NOT MEASUREMENT
SENSITIVE

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SUPERSEDING
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MILITARY STANDARD

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

ELECTROMAGNETIC EFFECTS REQUIREMENTS FOR SYSTEMS

AMSC: N/A

AREA: EMCS

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

FOREWORD

1. This Military Standard is approved for use within the Department of the Air Force and is available for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: ASD/ENES, Wright-Patterson AFB OH 45433-6503 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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TABLES

1. SCOPE

1.1 Purpose. This standard establishes requirements, verification criteria, and contractor tasks for electromagnetic effects protection of airborne, ground, and support systems. These effects include electromagnetic compatibility, electromagnetic interference, lightning, static electricity, radio frequency compatibility, electromagnetic pulse, electrical bonding, and grounding.

1.2 Application. This standard is applicable for complete systems, both new and modified, and is mandatory for use by the Department of the Air Force.

1.3 Use. This standard is primarily intended for use on airborne platforms. It can, however, with tailoring of specific design requirements and verification approaches be made applicable to any type of system. This document replaces MIL-E-6051 and MIL-B-5087 for Air Force use.

This standard is in two parts, the main body and a handbook portion. The main body of the standard specifies a baseline set of requirements. The handbook portion provides rationale, guidance, and lessons learned for each requirement which allows the procuring activity to effectively tailor the baseline requirements for a particular application.

1.4 Deviation. Deviations from this standard that will improve system performance or reduce development or life cycle costs shall be brought to the attention of the procuring activity. The procuring activity shall be advised when the requirements of this standard result in compromises in operational capabilities.

2. APPLICABLE DOCUMENTS

2.1 Government documents

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 listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto, cited in the solicitation (see 6.2).

STANDARDS

Military

MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-462	Electromagnetic Emissions and Susceptibility, Test Methods for
MIL-STD-1512	Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods
MIL-STD-1757	Lightning Qualification Test Techniques for Aerospace Vehicles and Hardware
MIL-STD-1795	Lightning Protection of AerospaceVehicles and Hardware
DOD-STD-2169	High Altitude Electromagnetic Pulse Environment

(Copies of DOD-STD-2169 may be requested by sending a DD Form 1425 to the Commander, Field Command, Defense Nuclear Agency, ATTN: FCLMC, Kirtland AFB, NM 87115-5000.)

MS25384	Electrostatic Discharge Jumper, Fuel Nozzle-to-aircraft
MS33645	Receptacle, Grounding, Installation of
MS90298	Connector, Receptacle, Electric Grounding

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

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 are those cited in the solicitation.

Air Force Occupational Safety and Health (AFOSH)

AFOSH Standard 127-38	Hydrocarbon Fuels - General
AFOSH Standard 161-9	Exposure to Radio Frequency Radiation

(Copies of AFOSH Standards are available from the Air Force Publications Distribution Center, 2800 Eastern Boulevard, Baltimore, MD 21220; phone (301) 962-7252/AV 723-1463.)

2.2 Order of precedence. 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

3.1 **Bond.** Any fixed union existing between two objects that results in electrical conductivity between the two objects. Such union occurs either from physical contact between conducting surfaces of the objects or from the addition of a firm electrical connection between them.

3.2 **Contractor, associate.** Any contractor subordinate to the prime contractor. Included under this heading are subcontractors, Group B contractors, vendors, and suppliers.

3.3 **Contractor, prime.** The contractor with responsibility for designing, integrating, and producing the overall system. Included under this heading are integrating contractors, airframe contractors, and Group A contractors.

3.4 **Electroexplosive device (EED).** Any electrically initiated explosive device within an electroexplosive subsystem which has an explosive or pyrotechnic output and which is actuated by the first element (initiator) of a pyrotechnic or explosive train.

3.5 **Electroexplosive subsystem.** All components of a subsystem required to actuate, control, and monitor an electrically initiated ordnance/pyrotechnic function.

3.6 **Electromagnetic environment.** The totality of electromagnetic phenomena existing at a given location.

3.7 **Electromagnetic interference (EMI).** Any electromagnetic disturbance, whether intentional or not, which interrupts, obstructs, or otherwise degrades or limits the effective performance of electronic/electrical equipment.

3.8 **Electromagnetic compatibility (EMC).** The capability of electrical and electronic systems, equipments, and devices to operate in their intended electromagnetic environment within a defined margin of safety and at design levels of performance without suffering or causing degradation as a result of electromagnetic interference.

3.9 **Electromagnetic pulse (EMP).** A wide-bandwidth transient electromagnetic field caused by a nuclear event.

3.10 **Grounding.** The bonding of an equipment case, frame, or chassis to an object or vehicle structure to ensure a common potential. The connection of an electric circuit or equipment to earth or to some conducting body of relatively large extent which serves in place of earth.

3.11 **High power microwave (HPM).** An offensive RF weapon designed to upset or damage systems.

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

3.13 **Lightning indirect effects.** Electrical transients induced by lightning in electrical circuits due to coupling of electromagnetic fields.

3.14 **Margins.** The difference between the subsystem/equipment design level and the subsystem/equipment stress level.

3.15 **Radio frequency (RF) compatibility.** The ability of the various antenna-connected RF receiver and transmitter subsystems contained within a system to function properly without performance degradation caused by antenna-to-antenna coupling between any two subsystems.

3.16 **Static electricity.** The stationary electrical charge produced and accumulated or stored on the surface of materials due to tribo-electric action (charge generation by friction, such as airflow, or by adhesive forces during separation), particle impingement, or electromagnetic field inducement.

3.17 **Subsystem/equipment.** Any electrical, electronic, or electromechanical device or collection of items intended to operate as an individual unit and performing a specific set of functions.

3.18 **System.** A composite of equipment, subsystems, skills, and techniques capable of performing or supporting an 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.

3.19 **Tailoring.** Tailoring is the process by which the requirements of a standard are adapted (that is, modified, deleted, or supplemented) to the characteristics or operational requirements of the item under development. The tailoring process does not constitute a waiver or deviation.

4. REQUIREMENTS

4.1 **General.** The system shall be designed to achieve electromagnetic compatibility among all subsystems and equipments within the system and with the external electromagnetic environment.

4.1.1 **System Electromagnetic Effects Program.** The prime contractor shall establish an overall integrated Electromagnetic Effects Program (EMEP) for the system. The program shall be structured to ensure that all the requirements of this standard are treated in a unified fashion resulting in a single integrated design approach. The overall program shall include the necessary design, planning, technical criteria, and management controls needed to achieve overall electromagnetic compatibility and to verify that the design requirements specified herein are met. The program shall be based on the requirements in this standard, the statement of work, system specification, and other applicable contract documents. The prime contractor shall direct each associate contractor to establish the technical effort and necessary management and controls to accomplish their individual parts of the overall EMEP.

4.1.1.1 **Electromagnetic Effects Control Plan.** The details of the EMEP shall be included in the system Electromagnetic Effects Control Plan (EMECP). The control plan shall be prepared and submitted in accordance with the requirements of the contract. The control plan shall be updated during the contract to reflect the evolution of the design (See 6.2).

4.1.1.2 **Electromagnetic Compatibility Advisory Board (EMCAB).** An electromagnetic compatibility advisory board shall be established to monitor the system EMEP, to provide means of expediting solutions of problems, and to establish high-level channels of coordination. The details of operation and proposed charter for the board shall be included in the system EMECP. Members of the board will include the prime contractor, invited associated contractors, and the Government project offices that are involved. The procuring activity may waive this requirement for systems that do not involve a sufficient number of participating organizations to justify such a board.

4.1.2 **Criticality categories.** The prime contractor shall establish the criticality categories for all subsystems/equipments using the following definitions. EMC categories are defined based upon the criticality of the function in the overall performance of the system.

a. Safety Critical (Category I)—EMC problems that could result in loss of life or loss of vehicle.

b. Mission Critical (Category II)—EMC problems that could result in nonfatal injury, damage to vehicle, mission abort or delay, or reduction in system effectiveness that would endanger the success of the mission.

c. Noncritical (Category III)—EMC problems that could result only in annoyance, minor discomfort, or loss of performance that does not reduce desired system effectiveness.

4.1.3 **Margins.** Margins shall be included in the design process to account for variability in system hardware and for uncertainties involved in verification of system-level design requirements. Margins of at least 20 dB for explosive circuits and 6 dB for safety critical systems for aircraft are required .

4.2 **Intra-system electromagnetic compatibility (EMC).** Each subsystem and equipment shall operate without performance degradation during concurrent operation of any combination of the remaining subsystems and equipment, subject to mission requirements.

4.3 **Electromagnetic interference (EMI).** Electromagnetic characteristics of individual electrical/electronic equipments shall be controlled to the extent necessary to ensure electromagnetic compatibility with the system and with the external environments. Specific requirements and test methods for each subsystem/equipment item shall be in accordance with MIL-STD-461 and MIL-STD-462. These requirements shall be tailored with the approval of the procuring activity to meet the specific needs of the system.

4.4 **External RF environment.** The system shall operate without performance degradation due to the electromagnetic environment produced by RF sources not part of and external to the system. The prime contractor shall determine the environment based on intended operational missions and obtain procuring activity approval. The RF environment included in table I is derived from commercial airline missions and shall be used as a baseline for aircraft.

TABLE I. External RF environment.

FREQUENCY (Hz)	ENVIRONMENT (V/m)	
	Peak	Average
10k-100k	50	50
100k-500k	60	60
500k-2M	75	75
2M-30M	200	200
30M-100M	30	30
100M-200M	150	30
200M-400M	70	70
400M-700M	1500	750
700M-1000M	1700	170
1G-2G	5000	1000
2G-4G	6700	850
4G-6G	6850	300
6G-8G	3600	670
8G-12G	3500	1270
12G-18G	3500	360
18G-40G	2100	750

4.5 **Radio frequency (RF) compatibility.** The system shall exhibit RF compatibility among all antenna-connected subsystems and equipment, subject to mission requirements. This requirement is also applicable between like platforms, such as aircraft formation flying, shelter-to-shelter ground systems, etc.

4.6 **Lightning.** The system shall be protected against both the direct and indirect effects of lightning such that the mission can be completed after exposure to the lightning environment. For aircraft, the requirements for protection, the procedures to be used in developing a lightning protection program, and the indirect effects environment for analysis purposes are defined in MIL-STD-1795. The direct effects threat for aircraft is defined in MIL-STD-1757. Facilities and mobile shelters shall include lightning protection provisions/devices to protect the facility and internal equipment against the lightning transients.

4.7 **Electromagnetic pulse (EMP).** The system shall be fully capable of completing its required missions when subjected to the EMP environments described in DOD-STD-2169.

4.8 **Electrostatic charge control.** The system shall control and dissipate the build-up of electrostatic charges to the extent necessary to protect personnel from shock hazards, to avoid fuel ignition hazards, and to prevent performance degradation or damage to electronics.

4.9 **Electrical bonding.** Electrical bonding measures shall be implemented for management of electrical current paths and control of voltage potentials to ensure required system performance and to protect personnel. Bonding provisions shall be compatible with other requirements imposed on the system for corrosion control.

4.9.1 **RF potentials.** All electronic and electrical items which have the capability of producing, radiating, or responding to electromagnetic energy shall be bonded to the ground subsystem with a resistance of 2.5 milliohms (DC) or less for metallic interfaces. For composite materials, bonding shall be accomplished at impedance levels consistent with the materials in use.

4.9.2 **Power current return paths.** Bonding provisions shall be provided for current return paths for the electrical power sources such that 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. For locations prone to fuel or fire hazards, voltage drops across equipment-to-structure interfaces under available fault current conditions shall not exceed 0.074 volts.

4.9.3 **Shock hazard.** To prevent shock hazards to personnel, all exposed electrically conductive items shall be bonded as necessary to limit voltages to less than 30 volts between the item and the ground subsystem.

4.10 **Radiation hazards.** The system shall be designed so that personnel, fuels, and electroexplosive devices (EEDs) are not exposed to unsafe levels of electromagnetic radiation and so that missions can be completed in a safe manner. The prime contractor is responsible for the overall design, planning, management, and demonstration of the system to ensure safety in these areas.

4.10.1 **Personnel hazards.** The system shall be designed so that personnel are not exposed to RF levels exceeding the permissible exposure limits (PELS) of AFOSH Standard 161-9.

4.10.2 **Fuel hazards.** The system shall include provisions such that the fuel hazard criteria of AFOSH Standard 127-38 are met during fuel operations.

4.10.3 **Electroexplosive subsystems.** The system shall protect electroexplosive subsystems from inadvertent operation under all electromagnetic environmental conditions specified in this standard. Electroexplosive devices (EEDs) shall have a minimum no-fire characteristic of 1 ampere/1 watt and shall not initiate when a 500-picofarad capacitor charged to 25 kilovolts (electrostatic discharge) is applied through a 5-kilohm resistor in both pin-to-pin and pin-to-case modes.

4.11 **Life cycle.** The EME protection design shall include full consideration of life-cycle aspects of the protection (e.g., identification of hardening elements and processes, repair, maintenance, integrity verification and inspection requirements). EME protection measures and techniques shall be designed to retain their effectiveness throughout the life of the system and its support subsystems. System protection shall include, but not be limited to, the following life-cycle considerations.

a. Maintenance. Protection designs shall either be accessible and maintainable or shall be designed to survive the design lifetime of the system without mandatory maintenance or inspection. Bonding, shielding, or other protection devices which can be disconnected, unplugged, or otherwise deactivated during maintenance shall be addressed in maintenance documentation, including required actions to restore their effectiveness.

b. Repair. Protection design measures shall be repairable or replaceable without degradation of the initial level of protection.

c. Surveillance. A program shall be established to ensure that the protection measures incorporated in the system design are not degraded with time or use. The system shall be designed such that the electromagnetic design features that require surveillance are accessible and can be tested or inspected as needed.

4.12 External grounds. Grounding jacks shall be installed on aircraft to permit connection of grounding cables for fueling, weapons handling, and other servicing operations. MS90298 or equivalent flush-mounted jacks shall be used and shall be installed to comply with MS33645. A jack is required at each gravity fuel inlet for fuel nozzle grounding. A minimum of two additional jacks for utility and helicopter aircraft and four for other aircraft types shall be provided for general servicing. For aircraft which carry weapons, additional jacks shall be located for convenience in handling ordnance.

4.12.1 Grounding jack installation. The grounding jacks shall be attached to structure so that the resistance between the mating plug and structure shall be no greater than 1.0 ohm (DC).

4.12.2 External grounds for servicing equipment. Each item of servicing equipment and support equipment shall have a grounding wire suitable for connection to an earth ground rod. In addition, all servicing equipment that handles flammables, explosives, oxygen, or other potentially hazardous materials shall have a permanent bonding cable attached for connection to the aircraft. The bonding and grounding cables shall use a plug complying with MS25384 for the connection to the aircraft and an approved fitting for connection to the ground rod.

4.12.3 External grounds for maintenance in repair facilities. Each equipment item, when removed from its primary structure (line replaceable units for aircraft, support equipment, or ground systems) for maintenance shall have provisions for connecting grounding wire between its chassis, transporting fixture, or protective enclosure (packaging) and the facility ground.

5. VERIFICATIONS

5.1 **General.** The prime contractor shall have overall responsibility for verifying that all design requirements of this standard have been met. Specific tasks may be delegated to the associate contractors by the prime as necessary. Verification shall be accomplished by qualification tests, analyses, and inspections, as appropriate, and subject to the approval of the procuring activity.

5.1.1 **Electromagnetic Effects Verification Procedures (EMEVP).** The prime contractor shall prepare an Electromagnetic Effects Verification Procedures (EMEVP) document (See 6.2). The EMEVP shall specify the detailed methodology to be employed for verifying each electromagnetic effects requirement as well as the success criteria for each subsystem and equipment. Procuring activity approval of the EMEVP shall precede the start of qualification testing.

5.1.2 **Electromagnetic Effects Verification Report (EMEVR).** The prime contractor shall prepare an Electromagnetic Effects Verification Report (See 6.2). The EMEVR shall provide documentation demonstrating that each requirement of this standard has been met.

5.1.3 **Margins.** Margins shall be verified for all electromagnetic environmental stresses.

5.2 **Intra-system electromagnetic compatibility (EMC).** The prime contractor shall verify by system-level test supplemented by any necessary analysis that all subsystems and equipment are electromagnetically compatible. The testing shall be performed on a production-configured system. The verification shall include testing and analysis to demonstrate that antenna-connected receivers are not degraded across their entire operating frequency range. For aircraft, sufficient intra-system EMC testing shall be accomplished prior to first flight to ensure that the vehicle is safe to fly.

5.3 **Electromagnetic interference (EMI).** Subsystems and equipment shall be tested using methods which are consistent with the individual imposed design requirement. Compliance with MIL-STD-461 requirements shall be demonstrated using the test methods of MIL-STD-462. EMI testing shall be completed prior to the performance of any formal qualification tests at the system level (intra-system electromagnetic compatibility, external RF environment, lightning, and electromagnetic pulse). Existing subsystem and equipment testing results may be submitted to the procuring activity for consideration of verification applicability.

5.4 **External RF environment.** The electromagnetic compatibility of the system with the external RF environment shall be verified by a combination of system-level and subsystem/equipment-level testing and any necessary analysis. Uniform illumination of the entire system at full threat is preferred. However, other approaches—such as lower level illumination with cable current monitoring together with full threat cable drives—are acceptable, subject to procuring activity approval.

5.5 **RF compatibility.** The overall system RF compatibility shall be verified by system-level test. Antenna-to-antenna coupling analysis and RF equipment-level testing shall be accomplished prior to system-level test.

5.6 **Lightning.** Lightning protection for both direct and indirect effects shall be verified in accordance with MIL-STD-1795.

5.7 **Electromagnetic pulse (EMP).** Compliance with EMP requirements shall be verified by a combination of system-level and subsystem/equipment-level testing and analysis.

5.8 **Electrostatic charge control.** Adequate control of electrostatic charging shall be verified by test, analysis, or inspection as appropriate and as approved by the procuring activity.

5.9 **Electrical bonding.** Compliance with electrical bonding requirements shall be verified by test, analysis, or inspection as appropriate for the particular bonding provision and as approved by the procuring activity. Compatibility with corrosion control techniques shall be verified by demonstration that manufacturing processes which address corrosion control have been implemented.

5.9.1 **RF potentials.** Bonding for RF potentials shall be demonstrated by tests.

5.9.2 **Power current return paths.** Bonding for power current return shall be demonstrated through analysis of electrical current paths, electrical current levels, and bonding impedance control levels.

5.9.3 **Shock hazards.** Bonding for shock hazard shall be verified through test, analysis, and inspection as appropriate for the particular application.

5.10 **Radiation hazard safety.** Safety with regard to RF effects on personnel, fuels operations, and the use of EEDs shall be demonstrated by testing, analysis, and inspection as applicable and as approved by the procuring activity.

5.10.1 **Personnel hazards safety.** Using the methods of measurement and calculation of AFOSH Standard 161-9, the prime contractor shall demonstrate that the system RF emitters will not affect the health and safety of personnel during any phase of the system missions.

5.10.2 **Fuels safety.** The prime contractor shall demonstrate that the system is designed to preclude accidental ignition of fuels due to RF emissions.

5.10.3 **Electroexplosive subsystems.** The prime contractor shall verify the protection of electroexplosive subsystems by demonstrating required margins during system-level evaluations (intra-system electromagnetic compatibility, external RF environments, lightning, and electromagnetic pulse). Compliance of electroexplosive devices with no-fire and electrostatic discharge requirements shall be in accordance with test methods 202 and 205 of MIL-STD-1512, respectively.

5.11 **Life cycle.** System design features implemented for EME protection shall be inspected for compliance with life cycle requirements for maintenance, repair, and surveillance capability. Demonstrations of maintainability, accessibility, and testability and the ability to detect degradations shall be performed. Maintenance and surveillance methodology and tools shall be identified in the EMEVR and appropriate maintenance publications.

5.12 **External grounds for aircraft.** Proper placement and marking of external ground provisions for the system shall be verified by inspection. Compliance with bonding requirements shall be verified by test.

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 electromagnetic effects requirements for systems with emphasis toward aircraft.

6.2 Issue of DODISS. When this standard is used in acquisition, the applicable issue of the DODISS must be cited in the solicitation (see 2.1.1).

6.3 Consideration of data requirements. The following data requirements should be considered when this specification is applied on a contract. The applicable Data Item Descriptions (DID's) should be reviewed in conjunction with the specific acquisition to ensure that only essential data are requested/provided and that the DID's are tailored to reflect the requirements of the specific acquisition. To ensure correct contractual application of the data requirements, a Contract Data Requirements List (DD Form 1423) must be prepared to obtain the data, except where DOD FAR Supplement 27.475-1 exempts the requirement for a DD Form 1423.

Reference Paragraph	DID Number	DID Title	Suggested Tailoring
4.1.1.1			
5.1.1		(See Appendix.)	
5.1.2			

The above DID's were those cleared as of the date of this standard. The current issue of DOD 5010.12-L, Acquisition Management Systems and Data Requirements Control List (AMSDL), must be researched to ensure that only current, cleared DID's are cited on the DD Form 1423.

***6.4* Responsible engineering office.** The office responsible for development and technical maintenance of this specification is ASD/ENACE, Wright-Patterson AFB OH 45433. Requests for additional information or assistance on this specification can be obtained from Jane M. White, ASD/ENACE, Wright-Patterson AFB OH 45433; DSN 785-55078, Commercial (513) 255-55078. Any information obtained relating to Government contracts must be obtained through contracting officers.

6.5 Subject term (key word) listing.

EMC
EMI
EMP
Lightning
RF compatibility
System safety

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HANDBOOK

FOR USE IN TAILORING MIL-STD-1818(USAF)

10. GENERAL

10.1 Scope. This handbook 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 each requirement and adapt them as necessary for a particular application.

10.2 Structure. This handbook follows the same general format as the main body of the standard except that the main heading and paragraphs unique to the handbook are numbered with an extra zero in the first portion of the paragraph identifier (for example: 10.2 rather than 1.2). Section 20 contains all of the information in the main body plus additional items found only in the handbook. In section 30, the wording from the main body of the standard is repeated with its main body paragraph number. The rationale, guidance, and lessons learned paragraphs then follow.

20. APPLICABLE DOCUMENTS

20.1 Government documents

20.1.1 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 issue of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto, cited in the solicitation.

SPECIFICATIONS

Military

MIL-E-4158	Electronic Equipment, Ground; General Requirements, for

STANDARDS

Military

MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-1512	Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods
MIL-STD-1542	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities
MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapon Systems

HANDBOOKS

MIL-HDBK-235	Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment, Subsystems and Systems
MIL-HDBK-237	Electromagnetic Compatibility Management Guide for Platforms, Systems, and Equipment
MIL-HDBK-419	Grounding, Bonding, and Shielding for Electronic Equipments and Facilities

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

20.1.2 Other government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this standard to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

Air Force Systems Command

AFSC DH 1-4	Electromagnetic Compatibility

(Copies of AFSC Design Handbooks are available from ASD/ENES, Wright-Patterson AFB, OH 45433-6503, phone (513) 255-6295/DSN 785-6295.)

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-89/2	Aircraft Lightning Handbook
DOT/FAA/CT-86/40	Aircraft Electromagnetic Compatibility

Military

AFAPL-TR-78-56	Static Electricity Hazards in Aircraft Fuel Systems
AFAPL-TR-78-89	Factors Affecting Electrostatic Hazards
AFWL-TR-85-113	Guidelines for Reducing EMP Induced Stresses in Aircraft

LA-5201-MS	Response of Airborne Electroexplosive Devices to Electromagnetic Radiation (AD 912 599)
TO 00-25-172	Ground Servicing of Aircraft and Static Grounding/Bonding
TO 31Z-10-4	Electromagnetic Radiation Hazards

(FAA publications and military technical reports 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. Air Force Technical Orders are available from Oklahoma City Air Logistics Center (OC-ALC/MMEDT), Tinker AFB, OK 73145-5990.)

20.2 Non-Government publications. The following document(s) form a part of this standard to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted shall be those listed in the issue of the DoDISS specified in the solicitation. The issues of documents which have not been adopted shall be those in effect on the date of the cited DoDISS.

Radio Technical Commission for Aeronautics

DO-160	Environmental Conditions and Test Procedures for Airborne Equipment

(Application for copies of this standard should be addressed to the Radio Technical Commission for Aeronautics, 1425 K Street NW, Washington DC 20005; phone (202) 682-0266.)

National Fire Protection Association

National Fire Codes, Vol. 7

(Application for copies of the Code should be addressed to the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269-9101.)

Society of Automotive Engineers, Inc.

AE4L-87-3	Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning
ARP 1972	Recommended Measurement Practices and Procedures for EMC Testing
ARP 1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP 4242	Electromagnetic Compatibility Control Requirements, Systems

(Application for copies should be addressed to the Society of Automotive Engineers Inc., 400 Commonwealth Drive, Warrendale PA 15096; phone (412) 776-4841.)

30. REQUIREMENTS AND VERIFICATIONS

In this section, each section 4 performance requirement is followed by its associated section 5 verification requirement. This is done to remind the user that the two should be tailored as a pair.

4.1 General. The system shall be designed to achieve electromagnetic compatibility among all subsystems and equipments within the system and with the external electromagnetic environment.

REQUIREMENT RATIONALE (4.1)

Systems today are complex from a materials usage and electronics standpoint. Many materials being used are not metallic and have unique electromagnetic properties which require careful design consideration. Flight critical electronics on aircraft are now common. Wide use of high power RF transmitters, sensitive receivers, other sensors, and additional electronics creates a potential for problems within the system or from external influences. The system must be designed to be compatible with itself, other systems, and the external electromagnetic environment to ensure required performance and to prevent costly redesigns after the fact for resolution of problems.

REQUIREMENT GUIDANCE (4.1)

The system and all associated subsystems/equipment, both airborne and ground, need to be designed 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. Since each system has its own unique requirements and characteristics, general EMC design criteria documents may not be adequate. System and subsystem/equipment control plans should be used to aid in management of programs and to describe requirement interpretation and specific design measures being implemented to meet requirements. The other requirements of this standard address specific aspects of the electromagnetic effects control area. Additional guidance on EMC can be found in MIL-HDBK-237 and SAE ARP 4242.

REQUIREMENT LESSONS LEARNED (4.1)

Electromagnetic effects requirements have been fairly successful in preventing problems on previous programs. Some of the problems which have occurred are discussed in subsequent lessons learned of this standard. Evolving system designs regarding changing materials and increasing criticality of electronics demand that effective electromagnetic effects controls be implemented.

5.1 General. The prime contractor shall have overall responsibility for verifying that all design requirements of this standard have been met. Specific tasks may be delegated to the associate contractors by the prime as necessary. Verification shall be accomplished by qualification tests, analyses, and inspections, as appropriate, and subject to the approval of the procuring activity.

VERIFICATION RATIONALE (5.1)

The prime contractor must be responsible for demonstrating that all requirements are satisfied.

VERIFICATION GUIDANCE (5.1)

Associate contractors would typically be assigned responsibility for demonstrating compliance with items such as electromagnetic interference 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. Testing is usually the most expensive approach;

however, it provides the highest confidence. Some of the requirements included in this standard specify the method to be used. For example, verification of electromagnetic interference requirements must be demonstrated by test. 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. If model confidence is high, testing may then be limited. For example, design of an aircraft for protection against EMP or the indirect effects of lightning has to rely heavily on analysis. The extent of a full-scale EMP or lightning test on the vehicle will depend on the confidence of the model and the criticality of aircraft functions.

VERIFICATION LESSONS LEARNED (5.1)

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

It is essential that the prime contractor provide qualified personnel to monitor associate contractor efforts, particularly in the electromagnetic interference area.

4.1.1 System Electromagnetic Effects Program. The prime contractor shall establish an overall integrated Electromagnetic Effects Program (EMEP) for the system. The program shall be structured to ensure that all the requirements of this standard are treated in a unified fashion resulting in a single integrated design approach. The overall program shall include the necessary design, planning, technical criteria, and management controls needed to achieve overall electromagnetic compatibility and to verify that the design requirements specified herein are met. The program shall be based on the requirements in this specification, the statement of work, system specification, and other applicable contract documents. Each associate contractor involved shall establish the technical effort and necessary management and controls to accomplish their individual parts of the overall EMEP.

REQUIREMENT RATIONALE (4.1.1)

A structured program is required to effectively manage and implement electromagnetic effects protection.

REQUIREMENT GUIDANCE (4.1.1)

Establishment of an overall integrated electromagnetic compatibility program for the system must be the responsibility of the prime contractor. Based on system-level architecture, he must allocate appropriate hardening requirements between system design features and associate contractor supplied subsystems and equipment. He must determine transfer functions from system-level environments to stresses at the subsystem/equipment-level and impose appropriate electromagnetic interference controls. The prime contractor must ensure that associate contractors establish suitable programs within their organizations. AFSC Design Handbook (DH) 1-4 should be used as a general design guide. DOT/FAA/CT-86/40 provides additional guidance based on commercial aircraft experience.

An EME protection program can be organized into five activities:

1. *Establish the external threat environment against which the system is required to demonstrate compliance of immunity.* The external EME environments to which the system should be designed and verified are defined in other paragraphs of this standard. The specific EMP and lightning environments are defined in this standard, while a generic external environment is provided.

The generic external RF environment must be tailored by the contractor for his particular system. The generic environment is based on data base surveys and assessments of known emitters in the U.S., Canada, and Western Europe for associated boundaries of commercial aircraft.

2. *Identify the system electrical/electronic equipments performing functions required for operation during application of the external threat.* The prime contractor must identify each electrical or electronic equipment performing functions in each criticality category. Normally all Category I and II equipments must be protected against all of the external threats.

3. *Establish the internal EME environment for each installed equipment.* All of the external EME environments specified in this standard will result in an internal EME environment imposed upon installed electronic/electrical equipments. This internal environment will be the result of many factors such as structural details, penetration of apertures and seams, and aircraft and cable resonances. The internal EME environment for each threat should be established by analysis/assessment, similarity to previously tested systems, or testing. The internal environment is usually expressed as the level of current stresses appearing at the interface to the equipment or electromagnetic field quantities. These internal stresses are typically associated with standardized requirements (MIL-STD-461) for equipment. The prime contractor needs to trade off the penalties of system or interconnecting wiring protection with those of equipment hardening to establish the most effective requirements for equipment from performance and cost standpoints.

4. *Design the system and equipment protection.* The electrical/electronic equipment is then designed to the internal EME environment determined in the above step. The equipment immunity levels must be above the internal environments by necessary margins accounting for criticality of the equipment and uncertainties in verification. Normally there are design and test requirements in MIL-STD-461/462 applicable for each of the external EME environments, but they may need modification for the particular system application. For example, the external lightning environment may result in internal environments above the transient susceptibility level specified in MIL-STD-461. If so, the prime contractor must tailor the limit for his particular system or reduce the internal environment to an acceptable level.

5. *Verify the protection adequacy.* The system and equipment EME protection design is subject to verification procedures described in the EMEVP. Verification of the adequacy of the protection design should be shown by demonstrating that the actual levels of the internal EME environments appearing at the equipment interfaces and enclosures do not exceed the EME qualification test levels of the equipment for each environment by required margins. All electronic and electrical equipments must have been qualified to their appropriate specification level. Systems-level testing is normally required to minimize the required-margin demonstration. Analysis may be acceptable under some conditions; however, the required margins will typically be larger.

These design and verification activities need to be documented in detail in the EMECP and EMEVP, as applicable.

REQUIREMENT LESSONS LEARNED (4.1.1)

It is important that all electromagnetic environments be treated in a single unified approach. Duplication of efforts in different disciplines have occurred in the past. For example, hardening to electromagnetic pulse and lightning-induced transients have 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 prime integrator facilities which place responsibility in different offices for each of the threats.

4.1.1.1 Electromagnetic Effects Control Plan. The details of the EMECP shall be included in the system Electromagnetic Effects Control Plan (EMECP). The control plan shall be prepared and submitted in accordance with the requirements of the contract. The control plan shall be updated during the contract to reflect the evolution of the design. (See 6.2)

REQUIREMENT RATIONALE (4.1.1.1)

The EMECP is needed to provide design information for protection against electromagnetic effects. The EMECP documentation also provides a means for reaching an agreed approach with the procuring activity and associate contractors for protection measures and controls.

REQUIREMENT GUIDANCE (4.1.1.1)

The EMECP is a contract deliverable document that will have to be updated periodically prior to final system or subsystem delivery. Its essential function is to provide a forum for the contractor to communicate information throughout the contractor's organization as well as to the procuring activity and associate contractors. Details on the required contents of the EMECP should be placed in a Data Item Description (DID). A DID for the EMECP is in preparation; until it is ready, it is recommended that the EMECP be described in the Statement of Work. For further guidance, contact the responsible engineering office (see 6.4). If an EMCAB is established on a program, the official minutes of the EMCAB may serve as a suitable substitute for updates to the EMECP.

REQUIREMENT LESSONS LEARNED (4.1.1.1)

A properly prepared EMECP reduces the likelihood of design surprises that result in incompatibilities. An effective EME design requires close coordination with all affected technologies early in the design phase for reducing potential problems. For example, poor cable installation could result in radiated emissions into the sensitive front end of communications receivers. Wire rerouting of individual cables may then become necessary.

4.1.1.2 Electromagnetic Compatibility Advisory Board (EMCAB). An electromagnetic compatibility advisory board shall be established to monitor the system EMEP, to provide means of expediting solution of problems, and to establish high-level channels of coordination. The details of operation and proposed charter for the board shall be included in the system EMECP. Members of the board will include the prime contractor, invited associated contractors, and the Government project offices that are involved. The procuring activity may waive this requirement for systems that do not involve a sufficient number of participating organizations to justify such a board.

REQUIREMENT RATIONALE (4.1.1.2)

The EMCAB is a useful management tool for establishing communications among all relevant parties involved in the system development. It provides an appropriate forum for raising concerns or problems in the EME area, for allowing discussion among members, and for promulgating proposed solutions.

REQUIREMENT GUIDANCE (4.1.1.2)

The need for an EMCAB is dependent primarily upon the number of parties involved and the complexity of the program. The number of associate contractors with significant influence on system-level EMC must be assessed. Also, the various military services have differing levels of centralization. Some have specialists at many different geographical locations while others are more centralized. Therefore, multi-service programs have a stronger need for an EMCAB. The requirement to establish an EMCAB generally needs to be specified in a Statement of Work type contractual document.

REQUIREMENT LESSONS LEARNED (4.1.1.2)

Experience has shown that co-chairing of the EMCAB by the prime contractor and the procuring activity is effective.

4.1.2 Criticality categories. The prime contractor shall establish the criticality categories for all subsystems/equipments using the following definitions. EMC categories are defined based upon the criticality of the function in the overall performance of the system.

a. Safety Critical (Category I)—EMC problems that could result in loss of life or loss of vehicle.

b. Mission Critical (Category II)—EMC problems that could result in nonfatal injury, damage to vehicle, mission abort or delay, or reduction in system effectiveness that would endanger the success of the mission.

c. Noncritical (Category III)—EMC problems that could result only in annoyance, minor discomfort, or loss of performance that does not reduce desired system effectiveness.

REQUIREMENT RATIONALE (4.1.2)

EMC criticality categories are established based upon the impact of EMI problems with a particular subsystem/equipment on the overall performance of the system. They are necessary to aid in assessing which areas need special emphasis and in determining appropriate hardening and verification requirements.

REQUIREMENT GUIDANCE (4.1.2)

Three categories are defined to assess the impact of EMI problems on system performance. Normally, Category 1 effects are those that impact critical safety functions; Category 2 effects are those that impact mission completion, and Category 3 effects are those that are nuisance items. The criticality categories are usually correlated with definitions established for safety, mission effectiveness assessments, or other purposes. Criticality categories depend on system configuration and mission requirements. Thus, subsystems which are considered Category 1 in one system may fall within Category 2 in another.

REQUIREMENT LESSONS LEARNED (4.1.2)

The EMC criticality categories assist the designer in ensuring that all systems and subsystems are adequately analyzed to determine that item's effect on flight safety for aircraft systems or mission completion. Tailoring of the EMC design can then be accomplished in a more efficient manner and should result in a system that is not overdesigned and overpriced.

5.1.1 Electromagnetic Effects Verification Procedures (EMEVP). The prime contractor shall prepare an Electromagnetic Effects Verification Procedures (EMEVP) document (See 6.2). The EMEVP shall specify the detailed methodology to be employed for verifying each electromagnetic effects requirement as well as the success criteria for each subsystem and equipment. Procuring activity approval of the EMEVP shall precede the start of qualification testing.

VERIFICATION RATIONALE (5.1.1)

These procedures provide a means for the prime contractor to communicate the details of his proposed methodology for verifying his electromagnetic effects protection design to the procuring activity.

VERIFICATION GUIDANCE (5.1.1)

The required content of the procedures is specified in a data item description. A DID for the EMEVP is in preparation; until it is ready, it is recommended that the EMEVP be described in the Statement of Work. For further guidance, contact the responsible engineering office (see 6.4). The procedures are intended to document the complete electromagnetic effects verification program for the system. The structure of the document is at the prime contractor's discretion. A possible approach is to provide a separate volume for each distinct area. However, it is important to emphasize that the intent of this standard is to integrate the overall electromagnetic effects area. Therefore, the prime contractor needs to verify different areas concurrently when possible. For example, protection against electromagnetic pulse and the indirect effects of lightning have much in common and duplication of efforts must be avoided.

Some referenced standards such as MIL-STD-1795 for lightning include separate detailed requirements for procedure documents. These requirements should be integrated with the data requirements of this document.

VERIFICATION LESSONS LEARNED (5.1.1)

Failure to effectively communicate to the procuring activity on how compliance with design requirements will be demonstrated can result in misunderstanding which can affect program success, costs, and schedules.

It is important that the procuring activity approve the procedures prior to the start of verification. The prime contractor can assume a large amount of risk if he pursues verification without approval. Accomplished efforts may need to be repeated.

5.1.2 Electromagnetic Effects Verification Report (EMEVR). The prime contractor shall prepare an Electromagnetic Effects Verification Report (See 6.2). The EMEVR shall provide documentation demonstrating that each requirement of this standard has been met.

VERIFICATION RATIONALE (5.1.2)

This report provides the means for the prime contractor to document that his design complies with the requirements in this standard.

VERIFICATION GUIDANCE (5.1.2)

The report documents the results of the verification efforts described in the EMEVP. The required content of the report is specified in the attached data item description. A DID for the EMEVR is in preparation; until it is ready, it is recommended that the EMEVR be described in the Statement of Work. For further guidance, contact the responsible engineering office (see 6.4).

VERIFICATION LESSONS LEARNED (5.1.2.1)

Not applicable.

4.1.3 Margins. Margins shall be included in the design process to account for variability in system hardware and for uncertainties involved in verification of design requirements. Margins of at least 20 dB for explosive circuits and 6 dB for safety critical systems for aircraft are required .

REQUIREMENT RATIONALE (4.1.3)

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. Safety factors must be included in the design to account for these types of concerns. In addition, uncertainties are present in the verification process due to methods of simulating the EME environments, accuracy of measured data, etc. Design margins address both of these areas and provide confidence that all production systems will survive the actual environment.

REQUIREMENT GUIDANCE (4.1.3)

Margins are generally applicable for all environments external to the system including lightning, EMP, and RF fields. Margins should also be used elsewhere, whenever practical.

The specific value established for the margin for a particular environment is an engineering judgment. If the margin is too large, then penalties in weight and cost will be inflicted on the design. If the margin is too small, then the likelihood of a undesirable system response becomes unacceptably high.

The size of the contribution to the margin from verification uncertainty is inversely proportional to the confidence given to the verification methodology. One method of verifying lightning protection is exposing an actual operational aircraft to a simulated severe lightning encounter (most severe flashes with worst case attachment points). With this method of verification, a relatively small overall margin should be required. Another method of verifying lightning protection is the use of low-level pulsed or continuous-wave 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 approximately 6 dB. Similar margins may be appropriate for pure analysis approaches which produce results which have been shown by previous testing to be consistently conservative for the particular type of aircraft being evaluated.

Another type of verification is utilizing an analysis which has not been previously verified to yield "accurate" results for the aircraft type of interest. The term "previously verified" in this case means that the analysis is based on accepted principles (i.e. EMC and lightning protection handbooks) but the particular aircraft configuration presented for certification has not been previously tested to determine the internal environment (cable responses). For this case, margins as large as 30 dB are not unrealistic. Sometimes a reasonable analysis may show such large margins; therefore, this method may be useful in some limited instances. Additional guidance is contained in proposed MIL-HDBK-XXXX, Nuclear Electromagnetic Pulse Hardness Verification Methods for Aerospace Systems. (For further information on MIL-HDBK-XXXX, contact Phillips Laboratory/WSR, phone (505) 846-0416, DSN 246-0416.)

For most approaches, margins typically fall in the range of 6 to 20 dB.

REQUIREMENT LESSONS LEARNED (4.1.3)

The use of margins for intra-system electromagnetic compatibility requirements among platform subsystems had been specified in early versions of requirements documents; however, these requirements were deleted in later versions 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 the required number of dB to decrease the relative level of the intentional signal to whatever interference is present. There is some controversy in this type of testing since the receiving circuit does not see its normal operating level. Margins for electroexplosive devices have been commonly demonstrated using techniques such as thermocouple sensing of temperature, RF detection, and temperature sensitive waxes.

The experience base for intra-system compatibility is that most problems occur in the areas of degradation of antenna-connected receivers from emissions radiating from interconnecting cables or other antenna-connected subsystems and degradation of subsystem performance due to transmissions from antennas, particularly in the HF, VHF, and UHF communication bands. Margins can be established and effectively evaluated in both of these areas using the techniques described in the appendix under paragraphs 5.2 and 5.4.

5.1.3 Margins. Margins shall be verified for all electromagnetic environmental stresses.

VERIFICATION RATIONALE (5.1.3)

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 GUIDANCE (5.1.3)

Some uncertainties such as system 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 data 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 electromagnetic effects test, the uncertainties are either errors or variations. The errors fall into categories of measurement, extrapolation (simulation), and repeatability. Variations are caused by system orientation with respect to the incident field, polarization of the incident field, and different system configurations (power on/off, refuel, ground alert, etc.). The variation 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. Variations in system hardware are separate from these considerations and must be included. This allowance is called the safety margin.

VERIFICATION LESSONS LEARNED (5.1.3)

An example of margin demonstration used during verification of lightning indirect effects and electromagnetic pulse protection is the demonstration that the current levels induced in system electrical cables by the particular environment is 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-462. Testing can also be performed at the system level. There are some concerns with induced waveforms determined at the system level being different than those used during equipment-level testing. Analysis techniques are available for waveform comparison such as norm attributes. Test techniques are available to inject measured current waveforms into electrical cables at amplified levels during a system-level test.

4.2 Intra-system electromagnetic compatibility (EMC). Each subsystem and equipment shall operate without performance degradation during concurrent operation of any combination of the remaining subsystems and equipment, subject to mission requirements.

REQUIREMENT RATIONALE (4.2)

It is essential within a system that the subsystems/equipment be capable of full performance at all times without degradation from EMI generated by other subsystems/equipment. Otherwise, the overall effectiveness of the system is compromised.

REQUIREMENT GUIDANCE (4.2)

This requirement is the most basic element of EMC concerns. There is little room for modification or relaxation of the requirement. Certain equipment or subsystems may be operated only during particular phases of a mission. If the prime contractor can demonstrate that a set of other equipment and subsystems will never be operated concurrently, then the requirement for intra-system compatibility can be relaxed for that condition.

REQUIREMENT LESSONS LEARNED (4.2)

Considering the complexity of modern systems, there are relatively few intra-system EMC problems found. This result can probably be attributed to successful controls being implemented in system design including hardening, EMI requirements on subsystems/equipment, and good grounding and bonding practices. 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 transmitter 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. Remarkably absent are problems due to cable-to-cable coupling of steady state noise and direct conduction of transient or steady state noise.

5.2 **Intra-system electromagnetic compatibility (EMC)**. The prime contractor shall verify by system-level test supplemented by any necessary analysis that all subsystems and equipment are electromagnetically compatible. The testing shall be performed on a production-configured system. The verification shall include testing and analysis to demonstrate that antenna-connected receivers are not degraded across their entire operating frequency range. For aircraft, sufficient intra-system EMC testing shall be accomplished prior to first flight to ensure that the vehicle is safe to fly.

VERIFICATION RATIONALE (5.2)

Verification of intra-system electromagnetic compatibility through test is the most basic element of demonstrating that electromagnetic effects design efforts have been successful.

VERIFICATION GUIDANCE (5.2)

Testing involves systematic evaluation of potential interference source versus victim pairs. The various subsystems and equipments on-board the system are individually exercised through their various modes and functions while the remaining items are monitored for degradation.

Flight testing of aircraft often begins before a thorough intra-system electromagnetic compatibility test is performed. Also, the aircraft used for initial flight testing are rarely in a production configuration. They typically will contain flight instrumentation and will be lacking some production avionics. It is essential that safety-of-flight (SOF) testing be done to satisfy safety concerns. This testing must include the exercising and evaluation of any aircraft functions that can affect safety.

An issue which needs to be addressed for each application is the use of instrumentation during the test. 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 to monitor signals to assess subsystem performance 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, electroexplosive devices require monitoring for assessment of margins. Some antenna-connected receivers, such as instrument landing systems (ILS) and identification of friend or foe (IFF), normally require a baseline input signal (set at minimum required performance levels) for degradation to be effectively evaluated.

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. It is therefore common practice to monitor all antenna-connected outputs with spectrum analysis equipment during the intra-system electromagnetic compatibility test.

RF compatibility between antenna-connected receivers is an element of intra-system electromagnetic compatibility and demonstration of compliance with that requirement needs to be integrated with these efforts. It is treated separately in this standard due to its importance and need for special attention.

VERIFICATION LESSONS LEARNED (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.

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 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 there is insignificant AM on the clock harmonic, the main result is a quieting of the receiver audio output due to automatic gain control (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. Due to the large number of channels on many receivers (UHF typically has 7000 channels), this technique may often not be practical. An increasingly popular technique is to monitor antenna-induced signal levels with a spectrum analyzer. A preselector is necessary to obtain adequate sensitivity. The received levels can then be easily assessed for potential receiver degradation. This technique has been found to be very effective. Use of a spectrum analyzer is also helpful for RF compatibility assessment.

Other than for electroexplosive devices, margin assessment is practical in several areas. Margins can be assessed for antenna-connected receivers using the spectrum analyzer technique. 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 paragraph 5.4 for external environments.

4.3 Electromagnetic interference (EMI). Electromagnetic characteristics of individual electrical/electronic equipments shall be controlled to the extent necessary to ensure electromagnetic compatibility with the system and with the external environments. Specific requirements for each subsystem/equipment item shall be in accordance with MIL-STD-461 and MIL-STD-462. These requirements shall be tailored with the approval of the procuring activity to meet the specific needs of the system.

REQUIREMENT RATIONALE (4.3)

Electromagnetic interference (emission and susceptibility) characteristics of individual equipments 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 equipments, 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. Also, system configurations are continuously changing as new or upgraded equipment is installed.

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 (4.3)

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 and MIL-STD-462 are tri-service coordinated documents which standardize EMI design and test requirements. These 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 industry standards such as SAE ARP 1972. Unique requirements may also be specified as necessary.

EMI requirements are separated into two areas, interference emissions from the subsystem and susceptibility (sometimes referred to as immunity) to external influences. Both of these areas have conducted and radiated controls. Most emission requirements are frequency domain related and data is 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.

REQUIREMENT LESSONS LEARNED (4.3)

The limits specified in MIL-STD-461 are not rigorously derived levels which, when exceeded, guarantee incompatibilities in the system installation. Past experience has shown that equipment compliance with its subsystem EMI requirements assures a high degree of system-level compatibility. Nonconformance 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 may develop. The limits have a proven record of success demonstrated by the relatively low incidence of problems at the system-level. In general, the limits have been established empirically for a worst-case configuration and environment. Tailoring needs to be considered for the peculiarities of the intended installation. There is usually reluctance to relax requirements since system configurations are constantly changing, and subsystems/equipments 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. In the past, it has been suggested that EMI requirements be generated through computer analysis of the system installation. Installations are usually much too complex to depend on computer modeling to produce reliable limits except perhaps for the case of antenna-to-antenna coupling.

There is often confusion regarding perceived safety 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 RS03 specifies electric fields which subsystems must tolerate. Requirement RE02 specifies allowable electric field emissions from subsystems. RE02 levels are orders of magnitude less than RS03 levels. Safety 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 RE02 and RS03 levels. This type of coupling is a minor concern for RE02. The driving reason for RE02 levels is coupling into sensitive RF receivers through antennas. The front-ends of receivers are typically many orders of magnitude more sensitive than aircraft wire-connected interfaces. Similarly RS03 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 safety margins that can be erroneously inferred from MIL-STD-461 do not exist.

5.3 Electromagnetic interference (EMI). Subsystems and equipment shall be tested using methods which are consistent with the individual imposed design requirement. Compliance with MIL-STD-461 requirements shall be demonstrated using the test methods of MIL-STD-462. EMI testing shall be completed prior to the performance of any formal qualification tests at the system level (intra-system electromagnetic compatibility, external RF environment, lightning, and electromagnetic pulse). Existing subsystem and equipment testing results may be submitted to the procuring activity for consideration of verification applicability.

VERIFICATION RATIONALE (5.3)

Testing is required to demonstrate compliance with electromagnetic interference requirements. Analysis tools are not available which can produce credible results to any acceptable degree of accuracy.

VERIFICATION GUIDANCE (5.3)

MIL-STD-462 provides a test method for each of the radiated and conducted emission and susceptibility requirements in MIL-STD-461.

RTCA DO-160 is the commercial aircraft industry's equivalent of MIL-STD-461 and MIL-STD-462. 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-461/462. Unmodified off-the-shelf equipment usually does not require requalification providing acceptable electromagnetic interference data exists (MIL-STD-461/462, DO-160, or other approved test methods). Some additional laboratory evaluation may be necessary to ensure their suitability.

VERIFICATION LESSONS LEARNED (5.3)

An effort is underway in revising the electromagnetic interference standards to orient testing toward 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 antenna-connected receivers which can be easily degraded if adequate controls are not maintained.

A popular area to impose high-level requirements is radiated susceptibility testing for electric fields (Method RS03 of MIL-STD-462). Laboratory capabilities for this type of test are limited by available test equipment. Levels above 200 V/m are difficult to obtain. Some test houses can obtain higher levels but are usually limited in frequency coverage.

4.4 External RF environment. The system shall operate without performance degradation due to the electromagnetic environment produced by RF sources not part of and external to the system. The prime contractor shall determine the environment based on intended operational missions and obtain procuring activity approval. The RF environment included in table I is derived from commercial airline missions and shall be used as a baseline for aircraft.

REQUIREMENT RATIONALE (4.4)

The threat presented by RF emitters around the world is becoming increasingly more hostile. Documents such as MIL-HDBK-235 list various land-based, ship-based, and airborne emitters. The electromagnetic fields from these emitters which may illuminate systems are very high and can certainly degrade system performance if not properly treated. The increasing use of flight critical avionics in aircraft demands consideration of these threats to ensure safety. The SAE developed the environments of table I as criteria for Federal Aviation Administration certification for commercial aircraft. These environments are quite severe and represent the absolute minimum that military aircraft must meet.

The external RF environment is also commonly referred to as the HIRF (high-intensity radiated fields) environment. This electromagnetic environment exists due to the transmission of electrical energy into free space. This energy is radiated from radar, radio, television, and other sources. These transmitters are ground-based, shipboard, or airborne.

The electromagnetic environment has been modeled using the databases that contain parameters pertaining to all authorized transmitters in the U.S. and other contributing European countries. The resulting HIRF envelope is a representation of electromagnetic field strength over a frequency range of 10 kHz to 40 GHz. This HIRF envelope has been verified by examining the databases for accuracy, and by taking measurements of field strength through flight tests at selected sites.

The FAA will be publishing a HIRF users manual which would be of benefit to anyone designing to this environment. At publication time, that document number was not available.

Assumptions for the calculation of the HIRF environment:

a. Excludes all single transmitters and restricted air space.

b. Main beam illumination by transmitting antenna is assumed.

c. Maximum main beam gain of a transmitter antenna is used.

d. Modulation of a transmitted signal is not considered except that a duty cycle is used to calculate the average power for pulsed transmitters.

e. Constructive ground reflections of high frequency (HF) signals—that is, direct and reflected waves—are assumed to be in phase.

f. Noncumulative field strength is calculated. Simultaneous illumination by more than one antenna is not considered.

g. Near-field corrections for the aperture and phased-array antennas are used.

h. Field strengths are calculated at minimum distances which are dependent on location of the transmitter and aircraft. The minimum distances are defined as follows.

(1) Airport environment (only six U.S. airports used).

(a) 250 feet, slant range, for fixed transmitters beyond a 5-nautical-mile boundary around the runway with the exception of airport surveillance radar and air route surveillance radar. For these two radar types a 500-foot slant range is used.

(b) 500 feet, slant range, for fixed transmitters beyond a 5-nautical-mile boundary around the runway.

(c) 50 feet for mobile emitters, including those on other commercial aircraft, and 150 feet for airborne weather radar.

(2) Air-to-air environment.

(a) 500 feet for noninterceptor aircraft with all transmitters operational.

(b) 100 feet for interceptor aircraft with only nonhostile transmitters operational.

(3) Shipboard environment.

A 2.4% gradient is used for the aircraft flight path, clearing the antenna by 300 feet. The ship is assumed to be 2.5 nautical miles from the end of the runway. Slant range is computed using maximum elevation angle. Where maximum elevation angle is not available, 45 degrees is used.

(4) Ground environments, including airport transmitters, while aircraft is in flight.

Aircraft are assumed to be at a minimum flight altitude of 500 feet and avoiding all obstructions, including transmitters, by 500 feet. Slant range is calculated for the maximum elevation angle for the transmitter antenna. If maximum elevation angle is not available, 90 degrees is assumed.

i. Field strength for each frequency band is the maximum for all transmitters within that band.

j. Peak and average.

(1) Peak field strength is based on the maximum authorized power of the transmitter and maximum antenna gain.

(2) Average field strength is 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. This applies to pulsed systems only. The average power for nonpulsed signals is the same as the peak power (that is, no modulation present).

REQUIREMENT GUIDANCE (4.4)

The electromagnetic environment 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, modulation, frequency, bandwidth, antenna gain, antenna scanning, etc. 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. Despite the severity of the electromagnetic environment, there have been relatively few operational problems. Evaluation of systems with respect to the external EM environment is sometimes referred to as electromagnetic vulnerability assessment.

When defining the external environment, 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. Ground-based systems will have specific environments depending upon their location and these must be defined by the procuring activity. No generic environment is provided for ground-based systems in this standard.

b. Appropriate standoff distance from each emitter. MIL-HDBK-235 typically specifies fields 50 feet from the emitter. Fields at the standoff distance need to be determined.

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 (HPM) and ultrawide band threat.

REQUIREMENT LESSONS LEARNED (4.4)

Without specific requirements and testing, problems caused by the external environment typically are not discovered until the system becomes operational. By the time interference is identified, the system is well into the production phase of the program, and changes will be expensive. In the past, the EM environment generated by the system's RF subsystems (electronic warfare, radars, communications, and navigation) was considered to be the worst-case environment. From a probability of exposure, these items still play a critical role. However, with aircraft flying lower and external transmitter power increasing, this situation is no longer the case.

In the past most aircraft used a series of cables, chains, cranks, and other mechanisms to operate the systems which gave the aircraft its ability to fly. Today many such mechanisms are being replaced or augmented with electronic circuits. These electronics often have full authority for functions such as engine controls, flight controls, and power generation and distribution, without which the aircraft is unable to fly. Electronic circuits may respond not only to their internal electrical signal flow but to any input which can couple into the electrical cables and wires and be conducted to the circuits.

As a further complication, the aircraft skin and structure have also evolved. The classic aircraft is made of aluminum and titanium structure with aluminum skin. Modern technology and the need to develop higher performance aircraft are providing alternatives such as carbon-epoxy structure and carbon-epoxy and kevlar skins. Aluminum is a good shield against the external EME and hence electronic circuits are provided protection; however, some composites are poor shields and provide little attenuation to the external electromagnetic environment.

Some examples of past problems are as follows. 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. Electronic fly-by-wire aircraft have experienced uncommanded flight control movements due to flying near high-power transmitters.

5.4 External RF environment. The electromagnetic compatibility of the system with the external RF environment shall be verified by a combination of system-level and subsystem/equipment-level testing and any necessary analysis. Uniform illumination of the entire system at full threat is preferred. However, other approaches—such as lower level illumination with cable current monitoring together with full threat cable drives—are acceptable, subject to procuring activity approval.

VERIFICATION RATIONALE (5.4)

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

VERIFICATION GUIDANCE (5.4)

Ideally, the entire aircraft 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 aircraft compared to the wavelength of frequency of test. At frequencies where the aircraft is small compared to the wavelength of the illumination frequency, it is necessary to illuminate the entire aircraft to obtain the proper responses. The aircraft is illuminated from a distance to obtain near uniform illumination at test level below the threat and induced levels on selected electrical cables are monitored. The induced levels are then scaled to full threat and compared to electromagnetic interference data. If sufficient data is not available, cables can be driven at required levels on-board the aircraft. The cable drive technique has been applied up to 400 MHz.

At frequencies where the size of the aircraft is large compared to the wavelength, localized (spot) illumination is adequate. This testing needs to be performed at full-threat levels since scaling techniques are not available.

Flight testing of aircraft may occur prior to formal verification of hardness to the external RF environment. The RF emitters that may be encountered during the flight test program must be reviewed and the status of the aircraft with regard to these emitters must be evaluated. Electromagnetic interference testing of subsystems can be used as a baseline of hardness. Limited testing of the flight test aircraft to specific emitters may be necessary or possible restrictions on allowable flight paths.

VERIFICATION LESSONS LEARNED (5.4)

In the frequency range where the system can resonate (typically 1 to 100 MHz), it is desirable to sweep rather than use spot frequencies. If sweeping is not possible then the spot checks should be at small increments. At system resonance, wiring that is approximately equal in length to the system will have the greatest potential of susceptibility. An example would be the flight control system for an aircraft, where cables run the entire length of the aircraft. Because of the lack of tunable high-power transmitters, system-level testing at higher frequencies is usually performed at selected frequencies of interest where there are a large number of emitters or a high effective radiated power (ERP) emitter.

Field problems and test results have shown that the main concern for system degradation, other than antenna-connected receivers, is the frequency range below 400 MHz. The size of typical aircraft and subsystem cables results in the most efficient coupling of RF energy in the HF (2–30 MHz) frequency range. Test data indicates a linear increase in induced levels with 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.

Another way of assessing coupling is to consider the size of a tuned aperture optimized for coupling at any frequency. The size of this aperture is proportional to the wavelength squared. 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 subsystems becomes even less efficient. As an example, the power coupled into a tuned aperture at 10 MHz from 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.

Caution must be exercised with aircraft utilizing flight critical electronic systems to ensure that they are not exposed to threats during flight testing that they have not been demonstrated to be capable of handling.

4.5 Radio frequency (RF) compatibility. The system shall exhibit RF compatibility among all antenna-connected subsystems and equipment, subject to mission requirements. This requirement is also applicable between like platforms, such as aircraft formation flying, shelter-to-shelter ground systems, etc.

REQUIREMENT RATIONALE (4.5)

RF compatibility is an essential element of system performance. Inability of an antenna-connected subsystem to properly receive intentional signals can significantly affect mission effectiveness. Achieving RF compatibility requires careful, strategic planning of the placement and operation of RF transceiver antennas on the system. This planning requires technical knowledge of all the subsystems involved; therefore, an RF compatibility effort must be included in the electromagnetic environmental effects program when a system is procured which includes antenna-connected equipment.

REQUIREMENT GUIDANCE (4.5)

RF compatibility objectives are: (1) to determine the location and operating characteristics of all antenna-connected equipment in the system; (2) to perform the necessary analyses and testing to determine whether the baseline configuration for the system is adequate for RFC; (3) to make appropriate modifications to the wiring, antenna placement, and operating procedures of these subsystems to eliminate RF interference if problems are identified; and (4) to perform followup testing to ensure that a design has been achieved which meets performance requirements.

Evaluations in a systems integration facility may be necessary to assess the performance of emission manager designs and the effectiveness of blanking schemes.

Antenna-to-antenna isolation information needs to be developed early in the program. Analysis tools provide a good starting point for assessment. The available tools produce accuracies of approximately an order of magnitude and tend to predict more problems than are actually present. Assumptions such as maximum power output of the transmitter, maximum sensitivity of receivers, simplification of antenna patterns, and harmonic content of the output account for the conservative prediction. The analysis results need to be supplemented by testing. Measurements should be made, in particular, for those subsystems where analysis predicts a problem. Measurements may be possible between specific antennas on a mockup or an early version of the system. As hardware becomes available, it is desirable to measure isolation in an anechoic chamber.

Further investigation may require a laboratory test of the two subsystems to verify the predicted interference. Some subsystems are less affected by interference than others due to signal processing ability to discriminate between the noise and the desired signal.

After a laboratory integration test has confirmed that an RF compatibility problem does exist, further study and investigation are required. Such techniques as frequency management, blanking/gating, filtering, interference suppression, and improvements in antenna-to-antenna isolation may be helpful in achieving RF compatibility.

REQUIREMENT LESSONS LEARNED (4.5)

An effective software tool for antenna-to-antenna coupling analysis on aircraft available through the Electromagnetic Compatibility Analysis Center is AAPG (Antenna inter-Antenna Propagation with Graphics). AAPG models the aircraft with a combination of cylinders or truncated cylinders and flat plates to estimate isolation as a function of free-space loss and shading by the fuselage and wings. Isolation in conjunction with the other parameters allow a first estimate of interference levels between subsystems. AAPG considers all signals as continuous; the program does not account for the effects of pulsed RF. Also, blanking is not considered in AAPG. Limitations of any analysis program must be considered when using the results to draw conclusions.

A common problem in systems occurs when the system uses both ECM (electronic countermeasures) and radar equipment operating at overlapping frequencies. The following design measures may be helpful to provide RF compatibility between these types of subsystems: notification, pulse tagging, utilization of coherent processing dead time, band slitting, and digital feature extraction.

A relatively new technique to attenuate an interfering signal at a receiver is frequency cancellation. This technique samples the interfering signal separate from the receiver's antenna, performs a phase inversion, and adds the result to the overall received signal. Thus, the interfering signal can be reduced substantially leaving the desired received signal essentially unaffected. The hardware to perform this action is complex and expensive.

5.5 RF compatibility. The overall system RF compatibility shall be verified by system-level test. Antenna-to-antenna coupling analysis and RF equipment-level testing shall be accomplished prior to system-level test.

VERIFICATION RATIONALE (5.5)

Verification of RF compatibility 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 is necessary to assess potential problems and to allow sufficient time for fixing subsystem problems.

VERIFICATION GUIDANCE (5.5)

Although an analysis is an essential part of the early stages of designing or modifying a system, test is the only truly accurate way of knowing that a design is working. An anechoic chamber is usually 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 that are classified.

VERIFICATION LESSONS LEARNED (5.5)

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 top testing should resolve compatibility questions beforehand.

4.6 Lightning. The system shall be protected against both the direct and indirect effects of lightning such that the mission can be completed after exposure to the lightning environment. For aircraft, the requirements for protection, the procedures to be used in developing a lightning protection program, and the indirect effects environment for analysis purposes are defined in MIL-STD-1795. The direct effects threat for aircraft is defined in MIL-STD-1757. Facilities and mobile shelters shall include lightning protection provisions/devices to protect the facility and internal equipment against the lightning transients.

REQUIREMENT RATIONALE (4.6)

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-89/2 is an excellent source of lightning characteristics and design guidance.

An additional reason for requiring protection is potential effects on personnel. Serious electrical shock may be caused by currents and voltages conducted via control cables or wiring leading to the cockpit from control surfaces or other hardware struck by lightning. This effect can be quite hazardous in high performance aircraft, particularly under the thunderstorms conditions during which lightning strikes generally occur.

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. This effect 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 (4.6)

While all airborne systems must 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 carrier aircraft. For personnel transport aircraft, the system must be protected against all lightning effects to prevent the loss of life. On fighter aircraft, complete protection is usually required; however, compromises may be necessary such as whether mission completion is a requirement. MIL-STD-1795 contains additional information on lightning protection.

Direct effects protection on all-metal aircraft has been generally limited to protection of the fuel system, antennas, and radomes, and to control of fuel tank skin thickness. Most of the Air Force 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 attention to details is required. In general, some metal will have to be put back into nonmetallic structures to provide adequate lightning protection.

MIL-STD-1757 provides the lightning environment for direct effects. FAA Advisory Circular AC-20-53 and its users manual provide requirements for protection of aircraft fuel systems.

Indirect effects protection has become much more important due to the increased use of electrical and electronic subsystems in aircraft and the dependence on these subsystems to keep the aircraft flying. Although the crew ejected, an aircraft was lost that went into a hard-over dive approximately two seconds after a strike.

MIL-STD-1795 provides the lightning environment to be used for indirect effects protection. In addition, FAA Advisory Circular AC-20-136, its users manual, and SAE AE4L-87-3 (Orange Book) provide similar requirements and indirect effects protection information. The MIL-STD-1795 and FAA requirements are consistent. (Both are based on work by the SAE.)

Specific protection measures for ground facilities are highly dependent on the types of physical structures and equipment involved. Devices such as lightning rods, arrestors, and ground grid in the pavement, and moisture content of the soil all influence the protection provided. The guidance provided in MIL-E-4158, MIL-STD-1542, MIL-STD-454, and the National Fire Code, Volume 7, address different design approaches to reduce lightning effects on equipment.

REQUIREMENT LESSONS LEARNED (4.6)

A lightning strike to an aircraft is described below. 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 many cases, the aircraft triggers the lightning event.

High peak currents occur after the stepped leader completes the path between charge centers and forms the return stroke. The average current is from 1-30 kA. Higher currents are very common with a peak current of 200 kA being a severe stroke (99th percentile). 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 transfer about 20 C. The second is a continuing current phase in with currents on the order of 200-400 amps flow for 0.1 to 1 second which transfer 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 restrikes is about one half of the initial high current peak.

5.6 Lightning. Lightning protection for both direct and indirect effects shall be verified in accordance with MIL-STD-1795.

VERIFICATION RATIONALE (5.6)

A lightning protection verification program in accordance with MIL-STD-1795 is essential to demonstrate that the design protects the aircraft from lightning threat environment.

VERIFICATION GUIDANCE (5.6)

There is no single approach to verifying the design. A well-structured test program supported by analysis is generally necessary. Section 40.6.1 of MIL-STD-1795 contains information on the elements that are accepted as leading to proof of design. These same elements can be used for other electromagnetic effects areas such as electromagnetic pulse and the external RF environment.

During development of an aircraft 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.

Flight testing of aircraft often occurs prior to verification of the immunity of the vehicle to lightning. 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.

VERIFICATION LESSONS LEARNED (5.6)

The naturally occurring lightning event is a complex phenomenon. The waveforms specified in MIL-STD-1757 and MIL-STD-1795 are the technical community's best effort at simulating the natural environment for dezine and test 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 has lightning protection installed and verified by testing. When the aircraft is struck, natural lightning often punctures the radome. Subsequent testing has been unable to duplicate the failure. This result is most likely caused by our inability to duplicate the naturally occurring lightning event.

4.7 Electromagnetic pulse (EMP). The system shall be fully capable of completing its required missions when subjected to the EMP environments described in DOD-STD-2169.

REQUIREMENT RATIONALE (4.7)

High-altitude EMP (HEMP) is relevant to aircraft. It is generated by a nuclear burst above the atmosphere which produces coverage over large areas. The entire continental US area can be exposed with a few bursts. DOD-STD-2169 defines the threat waveforms. In a nuclear war, it is probable that most military aircraft will be exposed to EMP.

REQUIREMENT GUIDANCE (4.7)

An EMP protection program should be established for military systems. The free-field EMP environment must be as specified in DOD-STD-2169. Such activities as identification of mission critical equipment, an EMP inherent hardness study, an EMP coupling analysis, development of EMP hardening concepts, and a complete verification of the EMP protection design must be part of the protection program. HEMP field waveforms are analytically described by a sum of exponentials. The complete HEMP signal is represented by three terms representing three time regimes: early time (E1), intermediate time (E2), and late time (E3) or magnetohydrodynamic EMP. These three components are described in detail in DOD-STD-2169. E1 is the primary concern for airborne systems. It is characterized by a short rise time and a large peak amplitude and occurs within 1 microsecond of a nuclear detonation. The spectral content of the E1 waveform together with the physical size of aircraft result in higher levels of coupling for E1 than the other waveforms. This situation occurs when it can be shown that the system's response to the E2 and E3 portions of the HEMP signal is insignificant. E2 and E3 have lower electric field amplitudes and E3, in particular, couples more effectively on very long landlines or submarine cables.

AFWL-TR-85-113 provides guidance on design considerations which address electromagnetic pulse concerns.

REQUIREMENT LESSONS LEARNED (4.7)

EMP poses a threat only to electronics in systems. There are no structural damage mechanisms. Due to the fast rise time and short pulse width of the EMP waveform, it results in an impulse 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.

The most frequently observed effect from EMP is system upset. Burnout of electronics has occurred; however, it has been rare and is not considered to be a problem. 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 buffering is present for protection. 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 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.

5.7 Electromagnetic pulse (EMP). Compliance with EMP requirements shall be verified by a combination of system-level and subsystem/equipment-level testing and analysis.

VERIFICATION RATIONALE (5.7)

An EMP protection verification program is required to demonstrate implemented measures meet the EMP design requirements.

VERIFICATION GUIDANCE (5.7)

The General Samuel Phillips Laboratory (formerly Weapons Laboratory) is preparing MIL-HDBK-XXXX, entitled "Nuclear Electromagnetic Pulse Hardness Verification Methods for Aerospace Systems." This handbook provides details on available test and analysis methodology for verifying EMP hardness. (For further information on MIL-HDBK-XXXX, contact Phillips Laboratory/WSR, phone (505) 846-0416, DSN 246-0416.)

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 can be used as part of design verification if they are properly documented. Documentation details should include a complete test hardware definition, test waveforms descriptions, instrumentation, and pass/fail criteria used to assess the test results.

The following are elements of an iterative process for designing and verifying protection of an air vehicle's electrical/electronic systems against the effects of EMP.

a. EMP coupling analysis. A coupling analysis should be conducted to determine the EMP free-field coupling into the air vehicle. Existing coupling data on similar aircraft designs should be used whenever possible. This analysis provides an estimate of the voltages/currents generated by the EMP at each interface of each mission-critical equipment and can be used to establish subsystem/equipment stress levels.

b. Identification of mission critical subsystems. Air vehicle subsystems and equipment that may be affected by EMP, and whose proper operation is critical or essential to the operation of the air vehicle, must be identified. The equipment locations within the air vehicle need to be determined.

c. Equipment strength determination. A study should be conducted consisting of analysis and engineering tests to determine the EMP inherent hardness of the mission critical equipment. These analyses and tests shall establish a lower bound on the upset and damage thresholds for each mission critical equipment.

d. Specification compliance demonstration. Verification that the aircraft meets EMP design requirements should be accomplished by demonstrating that the actual transient levels appearing at the equipment interfaces do not exceed the tolerances allowed by the individual equipment or subsystem specification and that the required design margins have been met. Verification may be accomplished by tests, analysis, a combination of both, or by similarity with previously demonstrated installations.

VERIFICATION LESSONS LEARNED (5.7)

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 entering a shielded volume which had not been designed for proper electrical bonding. 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 airframe sections.

Protection measures related to structural components should be evaluated for performance during assembly to verify that they meet requirements as installed in the airframe. 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 curvature of a final aircraft design may be so different from that which was modeled in the laboratory that the electromagnetic behavior is substantially altered. After assembly, access to some components may not be practical.

There are a number of ways to obtain system-level excitation for purposes such as quality control or hardening evaluation. Low-level continuous-wave illumination of the system or of individual components is relatively easy and can often reveal an oversight in airframe assembly or a deficiency in the design of a hardening element. Alternately, single point excitation can be done, even in a hanger, and can similarly reveal any obvious problems in the airframe shielding.

Tests of structural design 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 relatively painless. However, if the deficiencies are not found until the aircraft 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 air vehicle using a high-level EMP simulator is a high confidence method of demonstrating compliance.

4.8 Electrostatic charge control. The system shall control and dissipate the buildup of electrostatic charges to the extent necessary to protect personnel from shock hazards, to avoid fuel ignition hazards, and to prevent performance degradation or damage to electronics.

REQUIREMENT RATIONALE (4.8)

As aircraft fly, they encounter dust, rain, snow, and ice which result in an electrostatic charge buildup on the structure due to the phenomenon called precipitation static charging. This buildup of static electricity causes significant voltages to be present which can result in interference to equipment and constitute a shock hazard both to aircrew personnel during flight and to ground personnel after landing.

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 can create an electrostatic charge buildup on both the personnel and structure (particularly on nonconductive surfaces). This buildup can constitute a safety hazard to personnel or fuel or may damage electronics.

REQUIREMENT GUIDANCE (4.8)

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. Electrically conductive and nonconductive 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 nonconductive 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 nonconductive. For most applications, 10^6 to 10^9 ohms per square are required to dissipate the charge buildup. The shock hazard to personnel begins at about 3000 volts; therefore, the charge on system components should not be allowed to exceed 2500 volts.

Static electricity accumulates on aircraft in flight since there is no electrical path for the charges to flow to ground. Special control mechanisms become necessary. The developed voltage on an aircraft with respect to the surrounding air becomes high enough that 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. 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.

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. JP-4 fuel vapors can be ignited with about 0.25 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. All external aircraft fuel tanks must also be addressed. Additional information on static electricity and fuels is provided in AFAPL-TR-78-56 and AFAPL-TR-78-89.

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

REQUIREMENT LESSONS LEARNED (4.8)

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 nonconductive 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 air flow and personnel contact.

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 nonconductive materials should be prohibited from the tank during maintenance and clothing should be conductive or sprayed with a conductive spray.

Static discharges from the canopy were shocking pilots on a fighter aircraft during flight. Charges accumulating on the outside of the canopy apparently migrated slowly through the dielectric material and discharged to the pilot's helmet when a sufficient charge appeared on the inside surface. A conductive finish on the inside of the canopy fixed the problem.

5.8 Electrostatic charge control. Adequate control of electrostatic charging shall be verified by test, analysis, or inspection as appropriate and as approved by the procuring activity.

VERIFICATION RATIONALE (5.8)

Verification of protection design for electrostatic charging is necessary to ensure that adequate controls have been implemented.

VERIFICATION GUIDANCE (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 be normally be more appropriate. For demonstration that the aircraft will adequately discharge precipitation buildup during flight, actual flight through likely charging conditions might be necessary.

VERIFICATION LESSONS LEARNED (5.8)

For all structural components, this verification must be done during air vehicle assembly to verify that all components are adequately bonded to each other. After manufacturing is completed, access to some components may be restricted making verification difficult.

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.

4.9 Electrical bonding. Electrical bonding measures shall be implemented for management of electrical current paths and control of voltage potentials to ensure required system performance and to protect personnel. Bonding provisions shall be compatible with other requirements imposed on the system for corrosion control.

REQUIREMENT RATIONALE (4.9)

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 often tries to avoid electrical continuity between dissimilar materials, it is necessary to ensure that both disciplines are properly considered.

REQUIREMENT GUIDANCE (4.9)

The role of bonding is essentially to control voltage differences in the ground subsystem by providing low-impedance paths for current flow. Design and manufacturing policies which will assure adequate electrical bonding should be established early in the program. Special attention should be given to the interdependent relationship between electrical bonding and corrosion control. Unconventional joints should receive special attention to ensure their adequacy, particularly conductive joints in fuel vapor areas. SAE ARP 1870 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.

REQUIREMENT LESSONS LEARNED (4.9)

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 radios, susceptibility of electronics to external electromagnetic fields, radiation of interference into antenna-connected receivers, and lightning vulnerabilities.

5.9 Electrical bonding. Compliance with electrical bonding requirements shall be verified by test, analysis, or inspection as appropriate for the particular bonding provision and as approved by the procuring activity. Compatibility with corrosion control techniques shall be verified by demonstration that manufacturing processes which address corrosion control have been implemented.

VERIFICATION RATIONALE (5.9)

Verification of protection measures for electrical bonding is necessary to ensure that adequate controls are implemented.

VERIFICATION GUIDANCE (5.9)

The electrical bonding area involves a number of different concerns. Guidance is provided below under paragraphs 5.9.1, 5.9.2, 5.9.3, and 5.9.4. Detailed corrosion control requirements for air vehicles are imposed by documents such as MIL-STD-1568. For the purposes of this standard, demonstration is required that appropriate manufacturing processes are in place to address corrosion concerns.

VERIFICATION LESSONS LEARNED (5.9)

The adequacy of much electrical bonding can be evaluated through DC resistance measurements and inspection.

4.9.1 RF potentials. All electronic and electrical items which have the capability of producing, radiating, or responding to electromagnetic energy shall be bonded to the ground subsystem with a resistance of 2.5 milliohms (DC) or less for metallic interfaces. For composite materials, bonding shall be accomplished at impedance levels consistent with the materials in use.

REQUIREMENT RATIONALE (4.9.1)

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.

REQUIREMENT GUIDANCE (4.9.1)

The 2.5-milliohm level 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.

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.

REQUIREMENT LESSONS LEARNED (4.9.1)

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 bonding less critical since there is better rejection of common-mode noise. However, there is often a trade-off between interface design and the amount of wiring and number of connector pins since differential interfaces require the use of two wires and pins for each signal.

In metallic aircraft, the entire vehicle structure forms the ground plane. As designers have introduced composite materials, which are much less conductive than aluminum, there has been a need in some cases to introduce separate ground planes to maintain adequate control of electromagnetic effects.

5.9.1 RF potentials. Bonding for RF potentials shall be demonstrated by tests.

VERIFICATION RATIONALE (5.9.1)

Testing is the only acceptable method for demonstrating that the bonding requirement for RF potentials is satisfied.

VERIFICATION GUIDANCE (5.9.1)

The 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 2.5 milliohms 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.

VERIFICATION LESSONS LEARNED (5.9.1)

AC measurements can be performed; however, they require more sophisticated instrumentation. DC measurements have proven to provide a good indication of the quality 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.

4.9.2 Power current return paths. Bonding provisions shall be provided for current return paths for the electrical power sources such that 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. For locations prone to fuel or fire hazards, voltage drops across equipment-to-structure interfaces under available fault current conditions shall not exceed 0.074 volts.

REQUIREMENT RATIONALE (4.9.2)

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 (4.9.2)

Power quality standards, such as MIL-STD-704 for aircraft, control the supply voltage for utilization equipment within specified limits. The voltage is maintained at a monitoring location termed the "point of regulation" with allocations for allowable 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.

The fault condition requirement of 0.074 volts is derived from a figure appearing in a number of bonding documents including SAE ARP 1870 which displays fault current versus bonding impedance. The voltage is essentially constant at 0.074 volts. Although supporting documentation could not be located, the curves are apparently based on data which demonstrated that structural materials would exhibit sparking or arcing problems.

REQUIREMENT LESSONS LEARNED (4.9.2)

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.

5.9.2 Power current return paths. Bonding for power current return shall be demonstrated through analysis of electrical current paths, electrical current levels, and bonding impedance control levels.

VERIFICATION RATIONALE (5.9.2)

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 (5.9.2)

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 (5.9.2)

With metallic aircraft, voltage drops through structure are typically very low. Much higher levels are possible with graphite/epoxy structure.

4.9.3 Shock hazard. To prevent shock hazards to personnel, all exposed electrically conductive items shall be bonded as necessary to limit voltages to less than 30 volts between the item and the ground subsystem.

REQUIREMENT RATIONALE (4.9.3)

The system design must protect personnel from shock hazards.

REQUIREMENT GUIDANCE (4.9.3)

The 30-volt level is derived from MIL-STD-454, Requirement 1. Bonding provisions must be included to prevent hazardous voltages from appearing on any electrically conductive assembly. These voltages could result from sources such as broken components in assemblies allowing "hot" wiring to contact the housing or from electrical referencing of a circuit to the housing.

REQUIREMENT LESSONS LEARNED (4.9.3)

In the past, a bonding resistance of 0.1 ohm has been considered as adequate to prevent most shock hazards.

5.9.3 Shock hazards. Bonding for shock hazard shall be verified through test, analysis, and inspection as appropriate for the particular application.

VERIFICATION RATIONALE (5.9.3)

Adequate bonding must be verified to ensure personnel safety.

VERIFICATION GUIDANCE (5.9.3)

Verification is primarily achieved by demonstrating that voltages in excess of 30 volts are protected from inadvertent contact by personnel and that faults to electrically conductive surfaces will not result in voltages greater than 30 volts on the surface. These types of faults should normally trip circuit protection equipment.

VERIFICATION LESSONS LEARNED (5.9.3)

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 an 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.

4.10 Radiation hazards. The system shall be designed so that personnel, fuels, and electroexplosive devices (EEDs) are not exposed to unsafe levels of electromagnetic radiation and that the required missions can be completed in a safe manner. The prime contractor is responsible for the overall design, planning, management, and demonstration of the system to ensure safety in these areas.

REQUIREMENT RATIONALE (4.10)

It has been firmly established that sufficiently high electromagnetic fields can harm personnel, ignite fuel, and fire EEDs. Precautions must be exercised to ensure that unsafe conditions do not develop.

REQUIREMENT GUIDANCE (4.10)

See guidance for 4.10.1, 4.10.2,and 4.10.3.

REQUIREMENT LESSONS LEARNED (4.10)

See lessons learned for 4.10.1, 4.10.2, and 4.10.3.

5.10 Radiation hazard safety. Safety with regard to RF effects on personnel, fuels operations, and the use of EEDs shall be demonstrated by testing, analysis, and inspection as applicable and as approved by the procuring activity.

VERIFICATION RATIONALE (5.10)

Adequate design and controls regarding safety to radiation hazards must be verified.

VERIFICATION GUIDANCE (5.10)

Guidance is provided below under paragraphs 5.10.1, 5.10.2, and 5.10.3.

VERIFICATION LESSONS LEARNED (5.10)

Lessons learned are provided below under paragraphs 5.10.1, 5.10.2, and 5.10.3.

4.10.1 Personnel hazards. The system shall be designed so that personnel are not exposed to RF levels exceeding the permissible exposure limits (PELS) of AFOSH Standard 161-9.

REQUIREMENT RATIONALE (4.10.1)

The fact that heating is associated with absorption of RF power by humans was known nearly 50 years ago and led to the introduction of RF diathermy for medical and surgical purposes. The heat from RF field interactions simply adds to the metabolic heat load of the human. If the body's heat gain exceeds its ability to rid itself of excess heat, the body temperature rises. Therefore, if significant RF power is absorbed, an increase in body temperature is expected which could have a competing effect on metabolic processes, with potentially deleterious effects. Cataracts in the eyes are one of the more widely recognized effects of excess RF exposure. The eyes have difficulty coping with a thermal burden due to the relatively small blood circulation.

As with any electronics, there is an electromagnetic interference concern with the interaction of radio frequency fields and electronic medical prosthetic devices such as a cardiac pacemakers. Adverse biological effects can result.

REQUIREMENT GUIDANCE (4.10.1)

AFOSH Standard 161-9 contains the PEL criteria and detailed guidance on interpreting and applying the criteria. A few edited excerpts from AFOSH Standard 161-9 are provided here.

Air Force facilities normally have a Bioenvironmental Engineer (BEE) assigned who provides support in assessing and documenting RF hazards. In some cases warning signs will be necessary to indicate hazardous areas. The BEE will determine the locations and sizes of warning signs appropriate to a given facility or activity and will recommend suitable warning information to be printed on the black portion of the signs.

REQUIREMENT LESSONS LEARNED (4.10.1)

Aircraft-mounted radar and electronic countermeasures (ECM) systems present the greatest potential personnel hazard because they can be reached by persons at ground level.

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.

RF equipment radiating at frequencies below 1000 MHz and delivering less than 7 watts of power to the radiating device are considered nonhazardous.

Ground-to-air, air-to-ground, and ground mobile communications facilities do not usually require any controls. There are some exceptions. Most transmit at low power and for short periods of time.

5.10.1 Personnel hazards safety. Using the methods of measurement and calculation of AFOSH Standard 161-9, the prime contractor shall demonstrate that the system RF emitters will not affect the health and safety of personnel during any phase of the system mission.

VERIFICATION RATIONALE (5.10.1)

Safety regarding RF hazards to personnel must be verified.

VERIFICATION GUIDANCE (5.10.1)

AFOSH Standard 161-9 provides guidance on hazard determination and treatment. 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 technical order (TO) cautions. TO 31Z-10-4 provides methodology for calculating hazard distances.

VERIFICATION LESSONS LEARNED (5.10.1)

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 provides techniques for reduction of gain for certain types of antennas. Measurements may 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. While hazard criteria are primarily based on average power density and field strength levels (peak levels are also specified), probes 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 permissible exposure limit (PEL).

4.10.2 Fuel hazards. The system shall include provisions such that the fuel hazard criteria of AFOSH Standard 127-38 are met during fuel operations.

REQUIREMENT RATIONALE (4.10.2)

Fuel vapors can be ignited by an arc induced by a strong RF field. Therefore, the potential hazard of any fuel handling operation near an RF source must be addressed.

REQUIREMENT GUIDANCE (4.10.2)

The existence and extent of a fuel hazard are determined by comparing the actual RF power density to the safety criteria. Air Force TO 31Z-10-4 provides procedures for establishing safe operating distances.

RF energy can induce currents into any metal object. The amount of current, and thus the strength of a spark across a gap between two conductors, depends on both the field intensity of the RF energy and how well the conductors act as a receiving antenna. Many parts of an aircraft, a refueling vehicle, and/or the 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 nor control these factors. The hazard criteria must then be based on the assumption that an ideal receiving antenna could be inadvertently created with the required spark gap.

REQUIREMENT LESSONS LEARNED (4.10.2)

There is a special case where a fuel or weapon RF hazard can exist even though the RF levels are within the safe limits specified. This special case is for both the hand-held (1-5 watts) and mobile (5-50 watts) transceivers. The antennas on these equipments can generate hazardous situations when they are allowed to accidentally touch the aircraft, weapon, or support equipment. To avoid this hazard, transceivers should not be operated any closer than 10 feet from weapons, fuel vents, etc.

5.10.2 Fuels safety. The prime contractor shall demonstrate that the system is designed to preclude accidental ignition of fuels due to RF emissions.

VERIFICATION RATIONALE (5.10.2)

Safety regarding RF hazards to fuels must be verified.

VERIFICATION GUIDANCE (5.10.2)

TO 31Z-10-4 provides methodology for calculating hazard distances from RF emitters. An important issue is that fuel hazard criteria are 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 insure safety under certain operations such as refueling operations. Any required procedures must be carefully documented in technical orders or other appropriate publications.

AFOSH Standard 138-27 primarily addresses radars. Other types of RF emitters should be reviewed to insure that they do not pose a problem.

VERIFICATION LESSONS LEARNED (5.10.2)

See lesson learned for paragraph 5.10.1.

4.10.3 Electroexplosive subsystems. The system shall protect electroexplosive subsystems from inadvertent operation under all electromagnetic environmental conditions specified in this standard. Electroexplosive devices (EEDs) shall have a minimum no-fire characteristic of 1 ampere/1 watt and shall not initiate when a 500-picofarad capacitor charged to 25 kilovolts (electrostatic discharge) is applied through a 5-kilohm resistor in both pin-to-pin and pin-to-case modes.

REQUIREMENT RATIONALE (4.10.3)

EEDs (sometimes called squibs) are used for many purposes including ejecting stores from aircraft, escape systems, igniting rocket motors, and initiating warheads. RF energy can inadvertently fire EEDs due to induced currents in electroexplosive subsystem wiring. The consequences can be hazardous.

REQUIREMENT GUIDANCE (4.10.3)

The electrical circuit internal to an EED is simply a small resistive element termed a bridgewire. When the EED is intentionally fired, a current pulse is passed through the bridgewire, causing heating and resultant initiation of the explosive charge. RF fields can induce currents to flow in the bridgewire by coupling into the interface wiring. These currents will cause bridgewire heating that may inadvertently fire the EED. The accidental firing of EEDs 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 radio transmitters.

MIL-STD-1512 provides design criteria for electroexplosive circuits and for individual EEDs and portions of the document may be appropriate for certain applications. Much of MIL-STD-1512 is not normally applied due to the cost of performing the extensive tests which are specified.

REQUIREMENT LESSONS LEARNED (4.10.3)

The response of an EED to an RF energy field, and the possibility of detonation, depend on many factors. Some of these factors are transmitter power output, modulation characteristics, operating frequency, antenna propagation characteristics, EED wiring configuration (i.e. shielding, length, and orientation) and the thermal time constant of the bridgewire.

5.10.3 Electroexplosive subsystems. The prime contractor shall verify the protection of electroexplosive subsystems by demonstrating required margins during system-level evaluations (intra-system electromagnetic compatibility, external RF environments, lightning, and electromagnetic pulse). Compliance of electroexplosive devices (EEDs) with no-fire and electrostatic discharge requirements shall be in accordance with test methods 202 and 205 of MIL-STD-1512, respectively.

VERIFICATION RATIONALE (5.10.3)

Adequate design protection for electroexplosive subsystems and EEDs must be verified to insure safety.

VERIFICATION GUIDANCE (5.10.3)

Verification methods must show that electroexplosive subsystems will not inadvertently operate and EEDs will not inadvertently initiate or be dudded during handling, storage, or when installed in the system. MIL-STD-1512 provides test methods for verifying design characteristics of EEDs as components. Verification of adequate protection for EED installations in the system requires that margins be demonstrated during intra-system electromagnetic compatibility testing and during evaluations of the environments external to the system. Methods used to demonstrate margins during testing require instrumentation of the EED using techniques such as thermocouples, RF detectors, temperature sensitive waxes, fiber optics, and substitution of more sensitive elements.

VERIFICATION LESSONS LEARNED (5.10.3)

There are a number of concerns with EEDs and instrumentation techniques. The influence of the instrumentation on the normal thermal and electrical characteristics of the EED must be minimized. Even the removal of the explosive powder for both safety and instrumentation reasons will have some effect on heating and electrical characteristics due to changes in thermal capacity and dielectric properties. Devices with greater sensitivity used in place of the EED must have characteristics as close as possible to the EED, including electrical wiring and lead construction.

An important parameter which often does not receive adequate attention in safety evaluations is the thermal time constant of the EED. The temperature rise of EED bridgewires to a current step can be modeled as an exponential. The time constant is the point in time on an exponential curve where the exponent equals minus one and 63% of the final value has been reached. LA-5201-MS reports on a detailed study of EED characteristics which found typical time constants to be between 1 and 20 milliseconds. Heating and cooling time constants are similar. Time constants are not determined for EEDs as a standard practice.

Most instrumentation techniques in use are slow responding, particularly with respect to 1 millisecond. They will produce reasonable results for high duty cycle waveforms such as voice communications. For pulsed radar signals, these techniques rely on a long-term effect called thermal stacking, which is related to average power. Each pulse causes a small amount of heating followed by a relaxation period where some cooling occurs. After several thermal time constants, the temperature of the EED bridgewire reaches an equilibrium condition with some small temperature excursions about the equilibrium point.

This concept works well when the pulse width and pulse period are small compared with the time constant, for example, a 1-microsecond pulse and a 1-millisecond period with a 20-millisecond EED time constant. However, radars exist with pulse widths well over 1 millisecond and pulse rates may be low or not even relevant due to phased-array operation where consecutive pulses may be at completely different azimuth and elevation positions. Some examples follow. If a radar has a 5-millisecond pulse width and a 1-millisecond time constant EED is under consideration, the EED bridgewire will essentially reach thermal equilibrium during a single pulse and average power is irrelevant. The radar can be treated as continuous wave. If the radar has a 20-millisecond inter-pulse period (50-Hz pulse repetition frequency), a 1-millisecond EED bridgewire will cool completely between pulses for practical purposes and no thermal stacking takes place. Under this condition, the energy in the pulse is important for pulses which are short compared to the time constant, and the peak power is important for pulses which are long compared to the time constant. Most present instrumentation will not provide reliable results for these situations, and analytical techniques or special calibrations may be necessary to correct results.

4.11 Life cycle. The EME protection design shall include full consideration of life-cycle aspects of the protection (e.g., identification of hardening elements and processes, repair, maintenance, integrity verification, and inspection requirements). EME protection measures and techniques shall be designed to retain their effectiveness throughout the life of the system and its support subsystems. System protection shall include, but not be limited to, the following life-cycle considerations.

a. Maintenance. Protection designs shall either be accessible and maintainable or shall be designed to survive the design lifetime of the vehicle without mandatory maintenance or inspection. Bonding, shielding, or other protection devices which can be disconnected, unplugged, or otherwise deactivated during maintenance shall be addressed in maintenance documentation, including required actions to restore their effectiveness.

b. Repair. Protection design measures shall be repairable or replaceable without degradation of the initial level of protection.

c. Surveillance. A program shall be established to ensure that the protection measures incorporated in the system design are not degraded with time or use. The system shall be designed such that the electromagnetic design features that require surveillance are accessible and can be tested or inspected as needed.

REQUIREMENT RATIONALE (4.11)

Advanced avionics and structural concepts are offering tremendous advantages in increased performance of high-technology aircraft. These advantages will be seriously compromised, however, if EME protection concepts impact life cycle costs through excessive parts count, mandatory maintenance, or through costly repair requirements. In fact, performance may be so critical for some high-technology vehicles that excessive design penalties may either preclude the production of the vehicle or program management may decide not to provide protection. It is essential, therefore, that life-cycle considerations be included in the tradeoffs used to develop vehicle EME protection.

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

REQUIREMENT GUIDANCE (4.11)

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

EME protection schemes include specific design measures both internal to electrical and electronic enclosures and in the basic airframe. 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), the system manufacturer must provide the user with a maintenance and surveillance program which identifies protection schemes and devices and specifies maintenance intervals and procedures. Emphasis needs to be placed on critical functions for aircraft operational and mission performance. A thorough program may include visual inspections and testing using built-in-test and flightline test equipment. The user must assume the responsibility to implement the program for the life of the airframe and to modify the program as necessary to include conditions not originally anticipated. 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 nonlinear (transzorbs, zener diodes, varistors, etc.) filtering, circuit interface design (balance, grounding, etc.) and circuit signal processing characteristics.

The program must also address maintenance actions being performed on noncritical items which are in the same area as the critical items. These instructions are necessary to ensure that personnel do not inadvertently compromise the protection measures of the critical functions. The program must also include procedures addressing modifications to the aircraft. The modifications could involve either new or existing subsystems which perform critical functions. They could also involve modifications to the aircraft structure or subsystem components, such as wiring and protective devices.

REQUIREMENT LESSONS LEARNED (4.11)

Many times in the past, EME 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, benefitting both the airframe 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 documented in the applicable technical orders. 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 paragraphs 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 airframe of the airplane. If door spring fingers are employed, they must be kept clean, kept 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.

Proper 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. An example of bonding design is the contact between the back of an enclosure and the finger washers in the rear wall of the avionics 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.

5.11 Life cycle. System design features implemented for EME protection shall be inspected for compliance with life cycle requirements for maintenance, repair, and surveillance capability. Demonstrations of maintainability, accessibility, and testability and the ability to detect degradations shall be performed. Maintenance and surveillance methodology and tools shall be identified in the EMEVR and appropriate maintenance publications.

VERIFICATION RATIONALE (5.11)

Compliance with lifecycle requirements must be verified to insure that electromagnetic effects protection can be maintained and does not degrade with time.

VERIFICATION GUIDANCE (5.11)

Some electromagnetic effects protection measures—such as electrical contact of critical components and electromagnetic shielding effectiveness—cannot be maintained by visual inspections alone. Hardness surveillance testing will often be necessary.

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. Built-in test equipment, 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 (5.11)

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 lifecycle 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.

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 nonconductive 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.

4.12 External grounds. Grounding jacks shall be installed on aircraft to permit connection of grounding cables for fueling, weapons handling, and other servicing operations. MS90298 or equivalent flush-mounted jacks shall be used and shall be installed to comply with MS33645. A jack is required at each gravity fuel inlet for fuel nozzle grounding. A minimum of two additional jacks for utility and helicopter aircraft and four for other aircraft types shall be provided for general servicing. For aircraft which carry weapons, additional jacks shall be located for convenience in handling ordnance.

REQUIREMENT RATIONALE (4.12)

Grounding of an air vehicle to earth and to 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. Electroexplosive devices used in ordnance are potentially susceptible to inadvertent ignition from static discharge.

REQUIREMENT GUIDANCE (4.12)

Air Force Technical Order 00-25-172 provides requirements for grounding of aircraft during servicing.

MS90298 and MS33645 are implementing documents for NATO and ASCC international agreements. They allow for correct mating and identification marking so that hardware used by allied countries will be interoperable.

Bonding provisions are required for munitions that are stored in bunkers while in containers or exposed to the elements to reduce static charge buildup during handling. These include munitions-to-container, container-to-ground, munitions (not in containers)-to-ground.

REQUIREMENT LESSONS LEARNED (4.12)

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.

A review board concluded that a mishap with a missile was due to inadvertent ignition of the rocket propellant from electrostatic discharge. This incident occurred with the propellant itself and not with the electroexplosive device.

4.12.1 Grounding jack installation. The grounding jacks shall be attached to structure so that the resistance between the mating plug and structure shall be no greater than 1.0 ohm (DC).

REQUIREMENT RATIONALE (4.12.1)

Electrical resistance between the grounding jack and vehicle structure must be controlled to ensure that an adequate connection is present to dissipate static.

REQUIREMENT GUIDANCE (4.12.1)

Relatively poor electrical connections are adequate to dissipate static. However, controls must be imposed which indicate that a reasonable metal-to-metal connection is present. It is not difficult to obtain 2.5 milliohms in a new installation. Allowing values greater than 1.0 ohm could result in questionable or erratic connections being considered adequate.

REQUIREMENT LESSONS LEARNED (4.12.1)

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.

4.12.2 External grounds for servicing equipment. Each item of servicing equipment or aerospace ground equipment shall have a grounding wire suitable for connection to an earth ground rod. In addition, all servicing equipment that handles flammables, explosives, oxygen, or other potentially hazardous materials shall have a permanent bonding cable attached for connection to the aircraft. The bonding and grounding cables shall use a plug complying with MS25384 for the connection to the aircraft and an approved fitting for connection to the ground rod.

REQUIREMENT RATIONALE (4.12.2)

Proper grounding provisions are essential for safety.

REQUIREMENT GUIDANCE (4.12.2)

Earth grounding of servicing equipment is necessary to prevent shock hazards due to electrical faults in the equipment. Connection to the aircraft in the presence of potentially hazardous materials is necessary to prevent potential problems due to electrostatic discharges between servicing equipment hardware and aircraft structure. MS25384 plugs are mechanically compatible with the MS90298 grounding jacks specified above for installation on the aircraft. These plugs are also compatible with allied countries' aircraft, thus meeting NATO and ASCC standardization agreements.

REQUIREMENT LESSONS LEARNED (4.12.2)

The need for proper grounding is well established. See lessons learned for 4.12.

4.12.3 External grounds for maintenance in repair facilities. Each equipment item, when removed from its primary structure (line replaceable units for aircraft, support equipment, or ground systems) for maintenance shall have provisions for connecting grounding wire between its chassis, transporting fixture, or protective enclosure (packaging) and the facility ground.

REQUIREMENT RATIONALE (4.12.3)

Proper grounding provisions are essential for safety.

REQUIREMENT GUIDANCE (4.12.3)

Earth grounding of equipment being tested with associated servicing or support equipment is necessary to prevent shock hazards due to electrical faults or electrostatic charge buildup in the equipment. This connection will prevent potential personnel hazards.

REQUIREMENT LESSONS LEARNED (4.12.3)

The need for proper grounding is well established.

5.12 External grounds for aircraft. Proper placement and marking of external ground provisions for the system shall be verified by inspection. Compliance with bonding requirements shall be verified by test.

VERIFICATION RATIONALE (5.12)

To ensure safety, proper use and installation of external grounds for aircraft must be verified.

VERIFICATION GUIDANCE (5.12)

Proper bonding can be verified with an ohmmeter.

VERIFICATION LESSONS LEARNED (5.12)

Installation practices should be reviewed to ensure that corrosion protection is included.

CONCLUDING MATERIAL

Custodian:
Air Force 11

Preparing Activity:
Air Force - 11
(Project EMCS-F137)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

NOTE: This form may not be used to request copies of documents, not to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractural requirements.

I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER **MIL-STD-1818(USAF)**	2. DOCUMENT DATE *(YYMMDD)* **8 MAY 1992**

3. DOCUMENT TITLE
ELECTROMAGNETIC EFFECTS REQUIREMENTS FOR SYSTEMS

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)* (1) Commercial (2) AUTOVON *(If applicable)*	7. DATE SUBMITTED *(YYMMDD)*

8. PREPARING ACTIVITY

A. NAME ASD/ENES	B. TELEPHONE *(Include Area Code)* (1) Commercial (513) 255-6281 (2) AUTOVON *(If applicable)* 785-6281
C. ADDRESS *(Include Zip Code)* WRIGHT-PATTERSON AFB, OH 45433-6503	IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403, Falls Church VA 22041-3466 Telephone (703) 756-2340 AUTOVON 289-2340