts (mW) effective isotropic radiated power (EIRP). The total combined power radiated within a compartment and within the operating frequency band shall be limited to 250 mW total radiated power (TRP).

For surface ships, compliance shall be verified by test of electric fields generated below deck with all antennas (above and below decks) radiating and adherence to the total radiated power limits indicated. For submarines, compliance shall be verified by test or by analysis of the TRP of below deck transmitters.

Requirement Rationale (A.5.2.2):
Specific controls must be imposed to limit internal electromagnetic fields for ship applications to ensure that the variety of electronic equipment used onboard ships will be able to function with limited risk of performance degradation. This approach is partially due to the methodology by which equipment is installed on ships. For system applications other than ships, it is generally the responsibility of the system integrator to ensure that fields internal to the system are controlled to levels consistent with immunity characteristics of installed equipment.

The use of wireless devices such as radio frequency identification (RFID) systems, handheld transceivers, wireless local area network (WLAN), etc., is increasing rapidly for below deck applications. Since below deck spaces are reverberant they contain and reflect radiated RF energy. RF propagation within such spaces is well defined by MIL-STD-461, RS-103 alternate test procedure which delineates the characterization and use of Reverberation Chambers as EMI test facilities. Accordingly the proliferation of intentional emitters results in an increased EME. This increase of the ambient EME has been identified as the cause of interference to mission critical legacy equipment. Mitigation of this EMI requires that ships and subs be considered a total system composed of numerous sub-systems. Accordingly interface controls are required to assure total system EMC. This requirement is intended to limit the electromagnetic environment such that EMI from both direct illumination and reverberant energy do not exceed the MIL-STD-461 electric field radiated susceptibility requirement and therefore equipment located within this environment will function reliably and without electromagnetic environmental effects (E3) problems.

Requirement Guidance (A.5.2.2):

Many types of electronic equipment are used on ships which have not been designed to be used in higher level electric field environment. Most predominant in this group are NDI and commercial items. Therefore, the EME must be controlled to provide a level of assurance that the equipment will operate properly.

Output power limits of 25 and 100 mW EIRP for a single emitter (transmitter) in submarines and ships, respectively, are invoked for this standard. These limits assure reliable operation of legacy equipment. Since these legacy equipment were tested at 1 V/m for submarine applications and at 10 V/m for surface ships, it is necessary to establish criteria for each. Equation A-1 was used to predict the resultant field intensities for each at a distance of 1 meter. In the case of submarines, 25 mW EIRP will produce an electric field intensity of 0.87 V/m which aligns well with the 1 V/m testing done to comply with earlier versions of MIL-STD-461. Since surface ship equipment were tested in accordance with MIL-STD-461 at 10 V/m with all equipment consoles secured, and many of the wireless systems such as WLANs are continuously transmitting, it is deemed necessary to account for the enclosure/console Shielding Effectiveness (SE). This SE can be reasonably estimated at approximately 15 dB, which is to say that the electronics within should not be exposed to more than 2 V/m when consoles/enclosures are open. Accordingly, a limit for surface ships is proposed at 100 mW which will result in an exposure of 1.7 V/m with no external shielding.

$$|E| = \frac{1}{2r}\sqrt{\frac{\eta G_t P_t}{\pi}} \qquad \textit{Equation A-1}$$

Where:

$|E|$ = electric field intensity, V/m

G_t = transmitter antenna gain

P_t = transmitter power

r = distance from transmit antenna, meters (r = 1 m)

η = impedance of the medium, ohms (η = 377 Ω)

When considering the additive nature of transmitters within enclosed electrically reflective spaces one must consider Total Radiated Power (TRP) instead of EIRP. This is due to diffusion of the transmitted energy due to reflections. Any gain (directivity) imparted on the transmitted energy is lost in such spaces due to their reverberant nature. This is well understood and documented in the Reverberation Chamber alternate test methodology described in MIL-STD-461. The utility of using TRP, then, is to calculate volumetric (i.e., non-line-of-sight) electric field levels in enclosed spaces.

Submarine Applications: The requirement of 250 mW TRP for multiple emitters in a space is an attempt to control the total electric field within the compartment and is invoked for this standard. A space is defined as a functional area within a compartment (e.g. Sonar Equipment Space or Torpedo Room). The 250 mW TRP equates to a volumetric electric field strength of 6.75 V/m. The electric field strength of 6.75 V/m aligns with the electric field radiated susceptibility requirement, RS103, of MIL-STD-461 with a 3.4 dB safety margin and allows for variance in the cavity calibration factor. The cavity calibration factor (ccf) is used to predict the resultant maximum electric field as a function of frequency and total radiated power in that space. This power level was calculated as follows:

$$P_{in} \approx \left(\frac{E}{ccf}\right)^2 \qquad \textit{Equation A-2}$$

Where:

P_{in} = transmitter power, watts

E = electric field intensity, V/m

ccf = cavity calibration factor which is calculated as follows:

$$ccf = \frac{8\pi}{\lambda}\sqrt{\frac{5IL}{\eta_{rx}}} \qquad \textit{Equation A-3}$$

Where:

λ = wavelength, meters

η_{rx} = antenna efficiency

IL = insertion loss which is calculated as follows:

$$IL = \frac{P_{rcvd}}{P_{in}} \qquad \textit{Equation A-4}$$

Where:

P_{rcvd} = received power, watts

P_{in} = incident power into cavity, watts

A cavity calibration factor, ccf, of 13.5 was utilized for the calculation of maximum total input power into the submarine compartment.

Surface Ship Applications: In recent years NAVSEA, NAVSUP and ONR collectively provided resources to conduct a study of the reverberant nature of below deck spaces on Navy ships. This study was conducted on ten ships of various classes (CVN, LHD, DDG & FFG) and compiled data from over 100 spaces. Equation A-2 (above) was used to determine a bounding condition CCF from the measured insertion loss data. Due to the sheer volume of data collected, only the four ships which produced the highest CCF values are shown on FIGURE A-1.

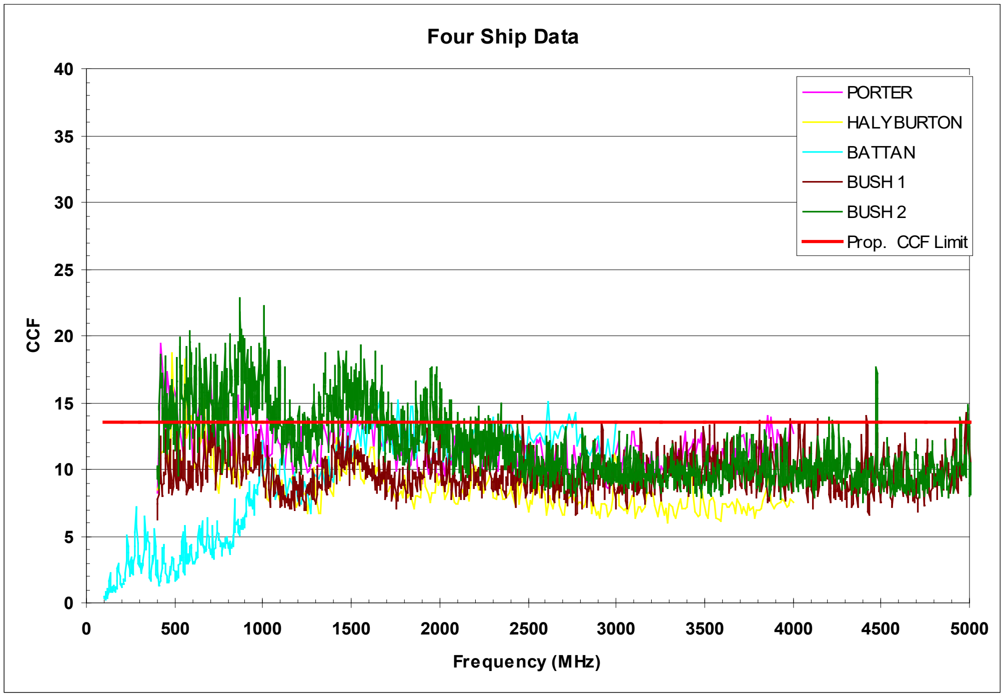


FIGURE A-1. CCF of select surface ships.

Also provided on FIGURE A-1 is the proposed CCF limit of 13.5, which equates to a TRP limit of 548 mW. It is readily apparent that the proposed limit does not encompass all of the measured data. It does however fit well at the industrial, scientific and medical (ISM) bands at 900 MHz and 2400 MHz and is above the vast majority of all measured data above 2000 MHz. Based on this analysis, it is the Navy's opinion that increasing the 13.5 CCF recommendation would be overly restrictive and that the risk of EMI would be sufficiently mitigated through a TRP limit of 550 mW.

A summary of these recommendations is provided in TABLE A-I.

TABLE A-I. Summary of recommendations.

Platform	Stand Off[1]	Max. EIRP[2]	Max. TRP[3]
Submarine	1 m	25 mW	250 mW
Surface Ship	1 m	100 mW	550 mW

NOTES:

1 Minimum distance between transmission source and safety or mission critical electronic equipment.

2 Maximum EIRP of a single device.

3 Maximum TRP of all devices within a single space. In cases where space boundaries are not clearly defined, a 30 feet radius from transmission source will be used to establish boundary.

Requirement Lessons Learned (A.5.2.2):

Compatibility problems have been experienced with electronic equipment due to inadequate control of field coupling below deck.

To date, the Navy has limited documented cases in which a wireless system implementation has caused EMI on platforms. However, documented cases do exist for a wireless local area network system that has been installed on multiple vessels. The system components have passed MIL-STD-461 requirements, and yet have caused mission-degrading EMI to legacy combat-critical systems aboard those platforms. Both complex cavity and direct line-of-sight mechanisms have been determined to be contributing to these EMI problems. A fundamental issue within the Navy results from the sheer volume of wireless technology users and technologies being used. Ships are manned with hundreds and, in some cases, thousands of sailors, each assigned to departments which have unique and, in many cases, conflicting requirements for wireless technologies. If left uncontrolled, the potential exists for a vast number of wireless networks required to serve the composite shipboard need. This condition will result in not only safety concerns from an EMI and HERO perspective, but create spectrum conflicts which will degrade overall shipboard performance. The intent of the guidance provided in this section is to enable the Navy to get in front of the wireless proliferation challenges from a platform design perspective, through application of an overarching limit on the number and location of wireless devices, to assure wireless functionality in a system of systems environment.

The requirement for individual transmitters and the requirement for total combine power are essential to bound the electric field levels in below decks spaces. These limits are harmonized with the electric field radiated susceptibility limit, RS103, of MIL-STD-461, that is to say, adherence with these limits will ensure that systems that are compliant with RS103 will be compatible in their intended environment and future increases to the RS103 levels should not be necessary.

Verification Rationale (A.5.2.2):

Testing is the only reliable method to determine the coupled EME to a reasonable level of certainty.

The requirement on intentional transmitters used below deck can be met by analysis or test.

Verification Guidance (A.5.2.2):

Significant characterization of below deck spaces has been conducted. These efforts resulted in an ability to apply controls which limit the ambient electric field based on power. Accordingly verification is simplified to monitoring the number and output power of emitters installed within said spaces.

Testing needs to be performed with frequency selective receivers (spectrum analyzer or EMI receiver) and appropriate antennas such as those used in the RE102 test procedures of MIL-STD-461. Mode stirred techniques is the preferred method for verification of this requirement. Broadband omnidirectional E-field sensors, such as those used in the RS103 test procedures of MIL-STD-461, can be used to search for areas of higher fields. Since these devices are broadband, they will detect the resultant E-field from all sources present within the bandpass of the device. The dominant source of the reading may not be obvious. Also, since these devices do not use the peak detection function present in spectrum analyzers and EMI receivers, indicated levels may be well below actual peak levels, particularly for pulsed fields.

Verification Lessons Learned (A.5.2.2):
Control of individual emitters output and the total combined power radiated within a compartment and within the operating frequency band is the only cost effective means to control the electromagnetic environment.

The techniques presented here are based on science which is well documented and adopted by industry through the International Electrotechnical Commission via IEC 61000-4-21 the Federal Aviation Administration via DO-160 and military via MIL-STD-461. Each of these standards committees recognizes the benefit of leveraging complex cavity effects for the purpose of testing electronic systems for EMI and adopted the use of Reverberation Chambers for such evaluations. Since the physics of a Reverberation Chamber are the same in any enclosed electrically reflective space, it is most appropriate to leverage this knowledge for the purpose of mitigating EMI in below deck spaces of submarines and ships.

Significant effort was made in generation of these requirements to assure no undue hindrance was applied which would stifle usage or implementation of wireless technologies while assuring to the greatest extent possible that such deployments will not create EMI to co-located equipment.

The need to impart limits on the below deck EME is not new as this document currently imparts limits in terms of electric field intensity. This expounds on that concept and provides a simplified means of assuring existing requirements are met.

A.5.2.3 Multipaction.

For space applications, equipment and subsystems shall be free of multipaction effects. Compliance shall be verified by test and analysis.

Requirement Rationale (A.5.2.3):
It is essential that RF transmitting equipment and signals not be degraded by the action of multipaction. It is essential that multipaction not result in spurious signals that interfere with receivers.

Requirement Guidance (A.5.2.3):
Multipaction is a resonant RF effect that happens in a high vacuum. An RF field accelerates free electrons resulting in collisions with surfaces creating secondary electrons. If the frequency of the signal is such that the RF field changes polarity in concert with the production of the secondary electrons, the secondary electrons are then accelerated resulting in more electrons leading to a major discharge and possible equipment damage. The guiding document for multipaction analysis is NASA TR 32-1500. This effect can be much worse in the presence of low partial pressure Paschen-minimum gasses, such as Helium. Helium venting during ascent is common on expendable launch vehicles (ELVs).

Requirement Lessons Learned (A.5.2.3):
Connectors, cables, and antennas have all been involved in multipaction incidents. Sometimes, the application of insulators on antennas or a vent in connectors is sufficient to limit multipaction or damage. In some cases, transmitted signal strength has been severely impacted. Multipaction in RF amplifier circuitry has been implicated in semiconductor and insulator degradation.

Verification Rationale (A.5.2.3):
Multipaction is a resonant phenomenon in the dimensions of frequency and power. Secondary electron emission decreases as electron energy rises. So a rapid increase in power (for example, a radar pulse) may well reduce the probability of multipaction. Analysis is absolutely necessary to determine how margin is shown. Since multipaction can show flaws in machining and dielectrics that no other test will indicate, testing also must be performed.

Verification Guidance (A.5.2.3):
All components experiencing RF levels in excess of 5 watts (less in space environments) need to be tested for multipaction. The test equipment must provide adequate power and transient levels to show margin with respect to the operating state. VSWR measurements provide a crude method of detecting multipaction; however, it is better to detect free electrons or changes in harmonic emissions.

Verification Lessons Learned (A.5.2.3):
For multipaction to occur, seed electrons must be present. In space, these electrons are provided by radiation. Some tests at sea level have shown no multipaction on components, while severe multipaction occurred in orbit. It is vital that a source of radiation or electrons be provided to get an accurate test. Some claim that some metals like aluminum are self-seeding. However, since the effect is strongly dependent on surface treatment, aluminum should not be depended upon to be self-seeding.

A.5.2.4 Induced levels at antenna ports of antenna-connected receivers.

Induced levels appearing at antenna ports of antenna-connected receivers caused by unintentional radio frequency (RF) emissions from equipment and subsystems shall not exceed critical receiver design thresholds such that system operational performance requirements are met. Compliance shall be verified by measurements at antenna ports of receivers over their entire operating frequency band.at the system level.

Requirement Rationale (A.5.2.4):

The need to evaluate antenna-connected receivers across their operating ranges is important for proper assessment. It has been common in the past to check a few channels of a receiver and conclude that there was no interference. This practice was not unreasonable in the past when much of the potential interference was broadband in nature, such as brush noise from motors. However, with the waveforms associated with modern circuitry such as microprocessor clocks and power supply choppers, the greatest chance for problems is for narrowband spectral components of these signals to interfere with the receivers. Therefore, it is common practice to monitor all antenna-connected outputs with spectrum analysis equipment during an intra-system EMC test. Analysis of received levels is necessary to determine the potential for degradation of a particular receiver.

Requirement Guidance (A.5.2.4):

Unintentional radiated emissions coupled to antennas can be above the noise floor of receivers resulting in performance degradation. In order to achieve reliable communications, the signal-to-noise ratio (SNR) should exceed a minimum value specific to each type of modulation and signal. For example, receivers using amplitude modulation (AM) voice transmissions typically require a minimum 10 decibels (dB) SNR at their specified sensitivity level. Binary phase shift keying (BPSK) often becomes useless when the SNR drops below 4 dB. Undesirable signals in-band to receivers can dramatically reduce the effective range of communication links or increase the likelihood of loss of information over data links.

Requirement Lessons Learned (A.5.2.4):

Compatibility and performance problems have been often experienced with receiver systems due to inadequate control of intra-system radiated emissions from equipment and subsystems.

Verification Rationale (A.5.2.4):

Measurements at the system level on production configured hardware and associated analysis are effective means to verify receiver performance.

Verification Guidance (A.5.2.4):

Measurements need to be performed with a spectrum analyzer (or an equivalent type of frequency selective equipment) at the antenna port of receivers over the entire frequency band of operation of the receiver against all potential sources of unintentional emissions to determine the impact with respect to the sensitivity of the receiver. Induced levels at receivers need to be determined and quantified so that potential degradation can be evaluated through analysis.

Verification Lessons Learned (A.5.2.4):
The most common receiver degradation being experienced is from microprocessor clock harmonics radiating from cabling. These signals are narrowband and stable in frequency. Considering a receiver designed to receive amplitude modulated (AM) signals, there are several responses that may be observed as discussed below. Similar analysis is applicable to other type receivers.

If an intentional signal above the squelch is present, the type of degradation is dependent on the location of the interfering signal with respect to the carrier. If the interfering signal is within a few hundred hertz of the carrier, the main effect will probably be a change in the automatic gain control (AGC) level of the receiver. If the interfering signal is far enough from the carrier to compete with the sideband energy, much more serious degradation can occur. This condition gives the best example of why squelch break is not an adequate failure criterion. AM receivers are typically evaluated for required performance using a 30%-AM, 1-kHz tone which is considered to have the same intelligibility for a listener as typical 80%-AM voice modulation. The total power in the sidebands is approximately 13 dB below the level of the carrier. Receiver specifications also typically require 10 dB (signal plus noise)-to-noise ratios during sensitivity demonstrations. Therefore, for an interfering signal which competes with the sidebands not to interfere with receiver performance, it must be approximately 23 dB below the carrier. An impact of this conclusion is that an interfering signal which is well below squelch break can cause significant range degradation in a receiver. If squelch break represents the true sensitivity required for mission performance, an interfering signal just below squelch break can cause over a 90% loss in potential range.

If no intentional signal is present and the clock harmonic does not have any AM associated with it, the main result is a quieting of the receiver audio output due to AGC action. To an observer, this effect might actually appear to be an improvement in receiver performance. If some AM is present at audio passband frequencies, a signal will be apparent that is dependent on the depth of the AM; however, the degree of receiver degradation cannot be effectively assessed since it is masked by the AGC.

Two acceptable methods of assessing degradation are apparent. A 30% AM signal can be radiated at each channel of interest at an induced level at the receiver which corresponds to the minimum required performance. Changes in intelligibility can be assessed with and without the interference present. Also, the level of the signal source can be varied and the resultant effects evaluated. Due to the large number of channels on many receivers (UHF receivers (225 – 400 MHz) typically have 7000 channels), this technique may often not be practical. An increasingly popular approach is to monitor antenna-induced signal levels with a spectrum analyzer or a real time spectrum analyzer which can capture a seamless time record of RF frequencies. A preamplifier is usually necessary to improve the noise figure of the analyzer and obtain adequate sensitivity. The received levels can then be easily assessed for potential receiver degradation. This technique has been found to be very effective.

A.5.3 External RF EME.

The system shall be electromagnetically compatible with its defined external RF EME such that its system operational performance requirements are met. TABLE I shall be used for deck operations on Navy ships, and TABLE II shall be used for ships operations in the main beam of transmitters for Navy ships. For space and launch vehicle systems applications, TABLE III shall be used. For ground systems, TABLE IV shall be used. For rotary wing aircraft, where shipboard operations are excluded, TABLE V shall be used. For fixed wing aircraft applications, where shipboard operations are excluded, TABLE VI shall be used. Unmanned vehicles shall meet the above requirements for their respective application. It should be noted that for some of the frequency ranges, limiting the exposure of personnel will be needed to meet the requirements of 5.9.1 for personnel safety.

Systems exposed to more than one of the defined EMEs shall use the worst case composite of the applicable EMEs. External RF EME covers compatibility with, but is not limited to, EME's from like platforms (such as aircraft in formation flying , ship with escort ships, and shelter-to-shelter in ground systems) and friendly emitters. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.

Requirement Rationale (A.5.3):

Increased multi-national military operations, proliferation of both friendly and hostile weapons systems, and the expanded use of the spectrum worldwide have resulted in operational EMEs not previously encountered. It is therefore essential that these environments be defined and used to establish the inter-system EMC design requirements. MIL-HDBK-235 catalogs various land-based, ship-based, airborne, and space emitters and associated environments that have resulted in the EME tables provided in this standard. Many of the electromagnetic fields produced by these emitters are very high and capable of degrading the performance of systems illuminated by them if they are not properly addressed. Even relatively low power personal communication system (PCS) items such as cellular phones, used in close proximity to sensitive electronic items, can create electromagnetic fields sufficient to degrade performance.

Operational problems resulting from the adverse effects of electromagnetic energy on systems are well documented. They include but are by no means limited to component failure, and unreliable Built in Test (BIT) indications. The extensive variety of potential problems underscores the importance of designing systems that are compatible with their intended operational EME.

Joint service operations further increase the potential for safety and reliability problems if systems are exposed to operational EMEs different from those for which they were designed. For example, Army systems, if designed for compatibility with a ground operation EME, may be adversely affected by exposure to a Navy shipboard "joint" environment.

The same transmitter does not necessarily drive the peak and average levels in a particular frequency range in any table. The average electric field levels in the tables are based on the average output power, which is the product of the maximum peak output power of the transmitter and maximum duty cycle. Duty cycle is the product of pulse width and pulse repetition frequency. $V_{Avg} = V_{Peak} \times (\text{duty cycle})^{1/2}$. This applies to pulsed systems only. The average power for non-pulsed signals is the same as the peak power (that is, no modulation present).

Each of the EME tables is briefly described in the following paragraphs. MIL-HDBK-235-1 provides general information and assumptions used to generate each of the EME tables. The specific parts of the handbook, as referenced below, give detailed rationale and assumptions used to derive the EME levels, as well as the characteristics of the emitters used to generate those levels.

TABLE I provides a roll-up table for the maximum external EME for deck operations in each designated frequency band on the weather and flight decks (including hangar decks) for each active Navy ship class.

TABLE II provides a roll-up table for the maximum external EME for ship operations in the main beam of transmitters in each designated frequency band for all Navy ships. The distances from the antenna vary with ship class and antenna configuration.

The EME levels shown on TABLE I are composite levels generated from the following major ship classes: Combatants (CG-47; DDG-51 Flights I, II, IIA and III; DDG-1000), Amphibious (LCC-19, LHA-6; LHD-1; LPD-17; and LSD-41 and -49), Carriers (CVN-68 and CVN-78), Mine Counter Measures (MCM-1), Patrol Coastal Craft (PC-1), and Littoral Combat Ships (LCS-1 and -2). The EME levels shown on TABLE II are composite levels generated from the aforementioned ship classes. For additional information on the assumptions used to derive the EME levels on U.S. Navy ships, see MIL-HDBK-235-2. For Coast Guard (USCG), Military Sealift Command (MSC), and Army ships, additional guidance can be found in MIL-HDBK-235-9.

Submarine external RF EME is not included as a stand-alone table in MIL-STD-464. The MIL-STD-461 RS103 field levels are generally adequate for many installations. However, submarine sail- and mast-mounted equipment and sensors may experience fields in excess of the 200 V/m RS103 requirement from nearby equipment and antennas co-located on the sail or mast. Analysis should be performed for sail and mast mounted equipment and sensors to determine the field intensities incident on the equipment due to on-hull RF emitters. MIL-HDBK-235-10 can be used in determining the submarine's RF emitters.

TABLE III provides the maximum external EME levels for space and launch vehicle systems. The EME levels are maximum EME levels derived from the EME levels for space systems in a low orbit (i.e., 100 nautical mile (nm) altitude) and the composite EME levels 1 kilometer (km) above various launch and recovery sites. For additional information on the assumptions used to derive these EME levels, see MIL-HDBK-235-3.

TABLE IV describes the minimum baseline EME for ground systems. The EME values for TABLE IV were derived from convoy or on-the-move operations (from mobile and portable platforms) and during base operations (from fixed and transportable systems) with each situation assuming certain separation distances from various classes of emitters. Dips in the EME were smoothed out so as not to imply a level of fidelity that does not really exist and to simplify testing. For additional information on the assumptions used to derive these EME levels, see MIL-HDBK-235-4.

TABLE V provides the external EME for rotary wing aircraft except during shipboard operations. The EME levels are composite levels generated from the following: Rotary Wing Aircraft In-Flight, Civilian Airfields during Landing and Take-off Operations, Military Airfield Operations, Expeditionary Airfield, and High Intensity Radiated Fields (HIRF) in Europe. The distances from the aircraft to airport and ground fixed and mobile emitters vary from 50 to 300 feet. For additional information on the assumptions used to derive these EME levels, see MIL-HDBK-235-5.

TABLE VI provides the maximum EME for fixed-wing aircraft systems except during shipboard operations. The EME levels are composite levels generated from the following: U.S. Fixed-Wing Aircraft In-Flight, Civilian Airfields during Landing and Take-off Operations, Military Airfield Operations, and Expeditionary Airfields. There are other documents and regulations that may define variations to the environment levels specified in TABLE V and TABLE VI. However, the levels in this standard represent the latest information available on these environments. For additional information on the assumptions used to derive these EME levels, see MIL-HDBK-235-6.

The actual operational electromagnetic environment that a system will encounter is highly dependent upon operational requirements and should be defined by the procuring activity. The EME tables provide a starting point for an analysis to develop the actual external radiated field environment based on the system's operational requirements. However, it is possible, due to special operational requirements or restrictions, for the actual environment to be higher or lower than these EME values. There is no substitute for well thought out criteria for a system based on its operational requirements. For all systems, the appropriate environment defined in MIL-HDBK-235 may be extracted and used for tailoring.

Proper environment definition must include both the modulation and polarization characteristics of a system to determine the peak and average fields over the entire frequency range. These requirements need to be based on the operational modulations of friendly, hostile, and civilian systems. For instance, amplitude modulation (AM) may cause substantial interference at low field levels, whereas continuous wave (CW) at significantly higher levels may not cause any interference. This type of difference can hold true for frequency modulation (FM) and pulse modulation (PM), as well as variations in polarization (vertical, horizontal, and circular).

Requirement Guidance (A.5.3):

The EME in which military systems and equipment must operate is created by a multitude of sources. The contribution of each emitter may be described in terms of its individual characteristics including: power level, modulation, frequency, bandwidth, antenna gain (main beam and sidelobe), antenna scanning, and so forth. These characteristics are important in determining the potential impact on system design. A high-powered emitter may illuminate the system for only a very short time due to its search pattern or may operate at a frequency where effects are minimized.

Antenna-connected receivers are not generally expected to operate without some performance degradation for the EME levels specified in the tables. In all cases, the receiver needs to be protected against burn-out. While the tables express the requirements in terms of a single level over a frequency band, it is quite unlikely that actual threat transmitters that drive the levels in the tables will be at the tuned frequency of a particular receiver. Some wide band devices, such as electronic warfare warning receivers, would tend to be the exception. It also needs to be recognized that the tables represent levels that will be seen infrequently in most instances.

Antenna-connected receivers have often been designed to operate without degradation with an out-of-band signal of 0 dBm present at the antenna port and levels that are 80 dB above sensitivity for signals within the tunable range (see early versions of MIL-STD-461). Since the levels represent reasonable requirements for minimum performance, receivers usually will perform substantially better. Calculations using the fields in the tables and typical receiver antenna characteristics show that levels at the receivers may be on the order of 50 dBm for peak fields and 30 dBm for average fields. Receiver performance cannot be assured without the use of external filtering. If there are operational performance issues with the absolute need for a particular receiver to be totally functional in a particular environment, design measures need to be implemented.

The external EME must be determined for each system. When considering the external EMEs (flight deck, airborne, battlefield and so forth), the following areas should be included in the evaluation.

a. Mission requirements. The particular emitters to which the system will be exposed depend upon its intended use. The various parts of MIL-HDBK-235 provide information on the characteristics of many friendly transmitters.

b. Appropriate standoff distance from each emitter. The various parts of MIL-HDBK-235 specify the fields at varying distances.

c. The number of sites and where they are located. The probability of intercept for each emitter and the dwell time should be calculated.

d. If applicable, high power microwave and ultra-wideband emitters should be included. See MIL-HDBK-235-8.

e. Operational performance requirements with options such as survivable only, degraded performance acceptable, or full performance required.

A platform design, while descriptively fitting the title of an external RF EME table (e.g., Fixed Wing or Rotary Wing), may not coincide with the platform’s operational EME definition. Strict attention must be payed to the assumptions used in deriving the tables to ensure appropriate EMC compliance.

Requirement Lessons Learned (A.5.3):
Without specific design and verification requirements, problems caused by the external EME typically are not discovered until the system becomes operational. By the time interference is identified, the system can be well into the production phase of the program, and changes will be expensive. In the past, the EME generated by the system's onboard RF subsystems (electronic warfare, radars, communications, and navigation) produced the controlling environment for many systems. From a probability of exposure, these items still play a critical role. However, with external transmitter power levels increasing, the external transmitters can drive the overall system environment.

Issues with external RF EMEs have become more visible due to more joint operations among the military services and unforeseen uses of systems. For example, some aircraft and weapons that were not originally intended for shipboard use have been deployed onboard ships.

A complication with modern systems is the use of specialized structural materials. The classic system is made of aluminum, titanium, or steel structures. Modern technology and the need to develop higher performance systems are providing alternatives using composites such as carbon-epoxy and Kevlar structure. Metals can provide good shielding against the EME and protection for electronic circuits. Electrically conductive composites typically provide system shielding comparable to metal at higher frequencies (approximately 100 MHz); however, at lower frequencies they do not perform as well. Some structure is made of non-conductive composites such as Kevlar which provide no shielding, unless they are treated with appropriate finishes.

High-powered shipboard radars have caused interference to satellite terminals located on other ships, resulting in loss of lock on the satellite and complete disruption of communication. The interference disables the satellite terminal for up to 15 minutes, which is the time required to re-establish the satellite link. Standoff distances of up 20 nautical miles between ships are required to avoid the problem.

A weapon system suffered severe interference due to insufficient channel selectivity in the receiver’s front end. Energy originating from electronic warfare systems and another nearby “sister” channelized weapon system (operating on a different channel but within the same passband) coupled into the victim receiver and was “processed,” severely degrading target detection and tracking capability. Installation of an electronically tuned filter immediately after the antenna countered the off-channel interference problem by: 1) eliminating receiver front-end amplifier saturation and 2) reducing overload of the system processor with extraneous in-band signals.

An aircraft lost anti-skid braking capability upon landing due to RF fields from a ground radar changing the weight-on-wheels signal from a proximity switch. The signal indicated to the aircraft that it was airborne and disabled the anti-skid system.

An aircraft experienced uncommanded flight control movement when flying in the vicinity of a high power transmitter, resulting in the loss of the aircraft. If the mission profile of the aircraft and the anticipated operational EME had been more accurately considered, this catastrophe could have been averted.

Aircraft systems have experienced self-test failures and fluctuations in cockpit instruments, such as engine speed indicators and fuel flow indicators, caused by sweeping shipboard radars during flight-deck operations. These false indications and test failures have resulted in numerous unnecessary pre-flight aborts.

Aircraft on approach to carrier decks have experienced interference from shipboard radars. One such problem involved the triggering of false "Wheels Warning" lights, indicating that the landing gear is not down and locked. A wave-off or preflight abort could occur due to this EMI induced condition.

Aircrews have reported severe interference to communications with and among flight deck crew members. UHF emissions in the flight deck environment caused interference severe enough that crews could not hear each other for aircrew coordination. This problem poses a serious hazard to personnel with the potential for damage to, or loss of, the aircraft and aircrew during carrier flight deck operations.

Verification Rationale (A.5.3):

There are many different RF environments that a system will be exposed to during its lifespan. Many threats will be seen only infrequently. Normal operational testing of a system may expose it to only a limited number of threats. Dedicated testing and analysis are required to verify the system capability in all RF environments it may see.

Verification Guidance (A.5.3):
External RF EME testing should be performed under laboratory conditions where the system under test and the simulated environment are controlled. Undesired system responses may require an EMV analysis to determine the impact of the laboratory observed susceptibility on system operational performance. Only under unusual circumstances is system verification accomplished or system susceptibilities investigated by operational testing in the actual external EME. There is much less control on variable conditions, fewer system functions can generally be exercised, and expenses can be much greater. The results of the EMV analysis and operational testing guide the possible need for system modification, additional analysis or testing.

System-level testing of large platforms such as aircraft, tanks, and ships, is usually done in an open area test site. The system's inter-system environment is evaluated to determine: which frequencies are of interest from the possible emitters to be encountered by the system when deployed, optimum coupling frequencies to the system, potential system EMV frequencies, available simulators, and authorized test frequencies. Based on these considerations and other unique factors to the system or program, a finite list of test emitters is derived. For each test emitter the system is illuminated and evaluated for susceptibilities. The test emitters may be swept with fixed frequency steps or may dwell at selected frequencies. For air delivered ordnance, system-level testing should include: preflight, captive-carry, and free-flight configurations.

Ideally, the entire system should be illuminated uniformly at full threat for the most credible demonstration of hardness. However, at most frequencies, test equipment does not exist to accomplish this task. Established test techniques are based on the size of the system compared to the wavelength of test frequency. At frequencies where the system is small compared to the wavelength of the illumination frequency (normally below 30 MHz), it is necessary to illuminate the entire system uniformly or to radiate the system such that appropriate electromagnetic stresses are developed within the system. Where illumination of the entire system is not practical, various aspects of the system's major physical dimensions should be illuminated to couple the radiated field to the system structure. At frequencies (normally above 400 MHz) where the size of the system is large compared to the wavelength, localized (spot) illumination is adequate to evaluate potential responses by illuminating specific apertures, cables and subsystems. 30 to 400 MHz is a transition region from one concept to the other where either technique may be appropriate, dependent upon the system and the environment simulator.

Typically, for a new system, 4 to 6 positions are used for low frequency illumination and 12 to 36 positions are used for spot illumination at higher frequencies. The emitters are radiated sequentially in both vertical and horizontal polarization. It usually is not practical to use circular and cross polarization. For an existing system which is undergoing retesting after installation of a new subsystem, 2 positions are normally used for low frequencies and 2 to 4 positions for high frequencies.

For the situation where the external environment exceeds all available simulators or it is necessary to achieve whole system illumination, the method of bulk current testing may be used. The system is illuminated from a distance to obtain near uniform illumination but at low levels. The induced current on the cable bundles from the uniform external field is measured. The induced current levels are then scaled to full current level based on the system's external environment. These extrapolated levels are compared to electromagnetic interference data on individual subsystems and equipment. If sufficient data is not available, cables can be driven at required levels on-board the system to evaluate the performance of the system. The cable drive technique has been applied up to 400 MHz.

The system during an inter-system EMC test is evaluated as a victim of interference from the environment. Modes of subsystems and equipment should include: BIT, operational procedures common to the test emitter environment, (for example, carrier deck operations versus airborne weapons release for an aircraft), and backup modes.

Pre-flight inter-system testing of air delivered ordnance is conducted to ensure that the system can successfully perform those pre-flight operations required during service use. Operations such as aircraft initiated BIT and mission or target data up-loading and down-loading are performed while exposing the weapon to the test EME.

Captive-carry inter-system testing of air delivered ordnance is conducted to verify weapon survivability following exposure to the main beam operational EMEs. Since this test simulates the weapon passing through the radar's main beam during takeoff and landing of the host platform, the weapon should be operated as specified for those flight conditions - typically standby or off. The duration of weapon exposure to the EMEs from the main beam should be based on normal operational considerations. Verification of system survivability may, in many cases, be made utilizing the weapon BIT function. However, if this is not possible, verification utilizing an appropriate system test set is required.

Free-flight testing of ordnance is performed utilizing an inert, instrumented weapon which is suspended in a low RF ambient environment (anechoic chamber) simulating free space or a mode-stirred chamber. Since the RF entry points and aspect angles associated with specific susceptibilities cannot be determined in the mode-stirred chamber, use of the anechoic chamber is sometimes required. The free-flight test program consists of evaluating weapon performance during the launch, cruise, and terminal phases of flight, while exposed to friendly and hostile EMEs.

The formal verification test of a system for inter-system EMC usually comes late in system development. A system such as an aircraft often undergoes extensive development and integration tests first. The external environment that may be encountered during these tests must be reviewed and the status of the aircraft with regard to the environment must be evaluated for safety prior to flight. EMI testing of the subsystems can be used as a baseline of hardness. Limited inter-system testing of the systems for safety concerns due to specific emitters may be necessary or possible restriction on allowable operation (such as aircraft flight paths) may need to be imposed.

For the U.S. Army aircraft community, system-level testing is performed on rotorcraft under the conditions in TABLE A-II. The fourth and fifth columns specify pulse modulation parameters to be used for the peak and average fields in TABLE V and TABLE II. In addition, testing is performed at the electric field levels in the second column of TABLE A-II using the modulation types listed in the third column for the specified frequency ranges identified in column one. This additional testing is intended to demonstrate performance for the types of modulations used in communications.

TABLE A-II. Specialized rotorcraft testing.

Frequency (MHz)	Electric Field for Simulating Communications (V/m – rms)	Modulation for Simulating Communications	Pulse Modulation for Peak/Average Fields in TABLE V	
			Pulse Width (µS)	Pulse Rep Freq (Hz)
0.01 – 2	200	CW, AM		
2 – 20	200	CW, AM	833.3	300
20 – 25	200	CW, AM, FM	833.3	300
25 – 150	200	CW, AM, FM		
150 – 250	200	AM, FM	20.0 – 25.0	200 – 310
250 – 500	200	AM, FM	25.0 – 33.0	300
500 – 1000	200	AM, FM	33.0	100 – 300
1000 – 2000	200	AM, FM	1.0 – 2.0	670 – 1000
2000 – 4000	200	AM, FM	1.0	250 – 600
4000 – 8000	200	AM, FM	1.0 – 2.0	250
8000 – 10000	200	AM, FM	1.0	150 – 250
10000 – 50000	200	CW, FM	1.0	1000

Verification Lessons Learned (A.5.3):

Failure to perform adequate inter-system EMC analysis or testing prior to system deployment has been shown to reduce the operational effectiveness and/or ability of military platforms, systems, ordnance, and equipment. For instance, a review of the numerous reports of Fleet EMI in the Navy's Air Systems EMI Corrective Action Program (ASEMICAP) Problem Management Database, demonstrates that many Fleet reported EMI incidents could have been prevented by completing an adequate verification program during the system's development. Access to the

ASEMICAP database for personnel with a demonstrated need can be arranged through the Naval Air Warfare Center, Aircraft Division, Code AIR-4.1.M, Patuxent River, MD.

Field problems and test results have shown the main concern for system degradation is the frequency range below 5 GHz with the majority of major problems below 1 GHz. At system resonance, maximum coupling usually occurs with the environment. Resonance of the system structural features, apertures, and cables is usually between 1 MHz and 1 GHz. Test data indicates a linear increase in induced cable current levels with the frequency up to the quarter-wave resonance of a structure where induced levels flatten out and oscillate up and down at the quarter-wave level with increasing frequency. To detect these resonances during test, it is desirable to either sweep or use small increments of frequency.

The predominance of problems at lower frequencies can be explained by considering coupling of a field to the effective area of a tuned aperture ($\lambda^2/4\pi$), which is proportional to the wavelength (λ) of the frequency squared. This aperture is an ideal area which is optimized for coupling maximum power from an incident field. This expression is multiplied in antenna theory by the gain of the antenna to determine the capture area of the antenna. The gain is simply assumed to be unity in this case. This concept can be viewed as either direct coupling through an aperture (opening) in system structure or coupling directly to subsystem circuitry treated as an antenna. As the wavelength becomes smaller with increasing frequency, the capture area becomes smaller and the received power is lower. In addition, as the frequency is increased, electrical cables are relatively poor transmission lines and coupling into subsystem becomes even less efficient, which leaves only direct penetration of enclosures as the main coupling path into the subsystem. As an example of the wavelength effect, the power coupled into a tuned aperture at 10 MHz for a given power density will be one million times greater than the power coupled into a tuned aperture at 10 GHz for the same power density: $(\lambda_1/\lambda_2)^2$ = (30 meters/0.03 meters)^2 = 1,000,000.

Typical test equipment used for the CW and high duty cycle tests are broadband distributed tube/transistor amplifiers and traveling wave tube (TWT) amplifiers together with long wire, vertical whip, double ridge horns, or dipole antennas. Typical test equipment used for pulsed tests are cavity tuned amplifiers, low duty cycle TWTs, magnetrons and klystrons with high gain horns.

A.5.4 High-power microwave (HPM) sources.

The system shall meet its operational performance requirements after being subjected to the narrowband and broadband HPM environments. Applicable field levels and HPM pulse characteristics for a particular system shall be determined by the procuring activity based on operational scenarios, tactics, and mission profiles using authenticated threat and source data such as the Capstone Threat Assessment Report. This requirement is applicable only if specifically invoked by the procuring activity. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.

Requirement Rationale (A.5.4):
The HPM area addressed by this requirement is as a threat which radiates high peak power electromagnetic pulses intended to disrupt or damage electronic systems. There are various other uses for HPM devices, such as in radar or electronic warfare technology. HPM devices nominally produce pulse peak power of 100 Megawatts or larger. Some devices produce a single pulse, while others produce multiple pulses. Delivery mechanisms can be an individual, vehicles, or large ground structures. Possible HPM devices have been postulated for several decades and the basic hardware devices have been available.

Requirement Guidance (A.5.4):
Operational scenarios and mission profiles must be examined to determine the probability of being targeted and the feasibility of such a threat being successful given the relatively limited range of effectiveness. Based on these operational scenarios and mission profiles that the systems are being designed to operate in, trade studies and analyses must be performed to determine effective distances from the HPM sources the systems will be required to operate and perform their missions. It is possible that as a result of such trade studies and analyses, the HPM requirement may not be applicable to a particular system since other RF energy environments such as those on 5.3 of this standard can effectively pose a more severe requirement. To determine the specific HPM threat for a specific platform the user of this standard must refer to the latest version of the individual Capstone Threat Assessment Reports to be obtained by the specific agency or service and must also refer to MIL-HDBK-235-8. MIL-HDBK-235-8 presents the method of usage/delivery for each specific threat system. Examples of method of usage/delivery are: man-portable, mobile ship/ground defense, UAV/Airborne attack, munitions attack, fixed air defense and others. The user of this document needs to determine a stand-off distance range against each method of usage/delivery based on operational scenarios, tactics, and/or mission profiles of their system. Once these distances are determined, the exact HPM environment for each threat can then be calculated. Front end protection of RF systems should then be employed with respect to the field strength of the threat.

Narrowband and wideband HPM sources are defined as follows:

Narrowband:	A signal or waveform with pbw* < 1%
Wideband:	A signal or waveform with pbw* > 1%

*pbw – percentage bandwidth: ratio of 3 dB down points of spectrum to center frequency

Narrowband HPM utilizes pulsed power to drive an electron beam diode or similar load that ultimately converts electron kinetic energy into coherent electromagnetic radiation. Narrowband HPM sources can often deliver over 1 GW of power in short bursts (typically <100ns pulse width).

Wideband, including ultra-wideband (UWB), HPM sources utilize fast switching techniques to drive impulse generators. The frequency content of the output pulse can be spread over several decades in frequency.

Although, repetitive pulses in short bursts (e.g., 100 pulses at 100 Hz) have been demonstrated, they tend to be at substantially lower source power levels (typical 15 times lower); therefore, single pulse shots were assumed.

For wideband HPM sources the typical repetition rate is 5 to 1000 Hz.

Since HPM sources have many manifestations, the objective when defining the HPM environment is to ensure flexibility to address many different operational scenarios and modes of employment. In calculating HPM environments, the probable range "r" of engaging a given threat against a military system must be determined since the electric field varies with the distance. The following equation is used to calculate far field power density at a given distance r.

$$p_d = \frac{\varepsilon G P_{in}}{4\pi r^2}$$ *Equation A-3*

Where p_d = power density at range r, with antenna gain G, power into antenna P_{in}, and antenna mismatch factor ε.

$$p_d = \frac{E^2}{Z_0}$$ *Equation A-4*

Where Z_0 is the impedance of free space (Z_0 = 377).

The two equations indicate that the magnitude of E is inversely proportional to distance.

HPM source parameters such as pulse width, pulse repetition frequency, modulation and other detailed information are specified in MIL-HDBK-235-8.

Requirement Lessons Learned (A.5.4):

High power microwave (HPM) sources have been under investigation for several years as potential weapons for a variety of combat, sabotage, and terrorist applications. Due to classification restrictions, details of this work are relatively unknown outside the military community. Due to the gigahertz-band frequencies (1 to 40 GHz) involved, HPM has the capability to penetrate not only radio front-ends, but also small shielding penetrations in system or equipment enclosures. At sufficiently high levels, the potential exists for damage to devices and circuits. However, induced voltages from fields are inversely proportional to wavelength at frequencies where the equipment is multiple wavelengths long. Therefore, higher frequencies of operation do not necessarily correlate with more effective performance of the HPM weapon.

Verification Rationale (A.5.4):
For systems with an HPM requirement, verification is necessary to demonstrate that implemented measures provide required protection. Both analysis and test are usually essential in verifying system performance.

Verification Guidance (A.5.4):
Determining the appropriate HPM environment tests levels requires detailed knowledge of the HPM weapon and its engagement scenario, the operational scenario of the target system to protect, and the shielding from the surrounding infrastructure. The obvious counter-measure is to shield or harden electronic equipment. Currently, only flight critical and mission critical systems and equipment are hardened. Retrofitting of hardening for existing equipment is difficult and can be costly. Testing for narrowband HPM threats should be performed using the exact threat waveforms or as close as technically feasible to the exact waveforms that are defined for each threat in MIL-HDBK-235-8. Testing for wideband HPM threats should be performed using the exact threat waveforms or as close as technically feasible to the exact waveforms that are defined for each threat in MIL-HDBK-235-8 or using a wideband waveform such as double exponentials that cover the Broad-Band Electric Field Distribution that is calculated.

Verification Lessons Learned (A.5.4):
HPM protection requires no unique hardening techniques other than perhaps front end protection of an RF system against a known threat field strength. Proper grounding, bonding, and shielding methods applicable to other electromagnetic environment requirements that are imposed on a system should be considered when developing hardening approaches and required verification.

A.5.5 Lightning.

The system shall meet its operational performance requirements when subjected to direct, indirect, and near strike lightning effects. Ordnance shall meet its operational performance requirements after experiencing a near strike in an exposed condition and a direct strike in a stored condition. Ordnance shall remain safe during and after experiencing a direct strike in an exposed condition. FIGURE 1 provides aspects of the lightning environment that are relevant for protection against direct effects. TABLE VII defines the waveform parameters applicable at the platform for lightning direct and indirect effects evaluations. Waveforms appropriate for direct effects include voltage Waveforms A, B, C, D, and current Components A, Ah, B, C, and D. Waveforms appropriate for indirect effects evaluations include current components A, D, and H which are individual components of the single stroke, multiple stroke and multiple burst waveform sets. FIGURE 2 provides the timing sequence and number of pulses required to replicate the multiple stroke and multiple burst environments. TABLE VIII shall be used for the near strike lightning environment. Compliance shall be verified by system, subsystem, equipment, and component level tests, analysis, or a combination thereof.

Requirement Rationale (A.5.5):
There is no doubt that lightning is hazardous for systems and that systems must include provisions for lightning protection. There is no known technology to prevent lightning strikes from occurring; however, lightning effects can be minimized with appropriate design techniques.

Lightning effects on systems can be divided into direct (physical) and indirect (electromagnetic) effects. The physical effects of lightning are the burning and eroding, blasting, and structural deformation caused by lightning, as well as the high pressure shock waves and magnetic forces produced by the associated high currents. The indirect effects are those resulting from the electromagnetic fields associated with lightning and the interaction of these electromagnetic fields with equipment in the system. Hazardous effects can be produced by lightning that does not directly contact system structure (nearby strikes). In some cases, both physical and electromagnetic effects may occur to the same component. An example would be a lightning strike to an antenna which physically damages the antenna and also sends damaging voltages into the transmitter or receiver connected to that antenna. DOT/FAA/CT-89/22 is an excellent source of lightning characteristics and design guidance.

An additional reason for requiring protection is potential effects on personnel. For example, serious electrical shock may be caused by currents and voltages conducted via mechanical control cables or wiring leading to the cockpit of an aircraft from control surfaces or other hardware struck by lightning. Shock can also be induced on flight crews under dielectric covers such as canopies by the intense thunderstorm electric fields. One of the most troublesome effects is flash blindness, which invariably occurs to a flight crew member looking out of the aircraft in the direction of the lightning and may persist for 30 seconds or more.

Requirement Guidance (A.5.5):
The direct effects environment is described on FIGURE 1. The indirect effects environment is described in TABLE VII and on FIGURE 2. In, TABLE VII the indirect effects environment is defined by specifying parameters of a double exponential waveform (except for component C, which is a rectangular pulse) for the various electrical current components. FIGURE 2 represents a model of the properties of lightning events which include a series of strokes of significant current spaced over time (multiple stroke) and many individual strokes of lower current more closely spaced and grouped in bursts over time (multiple burst). This model is intended to be associated only with potential upset of electronics through indirect effects and is not intended to address physical damage issues. FIGURE A-2 identifies important characteristics of the double exponential waveform and wavefront which are listed in TABLE A-III for each of the indirect effects current components. Both the direct and indirect effects environments are derived from SAE ARP5412. This ARP contains a more detailed description of the environment than provided above and includes additional waveforms.

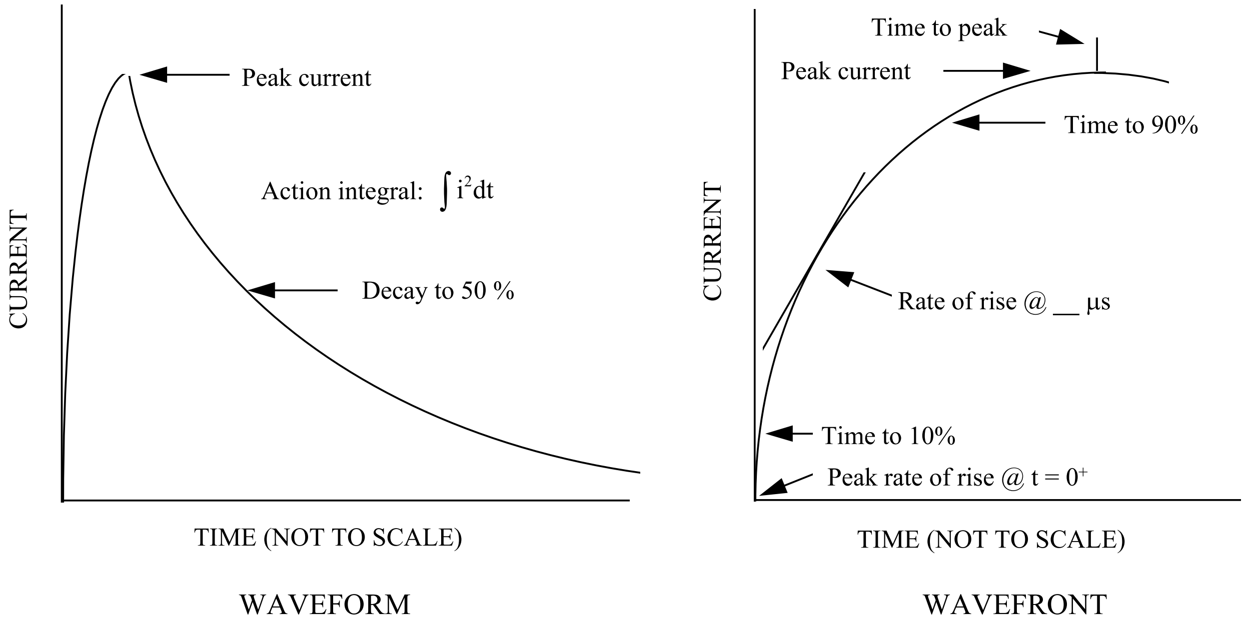


FIGURE A-2. Lightning indirect effects waveform parameters.

TABLE A-III. Lightning direct and indirect effects waveform parameters.

Current compo-nent	Peak current (kA)	Action Integral (A^2s)	Decay to 50% (µs)	Time to 10% (µs)	Time to 90% (µs)	Time to Peak (µs)	Rate of rise (A/s)	Peak rate of rise t = 0+ (A/s)
A	200	2.0×10^6	69	0.15	3.0	6.4	1.0×10^{11} @ 0.5 µs	1.4×10^{11}
B	Produces average current of 2 kA over a 5 millisecond period							
C	Defined as rectangular waveform for analysis purposes of 400 A for 500 milliseconds							
D	100	0.25×10^6	34.5	0.08	1.5	3.18	1.0×10^{11} @ 0.25µs	1.4×10^{11}
D/2	50	6.25×10^4	34.5	0.08	1.5	3.18	0.5×10^{11} @ 0.25µs	0.7×10^{11}
H	10	N/A	4.0	0.0053	0.11	0.24	N/A	2.0×10^{11}

The indirect lightning requirements specified in TABLE VII and on FIGURE 2 are associated with the electrical properties of a direct attachment of lightning. Ordnance is not generally required to function after a direct attachment in the exposed condition. However, it must survive the electromagnetic coupling effects of a near strike as defined in TABLE VIII. Ordnance is required to survive a direct attachment to the container where the ordnance is stored.

The near strike parameters in TABLE VIII are derived by modeling the lightning stroke as a vertical line charge. Use of Ampere’s Law for a constant magnetic field strength at a distance “r” away from the channel and taking the time derivative produces:

$$\frac{dH(t)}{dt} = \frac{dI(t)}{dt} / 2\pi r \qquad \textit{Equation A-6}$$

Where *H* is magnetic field, *I* is current, and *r* is the distance from the channel.

Using the maximum rate of change for Current Component A in TABLE A-III produces the magnetic field rate of change in TABLE VIII for a distance of 10 meters. For safety hazards, a minimum separation distance of 10 meters is assumed. Smaller separation distances are regarded as a direct strike event. Alternative separation distances for specific systems can be theoretically calculated by utilizing the "cone of protection" or "rolling sphere" calculation techniques. Additionally, for system survivability, separation distances greater than 10 meters may be acceptable when combined with appropriate analysis and justification. The development of the electric field rate of change is too involved for presentation in this standard. It is based on modeling a vertical leader approaching the earth as a line charge a specified distance above the ground. For the detailed development of the requirement (see U.S. Army report TR-RD-TE-97-01).

As nearby lightning gets closer to an object, the effects approach those associated with the definitions for direct or indirect lightning. The peak field intensity of extremely close lightning can reach 3×10^6 V/m. For any system hardened against the defined indirect effects lightning requirement, protection against nearby lightning is included. Many ground systems can accept some risk that the system operates only after a moderate lightning strike at a reasonable distance. For example, a requirement for equipment in a tactical shelter to survive a 90th percentile lightning strike at 50 m may represent a reasonable risk criteria for that shelter. This type of requirement would result in a high level of general lightning protection at a reduced design and test cost.

The direct and indirect effects environments, while describing the same threat, are defined differently to account for their use. The direct effects environment is oriented toward supporting available test methodology to assess the ability of hardware to protect against the threat. The indirect effects environment is more slanted toward supporting analysis. While these environments were developed for aircraft applications, they should represent a reasonable environment definition for other systems. Some recent measurements of natural lightning have indicated that spectral content of some strikes at higher frequencies may be greater than represented by the defined lightning models. For small systems, there could be some enhancement of coupling due to exciting of resonances.

In addition to ARP5412 previously mentioned, the SAE AE-2 committee has issued several other documents that thoroughly address the lightning discipline. ARP5415 as well as the FAA Advisory Circular AC 20-136 deal with certification of aircraft for indirect effects protection, ARP5577 provides guidance on certification of aircraft for direct effects protection, and ARP5414 addresses lightning zoning for aircraft, and ARP5416 details test methodology for evaluating both the direct and indirect effects of lightning.

While all airborne systems need to be protected against the effects of a lightning strike, not all systems require the same level of protection. For example, an air-launched missile may only need to be protected to the extent necessary to prevent damage to the aircraft carrying the missile. The system should remain safe to operate during and following a direct strike and all mission systems must recover to their pre-strike operational states.

Direct effects protection on all-metal aircraft has been generally limited to protection of the fuel system, antennas, and radomes. Most of the aircraft lost due to lightning strikes have been the result of fuel tank arcing and explosion. Other losses have been caused by indirect effects arcing in electrical wiring in fuel tanks. As aircraft are built with nonmetallic structures, protection of the fuel system becomes much more difficult and stricter attention to details is required. In general, some metal will have to be put back into nonmetallic structures to provide adequate lightning protection. FAA Advisory Circular AC 20-53 and its users' manual provide requirements for protection of aircraft fuel systems.

In aircraft, lightning protection against indirect effects has become much more important due to the increased use of electrically and electronically controlled flight and engine systems. Also, the nonmetallic skins that are being used on aircraft to save weight provide less shielding to the electromagnetic fields associated with lightning strikes. FAA Advisory Circular AC 20-136 and its user's manual provide indirect effects protection information.

If DO-160 and AC 20-136 are considered for use, the hazard terminology and various indirect effects transient requirements used by the civil air community need to be reviewed regarding their applicability to particular military procurements.

For space systems, the launch facility is expected to provide protection for the space and launch vehicles from a direct lightning strike. The space and launch vehicles themselves are not normally required to survive a direct strike. Indirect effects requirements for the space and launch vehicles apply for electromagnetic fields at a 100 meter or greater distance. The system should be capable of detecting any loss in operational performance before launch caused by a lightning strike.

Specific protection measures for ground facilities are highly dependent on the types of physical structures and equipment involved. Devices such as lightning rods, arrestors, ground grids in the pavement, and moisture content of the soil all influence the protection provided. The guidance provided in MIL-STD-1542, MIL-HDBK-454, and NFPA 780 addresses different design approaches to reduce lightning effects on equipment.

Requirement Lessons Learned (A.5.5):
Aircraft can be exposed to naturally occurring strikes or may initiate the lightning strike. The naturally occurring strike to an aircraft is described as follows. As an aircraft flies through an electric field between two charge centers, it diverts and compresses adjacent equipotential lines. The highest electric fields will occur at the aircraft extremities where the lines are most greatly compressed. If the aircraft intercepts a naturally-occurring lightning flash, the on-coming step leader will intensify the electric field and induce streamers from the aircraft extremities. One of these streamers will meet the nearest branch of the advancing step leader forming a continuous spark from the cloud charge center to the aircraft. The aircraft becomes part of the path of the leader on its way to a reservoir of opposite polarity charge, elsewhere in the same cloud (intra-cloud strike), in another cloud (inter-cloud strike), or on the ground (cloud-to-ground strike). In the case of aircraft initiated strikes, the electric field induces leaders to start propagating from entry and exit of the aircraft. Aircraft triggered lightning is a more likely event.

High peak currents occur after the stepped leader completes the path between charge centers and forms the return stroke. These peak currents are typically 30-40 kA; however, higher peak currents are encountered with peak currents in excess of 200 kA. The current in the return stroke rises rapidly with typical values of 10-20 kA/microsecond and rare values exceeding 100 kA/microsecond. Typically, the current decays to half its peak amplitude in 20-40 microseconds.

The lightning return stroke transports a few coulombs (C) of charge. Higher levels are transported in the following two phases of the flash. The first is an intermediate phase with currents of a few thousand amperes for a few milliseconds which transfers about 20 C. The second is a continuing current phase with currents on the order of 200-400 amps flowing for 0.1 to 1 second, which transfers about 200 C.

Typical lightning events include several high current strokes following the first return stroke. These occur at intervals of several milliseconds as different pockets in the cloud feed their charge into the lightning channel. The peak amplitude of the re-strikes is about one half of the initial high current peak.

When lightning strikes a platform, the electrical current distributes throughout any electrically conductive portions of the platform structure. Current levels that are developed internal to the platform are strongly dependent upon external structural materials and associated “skin” effect and current diffusion. For aircraft made of metallic structure, the currents on internal conductors, such as shielded cables, are often on the order of tens of amperes. For aircraft using large amounts of graphite epoxy based structure, currents can be on the order of 10 kA.

Internal currents on electrical conductors within fuel tanks can cause arcing and sparking that can potentially ignite fuel vapors if electrical bonding is not properly implemented. An important aspect in fuel vapor areas is that the current appears on all types of electrically conductive materials such as fuel tubes, hydraulic tubes, inerting lines, metal brackets, and conduits. There have been recent cases where it was found after the fact that bonding was not implemented properly and significant redesign efforts were required. There appears to be more of a tendency for inadequate bonding when purely mechanical systems are involved and where corrosion control concerns can dominate decisions.

The effects of lightning can cause physical damage to personnel and equipment. In one of numerous documented lightning incidences, lightning appeared to enter a Navy aircraft nose, travel down the right side, and exit on top of the right vertical tail. The pilot suffered from flash blindness for 10-15 seconds. Upon regaining his vision, the pilot noticed all cockpit electrical power was gone. After another 15 seconds had elapsed, all cockpit electrical power returned on its own, with no cockpit indications of any equipment malfunction.

In another case, lightning attached to the nose pitot tube, inducing transients that damaged all 28 volt DC systems. The pilot, disoriented, broke out of a cloud bank at 2000 feet above the ground, at 600 knots and a 45 degree dive. Nearly all cockpit instruments were dysfunctional – compass, gyrohorizon, and so forth. A secondary effect occurred but was not uncovered for several months. The lightning current path that carried the direct effects lightning current did what it was supposed to do, but the path was not inspected on landing. Over 800 man-hours were expended to correct electrical (28 volt DC) problems but no effort went into inspecting for direct effects damage to ensure the lightning protection system was intact. The rigid coax from the front of the radome to the bulkhead had elongated and nearly torn away from its attachment point at the bulkhead due to magnetic forces involved. This damage reduced the effectiveness of the designed lightning protection. Another secondary effect was the magnetization of all ferrous material which caused severe compass errors. The entire aircraft had to be degaussed.

Verification Rationale (A.5.5):
Verification of lightning requirements is essential to demonstrate that the design protects the system from the lightning threat environment.

Verification Guidance (A.5.5):
There is no single approach to verifying the design. A well-structured test program supported by analysis is generally necessary.

During development of system design, numerous development tests and analyses are normally conducted to sort out the optimum design. These tests and analyses can be considered part of the verification process, but they must be properly documented. Document details should include hardware definition, waveforms, instrumentation, and pass-fail criteria.

Flight testing of aircraft often occurs prior to verification of lightning protection design. Under this circumstance, the flight test program must include restrictions to prohibit flight within a specified distance from thunderstorms, usually 25 miles. Lightning flashes sometimes occur large distances from the thunderstorm clouds and can occur up to an hour after the storm appears to have left the area. Large pockets of charge can remain that can be discharged by an aircraft flying between oppositely charged pockets.

Verification Lessons Learned (A.5.5):
The naturally occurring lightning event is a complex phenomenon. The waveforms presented in this standard are the technical community's best effort at simulating the natural environment for design and verification purposes. Use of these waveforms does not necessarily guarantee that the design is adequate when natural lightning is encountered. One example is an aircraft nose radome that had included lightning protection, which had been verified as being adequate by testing techniques existing at the time. However, when the aircraft was struck, natural lightning often punctured the radome. Subsequent testing had been unable to duplicate the failure. However, the lightning community has now developed new test methodology for radomes that can duplicate the failures.

The use of non-metallic (composite) materials for parts such as fuel tanks and aircraft wings introduces the need for specific tests for sparking and arcing in these members. A test in the wet wing of an aircraft identified streamering and arcing from fastener ends. The tests resulted in a new process by the manufacturer to coat each fastener tip with an insulating cover.

A.5.6 Electromagnetic pulse (EMP).

The system shall meet its operational performance requirements after being subjected to the EMP environment. This environment is classified and is currently defined in MIL-STD-2169. This requirement is applicable only if invoked by the procuring activity. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.

Requirement Rationale (A.5.6):
High-altitude EMP (HEMP) is generated by a nuclear burst above the atmosphere which produces intense electromagnetic fields over large areas and is relevant to many military systems. The entire continental U.S. area can be exposed to high-level fields with a few bursts. MIL-STD-2169, a classified document, provides detailed descriptions of the components of the threat waveforms (E1, E2, and E3). FIGURE A-3 provides an unclassified version of the E1 free-field time-domain threat environment developed by the International Electrotechnical Commission (IEC). This waveform may be used for rough (order of magnitude) calculations but should not be used in design and testing of actual military systems. FIGURE A-4 contains the E1 frequency-domain spectrum. Note all military systems with an HEMP requirement are required to use the classified

HEMP environment in MIL-STD-2169. In a nuclear war, it is probable that most military systems will be exposed to HEMP.

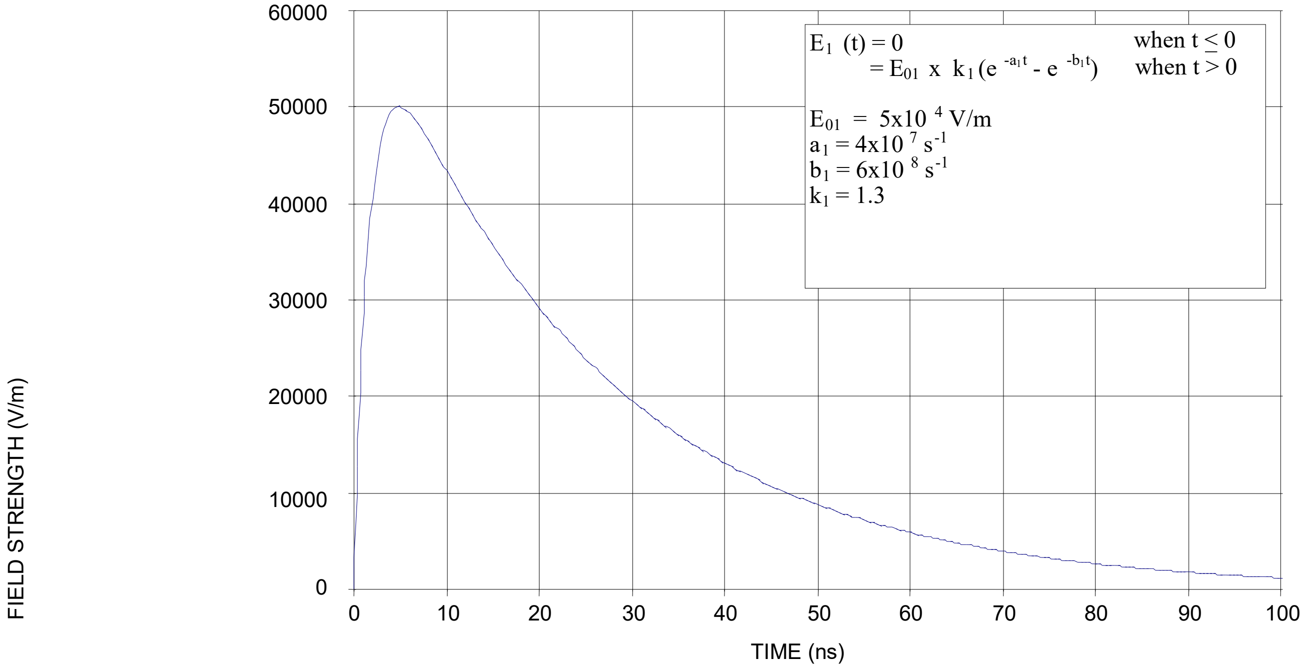


FIGURE A-3. Unclassified free-field EMP time-domain environment (IEC 61000-2-9).

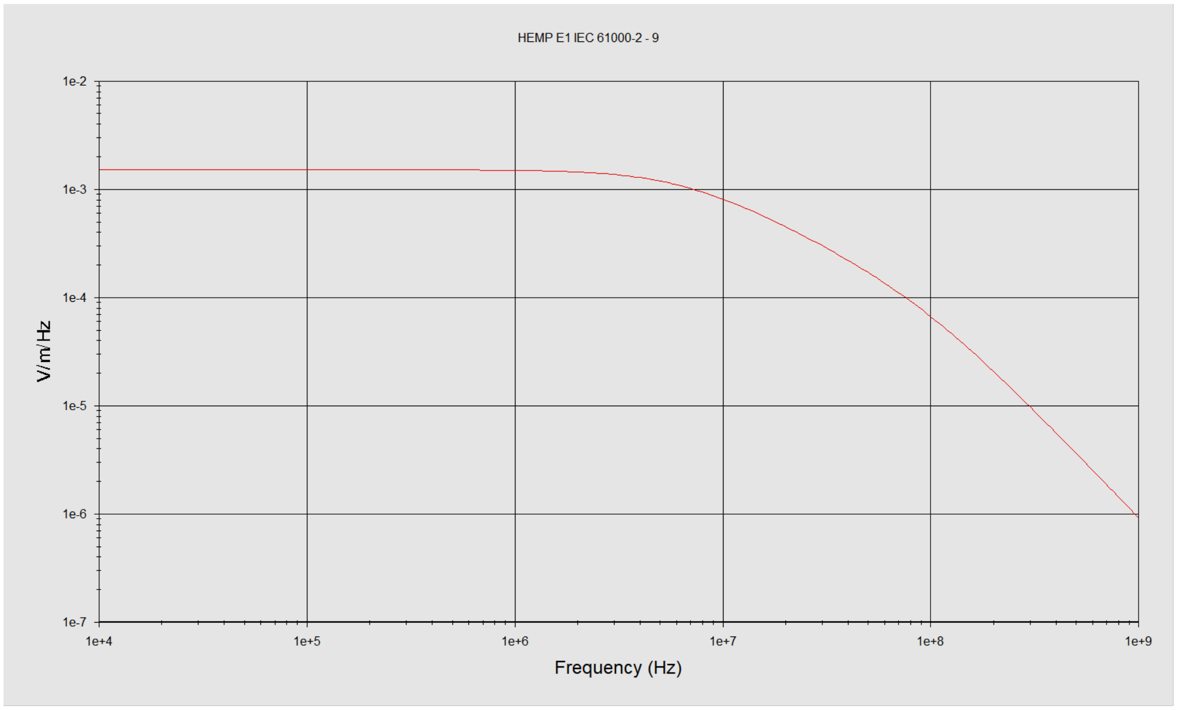


FIGURE A-4. Unclassified free-field EMP frequency domain environment (IEC 61000-2-9).

Requirement Guidance (A.5.6):
HEMP is propagated as a plane wave. The direction of propagation with respect to a system is determined by line of sight from the system to the burst point. For systems located directly beneath the burst (ground zero) and just south (northern hemisphere), the electric field is maximized and horizontally polarized (parallel to the earth's surface), whereas for systems located near the tangent to the earth from the burst point, the fields are essentially vertically polarized. Between these locations, the fields vary in a complex manner in amplitude and polarization with respect to direction and angle from the burst point. Since it is generally unknown where a system will be located with respect to the burst point, a prudent design approach is to harden against the maximum threat-level field and verify/assess/evaluate the system design by testing it to a horizontally polarized HEMP test environment and a vertically polarized HEMP test environment.

An unclassified composite waveform of the early-time (E1), mid-time (E2), and late-time (E3) HEMP environment is shown on FIGURE A-5.

HEMP (E1) is caused by prompt gamma rays released from the nuclear burst that interact with the atmosphere above 20 km altitude to generate an electromagnetic pulse that immediately propagates to the Earth's surface at the speed of light. This intense electromagnetic pulse couples well to local antennas, equipment in unshielded buildings (direct penetration and through apertures), and to short and long conductive lines. E1 contains strong in-band signals for coupling to MF, HF, VHF and some UHF receivers. The most common protection against the effects of E1 is accomplished using electromagnetic shielding, filters, and surge arresters. E1 can temporarily or permanently disrupt the operation of fixed facilities, mobile and transportable ground-based systems, aircraft, missiles, surface ships, and electronic equipment and components, especially commercial off-the-shelf (COTS) equipment which has become prevalent in most military systems. Thus, E1 effects must be considered in protecting essentially all terrestrial military systems and equipment that are required to be capable of operating in a HEMP environment.

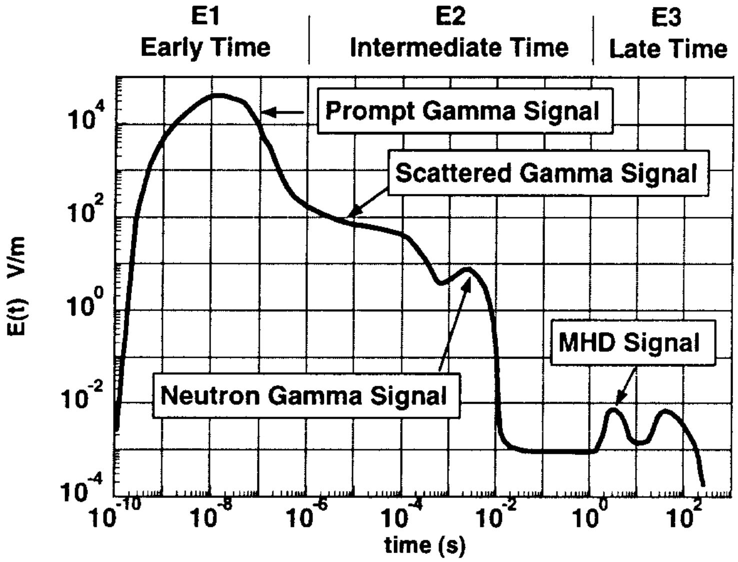


FIGURE A-5. Unclassified nominal HEMP composite environment (E1, E2, and E3).

Typical HEMP-induced currents on and in military systems are related to the lengths and shapes of conductive elements (such as a fuselage); to the size, number, and location of apertures in metal structural elements; to the size, number, and location of penetrating conductors and their proximity to each other (e.g., cross coupling); to the overall shielding effectiveness; and to a number of other factors. For aircraft and interconnected ground vehicles, peak external currents are on the order of 1000's of Amperes. Peak surface currents on ships are on the order of 1000's of Amperes while peak currents on isolated vehicles of modest size are less than that of aircraft and ships. Currents on HF, LF, and VLF antennas associated with these systems range from 100's to 1000's of Amperes.

The E2 intermediate time HEMP signal has two components: E2a scattered gamma signal followed by E2b neutron gamma signal. The scattered gamma HEMP (E2a) is a plane wave that couples well to long conductive lines, vertical antenna towers, and systems such as aircraft with trailing wire antennas. Protection against E2a is accomplished using EM filters and surge arresters.

The neutron inelastic gamma HEMP (E2b) couples well to long overhead and buried conductive lines and to extended VLF and LF antennas on submarines. Dominant frequencies overlap AC power and audio spectrums making filtering difficult. Since it is impractical to expose a system to a simulated E2b environment, pulsed current injection sources have been developed to test systems based on calculated E2b-induced currents on conductive long lines.

Magnetohydrodynamic (MHD) HEMP (E3) couples well to power and long communications lines including undersea cables. Low frequency content (sub Hertz) makes shielding and isolation difficult. Experience from geomagnetic storms and previous above-ground nuclear testing indicates significant probability of commercial power and landline disruption. Since it is impractical to expose a system to a simulated E3 environment, pulsed current injection sources have been developed to test systems based on calculated E3-induced currents on conductive long lines such as the commercial power grid. This requirement only applies to facilities and systems with a HEMP requirement that are connected to long conductive lines 10s to 100s kilometers long and to VLF antennas. MIL-STD-188-125-1 should be consulted for latest E3 testing requirements and pass/fail criteria.

FIGURE A-3 only addresses E1, since it is the most common portion of the HEMP waveform which is imposed on systems. MIL-STD-2169 addresses all aspects of the threat; its use is mandatory for all military systems with an HEMP requirement.

The requirement wording addresses meeting operational performance requirements “after” exposure to the HEMP environment. This wording is recognition that at the instant of the HEMP event, the electrical transients present within the system may be causing some disruption of performance. Immediately after the event or within some specified time frame (driven by system operational performance requirements), the system must function properly.

MIL-STDs for HEMP protection and system-level verification testing have been issued for use in procuring HEMP survivable, mission-critical systems including MIL-STD-188-125-1 HEMP Protection For Fixed Ground-Based C^4I Facilities, MIL-STD-188-125-2 HEMP Protection For Transportable Ground-Based C^4I Systems, MIL-STD-3023 HEMP Protection For Military Aircraft, and MIL-STD-4023 HEMP Protection For Military Surface Ships.

a. MIL-STD-188-125-1 HEMP Protection For Fixed Ground-Based C^4I Facilities and MIL-STD-188-125-2 HEMP Protection For Transportable Ground-Based C^4I Systems. MIL-STD-188-125-1 prescribes minimum performance requirements for low-risk protection of ground-based command, control, communications, computer, and intelligence (C^4I) facilities from mission-impacting damage and upset from the HEMP threat environments as defined in MIL-STD-2169. MIL-STD-188-125-1 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. The standard may also be used for other types of ground-based facilities that require hardening. MIL-HDBK-423 contains guidance on implementing the requirements of MIL-STD-188-125-1. MIL-STD-188-125-2 prescribes minimum performance and test requirements for low-risk protection of transportable ground-based C^4I facilities from mission-impacting damage and upset from the HEMP threat environments as defined in MIL-STD-2169. MIL-STD-3023 prescribes risk-based protection for military aircraft and MIL-STD-4023 prescribes risk-based protection for military surface ships. For both these standards, uncertainties present in the design implementation process and testing limitations are accounted for by a hardness margin that is subsumed into shielding effectiveness and hardness protection point-of-entry pass/fail criteria.

b. MIL-STD-3023 HEMP Protection For Military Aircraft. This standard establishes design margins, performance metrics, and test protocols for HEMP protection of military aircraft against functional upset and damage due to exposure to the HEMP threat environment in MIL-STD-2169. Since an aircraft's skin provides limited shielding, substantial HEMP-induced stresses (currents) can flow on cables and conductive structures internal to an aircraft. Therefore, aircraft HEMP hardening is achieved by deriving some shielding from the fuselage and wings; use of well-shielded cables and conduits; and by housing mission-critical systems in shielded racks or compartments with cable point-of-entry penetrations treated with low-impedance bonded cable shields, surge arrestors and filters, where required. Another key requirement in MIL-STD-3023 is that all internal mission-critical systems and equipment must be tested to MIL-STD-461 CS116 susceptibility requirements to establish known safe immunity levels, while externally mounted electronics equipment must also meet MIL-STD-461 RS105 requirements to establish known safe immunity levels. The standard specifies a user selectable Design Margin (DM) of 6 dB, 20 dB or 32 dB be demonstrated during DDT testing. This DM is based on known uncertainties inherent in design implementations, HEMP testing limitations, and it also accounts for known hardness degradation of in-service aircraft. Each major uncertainty factor used to derive these DM requirements was obtained thru analysis of an aircraft HEMP test database containing over 17,000 simulated HEMP test measurement records. DDT verification testing demonstrates the DM was met which then can be used to estimate an aircraft's survivability. Final verification testing is performed in three phases: active system test (AST), passive system test (PST), and direct drive test (DDT) which are detailed in the standard. AFWL-TR-85-113 provides guidance on design considerations which address electromagnetic pulse concerns for aircraft.

c. MIL-STD-4023 HEMP Protection For Military Surface Ships. This standard establishes hardness margins, performance-based criteria, and test procedures for HEMP protection of military surface ships. The standard specifies a user selectable Hardness Margin (HM), 6 dB or 20 dB, which must be demonstrated during DDT testing. This HM is based on known uncertainties inherent in the design implementation and HEMP testing, and also accounts for known hardness degradation of in-service ship protection treatments such as shield grounding adaptors (SGAs). The ship's hull and superstructure are imperfect shields but still help to limit large HEMP-induced currents from coupling and cross-coupling to equipment below deck. All conductive penetrations thru these ship surfaces are required to be protected with SGAs that help shunt large currents on topside cables and conduits to the exterior surfaces of the ship. Selected exterior apertures such as windows, doors and hatches also can have HEMP protection requirements. Similar to MIL-STD-3023, final verification of ship hardness is demonstrated thru successfully executing AST, PST and DDT test protocols.

While ionizing radiation is not within the scope of this document, some space vehicles have performance requirements during exposure to the ionizing radiation environments of a nuclear anti-satellite weapon. In those cases, the space vehicle and associated payload electronics need to be designed to operate through and survive the effects. MIL-STD-3053, Comprehensive Endo-/Exo-Atmospheric Nuclear Environment Standard (CANES) provides the warfighter the ability to evaluate their various atmospheric systems and understand their performance in nuclear weapons environments. Likewise, MIL-STD-3054 Nuclear Disturbed Communications Environment (NDCE) contains nuclear disturbed atmospheric environments, such as scintillation, that can adversely affect earth terminal, satellite transmissions and other terrestrial communications. Specific requirements should be placed in relevant contracts.

Requirement Lessons Learned (A.5.6):

HEMP poses a threat only to electrical and electronic equipment in systems. There are no structural damage mechanisms; however, EMP induced arcing of insulators on antenna systems can permanently damage the insulator, disabling the antenna. The EMP waveform results in a broadband transient excitation of the system. Transient currents are induced to flow at the natural resonance frequencies of the system. Currents may flow into internal portions of the system through direct conduction on electrical wiring or mechanical assemblies which penetrate external structure. The magnetic fields produced by the large external currents may couple voltages and currents into wiring internal to the system through any available apertures.

Ground-based military systems typically specify the HEMP environment even when other components of the nuclear environment are not specified. This threat is a plane wave electromagnetic field at ground level resulting from a high altitude burst. Hardening against ground-burst nuclear radiation environments is often not cost effective because a burst near enough to produce a radiation and electromagnetic threat is also close enough for the blast to disable the facility. Buried facilities such as ICBM launch sites are an exception.

The most commonly observed effect from EMP is system upset. Burnout of electronics has occurred less frequently. However, as electronic chip sizes continue to decrease (sub-micron), the amount of energy required for burnout will reduce, and designers must insure that adequate interface protection is present. Upsets can range from mere nuisance effects, such as flickers on displays and clicks in headsets, to complete lockups of systems. Upsets, which change the state of a system, can be either temporary (resettable) or permanent. Some upset cases can be reset almost instantaneously at the time a switch is activated while others, such as reloading of software, may take minutes. With the introduction of safety critical functions controlled by electronics in systems, potential effects from upsets can be life threatening.

Verification Rationale (A.5.6):

For systems with an EMP requirement, verification through testing is necessary to demonstrate that implemented measures provide required protection. Both analysis and test are usually essential in verifying system performance.

Verification Guidance (A.5.6):
Analysis is the starting point for initial system design and for hardening allocations. Development tests are generally conducted to clarify analysis predictions as well as to determine the optimum designs. These analyses and tests are part of the overall design verification.

High-altitude EMP protection standards have been developed for fixed ground-based facilities, transportable ground-based systems, aircraft and ships. Each of these standards contains detailed verification testing protocols and pass/fail criteria. Use of these standards is mandatory for DoD military system procurements that have a HEMP requirement.

The following are elements of an iterative process for designing and verifying protection of a system's electrical and electronic equipment against the effects of EMP.

a. EMP coupling analysis. A coupling analysis is necessary to determine the EMP free-field coupling into the system. Existing coupling data on similar system designs should be used whenever possible. This analysis provides an estimate of the voltages and currents generated by the EMP at each interface of each mission-critical equipment and can be used to establish stress levels to be included in electromagnetic interference (EMI) requirements imposed on the equipment. Requirements CS115, CS116, and RS105 of MIL-STD-461 provide a basis for appropriate EMI requirements for equipment.

b. Identification of relevant subsystems. Identification of relevant subsystems. Mission critical systems (MCS), subsystems and equipment that may be affected by EMP must be identified. The equipment's physical location within the system and its electrical connectivity to other equipment need to be determined.

c. Equipment strength determination. The inherent hardness of equipment without specific EMI susceptibility requirements needs to be determined. These results together with existing EMI requirements on equipment establish a lower bound on the upset and damage thresholds for each mission critical system.

d. Specification compliance demonstration. Verification that the system meets EMP protection design requirements is accomplished by demonstrating that the actual transient levels appearing at the equipment interfaces do not exceed the hardness levels of the individual equipment or subsystem and that the required design (hardness) margins have been met. Verification should be accomplished by a combination of test and analysis.

MIL-STD-188-125-1 and MIL-STD-188-125-2 contain verification test methods for demonstrating that C^4I fixed ground-based facilities and transportable ground-based systems meet HEMP requirements. The test methods describe coupling of threat-relatable transients using pulse current injection to penetrating conductors at injection points outside of the facility's electromagnetic shielding barrier. Residual internal responses are measured, and the operation of mission critical subsystems is monitored for upset or damage. The standard also contains shielding effectiveness and CW illumination test procedures used to measure the performance of the facility shield. MIL-STD-3023 and MIL-STD-4023 for HEMP protection of military aircraft and ships, respectively provide a similar verification test approach except that these standards require illuminating the aircraft and ships with a simulated plane wave HEMP threat environment and measuring the induced stresses at each MCS equipment interface. Each MCS must be tested to MIL-STD-461 CS116 to establish its immunity before being installed into the platform. A user selectable margin is then applied to the measured current stress which is then pulse current injected (PCI) at the same interface used in the MIL-STD-461 CS116 testing. This enables direct stress to immunity comparisons at common interfaces for each mission critical equipment throughout the system. Monitoring for upset and damage is also performed at this time.

Verification Lessons Learned (A.5.6):
Nuclear testing during the 1960's confirmed that the effects of nuclear EMP are significant well beyond the detonation site.

The choice of verification methods is somewhat dependent upon uncertainties associated with the available methods. Verification schemes that are oriented more toward analysis will usually introduce much larger uncertainties than test. Therefore, the required margins that must be demonstrated will be that much greater. Also, analysis is not capable of anticipating design flaws. For example, larger-than-anticipated current levels resulted during an aircraft system-level test due to metallic lines which had not been designed for proper electrical bonding entering a shielded volume. In another case, terminal protection devices did not operate due to the low impedance present in the circuit which they were designed to protect, and as a result, high current levels appeared in a shielded volume. Uncertainties in analysis can be reduced by selective testing of sections of the system.

Protection measures related to structural components should be evaluated for performance during assembly to verify that they meet requirements as installed in the system. After assembly, access to some components may not be practical. Passing a test in the laboratory does not necessarily mean that requirements will be satisfied in the actual assembly. Many times the final design contains materials, surfaces, or fasteners which are different from the laboratory model. Also, the complex geometry of a final system design may be so different from that which was modeled in the laboratory that the electromagnetic behavior is substantially altered.

There are a number of ways to obtain system-level excitation for purposes such as quality control or hardening evaluation. Low-level CW illumination of the system or of individual components is relatively easy and can often reveal an oversight in system assembly or a deficiency in the design of a hardening element. For aircraft, single point excitation (electrical connection of a signal source to a physical point on the external structure of the system) can be done (even in a hanger) and can similarly reveal any obvious problems in the airframe shielding.

Tests of structural design and hardening measures should be done as early in the assembly of the system as possible and should continue throughout the design process. If problems are uncovered during the initial assembly, the correction is usually straightforward. However, if the deficiencies are not found until the system is completed, the result can be a very expensive retrofit program. Analysis, laboratory testing, and system-level testing with low-level signals are important elements of compliance. However, a system-level test of a functioning system using a high-level EMP simulator is a high confidence method of demonstrating compliance.

A.5.7 Subsystems and equipment electromagnetic interference (EMI).

Individual subsystems and equipment shall meet interference control requirements (such as the conducted emissions, radiated emissions, conducted susceptibility, and radiated susceptibility requirements of MIL-STD-461) so that the overall system complies with all applicable requirements of this standard. Compliance shall be verified by tests that are consistent with the individual requirement (such as testing to MIL-STD-461).

Requirement Rationale (A.5.7):

EMI (emission and susceptibility) characteristics of individual equipment and subsystems must be controlled to obtain a high degree of assurance that these items will function in their intended installations without unintentional electromagnetic interactions with other equipment, subsystems, or external environments. The electromagnetic environment within a system is complex and extremely variable depending upon the various operating modes and frequencies of the on-board equipment. System configurations are continuously changing due to new equipment, and system upgrades and modifications. Equipment developed on one platform may be used on other platforms and may cause electromagnetic incompatibility. MIL-STD-461 provides a standardized set of interference control and test requirements which form a common basis for assessing the EMI characteristics of equipment.

Some of the primary factors driving the need for controls are the presence of sensitive antenna-connected receivers, which respond to interference generated within their tuning ranges, and the environments produced by on-board and external transmitters, lightning, and electromagnetic pulse.

Requirement Guidance (A.5.7):

The particular EMI requirements on individual items need to be specified based on system design concepts related to transfer functions between environments external to the vehicle and installation locations, isolation considerations with respect to other on-board equipment, and operational characteristics of other equipment. MIL-STD-461 is a tri-service coordinated document which standardizes EMI design and test requirements. Historically, MIL-STD-461 specified requirements while MIL-STD-462 provided test methodology. In 1999, MIL-STD-461E combined the material into one document allowing MIL-STD-462 cancellation.

MIL-STD-461 requirements should be used as a baseline. Appropriate requirements for a particular application may also be obtained from commercial specifications, such as RTCA DO-160 or other industry standards. DO-160 contains a variety of limits which the equipment manufacturer can choose as a qualification level for his equipment. For any EMI standard, care needs to be taken to ensure that appropriate limits are used for a particular application. Unique requirements may also be specified as necessary. For example, additional requirements may be necessary for reasons such as lightning protection of systems using composite structure or spectrum compatibility. Section A.5.7.2 of this standard provides additional guidance for the development of tailored EMI requirements for NDI and commercial items. Space vehicles should also comply with the additional EMI requirements of SMC-S-008 and AIAA-S-121.

EMI requirements are separated into two areas, interference emissions from the subsystem and susceptibility (sometimes referred to as immunity) to external influences. Each of these areas have conducted and radiated controls. Most emission requirements are frequency domain related and data are taken with spectral analysis equipment, current probes for conducted measurements, and antennas for radiated measurements. Susceptibility requirements are usually defined in terms of conducted drive voltages and currents for transients and modulated sinusoids to evaluate power and signal interfaces and electromagnetic field levels for radiated signals. Susceptibility measurements are performed with a wide variety of signal sources, power amplifiers, injection devices, and antennas.

An application where emission requirements may need to be imposed that are more stringent than the default limits in MIL-STD-461 concerns platforms or ground installations that perform intelligence, surveillance, and reconnaissance (ISR) missions. ISR can include the detection of weak signals across a wide portion of the frequency spectrum. Standard emission limits that are placed to protect other antenna-connected receivers in the installations may not provide sufficient protection to allow these receivers to be used optimally. As with any application, the actual controls that are necessary are based on transfer functions for coupling electromagnetic energy between the locations of the equipment and the antenna installations. There have been continuing issues with ISR equipment being placed in existing installations that weren’t originally designed for that type of application.

Electromagnetic coupling considerations for wiring and cable for space and launch vehicles can be found in MIL-HDBK-83575.

Requirement Lessons Learned (A.5.7):

The limits specified in MIL-STD-461 are empirically derived levels to cover most configurations and environments; however, they may not be sufficient to guarantee system compatibility. Tailoring needs to be considered for the peculiarities of the intended installation. The limits have a proven record of success demonstrated by the relatively low incidence of problems at the system-level. There is usually reluctance to relax requirements since system configurations are constantly changing, and subsystems/equipment are often used in installations where they were not originally intended to be used. Measurements of a particular environment are usually not available and actual levels would be expected to vary substantially with changes of physical location on the system and with changes in configuration.

Past experience has shown that equipment compliance with its EMI requirements assures a high degree of confidence of achieving system-level compatibility. Non-conformance to the EMI requirements often leads to system problems. The greater the noncompliance is with respect to the limits, the higher the probability is that a problem will develop. Since EMI requirements are a risk reduction initiative, adherence to the EMI requirements will afford the design team a high degree of confidence that the system and its associated subsystems will operate compatibly upon integration.

There is often confusion regarding perceived margins between emission and susceptibility requirements. The relationship between most emission control requirements and susceptibility levels is not a direct correspondence. For example, MIL-STD-461 requirement RS103 specifies electric fields which subsystems must tolerate. Requirement RE102 specifies allowable electric field emissions from subsystems. RE102 levels are orders of magnitude less than RS103 levels. Margins on the order of 110 dB could be inferred. The inference would be somewhat justified if the limits were strictly concerned with a one-to-one interaction such as wire-to-wire coupling of both RE102 and RS103 levels. This type of coupling is a minor concern for RE102. The driving reason for RE102 levels is coupling into sensitive RF receivers through antennas. The front-ends of receivers are typically many orders of magnitude more sensitive than wire-connected interfaces in systems. Similarly RS103 levels directly correspond to electromagnetic fields radiated from antenna-connected transmitters. These fields are typically orders of magnitude larger than fields produced by cable emissions. Consequently, the apparent excessive margins that can be erroneously inferred from MIL-STD-461 do not exist.

Verification Rationale (A.5.7):
Testing is required to demonstrate compliance with electromagnetic interference requirements. For most cases, analysis tools are not available which can produce credible results to any acceptable degree of accuracy.

Verification Guidance (A.5.7):
For programs using MIL-STD-461, it also provides corresponding test methods for each requirement (conducted and radiated requirements for emissions and susceptibility).

RTCA DO-160 is the commercial aircraft industry's equivalent of MIL-STD-461 for both requirements and test methodology. Some of the larger commercial aircraft companies have their own in-house standards which the FAA accepts for certification. Some military aircraft (primarily cargo type) have a mixture of military and commercial subsystems. Subsystems that are newly designed or significantly modified should be qualified to MIL-STD-461. Unmodified off-the-shelf equipment usually does not require requalification providing acceptable electromagnetic interference data exists (MIL-STD-461, DO-160, or other approved test methods). Section A.5.7.2 contains additional guidance on verification for NDI and commercial items. Some additional laboratory evaluation may be necessary to ensure their suitability for each particular application.

For first flight aircraft applications where equipment verification has not been completed, the following MIL-STD-461 (or equivalent) testing should be completed prior to flight to ensure flight safety: RE102, RS103, CE102, CS114, CS115, and CS116 for safety-critical equipment. In addition, CE102 and RE102 are required for all other equipment. These requirements are also applicable for Army ground systems in order to obtain safety release.

For ISR signal intelligence systems, RF emission characterization or EM noise floor survey of the host platform, ground or airborne, will be required to assess sensor sensitivity at its operational environment.

Verification Lessons Learned (A.5.7):

The "D" and subsequent revisions of MIL-STD-461 emphasize testing techniques which are more directly related to measurable system-level parameters. For instance, bulk cable testing is being implemented for both damped sine transient waveforms and modulated continuous wave. The measured data from these tests can be directly compared to stresses introduced by system-level threats. This philosophy greatly enhances the value of the results and allows for acceptance limits which have credibility.

An argument has sometimes been presented in the past that successful completion of an intra-system compatibility test negates the need to complete electromagnetic interference tests or to comply with requirements. Electromagnetic interference tests must be completed prior to system-level testing to provide a baseline of performance and to identify any areas which may require special attention during the system-level testing. Also, system-level testing exercises only a limited number of conditions based on the particular operating modes and parameters of the equipment and electrical loading conditions. In addition, electromagnetic interference qualification of the subsystems provides protection for the system with configuration changes in the system over time. One particular concern is the addition of new antenna-connected receivers to the system, which can be easily degraded if adequate controls are not maintained.

A.5.7.1 Portable Electronic Devices and Carry-On Equipment Requirements.

Portable electronic devices and carry-on equipment containing electronics which are not permanently installed or integrated into platforms and require airworthiness certification shall meet, as a minimum, the following EMI interface control requirements:

> *Safety Critical: All platform emissions and susceptibility requirements (such as those defined in MIL-STD-461) that are defined for safety critical equipment.*

Non-Safety Critical: All platform emissions requirements (such as those defined in MIL-STD-461).

If any part of the portable electronic device/carry-on equipment contains radio frequency transmission capability, then transmitter emissions characteristics shall be measured (such as in MIL-STD-461 Test Method CE106), in addition to the applicable requirements stated above. An aircraft EMC evaluation per 5.2 shall also be required to demonstrate platform compatibility of the portable electronic devices/carry-on equipment which have radio frequency transmitting capability.

If any part of the portable electronic device/carry-on equipment contains ordnance or is integrated into an ordnance system, then the HERO requirements stated within this standard shall also be met.

Compliance shall be verified by test per the applicable requirements.

Requirement Rationale (A.5.7.1):
See rationale for A.5.2.

Requirement Guidance (A.5.7.1):
See guidance for A.5.2.

Requirement Lessons Learned (A.5.7.1):
See lessons learned for A.5.2.

Verification Rationale (A.5.7.1):
See rationale for A.5.2.

Verification Guidance (A.5.7.1):
See guidance for A.5.2.

Verification Lessons Learned (A.5.7.1):
See lessons learned for A.5.2.

A.5.7.2 Non-developmental items (NDI) and commercial items.

NDI and commercial items shall meet EMI interface control requirements suitable for ensuring that system operational performance requirements are met. Compliance shall be verified by test, analysis, or a combination thereof.

Requirement Rationale (A.5.7.2):
NDI and commercial items may be installed in systems for any number of reasons - economic, availability, and so forth. When installed in the system, the NDI and commercial items need to comply with the system level E3 requirements of this standard. Therefore, NDI and commercial

items must have suitable EMI characteristics such that they are not susceptible to electromagnetic stresses present in their installation and that they do not produce interference which degrades other equipment. Most equipment built these days is designed and tested to some form of EMI requirement and the data may be available. Other equipment may require testing.

Requirement Guidance (A.5.7.2):

The use of NDI or commercial items presents a dilemma between the need for imposing EMI controls and the desire to take advantage of existing designs, which may have unknown or undesirable EMI characteristics. Blindly using NDI or commercial items carries a risk of incompatibilities onboard the system. To mitigate the risk, a suitability assessment is required to evaluate the installation environment and the equipment's EMI characteristics through a review of existing data, review of equipment design, or limited testing.

Existing EMI test data should be reviewed to determine if the equipment is suitable for the particular application intended. If a piece of NDI or commercial item is being considered for use as mission equipment on an aircraft, then the equipment should meet the same EMI requirements as imposed on other equipment on the aircraft. However, if the NDI or commercial item is being considered for use in an electromagnetically hardened ground shelter, then imposition of EMI requirements may not be necessary. Each potential use of NDI or commercial items needs to be reviewed for the actual usage intended, and a determination needs to be made of appropriate requirements for that application.

The Defense Industry EMC Standards Committee (DIESC) studied the suitability of using equipment in military applications that had been qualified to various commercial EMI standards. The DIESC performed detailed comparisons of requirements and test methodology of the commercial documents with respect to MIL-STD-461E. The results of this work are available in EPS-MIL-STD-461: "Results Of Detailed Comparisons Of Individual EMC Requirements And Test Procedures Delineated In Major National And International Commercial Standards With Military Standard MIL-STD-461E."

The following guidelines should be considered in selecting and utilizing NDI or commercial items in the system:

a. The equipment EMI characteristics may be considered adequate if the specific requirements for installed equipment on a particular system developed from transfer functions are less stringent than those to which the equipment was designed and applicable EMI test data is available to verify compliance. Compliance with the equipment-level EMI requirements does not relieve the developing activity of the responsibility of providing system compatibility.

b. Where compliance with applicable equipment-level EMI requirements cannot be substantiated, laboratory EMI testing should be performed to provide the data necessary to demonstrate compliance with the requirements.

c. If after evaluation of the equipment level EMI data, it is determined that the equipment would probably not meet the system compatibility requirements, then it is the responsibility of the developing activity to implement design modifications to meet the required EMI levels or to select other equipment with adequate characteristics.

Requirement Lessons Learned (A.5.7.2):

There have been both good and bad EMI results with the use of NDI and commercial items in the past. The military has taken some commercial aircraft avionics equipment and installed them on land-based military aircraft with good results. This is due to the fact that these equipment were tested and qualified to a commercial aircraft EMI specification such as RTCA DO-160. In some cases, the commercial avionics required EMI modifications to make them compatible with a more severe electromagnetic environment on the military aircraft. Forward-looking infrared sensors, originally developed for commercial police use, were not compatible in the Army helicopter EME and significant restrictions on their use needed to be imposed. A night vision system developed by the Army was procured by the Navy as NDI. Significant EMC problems were experienced aboard ship due to the higher shipboard EME.

Several instances have been noted in ground-based applications where EMI emissions from commercial digital processing equipment have interfered with the operation of sensitive receivers. Of particular concern are radiated emissions from processor clock signals causing interference with communications equipment that operates from 30 to 88 MHz. Most commercial equipment is qualified by testing at a distance of three meters. The problems have been largely caused by use of the commercial items at distances of one meter or closer where the fields will be higher.

An example of NDI and commercial item problems at the system-level, that most travelers have observed, is restrictions on the use of portable electronic devices on commercial aircraft during take-off and landings. These restrictions are in place because of several problems noted with coupling of interference from the portable electronics to antenna-connected receivers used for navigation and communications.

The military has successfully used NDI and commercial items in many other situations. Electronics maintenance shops generally use test equipment built to commercial EMI specifications or industry standards without requiring modifications. Ground system applications of data-processing equipment, displays, and office equipment used with other commercial items and NDI has been successful, where care has been taken with integration. The primary emphasis needs to be whether the equipment is suitable for that particular application.

When a delivered item is composed of a number of individual pieces of equipment, it is sometimes more cost-effective to qualify an integrated assembly rather than the individual pieces of equipment. Also, the performance of the integrated assembly, as installed in the system, is the more important issue since the EMI characteristics of the individual items may be modified by integration.

Verification Rationale (A.5.7.2):

When EMI requirements are needed on NDI or commercial items, then EMI testing data are required to demonstrate compliance with those requirements. The equipment cannot be susceptible to EMI that would degrade it or render it ineffective. Likewise, the equipment cannot be a source of EMI that impacts the operation of other equipment within the system. NDI and commercial items may have been previously qualified to a wide variety of types of EMI requirements. Analysis of the applicability of the particular type of EMI qualification in relation to a particular system installation will be necessary.

Verification Guidance (A.5.7.2):

Verification is required for the particular requirements imposed for the system installation. If the NDI or commercial items selected are currently in military use, then in all probability EMI test data exist which can be evaluated for suitability.

Verification requires an understanding of the installation environment both from the aspect of electromagnetic stresses present and potential susceptibility of equipment and from knowing the EMI characteristics of NDI and commercial items well enough to reach conclusions on system compatibility.

Verification Lessons Learned (A.5.7.2):

Most commercial equipment is qualified by testing at a distance of three meters. MIL-STD-461 uses one meter. When considering the use of NDI or commercial items, the location of the equipment with respect to system antennas needs to be considered in assessing the suitability of the equipment. The data from the three meter distance may be appropriate. It is difficult to translate the resulting commercial data to one meter. This situation is due to variable field impedances associated with near-field emissions and variations in indeterminate near-field emission patterns.

NDI and commercial avionics qualified to commercial standards, such as RTCA DO-160, are generally acceptable for military use on land-based aircraft, since the commercial and military EMI standards for airborne avionics are very similar in the tests required and the limits imposed. Over time, more general use electrical and electronic type devices are being required to meet some form of EMI requirement. In some cases, those would also be acceptable for military use, and, in other cases, more testing or qualification to a tighter limit may be required.

Some testing to characterize important qualities of the NDI and commercial items will often be necessary. For example, if coupling to particular receivers is the concern, an RE102 test from MIL-STD-461 limited to particular frequency bands may be all that is necessary.

A.5.7.3 Shipboard DC magnetic field environment.

Subsystems and equipment used aboard ships shall not be degraded when exposed to its operational DC magnetic environment (see DOD-STD-1399-070-1 (NAVY)). Compliance shall be verified by test.

Requirement Rationale (A.5.7.3):

High level DC magnetic fields are intentionally generated onboard ships during magnetic treatment. Magnetic treatment, such as deperming or flashing, is a process in which the vessel's permanent magnetization is changed or reduced by applying large magnetic fields. The vessel is required to have this process performed at a dedicated facility called a deperming facility. These fields are generated by a coil of wire, typically 500 thousand of circular mils (MCM), wrapped around the exterior of the vessel and thousands of amperes run through the coil. Ships may have a degaussing coil system installed on board for the purpose of reducing the ship's magnetic signature. These cables are energized by dedicated power supplies installed on the vessel. Control of the currents is based upon ship's heading and location on the earth.

Requirement Guidance (A.5.7.3):

DOD-STD-1399-070-1, provides requirements and guidance for protection of equipment against DC magnetic fields. Shipboard measurements have shown DC magnetic fields varying between 40 and 640 A/m dependent on location and time during normal operations and 1600 A/m during deperming. They tend to be the highest below the flight and weather decks. A typical requirement imposed on equipment is to operate in 400 A/m and to survive 1600 A/m. Another important parameter is the rate of change that the magnetic field can vary, which is 1600 A/m per second. Ship surveys to determine magnetic fields are useful in locating areas where the fields are less than 400 A/m or tailoring the requirement for a particular installation location. There will be cases where performance in 1600 A/m is required or where localized shielding will need to be used in the installation.

Requirement Lessons Learned (A.5.7.3):

Items most commonly influenced by DC magnetic fields and its variations are cathode ray tube monitors. The earth's magnetic field varies in magnitude between 24 and 56 A/m. These fields are as large as the ship generated field in some cases. Mobile platforms may experience changes of two times the local earth field simply through motion and the changing orientation of the platform. Unmodified commercial monitors can experience picture distortion when local fields change as little as 16 A/m.

Verification Rationale (A.5.7.3):

Testing is the only effective means to verify compliance.

Verification Guidance (A.5.7.3):
DOD-STD-1399-070-1 provides guidance on test methodology. Testing normally needs to be performed in all three axes of orientation, although this is not always possible because of equipment size.

Verification Lessons Learned (A.5.7.3):
Simulating the rate of change in the field is sometimes more important than the absolute field magnitude.

A.5.8 Electrostatic environments.

The system shall control and dissipate the build-up of electrostatic charges caused by precipitation static (p-static) effects, fluid flow, air flow, exhaust gas flow, personnel charging, charging of launch vehicles (including pre-launch conditions) and space vehicles (post deployment), and other charge generating mechanisms to avoid fuel ignition, inadvertent detonation or dudding or ordnance hazards, to protect personnel from shock hazards, and to prevent performance degradation or damage to electronics. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

Requirement Rationale (A.5.8):
Voltages, associated with static charging, and energy, released during discharges, are potentially hazardous to personnel, fuel vapors, ordnance, and electronics.

Dust, rain, snow, and ice can cause an electrostatic charge buildup on the system structure due to charge separation and the phenomenon called precipitation static charging.

Sloshing fuel in tanks and fuel flowing in lines can both create a charge buildup resulting in a possible fuel hazard due to sparking. Any other fluid or gas flowing in the system (such as cooling fluid or air) can likewise deposit a charge with potentially hazardous consequences.

During maintenance, contact of personnel with the structure and various materials can create an electrostatic charge buildup on both the personnel and structure (particularly on non-conductive surfaces). This buildup can constitute a safety hazard to personnel or fuel or may damage electronics. Potentially susceptible electronic parts are microcircuits, discrete semiconductors, thick and thin film resistors, integrated circuits, hybrid devices, and piezoelectric crystals, dependent upon the magnitude and shape of the electrostatic discharge (ESD) pulse.

Dudding results from the application or repeated application of energy below that required for initiation causing desensitization of the EID. If the EID has been desensitized, the recommended firing stimulus may not be sufficient to actuate the EID when the proper firing pulse is applied resulting in a dud. Ordnance is potentially susceptible to dudding from electrostatic discharge. The primary concern is discharge through the bridgewire of the EID used to initiate the explosive.

Space and launch vehicles experience charge separation effects in space from sunlight shining on the surface of the vehicles.

Requirement Guidance (A.5.8):
Any component of the system structure can accumulate an electrostatic charge and adequate means must be provided to dissipate the charge at low levels to prevent any significant voltage from developing. Electrically conductive and non-conductive materials behave differently. Charge deposits on conductive materials will migrate in the material such that all portions are at the same electrical potential. Charges deposited on purely non-conductive material cannot move and large voltage differences can exist over small distances.

Control of static charging is accomplished by ensuring that all structural surfaces are at least mildly conductive, that all components are electrically bonded, and that an electrical path to earth is provided. In general, conductive coatings need to be applied to all internal and external sections of the system structure which are electrically non-conductive. For most applications, resistive paths from 10^6 to 10^9 ohms (or 10^7 to 10^{10} ohms per square) are sufficient to dissipate the charge buildup. The factor of ten between the two ranges is due to the geometry of concentric rings used in electrode assemblies to measure surface resistivity. This conversion may not be appropriate for materials that are plated with metallic coatings or laminated. Values in the stated ranges are considered to be “static dissipative,” with lower values being termed “conductive.” For shielding purposes, lower values will produce superior shielding properties. However, in electronics maintenance and repair, static dissipative materials are actually more desirable since they minimize the discharge current from devices that already possess a charge. The shock hazard to personnel begins at about 3000 volts; therefore, the charge on system components should not be allowed to exceed 2500 volts.

ANSI/ESD S20.20, issued by the Electrostatic Discharge Association (ESDA), provides requirements for designing and establishing an ESD control program to minimize hazards to ESD sensitive devices. It is applicable for essentially all activity stages associated with electronic equipment from manufacturing, testing, packaging, and servicing to operational use. This document resulted from a cooperative effort between commercial and military experts. It forms the basis for ESD protection measures implemented by the U.S. Air Force for both contractual mechanisms during development and for the military operators and maintainers. ESD TR 20.20 is a handbook that provides guidance for applying ANSI/ESD S20.20.

Systems must incorporate features to minimize the possibility of sparks within the fuel system. The system design must consider the electrical conductivity of the fuels to be used and control the conductivity, if necessary. Fuel vapors can be ignited with about 0.2 millijoules of energy. As with structural features of the system, any component of the fuel system can accumulate an electrostatic charge and adequate means must be provided to dissipate the charge. Electrical bonding, grounding, and conductive coating measures need to be implemented. Fuel lines routed through fuel tanks require special attention.

The fuel system must also prevent sparking within the fuel tanks during refueling operations. Some useful requirements are: 1) bonding and grounding of fuel components, 2) limiting line velocities to no more than 30 feet per second, 3) limiting tank entry velocity to no more than 10 feet per second, and 4) refueling the tank from the bottom. Guidance for the control of static electricity during refueling of aircraft is presented in TO 00-25-172.

NASA document TP2361 provides design guidelines for space and launch vehicle charging issues. Subsystems and equipment installed aboard space systems should be able to meet operational performance requirements during and after being subjected to a 10 kV pulsed discharge. This value is derived from charging of insulation blankets and subsequent discharges in accordance with SMC-S-008 and AIAA-S-121.

Requirement Lessons Learned (A.5.8):
A maintenance person was working inside a fuel tank and experienced an arc from his wrench when removing bolts. It was found that maintenance personnel were routinely taking foam mats into the tank to lie on while performing maintenance. Friction between the mat and clothing allowed a charge buildup which caused the arc. All static generating materials should be prohibited from the tank during maintenance.

Many equipment failures have been attributed to ESD damage of electronic parts.

Verification Rationale (A.5.8):
Verification of protection design for electrostatic charging is necessary to ensure that adequate controls have been implemented.

Verification Guidance (A.5.8):
The selected verification method must be appropriate for the type of structural material being used and the particular type of control being verified. Relatively poor electrical connections are effective as discharge paths for electrostatic charges. Therefore, inspection would normally be appropriate for verifying that metallic and conductive composite structural members are adequately bonded provided that electrically conductive hardware and finishes are being used. For dielectric surfaces which are treated with conductive finishes, testing of the surface resistivity and electrical contact to a conductive path would normally be more appropriate.

For space and launch vehicles, ESD requirements are verified by a pulsed discharge at one per second for 30 seconds at a distance of 30 cm to exposed face of subsystems and equipment. This test is then repeated using a direct discharge from the test electrode to each top corner of the equipment under test. The discharge network is 100 pF in series with 1500 ohms.

Verification Lessons Learned (A.5.8):
To evaluate proper design of structural components, verification that all components are adequately bonded to each other often must be done during system assembly. After

manufacturing is completed, access to some components may be restricted making verification difficult.

A.5.8.1 Vertical lift and in-flight refueling.

The system shall meet its operational performance requirements when subjected to a 300 kilovolt discharge from a simulated aircraft capacitance of 1000 picofarads, through a maximum of one (1) ohm resistance with a circuit inductance not to exceed 20 microhenry. This requirement is applicable to vertical lift aircraft, in-flight refueling of any aircraft, any systems operated or transported externally by vertical lift aircraft. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

Requirement Rationale (A.5.8.1):
Any type of aircraft can develop a static charge on the fuselage from p-static charging effects addressed in 5.8.2 of this standard. Aircraft that have the capability for lifting cargo or performing in-flight refueling have special operational concerns. In the case of vertical lift, the accumulated charge can cause an arc between the hook and the cargo during pick-up or between the suspended cargo and the earth during delivery. In the case of in-flight refueling, the tanker aircraft can be at one voltage potential and the aircraft to be refueled will be at a different potential, possibly resulting in an arc during mating of the two aircraft. The maximum expected discharge level for either of these cases is 300 kV. The resulting electrical transients can affect both the aircraft and the suspended cargo.

Requirement Guidance (A.5.8.1):
For vertical lift capability, the requirement should be applied to both the lifting aircraft and the system being lifted. The concern is for the safe and satisfactory operation of the vertical lift system hardware and no degradation or permanent damage of other mission equipment. For in-flight refueling, the requirement should be applied to the equipment and subsystems that are functioning during refueling. Equipment located near the refueling hardware is of primary concern. Potential hazards due to the presence of ignitable fuel vapors also need to be addressed.

For sling loaded ordnance, requirement 5.8.3 is applicable. Examples of systems operated externally by vertical lift aircraft are dipping SONAR and apparatus used for helicopter rescue. The discharge occurs for these systems when the item approaches or contacts the surface of the earth or water.

Requirement Lessons Learned (A.5.8.1):
To protect personnel on the ground from receiving electrical shocks, it is standard practice for rotorcraft to touch the ground with the hook before it is connected to the cargo. As the cargo is lifted, the whole system (aircraft and cargo) will become recharged. Again, when the cargo is lowered to the ground, it must touch the ground to be discharged before handling by personnel.

The aircraft system and cargo often see several electrical discharges as the vertical lift process is executed.

During in-flight refueling, pilots have reported seeing arcing between the refueling probe and the fueling basket during mating. These discharges were several inches long. Based on these observations, the 300 kV number was derived.

Verification Rationale (A.5.8.1):
The path of the discharge is somewhat unpredictable. Inspections and analysis are needed to verify that assumptions on current flow path are reasonable and that protection is appropriately implemented. Testing is necessary to evaluate possible paths where the discharge event may occur. The 1000 picofarad capacitance used for testing represents a reasonable value for a large size aircraft.

Verification Guidance (A.5.8.1):
The testing for vertical lift equipment on the aircraft has involved injecting the cargo hook with discharges from a mini-Marx generator. Testing for the in-flight refueling has involved injecting the in-flight refueling probe on the aircraft with discharges from a mini-Marx generator. Both positive and negative discharge voltages have been used for both types of testing. Aircraft equipment are monitored for upset or failure.

Testing of the vertical-lift cargo has involved applying mini-Marx discharges to the shipping container or directly to the cargo system depending upon the configuration used in transport. The container should have discharges applied to several locations around the container. After the discharge, the system is checked for proper operation. ESD verification methods for ordnance items are addressed in 5.8.3.

Verification Lessons Learned (A.5.8.1):
Aircraft that have experienced discharges from in-flight refueling have had upsets to the navigation system resulting in control problems.

A.5.8.2 Precipitation static (P-static).

The system shall control p-static interference to antenna-connected receivers onboard the system or on the host platform such that system operational performance requirements are met. The system shall protect against puncture of structural materials and finishes and shock hazards from charge accumulation of 30 $\mu A/ft^2$ (326 $\mu A/m^2$). Compliance shall be verified by test, analysis, inspections, or a combination thereof.

Requirement Rationale (A.5.8.2):
As systems in motion encounter dust, rain, snow, and ice, an electrostatic charge buildup on the structure results due to precipitation static charging. This buildup of static electricity causes significant voltages to be present which can result in interference to equipment, puncture of

dielectric materials, and constitute a shock hazard to personnel. For aircraft applications, aircrew personnel may be affected during flight and ground personnel may be affected after landing.

Requirement Guidance (A.5.8.2):
Static electricity accumulates on aircraft in flight (p-static charging) because there is no direct electrical path to allow the charges to flow off the aircraft. Special control mechanisms become necessary to dissipate the charge. The accumulated charge develops a voltage on an aircraft with respect to the surrounding air. When the voltage becomes high enough, the air periodically breaks down in an impulse fashion at sharp contour points where the electric field is the highest. The sharp impulses produce broadband radiated interference which can degrade antenna-connected receivers, particularly lower frequency receivers. The impulses can occur so rapidly that the receivers produce only a hissing sound and become useless. Precipitation static dischargers are usually used to control this effect. These devices are designed to bleed the accumulated charge from the aircraft at levels low enough not to cause receiver interference.

The total charging current is dependent on weather conditions, the frontal surface area of the aircraft and the speed of the aircraft (V). The total charging current can be estimated by the following equation:

$$I_t = \mathrm{Q} \times \mathrm{C} \times S_a \times V$$ *Equation A-7*

Where:

I_t = total charging current, µA
Q = charge transfer per particle impacting the frontal surface, µC/particle
C = density of particles, particles/m^3
S_a = frontal surface area, m^2
V = aircraft velocity, m/s

Note though that the linear relationship with velocity does not hold true at higher speeds. This is reflected by use of an effective surface area term in the simplified equation:

$$I_t = \mathrm{I_c} \times \mathrm{S_{eff}}$$ *Equation A-8*

Where:

$\mathrm{I_c}$ = current charge density, µA/m^2
$\mathrm{S_{eff}}$ = effective frontal area, m^2

$\mathrm{S_{eff}}$ is a function of velocity. It tends to increase with speed. However, at supersonic velocities the charge rate decreases as the ice crystals melt on impact.

The following current densities have been determined for various types of clouds and precipitation:

Cirrus	50 to 100 µA/m^2

Strato-cumulus	100 to 200 μA/m^2
Snow	300 μA/m^2

On rare occasions, levels as high as 400 μA/m^2 have been observed.

Control of static charge accumulation is accomplished by ensuring that all structural surfaces are at least mildly conductive (megaohms). Conductive coatings need to be applied to all external sections of the system structure which are electrically non-conductive. Any component of the structure can accumulate an electrostatic charge, and adequate means must be provided to dissipate the charge at low levels to prevent any significant voltage from developing.

Requirement Lessons Learned (A.5.8.2):

A fighter aircraft was experiencing severe degradation of the UHF receiver when flying in or near clouds. Investigation revealed that the aircraft was not equipped with precipitation static dischargers. Installation of these devices solved the problem.

An aircraft had a small section of the external structure made of fiberglass. Post-flight inspections required personnel to get in close proximity to this non-conductive structural component. On several occasions, personnel received significant electrical shocks which caused them to fall from ladders and be injured. Corrective action was easily accomplished by applying a conductive paint to the surfaces exposed to airflow and personnel contact.

Static discharges from the canopy were shocking pilots on a fighter aircraft during flight. Charges accumulating on the outside of the canopy apparently induced a similar charge on a conductive finish that was on the inside of the canopy. When a discharge occurred on the outside of the canopy, the internal charge discharged to the pilot’s helmet. Proper grounding of the conductive finish on the inside of the canopy fixed the problem.

When an aircraft was flying in clouds during a thunderstorm, the pilot was unable to transmit or receive on the communications radio. Further investigations were performed with the most reasonable conclusion that the radio blanking was caused by electrostatic discharge. Several incidents were also reported where pilots and ground crews received shocks due to static discharges from aircraft canopies. These incidents occurred on the carrier deck after the aircraft had been airborne for several hours.

Canopies and dielectric finishes on structural materials have been punctured with resulting damage due to large voltages being present from static accumulation.

It was discovered on an aircraft that was experiencing p-static problems that the static dischargers had been installed using an adhesive that was not electrically conductive.

Verification Rationale (A.5.8.2):
Systems, subsystems and equipment must be verified to not pose a hazard when subjected to p-static charging. Conductive coating resistance must be verified to fall within the given range so as to not cause an excessive accumulation of electrostatic charge.

Verification Guidance (A.5.8.2):
Relatively poor electrical connections are effective as discharge paths for electrostatic charging. Therefore, inspection would normally be appropriate for verifying that metallic and conductive composite structural members are adequately bonded provided that electrically conductive hardware and finishes are being used. A device capable of measuring surface resistance within the given range should be used to test the resistance of the coated area.

Testing hardware which applies electrical charge to system surfaces must be able to isolate and identify corona sources, locate isolated metal, identify surface streamering problems, and allow for evaluation of effects to antenna-connected receivers.

Verification Lessons Learned (A.5.8.2):
Coordination between structural and electrical engineer personnel is necessary to ensure that all required areas are reviewed. For example, a structural component on an aircraft was changed from aluminum to fiberglass and experienced electrostatic charge buildup in flight which resulted in electrical shock to ground personnel. The structural engineer made this change without proper coordination, which resulted in an expensive modification to correct the shock problem.

A.5.8.3 Ordnance electrostatic discharge (ESD).

Ordnance shall meet their safety and system operational performance requirements for personnel-borne electrostatic discharge (PESD) and helicopter-borne electrostatic discharge (HESD) from stockpile to safe separation. Compliance shall be verified by test, analysis, inspection, or a combination thereof.

Requirement Rationale (A.5.8.3):
It has been established that electrostatic discharges can initiate, damage and or degrade ordnance devices. The electrostatic charge procedural control efforts such as grounding (e.g., wrist straps) and grounding requirements cannot preclude ESD from occurring during the life cycle of most ordnance. Ordnance, ordnance subcomponents and or energetic materials that might be exposed to ESD in an uncontrolled environment must be designed to remain safe and meet their operational performance requirements.

Ordnance ESD environment was established starting in June 1985 largely due to the efforts of the ESD Hazards panel and propulsion systems hazards subcommittee formed jointly by several organizations, including Air Force Rocket Propulsion Lab, John Hopkins University Applied Physics Laboratory (APL), US Army Missile Command, Naval Weapons Center, TRW, Lockheed, Hercules Inc., Electromagnetic Applications Inc., and Los Alamos National Laboratories. The activities of

ESD panel from 1985 to 1990 influenced the current ESD environment. The Pershing II incident on 11 January 1985 caused the death of three soldiers and the injury of sixteen others at Camp Redleg (Heibronn), Germany. The cause of the incident was determined to be ESD. Between 1964 and 1987, eight ESD related incidents have been documented by Johns Hopkins University APL. Investigations that followed these incidents significantly impacted the ordnance ESD environment.

Operability requirements have been present for ordnance and ordnance components for decades. MIL-STD-331 defines Safe, Safe for Use and Safe for Disposal for fuzes. It also defines the term “operable”, stipulating that a fuze must provide its required inputs and perform to the completion of its function and sequence, producing all required outputs within the operating period at the specified times. The reasons for addressing or evaluating operability for ordnance are related to safety. If ordnance is not evaluated for operability, undesirable scenarios can occur, such as:

1) Critical fire-circuit or safety interlock components can be defeated by an ESD Event.
2) ESD failures of susceptible subcomponents that can affect safety functionality or increase hazard risk in the powered up, test, through safe separation phases.

Requirement Guidance (A.5.8.3):
This requirement is based on charge levels that could possibly be developed by PESD and HESD. All ordnance subsystems should meet this requirement to provide high confidence of safe handling from stockpile to safe separation and to meet operational performance requirements.

Requirement Lessons Learned (A.5.8.3):
An ESD event can affect multiple electronic circuits and components in an ordnance system. Also, an ESD failed (shorted) component may cause heating of adjacent components and circuit boards. Heating can therefore cause unpredictable failures. Failed components can cause adverse effects that designs may not be robust enough to overcome. Energetics can be initiated indirectly by ESD or by the propagation of failures. Both, the paths and the propagation of failures are very difficult to model or predict reliably.

Verification Rationale (A.5.8.3):
ESD is known to affect energetic components. Experience has shown that many of the major ESD historical incidents/mishaps were caused by the ESD directly initiating energetic components. The susceptibility of energetics to PESD and HESD is well documented. Another example is where a PESD detonator susceptibility in the pin to case mode (through the energetic) was discovered but there was no susceptibility in the pin-to-pin mode. Ordnance energetic subcomponents should not be eliminated (or omitted) when evaluating ordnance in the PESD and HESD environments.

Energetics sensitivity can vary significantly with temperature and humidity. Propellants in the Pershing Incident were tested at ambient temperature and showed no reaction. However, ESD tests at a lower temperature (-12 °C, 10 °F) resulted in propellant reaction. The ability to charge or ground a system is variable and often unpredictable. To achieve the level of safety and prevent a potentially catastrophic event, it is imperative to design, build, and test Ordnance at the boundaries and at levels between the upper and lower thresholds of the ESD environmental hazard. Therefore, to assure interoperability, the jointly recognized ESD environment should be met by all services and DoD programs.

The path of the discharge is somewhat unpredictable. Inspections and analysis are needed to verify that assumptions on current flow path are reasonable and that protection is appropriately implemented. Due to the safety critical nature of maintaining explosive safety, the high confidence provided by testing is necessary to ensure the requirements are met.

Verification Guidance (A.5.8.3):

The ESD environment can directly affect (initiate) energetic components of ordnance. Instrumentation for measuring the transfer of ESD energy to the energetic components and the exact behavior of those components are not readily available. Thus, live energetic sub-components (live ordnance) should be included in ESD evaluation of ordnance and only “pass” or “fail” criteria can apply.

The path of the discharge is somewhat unpredictable. Inspections and analysis are needed to verify that assumptions on current flow path are reasonable and that protection is appropriately implemented. Assure temperature conditioning is implemented as per the verification rationale (A5.8.3) above.

Verification Lessons Learned (A.5.8.3):

See Lessons Learned for A.5.8.3.1 and A.5.8.3.2.

Also, temperature and humidity (environmental) conditioning of ordnance is strongly recommended as the electrical properties of insulators/energetics such as resistivity may be affected by temperature and time-temperature exposure. Thus temperature/humidity conditioning is necessary in order to obtain consistent results when ordnance is exposed to the ESD environment.

A.5.8.3.1 Personnel-borne ESD (PESD) for ordnance and ordnance systems.

Ordnance, ordnance subsystems and components shall meet their safety requirements when subjected to PESD environment and meet their system operational performance requirements after being subjected to PESD environment. The PESD environment is characterized by discharges up to 25 kV through 500 ohm and 5000 ohm resistors, from a 500 pf capacitance with a circuit inductance not to exceed 5 microhenry as delineated in joint documentation such as the JOTP-062. Compliance shall be verified by test, analysis or a combination thereof.

Requirement Rationale (A.5.8.3.1):
PESD exposure of ordnance items, ordnance electrical interfaces, and related systems, including but not limited to firing circuits and control electronics (weapon release, intent to launch, etc.) may result in a safety hazard and related operability malfunction that can lead to a hazard. These may include ordnance/ energetic initiation, Electro-explosive Device (EED)/Electrically Initiated Device (EID) initiation, firing circuit initiation, performance degradation, electrical interface malfunction, or dudding. PESD can occur during any of the stockpile to safe separation sequence (S4) phases such as: transportation/storage, assembly/disassembly, staged, loading/unloading, platform loaded.

The FIGURE A-6 in conjunction with the parameter values found in TABLE A-IV are recognized as the required parameters to accurately replicate the PESD environment's stimuli. There is one more component not shown on FIGURE A-6 which is an inductor that represents the physical inductance that exists when current runs through the charged body (capacitor) to the ordnance item and then to ground. Inductance affects the peak current, the risetime and the spectral components of the environment. The envelope boundary as well as the interim charge potential values of TABLE A-IV represent a jointly agreed upon set of ordnance PESD environment charge levels. The resistance values of 500 Ω and 5000 Ω per TABLE A-IV are important PESD environment resistances as they represent internal and external body resistance conditions. The element that represents the PESD energy storage element is the 500pF capacitor per TABLE A-IV and FIGURE A-6.

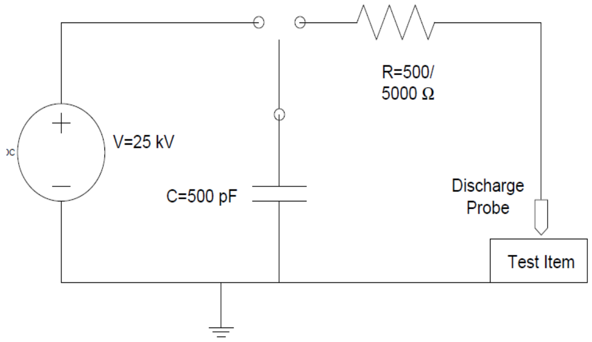
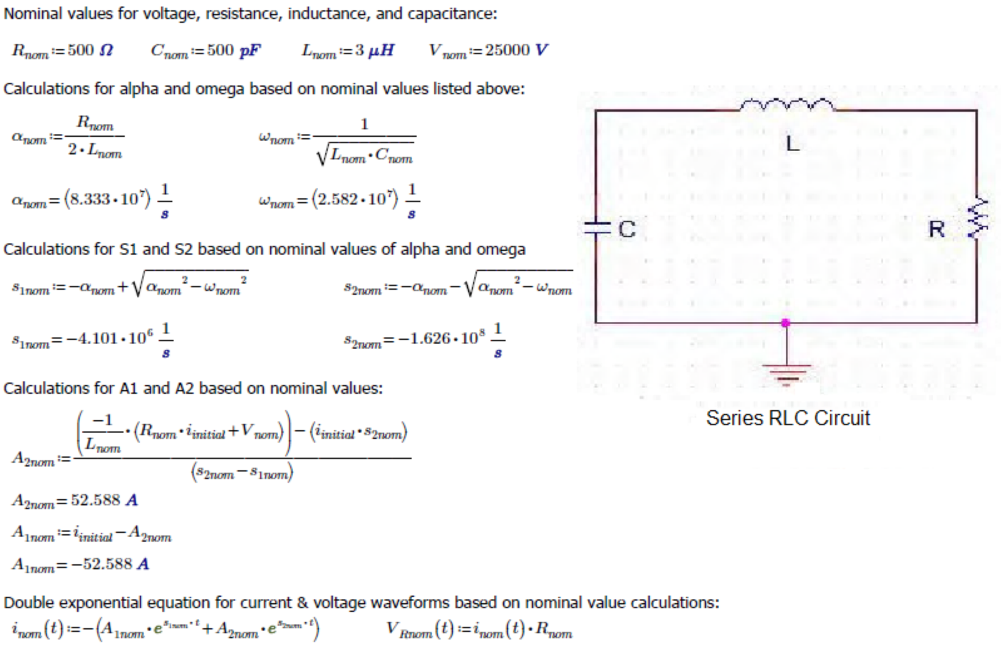


FIGURE A-6. PESD circuit.

TABLE A-IV. PESD parameters.

Charge Voltage	**Capacitance**	**Discharge Inductance**	**Series Resistance (Ohms)**	**Configuration**
± 25 kV ± 500 V	500 ± 5% pF	5 µH max	5000 ± 5% Ω	Bare Devices
± 25 kV ± 500 V	500 ± 5% pF	5 µH max	500 ± 5% Ω	AUR & Bare Devices
± 5 kV ± 500 V	500 ± 5% pF	5 µH max	500 ± 5% Ω	AUR
± 10 kV ± 500 V	500 ± 5% pF	5 µH max	500 ± 5% Ω	AUR
± 15 kV ± 500 V	500 ± 5% pF	5 µH max	500 ± 5% Ω	AUR
± 20 kV ± 500 V	500 ± 5% pF	5 µH max	500 ± 5% Ω	AUR

A mathematical example for the R-L-C circuit defined above with the resistance set to 500 and the inductance set to 3 µH is found on FIGURE A-7. Appendix B in the JOTP-062 includes additional information examples, and guidance.


Nominal values for voltage, resistance, inductance, and capacitance:

$R_{nom} := 500\ \Omega \quad C_{nom} := 500\ pF \quad L_{nom} := 3\ \mu H \quad V_{nom} := 25000\ V$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{nom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = (8.333 \cdot 10^{7})\ \frac{1}{s} \qquad \omega_{nom} = (2.582 \cdot 10^{7})\ \frac{1}{s}$$

Calculations for S1 and S2 based on nominal values of alpha and omega

$$s_{1nom} := -\alpha_{nom} + \sqrt{\alpha_{nom}{}^{2} - \omega_{nom}{}^{2}} \qquad s_{2nom} := -\alpha_{nom} - \sqrt{\alpha_{nom}{}^{2} - \omega_{nom}}$$

$$s_{1nom} = -4.101 \cdot 10^{6}\ \frac{1}{s} \qquad s_{2nom} = -1.626 \cdot 10^{8}\ \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{2nom} := \frac{\left(\frac{-1}{L_{nom}} \cdot (R_{nom} \cdot i_{initial} + V_{nom})\right) - (i_{initial} \cdot s_{2nom})}{(s_{2nom} - s_{1nom})}$$

$$A_{2nom} = 52.588\ A$$

$$A_{1nom} := i_{initial} - A_{2nom}$$

$$A_{1nom} = -52.588\ A$$

Double exponential equation for current & voltage waveforms based on nominal value calculations:

$$i_{nom}(t) := -\left(A_{1nom} \cdot e^{s_{1nom} \cdot t} + A_{2nom} \cdot e^{s_{2nom} \cdot t}\right) \qquad V_{Rnom}(t) := i_{nom}(t) \cdot R_{nom}$$

FIGURE A-7. PESD discharge circuit.

An illustration depicting the 500 Ω PESD circuit current pulse discharge high, nominal, and low environment traces overlaid on the same current (A) and time t(s) axes is shown on FIGURE A-8.

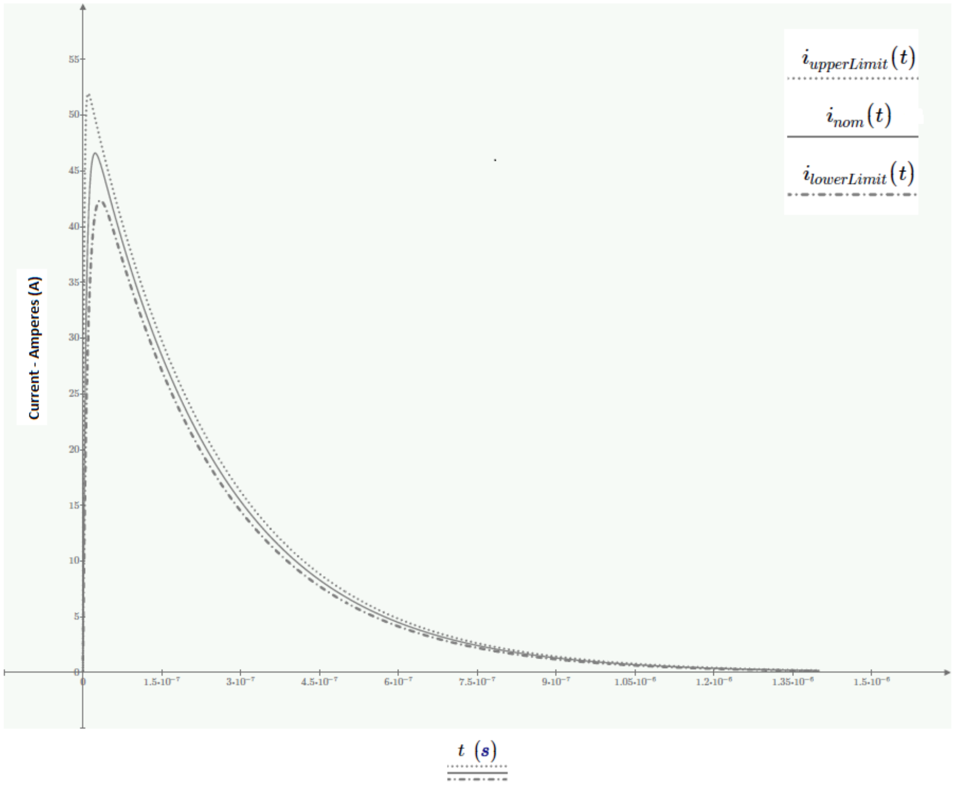


FIGURE A-8. PESD Current Waveforms, High, Nominal, Low for the 500 ohms model.

An illustration depicting the 500 Ω PESD circuit current pulse discharge high, nominal, and low environment traces overlaid on the same current (A) and time t(s) axes is shown on FIGURE A-9. The PESD environments apply to all exposed susceptible ordnance points, connectors, connector pins, of the bare device or All Up Round.

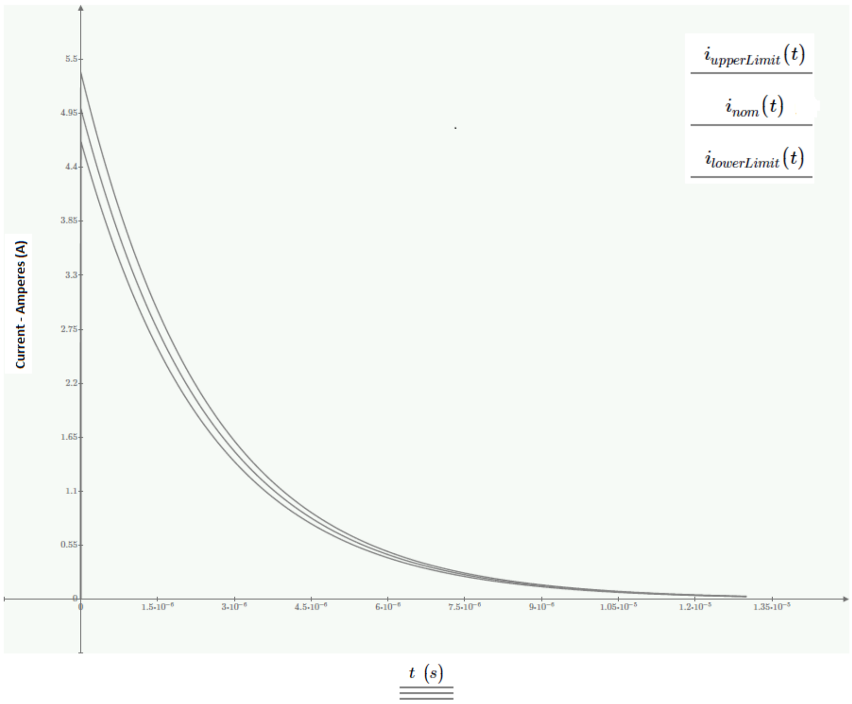


FIGURE A-9. PESD Current Waveforms, High, Nominal, Low for the 5000 ohms model.

Requirement Guidance (A.5.8.3.1):
This requirement is based on charge levels that could possibly be developed on personnel. All ordnance subsystems should meet this requirement to ensure safe personnel handling.

Requirement Lessons Learned (A.5.8.3.1):
Ordnance systems have been initiated by PESD resulting from human contact. Historically PESD testing and evaluation was not commonly executed in the same uniform manner by all services. Joint Service validation testing was performed to: (1) harmonize the differences in the existing ESD test procedures used by each of the Services; (2) reduce redundant testing; and (3) meet ordnance safety. The culmination of these efforts resulted in Joint Ordnance Test Procedure JOTP-062. The JOTP-062 document evaluated the existing ESD test approach used by each of the Services, and the general requirements in this standard to determine a common Joint Service ESD test approach. The JOTP-062 provides all procedures, requirements, and data necessary to produce consistent and repeatable results independent of the test facility, test site, or Service conducting the testing.

The DoD has historically distinguished non-ordnance electronics from ordnance, and from ordnance electronics as noted per MIL-STD-1686 (DoD Standard Practice Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts Assemblies and Equipment).

MIL-STD-1686 excludes Electrically Initiated Explosive Devices (EID). Similarly, MIL-STD-461 is also limited non-ordnance to electronics subsystems.

A document on the Protection of Trident Electronic Equipment from the Hazards of ESD, documents that walking across the carpet can build a voltage charge of 35,000 volts at 20% relative humidity. The potential drops to 1500 volts during the same walking activity at high humidity levels of 65% - 90%. A poly bag picked up from a bench yielded an electrostatic potential of 20,000 Volts at low humidity and then 1200 volts at higher humidity. The higher static voltages developed in low humidity conditions are significantly higher than degradation levels of semiconductors. A fingertip electromagnetic field model demonstrated that a 30 kV PESD potential can develop before the dielectric breakdown of air is achieved at a field strength of 3 MV/m. An independent study published on the 2016 IEEE transactions, (Effect of Human Activities and Environmental Conditions on Electrostatic Charging), documents the result of 588 total experiments. The study shows that charging voltages exceeding +20 kV were developed at low humidity levels (72 F, RH 5%). The study was not designed to measure voltages above the 20 kV level thus the instrumentation threshold was exceeded (saturated) and the charge potentials above this level were not documented. Therefore, there is compelling evidence to establish the PESD ± 25 kV charge potential envelope.

PESD environment exists and prevails in the lower to mid envelope levels as the potential charge is dependent on humidity as previously discussed. Ordnance systems can incorporate intentional or unintentional voltage breakdown elements such as spark gaps, Metal Oxide Varistors (MOV), Transient Voltage Suppressors (TVS) and other components. Such components may work well at higher ESD potentials. However, these PESD protective mechanisms may not activate/function at lower PESD environmental potential stimuli even though lower potentials are more common at higher humidity levels. The second reason for incorporating intermediate (between thresholds) PESD charge potential levels is less obvious; however, it may be just as important since documentation shows systems' dependencies on ESD amplitudes. High ESD initialization amplitudes produce lower frequency spectral components. Mid-range and low range ESD levels can develop higher ESD spectral components. The significance is that the higher frequencies and higher bandwidth frequency components have a greater chance of affecting susceptible electronic components via electromagnetic coupling mechanisms discussed previously.

The technical rationale for the 500 pF capacitor is based on the results of 1963 experiments that showed 150 pF to 1500 pF personnel borne capacitance. In addition, the above referenced 2016 IEEE transactions report, documented measured human body capacitance values ranging from 65 pF to 1200 pF.

Testing has revealed that the hand to hand and hand to foot average body impedance is about 520 ohms and the wet finger resistance is determined to be approximately 460 ohms. The Open Access Journal of Plastic Surgery on the conduction of electrical current to and through the human body reports human body resistances of 100,000 Ω for calloused dry hands and that the approximate internal body resistance is 300 ohms. Further, the skin is reported to act as an electrical device similar to a capacitor that provides lower impedance at higher frequencies. Dynamic skin resistance tests show dynamic resistance values of 430 Ω (hand contact) to 1900 Ω (fingertip contact).

Verification Rationale (A.5.8.3.1):

Due to the safety critical nature of maintaining explosive safety, the high confidence provided by testing is necessary to ensure that requirements are met. The JOTP-062 is a product of the joint services and it is the result of multiple years of experience on this subject field. Verification rational has been incorporated into the JOTP-062 through multiple program iterations of ESD environment exposure. PESD Environmental data obtained using the JOTP-062 will facilitate operability and harmonization amongst the services.

Verification Guidance (A.5.8.3.1):

Verifying source calibration curves as per FIGURE A-8 and FIGURE A-9 and source parameters as per TABLE A-IV is necessary to ensure a consistent PESD verification procedure. Live ordnance verification is required and only “pass” or “fail” criteria can apply.

Verification Lessons Learned (A.5.8.3.1):

The JOTP-062 provides of extensive verification lessons learned over years of PESD environment experience by the joint services. Implementation details that are addressed in the JOTP-062 and that are critical for test facilities to maintain the required consistency of the PESD threat environment during verification testing are:

- Test equipment switching methods such as using spark gaps.
- Temperature and humidity conditioning per A.5.8.3 Verification Lessons Learned.
- Energetics used in the particular ordnance.

The effects of switching for implementation of test equipment are significant and have been documented in the literature. Switching affects test equipment output risetimes, amplitudes, impedance characteristics, and transmitted spectral/frequency components. Switching can cause variability or inconstancies between laboratories and associated test equipment. Test experience dictates that the risetime allowance built into the 5 μH of inductance adequately addresses the air-switching effects. The inductance is inherent in the geometry of the discharging body. Inductance affects the risetime of the PESD signal. The risetime, in turn, affects the spectral characteristics, or frequency components that are found in the environment stimulus. It has been found that risetimes in the order of 500 picoseconds are possible. Practically, test equipment rise times in the 1 to 18 nanoseconds may be expected for the 500 Ω PESD circuit. PESD circuit 500 Ω calibration calculations and 5000 Ω calibration calculations yield a range of rise times associated with various PESD environment inductances.

A.5.8.3.2 Helicopter-borne ESD (HESD) for ordnance and ordnance systems.
Ordnance, ordnance subsystems and components shall meet their safety requirements when subjected to HESD environment and meet their system operational performance requirements after being subjected to HESD environment. The HESD environment is characterized by a discharge up to 300 kV with circuit resistance not to exceed 1 ohm and circuit inductance not to exceed 20 microhenry as delineated in joint documentation such as the JOTP-062. The ordnance systems fielded configuration in the intended operating environment is the basis of the assessment in the HESD evaluation. Compliance shall be verified by test, analysis or combination thereof.

Requirement Rationale (A.5.8.3.2):
HESD exposure of ordnance items, ordnance electrical interfaces, and related systems, including but not limited to firing circuits and control electronics (weapon release, intent to launch, etc.) may result in a safety hazard and related operability malfunction that can lead to a hazard. These may include ordnance/ energetic initiation, Electro-explosive Device (EED)/Electrically Initiated Device (EID) initiation, firing circuit initiation, performance degradation, electrical interface malfunction, or dudding. HESD can occur during any of the stockpile to safe separation sequence (S4) phases such as: transportation/storage, assembly/disassembly, staged, loading/unloading, platform loaded. The maximum expected discharge level for HESD is 300 kV. Helicopter charge voltage levels have been measured to be as high as 200 kV. Measurements of significantly higher voltages were reported during arctic-snow conditions. Charging currents as high as 50 µA were measured at a 5440 foot mountain-top with the aircraft hovering 10 ft above the ground. During the 1960's the Royal Aircraft Establishment, Farnborough reported Sea King (SH-3) helicopter voltages exceeding 1 MV.

Ordnance must be developed, built and qualified to assure it meets their safety and operational performance requirements when exposed to the HESD environment. Ordnance subcomponents and or energetic materials that may be exposed separately during the life cycle to HESD should also meet their safety and operational performance requirements in the configuration that the exposure might occur.

The circuit producing the HESD environment is essentially a capacitor that is switched to the ordnance item that is in a S4 configuration. The charged capacitor represents the energy in an ungrounded (hovering or poor ground) operating helicopter or rotary wing aircraft. Implementing the environment in a controlled manner that can produce consistent/repeatable results of the environment typically requires a Marx generator as shown on FIGURE A-10. Inductance and resistance must be part of the discharge circuit forming an R-L-C circuit as shown on FIGURE A-11. TABLE A-V includes the circuit parameters required to accurately replicate the HESD environment's stimuli. FIGURE A-11 is a mathematical simulation example. The discharge RLC circuit has assigned voltage parameters as well as Resistance, Inductance, Capacitance (R, L, C) values. RLC circuit mathematics with the resistance element R assigned at 1.5 Ω and inductance L at 10 µH is shown on FIGURE A-11. The values are useful for the example but can be changed to represent various configurations. The expected output is a decaying under-damped signal as shown by the waveforms on FIGURE A-12.

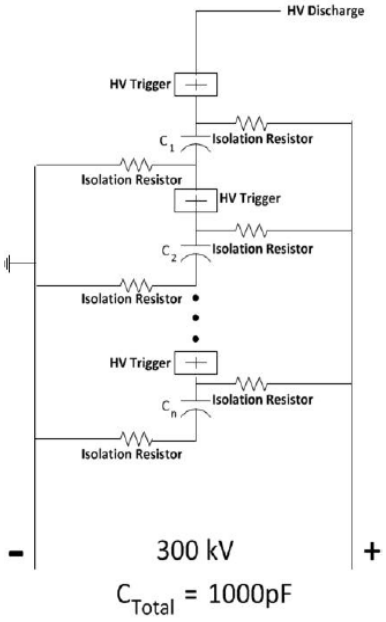
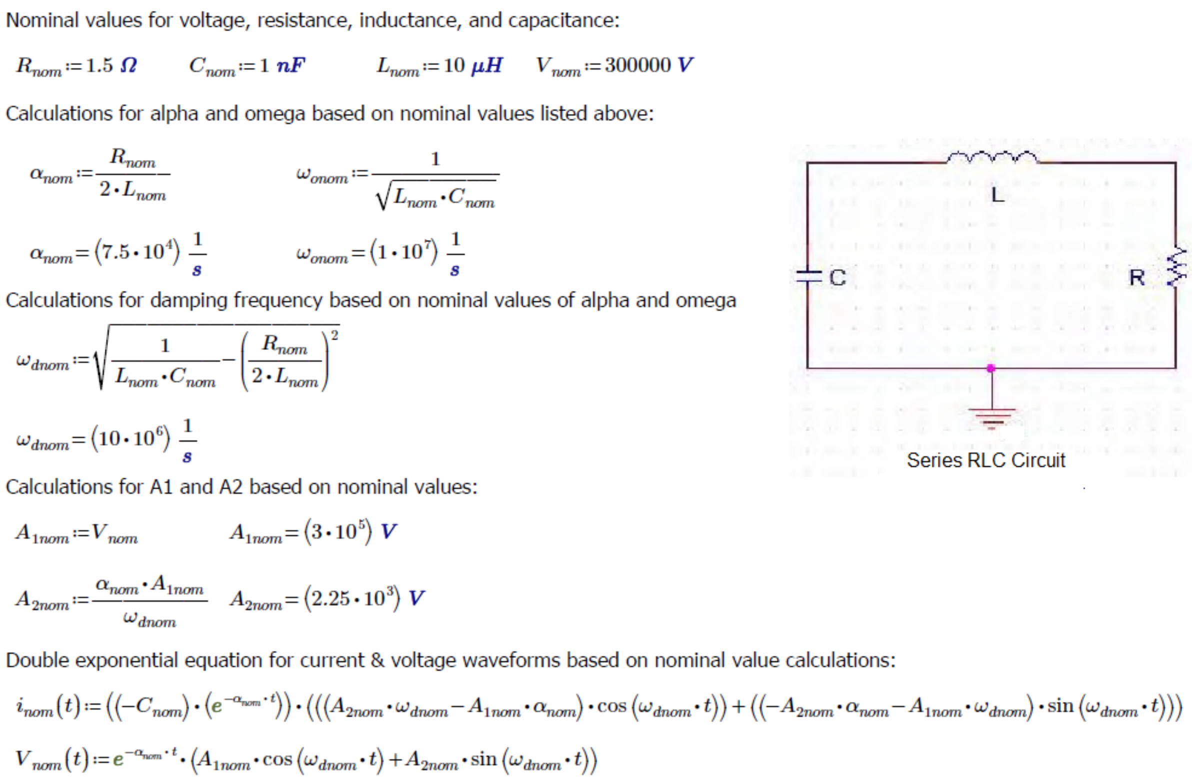


FIGURE A-10. Marx generator.


Nominal values for voltage, resistance, inductance, and capacitance:

$R_{nom} := 1.5\ \Omega \qquad C_{nom} := 1\ nF \qquad L_{nom} := 10\ \mu H \qquad V_{nom} := 300000\ V$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{onom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = \left(7.5 \cdot 10^{4}\right) \frac{1}{s} \qquad \omega_{onom} = \left(1 \cdot 10^{7}\right) \frac{1}{s}$$

Calculations for damping frequency based on nominal values of alpha and omega

$$\omega_{dnom} := \sqrt{\frac{1}{L_{nom} \cdot C_{nom}} - \left(\frac{R_{nom}}{2 \cdot L_{nom}}\right)^{2}}$$

$$\omega_{dnom} = \left(10 \cdot 10^{6}\right) \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{1nom} := V_{nom} \qquad A_{1nom} = \left(3 \cdot 10^{5}\right) V$$

$$A_{2nom} := \frac{\alpha_{nom} \cdot A_{1nom}}{\omega_{dnom}} \qquad A_{2nom} = \left(2.25 \cdot 10^{3}\right) V$$

Double exponential equation for current & voltage waveforms based on nominal value calculations:

$$i_{nom}(t) := \left(\left(-C_{nom}\right) \cdot \left(e^{-\alpha_{nom} \cdot t}\right)\right) \cdot \left(\left(\left(A_{2nom} \cdot \omega_{dnom} - A_{1nom} \cdot \alpha_{nom}\right) \cdot \cos\left(\omega_{dnom} \cdot t\right)\right) + \left(\left(-A_{2nom} \cdot \alpha_{nom} - A_{1nom} \cdot \omega_{dnom}\right) \cdot \sin\left(\omega_{dnom} \cdot t\right)\right)\right)$$

$$V_{nom}(t) := e^{-\alpha_{nom} \cdot t} \cdot \left(A_{1nom} \cdot \cos\left(\omega_{dnom} \cdot t\right) + A_{2nom} \cdot \sin\left(\omega_{dnom} \cdot t\right)\right)$$

FIGURE A-11. HESD discharge circuit.

The three traces shown on FIGURE A-12 are mathematical simulation outputs that represent HESD current waveforms with upper, nominal, and lower limits. Note, the range of amplitudes are inherent from the range of parameters included in TABLE A-V. Inductance from HESD test equipment contributes to the variations in amplitude.

TABLE A-V. HESD parameters.

Charge Voltage	Capacitance	Discharge Inductance	Series Resistance (Ohms)
+ 300 kV + 500 V	1000 pF + 5%	< 20 µH	< 1 Ω
+ 50 kV + 500 V	1000 pF + 5%	< 20 µH	< 1 Ω
+ 100 kV + 500 V	1000 pF + 5%	< 20 µH	< 1 Ω
+ 150 kV + 500 V	1000 pF + 5%	< 20 µH	< 1 Ω
+ 200 kV + 500 V	1000 pF + 5%	< 20 µH	< 1 Ω
+ 250 kV + 500 V	1000 pF + 5%	< 20 µH	< 1 Ω

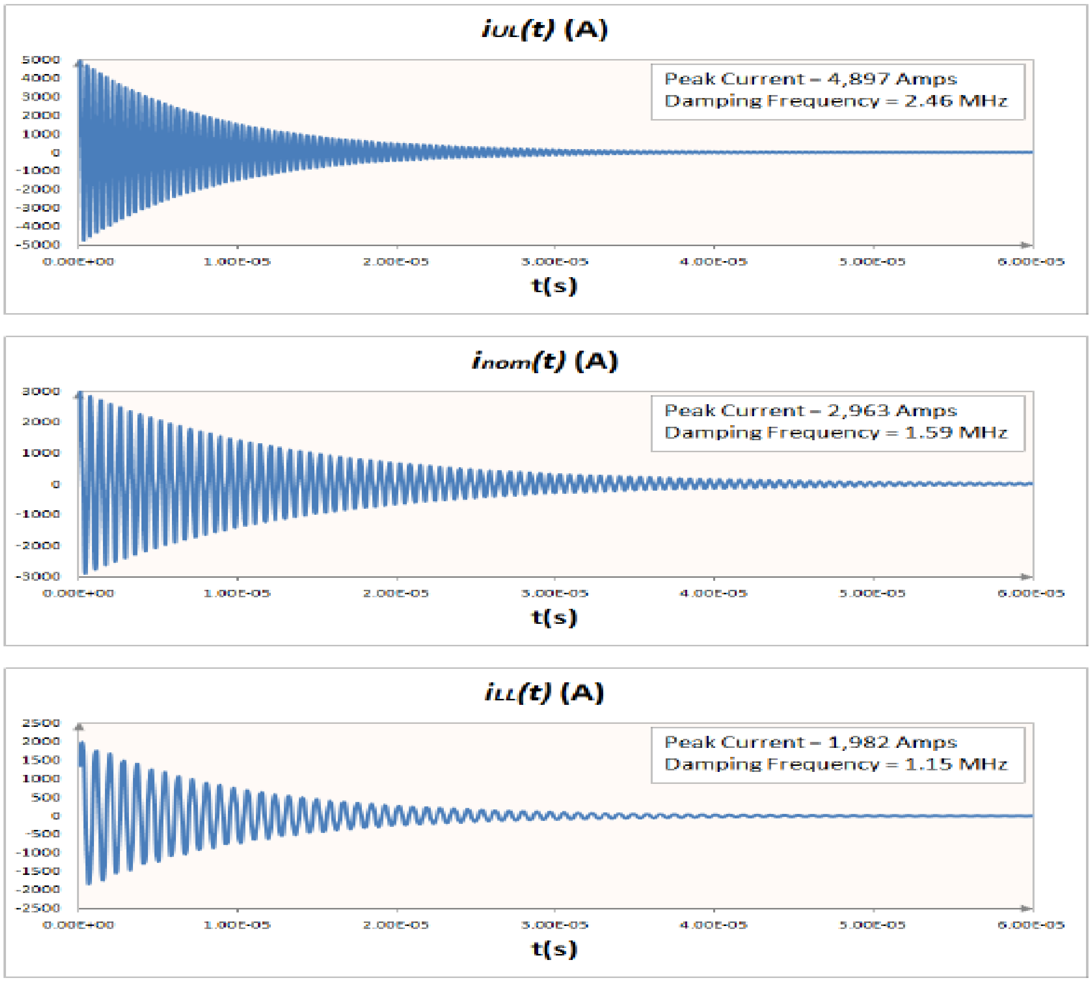


FIGURE A-12. Current waveforms, high—nominal—low.

Requirement Guidance (A.5.8.3.2):

This requirement is based on charge levels that could possibly be developed on operating helicopters and rotary winged aircraft. All explosive subsystems should meet this requirement to guarantee safe helicopter handling.

Requirement Lessons Learned (A.5.8.3.2):

Ordnance systems have been initiated by HESD resulting from Helicopter and rotary winged aircraft operations.

Verification Rationale (A.5.8.3.2):

Due to the safety critical nature of maintaining explosive safety, the high confidence provided by testing is necessary to ensure that requirements are met. The JOTP-062 is a product of the joint services and it is the result of multiple years of experience on this subject field. Verification rational has been incorporated into the JOTP-062 through multiple program iterations of ESD environment exposure. HESD Environmental data obtained using the JOTP-062 will facilitate operability and harmonization amongst the services.

Verification Guidance (A.5.8.3.2):

Verifying source calibration curves as per FIGURE A-12 and assuring source parameters as per Table A- V is necessary to ensure a consistent HESD verification procedure. Live ordnance verification is required and only “pass” or “fail” criteria can apply.

Verification Lessons Learned (A.5.8.3.2):

Historically HESD testing and evaluation was not commonly executed in the same uniform manner by all services. Joint Service validation testing was performed to: (1) harmonize the differences in the existing ESD test procedures used by each of the Services; (2) reduce redundant testing; and (3) meet ordnance safety. The culmination of these efforts resulted in Joint Ordnance Test Procedure (JOTP)-062. The JOTP-062 document evaluated the existing ESD test approach used by each of the Services, and the general requirements in this standard to determine a common Joint Service ESD test approach. The JOTP-062 provided all procedures, requirements, and data necessary to produce consistent and repeatable results independent of the test facility, test site, or Service conducting the testing. Due to the safety critical nature of maintaining explosive safety, the high confidence provided by qualification is necessary to ensure that requirements are met. HESD Environmental data obtained using the JOTP-062 will facilitate operability and harmonization amongst the services.

Naval Weapons Laboratory (NSWCDD) measured 770 pF capacitance, helicopter to ground, at a few feet from the ground level. The capacitance was extrapolated by curve fitting to 1100 pF close the ground. The capacitance curve-fitting correlated well from multiple elevation points to 60 feet. Helicopter charging levels at more humid conditions have been reported and they are significantly lower. CH-46 Aircraft capacitances have been measured and reported in graphical form. The 1971 NWL Dahlgren report shows the helicopter measured capacitance of 1120 pF at ¼ inch above the ground.

Temperature and humidity (environmental) conditioning of ordnance is strongly recommended as the electrical properties of insulators/energetics such as resistivity may be affected by temperature and time-temperature exposure. Thus temperature and humidity conditioning in order to obtain consistent results when ordnance is exposed to the ESD environment is required. The JOTP-062 provides verification lessons learned over years of ESD environment experience by the joint services.

A.5.8.4 Electrical and electronic subsystems.

Systems shall assure that all electrical and electronic devices that do not interface or control ordnance items shall not be damaged by electrostatic discharges during normal installation, handling and operation. The ESD environment is defined as an 8 kV (contact discharge) or 15 kV (air discharge) electrostatic discharge. Discharging from a 150 picofarad capacitor through a 330 ohm resistor with a circuit inductance not to exceed 5 microhenry to the electrical/electronic subsystem (such as connector shell (not pin), case, and handling points). Compliance shall be verified by test (see AECTP-500, Category 508 Leaflet 2).

Requirement Rationale (A.5.8.4):

Electrical and electronic subsystems contain sensitive electronic components that can be inadvertently damaged by human electrostatic discharges during remove and replace, transportation, and other maintenance actions. Although included in this system level standard, this requirement and associated verification methodology is applicable at the equipment level.

Requirement Guidance (A.5.8.4):

This requirement is based on charge levels that could possibly be developed on personnel during remove and replace, transportation, and other maintenance actions.

Requirement Lessons Learned (A.5.8.4):

Many equipment failures have been attributed to ESD damage of electronic parts.

Verification Rationale (A.5.8.4):

To avoid mission and schedule impacts and the cost of expensive repairs, the high confidence provided by testing is necessary to ensure that requirements are met.

Verification Guidance (A.5.8.4):

The 150 picofarad and 330 ohm resistor are used to simulate a human discharge represented by a double exponential waveform with a rise time of 2-10 nanoseconds and a pulse duration of approximately 150 nanoseconds. At a minimum, five discharges made of positive polarity and five discharges of negative polarity are to be applied to the case, seams, connectors and any other locations on the equipment case where ESD is likely to penetrate internal circuitry and that are accessible during installation or transport of the equipment. The subsystem/ equipment should be powered and monitored during test.

Verification Lessons Learned (A.5.8.4):

Many equipment failures described as “EMI problems,” have been the result of an electrostatic discharge during handling or transportation of the equipment.

A.5.9 Radiation hazards (RADHAZ).

The system design shall protect personnel, fuels, and ordnance from hazardous effects of electromagnetic radiation. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

Requirement Rationale (A.5.9):
It has been firmly established that sufficiently high electromagnetic fields can harm personnel, ignite fuel, and fire EIDs. Precautions must be exercised to ensure that unsafe conditions do not develop.

Requirement Guidance (A.5.9):
See guidance for A.5.9.1, A.5.9.2, and A.5.9.3.

Requirement Lessons Learned (A.5.9):
See lessons learned for A.5.9.1, A.5.9.2, and A.5.9.3.

Verification Rationale (A.5.9):
See rationale for A.5.9.1, A.5.9.2, and A.5.9.3.

Verification Guidance (A.5.9):
See guidance for A.5.9.1, A.5.9.2, and A.5.9.3.

Verification Lessons Learned (A.5.9):
See lessons learned for A.5.9.1, A.5.9.2, and A.5.9.3.

A.5.9.1 Hazards of electromagnetic radiation to personnel (HERP).

The system shall comply with current DoD criteria for the protection of personnel against the effect of electromagnetic radiation. DoD policy is currently found in DoDI 6055.11. Compliance shall be verified by test, analysis, or combination thereof.

Requirement Rationale (A.5.9.1):
The proven adverse biological effects of non-ionizing (electromagnetic) radiation are thermal, resulting from overheating of human body tissue. Overheating results when the body is unable to cope with or adequately dissipate heat generated by exposure to RF energy. The body’s response is dependent on the energy level, time of exposure, and ambient temperature. Unlike ionizing radiation, no cumulative effects from repeated exposure or molecular changes that can lead to significant genetic damage to biological tissues have been proven. RF exposure guidelines and procedures have been adopted and promulgated to protect DoD personnel from the deleterious effects of RF exposure.

Requirement Guidance (A.5.9.1):
DoDI 6055.11 implements the HERP criteria for military operations.

Requirement Lessons Learned (A.5.9.1):
Radar and ECM systems usually present the greatest potential personnel hazard due to high transmitter output powers and antenna characteristics and possible exposure of servicing personnel.

Personnel assigned to repair, maintenance, and test facilities have a higher potential for being overexposed because of the variety of tasks, the proximity to radiating elements, and the pressures for rapid maintenance response.

Verification Rationale (A.5.9.1):
Safety regarding RF hazards to personnel must be verified.

Verification Guidance (A.5.9.1):
DoDI 6055.11 provides detailed methodology for assessing hazards.

An RF hazard evaluation is performed by determining safe distances for personnel from RF emitters. Safe distances can be determined from calculations based on RF emitter characteristics or through measurement. Once a distance has been determined, an inspection is required of areas where personnel have access together with the antenna's pointing characteristics. If personnel have access to hazardous areas, appropriate measures must be taken such as warning signs and precautions in servicing publications, guidance manuals, operating manuals, and the like.

Air Force TO 31Z-10-4, NAVSEA OP 3565, and Army TB MED 523 provide technical guidance and methodology for assessing RF hazards.

Verification Lessons Learned (A.5.9.1):
Safe distance calculations are often based on the assumption that far-field conditions exist for the antenna. These results will be conservative if near-field conditions actually exist. TO 31Z-10-4 and OP 3565 provide techniques for calculating the reduction of gain for certain types of antennas. Measurements may be desirable for better accuracy.

Before a measurement survey is performed, calculations should be made to determine distances for starting measurements to avoid hazardous exposures to survey personnel and to prevent damage to instruments. Since hazard criteria are primarily based on average power density and field strength levels (peak levels are also specified), caution needs to be exercised with the probes used for measurements because they have peak power limits above which burnout of probe sensing elements may occur.

When multiple emitters are present and the emitters are not phase coherent (the usual case), the resultant power density is additive. This effect needs to be considered for both calculation and measurement approaches.

In addition to the main beam hazard, localized hot spots may be produced by reflections of the transmitted energy from any metal structure. These results can occur in areas having general power densities less than the maximum permissible exposure limits.

Experience has shown aboard ships, that unless personnel observe the restrictions (clear zones) around emitting radiators, personnel can be affected by extensive exposure to electromagnetic radiation.

A.5.9.2 Hazards of electromagnetic radiation to fuel (HERF).

Fuels shall not be inadvertently ignited by radiated EMEs. The EME includes onboard emitters and the external EME (see 5.3). Compliance shall be verified by test, analysis, inspection, or a combination thereof.

Requirement Rationale (A.5.9.2):
Fuel vapors can be ignited by an arc induced by a strong RF field.

Requirement Guidance (A.5.9.2):
The existence and extent of a fuel hazard are determined by comparing the actual RF power density to established safety criteria. TO 31Z-10-4 and OP 3565 provide procedures for establishing safe operating distances.

RF energy can induce currents into any metal object. The amount of current, and thus the strength of an arc or spark produced between two electrical conductors (or heating of small filaments) depends on both the field intensity of the RF energy and how well the conducting elements act as a receiving antenna. Many parts of a system, a refueling vehicle, and static grounding conductors can act as receiving antennas. The induced current depends mainly on the conductor length in relation to the wavelength of the RF energy and the orientation in the radiated field. It is not feasible to predict or control these factors. The hazard criteria must then be based on the assumption that an ideal receiving antenna could be inadvertently created with the conductors.

Requirement Lessons Learned (A.5.9.2):
There is a special case where a fuel or weapon RF hazard can exist even though the RF levels may be within the safe limits. This special case is for both the hand-held (1-5 watts) and mobile (5-50 watts) transceivers. The antennas on this equipment can generate hazardous situations if they touch the system, ordnance, or support equipment. To avoid this hazard, transceivers should not be operated any closer than 10 feet from ordnance, fuel vents, and so forth.

Verification Rationale (A.5.9.2):
Safety regarding RF hazards to fuels must be verified. A majority of the verification is done by inspection and analysis with testing limited to special circumstances.

Verification Guidance (A.5.9.2):
TO 31Z-10-4 and OP 3565 provide methodology for calculating hazard distances from RF emitters. An important issue is that fuel hazard criteria are usually based on peak power, while hazard criteria for personnel are based primarily on average power. Any area in the system where fuel vapors may be present needs to be evaluated. Restrictions on use of some RF emitters may be necessary to ensure safety under certain operations such as refueling operations. Any required procedures must be carefully documented in technical orders or other appropriate publications.

The volatility and flash point of particular fuels influence whether there is a hazard under varying environmental conditions.

Verification Lessons Learned (A.5.9.2):
See lesson learned for section A.5.9.1.

A.5.9.3 Hazards of electromagnetic radiation to ordnance (HERO).

Ordnance that contain EIDs shall remain safe and operational during and after exposure to the external EME levels of TABLE IX for both direct RF induced actuation of the EID and inadvertent activation of an electrically powered firing circuit. Relevant ordnance phases involving unrestricted and restricted levels in TABLE IX are listed in TABLE X. In order to be assigned a HERO classification of "HERO SAFE ORDNANCE" at the all-up round or appropriate assembly level, the ordnance or system under test (SUT) must be evaluated against, and be in compliance with, TABLE IX. Compliance shall be verified by test (such as in MIL-HDBK-240), analysis, or a combination thereof. EIDs shall have a margin of at least 16.5 dB of maximum no-fire stimulus (MNFS) for safety assurances and 6 dB of MNFS for other applications. Compliance shall be verified by test, analysis, or a combination thereof. Instrumentation installed in system components during testing for margins shall capture the maximum system response and shall not adversely affect the normal response characteristics of the component. When environment simulations below specified levels are used, instrumentation responses may be extrapolated to the full environment for components with linear responses (such as hot bridgewire EIDs). When the response is below instrumentation sensitivity, the instrumentation sensitivity shall be used as the basis for extrapolation. For components with non-linear responses (such as semiconductor bridge EIDs), no extrapolation is permitted.

Requirement Rationale (A.5.9.3):
RF energy of sufficient magnitude to fire or dud EIDs can be coupled from the external EME via ordnance subsystem wiring or capacitively coupled from nearby radiated objects. The possible consequences include both hazards to safety and performance degradation. TABLE IX is based on a composite of the maximum levels from the other EME tables in 5.3 and operational constrains regarding joint ordnance. Rationale and assumptions that resulted in the final TABLE IX are detailed in MIL-HDBK-235-7. One additional note is the difference in the average EM environment for the 8500 to 11000 MHz frequency range between TABLE II and TABLE IX. Evaluation of the operational constraints, transmitter concept of operations, and EM

environment determined that Joint ordnance would be restricted to a lower level as shown in TABLE IX. Unless otherwise specified by the procuring activity, all ordnance is to be designed to operate in the joint EM environment detailed in TABLE IX. However, if it is known that an ordnance item will be launched from a surface combatant, the level in the 2700 to 3600 MHz and 8500 to 11000 MHz ranges may be modified to address higher naval platform EM environments detailed in MIL-HDBK-235-7. Consequently, in order to be assigned a HERO classification of "HERO SAFE ORDNANCE" at the all-up round or appropriate assembly level, the ordnance or SUT must be evaluated against, and be in compliance with, TABLE IX.

Requirement Guidance (A.5.9.3):

Ordnance includes weapons, rockets, explosives, EIDs themselves, squibs, flares, igniters, explosive bolts, electric primed cartridges, destructive devices, and jet assisted take-off bottles.

TABLE IX specifies both "unrestricted" and "restricted" environments. The unrestricted environment represents the worst case levels to which the ordnance may be exposed. The restricted environment involves circumstances where personnel are directly interacting with the ordnance (assembly/disassembly, loading/unloading). For the special case of handling operations, the environment is intentionally restricted to prevent personnel from being exposed to hazardous levels of EM energy or contact currents (see 5.9.1). However, these operations also tend to increase coupled levels into the ordnance because of actions such as mating and de-mating of electrical connectors. Therefore, ordnance must be designed to be safe under these types of actions at the lower fields associated with the restricted levels.

In order to meet the requirements for joint operations or to achieve the HERO classification of "HERO SAFE," ordnance must be tested to the full range of EME levels in TABLE IX for all the military services and all phases and configurations of the ordnance. Specific environments for joint ordnance include both near-field and far-field conditions. In certain cases, ordnance systems may be exposed to levels other than those indicated in TABLE IX. Special consideration must be given to the platform emitters to ensure that the required EME reflects their levels at the ordnance location. For example, the Close-In Weapon System installed aboard some Navy ships is in proximity to high-power HF antennas and the ordnance systems found on some ground vehicles (e.g., Mine Resistant Ambush Protected (MRAP) vehicles) are virtually co-located with the platform antennas requiring certification to levels exceeding even those in the unrestricted category. The appropriate levels amount to an upward tailoring of the MIL-STD-464 levels. Furthermore, for platform antennas in proximity to ordnance, an intra-system HERO test may be required to address both the EMEs exceeding those found in TABLE IX and to address potential near-field affects. Conversely, for some air-launched systems found on aircraft that will never operate in a shipboard environment, it may be reasonable to reduce EME HERO levels such that the item is evaluated against its intended operational environment. Thus, field strength levels may be tailored up or down, depending on the EME expected to be encountered throughout all phases and configurations of the ordnance; however, even though an item may be evaluated against a tailored environment, an item must be tested to the full range of EME levels in TABLE IX to achieve the HERO classification of "HERO SAFE ORDNANCE." All such tailoring must be addressed on an individual basis.

The accidental initiation of EIDs by RF energy is not a new concern. Commercial manufacturers of blasting caps have warned their customers for many years about the potential hazard involved in using electrically fired blasting caps in the vicinity of transmitters. Most EIDs employ a small resistive element called a bridgewire. When the EID is intentionally initiated, a current pulse is passed through the bridgewire, causing heating and resultant initiation of the explosive charge or functioning of the device. RF induced currents will cause bridgewire heating that may inadvertently actuate the EID. Interface wiring to the EID generally provides the most efficient path for RF fields to couple energy to the bridgewire. However, RF energy can also fire extremely sensitive devices, such as electric primers, as a result of capacitive coupling from nearby radiated objects. RF energy may also upset energized EID firing circuits, causing erroneous firing commands to be sent to the EID. Non-bridgewire types of EIDs are being increasingly used for many ordnance applications. The electrothermal behavior of these devices differs considerably from bridgewire devices; many have much faster response times and exhibit non-linear response characteristics.

EIDs should have the highest Maximum No-Fire Stimulus (MNFS) that will allow the EID to meet system requirements. Each EID must be categorized as to whether its inadvertent ignition would lead to either safety or performance degradation problems (i.e., "reliability"). A safety consequence is the inadvertent actuation of an EID that creates an immediate catastrophic event that has the potential to either destroy equipment or to injure personnel, such as the firing of an inline rocket motor igniter by RF energy; or the inadvertent actuation of an EID that increases the probability of a future catastrophic event by removing or otherwise disabling a safety feature of the ordnance item. This, for example, might be caused by the RF initiation of a piston actuator that removes a lock on the S&A rotor of an artillery fuze, thus allowing a sensitive detonator to rotate in-line with the explosive train. Performance degradation can be any condition which does not have safety implications and is referred to as "reliability." Performance degradation may occur because an EID may have been desensitized as a result of multiple low-level exposures, which would prevent it from firing when needed, or because it already had been ignited. "Safety" and "reliability" categorizations should be determined by the procuring activity.

NASA document TP2361 provides design guidelines for space and launch vehicle charging issues. Subsystems and equipment installed aboard space systems should be able to meet operational performance requirements during and/or after being subjected to representative discharges simulating those due to spacecraft charging.

Requirement Lessons Learned (A.5.9.3):

The response of an EID to an RF energy field, and the possibility of detonation, depends on many factors. Some of these factors are transmitter power output, modulation characteristics, operating frequency, antenna propagation characteristics, EID wiring configuration (such as shielding, length, and orientation) and the thermal time constant of the device.

Several incidences onboard Navy ships involving the inadvertent firing of rockets and missiles have resulted in catastrophic loss of life and equipment.

There have been numerous explosive mishap reports involving RF induced, uncommanded actuation of automatic inflators worn by aircrew personnel both on flight decks and in-flight while launching from and landing on the carrier. These problems pose a tremendous hazard to aircrews, especially those in-flight at the time of occurrence.

Use of uncertified systems onboard ships due to joint operations has resulted in operational restrictions on shipboard emitters.

Verification Rationale (A.5.9.3):
Adequate design protection for electro-explosive subsystems and EIDs must be verified to ensure safety and system performance. Unless a theoretical assessment positively indicates that the RF-induced energy on EID firing lines or in electronic circuits associated with safety-critical functions is low enough to assure an acceptable safety margin in the specified EME (bearing in mind the possible inaccuracies in the analysis technique), it will be necessary to conduct a practical test.

Verification Guidance (A.5.9.3):
Verification methods must show that electro-explosive subsystems will not inadvertently operate and EIDs will not inadvertently initiate or be dudded during handling, storage, or while installed in the system. Assessment of the immunity of an EID is based upon its no-fire threshold. For acceptance, it must be demonstrated that any RF-induced energy in an EID circuit in the specified EME will not exceed a given level expressed as a margin in dB below the maximum no-fire threshold sensitivity for the EID concerned. Refer to MIL-HDBK-240 for test guidance.

HERO testing should include exposure of the ordnance to the test EME in all life cycle configurations, including transportation/storage, assembly/disassembly, loading/unloading, staging, platform-loaded, and immediate post-launch. The system should be exposed to the test EME while being exercised with operating procedures associated with those configurations. For system configurations exclusively involving the presence of personnel, such as assembly and disassembly or loading and downloading, the restricted levels in TABLE IX must be used with time averaging considerations related to personnel exposure being applied, where necessary, to meet the applicable personnel hazards criteria (see A.5.9.1).

TABLE A-VI shows the appropriate field intensity levels from TABLE IX as they relate to slow versus fast responding EIDs and energized versus non-energized firing circuits in all phases and configurations of ordnance. Whether an EID is considered slow or fast responding depends on the response time of “the device” relative to the pulse widths and pulse repetition frequency of radars. See MIL-HDBK-240 for discussions on thermal time constants.

TABLE A-VI. HERO EME test levels.

Stockpile-to-Safe Separation Phases	**EME Levels**[1]	
	Non-energized firing circuits or slow-responding EIDs	**Energized firing circuits or fast-responding EIDs**
Transportation/storage	Unrestricted average levels	Unrestricted peak levels[2,3]
Assembly/disassembly	Restricted average levels	Restricted peak levels
Staged	Unrestricted average levels	Unrestricted peak levels[2,3]
Loading/unloading	Restricted average levels	Restricted peak levels[4]
Platform-loaded	Unrestricted average levels	Unrestricted peak levels[2]
Immediate post-launch	Unrestricted average levels	Unrestricted peak levels[2]

NOTES

1. Applicable field intensity levels are specified in TABLE IX.
2. Unrestricted peak levels should be used unless tailored environments have been developed.
3. Applies to fast-responding EIDs only.
4. Some firing circuits may be energized during the loading/unloading sequence in order to accomplish pre- and post-loading diagnostic procedures.

For stockpile-to-safe-separation phases where personnel are required to handle the ordnance, exposure of personnel must be limited to field strength levels considered safe in accordance with DoDI 6055.11 (see A.5.9.1). The “restricted” levels in TABLE IX are based on actual radiated levels to which personnel are exposed in normal operational situations. There are some instances where the restricted levels in TABLE IX exceed the continuous (6 minutes or more) Permissible Exposure Limits (PELs) cited in the instruction. In such cases, test personnel must limit the duration of their exposure to appropriate intervals less than 6 minutes. Refer to DoDi 6055.11 for specific guidance on how to determine maximum exposure times as a function of frequency and field strength. In addition to limits on the radiated field levels, there are also limits on induced/contact current (I/CC) levels that can result from exposure to radiated environments. Guidance to ensure compliance with radiated PELs and I/CC limits is provided in DoDI 6055.11.

MIL-HDBK-240 provides discussion regarding a minimum set of frequencies where testing should be performed. Testing should also be performed at any frequencies known to be system resonances. Swept frequency testing is preferable but it is usually not practical at the field strength levels that are required.

The test EME should simulate the specified EME to the extent necessary to stimulate maximum EID and firing circuit responses. This requires an appropriate representation of the specified EME with respect to frequency, field strength (power density), field polarization, and illumination angle. For radar EME levels, representative pulse widths, pulse repetition frequencies, and beam dwell periods should be chosen to maximize system response with due consideration for the response times of EIDs and firing circuits. Refer to MIL-HDBK-235-7 for specific operational characteristics and MIL-HDBK-240 for detailed guidance.

A.5.10 Life cycle, E3 hardness.

The system operational performance and E3 requirements of this standard shall be met throughout the rated life cycle of the system and shall include, but not be limited to, the following: maintenance, repair, surveillance, and corrosion control. Compliance shall be verified by test, analysis, inspections, or a combination thereof. Maintainability, accessibility, testability, and the ability to detect degradations shall be demonstrated.

Requirement Rationale (A.5.10):

Advanced electronics and structural concepts are offering tremendous advantages in increased performance of high-technology systems. These advantages can be seriously compromised, however, if E3 protection concepts impact life cycle costs through excessive parts count, mandatory maintenance, or costly repair requirements. It is essential, therefore, that life-cycle considerations be included in the tradeoffs used to develop E3 protection.

Corrosion control is an important issue in maintaining EMC throughout the system’s life cycle.

It is important that protection provisions that require maintenance be accessible and not be degraded due to maintenance actions on these provisions.

Requirement Guidance (A.5.10):

There are normally a number of approaches available for providing E3 protection. The particular design solution selected must give adequate consideration to all aspects of the life cycle including maintenance and need for repair.

E3 hardening features should either be accessible and maintainable or should survive the design lifetime of the system without mandatory maintenance or inspection. Protection measures which require maintenance should be repairable or replaceable without degradation of the initial level of protection. The system design should include provisions to restore the effectiveness of bonding, shielding, or other protection devices which can be disconnected, unplugged, or otherwise deactivated during maintenance activities.

E3 protection schemes include specific design measures both internal to electrical and electronic enclosures and in the basic system structure. Factors such as corrosion, electrical overstress, loose connections, wear, misalignment, dirt, paint, grease, sealant, and maintenance actions will degrade the effectiveness of some protection measures with time.

To ensure continued protection (hardness) throughout the system life-cycle, protection schemes and devices must be identified and maintenance intervals and procedures specified. Emphasis needs to be placed on critical functions for system operational and mission performance. The user must assume the responsibility to maintain the hardness for the life of the system and to modify procedures as necessary to include conditions not originally anticipated. Maintenance publications should document required actions. Some of the design features affecting hardness are overbraiding of electrical cables, integrity of shielded volumes, electrical bonding of surfaces, linear (resistance, capacitance and inductance) and non-linear (such as transzorbs, zener diodes, and varistors) filtering, circuit interface design (balance, grounding, and so forth), and circuit signal processing characteristics.

Maintenance actions must also be addressed which are performed on non-critical items which are in the same area as the critical items to ensure that personnel do not inadvertently compromise the protection measures of the critical functions. Procedures addressing modifications to the system which involve either new or existing subsystems which perform critical functions must be considered. They could also involve modifications to the system structure or subsystem components, such as wiring and protective devices.

E3 maintenance should be integrated into normal system maintenance and repair cycles. Separate independent maintenance is undesirable.

Electromagnetic design features that require scheduled maintenance should be accessible so they can be tested or inspected.

In deployment, space-based equipment cannot be routinely inspected or serviced. Therefore, the space vehicle must have features that are designed for unattended operation and durability for the life of the mission.

Requirement Lessons Learned (A.5.10):
Many times in the past, E3 protection has been installed without sufficient thought being given to maintenance and repair. It is often very difficult to access protection measures to determine if they are still effective. By considering the problem of access and test during design, it can be relatively simple to provide protection measures which will allow maintenance checks to be made while minimizing any negative impacts to the design. Also, design techniques oriented toward better maintenance access can provide capability for quality control checks during assembly, benefiting both the system manufacturer and user.

“Don't design it if it can't be repaired." Protection must be designed so as to be easily repairable. The protection system and any repair details must be appropriately documented. For example, if lightning diverter strips or buttons are used on radomes, the maintenance information must reflect any precautions, such as not painting. If fuel tank skins should not be painted to prevent puncture by lightning, this information must be documented with rationale.

Some key areas which require special consideration are addressed in the sections below.

Access doors made of composite materials which are an element of the shielding for a volume are generally designed to be bonded electrically to the system structure. If door spring fingers are employed, they must be kept clean, free from damage, and aligned at all times. Good contact between the door frame around the access door and the spring fingers is critical for maintaining shielding integrity. The bonding area must be inspected to ensure that the bonding effectiveness has not been degraded by dirt, corrosion, sealant and paint overruns, damage, or misalignment.

Screens using wire mesh have been used to shield openings in structure. These screens need to be treated in a fashion similar to the access doors.

Effective electrical bonding of electrical and electronic enclosures to system structure is often essential for proper operation in the various electromagnetic environments. Surfaces on the enclosures and structure must be kept clean to maintain proper bonding. Documentation associated with the system should clearly show areas needed for bonding and the appropriate finishes which should be on the surfaces. Painting of areas intended for electrical bonding has been a common cause of EMC problems. An example of bonding design is the contact between the back of an enclosure and the finger washers in the rear wall of the electronics rack. Other electrical bonds which require attention may be in the form of flat bands or braids across shock mounts or structural members.

It is important that replacement hardware conform to the original design concept. For example, when damaged cables are repaired, shield termination techniques established for the design must be observed.

An example of a subtle change in hardware configuration to the original design concept can be found in a life vest. The life vest was fielded with a bridgewire EID that could be fired by a salt-water activated battery pack that had been hardened and certified for HERO. After introduction into the fleet, an engineering change proposal was developed, and approved, to modify the type of battery used in the battery pack. The change was not submitted for HERO consideration. When the life vests were equipped with the new battery pack and used on board Navy ships, there were reports of uncommanded activation of the vests during flight operations and on the flight deck. The subsequent investigation found that the new battery pack made the EID subsystem resonant to a ship radar system; thereby, creating susceptibility problems.

Verification Rationale (A.5.10):
Compliance with life cycle requirements must be verified to ensure that E3 protection can be maintained and does not degrade with time. Verification can range from inspection of proper documentation to actual demonstration of techniques.

Verification Guidance (A.5.10):
Some E3 protection measures, such as electrical contact of critical components and electromagnetic shielding effectiveness, cannot be maintained by visual inspections alone. Some testing will probably be necessary; however, the need for any hardness surveillance testing should be minimized as much as possible.

The techniques and time intervals for evaluating or monitoring the integrity of the system protection features need to be defined. The user will probably need to adjust the maintenance intervals after attaining experience with the degradation mechanisms. BIT capability, test ports, resistance measurements, continuity checks, transfer impedance measurements, and transfer function measurements are some of the means available for use in the periodic surveillance of system integrity. For evaluation of possible degradation, a baseline of the system as delivered to the user is necessary.

Verification Lessons Learned (A.5.10):
The manufacturer of the system has the best understanding of the system protection measures. His role in defining appropriate requirements for various protection measures in a manner which can be effectively verified at the system-level and evaluated during maintenance is key to a successful life cycle program. These considerations include the need for easy access to protection measures requiring evaluation. Otherwise the performance of some protection measures may be neglected. In some cases, other system design considerations may be overriding. In such cases, it is often possible to provide features in the design (such as test tabs or special connectors) which will permit a test measurement to be made without time-consuming disassembly.

Most shielded cable failures occur at the connector and a resistance meter capable of measuring milliohms is usually sufficient for locating these failures. Testing on several aircraft has shown that holes or small defects in the shields themselves are not a significant problem. It takes major damage to the shield for its effectiveness to be degraded. In addition, time domain reflectometers can be used to locate discontinuities or changes in protection schemes. Measurements after the system is fielded can be compared to baseline measurements.

Cable shield testers are available for more thorough evaluation of shield or conduit performance. A current driver is easily installed on the outside of the cable; however, a voltage measurement on wires internal to the shield requires access to these wires. If an electrical connector is sufficiently accessible, the voltage measurement is straightforward. In some cases, cables pass through bulkheads without the use of connectors and access is not readily available. A possible solution is to include a pick-off wire attached to one of the wires within the bundle which is routed to a connector block accessible to technicians.

An aperture tester can be used to monitor the integrity of RF gaskets and screens protecting apertures on the system. An existing tester uses a stripline on the outside of the system structure to drive a current across the aperture and the voltage developed across the aperture within the structure is measured. The installation of the stripline has not been difficult; however, paint and non-conductive materials on the inside of structure have hampered the ability to measure induced voltages across doors and window frames. Test tabs or jacks would have greatly simplified the measurement.

Frequent performance of surveillance checks after initial deployment can help in refining maintenance intervals by determining degradation mechanisms and how fast degradation develops.

Life cycle considerations must include the fact that systems are often modified soon after they are fielded and frequently throughout their life. Sometimes the modifications are small and can be qualified with a limited effort. Often there are major changes to system structure as well as to the electronics. The addition of major new subsystems can introduce new points of entry for electromagnetic energy into protected areas, and a major requalification of the system may be necessary. Also, if enough small modifications are made over a period of time, the hardness of the system may be in doubt and requalification should be considered.

EMI hardness evaluations under the Navy's Air Systems' EMI Corrective Action Program (ASEMICAP) have shown that the hardness of aircraft is degraded over time. Electrical inspections have shown numerous instances of foreign object damage, excessive chaffing of wires, and improper splicing and terminations. Bonding measurements performed over a ten year period on a Navy fighter aircraft indicates 10-15% out of specification conditions on a new aircraft, 40-60% out of specification conditions on a five year old aircraft and 70-80% out of specification conditions on a ten year old aircraft. These out of specification bonding conditions result in inadequate termination of shields and boxes and degrade shielding effectiveness. During EMC tests, the effects of corrosion and maintenance practices on the EMC design have been noted. For example, composite connectors were incorporated in the pylons of a Navy attack aircraft to correct a severe corrosion problem on the existing aluminum connectors. The composite connectors are more resistant to the corrosion than aluminum. They do, however, oxidize and produce a powdery residue on the connector. The maintenance personnel would then wire brush this residue, thereby eliminating the outer conductive coating, severely degrading the connector conductivity, and introducing potentially more severe corrosion problems.

A.5.11 Electrical bonding.

The system, subsystems, and equipment shall include the necessary electrical bonding to meet the E3 requirements of this standard. Compliance shall be verified by test, analysis, inspections, or a combination thereof, for the particular bonding provision.

Requirement Rationale (A.5.11):

Good electrical bonding practices have long been recognized as a key element of successful system design. An indicator of the importance of electrical bonding is that the first item often assessed when EMC problems occur is whether the bonding is adequate. Since electrical bonding involves obtaining good electrical contact between metallic surfaces while corrosion control measures often strive to avoid electrical continuity between dissimilar materials, it is essential that the (potentially conflicting) requirements of each discipline be fully considered in the system design.

Systems generally include ground planes to form equipotential surfaces for circuitry. If voltage potentials appear between electronics enclosures and the ground plane due to internal circuitry operation, the enclosure will radiate interference. Similarly, electromagnetic fields will induce voltage potentials between poorly bonded enclosures and the ground plane. These potentials are imposed as common-mode signals on all circuitry referenced to the enclosure. The same two effects will occur for poorly bonded shield terminations.

Without proper bonding, lightning interaction with systems can produce voltages which can shock personnel, ignite fuel through arcing and sparking, ignite or dud ordnance, and upset or damage electronics. Lightning requirements are described under 5.5 in terms of a description of the environment. There are no specific levels defined under 5.11 because of the wide variety of possible needs based on the particular platform and physical location within the platform. While electrical bonding is an important aspect in achieving an acceptable lightning design, it is only one element of an overall design to deal effectively with lightning. In the past, lightning requirements for aircraft were actually defined in the electrical bonding specification, MIL-B-5087 which has been cancelled and superseded by this standard. In this standard, lightning requirements are more appropriately defined at a higher level, since design involves much more than just bonding.

It is essential that system electrical and electronic equipment be provided with adequate voltage levels from prime power sources for proper operation. Electrical fault conditions must not introduce potential fuel or fire hazards due to arcing or sparking from melted or vaporized structural material. Bonding provisions help control voltage drops in power current return and fault paths.

The system design must protect personnel from shock hazards.

Requirement Guidance (A.5.11):
The role of bonding is essentially to control voltage by providing low-impedance paths for current flow. Unconventional joints should receive special attention to ensure their adequacy, particularly conductive joints in fuel vapor areas. SAE ARP1870 provides details on electrical bonding concepts for aerospace systems and examples of bonding techniques. MIL-HDBK-419 provides guidance for grounding, bonding, and shielding of land-based facilities, including installed electronic equipment. MIL-STD-1310 provides guidance for electrical bonding onboard ships.

Special attention should be given to the interdependent relationship between electrical bonding and corrosion control. Design techniques for effective corrosion protection, such as the use of finishes which are not electrically conductive, can result in lack of bonding. Conversely, obtaining a good electrical bond can lead to potential corrosion problems, if the bonding is not properly implemented.

While specific bonding levels needed to obtain required performance are system dependent, 2.5 milliohms has long been recognized as an indication of a good bond across a metallic interface, particularly aluminum. There is no technical evidence that this number must be strictly met to avoid problems. However, higher numbers tend to indicate that a quality assurance problem may be present and bonding may be degrading or not under proper control. Higher values may be more appropriate for other metals such as stainless steel or titanium. Also, composite materials will exhibit much higher levels and imposed requirements should be consistent with those materials. Selected bonding levels need to be justified for design and demonstrated as being adequate, particularly when they deviate from traditional norms used in the past.

Controls need to be implemented in shield termination paths through connector assemblies. A realistic value would be on the order of 10 milliohms from the shield to the electronics enclosure for a cadmium-plated aluminum assembly, with 2.5 milliohms maximum for any particular joint.

Bonding measures for prevention of fuel ignition hazards from electrical fault currents need to address areas with flammable vapors, installed electrical equipment (such as fuel pumps), electrical paths of fault currents, available levels of fault current, and the bonding value necessary for the implemented design architecture to prevent arcing, sparking, and hot spots.

Requirement Lessons Learned (A.5.11):
Historically, MIL-B-5087 (superseded by this document) first established electrical bonding requirements for aircraft in 1949. Several electrical bonding classes were defined and eventually designated in subsequent revisions as follows:

a. Class A for antenna installation – no bonding resistance specified.

b. Class C for current return path – fault current versus resistance.

c. Class H for shock hazard – 0.1 ohm.

d. Class L for lightning protection – control internal vehicle voltages to 500 volts.

e. Class R for RF potentials – 2.5 milliohms from electronic units to structure.

f. Class S for static charge – 1.0 ohm.

MIL-B-5087 also provided several approved bonding techniques including the specific hardware that was to be used for electrical bonding. This approach was in essence providing the contractor with a bonding design requirement followed by direction on how to achieve the requirement. There were also less obvious requirements in the standard such as a 2.5 milliohm requirement on connector shells, when used to electrically bond shields. Over the years, the 2.5 milliohm class R requirement became synonymous with MIL-B-5087 and was universally accepted as a design requirement for electronic units to vehicle structure. No scientific basis has been found for this 2.5 milliohm requirement other than the fact that it is a value that can be achieved with good metal-to-metal contact. It therefore represents a good design requirement to ensure that positive electrical bonding is included in the design. The rationale behind this class R bond was most likely to assure that the return circuit impedances were kept very low due to the extensive use of single end circuits in that time frame. Modern electronics uses primarily balanced circuits and the need for this low class R bond is less obvious.

Bonding requirements are still important in today's systems, only from a different perspective. The equipment case-to-structure class R requirement probably is not important in most instances; however, the 2.5 milliohm is still a good number for several other electrical bonds such as terminating shields to connectors and bonding a connector to the equipment case. It is also a good value as a design goal where a good bond is needed for other purposes. It mainly requires the designer to design an intentional bonding path.

The other bonding values of MIL-B-5087 for shock protection, current return paths, and static charge are still valid numbers for use today.

Numerous instances of the need for good bonding have been demonstrated. Bonding improvements or corrections have solved many system problems including precipitation static in UHF receivers, susceptibility of electronics to external electromagnetic fields, radiation of interference into antenna-connected receivers, and lightning vulnerabilities.

The actual need for certain bonding in a particular application is not easily ascertained. It is dependent on various items such as the shielding topology, type of circuit interfaces, and the use of the enclosure as a ground reference for circuits and filters. For example, a subsystem which is wholly contained (all enclosures and cable interfaces in a continuous unbroken shield) typically does not necessarily require bonding for RF potential control. External currents will remain outside the shield and internal currents will remain inside. This configuration is rare. The increasing use of differential interface circuits makes equipment enclosure-to-vehicle structure bonding less critical since there is better rejection of common-mode noise.

In systems using basically metallic structure, the entire vehicle structure forms a ground plane. The introduction of composite materials in structure, which are much less conductive than metals, has created a need in some cases to introduce separate ground planes to maintain adequate control of E3.

Verification Rationale (A.5.11):
Verification of protection measures for electrical bonding is necessary to ensure that adequate controls are implemented.

Verification Guidance (A.5.11):
The electrical bonding area involves a number of different concerns. The particular verification methodology needs to be tailored for the bonding control being assessed. Many elements require more than one form of verification. When bonding values in the several milliohm range or less is required, accurate testing with a four point probe is a necessity. When much higher values are adequate, inspection of surface finishes and mounting techniques supplemented by analysis can be acceptable. Verification that bonding for lightning protection and antenna patterns is adequate generally requires system-level testing. Analysis is an element of assessing structural voltage drops for power returns, fuel ignition hazards, and personnel shock.

Requirements for electrical continuity across external mechanical interfaces on electrical and electronic equipment are normally verified during the development of the equipment. The equipment to structure interface is normally verified at the system-level. A measurement is made from an enclosure surface to the next major assembly. For example, in an installation with an enclosure mounted in a tray, separate measurements would be applicable from the enclosure to the tray and from the tray to structure. The measurement is normally performed with a DC resistance meter. Ideally, the impedance should be maintained as high in frequency as possible. The impedance will normally remain low for enclosures that are hard-mounted to structure. However, for enclosures installations which use bonding straps, such as shock mounts, the impedance of bonding straps will be significant due to the inductance of the strap. A 5:1 length to width ratio or less is generally considered to be necessary for a bonding strap to be effective.

Use of low current and voltage bonding meters, inspection and analysis of bonding paths, and determination of the number of mechanical interfaces in a bonding path are some of the aspects of verification.

Verification of electrical bonding measures for design against electrical shock is primarily achieved by demonstrating that voltage faults to electrically conductive surfaces will not result in hazardous voltages on the surface. These types of faults should normally trip circuit protection equipment.

Verification Lessons Learned (A.5.11):

The adequacy of much electrical bonding can be evaluated through DC or low frequency AC resistance measurements and inspection. RF measurements can be performed; however, they require more sophisticated instrumentation, can provide misleading results, and are not recommended. DC measurements have proven to provide a good indication of the quality of a bond. An exception where high frequency measurements can be effective is transfer impedance measurements of shielded cables. Under this type of evaluation, a known RF current is driven on the cable shield and the voltage developed along the inside of the shield is measured. Electrical bonding levels of shield terminations and connector assemblies are included in the overall measured value.

Bonding meters are normally four point devices which determine the resistance of a bond by driving a known current between two probes and then measuring the voltage drop across the bond with two other probes. Large applied voltages and currents can influence the measurement by burning through contamination that might be on bonding surfaces. It is better to use lower voltage and current devices to determine the value of a bond.

Torque requirements on bolts and screws plays a role in the effectiveness and life-cycle durability of a bond.

Bonding measurements often require that a protective finish be penetrated with electrical probes to obtain good electrical contact. Care should be taken so that a corrosion problem is not introduced.

For lightning protection, metallic structural members (aluminum, steel, titanium, and so forth) provide the best opportunity to achieve an electrical bond on the order of 2.5 milliohms. A bond of this level will limit the induced voltage on system cabling to 500 volts from lightning strike attachments (200 kA) to system structure.

Overpainting of structure for corrosion control prior to ensuring an electrical bond has been documented as the leading cause of poor or ineffective bonds.

P-static testing has found open bonds such as antenna mounting provisions which are electrically isolated from system structure.

A.5.11.1 Power current return path.

For systems using structure for power return currents, bonding provisions shall be provided for current return paths for the electrical power sources such that the total voltage drops between the point of regulation for the power system and the electrical loads are within the tolerances of the applicable power quality standard. Compliance shall be verified by test or analysis of electrical current paths, electrical current levels, and bonding impedance control levels.

Requirement Rationale (A.5.11.1):
It is essential that system electrical and electronic equipment be provided with adequate voltage levels from prime power sources for proper operation. Electrical fault conditions must not introduce potential fuel or fire hazards due to arcing or sparking from melted or vaporized structural material.

Requirement Guidance (A.5.11.1):
Power quality standards, such as MIL-STD-704 for aircraft and MIL-STD-1399-300-1 for ships, control the supply voltage for utilization equipment within specified limits. The voltage is maintained at a monitoring location termed the “point of regulation” with allowances for voltage drops beyond this point to the input of the utilization equipment. These drops must be controlled through wire conductor type and size selection and current return path design. Most aircraft use structure as the return path for power currents. Bonding provisions must be incorporated to control the impedance of this path. Space vehicle power systems generally prohibit the use of structure as power return and should use the requirements of SMC-S-008 and AIAA-S-121 as guidance.

Requirement Lessons Learned (A.5.11.1):
Maintaining required voltage levels on metallic aircraft at utilization equipment has not been a problem since the current return paths have low impedance. With increasing use of composites, the need for separate wire returns or implementation of a ground plane becomes a consideration.

Verification Rationale (A.5.11.1):
Voltage drops present in power current return paths must be evaluated to ensure that electrical power utilization equipment receive power in accordance with power quality standards and to ensure that fuel and fire hazards are avoided.

Verification Guidance (A.5.11.1):
On most military aircraft, aircraft structure is used as the current return for electrical power. The controls on bonding between structural members, the resistance of structure, and electrical current levels need to be considered. For aircraft which use wired returns, the resistance of the wire is the primary consideration. The location of the point of regulation for the power system also plays a role.

Verification Lessons Learned (A.5.11.1):
With metallic aircraft, voltage drops through structure are typically very low. Much higher levels are possible with graphite/epoxy structure.

A.5.11.2 Antenna installations.

Antennas shall be bonded to obtain required antenna patterns and meet the performance requirements for the antenna. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

Requirement Rationale (A.5.11.2):

Good electrical bonding is a key element of successful antenna installation. Poor bonding can result in changes to the desired antenna patterns and degradation of the effective apertures.

Communications antennas such as blade antennas, often become attachment points for lightning. Without proper bonding, lightning can produce voltages which can severely damage antenna-connected equipment.

Antennas are being connected to composite structures via metallic mesh. This “pseudo ground plane” must be capable of conducting lightning induced currents.

Requirement Guidance (A.5.11.2):

Bonding provisions required to attain adequate antenna patterns and required antenna gains are system dependent. Typically, counterpoises or ground planes associated with antennas are designed to provide negligible impedance at the operating frequencies of the equipment. Additionally, antenna designs that require a low resistance RF path for efficient operation should have a low impedance path of minimum length to the appropriate metallic portion of the antenna.

Requirement Lessons Learned (A.5.11.2):

Poor bonding of antennas has resulted in degraded operations of communications and navigation equipment. P-static generation at the antenna base has significantly degraded equipment performance for VHF receivers. Additionally, severe lightning damage has occurred on blade antennas with a poor ground plane, specifically, on composite panels. Damage has been severe enough as to require replacement of the antenna and the entire panel.

Verification Rationale (A.5.11.2):

Verification of bonding for antennas is necessary to ensure that adequate antenna patterns and gains are achieved while providing sufficient low impedance paths for currents induced by p-static, RF, and lightning sources.

Verification Guidance (A.5.11.2):

Verification of bonding measures for antennas is achieved by demonstrating there is a low impedance path between the conducting portions of the antenna and the counterpoise or ground plane. Antenna patterns and gains can be verified in anechoic chambers or in an RF quiet environment.

Verification Lessons Learned (A.5.11.2):
The adequacy of antenna bonds can be evaluated through antenna pattern measurements, DC resistance measurements, and inspection. AC measurements are desired; however, they require more sophisticated measurement equipment and procedures.

A.5.11.3 Mechanical interfaces.

The system electrical bonding shall provide electrical continuity across external mechanical interfaces on electrical and electronic equipment, both within the equipment and between the equipment and other system elements, for control of E3 such that the system operational performance requirements are met. For instances where specific controls have not been established for a system and approved by the procuring activity, the following direct current (DC) bonding levels shall apply throughout the life of the system.

a. *10 milliohms or less from the equipment enclosure to system structure, including the cumulative effect of all faying surface interfaces.*

b. *15 milliohms or less from cable shields to the equipment enclosure, including the cumulative effect of all connector and accessory interfaces.*

c. *2.5 milliohms across other individual faying surfaces within the equipment, such as between subassemblies or sections.*

Compliance shall be verified by test, analysis, inspections, or a combination thereof.

Requirement Rationale (A.5.11.3):
Mechanical bonding (formerly designated Class R “Radio Frequency” in MIL-B-5087) is necessary to avoid coupling of interference signals present in the system to subsystems. These interference signals may be generated by other subsystems, the external EME, lightning, p-static, power system ground currents, and so forth. The interference signals from subsystems are usually RF noise on power and control circuits that are seen on subsystem grounds. With a low resistance between a subsystem and the rest of the system, potential differences can be controlled to low values.

Requirement Guidance (A.5.11.3):
There is a general requirement for all systems to address and implement bonding measures, without specific control levels being stated. An important issue is that bonding be “under control” and at “known levels.” Bonding must not be haphazard or erratic. Repeatability of performance from system to system and over time is critical. Specific control levels are the responsibility of the developing activity to propose and obtain procuring activity approval.

There are bonding levels provided in the requirement where specific alternative controls have not been developed for a platform. The levels are specified to take several items into consideration. They involve the entire interface between equipment enclosure and system hardware as a whole, without addressing each individual mechanical interface. Both system integrator provisions (such as electrical harnesses, equipment mounting racks, and surface/material treatments) and equipment manufacturer provisions (such as connector installation and surface/material treatments) are included. The values take into account that several faying surface interfaces are often included. For example, the cable shield termination requirement will often include the following interfaces: shield to backshell, backshell to connector shell, mating between connector shells, and connector shell to enclosure. Also, the levels are specified as a requirement "at the end of life," which addresses the life cycle aspects of this standard. In general, lower values than those specified will be required during manufacturing to account for degradation over time. The expected degradation over time must be understood.

There will be instances where the 10 milliohm value from equipment enclosure to system structure may not be adequate. Army aviation has experienced an issue on board rotary wing aircraft when a particular bond exceeded 8 milliohms. This example emphasizes that it is best to review individual situations to determine actual bonding requirements based on the equipment involved and the environments being encountered.

The 15 milliohm bonding requirement from cable shields to the enclosure is an important element of the overall transfer impedance performance of a shielded cable. The transfer impedance is the relationship of a common mode voltage developed within the shield that is impressed on interface circuits relative to currents flowing on the shield. Ideally the connector assembly transfer impedance should be low enough that the transfer impedance of the entire cable shield is the dominant factor in the overall transfer impedance of the entire shield and terminating connector assemblies.

Poor mechanical bonding on ships has resulted in the "rusty bolt" effect where intermodulation products are generated by non-linear effects of the improper bonds. See discussion in A.5.2.1 for additional information.

Requirement Lessons Learned (A.5.11.3):

Most EMC handbooks contain information on various techniques to obtain a successful mechanical "Class R" bond. Specific techniques are not required in this standard to allow a more flexible implementation of bonding. The use of 2.5 milliohms in the past has precluded many EMI problems. On one aircraft, the rudder was found to shake while being subjected to the external environment. The problem was determined to be that the aileron rudder interconnect subsystem was not mechanically bonded. Once bonded, the rudder was stable.

Measurements during several years of Navy ASEMICAP tests have revealed equipment bonding measurements that do not always meet the 2.5 milliohm requirement. Extensive E3 tests afterwards generally have not connected any EMI problems with the degraded bonding. This extensive data base has supported the concept that it is possible under some conditions to exceed 2.5 milliohms and still have adequate E3 control.

Bonding requirements in the past have largely focused on bonding between an equipment enclosure and system structure. In many cases, it has been recognized that bonding of cable shields is more critical to performance than enclosure bonding. There are even cases where it is desirable to isolate an enclosure from structure, such as to prevent large lightning currents from flowing along a particular cable harness. For these cases, it is essential to ensure that the electronics and filtering in the enclosure are configured such that the lack of a bond will not be detrimental.

Verification Rationale (A.5.11.3):
Testing is required to actually measure a low impedance bond. Inspection of drawings and processes can ensure that bonding provisions are properly implemented. Analysis of the role of bonding in providing overall E3 protection is necessary.

Verification Guidance (A.5.11.3):
The first step in verification is to review the bonding implementation to determine the amount of resistance required from the equipment enclosure to the system ground reference. Next an analysis is made of the points where the measurement can be made. Based on the measurement points, the resistance between the two points is calculated using the total of the mechanical bonds in the path. When actually performing the measurement, first visually inspect the bonds to verify their presence and proper construction. Then, remove all other connections to the equipment to ensure that only the mechanical bonding is being measured and not the equipment safety ground or other grounding provisions.

Verification Lessons Learned (A.5.11.3):
Bonding meters that use high voltage and current which may arc or burn through contamination in junctions thus giving optimistic readings should be avoided.

When bonding was accomplished as outlined above with the calculation of the total resistance across a number of faying surfaces, a common problem has been avoided of over-designing the bonding. Measurements can be made using a common point on the system for one probe, thereby simplifying the test.

A.5.11.4 Shock, fault, and ignitable vapor protection.

Bonding of all electrically conductive items subject to electrical fault currents shall be provided to control shock hazard voltages and allow proper operation of circuit protection devices. For interfaces located in fuel or other flammable vapor areas, bonding shall be adequate to prevent ignition from flow of fault currents. Compliance shall be verified by test, analysis, or a combination thereof.

Requirement Rationale (A.5.11.4):
Personnel must be protected from hazardous voltages. For circuit protection devices to work properly, bonding must be adequate to allow sufficient fault current flow to trip the devices in a timely manner. Flow of electrical fault currents across poorly bonded interfaces can cause arcing, sparking and hot spots due to heating of materials that may result in ignition of flammable vapors.

Requirement Guidance (A.5.11.4):
Voltages on conductive surfaces can result from sources such as broken components in assemblies allowing “hot” wiring to contact the housing or from electrically referencing a circuit to the housing (such as capacitive filtering). The requirement addresses any electrically conductive portion of the system which can become “hot” from contact with higher voltage wiring. It is not limited to electrical and electronic housings. MIL-HDBK-454, Guideline 1, suggests protection from voltages in excess of 30 volts rms and DC.

Requirements to prevent ignition of flammable vapors need to consider any paths where significant fault currents may flow. Most prominent are fault paths associated with electrical devices that receive prime electrical power for operation, such as fuel pumps or valves. Considerations should address issues such as available fault currents, structural materials used, areas always immersed in fuel, surface finishes (both bonding areas and exposed surfaces), sealants, and types of debris potentially present.

Past studies on electrical bonding for fault currents in flammable vapor areas have determined that bonding requirements are related to a particular voltage appearing across the interface under fault conditions. Since the developed voltage is directly proportional to the fault current for a fixed resistance, required bonding levels vary dependent on the available fault current. An ignition threshold was found to be 0.37 volts for an aluminum safety wire with a point contact in parallel with the intended bonding path. A safety factor of five has been used to account for degradation over time and variability in testing with 0.074 volt bonding criteria resulting. Under this approach, the available fault current for a circuit is first calculated by dividing the source voltage by the wiring resistance in the circuit. For example, using a 115 volt, 400 Hz, source and 200 milliohms of wiring resistance, the available fault current is 575 amperes. The required bonding resistance is determined by dividing 0.074 volts by 575 amperes with a result of 0.13 milliohms. Bonding levels specified in SAE ARP1870 for fault currents are based on the study results. Other work found that less severe bonding levels were appropriate for safety wire made of stainless steel rather than aluminum.

Flammable vapors can be ignited through electrical arcs, sparks (hot particles and voltage breakdown), and thermal hot spots. As an example of an ignition threshold, JP-5 fuel vapors can be ignited by thermal hot spots at 245 degrees Centigrade.

Requirement Lessons Learned (A.5.11.4):
Powerline filtering arrangements in electronics which isolate the powerline neutral from chassis can result in hazardous voltages on the enclosure if the frame ground is disconnected. Typically, filters will be present on both the high side and the return which will have capacitance to the chassis. If the chassis is floating with respect to earth ground, the capacitors act as a voltage divider for AC waveforms with half the AC voltage present on the case with respect to earth. The value of the capacitors determines the amount of current that may flow.

For circuit protection to work quickly and effectively, fault currents well in excess of the rating of the circuit are necessary. For example, a circuit breaker can take tens of seconds to interrupt a circuit at a current twice its rating.

Verification Rationale (A.5.11.4):
Some testing will probably be necessary to evaluate bonds. Analysis will be necessary to determine where potentially hazardous voltages exist and to assess fault conditions.

Verification Guidance (A.5.11.4):
System elements where potentially hazardous voltages may appear need to be identified. Fault current paths and associated electrical bonding provisions need to be assessed for adequacy. A traditional control level for shock hazard protection contained in MIL-B-5087 and MIL-STD-1310 was 0.1 ohms. This level is somewhat arbitrary but it may be a suitable control for some applications.

Verification Lessons Learned (A.5.11.4):
The level of bonding necessary to meet this requirement will normally require that four point bonding meters discussed in A.5.11 be used for measurements.

A.5.12 External grounds.

The system and associated subsystems shall provide external grounding provisions to control electrical current flow and static charging for protection of personnel from shock, prevention of inadvertent ignition of ordnance, fuel and flammable vapors, and protection of hardware from damage. Compliance shall be verified by test, analysis, inspections, or a combination thereof.

Requirement Rationale (A.5.12):
External grounds are necessary to provide fault current paths for protection of personnel from shock hazards and to dissipate static electricity for prevention of hazards to personnel, flammable vapors, ordnance and electronic hardware.

All telecommunications and electronic facilities are inherently referenced to earth by capacitive coupling, accidental contact, and intentional connections. Therefore, “ground” must be looked at from a total system viewpoint, with various subsystems comprising the total facility ground system. The facility ground system forms a direct path of known low impedance between earth and the various power, communications, and other equipment that effectively extends in approximation of ground reference throughout the facility. The facility ground system is composed of an earth electrode subsystem, lightning protection subsystem, fault protection subsystem, and signal reference subsystem.

For safety reasons, both the MIL-STD-188-124 and the National Electrical Code in NFPA 70 require that electrical power systems and equipment be intentionally grounded. Therefore, the facility ground system is directly influenced by the proper installation and maintenance of the power distribution systems. The intentional grounding of electrical power systems minimizes the magnitude and duration of overvoltages on an electrical circuit, thereby reducing the probability of personnel injury, insulation failure, or fire and consequent system, equipment, or building damage.

Requirement Guidance (A.5.12):
Many portions of a system require a grounding scheme to ensure that a suitable current path is available for sufficient currents to flow in the event of an electrical fault to trip circuit protection devices. All electrically conductive surfaces with which personnel may come in contact need to be bonded to the ground reference to prevent hazardous voltages from appearing on the surfaces during faults and to provide a path for the resultant fault currents to trip the protection devices.

Grounding provisions are often necessary under certain operations to provide a current path to prevent static electricity charges from accumulating, such as during ordnance handling, refueling or other flammable vapor operations, and maintenance actions on sensitive electronics.

Grounding provisions are usually required for munitions that are stored in bunkers while in containers, or when exposed to the elements to reduce static charge buildup during handling. These include munitions-to-container, container-to-ground, and munitions (not in containers)-to-ground.

General Tactical Ground Shelter Grounding Guidance:

The facility ground system connects any metallic element of the associated subsystems to earth by way of an earth-electrode configuration. It establishes a reference potential common to any equipment or subsystem and makes the ground potential available throughout the system. In general, four subsystems comprise the facility ground system and should be addressed during the design and installation of any electrical and electronic equipment, subsystem, and system. Although, it is not possible to have a fixed set of rules governing the grounding of all conceivable electrical or electronic equipment or system configurations, the guidelines presented here should be adapted to the requirement of a particular tactical installation. More detailed guidance is provided in MIL-STD-188-124 and MIL-HDBK-419.

It is important that serious consideration be given to grounding implementation. Proper grounding can have a significant impact on the ability to maintain operations under adverse conditions. This section contains grounding requirements for tactical deployments of mobile equipment. Grounding methods set forth are based not only on implementation considerations but also on complying with specific measured resistance requirements. The tactical deployments of mobile equipment are considered to be of four types: stand-alone equipment, stand-alone shelters, collocated equipment and collocated shelters.

A stand-alone shelter is comprised of equipment housed in a mobile metallic shelter and, typically, is not situated close enough to other equipment to merit construction of a common extensive earth electrode subsystem between its interfacing systems. Power supplied to the shelter may come from a power generator or a commercial source. Interfacing with the shelter may be through the power cable. The need for grounding stand-alone shelters is to provide a ground for: 1) the fault protection subsystem, 2) “bleeding off” static charges or EMI from interfacing signal cables, 3) the signal reference subsystem, and 4) the lightning protection subsystem.

Collocated mobile equipment are equipment operating individually but hosted together within a single transportable enclosure, such as a tarpaulin. Typically, these equipment are not rack mounted and may be situated on the earth. Intra-enclosure communication links may exist among equipment, but normally links are established between equipment and an external system. Basic operational characteristics of collocated equipment are similar to stand-alone equipment. Grounding requirements are primarily for personnel safety from lightning and power faults.

Collocated shelters are transportable metallic shelters that share common signal or power cables and are classified in two general categories; those located within 8 meters (26.5 feet) of one another, and those located greater than 8 meters from one another. Collocated shelter configurations are typically of an equipment system that must be housed in multiple shelters. Grounding requirements for collocated shelters are required to provide personnel and equipment protection from the effects of lightning and power faults and to provide a reference for signal grounds. Particular consideration must be given to collocated shelters receiving power from the same power source or communicating over inter-shelter signal cables. The need to establish an all-encompassing shelter grounding system for collocated shelters situated more than eight meters apart should be a function of ground resistance measurements taken at each shelter site. The ground system of each shelter should be interconnected as shown in MIL-HDBK-419. If noise or other undesirable effects are produced as a result of higher ground resistance differences, the system having the higher resistance can be reduced by use of chemical treatment or enhancement per MIL-HDBK-419.

Fixed prefabricated shelters are generally designed having the major components prefabricated and then assembled on-site into a fixed shelter which can be considered as a fixed facility. As such, it should have its own earth electrode subsystem (ring ground). It should also have a lightning protection subsystem meeting the requirements of MIL-HDBK-419, whenever the shelter is located outside the cone of protection of a higher grounded tower. The shell of metallic prefabricated shelters should be constructed to be electrically continuous and should be grounded to the earth electrode subsystem to bleed off static charges and reduce the effects of interference to C-E equipment and circuits. If metallic and electrically continuous, the skin of a fixed prefabricated shelter may serve as the equipotential plane. If the skin is not metallic or electrically continuous, a separate equipotential plane will be required.

At space vehicle launch systems and facilities, the launch vehicle should be earth grounded at the launch site. It is important that ground loops be controlled for electrical interfaces between launch vehicles and space vehicles to prevent problems.

Requirement Lessons Learned (A.5.12):
Ignition of ordnance and fuel vapors and damage to electronics have all occurred from static discharges.

Verification Rationale (A.5.12):
To ensure safety, proper use and installation of external grounds for the system must be verified.

Verification Guidance (A.5.12):
Inspection is appropriate for verification that external grounding provisions have been implemented.

Verification Lessons Learned (A.5.12):
Installation practices should be reviewed to ensure that corrosion protection is included.

A.5.12.1 Aircraft grounding jacks.

Grounding jacks shall be attached to the system to permit connection of grounding cables for fueling, stores management, servicing, maintenance operations and while parked. ISO 46 contains requirements for interface compatibility. Grounding jacks shall be attached to the system ground reference so that the resistance between the mating plug and the system ground reference does not exceed 1.0 ohm DC. The following grounding jacks are required:

a. *Fuel nozzle ground. A ground jack shall be installed at each fuel inlet. To satisfy international agreements for interfacing with refueling hardware, the jack shall be located within 1.0 meter of the center of the fuel inlet for fuel nozzle grounding.*

b. *Servicing grounds. Ground jacks shall be installed at locations convenient for servicing and maintenance.*

c. *Weapon grounds. Grounding jacks shall be installed at locations convenient for use in handling of weapons or other explosive devices.*

Compliance shall be verified by test and inspections.

Requirement Rationale (A.5.12.1):

Grounding between air vehicles and servicing equipment is essential to prevent safety hazards from electrostatic charging effects. The grounding provisions provide paths for equalization of voltage potentials between various points. Grounding jacks must be located at a sufficient number of locations to provide ease of maintenance and to comply with international agreements.

It is well established that sparks due to voltage potential differences between aircraft and servicing equipment can be sufficient to ignite fuel vapors. The motion of fuel during refueling operations is a large contributor to static charging. There is also a concern to prevent electrostatic discharge during ordnance handling. EIDs used in ordnance are potentially susceptible to inadvertent ignition from static discharge.

Electrical resistance between the grounding jack and vehicle structure must be controlled to ensure that an adequate connection is present to dissipate static charge.

Requirement Guidance (A.5.12.1):

Relatively poor electrical connections (much greater than the specified one ohm) are adequate to dissipate static charge. However, controls must be imposed which indicate that a reasonable metal-to-metal connection is present. Allowing values greater than 1.0 ohm could result in questionable or erratic connections being considered adequate.

Technical Order 00-25-172 provides requirements for grounding of Air Force aircraft during servicing. MIL-HDBK-274 provides information for naval aircraft operations and maintenance personnel to ensure that aircraft are properly and safely electrically grounded for both static and power.

Connection between the aircraft and servicing equipment in the presence of potentially hazardous materials is necessary to prevent potential problems due to electrostatic discharges between servicing equipment hardware and aircraft structure.

International agreements require common interfaces for aircraft static grounding. ISO 46 provides the physical description of grounding jack provisions to ensure interface compatibility. MIL-DTL-83413 specifies hardware for aircraft static grounding.

Requirement Lessons Learned (A.5.12.1):

Aircraft fuel fires have been attributed to electrostatic discharge. Precisely demonstrating that an electrostatic discharge caused a mishap is usually not possible due to difficulty in reproducing conditions that were present.

Grounding jacks on aircraft in the field have been found to be electrically open-circuited with respect to the aircraft structure due to corrosion. It is important that corrosion control measures be implemented at the time of installation.

Verification Rationale (A.5.12.1):
To ensure safety, compliance with provisions for grounding jacks must be verified.

Verification Guidance (A.5.12.1):
Placement of jacks can be verified by test of required distances and inspection. Proper bonding resistance can be verified by test with an ohmmeter.

Verification Lessons Learned (A.5.12.1):
The availability of grounding jacks on modern aircraft has minimized the probability of an explosion during fueling and ordnance handling.

Proper treatment of surfaces should be reviewed to determine if measures have been implemented to ensure that life cycle issues have been addressed such that corrosion will not degrade electrical bonding of the jacks over time.

A.5.12.2 Servicing and maintenance equipment grounds.

Servicing and maintenance equipment shall have a permanently attached grounding wire suitable for connection to earth ground. All servicing equipment that handles or processes flammable fuels, fluids, explosives, oxygen, or other potentially hazardous materials shall have a permanently attached grounding wire for connection to the system. Compliance shall be verified by inspection.

Requirement Rationale (A.5.12.2):
Grounding provisions are required to prevent electrical shocks to personnel and potential arcing in the presence of hazardous materials.

Requirement Guidance (A.5.12.2):
Electrical fault conditions within the servicing and maintenance equipment can cause hazardous voltages to appear on the structure of the equipment. The grounding wire for connection to earth is necessary to allow fault currents to flow and actuate circuit protection devices, thereby removing the hazardous voltage. If an earth ground is always present through the power cord to the equipment, then separate ground provision should not be necessary. The grounding wire for connection to the system prevents voltage differences from developing due to static charging effects, which can cause arcing and potential ignition of flammable vapors. If the servicing connection is designed to provide an electrically conductive path between the system and the servicing equipment, then a separate grounding wire should not be necessary.

Requirement Lessons Learned (A.5.12.2):
Not applicable

Verification Rationale (A.5.12.2):
The implementation of grounding needs to be verified.

Verification Guidance (A.5.12.2):
Inspection of hardware or drawings is adequate to ensure that appropriate grounding provisions are included.

Verification Lessons Learned (A.5.12.2):
Not applicable.

A.5.13 TEMPEST.

National security information shall not be compromised by emanations from classified information processing equipment. Compliance shall be verified by test, analysis, inspections or a combination thereof. (NSTISSAM TEMPEST/1-92 and CNNS Advisory Memorandum TEMPEST 01-02 provide testing methodology for verifying compliance with TEMPEST requirements.)

Requirement Rationale (A.5.13):
Compromising emanations are unintentional intelligence bearing signals, which if intercepted and analyzed, would disclose national security information transmitted, received, handled, or otherwise processed by any classified information processing system. The requirement for TEMPEST is found in DoDD C-5200.19 (classified). For Air Force aircraft, this requirement is generally applied to the communications subsystem only.

Requirement Guidance (A.5.13):
Baseline requirements are contained in NSTISSAM TEMPEST/1-92, NSTISSAM TEMPEST/1-93, NSTISSAM TEMPEST/2-95, CNNS Advisory Memorandum TEMPEST 01-02, and Navy publication IA PUB-5239-31.

The need to apply TEMPEST requirements is determined by the certified TEMPEST technical authority (CTTA). The CTTA considers several vulnerability and threat factors to determine the residual risk to which the information is exposed. The CTTA then determines if countermeasures are required to reduce risk to an acceptable level and identifies the most cost effective approach to achieving imposed TEMPEST requirements.

Points of contact for the military services are as follows:

Air Force: HQ AFCA/TCBA-CTTA, 203 West Losey St, Room 2100, Scott AFB, IL 62225-5222. Telephone: (618) 256-5588. By e-mail: AFCA.CTTA.EMSEC@us.af.mil.

Army: Army TEMPEST Program Manager, 310th Military Intelligence Battalion, IAMG-C-TMP, 4552 Pike Road, Fort George G. Meade, MD 20755. Telephone: (301) 677-4440. By e-mail: 902d310thTEMPEST@mi.army.mil.

(Navy TEMPEST is covered under Information Assurance.)

Navy: Inquiries on the Navy TEMPEST policy may be directed to: https://infosec.navy.mil.

Requirement Lessons Learned (A.5.13):
In some cases, the RE102 limits of MIL-STD-461 are considered an acceptable risk level for TEMPEST control of unintentional radiated electromagnetic emissions.

Additional TEMPEST lessons learned fall into three categories: 1) cases where inadequate requirements were levied on the system; 2) cases where requirements were appropriate, but implementation or procedural errors resulted in potentially compromising emissions; and 3) cases where unnecessarily harsh requirements were levied on the system resulting in questionable expenditure of program funds. The former and latter categories have been judged to be equally inappropriate. The second must be considered as cost and risk trades for the program. To address these three issues, National Policy established the CTTAs to ensure a balance of risk and cost through implementation of a risk management process.

Verification Rationale (A.5.13):
Good EMC design practices can significantly reduce, but not necessarily eliminate, the risk of compromising national security information. Depending upon the environment in which these systems will operate, this risk may be unacceptable. The CTTA should take into account the risk (such as the location, the level being processed, amount being processed, and so forth) and weigh it against the cost prior to accepting TEMPEST compliance by analysis or inspection.

Verification Guidance (A.5.13):
Test guidelines can be found in the documents referenced in the verification requirement.

Verification Lessons Learned (A.5.13):
Due to the nature of TEMPEST testing, lessons learned are often classified. While most programs take TEMPEST into account during the design phase, a large number of discrepancies are still found. Strictly using analysis to verify system performance can be inherently risky. When certification tests have been run on systems, the tests have sometimes revealed that a system did not meet the applicable standards. It is important to note that the CTTA may consider the option of analysis or test certification as a trade-off for possible cost savings versus the risk associated with a specific program.

A.5.14 System radiated emissions.

The system shall control radiated fields necessary to operate with the other co-located systems and to limit threat capability to detect and track the system commensurate with its operational requirements.

A.5.14.1 Emission control (EMCON).

When tactical EMCON conditions are imposed, surface ships, submarines and airborne systems electromagnetic radiated emissions shall not exceed -110 dBm/m2 (5.8 dBµV/m) at one nautical mile or -105 dBm/m2 (10.8 dBµV/m) at one kilometer in any direction from the system over the frequency range of 500 kHz to 40 GHz, when using the resolution bandwidths listed in TABLE XI. Compliance shall be verified by test and inspection.

Requirement Rationale (A.5.14.1):

EMCON generally provides for protection against detection by hostile forces who may monitor the electromagnetic spectrum for any emissions that indicate that presence and operation of military electronics. These “unintentional” emissions may originate from spurious signals, such as local oscillators, being present at antennas or from electromagnetic interference emissions from platform cabling caused by items such as microprocessors.

Operations on Naval ships are frequently conducted in electromagnetic silence which is the most stringent state of EMCON. Other systems located onboard the ship (such as aircraft, tow tractors, fire control radars, and ship communication systems) are not permitted to transmit on any radios, radars, and navigation equipment over the frequency range of 500 kHz to 40 GHz. This operation has resulted in requiring systems that deploy on ships to be capable of controlling emissions from their onboard active transmitters by quickly changing operating mode to receive, standby, or off and to control all other unintentional emissions such that they are undetectable.

After aircraft have been launched from the ship, EMCON is frequently used to avoid detection of the aircraft.

The Air Force considers EMCON to be an aspect of enhancing “low observable” properties of a platform.

Requirement Guidance (A.5.14.1):

The highest state of EMCON used aboard Naval ships is complete RF silence; however, other states of EMCON exist. Based on the activity of possible threats and operational needs for safety and security, normal active emissions are permitted for selected frequency ranges. For instance, if normal UHF communications is authorized, then it could be called EMCON Alpha. Further states are set depending upon which transmitters (frequency ranges) are authorized to be active. Typically, the systems being developed under this standard will be either all on or all in the EMCON mode with no sub-states. Some subsystems are normally in a non-emitting mode and are not controlled by the EMCON function. A system such as the UHF communications is always in receive unless the operator presses the push-to-talk button. Therefore, it is already in a non-emitting mode, and if EMCON Alpha was authorized, the radio could transmit without deactivating the EMCON function. It is important to note the need for complete electromagnetic silence from all aspects of the system. Positively no emissions in excess of the specified level are permitted from antenna-connected sources or from unintentional sources such as cables and equipment.

The Navy is experiencing substantial increase in the number and types of wireless technologies being deployed on ships, subs, and aircraft. In many instances, these technologies are COTS equipment used in interior compartments, and the crews typically want to use the wireless technologies even during radio silence conditions. Platform-level EMCON measurements to date on Navy ships indicate that the EMCON limit can be exceeded by substantial margin, depending on location of the wireless equipment within the platform and other factors such as whether doors or hatches are open or closed. It is recommended that if the EMCON limit due to COTS wireless technology use results in exceeding the EMCON limit, the Program Manager should ensure that a susceptibility assessment is performed to determine the risk to the platform and take appropriate action to mitigate the risk. It is expected that this assessment, at minimum, will take into account the geographic operating region (e.g., near the coast of a metropolitan area, at a pier in a port, or in open water away from sea traffic) and the associated ambient electromagnetic environment.

Requirement Lessons Learned (A.5.14.1):
Radio silence, now called EMCON, was used very effectively during World War II to hide the location of Naval ships from the Japanese. EMCON was used by Naval forces in the Vietnam War and Korean War to deploy aircraft over the forward edge of the battle area. These tactics continue today in modern Naval forces.

Local oscillator emissions must be controlled for a system to meet EMCON requirements.

Verification Rationale (A.5.14.1):
Almost all systems have a variety of apertures that are sources of unintentional radiation. Since many of these apertures are inadvertent, it is only possible to find some emissions by test. Analysis is not reliable.

Verification Guidance (A.5.14.1):
The measurement of the EMCON level is normally conducted in an anechoic chamber at a distance close to the system where normal laboratory equipment can be used to detect the emissions. After several years of EMCON tests by the Naval Air community, the distance commonly used is 10 meters from the system. At this distance the values measured are related to the EMCON limit through the inverse square law of EM propagation. The following equation is used:

$$P_d = \frac{P_t G_t}{4\pi r^2}$$ *Equation A-8*

where:

P_d = Power density (watts/meter^2)
P_t = Power transmitted (watts)
G_t = Gain of transmitting antenna
r = Radius from aircraft (meters)

Since the power density is proportional to 1/r^2 with other parameters remaining constant, the limit at 10 meters, assuming far-field conditions are maintained, is calculated by:

$$\text{Limit} = -110\ \text{dBm/m}^2 + 20 \log (1852\ \text{meters per nautical mile}/10\ \text{meters}) = -64.6\ \text{dBm/m}^2.$$

EMCON measurements are made at 4 positions around the system, usually at 45, 135, 225 and 315 degrees from the front. Additional positions are added above, below and around the system based on antennas positions and apertures. The measurement equipment used to detect the emission is a spectrum analyzer augmented with a preamplifier or an EMI receiver with a noise figure capable of having 6 dB or more margin between the noise floor and the derived EMCOM limit. No distinction is made between narrow or broadband signals. Receiver dwell time must be sufficient to capture the peak value of signals whose level varies with time. At each position, an ambient measurement is made with all equipment on the system turned off, followed immediately by a system EMCON measurement. The two measurements are compared to remove emissions common to both. Emissions that remain in the emission measurement are evaluated if they exceed the derived EMCON level. Those emissions that exceed the level undergo further testing and analysis to determine compliance. Issues such as near-field effects and ground reflections need to be considered. On mature systems which are having additional capability added, the ambient measurement can be used to measure the system's active emissions, and the EMCON measurement then detects the new capability in the EMCON mode. Pre-existing emissions from the mature system are removed from evaluation.

The developing activity can show by analysis of extrapolated measurements that the system does not radiate above the EMCON limit. The extrapolated MIL-STD-461E limit (for fixed wing aircraft "external" and helicopter applications) is less than the EMCON limit at all frequencies. For example, the maximum RE102 value of 69 dBμV/m occurs at 18 GHz and is 2 dB below the EMCON limit. Extrapolating 69 dBμV/m to 1 nautical mile (1852 meters), assuming far-field conditions and using the relationship that Pd = E2/377 (where Pd is power density and E is field strength), yields:

$$69\ \text{dB}\mu\text{V/m} - 116\ (\text{dBm/ m}^2)/(\text{dB}\mu\text{V/m}) - 20 \log (1852\ \text{meters}/1\ \text{meter}) = -112\ \text{dBm/m}^2$$

Since this extrapolation uses near-field measurements to determine far-field values, there is some uncertainty concerning actual far-field levels. The far field levels will tend to be higher than those predicted. However, the example uses a worst-case point on the RE102 curve and the technique is considered to be valid for the purposes of the EMCON requirement.

Verification Lessons Learned (A.5.14.1):

For equipment which is required to meet the radiated emission limits of MIL-STD-461, there is assurance that the overall system will comply with the EMCON requirement for any emission contributions from this equipment at most frequencies of interest. When other EMI standards are imposed, analysis is necessary to determine whether the requirements are adequate for EMCON at the system-level.

Naval ship subsystems typically have a standby select switch for powering up the subsystems without deliberately transmitting.

A.5.14.2 Platform radiated emissions.

Unintentional radiated emissions from Army tactical ground vehicles shall be controlled such that antenna-connected receivers located in the operational vicinity of the vehicle are not adversely impacted. Key parameters (such as frequency range, emission limit, ambient conditions) shall be defined by the procuring activity and shall be based upon the expected operational scenarios of the vehicle and the nearby receiver characteristics. Compliance shall be verified by test and analysis.

Requirement Rationale (A.5.14.2):

In the modern net centric battlefield, systems are deployed with different mission equipment packages (MEPs). These MEPs have variations in equipment to include: different communication packages over and above standard VHF and UHF transceivers, GPS receivers and non-communication receiver systems. As such, standard Intra-System EMC addresses only equipment and subsystems associated with the system under consideration and does nothing to address the interactions with other collocated receiver systems in a separate tent, building, on a vehicle or shelter. Examples are when inter-system interference occurs within a convoy of vehicles, or when a vehicle maneuvers or positions around tents, buildings, or shelters. In such cases, vehicles may have collocated antenna-connected systems with different MEPs. One system may exhibit electromagnetic radiation (EMR) characteristics which interfere with the optimal operation of other collocated systems.

Communications, which include antenna systems, are left mounted to the shelter or vehicles to support the mission. Some of these shelters/vehicles are parked as close as a meter from each other. In maneuver elements, tactical vehicles with various MEPs are also grouped to form a forward Tactical Operations Center (TOC) or command post. These elements tend to keep equipment in the vehicle/shelter so they can quickly jump to the next location or get out of harm’s way. Additional concerns are equipment and subsystems that are added in the field based on mission requirements. These subsystems include specialized detection equipment or upgraded communications.

Requirement Guidance (A.5.14.2):
Operational scenarios and mission profiles must be examined to determine the probability of tactical ground vehicles falling in a category that would be collocated near other systems using antenna-connected receivers.

Requirement Lessons Learned (A.5.14.2):
The fundamental issue driving this requirement is the lack of establishing and assessing radiated emissions at the equipment level, which if performed, would have removed the need for additional efforts at the TOC or command post level. As a result, many issues have arisen during the efforts to digitize the battlefield. Communications are more critical as a force multiplier and commanders rely on communications more extensively than ever before. This has come to realization during current conflicts and the integration of complex electronic equipment such as computers, sensors, and electronic engine controls on a vehicle. The integration of these items without establishing and verifying proper equipment radiated emissions levels can produce interference with collocated antenna-connected receivers.

Verification Rationale (A.5.14.2):
Testing and analysis are required to evaluate the potential for unintentional radiated emissions from tactical vehicles affecting antenna-connected receivers associated with collocated systems.

Verification Guidance (A.5.14.2):
Ideally, an inter-system EMC source/victim evaluation, similar to that performed during intra-system EMC on a single platform, should be performed at realistic distances. Because the victim system is not typically available to support inter-system testing, the victim system may be simulated instead. The simulation consists of an antenna system elevated above the ground of the facility floor to a level commensurate with points of interest on the vehicle or the victim system. It should be emphasized that if the victim system is a metal platform, that elevation consists of a metallic ground plane at the level of the top parts of the victim vehicle to which antennas are mounted. Antennas of the same type as used by typical victim systems (such as data radios and mobile satellite systems) are mounted on the elevated level.

These antennas are connected via coaxial transmission lines to EMI receivers, spectrum analyzer or real time spectrum analyzer systems. A preamplifier is usually necessary to improve the noise figure of the spectrum analyzer and obtain adequate sensitivity.

In an effort to improve accuracy and minimize the impacts of the EM environment, such as reflections and ambient interference, an anechoic chamber is often used with an external control room for receiver system. An open area test site that has a sufficiently low EM ambient level with the receiver systems located at some distance from the test setup where the emissions from the test instrumentation will not affect the measurements.

The technique is to monitor antenna-induced signal levels with a spectrum analyzer or a real-time spectrum analyzer which can capture a seamless time record of RF frequencies. For this technique, antennas of the same type that are used on the typical victim systems (such as data radios, networking radios, and mobile satellite systems) are mounted at elevated levels. The received levels can then be easily assessed for potential receiver degradation. This technique has been found to be very effective.

Other techniques such as those used to assess radiated emissions at the equipment level can be employed to obtain field strength data versus frequency and as such, they can be used as risk reduction surveys to obtain insight into possible inter-system issues that can affect the EMC of the TOC. However, these techniques alone cannot be used as the sole verification of this requirement. The performance criteria would be related to sensitivity levels of the receivers of the victim system, similar to measurements under A.5.2.4.

A.5.15 EM spectrum compatibility.

Spectrum-dependent systems shall comply with the DoD, national, and international spectrum regulations for the use of the electromagnetic spectrum (such as National Telecommunications and Information Administration (NTIA) "Manual of Regulations and Procedures for Radio Frequency Management" and DoDI 4650.01). Compliance shall be verified by test, analysis, or a combination thereof, as appropriate for the development stage of the system.

Requirement Rationale (A.5.15):

The availability of adequate spectrum to support military electronic systems and equipment is critical to maximizing mission effectiveness. Spectrum planning and frequency management must be given appropriate and timely consideration during the development, procurement, and deployment of military assets that utilize the electromagnetic spectrum. To ensure maximum compatibility among the various worldwide users of the electromagnetic spectrum, it is essential that spectrum-dependent equipment comply with spectrum usage and management requirements. The DoD's use of the spectrum is constantly being challenged by the commercial sector. It is expected that the military's control of the spectrum will diminish in favor of commercial use. As more and more spectrum is taken away, the available spectrum must be managed as efficiently as possible to ensure the success of all military operations.

Requirement Guidance (A.5.15):

The U.S. national hierarchy for spectrum management was established by the Communication Act of 1934. Under the Communications Act, the Federal Communications Commission (FCC) oversees the U.S. civilian use of the spectrum, and the Department of Commerce, NTIA, oversees the federal Government's use of the spectrum. The Director, NTIA, executes these duties through the Interdepartment Radio Advisory Committee (IRAC), which consists of representatives from Government departments and agencies, including a representative from each military service. The Assistant Secretary of Defense for Networks and Information Integration/Department of Defense Chief Information Officer (ASD(NII)/DoD CIO) oversees spectrum management within the DoD. Additionally, the International Telecommunications Union (ITU) establishes world-wide radio regulations.

Spectrum certification is a legal statute derived from applicable provisions of 47 United States Code (U.S.C.) Sections 305 and Chapter 8, Office of Management and Budget (OMB) Circular No. A-11, 47 CFR Part 300. OMB Circular No. A-11 states the following: "Estimates for the development or procurement of major communications-electronics systems (including all systems employing space satellite techniques) will be submitted only after certification by the National Telecommunications and Information Administration, Department of Commerce, that the radio frequency required for such systems is available." Equipment Spectrum Certification (ESC) denotes the supportability of an electronic system or equipment for operation in a designated frequency band. The DoD ESC process requires that a DD Form 1494, “Application for Frequency Allocation,” be submitted through appropriate Service Frequency Management Office for approval. Instructions are delineated by each service for compliance with ESC regulations. An approved frequency allocation authorizes the development or procurement of spectrum-dependent systems in a defined frequency band or specified frequencies. Without an approved frequency allocation, the program manager does not have the authority to procure spectrum-dependent equipment, including commercial spectrum-dependent items. The program manager is responsible for obtaining an approved frequency allocation for his system. Contractors may support the program manager in acquiring data for describing the item, but the program manager has the responsibility for submitting the frequency allocation application. The various stages applicable for obtaining ESC are defined below:

a. Stage 1 (Conceptual) approval is required for the Pre-Concept phase. A frequency allocation for Stage 1 must be requested (DD Form 1494) and approved prior to the releasing of funds for studies or assembling "proof-of-concept" test beds. The spectrum-dependent system purpose, planned frequency range and power, and any other planned or estimated details that are available on the item must be provided.

b. Stage 2 (Experimental) approval is required prior to contracting for the Concept Exploration and Definition phase. An approved frequency allocation for Stage 2 is required prior to the release of funds for building a radiating test model or obtaining an approved frequency assignment for experimental usage. Estimated and calculated data can be used for nearly all of the blocks on DD Form 1494 when requesting a frequency allocation for Stage 2.

c. Stage 3 (Developmental) approval is required prior to contracting for the Engineering and Manufacturing Development phase. An approved frequency allocation for Stage 3 is required prior to the release of funds for developmental and operational testing. Frequency assignments must likewise be obtained prior to operation of spectrum-dependent equipment. Calculated data is acceptable during Stage 3.

d. Stage 4 (Operational) approval is required prior to contracting for the Production and Deployment phase. Prior to contracting for production units, an approved frequency allocation for Stage 4 is mandatory. Measured data is mandatory for Stage 4. Calculated data is generally unacceptable. Commercial items normally require Stage 4 approval; however, if extensive modifications to the commercial item are planned, then Stage 3 may be appropriate.

Spectrum Supportability Risk Assessment (SSRA).

A Spectrum Supportability Risk Assessment (SSRA) is an assessment performed by program managers (PMs) and materiel developers (MATDEVs) on all programs that are acquiring or incorporating spectrum-dependent systems (SDS). The purpose is to identify and assess an acquisition's potential to affect the required performance of the newly acquired system or platform other existing systems or platforms within the operational electromagnetic environment (EME). The assessment is accomplished with due consideration given to regulatory, technical, and operational spectrum and electromagnetic (EM) environmental effects (E3) issues and assigned risks.

An SSRA is comprised of four primary parts: Regulatory, Technical, Operational, and E3 Risk Assessment. They are defined as follows:

- Regulatory - The Regulatory component of the SSRA addresses the equipment spectrum certification (ESC) with respect to the radio services authorized within the tables of allocations (TOAs) of the U.S. and intended host nations (HNs). The Regulatory component of the SSRA for space systems should also identify International Telecommunications Union (ITU) registrations for other space systems registered in the frequency band being sought for operation. As the system matures, the Regulatory component should contain additional spectrum insights from the ESC and HN coordination (HNC) processes.

- Technical - The Technical component of the SSRA focuses on candidate technologies and available technical parameters, such as system type, platform type, bandwidth requirements, etc., to generate initial quantification of potential mutual interactions. For example, if sufficient data is available, an analysis may determine frequency-distance (F-D) relationships required to preclude EMI based on generic interference-to-noise (I/N) ratios and potential interactions that will require further study. Specific capabilities, such as automatic power control, which may affect the F-D curves, should be included.

- Operational - The Operational component of the SSRA assesses the full complement of SDS anticipated to be in the operational environment. As data or hardware becomes available, analyses should be performed and/or updated to determine if the system meets its operational performance requirements as specified in the JUONS or ONS, or the acquisition documents (e.g.

ICD, CDD, CPD, or ISP). F-D separations and mitigation measures and/or TTPs that may be needed to reduce risks to acceptable levels should also be identified.

- E3 Risk - The E3 Risk component of the SSRA assesses the impact of the operational EME on the platform, system, or equipment being procured. EMI tests and analyses are conducted to ensure mutual electromagnetic compatibility (EMC) and effective E3 control among ground-, air-, maritime, and space-based platforms, electronic and electrical systems, subsystems, and equipment, and with the existing natural and man-made EMEs such as lightning and EMP.

The detail and scope of each SSRA depends upon the system’s entry point into the Defense Acquisition System, the complexity of the system, knowledge of the SDS to be acquired or integrated, and the intended operational EME. SSRAs are to be prepared, updated, and submitted for approval to the appropriate Service review authority, usually the DoD or Service Chief Information Officer (CIO), prior to each acquisition MS and readiness reviews. The level of detail increases as the item's design matures and as more information becomes available. In general, each PM/MATDEV is required to prepare and submit an SSRA when the acquisition includes or incorporates an SDS, including commercial items (CI) and non-developmental items (NDI) that are spectrum dependent, or a platform that includes SDS.

Frequency Assignments.

Prior to operating certified spectrum-dependent systems and equipment, a frequency assignment which authorizes the use of specified frequencies is required. Design requirements for radar systems which are related to spectrum supportability are provided in 5.3, “Radar Spectrum Engineering Criteria,” of the NTIA manual. Analysis techniques addressing spectrum compatibility are found in Air Force document R-3046-AF.

Additional coordination is required for satellite systems pursuant to the NTIA Manual and the International Radio Regulations. Information required for Advanced Publication of a space system must be submitted to the NTIA Spectrum Planning Subcommittee (SPS) via the Military Communications Electronics Board (MCEB) Frequency Panel, Equipment Spectrum Guidance Permanent Working Group (ESG PWG) at the time of the Stage 2 DD Form 1494 submission.

Approval of spectrum supportability in a particular frequency band does not guarantee that the requested frequency(ies) will be available to satisfy the system’s operational spectrum requirements over its life cycle. Frequency assignments must be obtained before the system can operate in training or operational environments. Frequency assignments are issued by designated authorities of sovereign nations, such as telecommunications agencies within foreign countries, and the NTIA for the United States and Possessions. Under certain conditions, other designated authorities, such as DoD Area Frequency Coordinators may grant temporary or limited frequency assignments or the Unified and Specified Commanders may sub-allocate frequency assignments. Procedures for obtaining frequency assignments are delineated in the Services' or Combatant Commands' regulations.

Requirement Lessons Learned (A.5.15):
Currently there are numerous incidences of co-site, intra-ship, and inter-ship interference, as well as interference with the civilian community. For example, the Honolulu Airport air traffic control radars have been degraded by shipboard radars stationed adjacent to Pearl Harbor. A program manager developed a system without requesting spectrum certification. After development, it was discovered that the system had the potential to interfere with other critical systems. Costly EMC testing and operational restrictions resulted, impacting the ability to meet mission requirements. Both items could have been avoided if spectrum management directives had been followed.

A base communications officer funded the purchase of commercially approved equipment. The user was unable to get a frequency assignment because the equipment functioned in a frequency range authorized for only non-Government operation. A second system had to be purchased to satisfy mission requirements. A tactical user bought commercial items as part of a deployable communications package. Because ESC was not acquired and resulting host nation coordination for the use of that equipment was not accomplished, the user found that they were unable to use the equipment in the host European and Asian countries. This problem would have been identified prior to purchase had the proper coordination taken place. The user was unable to meet communication needs and had to buy additional equipment to satisfy requirements.

Verification Rationale (A.5.15):
In accordance with DoD Directive 4650.1, "Policy for Management and Use of the Electromagnetic Spectrum," Jan 9, 2009, program managers are responsible for ensuring compliance of their programs with U.S. and host nation electromagnetic spectrum regulations. Program managers should submit written determinations to the Component Chief Information Officer (CIO) or equivalent that the electromagnetic spectrum necessary to support the operation of the system during its expected life cycle is or will be available in accordance with DoD Instruction 4650.01. These determinations will be the basis for recommendations provided to the MDA by the Component CIO or equivalent. ESC practices must be properly followed including verification of the characteristics of spectrum-dependent systems, subsystems, and equipment to ensure that they are in compliance with spectrum usage requirements.

SSRAs are required to determine and document if adequate spectrum is available to support system operation in DoD, Allied, and Coalition operations and to identify and mitigate potential electromagnetic interference (EMI) problems that might affect system or operational performance.

Verification Guidance (A.5.15):
Frequency allocation requests must include technical information on the operating characteristics of the equipment to assist authorities in determining the disposition of the request. When requesting a frequency assignment, the developing activity should verify that the DoD Frequency Coordinator has approved the request as required. The data required is detailed on the DD Form 1494. The stage of the request determines the level of testing or analysis required. Both MIL-STD-461 and MIL-STD-449 provide guidance for measuring the electromagnetic signal characteristics.

Requirements for the submission of SSRAs during the Defense Acquisition System (DAS) process are established by the following:

- DoDI 5000.02 requires the submission of the SSRA at milestone reviews and prior to requesting authorization to operate (for other than testing) in the U.S, or in host nations (HNs).
- DoDI 4650.01 requires the submission of an SSRA prior to each acquisition milestone and the inclusion of SSRAs in the Information Support Plan (ISP).
- Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 6212.01 requires the submission of SSRAs prior to each acquisition MS and readiness reviews.
- DoDI 8330.01 requires that the risks and issues for information technology and national security systems be included in the Information Support Plan (ISP).

Additional guidance for preparing an SSRA is provided in the “Joint-Services Guide for Development of an SSRA,” (replace with DoD Manual 4650.01 when/if published in time).

Verification Lessons Learned (A.5.15):
Over the past several decades, significant military assets have been forfeited or lost due to failure to address E3 control and spectrum supportability (SS) during the acquisition process. Additionally, many fielded systems operate with limited capabilities and mission constraints due to vulnerabilities that would have been discovered if E3 and SS were addressed early during acquisition as reported in a recent General Accounting Office Report, “GAO-03-617R, Defense Spectrum Management,” that addressed the lack of enforcement of SS requirements during the acquisition process.

CONCLUDING MATERIAL

Custodians:	Preparing Activity:
Army - SY	Air Force - 11
Navy - AS	
Air Force - 11	(Project EMCS-2016-003)

Review Activities:

Army - AC, AM, AR, AT, AV, CE, CR, GL, MD, MI, PT, TE
Navy - CG, EC, MC, OS, SH, YD
Air Force - 13, 19, 22, 84
Other - DS, NS

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database https://assist.dla.mil.