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Space Administration

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GATEWAY
ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E3) REQUIREMENTS

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REVISION AND HISTORY PAGE

Revision No.	Change No.	Description	Release Date
-	CXXXX	Initial Release (Reference DSG-CBD XXXXXX/X-X, dated XX/XX/XX)	XX/XX/XX
A	CXXXX	Revision A (Reference DSG-CBD XXXXXX/X-X, dated XX/XX/XX)	XX/XX/XX

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1.0 INTRODUCTION

Electromagnetic Compatibility (EMC) is essential to the success of any vehicle design that incorporates a complex assortment of electronic, electrical, and electromechanical systems and sub-systems 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 or vehicles to operate successfully when exposed to the effects of its expected and/or specified electromagnetic environments.

1.1 PURPOSE

This document establishes the Electromagnetic Environmental Effects (E3) Requirements for the Gateway Program. These requirements will be used in the development and operation of the various elements that will compose the overall Gateway vehicle.

1.2 SCOPE

This document provides detailed E3 requirements and associated verification activities applicable to Gateway and its elements. The Gateway Program and Gateway element developers are responsible for decomposing the pertinent requirements onto the element subsystem and component level based on the element's specific configuration in order to produce a compatible Gateway vehicle.

E3 requirements applicable to the Orion Vehicle are contained in MPCV 70080. E3 requirements applicable to the Space Launch System (SLS) vehicle are contained in SLS-RQMT-040.

1.3 CHANGE AUTHORITY/RESPONSIBILITY

Proposed changes to this document shall be submitted via a Change Request (CR) to the appropriate Gateway Board for consideration and disposition.

All such requests will adhere to the DSG Configuration Management Change Process documented in DSG-PLAN-004.

The appropriate NASA Office of Primary Responsibility (OPR) identified for this document is ES45.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

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

Document Number	Document Revision	Document Title
DSG-RQMT-001	Initial Release Pending	Gateway System Requirements
DSG-RQMT-007	Initial Release Pending	Gateway Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Document
IEC 61000-4-2	Edition 2.0 (2008-12)	Electromagnetic compatibility (EMC) 0 Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test
MIL-STD-461	Revision G	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-1576 (USAF)	Revision Basic & Notice 1	Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems
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
NASA-STD-3001, Volume 2	Revision A	NASA Space Flight Human-System Standard Volume 2: Human Factors, Habitability, and Environmental Health

2.2 REFERENCE DOCUMENTS

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

Document Number	Document Revision	Document Title
AFWAL-TR-88-4143		Design Guide: Designing and Building High Voltage Power Supplies
CISPR 22	Revision 6.0 (2008-09)	Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement
CISPR 24	Revision 2.0 (2010-08)	Information technology equipment – Immunity characteristics – Limits and methods of measurement

Document Number	Document Revision	Document Title
CISPR 32	Revision 2.0 (2015-03)	Electromagnetic compatibility of multimedia equipment – Emission requirements
CISPR 35	Revision 1.0 (2016-08)	Electromagnetic compatibility of multimedia equipment – Immunity requirements
ECSS-E-20-01A	Revision 1	Space Engineering - Multipaction Design and Test
MPCV 70080	Revision A	Cross Program Electromagnetic Environmental Effects (E3) Requirements Document
MIL-STD-464	Revision C	Electromagnetic Environmental Effects Requirements for Systems
MIL-HDBK-83575	Revision Basic	General Handbook for Space Vehicle Wiring Harness Design and Testing
NASA-HDBK-4002	Revision A	Mitigating In-Space Charging Effects — A Guideline
NASA-HDBK-4006	Baseline	Low Earth Orbit Spacecraft Charging Design Handbook
NASA-HDBK-4007	Baseline	Spacecraft High-Voltage Paschen and Corona Design Handbook
NASA-RP-1354		Spacecraft Environments Interactions: Protecting Against the Effects of Spacecraft Charging
NASA-RP-1368		Marshall Space Flight Center Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook
NASA-RP-1375		Failures and Anomalies Attributed to Spacecraft Charging
NASA-TP-2361		Design Guidelines for Assessing and Controlling Spacecraft Charging Effects
RTCA/DO-160	Revision G	Environmental Conditions and Test Procedures for Airborne Equipment
SAE ARP-5412	Revision B	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 A	Aircraft Lightning Test Methods
SLS-RQMT-040	Revision E	Space Launch System Program (SLSP) Electromagnetic Environmental Effects (E3) Requirements

Document Number	Document Revision	Document Title
SLS-SPEC-159	Revision E	Cross-Program Design Specification for Natural Environments (DSNE)
TOR-2014-02198		Standard/Handbook for Radio Frequency (RF) Breakdown Prevention in Spacecraft Components
TOR-2014-02546		Standard/Handbook for RF Ionization Breakdown Prevention in Spacecraft Components

3.0 E3 DESIGN REQUIREMENTS - GENERAL

3.1 MARGINS

[CA0001] Safety critical systems, subsystems, and equipment shall have a margin of at least 6 deibels (dB) **<TBR-DSG-RQMT-001>** between its threshold of susceptibility and the Gateway 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.

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, and includes 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 from factors such as differences in cable harness routing and makeup, adequacy of shield terminations, conductivity of finishes on surfaces for electrical bonding, component differences in electronics boxes, and degradation with aging and maintenance. 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 DSG-RQMT-007 means the subsystem or equipment has demonstrated a 6 dB margin with respect to the Gateway EME. In other cases, further analysis may be required or mitigating circumstances, such as element pressure hull attenuation, must 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.

3.2 INTRA-SYSTEM EMC

[CA0002] Gateway 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 Gateway 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

[CA0003] The Gateway 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 Gateway 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

[CA0004] Gateway elements and systems shall be electromagnetically compatible with the external RF EME defined in Tables 3.4-1 **<TBR-DSG-RQMT-002>** to ensure compliance with operational performance requirements.

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 Gateway systems. Many of these emitters generate very high intensity RF fields. This requirement ensures Gateway integrated vehicles and individual Gateway elements are electromagnetically compatible with the external RF EME during ground and flight operations. The table includes the electric field strength in volts per meter (V/m) from ground based emitters at 100 nautical miles in the frequency range from 10 megahertz (MHz) to 35,200 MHz. The table also includes the maximum field strength from Gateway, Visiting Vehicle, and other nearby emitters.

TABLE 3.4-1 EXTERNAL RF EME

Frequency (MHz)	Peak (V/m)	Average (V/m)
11 – 12	27	27
108.00	17	17
404.00 – 420.00	11	5
410.00 – 420.00	**<TBD-DSG-RQMT-001>**	
420.01 – 437.00	14	14
437.01 – 447.00	23	14
447.01 – 450.00	14	14
1175 – 1375	30	8
1550 – 1786.99	14	5

Frequency (MHz)	Peak (V/m)	Average (V/m)
1787.00	43	43
1787.1 – 2090.99	14	5
2025 – 2110	**<TBD-DSG-RQMT-001>**	
2091.00	30	30
2091.1 – 2110.00	14	5
2110.01 – 2120.00	30	30
2120.01 – 2144.99	14	5
2145.00	93	5
2145.1 – 2379.99	14	5
2200 – 2290	**<TBD-DSG-RQMT-001>**	
2380.00	189	189
2380.1 – 2839.99	14	7
2840.00	24	6
2840.1 – 2869.99	14	6
2870.00	24	6
2870.1 – 2950.99	14	6
2951.00	22	5
2951.1 – 3999.99	14	6
4000.00	85	85
4000.1 – 5399.99	15	5
5180 – 5825	**<TBD-DSG-RQMT-001>**	
5400.00 – 5659.99	27	5
5660.00	27	11
5660.1 – 5850	27	5
5850.1 – 5925.00	27	25
5925.01 – 6425	9	9
7155 – 7189	24	24
7209	6	6
8450 – 8500	**<TBD-DSG-RQMT-001>**	
8500 – 8559.99	7	5
8560.00	117	117
8560.1 – 9354.99	7	5

Frequency (MHz)	Peak (V/m)	Average (V/m)
9355.00	142	5
9355.1 – 9999.99	7	5
10000.00	48	5
10593.00	10	10
14000 – 14500	10	10
16700	17	10
22550 – 23150	**<TBD-DSG-RQMT-001>**	
23530 – 23575	24	24
25500 – 27000	**<TBD-DSG-RQMT-001>**	
34316	7	7
34500 – 35200	11	11

Note: Table entries in *italics* are Gateway, Visiting Vehicle, and other nearby emitters. All others are from ground based emitters and represent the field level at a 100 nautical mile altitude.

3.5 LIGHTNING EFFECTS

[CA0005] Gateway systems, subsystems, or components shall meet their operational performance requirements or not propagate a hazard after exposure to a nearby lightning strike as described in the following documents:

a. Society of Automotive Engineers (SAE) Aerospace Recommend Practice (ARP) 5412B, Aircraft Lightning Environment and Related Test Waveforms, Section 6
b. MIL-STD-464C, Electromagnetic Environmental Effects Requirements for Systems, Section 5.5 and Table 8.

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 and 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-464C, Table 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 Equipment, describe tests that should be considered for a verification approach.

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

[CA0006] Individual systems, subsystems and equipment, shall meet EMI control requirements contained in DSG-RQMT-007, Gateway Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Document.

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 ITE Used As or That Interface with Flight Hardware

[CA0007] NDIs and commercial information technology equipment (ITE) and other items used as flight hardware or that interface with flight hardware shall meet EMI control requirements of DSG-RQMT-007, Gateway Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Document.

Rationale: ITE includes, for example, 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 or that interface with 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 things like cable testers that interface with cables before they are connected to avionics.

3.7 ELECTROSTATIC DISCHARGE (ESD) CONTROL

3.7.1 ESD Design Control and Withstand Ratings

[CA0008] 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

[CA0009] Individual Gateway elements and the Gateway integrated vehicle shall mitigate plasma vehicle charging to protect against puncture of materials and finishes and shock hazards from charge accumulation, and to control electromagnetic interference caused by electrostatic discharge arising from vehicle charging. Plasma environments are described in 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-4002A, Mitigating In-Space Charging Effects - A Guideline; NASA-HDBK-4006, Low Earth Orbit Spacecraft Charging Design Handbook; NASA-RP-1354 (Nov. 1994), Spacecraft Environments Interactions: Protecting Against the Effects of Spacecraft Charging; NASA-RP-1375 (Aug. 1995), Failures and Anomalies Attributed to Spacecraft Charging; and NASA-TP-2361 (1984), Design Guidelines for Assessing and Controlling Spacecraft Charging Effects,NASA-HDBK-4007 Baseline Spacecraft High-Voltage Paschen and Corona Design Handbook, NASA-STD-4003 A Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.

3.7.3 Solar Array Charging

[CA0010] Gateway elements that have high voltage solar arrays, voltages greater than 55 Volts (V), shall comply with NASA-STD-4005A.

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 Low Earth Orbit Spacecraft Charging Design Standard, will ensure that solar array operations will be protected from the natural plasma environment without compromising safety or performance. NASA-HDBK-4006 Low Earth Orbit Spacecraft Charging Design Handbook contains guidelines for high voltage solar array design.

3.8 MULTIPACTION

[CA0011] Gateway 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 Gateway systems that RF transmitting equipment and signals not be degraded by the action of *multipaction. It is also essential that multipaction effects not result in spurious signals that interfere with receivers.*

Suggested references are, AEROSPACE REPORT NO. 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 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

[CA0012] Gateway elements that have RF emitters shall comply with NASA-STD-3001, Vol2. Rev A.

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.

The intent of this paragraph is to provide the appropriate documentation to assess the hazards associated with high powered RF transmitters.

3.9.2 Hazards of Electromagnetic Radiation to Fuel

[CA0013] Individual Gateway elements and the Gateway integrated vehicle 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, and 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).

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 must 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

[CA0014] Pyrotechnic systems and subsystems contained in Gateway integrated vehicles and individual Gateway elements 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 stipulated in Table 3.9.3-1.

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.

TABLE 3.9.3-1 MIL-STD-1576 APPLICABLE REQUIREMENTS

MIL-STD-1576 Applicable Paragraphs	Gateway Tailored
4.4.1a	The level is to be 16.5 dB below the dc Maximum No-Fire Stimulus (MNFS)
4.4.1b	No tailoring required.
4.4.2	No tailoring required.
5.1	No tailoring required.
5.2	A-A-59569 can be used to verify the optical shield coverage requirement.
5.3	No tailoring required.
5.4	No tailoring required.
5.5	No tailoring required.
5.7.1	No tailoring required.
5.7.2a	The level is to be 16.5 dB below the dc MNFS.
5.7.2b	No tailoring required.
5.7.3	No tailoring required.
5.7.4	No tailoring required.
5.7.5	No tailoring required.
5.7.6	No tailoring required.
5.8.1	No tailoring required.

5.8.2a	The level is to be 16.5 dB below the dc MNFS.
5.8.2b	No tailoring required.
5.8.2c	No tailoring required.
5.11.1.1a	Bruceton or Neyer statistical methods may be utilized.
5.11.1.1b	No tailoring required.
5.12.1.2	No tailoring required.

3.10 LIFE CYCLE AND MAINTAINABILITY

[CA0015] Gateway integrated vehicles, individual Gateway elements, and their systems, subsystems, and equipment, shall meet the E3 requirements of this document throughout their life cycle including (as applicable) the following 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

> *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

[CA0016] Gateway elements, systems, subsystems, and equipment shall comply with NASA-STD-4003A.

> *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

[CA0017] Electrical power systems in Gateway elements and the Gateway integrated 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 Handbook for more information on distributed single point ground architecture.

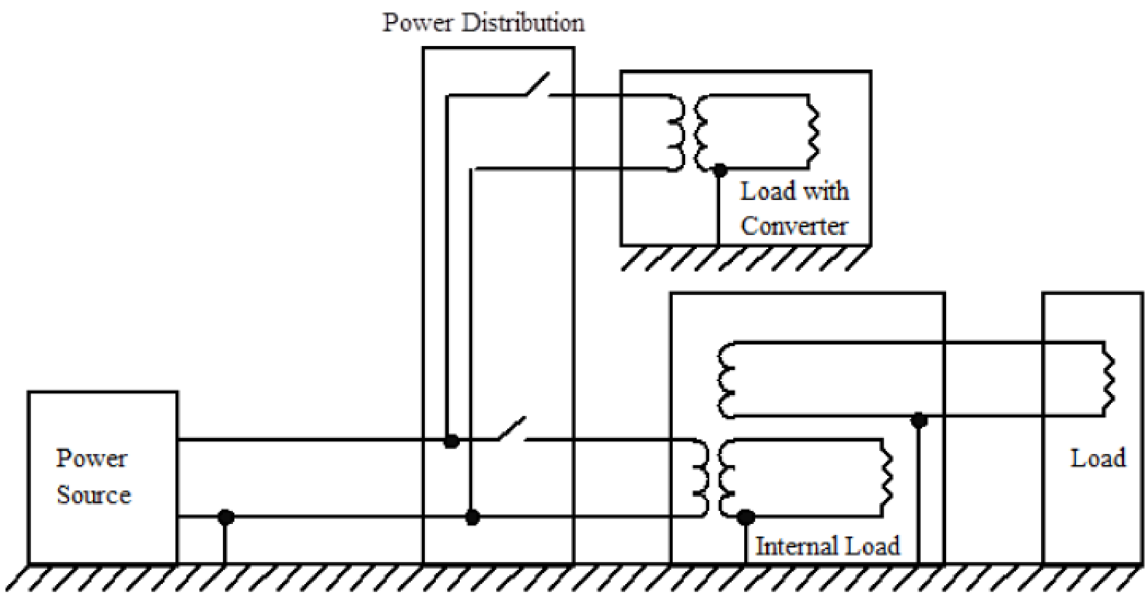

FIGURE 3.12-1 DISTRIBUTED SINGLE POINT GROUND ARCHITECTURE CONCEPT

3.12.1 Provision for Electrical Fault Clearing

[CA0018] Each isolated Gateway 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

[CA0019] Primary Gateway 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, 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

[CA0020] Gateway 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 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

[CA0021] Signal returns routed external to Gateway subsystems or equipment (that is, outside the equipment enclosure) shall be isolated from chassis/structure by a minimum of 1 megohm. This requirement does not apply to Balanced Differential Circuitry and Coaxial/Triaxial 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 (Coax) is given special considerations and is addressed in Paragraphs 3.12.6 and 3.12.7.

3.12.5 Balanced Differential Circuit Isolation

[CA0022] Balanced differential circuits routed external to Gateway equipment shall be isolated from structure by a minimum of 6 kilohms or greater.

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.

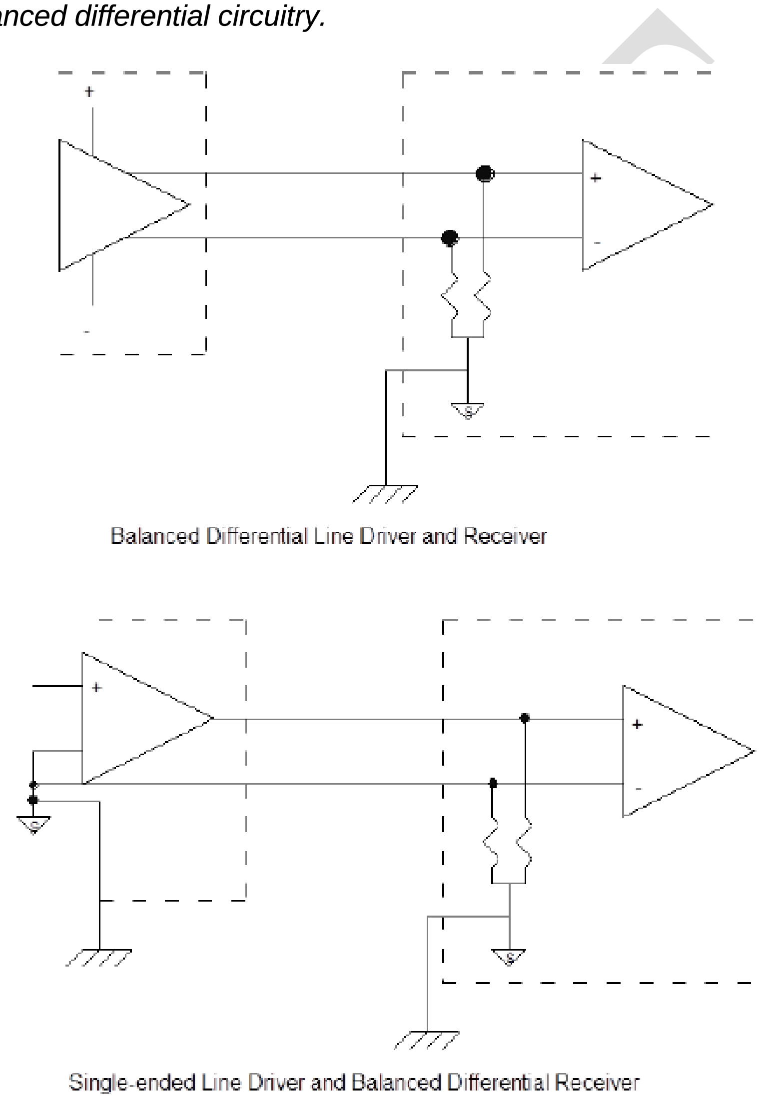

FIGURE 3.12.5-1 GENERIC EXAMPLES OF BALANCED DIFFERENTIAL CIRCUITRY

3.12.6 Coaxial and Triaxial Cabling

[CA0023] Coax and/or triaxial cabling where the outer most conductor provides the signal return path that is utilized in Gateway 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.).

3.12.7 Coaxial Circuit Isolation

[CA0024] Coaxial and/or triaxial cable shall not be used to interconnect equipment utilizing different power sources unless electrical isolation is provided (opto isolators, transformers, etc.).

Rationale: The intent is to mitigate interference that may be caused by low frequency external shield currents.

3.13 SIGNAL, COMMAND, CONTROL, AND POWER RETURNS

[CA0025] All Gateway 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

[CA0026] 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.

On other programs and projects that imposed this requirement, the specific requirement ended with the phrase "except at the single point ground." This was 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. However, this phrase 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 Gateway 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 are isolated such that no intentional current flow through structure or through an unintentional return path.*

3.13.2 Signal, Command, Control, and Power Return Isolation from Harness Shields

[CA0027] Harness shields shall be dc isolated by a minimum of 1 megohm from all signal, command, control, and power circuits routed externally to Gateway systems, subsystems, and equipment.

Rationale: Isolating returns from harness shields prevents the unintentional introduction of electrical noise into the circuit. 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.

3.13.3 Isolation of Signal Returns for Circuits Using Separate Power Sources

[CA0028] Signal returns for Gateway circuits using separate derived power sources shall be isolated from other returns by a minimum of 1 megohm.

Rationale: The use of separate returns minimizes noise voltages created by currents flowing through common impedances. Isolating returns from harness shields prevents the unintentional introduction of electrical noise into the circuit. 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.

3.14 CABLE AND WIRE DESIGN FOR ELECTROMAGNETIC COMPATIBILITY

3.14.1 Circuit Classification

[CA0029] 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. MIL-HDBK-83575 should be used as a guide, specifically paragraphs 3.8.4, 3.8.10.3, 3.10.8, 3.10.12 thru 3.10.15, 3.12.1, 3.12.2, and 3.14.4.

3.14.2 Wire and Cabling Bundling, Routing, and Separation Requirements

[CA0030] 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

a) **[CA0031]** Shields on individual cables that interconnect Gateway systems, subsystems, and equipment, shall be terminated to connector backshells at cable ends and at intermediate break points such as bulkhead feed-throughs.

b) **[CA0032]** Shields on individual cables and harnesses that interconnect Gateway systems, subsystems, and equipment, and that are not contained within a harness overbraid or gross overshield, shall not be terminated into connector pins.

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.

3.14.3.2 Use of Direct wire or “Pigtail” Shield Terminations

[CA0033] Direct wire or “Pigtail” shield terminations for shields on individual cables and harnesses that interconnect Gateway systems, subsystems, and equipment, and that are not contained within a harness overbraid or gross overshield, shall not be used.

Rationale: Direct wire or “pigtail” terminations severely degrade cable and harness shielding effectiveness, and can lead to undesirable or non-compliant cross-talk induced interference, and/or radiated emissions and susceptibility performance. Shields of individual cables and harnesses wholly contained within an overbraid or gross overshield may be terminated to connector pins in instances where such shields are not electrically common to the overbraid or gross overshield.

3.14.3.3 Harness Overbraid or Gross Overshield Termination

[CA0034] Harness overbraid or gross overshields, and shields of coaxial or triaxial cables, 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

[CA0035] Gateway systems, subsystems, and equipment, and cables and harnesses that interconnect them, shall be qualified to 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) "Spacecraft High Voltage Design Guidelines," W.G. Dunbar, D.K. Hall, H. Kirkici, G.B. Hillard, and D.L. Schweickart, MSFC [unpublished], 1994.

4.0 E3 DESIGN VERIFICATIONS – GENERAL

Verification methods are provided within this section for the corresponding requirements in Section 3.0 The verification methods, defined below, are also defined in DSG-PLAN-009, NASA Gateway Verification and Validation Plan.

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

[CA0001V] Margins 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 an equipment or a system design can withstand or tolerate the required electromagnetic stress and remain operational, or

b. In cases where test is determined not to be possible, analysis has verified that the design thresholds of susceptibility of the system, subsystems, and equipment are above the maximum stress level allowed to occur within the equipment or system, and are greater than or equal to the electromagnetic stress levels the equipment or system is required to withstand or tolerate.

Note: In many cases, compliance with the conducted and radiated susceptibility limits of DSG-RQMT-007 means the subsystem or equipment has demonstrated a 6 dB margin with respect to the Gateway EME. In other cases, further analysis may be required or mitigating circumstances, such as element pressure hull attenuation, must 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

[CA0002V] Intra-system EMC within Gateway systems shall be verified through test and analysis. Tests shall verify that EMC has been achieved for all planned simultaneous subsystem operations, and can be maintained at certification levels over the design life cycle. Analysis shall verify that EMC has been achieved and that it can be maintained at certification levels over the design life cycle, for operational conditions that are impractical to test on the ground. Verification is considered successful when analyses and tests show that the system successfully complies with design, functional and operational performance requirements.

4.3 EXTERNAL COMPATIBILITY

[CA0003V] EMC between Gateway Systems and external interfaces shall be verified through test, analysis, and inspection. The test shall verify that EMC for all planned simultaneous operations with external interfaces including transportation systems, recovery systems, RF systems (e.g. Tracking and Data Relay Satellite System, Range Safety), and other vehicles has been achieved successfully for all planned simultaneous subsystem operations and can be maintained at certification levels over the design life cycle. Analysis shall verify that EMC for all planned simultaneous operations with external interfaces has been achieved successfully for all planned simultaneous subsystem operations and can be maintained at certification levels over the design life cycle, in cases where testing is impractical. Inspection shall verify that all Gateway Systems comply with all requirements provided herein.
Verification is considered successful when the following three conditions are satisfied:

a. During the test all systems successfully comply with design, functional and operational performance requirements when exposed to the defined external RF environment.
b. Analysis results show all systems successfully comply with design, functional and operational performance requirements when exposed to the defined external RF environment.

4.4 EXTERNAL RADIO FREQUENCY (RF) ELECTROMAGNETIC ENVIRONMENT

[CA0004V] Compatibility with the external EME shall be verified by test and analysis. The test shall verify that the system meets functional and performance requirements without degradation in the presence of the electromagnetic environment. The analysis shall verify that the system operates without degradation in the presence of the EME for operational conditions that are impractical to test on the ground, such as

a. Ascent
b. Docking
c. Cis-lunar transfer

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

4.5 LIGHTNING EFFECTS

[CA0005V] Operational performance of Gateway systems or prevention of hazard propagation after exposure to lightning indirect effects shall be verified by a combination of analysis and test of systems, subsystems, and equipment. Tests shall verify that Gateway systems can meet operational performance requirements and/or do not propagate a hazard during and after exposure to lightning environments. 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 or across element interfaces.

Verification is considered successful when the following conditions are satisfied:

a. During the tests, all systems 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

[CA0006V] The verification shall be by test. Tests shall be conducted to verify compliance with DSG-RQMT-007 using flight, or flight-like, cables. Flight-like cables have the same configuration with the same methods of shield termination. Equipment Under Test (EUT) must 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.

b. Equipment and subsystems are immune to interference when subjected to susceptibility test levels.

4.6.1 Non-developmental items (NDIs) and Commercial ITE Used As or That Interface with Flight Hardware

[CA0007V] The verification shall be by test and/or analysis and inspection. Tests shall be conducted to verify compliance with DSG-RQMT-007 using flight, or flight-like, cables. Flight-like cables have the same configuration with the same methods of shield termination. EUT must be bonded to the copper bench top in the same manner as it is bonded to vehicle structure during flight.

Analysis shall evaluate NDI and Commercial ITE proposed use and electromagnetic environment thereof to determine if commercial certifications will:

1) Encompass the conducted and radiated EME such that the NDI and Commercial ITE will meet operational and performance requirements when exposed to said EME

2) The use of NDI and Commercial ITE do not compromise the EMC of the integrated Gateway subsystems, systems, and elements.

Inspection shall verify that NDI and Commercial ITE have appropriate certifications to commercial EMI standards such as International Special Committee on Radio Interference (CISPR) 22: 2008, CISPR 24: 2010, CISPR 34:2015, CISPR 35:2016, or RTCA DO-160..

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

a. Emissions are below limits of DSG-RQMT-007.

b. Equipment and subsystems are immune to interference when subjected to susceptibility test levels of DSG-RQMT-007.

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

4.7 ELECTROSTATIC DISCHARGE (ESD) CONTROL

4.7.1 ESD Design Control and Withstand Ratings

[CA0008V] 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 International Electrotechnical Commission (IEC) 61000-4-2 (2008), Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic Discharge Immunity Test or MIL-STD-461, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, requirement CS118. Verification shall be considered successful when inspection shows personnel accessible test points have been identified and testing shows immunity to damage from ESD event waveforms of IEC 61000-4-2 or MIL-STD-461, CS118.

4.7.2 Plasma Vehicle Charging Control

[CA0009V] 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 and installation measurements demonstrate that 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

1. All conductive surfaces exposed to plasma charging are shown to be connected to structure through a path of resistance no greater than 1×10^9 ohms.

2. 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 1×10^9 ohms, and to exhibit a resistivity thickness product of $\rho * d \leq 1 \times 10^9$ 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.

Verification shall be considered successful for materials that cannot be made at least partially conductive and that are exposed to plasma charging when a detailed analysis has been performed based on spacecraft geometry, material properties, and the spacecraft charging environment as defined in section 3.3.3 of SLS-SPEC-159A, Cross-Program Design Specification for Natural Environments (DSNE), as deemed applicable by mission parameters. The analysis shall show:

a. that 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 1×10^4 V/centimeter, or

b. that 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 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

[CA0010V] The ability of high voltage solar arrays (> 55 V) and/or other units with exposed electrical contacts that may charge to high negative voltages (< -200 V) with respect to the dielectrics they are touching, or to function at their design voltages in the space plasma environment without charging, arcing or collecting sufficient current from the plasma to affect safety or performance shall be verified by test. 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/repressurization 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 2.4×10^{-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

[CA0011V] 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.

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

[CA0012V] Safety regarding RF hazards to personnel shall be verified by analysis, tests, and inspection. Analysis shall verify that internally and externally generated RF maximum capabilities have been properly identified, and appropriate safe distances have been determined based on human exposure limits. Testing shall verify compliance with Gateway requirements by demonstrating that internally and externally generated RF capabilities are in compliance with prescribed RF environments. Inspection shall verify that proper operational constraints have been implemented to prevent RF systems operations when personnel must be located closer to RF source than the identified safe distances, i.e. encroachment within RF keep out zones.

Verification shall be considered successful when the test, analysis, and inspection show that Gateway requirements for RF safety hazard mitigation have been satisfied.

4.9.2 Hazards of Electromagnetic Radiation to Fuel

[CA0013V] 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. When deemed necessary, testing shall verify compliance with Gateway 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 Gateway requirements for safety regarding RF hazards to fuel have been satisfied.

4.9.3 Hazards of Electromagnetic Radiation to Ordnance

[CA0014V] 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 Gateway requirements by demonstrating that pyrotechnic response to prescribed RF environments is below the specified 16.5 dB safety margin. 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 Gateway requirements for safety regarding RF hazards to pyrotechnics have been satisfied.

4.10 LIFE CYCLE AND MAINTAINABILITY

[CA0015V] 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.
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4.11 ELECTRICAL BONDING

[CA0016V] 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 1) each bonding joint is shown to have the correct bonding class requirement, 2) the fabrication and installation procedure will result in a proper electrical bond, and 3) the tested bonds meet the identified bond class resistance limits.

4.12 ELECTRICAL POWER SYSTEMS (EPS) COMMON REFERENCE

[CA0017V] 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 its 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

[CA0018V] 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 it is 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

[CA0019V] 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 it can be shown that primary power is dc isolated from secondary power.

4.12.3 Equipment Power Input Isolation

[CA0020V] 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 it can be shown that each power input is isolated from chassis/structure by 1 megohm.

4.12.4 Signal Return Isolation from Chassis/Structure

[CA0021V] 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 signal returns are shown to be isolated from chassis/structure, except at a single reference to structure.

4.12.5 Balanced Differential Circuit Isolation

[CA0022V] 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 by at least six kilohms.

4.12.6 Coaxial and Triaxial Cabling

[CA0023V] The use of coaxial and triaxial cabling only when all frequency components of the signal are greater than or equal to 1 MHz shall be verified by analysis and inspection. Analysis shall verify that each signal carried on coaxial or triaxial 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 or triaxial cabling. Inspection of drawings and installation records shall verify that coaxial and triaxial cabling signals 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 coaxial and triaxial cabling are only used when all frequency components of the signal are greater than or equal to 1 MHz.

4.12.7 Coaxial Circuit Isolation

[CA0024V] Verification that coaxial or triaxial cable is not used in a manner that interconnects equipment utilizing different power sources unless electrical isolation is provided shall be verified by analysis and inspection. Analysis shall verify that coaxial or triaxial cabling interconnecting equipment utilizing different power sources maintain the proper isolation, 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 coaxial or triaxial cabling interconnecting equipment utilizing different power sources maintain the proper isolation.

Verification shall be considered successful when analysis and inspection of drawings and installation records show that the use of coaxial or triaxial cabling does not interconnect different power sources.

4.13 SIGNAL, COMMAND, CONTROL, AND POWER RETURNS

[CA0025V] Verification that all signal, command, control, and power circuits routed wholly or partially external to Gateway 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 Gateway 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 Gateway 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

[CA0026V] 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.

4.13.2 Signal, Command, Control, and Power Return Isolation from Harness Shields

[CA0027V] Verification that signal, command, control, and power circuits are dc isolated from harness shields 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 signal, command, control, and power circuits are dc isolated from harness shields 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 signal, command, control, and power circuits are dc isolated from harness shields 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 signal, command, control, and power circuits are dc isolated from harness shields by a minimum of 1 megohm, individually, when not terminated by the signal circuit's single point ground/reference.

4.13.3 Isolation of Signal Returns for Circuits Using Separate Power Sources

[CA0028V] The isolation of signal returns for circuits using separate derived power sources shall be verified by analysis and inspection. Analysis shall verify isolation of signal returns for circuits using separate derived power sources, 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 isolation of signal returns for circuits using separate derived power sources.

The verification shall be considered successful when analysis and inspection of drawings and quality records (Quality records include workmanship resistance measurements) indicates that each electrical power source is dc isolated from chassis, structure, equipment conditioned power return/reference, and signal returns by a minimum of 1 megohm.

4.14 CABLE AND WIRE DESIGN FOR ELECTROMAGNETIC COMPATIBILITY

4.14.1 Circuit Classification

[CA0029V] 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

[CA0030V] 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. The 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

a) **[CA0031V]** Verification shall be by inspection. Inspection shall verify that shields on individual cables that interconnect Gateway systems, subsystems, and equipment, shall be terminated to connector backshells at cable ends and at intermediate break points such as bulkhead feed-throughs. The verification shall be considered successful when inspection of drawings and quality records (Quality records include workmanship measurements) indicates shields on individual cables that interconnect Gateway systems, subsystems, and equipment, shall be terminated to connector backshells at cable ends and at intermediate break points such as bulkhead feed-throughs

b) **[CA0032V]** Verification shall be by inspection. Inspection shall verify shields on individual cables and harnesses that interconnect Gateway systems, subsystems, and equipment, and that are not contained within a harness overbraid or gross overshield, are not terminated into connector pins. The verification shall be considered successful when inspection of drawings and quality records (Quality records include workmanship measurements) indicates shields on individual cables and harnesses that interconnect Gateway systems, subsystems, and equipment, and that are not contained within a harness overbraid or gross overshield, are not terminated into connector pins.

4.14.3.2 Use of Direct wire or “Pigtail” Shield Terminations

[CA0033V] Verification shall be by inspection. Inspection shall verify that wire shield pigtail terminations are not used unless they are contained within a harness overbraid or gross overshield. The verification shall be considered successful when inspection of drawings and quality records (Quality records include workmanship measurements) indicates that wire shield pigtail terminations are not used unless they are contained within a harness overbraid or gross overshield.

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4.14.3.3 Harness Overbraid or Gross Overshield Termination

[CA0034V] 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

[CA0035V] Verification shall be by test or 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/m^2). However, analysis or inspection can be performed in lieu of testing if the equipment is operated at vacuum or the high voltage components and circuits are encapsulated or contained within a hermetically sealed chassis containing a dry, high dielectric gas.
Verification is considered successful when any of the following are met:

1. Testing shows that coronal discharges do not occur in equipment operating at pressures greater than 1.0×10^{-1} Newton/meter^2 (N/m^2).
2. Analysis shows that the equipment design maintains an internal pressure of 1.0×10^5 N/m^2 inside the sealed chassis over the operational lifetime of the equipment.
3. 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

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
dB	Decibel
dc	Direct Current
DSG	Deep Space Gateway
DSNE	Design Specification for Natural Environments
E3	Electromagnetic Environmental Effects
EED	Electroexplosive Device
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
EPS	Electrical Power System
ESD	Electrostatic Discharge
EUT	Equipment Under Test
GEO	Geosynchronous Orbit
HDBK	Handbook
IEC	International Electrotechnical Commission
ITE	Information Technology Equipment
LEO	Low Earth Orbit
M	meter
MHZ	Megahertz
MIL	Military
NDI	Non-developmental items
N/m^2	Newton per square meter
OPR	Office of Primary Responsibility
RF	Radio Frequency
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers
SBU	Sensitive But Unclassified
SLS	Space Launch System
SPG	Single Point Ground

STD	Standard
TBD	To Be Determined
TBR	To Be Resolved
V	Volt
V/m	Volts per meter

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
OPEN WORK

B1.0 TO BE DETERMINED

The table To Be Determined Items lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The TBD item is numbered based on the document number, including the annex, volume, and book number, as applicable (i.e., **<TBD-XXXXX-001>** is the first undetermined item assigned in the document). As each TBD is resolved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

TABLE B1-1 TO BE DETERMINED ITEMS

TBD	Section	Description
TBD-DSG-RQMT-001	3.4	The specific field level from onboard, visiting vehicle, or nearby emitters will be defined as RF system design matures

B2.0 TO BE RESOLVED

The table To Be Resolved Issues lists the specific To Be Resolved (TBR) issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The TBR issue is numbered based on the document number, including the annex, volume, and book number, as applicable (i.e., **<TBR-XXXXX-001>** is the first unresolved issue assigned in the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

TABLE B2-1 TO BE RESOLVED ISSUES

TBR	Section	Description
TBR-DSG-RQMT-001	3.1	Traditionally, a 6 dB margin has been deemed adequate to ensure that all uncertainties due to environment and test methods are accounted for. However, on past programs and projects, when analysis was used as a verification methodology, a larger margin was required. Given the advanced levels of analytical technology it is necessary to determine whether 6 dB is adequate or a larger margin required. This requires a balance between program costs and

		risks to achieve an adequate margin that is not unduly burdensome to the Gateway Program
TBR-DSG-RQMT-002	3.4	The on orbit RF environment due to ground based emitters contained in Table 3.4-1 was first defined in 2006 for the Constellation Program. The definition was based on information provided the Defense Information Systems Agency's Joint Spectrum Center. It is assumed the on orbit environment has changed since the spectrum usage has changed as well as the number of world-wide civilian and government emitters currently operating. The NASA E3 community has been unable to secure the appropriate funding to obtain a more up-to-date set of data from the Joint Spectrum Center in which to define the on orbit environment. Until the new data is obtained and new on orbit definition can be generated, there will be an uncertainty that the actual on orbit environment is adequately enveloped by the information of Table 3.4-1