METRIC

National Aeronautics and Space Administration

MSFC-STD-3790
REVISION: Baseline
EFFECTIVE DATE: June 10, 2025

George C. Marshall Space Flight Center
Huntsville, Alabama 35812

ED01

MSFC TECHNICAL STANDARD

Electromagnetic Environmental Effects (E3) System Level Requirements for Space Vehicles

CHECK THE MASTER LIST -
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline	Baseline	6/10/2025	Initial Baseline. This standard was authorized by the MSFC Technical Standards Document Control Board (DCB).

TABLE OF CONTENTS

APPENDICES

FIGURES

TABLES

1.0 SCOPE

1.1 INTRODUCTION

Electromagnetic Compatibility (EMC) is essential to the success of any space vehicle designs that incorporates a complex assortment of electronic, electrical, and electromechanical systems and subsystems that is expected to meet operational and performance requirements while exposed to a changing set of electromagnetic environments composed of both man-made and naturally occurring threats. The combined aspects of these environments are known as Electromagnetic Environmental Effects (E3). The attainment of EMC is accomplished through the application of sound engineering principles and practices that enable a complex vehicle to operate successfully when exposed to the effects of its expected and/or specified electromagnetic environments (including the effects generated by visiting vehicles).

The NASA Office of Primary Responsibility (OPR) for this document is the Marshall Space Flight Center (MSFC) Engineering Directorate (ED), ES31, Electromagnetic Effects discipline lead organization.

1.2 PURPOSE

The purpose of this requirements document is to define a common set of electromagnetic design, control, test, and verification for each of the various space vehicles.

This is a generic E3 requirements document that is intended to be used by space vehicles. This document provides the E3 requirements needed to achieve EMC with respect to both the external electromagnetic environment and the induced electromagnetic environments.

1.3 SCOPE

This document provides detailed E3 requirements and associated verification activities applicable to a space vehicle. The program utilizing this Marshall Space Flight Center (MSFC) standard is responsible for decomposing the pertinent requirements onto the element subsystem and component level based on the element's specific configuration to produce a compatible vehicle.

1.4 LANGUAGE USAGE

In this specification, "shall" denotes a mandatory action; "should" denotes a good practice and is recommended, but not required; "may" or "can" denotes discretionary privilege or permission; "will" denotes an expected outcome; and "are/is" denotes descriptive material.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following data items include specifications, models, standards, guidelines, handbooks, and other special publications. The data items listed in this paragraph are applicable to the extent specified herein.

TABLE 2.1-1 APPLICABLE DOCUMENTS

Document Number	Document Revision	Document Title
CISPR 22	Revision 6.0 (2008-09)	Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement
CISPR 24	Revision 2.1 (2015-04)	Information technology equipment – Immunity characteristics – Limits and methods of measurement
CISPR 32	Revision 2.0 (2019-10)	Electromagnetic compatibility of multimedia equipment – Emission requirements
CISPR 35	Revision 1.0 (2016-08)	Electromagnetic compatibility of multimedia equipment – Immunity requirements
IEC 61000-4-2	Edition 2.0 (2008-12)	Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test
MSFC-SPEC-521	Revision D	Electromagnetic Compatibility Requirements for Equipment and Subsystems
NASA-STD-4003	Revision A	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
NASA-STD-4005	Revision A	Low Earth Orbit Spacecraft Charging Design Standard
SLS-SPEC-159	Rev I	Cross-Program Design Specification for Natural Environments (DSNE)

Document Number	Document Revision	Document Title
MIL-STD-1576 (USAF)	Revision Basic & Notice 1	Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document.

TABLE 2.2-1 REFERENCE DOCUMENTS

Document Number	Document Revision	Document Title
AIAA 2004-1260	Baseline	Paschen Considerations for High Altitude Airships
Commercial Item Description A-A-59569D	Revision D	Braid, Wire (Copper, Tin-Coated, Silver-Coated, or Nickel Coated, Tubular or Flat)
ECSS-E-20-01A	Revision 1	Space Engineering - Multipaction Design and Test
FED-STD-228	Revision A	Test Methods for Cables and Wire, Insulated
IEEE C95.1-2019	(Feb. 2019)	IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz
ISSN 1330-0008	(Oct. 2002)	Measurements of the Breakdown Potentials for Different Cathode Materials in the Townsend Discharge.
MIL-STD-464	Revision D	Electromagnetic Environmental Effects Requirements for Systems
MSFC-SPEC-3635	Revision C	Pyrotechnic System Specification
NASA-HDBK-4002	Revision B	Mitigating In-Space Charging Effects - A Guideline

Document Number	Document Revision	Document Title
NASA-HDBK-4006	Revision A	Low Earth Orbit Spacecraft Charging Design Handbook
NASA-HDBK-4007	Baseline	Spacecraft High-Voltage Paschen and Corona Design Handbook
NASA-RP-1354	(Nov. 1994)	Spacecraft Environments Interactions: Protecting Against the Effects of Spacecraft Charging
NASA-RP-1368	Baseline	Marshall Space Flight Center Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook
NASA-RP-1375	(Aug. 1995)	Failures and Anomalies Attributed to Spacecraft Charging
NASA-TP-2361	(1984)	Design Guidelines for Assessing and Controlling Spacecraft Charging Effects
RTCA/DO-160	Revision G, Ch 1	Environmental Conditions and Test Procedures for Airborne Equipment
SAE ARP-5412	Revision C	Aircraft Lightning Environment and Related Test Waveforms
SAE ARP-5415	Revision A	User’s Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
SAE ARP-5416	Revision B	Aircraft Lightning Test Methods
TOR-2014-02198	(2014)	Standard/Handbook for Radio Frequency (RF) Breakdown Prevention in Spacecraft Components
TOR-2014-02546	Baseline	Standard/Handbook for RF Ionization Breakdown Prevention in Spacecraft Components

3.0 E3 DESIGN REQUIREMENTS - GENERAL

3.1 MARGINS

[CV001] Safety critical systems, subsystems, and equipment shall have a margin of at least 6 decibels (dB) between its threshold of susceptibility and the space vehicle's Electromagnetic Environment (EME). The critical designation applies to:

1. Systems, subsystems, and equipment whose loss of function, malfunction, or degradation of performance due to EME could result in a critical or catastrophic hazard or,

2. Systems, subsystems, and equipment whose loss of inhibits due to EME could result in critical or catastrophic hazards.

Note: Pyrotechnic margins are addressed as part of the Hazards of Electromagnetic Radiation to Ordnance requirements set and documented in Section 5.0 herein.

> *Rationale: A margin is the difference between the electromagnetic stress level the equipment or system is required to withstand or tolerate and still remain operational, and the maximum stress level allowed to occur within the equipment or system. The electromagnetic stress of concern here is generally sourced external to the equipment or system including electrostatic charging and discharge effects and inter-system interference. Also of concern are any effects caused by either intra- or inter-system interference effects on pyrotechnic devices or related circuitry. Variability exists in system hardware form 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. In addition, uncertainties are inherently present in the verification process itself, caused by choice of methodology, limitations in simulation of a particular environment, and accuracy of measured data. Proper application of margins thus provides confidence that the design will perform as advertised in its prescribed operational environments.*
>
> *In many cases, compliance with the conducted and radiated susceptibility limits of their respective electromagnetic test requirements mean the subsystem or equipment has demonstrated a 6 dB margin with respect to the space vehicle's EME. In other cases, further analysis and/or mitigation may be required, such as, but not limited to, ensuring element pressure hull attenuation compliance. It is not intended for the hardware developer to simply double the susceptibility test limits to demonstrate this safety margin; the hardware developer should understand the failure mechanisms that could lead to a critical or catastrophic hazard and ensure that any noise energy due to the EME coupled into the subsystem or equipment is 6 dB below the threshold-of-susceptibility, even when system variability is taken into account.*

Typically, margins are not imposed on systems, subsystems, and equipment that do not have a critical designation. However, the procuring activity has the option to impose margins as deemed necessary.

3.2 INTRA-SYSTEM EMC

[CV002] The space vehicle's elements and systems shall be electromagnetically compatible between all elements, systems, subsystems, and equipment.

Rationale: This requirement ensures that (1) the various elements that comprise the space vehicle's architecture are electromagnetically compatible with each other and within themselves, and (2) the Radio Frequency (RF) communications systems used by each element are compatible with each other.

3.3 EXTERNAL COMPATIBILITY

[CV003] The space vehicle's elements and systems, as well as the integrated vehicle, shall be electromagnetically compatible with external interfaces.

Rationale: This requirement ensures that (1) the various elements that comprise the space vehicle's architecture are electromagnetically compatible with each other and within themselves, and (2) the RF communications systems used by each element are compatible with each other.

3.4 EXTERNAL RADIO FREQUENCY (RF) ELECTROMAGNETIC ENVIRONMENT

[CV004] The space vehicle's elements and systems shall be electromagnetically compatible with the external on-orbit RF EME defined in Table 3.4-1, launch vehicle EME, other visiting vehicle's EME, and extravehicular mobility unit's EME to ensure compliance with operational performance requirements.

The launch vehicle, other visiting vehicles (VV), and extravehicular mobility units RF EMEs will be defined at the interface per the Interface Requirements Document (IRD) between the space vehicle and respective interface.

Rationale: The use of RF emitters is constantly increasing. On-board emitters, as well as tracking, range safety, and other launch site emitters will illuminate the space vehicle's systems. Many of these emitters generate very high intensity RF fields. This requirement ensures the integrated vehicles and individual vehicle elements are electromagnetically compatible with the external RF EME during Ground and flight operations. Table 3.4-1 includes the actual electric field strength peak in volts per meter (V/m) from Earth-based emitters at 100 nautical miles in the frequency range from 1 megahertz (MHz) to 40,000 MHz. The values in Table 3.4-1 may be adjusted for the altitude at which the system becomes operational, typically a lower value than shown in the table. Figure 3.4-1 shows *the same information but with a background RF level and rounded up values from Table 3.4-1.*

The 150 V/m RS103 test levels may be lower than the RF environment which could illuminate external equipment. The RS103 test levels were chosen because these levels do not exceed the capabilities of commonly available EMI test equipment. In such cases where the environment exceeds the RS103 test level, other mitigation strategies may be required. Mitigation could include additional shielding, demonstrating that the equipment is incapable of responding to the frequency range in question (and no damage would occur if exposed to the higher levels), or other mitigations. All exceedance mitigation strategies shall be clearly documented.

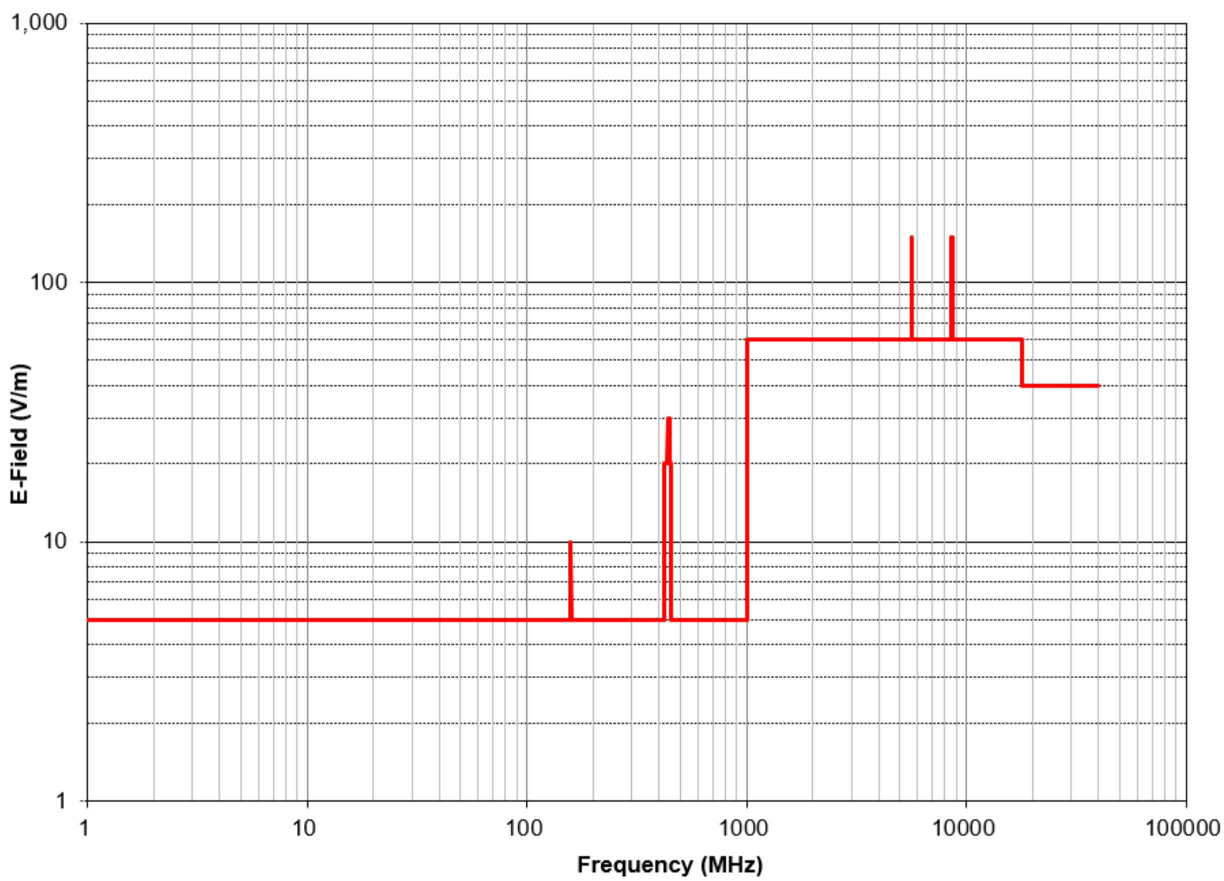

FIGURE 3.4-1 EXTERNAL RF EME DUE TO EARTH-BASED EMITTERS

TABLE 3.4-1 EXTERNAL RF EME DUE TO EARTH-BASED EMITTERS

Frequency (MHz)	Peak (V/m)
158	6
420.01-437.00	14
437.01-447.00	23
447.01-450	14
5650-5672.99	150
8500-8600.99	150

3.5 LIGHTNING EFFECTS

[CV005] Space vehicle systems, subsystems, or components shall meet their operational performance requirements and not propagate a hazard after exposure to a nearby lightning strike as described in the Launch Service Providers Lighting Requirements and/or Launch Vehicle Payload Requirements.

Note: Lightning indirect effects result when the electromagnetic fields and structural voltage rises produced by a strike near the vehicle induce voltages and current transients into electrical and electronic equipment. The purpose of this requirement is to assure that the space vehicle has some level of immunity to those transients so that “go/no-go” decisions can be made in a timely fashion after the vehicle experiences a lightning event and prevent costly “roll-back” scenarios. Lightning waveform definitions are contained in ***SAE ARP-5412, Aircraft Lightning Environment and Related Test Waveforms***. The specific lightning environment at each launch site and vehicle will vary due to differences in launch configurations and launch site lightning protection systems.

Rationale: Lightning indirect effects may result when the electromagnetic fields and structural voltage rises produced by a strike near the vehicle induce voltages and current transients into electrical and electronic equipment. The purpose of this requirement is to assure that the vehicle has some level of immunity to those transients so that “go/no-go” decisions can be made in a timely fashion after the vehicle experiences a lightning event. Immunity assurance will prevent costly “roll-back” scenarios. Lightning waveform definitions are contained in ***SAE ARP-5412***. *The specific lightning environment at each launch site will vary due to differences in launch vehicle configurations and launch site lightning protection systems.* ***MIL-STD-464, Electromagnetic Environmental Effects***

> ***Requirements for Systems,*** *Table 8 provides a generic lightning environment which can be used as a starting point for compliance until the element launch vehicle and launch site is identified. Information detailing requirement decomposition processes for lightning indirect effects is contained in* ***SAE ARP-5415, User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning. SAE ARP-5416, Aircraft Lightning Test Methods****, and* ***Radio Technical Commission for Aeronautics (RTCA)/DO-160, Environmental Conditions and Test Procedures for Airborne Equipmen****t, describe tests that should be considered for a verification approach.*

3.6 ELECTROMAGNETIC INTERFERENCE (EMI) CONTROL FOR SYSTEMS, SUBSYSTEMS, AND EQUIPMENT

[CV006] Individual systems, subsystems, and equipment, shall meet EMI control requirements contained in ***MSFC-SPEC-521, Electromagnetic Compatibility Requirements for Equipment and Subsystems***.

> *Rationale: Individual equipment, subsystem, and system EMI characteristics, such as conducted and radiated emissions; and conducted and radiated susceptibility, must be controlled to obtain a high degree of assurance that these items will function in their intended installations without unintentional electromagnetic interactions between other equipment, subsystems, or external environments.*

3.6.1 Non-Developmental Items (NDIs) and Commercial Information Technology Equipment (ITE) Used as Flight Hardware

[CV007] NDIs and ITE used as flight hardware shall meet EMI control requirements of ***MSFC-SPEC-521***.

> *Rationale: ITE and NDI are devices capable of transmitting interference signals. Examples of ITE include data processing equipment, office machines, electronic business equipment, and telecommunications equipment. NDI includes, for example, Commercial Off-The-Shelf (COTS) equipment and subassemblies. NDI and commercial ITE or other items that are used as flight hardware are subject to the same equipment and subsystem EMI specifications at the interface as other hardware developed for that system. This requirement is not applicable to Ground Support Equipment (GSE), Test Support Equipment (TSE), or test equipment. Each hardware provider or partner should develop E3 requirements for GSE, TSE, and test equipment to protect flight hardware during testing and Ground Operations*

3.7 ELECTROSTATIC DISCHARGE CONTROL

3.7.1 ESD Design Control and Withstand Ratings

[CV008] Electronic equipment and components shall demonstrate immunity to ESD events associated with operational deployment and operations.

> *Rationale: Electronic equipment and components are routinely exposed to ESD associated with orbital operations, including removal from packaging, installation, and electrical transients resulting from plasma vehicle charging processes. Failures caused by ESD result from the rapid transfer of charge (current) and the short duration, high-energy radiated electromagnetic fields generated during the ESD event. The effects of these failures may be immediate or latent (delayed), with the failure mode ranging from a temporary deviation in the subsystem's specified performance to damage requiring repair or replacement of the affected component(s) or subsystem.*

3.7.2 Plasma Vehicle Charging Control

[CV009] Individual space vehicle elements shall mitigate plasma vehicle charging to protect against puncture of materials and finishes; shock hazards from charge accumulation, and to control electromagnetic interference caused by electrostatic discharge arising from vehicle charging. Plasma environments are described in ***Space Launch System (SLS)-SPEC-159, Cross-Program Design Specification for Natural Environments (DSNE).***

> *Rationale: Spacecraft charging is a complex physical phenomenon that varies dramatically with orbital altitude, plasma density, vehicle design, and many other factors. Underlying physics, and appropriate requirements, associated with Plasma Vehicle Charging are contained in multiple references. These include:* ***NASA-HDBK-4002, Mitigating In-Space Charging Effects - A Guideline; NASA-HDBK-4006, Low Earth Orbit Spacecraft Charging Design Handbook****;* ***NASA-RP-1354, Spacecraft Environments Interactions: Protecting Against the Effects of Spacecraft Charging****;* ***NASA-RP-1375, Failures and Anomalies Attributed to Spacecraft Charging;*** *and* ***NASA-TP-2361, Design Guidelines for Assessing and Controlling Spacecraft Charging Effects****;* ***NASA-HDBK-4007, Spacecraft High-Voltage Paschen and Corona Design Handbook****;* ***NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment****.*

3.7.3 Solar Array Charging

[CV010] Space vehicle elements that have high voltage solar arrays and voltages greater than 55 Volts (V) shall comply with ***NASA-STD-4005A, Low Earth Orbit Spacecraft Charging Design Standard****.*

Rationale: Solar arrays and other units with exposed electrical contacts interact with the space plasma environment. These interactions may cause interference or damage due to arcing or current collection. Compliance with the requirements of ***NASA-STD-4005****, will ensure that solar array operations will be protected from the natural plasma environment without compromising safety or performance.* ***NASA-HDBK-4006*** *contains guidelines for high voltage solar array design.* ***NASA-HDBK-4002*** *contains recommendations for multiple plasma environments and points to* ***NASA-STD-4005*** *for solar array design to mitigate spacecraft charging effects.*

3.8 MULTIPACTION

[CV011] Space vehicle systems, subsystems, and equipment shall be free of multipaction effects.

Rationale: Multipaction is a resonant RF effect that occurs in a high vacuum. An RF field accelerates free electrons resulting in collisions with surfaces, thus liberating secondary electrons. In the case where the frequency of the signal is such that the RF field changes polarity in concert with the liberation of secondary electrons, an effect similar to an avalanche process results. This effect can lead to strong electrical discharges that can easily disrupt communications and navigation subsystems, and can, under severe conditions, lead to permanent equipment damage. It is, therefore, essential within the space vehicle systems that RF transmitting equipment and signals are not degraded by the action of multipaction. It is also essential that multipaction effects do not result in spurious signals that interfere with receivers.

Suggested references are:

AEROSPACE REPORT NO. Technical Operating Report (TOR)-2014-02198, Standard/ Handbook for Radio Frequency (RF) Breakdown Prevention in Spacecraft Components, AEROSPACE REPORT NO. TOR-2014-02546, Standard/Handbook for RF Ionization Breakdown Prevention in Spacecraft Components*, and* ***European Cooperation for Space Standardization (ECSS)-E-20-01A Rev.1, Space Engineering - Multipaction Design and Test.***

3.9 ELECTROMAGNETIC RADIATION HAZARDS

3.9.1 Hazards of Electromagnetic Radiation to Personnel

All devices that generate Radio Frequency radiation (including, but not limited to, antennas and wireless systems) should limit the amount of this radiation to which the crew can be exposed. RF safety requirements for ground personnel are found in ***Institute of Electrical and Electronics Engineers (IEEE) C95.1-2019****.*

If the space vehicle program utilizes tailored limits of ***IEEE C95.1-2019***, the requirement should follow the tailored limits.

Rationale: Radar and highly directional, high power RF systems usually present the greatest potential personnel hazard due to high transmitter output powers, antenna characteristics, and possible exposure of Ground Support and astronaut personnel.

3.9.2 Hazards of Electromagnetic Radiation to Fuel

[CV012] Individual space vehicle elements shall protect against the inadvertent ignition of fuels and propellants caused by the exposure to RF electromagnetic energy.

Rationale: The existence and extent of fuel ignition hazards are determined by comparing the actual incident RF power density to established safety criteria. Safe operating distances need to be determined based on fuel and propellant characteristics, the defined RF threat environment (i.e., the RF environment known to exist in the vicinity that can exceed ignition thresholds of the subject fuel or propellant), and compliance with necessary margins.

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

3.9.3 Hazards of Electromagnetic Radiation to Ordnance

[CV013] Pyrotechnic systems and subsystems contained in space vehicles shall comply with electromagnetic compatibility requirements of ***MIL-STD-1576 (Basic and Notice 1), Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems***, as modified for space vehicles and documented in Section 5 herein.

If the program utilizing this document already has a program-specific requirement set for pyrotechnics that duplicates requirements in Section 5, the program-specific requirements take precedence. If the program-specific requirements do not contain requirements similar to those in Section 5 herein, the Section 5 requirement subset shall be flowed to the program.

Note: This is from ***MIL-STD-1576***, Paragraph 4.4.1. The 20 dB margin of ***MIL-STD-1576*** is reduced to 16.5 dB for space vehicles.

Rationale: The design of pyrotechnic systems must preclude hazards from unintentional initiation and from failure to fire. RF energy of sufficient magnitude to degrade or fire pyrotechnics can be electromagnetically coupled into a pyrotechnic subsystem from the external electromagnetic environment. The possible consequences include both hazards to safety and performance degradation. Compliance with these requirements ensures prevention of performance degradation or inadvertent activation of Electroexplosive Devices (EEDs) or firing circuits. These requirements apply to all systems and subsystems utilizing explosive or pyrotechnic components, particularly electrically-initiated components. Assurance of safety of pyrotechnic systems from an EMC perspective is directly dependent on compliance with these requirements.

*Note: **MIL-STD-1576**, although cancelled by the United States Air Force Space and Missile Systems Center, is a NASA-Endorsed Standard. Although still publicly available on the Internet, the pertinent requirements from that document are provided in Section 5.*

3.10 LIFE CYCLE AND MAINTAINABILITY

[CV014] Space vehicles and their systems, subsystems, and equipment, shall meet the E3 requirements of this document throughout the following life cycle requirements:

a. Assembly
b. Storage
c. Handling
d. Packaging
e. Transportation
f. Checkout
g. Launch
h. Integration with other elements
i. Vehicle reconfiguration
j. Normal in-flight operation
k. Emergency and planned contingency operations
l. Disposal

Rationale: Advanced electronics and structural concepts offer tremendous advantages in increased performance of high-technology systems. These advantages may be lost or compromised if E3 protection concepts impact life cycle costs through excessive parts count, mandatory maintenance, or costly repair requirements. It is essential that life cycle considerations be included in any tradeoffs used to develop E3 protection. As an example, corrosion control is an important issue in maintaining EMC throughout the system's life cycle. It is important that design features that provide for corrosion control and that also *require periodic maintenance be accessible and not be degraded due to maintenance actions.*

3.11 ELECTRICAL BONDING

[CV015] Space vehicle elements, systems, subsystems, and equipment shall comply with ***NASA-STD-4003***.

Note: For pyrotechnic devices see program-specific ordinance bonding requirements

Rationale: Proper electrical bonding in accordance with bonding classifications and pertinent to the specific application is necessary to meet performance, safety, and EMC requirements.

3.12 ELECTRICAL POWER SYSTEMS (EPS) COMMON REFERENCE

[CV016] Electrical Power Systems (EPS) in the space vehicle shall incorporate a common reference using a distributed single point ground (SPG) architecture.

Rationale: Providing a common reference (sometimes referred to as a "ground plane") for power return enhances safety and operability of electrical circuits. A common reference to structure prevents unwanted direct current (DC) and alternating current (AC) noise currents from circulating through circuit shielding and structure, thereby minimizing potential EMI problems. In order to establish a distributed SPG, it is necessary to define isolation requirements for both primary and secondary EPS at equipment interfaces. Isolation requirements prevent multiple connections to structure that could create detrimental ground loops. See Figure 3.12-1 for illustration of a distributed single point ground architecture or see ***NASA-RP-1368, Marshall Space Flight Center Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook*** *for more information on distributed single point ground architecture.*

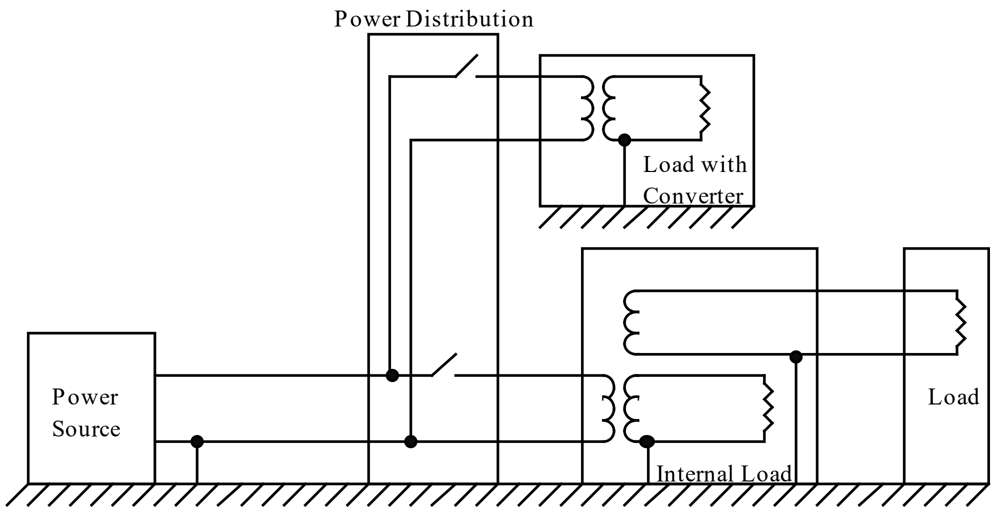

FIGURE 3.12-1 DISTRIBUTED SINGLE POINT GROUND ARCHITECTURE CONCEPT

3.12.1 Provision for Electrical Fault Clearing

[CV017] Each isolated space vehicle power source that provides power to equipment outside the power source chassis shall have the power return line connected to chassis/structure at one, and only one point for each source, to provide a fault current return path for circuit protection devices (fuses, circuit breakers, etc.).

Rationale: Electrical power circuits require a current return path, such that if an electrical fault to chassis/structure occurs, circuit protection devices are able to operate properly and prevent fire or shock hazards to personnel.

3.12.2 Primary to Secondary Power Isolation

[CV018] Primary space vehicle EPS shall be DC isolated from secondary power systems by a minimum of 1 megohm.

Rationale: DC isolation of primary and secondary electrical power systems is necessary to mitigate EMI problems or prevent circulating DC currents. Primary electrical power is power provided by system generation sources (e.g., solar arrays, fuel cells, Range to Grounds (RTGs)). Secondary power is power derived from primary power and conditioned by one or more power conversion stages. The 1 megohm value is used as pass/fail criteria *only. This requirement should not be interpreted to mean that a physical resistor should be installed to provide isolation in order to meet this requirement.*

3.12.3 Equipment Power Input Isolation

[CV019] Space vehicle equipment power inputs shall be DC isolated from chassis/structure by a minimum of 1 megohm.

Rationale: DC isolation of primary and secondary electrical power systems is necessary to mitigate EMI problems and/or prevent circulating DC currents. The 1 megohm value is used as pass/fail criteria only. This requirement should not be interpreted to mean that a physical resistor should be installed to provide isolation in order to meet this requirement.

3.12.4 Signal Return Isolation from Chassis/Structure

[CV020] Signal returns routed external to space vehicle subsystems or equipment (that is, outside the equipment enclosure) shall be isolated from chassis/structure by a minimum of 1 megohm, except at its single reference to structure. This requirement does not apply to Balanced Differential Circuitry and Coaxial cabling.

Rationale: Signal returns include, but are not limited to, analog, digital, discrete, and control signals, and must be isolated from chassis/structure to mitigate DC coupling of interference caused by chassis/structure electrical noise currents. The 1 megohm value is used as pass/fail criteria only. This requirement should not be interpreted to mean that a physical resistor should be installed to provide isolation in order to meet this requirement. Balanced differential circuitry is given special considerations and is addressed in Paragraph 3.12.5. Circuitry utilizing Coaxial Cabling is given special considerations and is addressed in Paragraphs 3.12.6.

3.12.5 Balanced Differential Circuit Isolation

[CV021] Balanced differential circuits routed external to space vehicle equipment shall be isolated from structure by a minimum of 6 kilohms.

Rationale: The use of balanced differential line drivers and receivers provides a high degree of common mode noise rejection, making in it an excellent means of sending and receiving data between equipment. Even circuitry that does not utilize a balanced line driver still has a high degree of common mode rejection given that the output impedance of the source is low compared to the impedance of the balancing resistors. The 6 kilohms value is based on the design of commercially available integrated circuits. Line drivers and receivers having balanced receivers and low impedance drivers are considered balanced *circuits, even though the source may be referenced to vehicle structure. See Figure 3.12.5-1 for generic examples of balanced differential circuitry.*

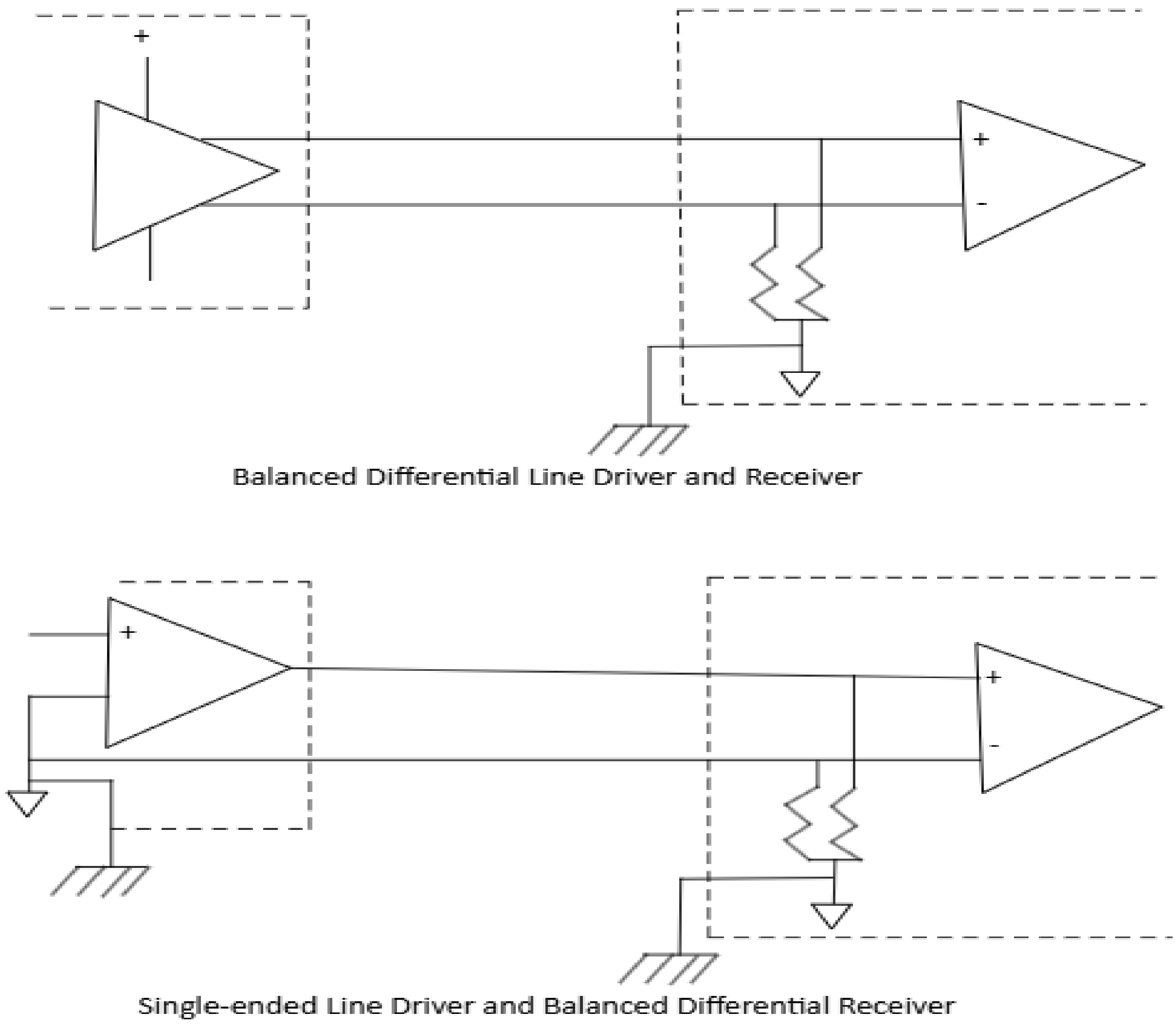

FIGURE 3.12.5-1 GENERIC EXAMPLES OF BALANCED DIFFERENTIAL CIRCUITRY

3.12.6 Coaxial Cabling

[CV022] Coaxial cabling where the outer most conductor provides the signal return path that is utilized in space vehicle elements and systems shall be permitted only when all frequency components of the signal are greater than or equal to 1 MHz.

Rationale: The intent is to mitigate interference that may be caused by low frequency external shield currents. For applications above 400 MHz and in critical RF circuits, electrical characteristics, such as attenuation, capacitance, structural return loss, environmental requirements, short leads, and grounding should be specifically considered and documented in the cable design. Coaxial and/or triaxial cable should not be used to interconnect equipment utilizing different power sources unless electrical isolation is provided (opto-isolators, transformers, etc.).

3.13 SIGNAL, COMMAND, CONTROL, AND POWER RETURNS

[CV023] All space vehicles systems, subsystems, and equipment signal, command, control, or power circuits routed wholly or partially external to their respective systems, subsystems, and equipment, shall employ separate dedicated returns routed and co-located with their respective signal, command, control, or power circuits.

Rationale: The use of separate returns minimizes noise voltages created by currents flowing through common impedances.

3.13.1 Signal, Command, Control, and Power Return Isolation

[CV024] All signal, command, control, and power circuit returns shall be isolated from other signal, command, control, and power circuit returns by a minimum of 1 megohm.

Rationale: Isolating circuit returns prevents conducted crosstalk between individual and unrelated circuits. The 1 megohm value is used as pass/fail criteria only. This requirement should not be interpreted to mean that a physical resistor should be installed to provide isolation in order to meet this requirement.

The phrase “except at the single point Ground”, when used to acknowledge that an isolation measurement at the system level, with all equipment, cabling, and interconnections installed would result in a value much, much less than 1 megohm - does little to elucidate the understanding of the requirement or the purpose of providing isolation between various circuit returns.

The aim of this requirement is to ensure that signal, command, control, and power circuit returns are not interconnected in such a manner that results in multiple chassis references *that allow EMI noise or circulating DC currents in the vehicle structure. It also prevents signal returns from using alternate, unintended current return paths that would allow increased noise coupling paths and circuits. For example, a transmit circuit in one equipment may have its return referenced through its power circuitry to chassis while the corresponding receive circuit in the second equipment would be properly isolated from chassis. Correspondingly, the receive circuit in the first equipment would be properly isolated from chassis, while the transmit circuit in the second equipment is chassis referenced. In this manner, the isolation between the two channels is isolated, such that there is no intentional current flow through structure or through an unintentional return path.*

3.14 CABLE AND WIRE DESIGN FOR ELECTROMAGNETIC COMPATIBILITY

3.14.1 Circuit Classification

[CV025] Circuits or cables shall be categorized according to their interference and susceptibility characteristics.

Rationale: The determination of wiring and cabling treatment (cable shielding, twisting, controlled impedance, routing, etc.) is based on frequency, sensitivity, operating voltage, and impedance, so that noisy circuits can be routed or separated away from sensitive circuits. ***SSP 30242, Space Station Cable/Wire Design and Control Requirements for Electromagnetic Compatibility*** *may be used as a guide.*

3.14.2 Wire and Cable Bundling, Routing, and Separation Requirements

[CV026] Cables and harnesses shall be designed, grouped and/or bundled, and routed to control cable-to-cable crosstalk, such that the system operational performance requirements are met.

Rationale: Cables and harnesses must be routed in close proximity within the available volume of a spacecraft. Currents flowing in these cables and harnesses generate both electric and magnetic fields that will couple in the near field and induce currents and voltages into co-located circuits. These induced currents and voltages are referred to as cross-talk. Without proper cable and harness design, grouping, and routing, cross-talk will degrade susceptible circuits and can result in loss of proper control of systems, loss of communications, or other undesirable effects.

3.14.3 Shield Termination

3.14.3.1 Individual Cable Shield Termination

[CV027] Shields on individual cables that interconnect space vehicle systems, subsystems, and equipment, shall be terminated to connector backshells at cable ends and at intermediate break points, such as bulkhead feedthroughs unless contained in an overall harness shield that meets the requirements of Paragraph 3.14.3.2.

Rationale: Cable shields should be terminated at all ends to maximize shielding effectiveness. Circumferential termination is the preferred method. Termination into connector pins of cable and harness shields that are not otherwise protected by overbraid or a gross overshield severely degrades the shielding effectiveness of the cable or harness shield and that of the enclosure that is penetrated by the shield termination. Pigtail termination of shields degrades the shielding effectiveness proportional to how long the pigtail is due to the added inductance. Therefore, pigtails should be kept as short as possible. If pigtails are used, the EMI test needs to represent this "flight-like" cable connector configuration.

3.14.3.2 Harness Overbraid or Gross Overshield Termination

[CV028] Harness overbraid or gross overshields shall be terminated peripherally (360 degrees) through connector backshells at all ends and at intermediate break points.

Rationale: Peripheral terminations provide the lowest impedance termination and enable flexibility and latitude in the termination of individual cable and harness shields that are wholly contained within the overbraid or gross overshield volume.

3.15 CORONA

[CV029] Space vehicle systems, subsystems, and equipment, and cables and harnesses that interconnect them, shall operate without corona/arcing due to the ionization of gases at any atmospheric pressure that may be encountered.

Rationale: Corona/arcing can cause EMI problems and/or contribute to hardware failures.

Reference:

(1) AIAA 2004-1260, "Paschen Considerations for High Altitude Airships," D.C. Ferguson and G.B. Hillard, reference measurements by W.G. Dunbar

(2) "Measurements of the Breakdown Potentials for Different Cathode Materials in the Townsend Discharge," M.A. Hassouba, F.F. Elakshar and A.A. Garamoon, FIZIKA A 11 (2002) 2, 81-90.

3.16 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E3) CONTROL PLAN

The Electromagnetic Environmental Effects (E3) Control Plan defines the approach for implementation of an Electromagnetic Effects (EME) Control Program. E3 engineers should have a systems engineering overview of the design, manufacturing, and test activities relevant to the system to properly support development of the E3 Control Plan. This will ensure that bonding, isolation, shielding, and other requirements of this document are addressed by the hardware items produced.

The Electromagnetic Environmental Effects (E3) Control Plan should document an approach for implementation of an EMC control program for the element. The detailed plan should consider the following areas:

a. Internal organization and responsibility.

b. System compatibility.

c. Subsystem compatibility.

d. Subsystem and equipment requirements.

e. Electromagnetic interference safety margins for critical equipment.

f. Interference and susceptibility control.

g. Degradation criteria.

h. Cable design and routing.

i. Electrical power and electrical interface.

j. Power frequency leakage current.

k. Electrical bonding.

l. Circuit grounding and isolation.

m. Lightning protection.

n. Lightning critical items list.

o. Static electricity (e.g., triboelectrification, electrostatic discharge, corona, and P-Static).

p. Personnel hazards.

q. Pyrotechnics and bridge wire actuated devices (BWAD's).

r. Spacecraft charging controls.

s. EMC analysis requirements.

t. EMC verification planning and methodology.

u. EMC, lightning protection, and ESD documentation and reports.

The plan should include design and test requirements which will assure compatibility within the element as well as with all external interfaces. This includes modification of equipment level requirements to be compatible with special element requirements and the EMC sections of applicable interface requirements.

3.17 ELECTROMAGNETIC INTERFERENCE (EMI) TEST REPORT

The equipment level EMI qualification test report should include, as a minimum, the following information:

a. Description of the equipment under test (EUT), including its function, characteristics, and description of cables used during testing.

b. List of tests performed with pass/fail indications.

c. Any approved deviations from test procedures or limits.

d. Traceability of test equipment calibration.

e. A reference to the approved EMI test procedure.

f. Nomenclature of test equipment.

g. Serial numbers of test equipment and version of software used.

h. Calibration due date of test equipment.

i. Photographs or diagrams of the actual test set up and EUT, with identification.

j. Transfer impedance of current probes.

k. Antenna factors.

l. Impedance values of Line Impedance Stabilization Networks (LISN).

m. The ambient radiated and conducted electromagnetic emission profile of the test facility.

n. Scan speeds.

o. Measurement receiver bandwidths.

p. Antenna polarization.

q. Power line voltages, frequencies (where applicable), and power consumption or current usage.

r. Low-noise amplifiers (LNA) compression points

3.18 MODIFICATIONS TO REQUIREMENTS

If an equipment developer adds additional or more stringent requirements than those stated here to the equipment manufacturers, those new requirements should be documented in detail in the systems level E3 Control Plan.

4.0 E3 DESIGN VERIFICATIONS GENERAL

Verification methods are provided within this section for the corresponding requirements in Section 3.0.

Inspection - Verification by inspection is the physical evaluation of equipment and/or documentation to verify design artifacts. Inspection is used to verify construction features, workmanship, and physical dimensions and condition (such as cleanliness, surface finish, and locking hardware).

Demonstration - Verification by demonstration is the actual operation of flight or ground equipment or teams to evaluate its functional performance and/or its interfaces to other equipment or teams. The primary distinction between demonstration and test is that demonstrations provide qualitative results, whereas tests provide quantitative results.

Analysis - Verification by analysis is a process used in lieu of (or in addition to) testing and inspection. Analysis techniques may include statistics and qualitative analysis, computer and hardware simulations, and computer modeling. Analysis should be used only when all of the following conditions apply: (1) rigorous and accurate analysis is possible, (2) verification by test is not feasible or cost effective, and (3) verification by inspection is not adequate.

When conducting Verification by analysis, the models, simulations, and analysis tools must be accredited by the Program and Element/Modules to certify appropriate fidelity and software development quality. The accreditation authority ensures that the tools have sufficient pedigree to provide usable information for decision-making, at the level of criticality required.

Test - Verification by test is the actual operation of flight, flight-like, and/or ground equipment with the necessary test support equipment and test environment. Test also applies to hardware verifications done on flight-like systems in test facilities, such as a System Integration Laboratory (SIL) and a Multi-Element Integration Test (MEIT) lab.

4.1 MARGINS

[CV001V] EMC Margin shall be verified by test, analysis, or a combination thereof.

Verification shall be considered successful when the following conditions are met:

a. Tests have verified through physical demonstration that equipment or a system design can withstand or tolerate the required electromagnetic stress and remain operational, or

b. Analysis has verified that the design thresholds of susceptibility for the system, subsystems, and equipment are 6dB above the maximum stress level allowed/expected to occur within the system.

Note: In many cases, compliance with the conducted and radiated susceptibility limits of MSFC-STD-521 means the subsystem or equipment has demonstrated a 6 dB margin with respect to the vehicle's EME. In other cases, further analysis may be required or mitigating circumstances, such as element pressure hull attenuation, should be taken into consideration. **It is not intended the hardware developer simply double the susceptibility test limits to demonstrate this safety margin;** the hardware developer should understand the failure mechanisms that could lead to a critical or catastrophic hazard and ensure that any noise energy due to the EME coupled into the subsystem or equipment is below the threshold of susceptibility, even when system variability is taken into account.

4.2 INTRA-SYSTEM EMC

[CV002V] Intra-system EMC within the space vehicle systems shall be verified through analysis and test. Verification shall include EMC for all planned simultaneous operations, including RF systems, and shall be maintained at certification levels over the design life cycle.

Verification shall be considered successful when the following conditions are met:

a. Tests have verified through physical demonstration that equipment or a system design can withstand or tolerate the required electromagnetic stresses and remain operational,

b. Tests have verified through physical demonstration that equipment or a system design can remain below the required electromagnetic emissions and remain operational, and

c. Analysis has verified that the design’s testing performed prove that the space vehicle systems and elements are compatible within themselves and each other while meeting the design, functional, and operational performance requirements.

4.3 EXTERNAL COMPATIBILITY

[CV003V] Space vehicle systems and external interface EMC shall be verified through test, analysis, and inspection. EMC verification shall include all planned simultaneous operations that interface with the space vehicle, including transportation systems, recovery systems, RF systems (e.g., Tracking and Data Relay Satellite System, Range Safety), and other EMI emitting entities. EMC verification shall be achieved for all planned simultaneous subsystem operations and shall be maintained at certification levels over the design life cycle. Inspection shall verify that all space vehicle systems comply with all requirements provided herein.

Verification shall be considered successful when the following conditions are met:

a. Testing or a combination of analysis and test have verified equipment, and subsystems successfully comply with design, functional and operational performance requirements when exposed to planned simultaneous operations.

b. Analysis results have verified all systems successfully comply with design, functional and operational performance requirements when exposed to planned simultaneous operations.

c. Inspection has verified the contents of external Interface Requirements Document (IRD) verification submittals demonstrate compliance of the interface.

4.4 EXTERNAL RADIO FREQUENCY (RF) ELECTROMAGNETIC ENVIRONMENT

[CV004V] External EME EMC shall be verified by analysis of test results. The system shall meet functional and performance requirements without degradation from the presence of the electromagnetic environment. Analyses shall use system, subsystem, or equipment test results to show hardware's minimal immunity levels.

Verification shall be considered successful when analysis results verify that the system is compatible with the external EME.

NOTE: The levels shown in Table 3.4-1 are Worst Case environments. It is assumed that the actual levels expected at the system level would be derived from those in the Tables; the derived levels and rationale for derivation should be included in the verification data.

4.5 LIGHTNING EFFECTS

[CV005V] During and after lightning exposure, qualification tests and analysis shall verify that all vehicle systems meet EMC operational performance requirements and/or do not propagate a hazard. Analysis shall compare all test data and hardware configurations to ensure operational and performance requirements during and after exposure to lightning indirect effects and/or hazard propagation is prevented within and across element interfaces.

Verification shall be considered successful when the following conditions are met:

a. During the tests, all systems shall successfully complete functional and operational performance requirements or have demonstrated prevention of hazard propagation.

b. Analysis shows that all configurations demonstrate compliance with functional and operational performance requirements or have demonstrated prevention of hazard propagation.

4.6 ELECTROMAGNETIC INTERFERENCE (EMI) CONTROL FOR SYSTEMS, SUBSYSTEMS, AND EQUIPMENT

[CV006V] EMI control for systems, subsystems and equipment verification shall be by test to verify compliance with ***MSFC-SPEC-521*** using flight, or flight-like, cables. Flight-like cables must have the same configuration using the same methods of shield termination as the flight cable harness. Equipment Under Test (EUT) shall be bonded to the copper bench top in the same manner as it is bonded to vehicle structure during flight.

Verification shall be considered successful when the following conditions are met:

a. Emissions are below limits of ***MSFC-SPEC-521***

b. Equipment and subsystems are immune to interference when subjected to susceptibility test levels of ***MSFC-SPEC-521***

Note: The Visiting Vehicle interface requirements documents and annexes may impose additional susceptibility test levels.

4.6.1 Non-Developmental Items (NDIs) and Commercial ITE Used as Flight Hardware

[CV007V] NDIs and Commercial ITEs EMC verification shall be by test, analysis and inspection to verify compliance with ***MSFC-SPEC-521*** using flight, or flight-like, cables. Flight-like cables must have the same configuration using the same methods of shield termination as the flight cable harness. EUT shall be bonded to the copper bench top in the same manner as it is bonded to vehicle structure during flight.

When used as flight hardware, the analysis for the NDI and Commercial ITE that are certified to the appropriate commercial certifications shall:

1) Encompass the conducted and radiated EME and shall meet operational and performance requirements when exposed to said EME, and

2) Shall not compromise the EMC of the integrated space vehicle subsystems, systems, and elements.

Inspection shall verify that NDI and Commercial ITE have appropriate certifications that meet the Commercial EMI standards specified by - International Special Committee on Radio Interference (**CISPR**) **22**: 2008, **Information technology equipment – Radio Disturbance Characteristics – Limits and methods of measurement**, **CISPR 24**: 2010, **Information technology equipment – Immunity characteristics – Limits and methods of measurements**, **CISPR 35**: 2016, **Electromagnetic compatibility of multimedia equipment – Immunity requirements**, or ***RTCA/DO-160***.

Verification shall be considered successful when the following conditions are met:

a. Emissions are below limits of ***MSFC-SPEC-521***.

b. Equipment and subsystems are immune to interference when subjected to susceptibility test levels of ***MSFC-SPEC-521***.

Or verification shall be considered successful when the analysis results show the use of NDIs and commercial ITE, certified to appropriate commercial certifications, shall not compromise operational and performance requirements or compromise the EMC of the integrated space vehicle, vehicle subsystems, systems, and elements.

Note: The Visiting Vehicle interface requirements documents and annexes may impose additional susceptibility test levels.

4.7 ELECTROSTATIC DISCHARGE (ESD) CONTROL

4.7.1 ESD Design Control and Withstand Ratings

[CV008V] Subsystem and equipment immunity to ESD events associated with operational deployment and operations shall be verified by test and inspection.

Inspection shall verify that appropriate test points have been identified and tested. Test points should include, as a minimum, those areas that are accessible by persons during operations, installation, or remove and replace events; especially those occurring on orbit. Areas accessible only during maintenance operations are excluded. Testing shall verify immunity-to-damage - when exposed to the 8 kilovolt (kV) contact discharge or the 15 kV air discharge waveform in accordance with ***IEC 61000-4-2 (2008), Electromagnetic Compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic Discharge Immunity Test*** or ***MSFC-SPEC-521***, requirement CS118.

Verification shall be considered successful when inspection shows personnel accessible test points have been identified and testing shows immunity-to-damage/upset from ESD event waveforms - in cases where the equipment performs a critical function . See ESD event waveform information in ***IEC 61000-4-2*** or ***MSFC-SPEC-521***, CS118.

4.7.2 Plasma Vehicle Charging Control

[CV009V] Mitigation of plasma vehicle charging effects shall be by inspection and analysis. Inspection shall verify that proper bonding of conductive and partially conductive surfaces by verifying hardware fabrication methods and processes - along with installation measurements that demonstrate proper electrical bonding has been achieved. Analysis shall verify compliance with requirements by demonstrating that deposition of electrostatic charge on the outer mold line of the vehicle shall not cause puncture of materials, degradation of finishes, electrical discharges or shock hazards to personnel, or RF interference to on-board avionics, electrical systems, or sensitive antenna-connected communications and tracking system receivers.

Verification shall be considered successful when the following conditions are met:

a. All conductive surfaces exposed to plasma charging are shown to be connected to structure through a path of resistance no greater than $1x10^9$ ohms.

b. All partially conductive paints or similar materials, applied over conductive substrates or over the top of non-conductive or dielectric substrates, and exposed (Line of Sight) to plasma charging, are shown to be connected to structure at the edges - through a path of resistance no greater than $1x10^9$ ohms and exhibit a resistivity thickness product of $\rho * d \leq 1x10^9$ ohm*centimeter^2, where ρ is the bulk resistivity of the partially conductive material in ohm-centimeters, and d is the thickness of the partially conductive material in centimeters.

c. All materials that cannot be made at least partially conductive and are exposed (Line of Sight) to plasma charging shall perform a detailed analysis based on spacecraft geometry, material properties, and the spacecraft charging environment as defined in Section 3.3.3 of SLS-SPEC-159, Cross-Program Design Specification for Natural Environments (DSNE), as deemed applicable by mission parameters. The analysis shall show the following:

   1. All dielectric surface voltages are less than 500V positive with respect to adjacent exposed conductive surfaces and that no interface between dielectric surfaces and adjacent exposed conductive surfaces exhibits an electric field intensity greater than $1x10^4$ V/centimeter, or

   2. Electrostatic discharges resulting from elevated dielectric surface voltages relative to exposed conductive surfaces, or elevated dielectric to conductive surface interface electric field intensities, do not cause undesirable or intolerable Thermal Protection System (TPS) contamination or damage leading to degradation of thermal protective capability or undesirable or intolerable electromagnetic interference, upset, or permanent damage to avionic or electrical systems.

4.7.3 Solar Array Charging

[CV010V] The EMC of high voltage solar arrays (> 55 V) and/or other units with exposed electrical contacts shall be verified by test. High voltage solar arrays may charge to high negative voltages (< -200 V) with respect to the dielectrics they are touching. EMC requires that they function at their design voltages in the space plasma environment without charging, arcing or collecting sufficient current from the plasma that would affect safety or performance. Compliance shall be demonstrated by test using the methods listed below. The testing required is determined by the type of plasma environment and both tests may be required.

Verification shall be considered successful when test results show that solar arrays and/or other units with exposed electrical contacts function at their design voltages and collect currents that are not in excess of those defined below, have trigger arc thresholds greater than or equal to twice the array string voltage or unit floating voltage, and are not capable of supporting sustained arcs. These tests may be performed as part of the unit thermal vacuum or depressurization/re-pressurization qualification test provided all of the requirements of this section are met.

During testing, the unit is placed in a vacuum chamber at a neutral pressure lower than 2.4 x 10^{-5} torr. There are two types of plasma tests that may be necessary - under Low Earth Orbit (LEO) conditions and under Geosynchronous Earth Orbit-type (GEO-type) conditions. GEO-type conditions may be assumed to apply in lunar-transit orbits above about 10,000 km altitude, in the vicinity of the moon, and on the lunar surface. In the LEO testing, a plasma source will generate a plasma with electron densities between 10^5 and 10^6 electrons/centimeter^3 and electron temperatures between 0.1 and 5 electron-volts.

4.8 MULTIPACTION

[CV011V] Freedom from multipaction effects shall be verified through test and analysis. Analysis shall verify that sufficient margin can be demonstrated through test, and how that demonstration is to be shown. Based on the completed analysis results, the test shall verify that multipaction effects do not occur under high vacuum conditions for RF equipment.

Verification is considered successful when analyses and tests show that the equipment or subsystem is free of multipaction effects in high vacuum conditions.

4.9 ELECTROMAGNETIC RADIATION HAZARDS

4.9.1 Hazards of Electromagnetic Radiation to Personnel

No Verification Required.

4.9.2 Hazards of Electromagnetic Radiation to Fuel

[CV012V] Safety regarding RF hazards to fuels shall be verified by inspection and analysis with testing limited to special circumstances. Inspection and analysis shall verify that adequate control measures have been incorporated into the design to preclude fuel ignition, such as shielding and proper electrical grounding and bonding of any conductors in near proximity to fuel containment vessels, fuel hoses, ducts, and so forth. Operational considerations also will be included in the analysis, identifying internally and externally generated RF maximum capabilities and compliance with necessary margins. When deemed necessary, testing shall verify compliance with space vehicle requirements by demonstrating that exposure of fuel samples cannot be ignited by exposure to prescribed RF environments.

Verification shall be considered successful when inspection, analysis, and tests show that the space vehicle requirements for safety regarding RF hazards to fuel have been satisfied.

4.9.3 Hazards of Electromagnetic Radiation to Ordnance

[CV013V] Pyrotechnic devices and systems performance degradation shall be verified by analysis, tests, and inspection. Tests shall be required, unless a theoretical assessment positively indicates that the RF-induced energy on EED firing lines or in electronic circuits associated with safety-critical functions is low enough to assure an acceptable safety margin in the specified EME (bearing in mind the possible inaccuracies in the analysis technique). Analysis shall verify that adequate control measures have been incorporated into the design, such as shielding, cable routing, proper electrical grounding and bonding. Operational considerations also will be included in the analysis, identifying internally and externally generated RF maximum capabilities. Testing shall verify compliance with space vehicle requirements by demonstrating that pyrotechnic response to prescribed RF environments is below the specified 16.5 dB safety margin – ***see MSFC-SPEC-3635, Pyrotechnic System Specification***. Inspection shall verify that proper operational constraints are implemented when operational controls are necessary to maintain 16.5 dB safety margin.

Verification shall be considered successful when test, analysis, and inspection show that the space vehicle requirements for safety regarding RF hazards to pyrotechnics have been satisfied.

4.10 LIFE CYCLE AND MAINTAINABILITY

[CV014V] Life cycle hardness shall be demonstrated by inspection, analysis, test, or a combination thereof. Inspection and/or analysis shall verify that design features and considerations that have been incorporated into various subsystems and equipment will act together in an integrated sense to guarantee the longevity of electromagnetic hardness characteristics, without unnecessarily driving up parts counts or maintenance costs. Tests shall verify that various combinations of features provide for electromagnetic protection.

Verification shall be considered successful when inspection, analysis, and test demonstrate that various design features and techniques can act together to provide a complete electromagnetic protection without incurring unnecessary parts counts or maintenance costs.

4.11 ELECTRICAL BONDING

[CV015V] Electrical bonding shall be verified by test, analysis, and inspection. Testing shall verify the adequacy of electrical bonding processes and procedures for each bonding class. Analysis shall verify that correct bond classes have been identified and bonding paths are designed to meet identified bonding class requirements. Inspection shall verify that proper bonding processes, procedures, and classes have been identified in hardware drawings and documentation. Inspection shall also verify that hardware fabrication and installation measurements demonstrate that proper electrical bonding has been achieved.

Verification shall be considered successful when the following conditions are met:

a. Inspection shows each bond joint is shown to have the correct bonding class requirements,

b. Analysis of the fabrication and installation procedures will result in a proper electrical bond, and

c. Testing of sample bonds meet the identified bond class resistance limits.

4.12 ELECTRICAL POWER SYSTEMS (EPS) COMMON REFERENCE

[CV016V] Verification that each electrical power source is DC isolated from chassis, structure, equipment conditioned power return/reference, and signal circuits by a minimum of 1 MΩ, individually, except at the power bus' single point Ground, shall be verified by inspection. Inspection shall verify that that each isolated electrical power source or paralleled sources is connected to structure at no more than one point.

The verification shall be considered successful when inspection of drawings and quality records (Quality records include workmanship resistance measurements) indicates that each isolated electrical power source is connected to structure at no more than one point.

4.12.1 Provision for Electrical Fault Clearing

[CV017V] Ground referencing for electrical fault clearing shall be verified by inspection. Inspection shall verify that the design provides a fault current return path to allow circuit protection devices to clear electrical faults.

Verification shall be considered successful when inspection has shown that each power circuit has one, and only one, path to structure that is capable of carrying any fault current that may occur until a circuit breaker or fuse disconnects the faulty circuit.

4.12.2 Primary to Secondary Power Isolation

[CV018V] Power isolation shall be verified by analysis and inspection. Analysis shall verify that primary power is isolated from secondary power even in unpowered or operational modes, such as standby mode, so that unpowered circuitry cannot create a sneak path that bypasses isolation. Inspection of drawings and installation records shall verify that each primary power system is DC isolated from secondary power systems.

Verification shall be considered successful when analysis shows no sneak path from primary to secondary power exists and inspection shows that that primary power is DC isolated from secondary power.

4.12.3 Equipment Power Input Isolation

[CV019V] Equipment input isolation shall be verified by analysis and inspection.

Analysis shall verify that that each power input is DC isolated from chassis/structure even in unpowered or operational modes, such as standby mode, so that unpowered circuitry cannot create a sneak path that bypasses isolation. Inspection of drawings and installation records shall verify that each power input is DC isolated from chassis/structure.

Verification shall be considered successful when analysis shows no sneak path to chassis/structure exists and inspection shows that each power input is isolated from chassis/structure by 1 megohm.

4.12.4 Signal Return Isolation from Chassis/Structure

[CV020V] Signal return isolation shall be verified by analysis and inspection.

Analysis shall verify that the circuit return design provides DC isolation from chassis/structure, except at a single reference to structure, even in unpowered or operational modes, such as standby mode, so that unpowered circuitry cannot create a sneak path that bypasses isolation. Inspection of drawings and installation records shall verify that the circuit return design provides DC isolation from chassis/structure, except at a single reference to structure.

Verification shall be considered successful when analysis and inspection show signal returns are shown to be isolated from chassis/structure, except at a single reference to structure.

4.12.5 Balanced Differential Circuit Isolation

[CV021V] Balanced differential circuit isolation shall be verified by analysis and inspection. Analysis shall verify that each balanced differential signal return is isolated from chassis/structure by 6 kilohms even in unpowered or operational modes, such as standby mode, so that unpowered circuitry cannot create a sneak path that bypasses isolation. Inspection of drawings and installation records shall verify that each balanced differential signal return is isolated from chassis/structure by 6 kilohms.

Verification shall be considered successful when analysis and inspection shows that balanced differential signal returns are isolated from structure/chassis equal to or greater than six kilohms.

4.12.6 Coaxial Cabling

[CV022V] Verification that coaxial cabling is only used when all frequency components of the signal are greater than or equal to 1 MHz shall be by analysis and inspection. Analysis shall verify that each signal carried on coaxial cabling have frequency components that are all greater than or equal to 1 MHz, even in unpowered or operational modes, such as standby mode, so that unpowered circuitry cannot create a sneak path that allows lower frequency components onto the coaxial cabling. Inspection of drawings and installation records shall verify that electrical/electronic circuits using coaxial cabling have frequency components that are all greater than or equal to 1 MHz.

Verification shall be considered successful when analysis and inspection of drawings and installation records show that electrical/electronic circuits using coaxial cabling are only used when all frequency components of the signal are greater than or equal to 1 MHz.

4.13 SIGNAL, COMMAND, CONTROL, AND POWER RETURNS

[CV023V] Verification that all signal, command, control, and power circuits routed wholly or partially external to space vehicle systems, subsystems, and equipment employ separate dedicated returns routed and co-located with their respective signal, command, control, or power circuits shall be by inspection. Inspection of drawings and installation records shall verify that the signal, command, control, and power circuits routed wholly or partially external to space vehicle systems, subsystems, and equipment employ separate dedicated returns routed and co-located with their respective signal, command, control, or power circuits.

The verification shall be considered successful when inspection of drawings and quality records (Quality records include installation records and as-built compliance records) indicates that all signal, command, control, and power circuits routed wholly or partially external to space vehicle systems, subsystems, and equipment employ separate dedicated returns routed and co-located with their respective signal, command, control, or power circuits.

4.13.1 Signal, Command, Control, and Power Return Isolation

[CV024V] Verification that the circuit conductors are DC isolated from signal, command, control, and power circuit returns by a minimum of 1 megohm, individually, when all grounds are not terminated to the single point Ground/Reference shall be verified by analysis and inspection. Analysis shall verify that the circuit conductors are DC isolated from signal, command, control, and power circuit returns by a minimum of 1 megohm, individually, when all grounds are not terminated to the single point ground/reference, even in unpowered or operational modes, such as standby mode, so that unpowered circuitry cannot create a sneak path that bypasses isolation. Inspection of drawings and installation records shall verify that the circuit conductors are DC isolated from signal, command, control, and power circuit returns by a minimum of 1 megohm, individually, when all grounds are not terminated to the single point ground/reference.

The verification shall be considered successful when analysis and inspection of drawings and quality records (Quality records include workmanship resistance measurements) indicates that circuit conductors are DC isolated from signal, command, control, and power circuit returns by a minimum of 1 megohm, individually, when not terminated by the signal circuit’s single point Ground/Reference.

4.14 CABLE AND WIRE DESIGN FOR ELECTROMAGNETIC COMPATIBILITY

4.14.1 Circuit Classification

[CV025V] Cable and wiring allocation into different classes shall be verified by inspection. Inspection shall verify that cable and wiring has been allocated into classes having similar signal and power characteristics.

Verification shall be considered successful when inspection of verification submittal information shows compliance for circuit classification.

4.14.2 Wire and Cabling Bundling, Routing, and Separation Requirements

[CV026V] Verification shall be by inspection. Inspection shall verify that all circuits routed together in a bundle are of the same EMC classification and that each bundle type is physically separated from other bundles according to their classification.

Verification shall be considered successful when inspection of drawings and quality records (Quality records include workmanship measurements) indicates that all circuits routed together in a bundle are of the same EMC classification and that each bundle type is physically separated from other bundles according to their classification.

4.14.3 Shield Termination

4.14.3.1 Individual Cable Shield Termination

[CV027V] Verification shall be by inspection. Inspection shall verify that shields on individual cables that interconnect space vehicle systems, subsystems, and equipment, shall be terminated to connector backshells at cable ends and at intermediate break points, such as bulkhead feedthroughs.

Verification shall be considered successful when inspection of drawings and quality records (Quality records include workmanship measurements) indicates shields on individual cables that interconnect space vehicle systems, subsystems, and equipment, are terminated to connector backshells at cable ends and at intermediate break points, such as bulkhead feedthroughs.

4.14.3.2 Harness Overbraid or Gross Overshield Termination

[CV028V] Overall cable shield termination shall be verified by inspection. Inspection shall verify that overall cable shields are terminated peripherally (360 degrees) through connector backshells.

Verification shall be considered successful when inspection of drawings and installation documentation shows that overall shields are terminated peripherally (360 degrees) through connector backshells.

4.15 CORONA

[CV029V] Verification shall be by test, analysis, or inspection. Test is required for equipment containing high voltages (> 190 V peak) that may be exposed to partial pressures (> 1.0 × 10-1 N/m2). However, analysis or inspection can be performed in lieu of testing if the equipment is operated in a vacuum, or the high voltage components and circuits are encapsulated or contained within a hermetically sealed chassis that contains a dry, high dielectric gas.

Verification is considered successful when any of the following are met:

a. Testing shows that coronal discharges do not occur in equipment operating at pressures greater than 1.0 × 10-1 Newton/meter2 (N/m2).

b. Analysis shows that the equipment design maintains an internal pressure of 1.0 × 105 N/m2 inside the sealed chassis over the operational lifetime of the equipment.

c. Inspection of design shows that the high voltage circuits or components are encapsulated in an insulating medium with dielectric strength of 10 kilovolts/millimeter or greater

4.16 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E3) CONTROL PLAN

No verification required.

4.17 ELECTROMAGNETIC INTERFERENCE (EMI) TEST REPORT

No verification required.

4.18 MODIFICATIONS TO REQUIREMENTS

No verification required.

5.0 MIL-STD-1576 REQUIREMENTS

The following requirements are the applicable requirements from MIL-STD-1576, as modified for use in space vehicles. Verification is called out in 4.9.3.

5.1 INADVERTENT ACTIVATION

The electroexplosive subsystem shall be designed to limit the power produced at each EED by the electromagnetic environment acting on the subsystem to a level at least 16.5 dB below the maximum pin-to-pin DC no-fire power of the EED.

The electroexplosive subsystem shall be designed to limit the power produced at each device in the firing circuit that can complete any portion of the firing circuit to a level at least 6 dB below the minimum activation power for each of the safety devices.

Note: This is from ***MIL-STD-1576***, Paragraph 4.4.1. The 20 dB margin of ***MIL-STD-1576*** is reduced to 16.5 dB for space vehicles.

5.2 DIRECT COUPLING TO THE EED AND ELECTROEXPLOSIVE SUBSYSTEM (EES)

EEDs shall not fire in either the pin-to-pin or the pin-to-case mode due to direct coupling of the specified electromagnetic environment into the EES.

Note: This is from ***MIL-STD-1576***, Paragraph 4.4.2.

5.3 POWER SOURCE

a. Separate and dedicated power distribution points shall be used for the Electroexplosive Subsystem firing sources. A firing source can share the same power source with other loads, but all currents flowing from the firing source point shall be for firing circuits only.
b. If the host vehicle supplies power to the Firing Source Circuit, one of the following options shall be employed:
    1. The return side of the Firing Source Circuit, shall not be grounded on the payload side of the interface and shall be isolated from payload structure by at least 10k ohms measured at 1.5 times the bus voltage or greater, or equivalent isolation.
    2. Isolation transformers shall be employed in the Firing Source Circuit to provide at least 10k ohms isolation between the payload return circuit and the host vehicle return circuit when measured at 1.5 times the bus voltage or greater.

Note: This is from ***MIL-STD-1576***, Paragraph 5.1.

5.4 SHIELDS

a. The firing circuit, including the EED, shall be completely shielded, or shielded from the EED back to a point in the firing circuit so that the isolators eliminate RF entry into the shielded portion of the system. Isolators which provide 16.5 dB attenuation (regardless of source and load impedances) shall be considered acceptable - at all frequencies of the expected electromagnetic environment. The adequacy of RF protection provided by these isolators can also be demonstrated by test **or** analysis for each specific usage (i.e., the necessary protection is dependent on the configuration of unshielded circuits connected at this point and the expected electromagnetic environment)
b. Cable shielding shall provide a minimum of 85 percent of optical coverage. The method for determining optical coverage shall be in accordance with ***Federal (FED)-STD-228A, Test Methods for Cables and Wire, Insulated***; or ***Commercial Item Description A-A-59569D, Braid, Wire (Copper, Tin-Coated, Silver-Coated, or Nickel Coated, Tubular or Flat)***.
c. Other than the optical coverage allowance mentioned in subparagraph b., there shall be no gaps **or** discontinuities in the shielding; including, the termination at the back faces of the connectors nor apertures that are in any container which houses elements of the firing circuit.
d. Shields terminated at connector shall provide 360-degree continuous shield continuity without gaps.
e. Shields shall not be used as intentional current-carrying conductors but may use multiple-point Ground to structure.
f. Multiple point grounding of shields to structure is recommended.

Note: This is from ***MIL-STD-1576***, Paragraph 5.2. Optical coverage determination per Commercial Item Description A-A-59569 is also allowed for space vehicles.

5.5 SHIELDING CAPS

All electroexplosive devices and safe and arm devices shall have shielding caps attached during storage, handling, transporting, and installation. The shielding cap shall have a solid metal outer shell which makes electrical contact with the EED case in the same manner as the mating connector for the EED.

Note: This is from ***MIL-STD-1576***, Paragraph 5.3.

5.6 CABLES

a. Electrical cables may be fabricated, such that several electro explosive subsystem circuits are contained in a common shielded cable bundle, provided that the requirement Paragraph 5.7.2a (Paragraph 5.9.a herein) are met.
b. There shall be no splices used to join elements of ordnance cables.
c. A connector shall be provided wherever mating or demating of a circuit is required.
d. All cable runs shall be routed as close to metal structure as feasible.

Note: This is from ***MIL-STD-1576***, Paragraph 5.4.

5.7 INSULATION RESISTANCE

a. All current-carrying components and conductors shall be electrically insulated from each other and system Ground.
b. The insulation resistance between all insulated parts, at a potential of 500V minimum, DC, shall be greater than 2 megohms after exposure to the environment specified herein. (For the NASA Standard Initiator (NSI), the potential shall not exceed 250V, DC and only one 250V, DC test shall be permitted. All other NSI testing should be at 50V, DC.)

Note: This is from ***MIL-STD-1576***, Paragraph 5.5.

5.8 WIRING

a. Shielded twisted pairs shall be used unless other configurations can be shown to be more effective.
b. Any grounding of the firing circuits shall be done at one point only. The return path, on all circuits, shall be selected to minimize voltage buildup and transients on the firing circuit return with respect to the single point Ground.

c. Ungrounded firing output circuits shall be connected to structure by static bleed resistors.
d. Structural Ground shall not be used as return for ordnance circuitry.
e. The source circuits shall terminate in a connector with socket contacts.
f. The design shall preclude sneak circuits and unintentional electrical paths.

Note: This is from ***MIL-STD-1576***, Paragraph 5.7.1.

5.9 ELECTRICAL ISOLATION

a. Firing circuits that do not share a common fire command shall be electrically isolated from one another, such that current in one firing circuit does not induce a current greater than 16.5 dB below the no-fire current level in any firing output circuits.
b. Control circuits shall be electrically isolated so that a stimulus in one circuit does not induce a stimulus greater than 16.5 dB of the actuation level in any firing circuit.

Note: This is from ***MIL-STD-1576***, Paragraph 5.7.2. The 20 dB margin of ***MIL-STD-1576*** is reduced to 16.5 dB for space vehicles in Subparagraph a.

5.10 PHYSICAL SEPARATION

Firing output circuits shall be physically separated from all other types of circuits.

Note: This is from ***MIL-STD-1576***, Paragraph 5.7.3.

5.11 ELECTROSTATIC PROTECTION

Electroexplosive devices shall be protected from electrostatic hazards by the placement of resistors from line-to-line and from line-to-ground (structure). The placement of line-to-ground (structure) static bleed resistances does not violate the single-point ground requirements of this Standard, as long as the parallel combination of these resistors are 10k ohms - 100k ohms.

Note: This is from ***MIL-STD-1576***, Paragraph 5.7.4.

5.12 MONITOR CIRCUITS (PORTABLE OR BUILT-IN)

a. Application of operational voltage to the monitor circuit shall not compromise the safety of the firing circuit, nor cause the electroexplosive subsystem to be armed.
b. Monitoring currents shall be limited to one-tenth of the no-fire current level of the EED or 50 milliamps, whichever is less.
c. Monitor-circuits and test equipment that applies current to the bridgewire shall be designed to limit the open circuit output voltage to one volt.

d. Fault tolerance requirements of Paragraph 4.2 (in MIL-STD-1576) shall apply – needed to monitor circuits and associated equipment.

Note: This is from ***MIL-STD-1576***, Paragraph 5.7.5.

5.13 CONTROL CIRCUITS

It must be demonstrated that the host vehicle's command and control interfaces that are used for any arming or firing functions in the payload, cannot be actuated or triggered by return currents flowing in the host vehicle or payload structure. Use of differential drivers and receivers, transformers or optical couplers, or other floating control circuits are a possible means of accomplishing this.

Note: This is from ***MIL-STD-1576***, Paragraph 5.7.6.

5.14 TYPE

All connectors used with the electroexplosive devices shall:

a. be approved by the procuring activity,
b. have a stainless steel shell or suitable electrically conductive finish,
c. complete the shell-to-shell connection before the pins connect, and
d. provide for 360 degree shield continuity.

Note: This is from ***MIL-STD-1576***, Paragraph 5.8.1.

5.15 PIN ASSIGNMENTS

a. The circuit assignments and isolation of pins with in any EES circuit connector shall be such that any single short circuit occurring as a result of a bent pin or contamination will not result in more than 50 milliamperes or 15% of the no fire current, whichever is less, when applied to any electroexplosive device.
b. There shall be only one wire per pin, and in no case shall a connector pin be used as a terminal or tie-point for multiple connections.

Spare pins are prohibited in connectors which are part of firing output circuitry.

Note: This is from ***MIL-STD-1576***, Paragraph 5.8.2. The 20 dB margin of ***MIL-STD-1576*** is reduced to 16.5 dB for space vehicles in Subparagraph a.

5.16 NO-FIRE SENSITIVITY

a. Unless otherwise specified, electroexplosive devices shall be designed to withstand a constant direct current firing pulse of up to 1 ampere and 1 watt power (minimum) for a period of 5 minutes (minimum) duration without initiation or deterioration of performance,(dudding). The DC no-fire shall be determined by Test Method 2203 (Bruceton Test) at room temperature (25 degrees C) or Neyer Test Method (or equivalent penalty test). The EED should be held in a mounting device to minimize heat transfer - away from the initiator. Test Method 2203 (Bruceton Test) or Neyer method (or equivalent penalty test) shall indicate that the 0.1% firing level (with 95% confidence) is 1 ampere or more.
b. EEDs shall not fire, dud, or deteriorate in performance as a result of being subjected to an electrostatic of 25,000 volts from a 500 picofarad capacitor applied in the pin-to-case mode with no resistor in series and in the pin-to-pin mode with a 5k ohm resistor in series. EEDs using an external spark gap require procuring activity approval.

Note: This is from ***MIL-STD-1576***, Paragraph 5.11.1.1. The Neyer Test Method (or equivalent penalty test) may be used by space vehicles for determination of maximum no-fire and minimum all fire currents.

5.17 RF SUSCEPTIBILITY

The protection for the EEDs shall be provided by a metallic enclosure which provides 360 degrees of coverage.

Note: This is from ***MIL-STD-1576***, Paragraph 5.12.1.2.

APPENDIX A - ACRONYMS AND ABBREVIATIONS AND GLOSSARY OF TERMS

A1.0 ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
AIAA	American Institute of Aeronautics and Astronautics
ARP	Aerospace Recommended Practice
CISPR	International Special Committee on Radio Interference
COTS	Commercial Off-The-Shelf
CR	Change Request
CUI	Controlled Unclassified Information
dB	Decibel
dBi	Decibel Isotropic
DC	Direct Current
DAA	Document Availability Authorization
DSG	Deep Space Gateway
DSNE	Design Specification for Natural Environments
E3	Electromagnetic Environmental Effects
EAR	Export Administration Regulations
ECSS	European Cooperation for Space Standardization
ED	Engineering Directorate
EED	Electroexplosive Device
EES	Electroexplosive Subsystem
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
EPS	Electrical Power System
ESD	Electrostatic Discharge
EVA	Extravehicular Activity
EUT	Equipment Under Test
FED	Federal
GEO	Geosynchronous Orbit
GHz	Gigahertz
GSE	Ground Support Equipment
HDBK	Handbook
HSR	Human-System Requirements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ITE	Information Technology Equipment
IRD	Interface Requirements Document
ISS	International Space Station
kV	Kilovolt

LEO	Low Earth Orbit
M	meter
MSFC	Marshall Space Flight Center
MEIT	Multi-Element Integration Test
MHz	Megahertz
MIL	Military
NASA	National Aeronautics and Space Administration
NDI	Non-developmental items
N/m^2	Newton per square meter
NSI	NASA Standard Initiator
OPR	Office of Primary Responsibility
RF	Radio Frequency
RQMT	Requirement
RTCA	Radio Technical Commission for Aeronautics
RTG	Range to Ground
SAE	Society of Automotive Engineers
SBU	Sensitive But Unclassified
SIL	System Integration Laboratory
SLS	Space Launch System
SPEC	Specification
SPG	Single Point Ground
SSP	Space Station Program
STD	Standard
TBD	To Be Determined
TBR	To Be Resolved
TOR	Technical Operating Report
TPS	Thermal Protection System
TSE	Test Support Equipment
USAF	United States Air Force
V	Volt
V/m	Volts per meter
VV	Visiting Vehicle
WiFI	Wireless Fidelity

A2.0 GLOSSARY OF TERMS

Term	Description
Flight	This is the sequence of events that takes place between liftoff and landing of a transportation vehicle.
Spacecraft Charging	The process by which all orbiting spacecraft accumulate electric charge from the natural space plasma.

APPENDIX B - VERIFICATION APPLICABILITY MATRIX

B1.0 VERIFICATION APPLICABILITY

Due to the unique nature of the E3 discipline, many of the requirements contained herein may be verified at both the subsystem level or at the system vehicle level (two or more subsystems). Although it may appear redundant, in some cases the E3 verification may cross several interfaces and several levels of integration. The verification method used at the subsystem level may be different from that used at the system level. Table B1-1 defines the verification applicability and activities for system and subsystem verification that are required to ensure the space vehicle is electromagnetically compatible within each subsystem, within the integrated vehicle, and compatible with Visiting Vehicles. The subsystem level denotes the verification methodology at the subsystem level or some level below it (e.g., EMI testing will likely occur at the equipment/component vendor level; because it is listed at subsystem level there is not an expectation that the same tests will be repeated at subsystem level solely for verification).

TABLE B1-1 VERIFICATION APPLICABLITY MATRIX

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
CV001	Margins	Analysis, Audit	System level verification shall be combination audit of subsystem level verification closures and integrated vehicle analysis	Test, Analysis	Subsystem level verification shall be either by test, analysis supported by component level test results, or a combination of subsystem or system level test and analysis
CV002	Intra-System EMC	Analysis, Audit	System level verification shall be combination audit of subsystem level verification closures and integrated vehicle analysis	Test, Analysis	Subsystem level verification shall be either by test, analysis supported by component level test results, or a combination of subsystem or

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
					system level test and analysis
CV003	External Compatibility	Audit, Analysis	System level verification shall be combination audit of subsystem level verification closures, VV IRD verification closures, and integrated vehicle analysis	Test, Analysis, Inspection	Subsystem level verification shall be by test, analysis supported by component level test results, and inspection of other documentation
CV004	External Radio Frequency (RF) Electromagnetic Environment	Audit, Analysis	System level verification shall be combination audit of subsystem level verification closures and integrated vehicle analysis	Analysis	Subsystem level verification shall be by analysis supported by component level test results, including a combination of equipment, element, or module test and analysis
CV005	Lightning Effects	Audit	System level verification shall be audit of subsystem level verification closures	Analysis, Test	Subsystem level verification shall be by test and/or analysis supported by component level test results, or a combination of element or module test and analysis

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
CV006	Electromagnetic Interference (EMI) Control for Systems, Subsystems, and Equipment	Audit, Analysis	System level verification shall be audit of subsystem level verification closures and analysis of subsystem/ component level waivers and deviations	Test, Analysis	Subsystem level verification shall be a combination of test of subsystems and component level test (testing may be performed by vendor and results provided as subsystem level verification).
CV007	Non-Developmental Items (NDIs) and Commercial ITE Used as Flight Hardware	Audit, Analysis	System level verification shall be audit of subsystem level verification closures and analysis of component level waivers and deviations	Test, Analysis, Inspection	Subsystem level verification shall be a combination of test of subsystems and equipment, analysis of GFE verification closures, and analysis of component level waivers and deviations
CV008	ESD Design Control and Withstand Ratings	Audit, Analysis	Subsystem level verifications required to complete CV001, CV002, and CV003	Test, Inspection	Subsystem level verification shall be a combination of test of subsystems and components and/or inspection of GFE verification closures and vendor provided test results

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
CV009	Plasma Vehicle Charging Control	Analysis, Audit	System level verification shall be analysis of the integrated vehicle, along with the Visiting Vehicle based on subsystem analytical results	Analysis, Inspection	Subsystem verification shall be analysis of the subsystem and component level test
CV010	Solar Array Charging	Inspection	Inspection of subsystem level verification	Test	Subsystem level verification shall be by test to show the design functions in the expected plasma environment
CV011	Multipaction	Audit	System level verification shall be audit of subsystem level verification closures	Test, Analysis	Subsystem level verification shall be by test and/or analysis
CV012	Hazards of Electromagnetic Radiation to Fuel	Audit, Analysis	System level verification shall be audit and analysis of the integrated vehicle, along with the Visiting Vehicle based on subsystem analytical results	Inspection, Analysis	Subsystem level verification shall be inspection of component level test results and analysis
CV013	Hazards of Electromagnetic Radiation to Ordnance	Audit, Analysis	System level verification shall be audit and analysis of the integrated vehicle, along with the Visiting Vehicle	Analysis, Test, Inspection	Subsystem verification shall be inspection of component level

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
			based on subsystem test and analytical results		test results and analysis
CV014	Life Cycle and Maintainability	Audit	System level verification shall be audit of subsystem level verification closures	Inspection, Analysis, Test	Subsystem level verification shall be inspection of component level test results and analysis
CV015	Electrical Bonding	Analysis, Inspection, Audit	System level verification shall be audit and analysis of the integrated vehicle, along with the Visiting Vehicle based on subsystem level test and analytical results	Test, Analysis, Inspection	Subsystem level verification shall be test, analysis, and inspection
CV016	Electrical Power Systems (EPS) Common Reference	Audit, Inspection	System level verification shall be audit of subsystem level verification closures and inspection of the integrated vehicle design, along with the Visiting Vehicle IRD verification closures	Inspection	Subsystem level verification shall be by inspection of component level verifications
CV017	Provision for Electrical Fault Clearing	Audit, Inspection	System level verification shall be audit of subsystem level verification closures and inspection of the	Inspection	Subsystem level verification shall be by inspection of component level verifications

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
			integrated vehicle design, along with the Visiting Vehicle IRD verification closures		
CV018	Primary to Secondary Power Isolation	Audit, Inspection	System level verification shall be audit of subsystem level verification closures and inspection of the integrated vehicle design, along with the Visiting Vehicle IRD verification closures	Analysis, Inspection	Subsystem level verification shall be by analysis and inspection
CV019	Equipment Power Isolation	Audit, Analysis	Subsystem Level verifications required to complete CV018	Analysis, Inspection	Subsystem level verification shall be by analysis and inspection
CV020	Signal Return Isolation from Chassis/ Structure	Audit, Analysis	Subsystem level verifications required to complete CV018	Analysis, Inspection	Subsystem level verification shall be by analysis and inspection
CV021	Balanced Differential Circuit Isolation	Audit, Analysis	Subsystem level verifications required to complete CV018	Analysis, Inspection	Subsystem level verification shall be by analysis and inspection
CV022	Coaxial Cabling	Audit, Analysis	Subsystem level verifications required to complete CV018	Analysis, Inspection	Subsystem level verification shall be by analysis and inspection

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
CV023	Signal, Command, Control, and Power Returns	Audit, Inspection	Subsystem level verifications required to complete CV018	Inspection	Subsystem level verification shall be by inspection
CV024	Signal, Command, Control, and Power Return Isolation	Audit, Analysis	Subsystem level verifications required to complete CV018	Analysis, Inspection	Subsystem level verification shall be by analysis and inspection
CV025	Circuit Classification	Audit, Inspection	Subsystem level verifications required to complete CV001, CV002, and CV003	Inspection	Subsystem level verification shall be by inspection
CV026	Wire and Cabling Bundling, Routing, and Separation Requirements	Audit, Inspection	Subsystem level verifications required to complete CV001, CV002, and CV003	Inspection	Subsystem level verification shall be by inspection
CV027	Individual Cable Shield Termination	Audit, Inspection	Subsystem level verifications required to complete CV001, CV002, and CV003	Inspection	Subsystem level verification shall be by inspection
CV028	Harness Overbraid or Gross Overshield Termination	Audit, Inspection	Subsystem level verifications required to complete CV001, CV002, and CV003	Inspection	Subsystem verification shall be by inspection
CV029	Corona	Audit, Inspection	Subsystem level verifications required to	Test, Analysis, Inspection	Subsystem verification shall be by test and/or

Req. #	Requirement	System Level Methods	System Level Notes	Subsystem Level Method	Subsystem Level Notes
			complete CV001, CV002, and CV003		analysis and inspection