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George C. Marshall Space Flight Center

Huntsville, Alabama 35812

ED01

MSFC TECHNICAL STANDARD

**ELECTROMAGNETIC COMPATIBILITY
REQUIREMENTS FOR EQUIPMENT AND
SUBSYSTEMS**

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DOCUMENT HISTORY LOG

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Revision	D	6/13/2025	<p>Revision D was authorized by the MSFC Technical Standards Document Control Board (DCB).</p> <p>Added Section 1.7 Language Usage.</p> <p>Evaluated all documents that are applicable and referenced for current release status and updated as needed.</p> <p>Aligned Section 3.1 and 3.2 requirements to up-to-date requirements provided from Gateway, International Space Station (ISS), and Human Landing System (HLS) Programs.</p> <p>Revised CE101 test method and limit to encompass CE101/CE102 test intent. Removed CE102 test.</p> <p>Renamed CE108 test to CE104 test and updated test limits to align with system level requirement implementation.</p> <p>Renamed RE101 test to RE101A test and updated test limit. Added RE101D test.</p> <p>Modified RE102, CS101, RS101, and RS103 test limits to align with system level requirement implementation.</p> <p>Added CS103, CS104, and CS105PN antenna susceptibility test.</p> <p>Modified CS114 test to include a differential and common mode test setups and revised test limits.</p> <p>Added Section C.2 DOCUMENTS to correlate to Section 2.0.</p>

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1.0 INTRODUCTION

1.1 Background

Marshall Space Flight Center – Specification (MSFC-SPEC)-521 was initially published in 1978 to (1) interpret and integrate the various electromagnetic compatibility (EMC) requirements found in Shuttle, Spacelab, and payloads system documentation, and (2) document them for payload subsystems and equipment. The requirements of this specification, from its basic revision through revision B, were primarily derived from the *Spacelab Payload (SLP) Accommodation Handbook, SLP-2104*; the *Orbiter/Spacelab Interface Control Document (ICD), 2-05301*; *Military Standard (MIL-STD)-461*; *National Space Transportation System (NSTS)-SL-E-0002*; the *Material Science Laboratory (MSL) User's Handbook, JA655*; and the *Space Shuttle Payload Accommodations Handbook, Volume XIV of NSTS 07700*.

Although written specifically for Spacelab payloads, the specification became a *de facto* EMC standard for MSFC hardware where equipment and system level requirements did not exist or were unknown at the beginning of the development process.

Currently, *MIL-STD-461, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*; and *MIL-STD-464, Electromagnetic Environmental Effects Requirements for Systems*; are the engineering standards endorsed by the National Aeronautics and Space Administration (NASA) Office of Chief Engineer for electromagnetic interference (EMI) control and system-level EMC. *MIL-STD-461* and *MIL-STD-464* are applicable to all activities and agencies of the Department of Defense (DoD). Because of the broad applicability of these standards, the documents allow for tailoring of requirements commensurate with the intended installation and operation of the equipment and subsystems.

Because *MIL-STD-461* and *MIL-STD-464* are intended for all DoD activities, the scope of requirements exceeds those generally required for spaceflight programs and projects. Blind compliance with these standards frequently results in over-specification and excessive costs.

In accordance with *NASA Procedural Requirements (NPR) 7120.10, Technical Standards for NASA Program and Projects*; *MSFC-SPEC-521D*, presented herein, is a tailored version of *MIL-STD-461, MIL-STD-464, and GP11461, Gateway Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*. The scope of the specification is intended to meet the needs of a substantial majority of MSFC Programs and Projects to prevent over-specification of requirements, yet still maintain EMC.

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.

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1.2 Purpose

The basic EMC requirement for a system is that all included subsystems shall be able to operate compatibly during the mission. To accomplish this, requirements are imposed at two levels: one at the system level, the other at the equipment or subsystem level. While some system-level requirements are outlined here, the primary objective of this document is to define equipment-level requirements to which the equipment developer shall adhere.

1.3 Scope

This document defines the minimum EMC requirements to be imposed on any electrical and/or electronic equipment to be transported by launch vehicle or spacecraft carrier systems. This includes experiment equipment and flight support equipment subsystems that are payload elements of the launch vehicle, spacecraft, or free-flying satellite.

Since this specification is intended to provide, at low cost, reasonable confidence that equipment can operate compatibly within the operating environment, only the most important emission and susceptibility requirements have been chosen. Some requirements have been converted into more usable terms, and some have been modified to be more easily verified.

The intent of this specification is to address the EMC needs of 80 percent of equipment and subsystems developed for small MSFC projects. As such, for example, not all requirements of *MIL-STD-461* are represented in Section 3 of this document. Other requirements, necessary to achieve EMC on previous NASA Programs and Projects, are contained in Section 3. Information is provided in the Appendices to aid the Program, Project manager, and Electromagnetic Environmental Effects (E3) engineer in developing these requirements. In addition, this document serves as an equipment level specification for the Commercial Low Earth Orbit Development Program (CLDP).

Recognizing that a discussion of EMC requirements at the hardware equipment level also brings into focus certain system-level requirements, some system-level aspects of an EMC program are referred to in this specification: for example, the design and arrangement of hardware equipment enclosure connectors must be in concert with the compatible development of the system’s interconnecting wiring and cabling; and proper attention must be paid to the development of an electrical bonding plan that will be compatible with the bonding provisions being designed into the hardware items that are within the scope of this document. These and other higher-level considerations may be examined in the system E3 Control Plan.

1.4 E3 Control Plan

The system-level E3 Control Plan (MSFC Standard Data Requirements Document # STD/Design and Development Engineering (DE)-EMP) is a requirement of *Marshall Procedural Requirements (MPR) 7123.1, MSFC Systems Engineering Process Requirements*; and is

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applicable to the system (whole payloads, free-flying satellites, rocket stages, etc.) under consideration.

E3 engineers must have a system 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 satisfactorily addressed by the hardware items produced.

1.5 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.

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1.6 Modifications to Requirements

If an equipment developer intends to place on equipment builders additional or more stringent requirements than those stated here, those new requirements to be imposed must first be documented in detail. Two acceptable methods of documenting details of new requirements would be: (1) In the systems level E3 control plan, or (2) as a line item in the preliminary requirements review documentation.

Note: An E3 Control Plan is not necessarily required at the equipment level.

1.7 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 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	Revision	Document Title
MIL-STD-461	Rev G	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MPR 7123.1	Rev C	MSFC Systems Engineering Process and Requirements
NASA-STD-4003	Rev A	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
NPR 7120.10	Rev B	Technical Standards for NASA Programs and Projects

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2.2 Reference Documents

Document Number	Revision	Document Title
GP 10009	Rev C	Gateway Electrical Power Quality Specification Requirements for 120 VDC
GP 11461	Rev A	Gateway Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
JSC-CR-06070	Baseline	Space Vehicle RF Environments
MIL-STD-464	Rev C	Electromagnetic Environmental Effects Requirements for Systems
MSFC-HDBK-3697	Baseline	Electrical Bonding Design Guide Handbook
MSFC-SPEC-3659	Baseline	Process Specification for Electrical Bonding
MSFC-STD-3790	Baseline	Electromagnetic Environmental Effects (E3) System Level Requirement for Space Vehicles
NASA RP 1368	Baseline	Marshall Space Flight Center Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook (MSFC Center Director's Discretionary Fund Final Report, Project 93-15)
RTCA DO-160	Rev G	Environmental Conditions and Test Procedures for Airborne Equipment, Section 20, Radio Frequency Susceptibility (Radiated and Conducted) and Section 21, Emission of Radio Frequency Energy
SAE AS5698	Rev A	Space Power Standard
SL-E 0002, Book 3, Volume 1	Baseline	Space Shuttle Specification: Electromagnetic Interference Characteristics, Requirements for Equipment – Book 3 New or Modified Equipment
SSP 30242	Rev K	Space Station Cable/Wire Design and Control Requirements for Electromagnetic Compatibility

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

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TOR-2022-01686	Rev C	Cape Canaveral Radio Frequency Environment: Eastern Range

2.3 Order of Precedence

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

3.0 REQUIREMENTS

The system level specifications found in Section 3.1 and 3.2 are applicable. In cases where a program or project system level requirement exists that conflict with those of Section 3.1 and 3.2, the program or project system level requirements take precedence. However, the requirements contained herein are compatible with most, if not all current program and project EMC specifications.

*Note: System level requirements applicable to pyrotechnic devices and subsystems are found in E3 system level requirements documents such as **MSFC-STD-3790 Electromagnetic Environmental Effects (E3) System Level Requirement for Space Vehicles**.*

3.1 System Compatibility

3.1.1 Functional Compatibility

Equipment shall not generate interference that degrades performance or causes malfunction on the platform, in the carrier, or in other subsystems. Equipment shall not malfunction due to susceptibility to emissions in its operating environment.

3.1.2 Margins

Safety critical systems, subsystems, and equipment shall have a margin of at least 6 decibels (dB) between its threshold of susceptibility and the applicable 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.

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Note: A 16.5 dB margin is required for pyrotechnic devices. The power produced by the EME at the pyrotechnic device shall be 16.5 dB below the maximum no-fire stimulus of the device.

Rationale: A margin is the difference between the electromagnetic stress level the equipment or system is required to withstand or tolerate and 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 device will perform as designed in its prescribed operational environments.

In some cases, compliance with the conducted and radiated susceptibility limits contained herein means the subsystem or equipment has demonstrated a 6 dB margin with respect to the spacecraft system 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 considered.

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 Design Requirements

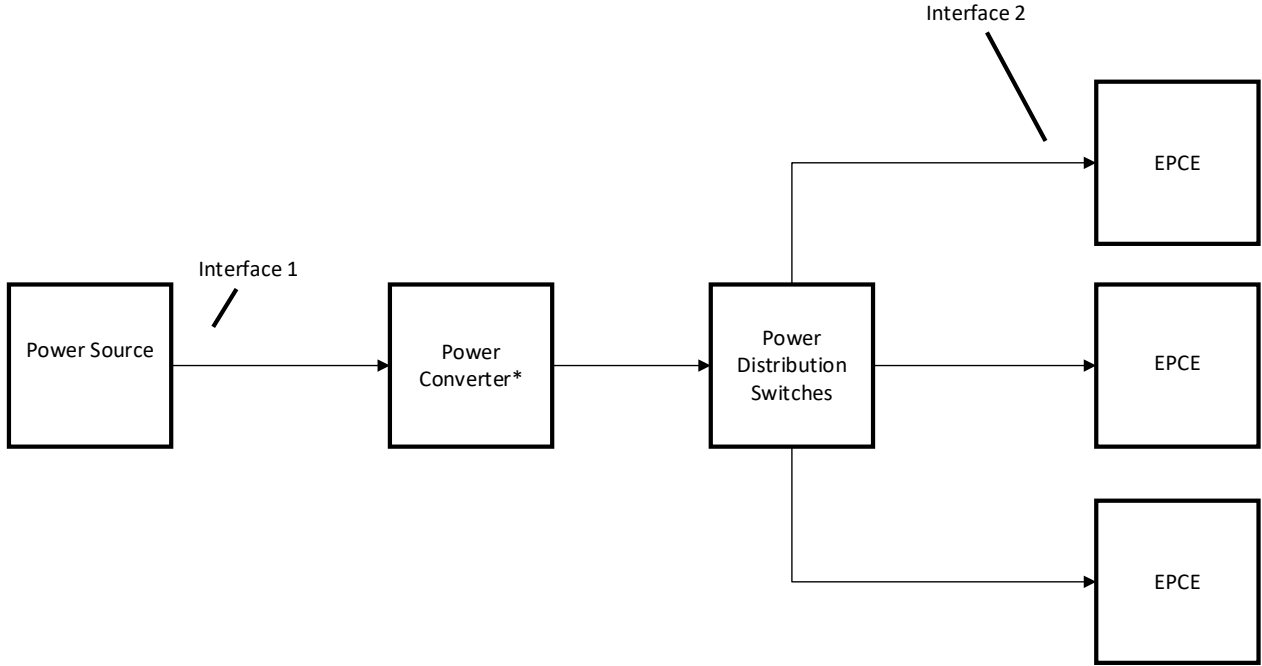
3.2.1 Primary Power

Primary Power is considered the distributed vehicle power (e.g., 120 volt (V) or 28 V vehicle power) and secondary power refers to conditioned power (e.g., 15V direct current (DC) power).

As seen in Figure 1, Electrical Power System (EPS) Interface 1 is the point at which the voltage source is mated to a common interface (bus tie) for the Power System. EPS Interface 2 is at the

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input terminals or input connector pins for electrical loads, or electrical power consuming equipment (EPCE), which are fixed.



* In some cases, no power conversion exists between the power source and the distribution switches

Figure 1. EPS Power Interfaces

3.2.1.1 System

Primary Power shall incorporate a common reference using a distributed single point ground (SPG) architecture. In each electrical power domain, there is one and only one reference to vehicle chassis or structure.

Rationale: An electrical system is referenced to ground for three reasons: safety, enhanced operability of the circuit, and EMI control. Some electrical circuits require grounding to a common reference plane (“ground” plane) to operate efficiently. A single reference to structure prevents unwanted DC and noise currents from circulating through structure, thereby mitigating potential EMI problems. To establish a distributed SPG for the EPS, it is necessary to define isolation requirements at the equipment interface, typically the load or EPCE. It is also necessary to ensure that secondary electrical power systems and electrical signals routed external to equipment meet the isolation requirements to prevent multiple references to structure (ground loops).

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3.2.1.2 Equipment Power Ground Reference

3.2.1.2.1 Interface 1

Power sources shall reference to vehicle chassis, structure, or the return conductor of the voltage output. If more than one voltage is sourced, then the power source shall connect the reference or neutral lead to chassis or structure.

The grounding circuit should be fully enclosed in the chassis of the voltage source (e.g., no grounding lead requiring an external connection should be used).

3.2.1.2.2 Interface 2

Power consumers/converters/conditioners/distributors/etc. connected to primary power shall maintain at least 1 Megohm ($M\Omega$) dc isolation between both the high and return lines when measured against chassis. This includes all operational modes.

3.2.1.2.3 Primary Power to Secondary Power Isolation

Isolation between input primary power lines (hot and return) and each secondary power line shall be greater than 1 $M\Omega$ DC.

Equipment using alternating current (AC) power shall limit capacitance to case so that the device meets the leakage current requirements of the applicable Underwriters Laboratories (UL) specification for the equipment or program safety specification.

3.2.1.3 Equipment/LRU Signals Grounding Considerations

3.2.1.3.1 Signal Grounding

Signal circuitry routed external to equipment shall be isolated from chassis/structure by at least 1 $M\Omega$ except at a single reference to structure on the transmit or source end (when a reference is necessary for signal integrity).

3.2.1.3.2 Signal Returns

Each signal, command, control, and power circuit routed externally to the equipment shall employ a separate return and shall be isolated from harness shields and destination chassis by a minimum resistance of 1 $M\Omega$.

Signal returns for circuits using separate derived power sources shall be isolated by a minimum resistance of 1 $M\Omega$.

Note: Some data bus protocols such as Electronics Industries Association (EIA) Recommended Standard (RS)-232 and RS-423 utilize one return for multiple signals. The intent of this requirement is met when equipment meets such data bus protocols and complies with the other requirements of this specification.

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Commentary: Testing isolation of signal returns must be performed prior to connecting cables and equipment. Connector pins, connected to signal returns in the equipment containing the power source, should measure continuity to chassis ground. Signal returns in cables or equipment not containing or connected to the power source should measure at least 1 MΩ when measured from return to equipment chassis or cable shield. At least 1 MΩ should also be measured between signal returns for circuits using separate derived power sources.

3.2.1.3.3 Balanced Differential Circuit Isolation

Balanced differential circuits external to equipment shall be isolated from chassis by 6 Kilohms (kΩ) or greater. Line drivers and receivers having balanced receivers and low impedance drivers are considered balanced circuits even though the source is referenced to ground.

3.2.1.3.4 Coaxial Shields

Coax cabling shall be permitted only when all frequency components of the signal are greater than or equal to 1 Megahertz (MHz). Coax shall not be used as interconnects between equipment utilizing different power sources unless electrical isolation is provided (opto-isolators, transformers, etc.) to prevent violation of SPG architecture.

3.2.2 Enclosure Shielding

Thin shields of aluminum, copper, or steel are effective for radio frequency (RF) radiated fields. However, for low frequency magnetic fields (<500 Kilohertz (kHz)), either thicker steel or magnetic material (with a high relative magnetic permeability, μ_r) is required. The shielding effectiveness of an enclosure is degraded by the holes, seams, and joints in the enclosure. Leakage through seams, holes, and joints is usually a greater concern than the shielding effectiveness of the enclosure material. The following are some general guidelines for enclosure shielding:

- a. The maximum linear dimension of the opening, not the area, determines the amount of leakage.
- b. A slot or rectangular hole may act as a slot antenna when the maximum linear dimension of the slot becomes greater than 1/10 of a wavelength.
- c. Many holes will allow less leakage than one large hole of the same total area.
- d. An aperture with a depth greater than the maximum linear dimension of the aperture will act as a waveguide. This waveguide will offer greater attenuation than a “regular” hole pattern for frequencies lower than the waveguide’s critical frequency. The critical frequency is roughly the frequency whose half wavelength equals the maximum linear dimension of the opening.
- e. Good electrical contact along seams or joints is necessary to maintain shielding effectiveness. The mechanical design must provide for a conductive finish and adequate contact force between the mating surfaces.

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- f. For equipment enclosures that require ventilation, the following materials (in descending order of attenuation) should be used to cover the opening:
 1. Waveguide below cutoff panels (honey-comb panels)
 2. Perforated metal sheet
 3. Woven or knitted metal mesh.

3.2.3 Electrical Bonding

The equipment shall have provisions to allow its case/enclosure(s) to be bonded to structure in accordance with *NASA-STD-4003*.

3.2.3.1 Bonding Provisions

The bonding provisions shall be for metal-to-metal contact of bare surfaces or surfaces with a qualified conductive finish or for a ground-strap-to-structure bond.

3.2.3.2 Bonding Contact Area

The bonding surface area shall be 4 times the cross-sectional area of a cable conductor that could safely carry the expected current in the bond path.

3.2.3.3 Bonding Area Preparation

This bonding surface area shall be prepared such that it is clean and free of paint or any type of non-conductive conversion coating. Bare, clean, metal-to-metal contact will ensure a low-impedance connection between mating surfaces.

3.2.3.4 Bonding Straps

If a bonding strap is used, it shall have a length-to-width ratio less than 5:1. The preferred method of bonding is through the mounting surface to structure.

Note: MSFC-HDBK-3697, Electrical Bonding Design Guide Handbook, provides guidance on electrical bond design. In most instances, equipment bond interfaces will be required to comply with Class H and Class R bond of NASA-STD-4003. MSFC-SPEC-3659, Process Specification for Electrical Bonding, should be used to ensure that the process to establish safe and repeatable electrical bonds. While it has been long understood that bonding verification required testing only, the verification process is multistep. The design must be inspected to show that the electrical bond path is a deliberate design, the manufacturing process inspected to show that the as-built hardware results in a safe and repeatable bond path, and the workmanship process shows the as-built hardware complies with the design.

3.2.4 Circuit Classification

Wiring classification criteria is typically dependent on frequency content, voltage level, current amplitude and circuit impedance. Wire bundles of differing EMC classification shall be physically separated from each other. Where no metallic shield, other than an individual braided shield, exists between them, each classification shall be separated from all other classes by a

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minimum of 5 centimeters. Exceptions for short runs are allowed where all classes may be routed together for parallel runs totaling less than 3 feet in length. When both power and signal circuits are present at the interface, a minimum of two connectors should be used. In cases where only one connector exists on an enclosure, the pins should be assigned to facilitate separation of the wire bundles outside the enclosure. Separation of these wire classes internal to experiment subsystems is recommended.

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, in cases where cable separation is required by the program.

3.2.5 Wire Twisting

Circuits that interconnect equipment shall provide for minimum loop coupling and maximum field cancellation by twisting of return with high side, including both signal and power circuits.

3.2.5.1 Group Wire Twisting

Multiple circuits using a common return shall be twisted as a group. Twisting tighter than that required to hold the wires together is usually unnecessary.

3.2.6 Wire Shielding

Wire shields shall cover the twisted pair or twisted group rather than individual wires.

3.2.6.1 Shield Current

No shield shall intentionally carry current except for coax cables used with radio frequencies only (1MHz and above).

3.2.6.2 Shield Termination

Circuit cable shields shall be terminated to the equipment case at each end. The preferred method of terminating shields is through a conductive backshell that makes good electrical contact to the equipment case. Electrical connectors that may be used to terminate cable shields shall be installed to provide a low impedance path to the equipment case.

Overall shields may be used over a cable bundle for additional protection and shall be terminated to equipment case at each end.

3.2.6.3 Shield Termination Bonding

Electrical connectors that may be used to terminate cable shields shall be installed to provide a low impedance path to the equipment case that complies with the Class R bonding requirements of *NASA-STD-4003*.

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3.3 Subsystem and Equipment Emission and Susceptibility Requirements

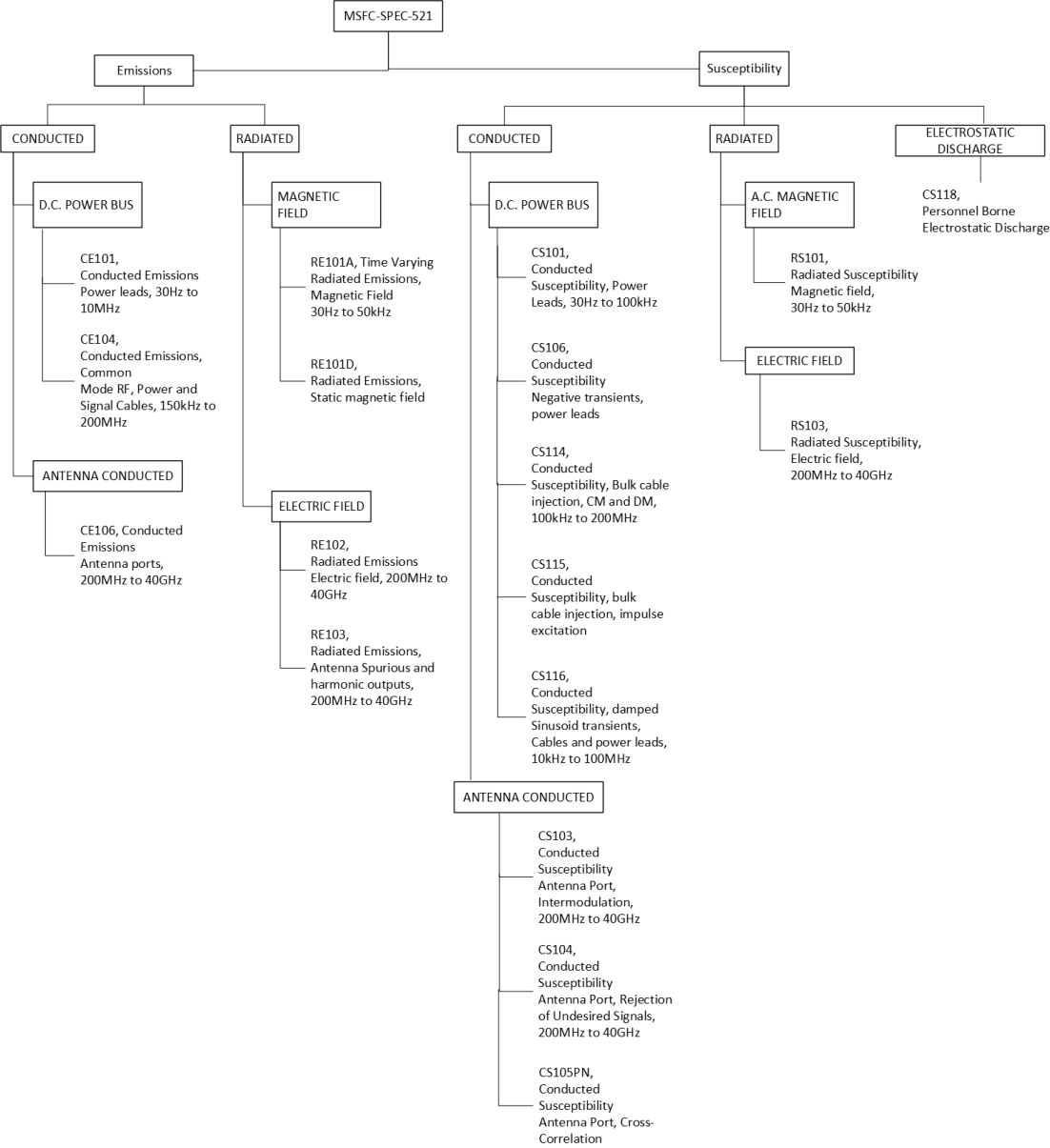


Figure 2. MSFC-SPEC-521D Test Summary Chart

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3.3.1 Equipment Produced Emission

Conducted and radiated emissions produced by payload equipment shall be controlled as follows.

3.3.1.1 Conducted Emissions (CE)

3.3.1.1.1 Conducted Emissions, Power Leads, Differential Mode, (CE101)

This requirement is applicable from 30Hz to 10MHz for all primary power leads, including returns, which obtain power from other sources not part of the EUT.

3.3.1.1.1.1 CE101 Limits

Conducted emissions on power leads shall not exceed the applicable values shown in Figure 3 for equipment powered by 120 Volts direct current (Vdc), Figure 4 for equipment powered by 28 Vdc loads.

Note: The limits for the 120 Vdc and 28 Vdc loads may be relaxed by $20 \log(I)$, where I is the maximum steady current draw of the load.

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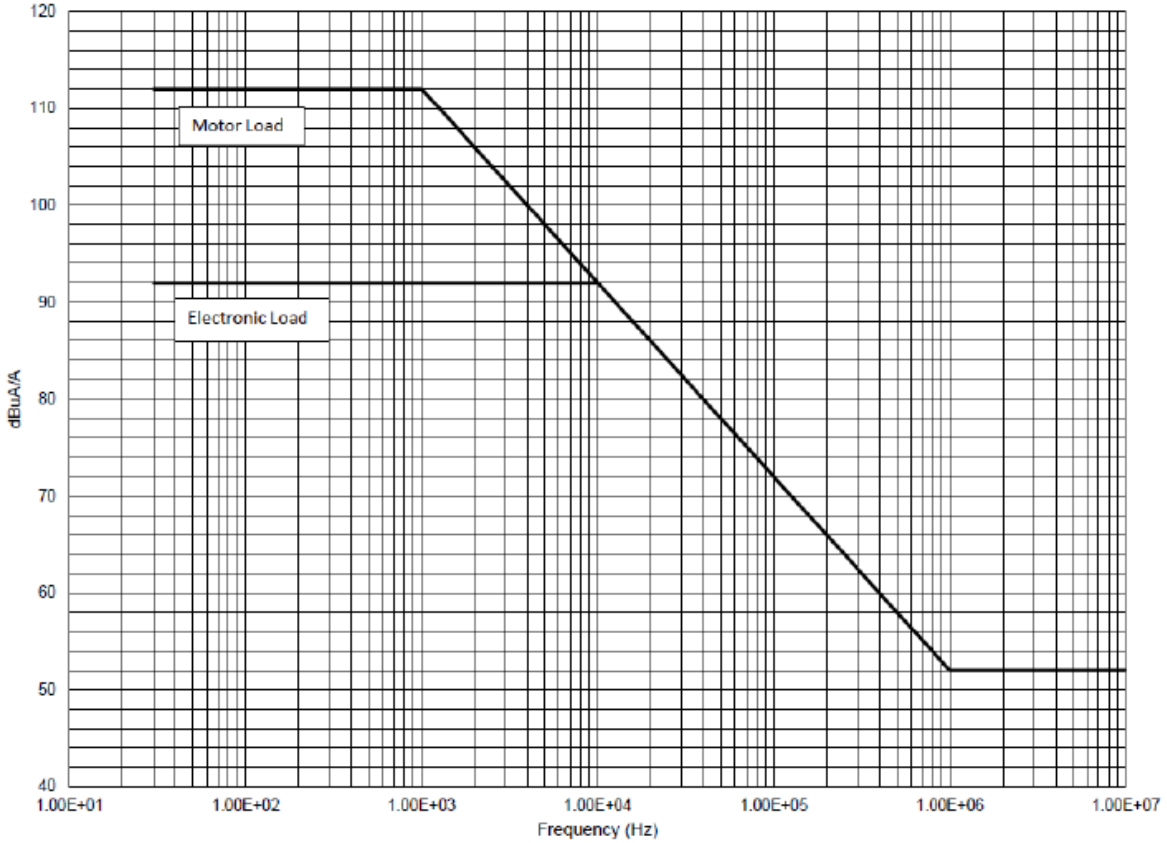


Figure 3. CE101 Limit for Equipment Powered from 120 Vdc Power Bus

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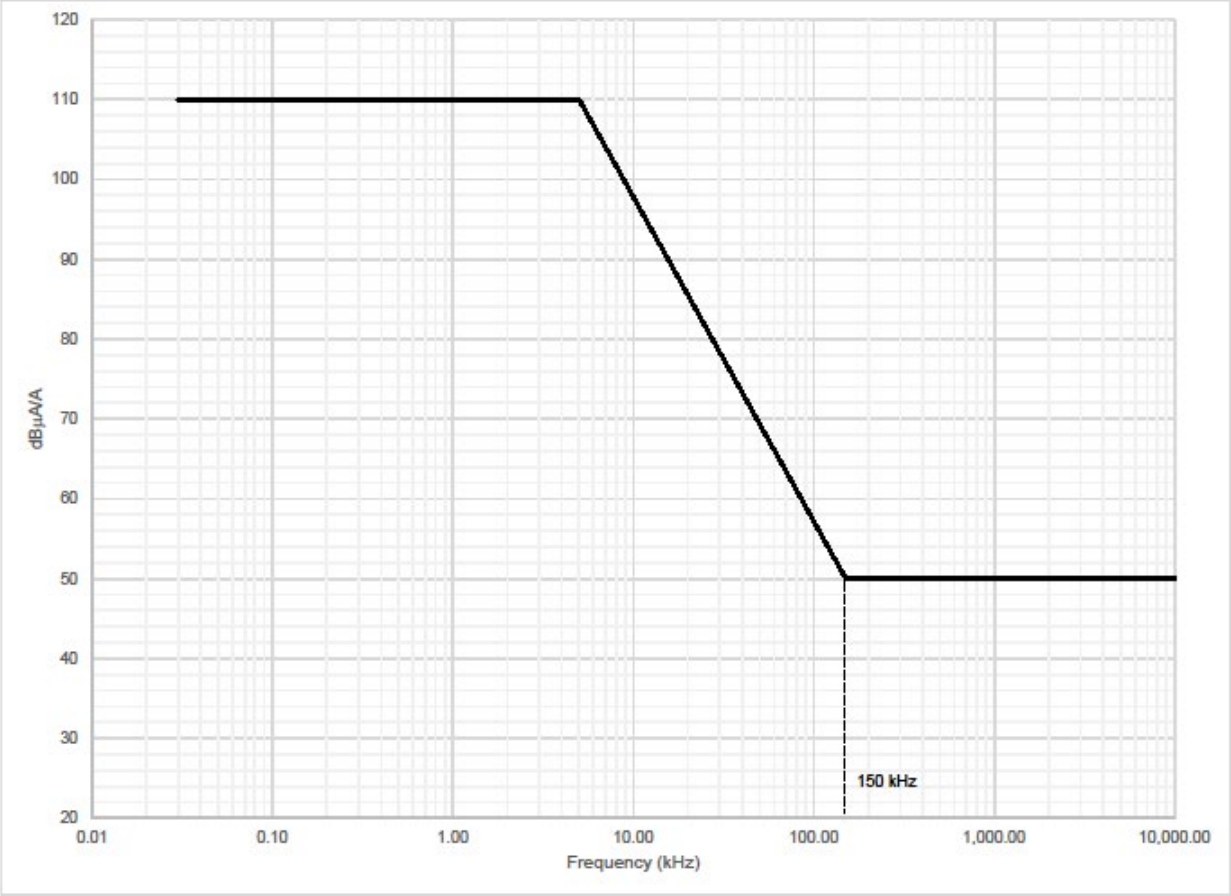


Figure 4. CE101 Limit for Equipment Powered from 28 Vdc Source

3.3.1.1.2 Conducted Emissions, Common-Mode Radio Frequency Current, Power and Signal Cables (CE104)

This requirement is applicable from 150kHz to 200MHz for all cables. The requirement does not apply at the transmitter fundamental frequencies. This test procedure is used to verify that common mode RF currents on all cables do not exceed the specified limit.

3.3.1.1.2.1 CE104 Limits

Conducted emissions on power and signal cables shall not exceed the applicable values shown on Figure 5.

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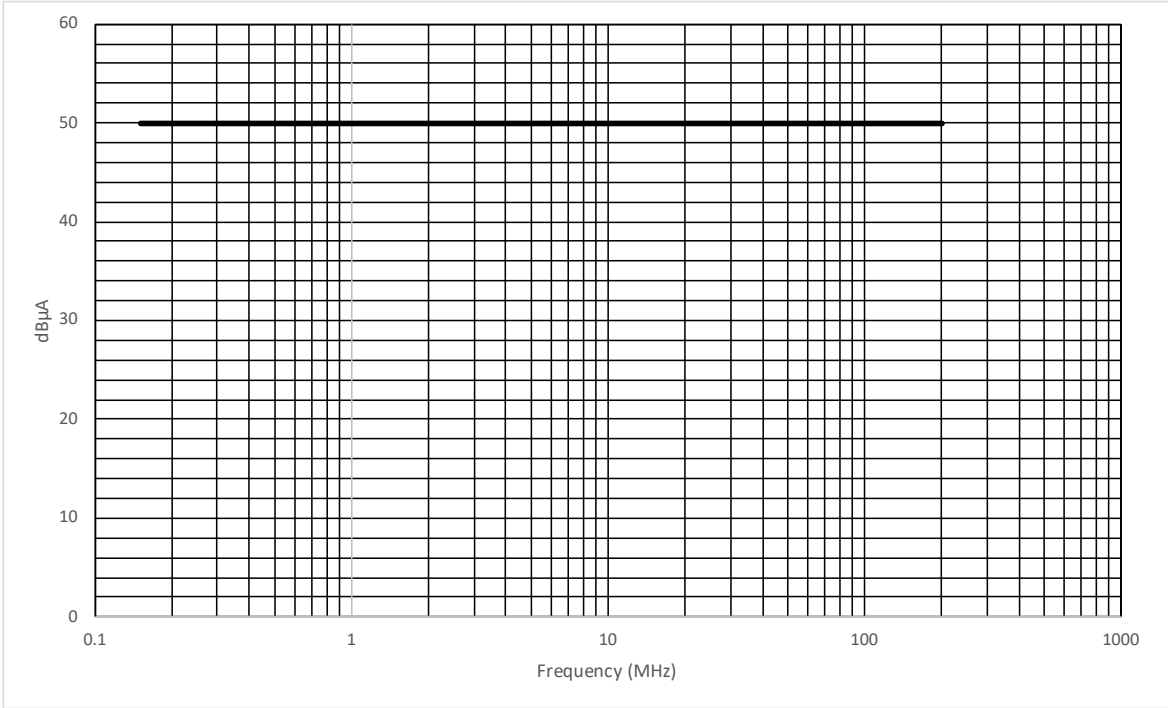


Figure 5. CE104 BCE Limit for All Applications

3.3.1.1.3 Conducted Emissions, Antenna Terminal (CE106)

This requirement is applicable from 200 MHz to 40 GHz for the antenna ports of transmitters, receivers, and amplifiers. The requirement is not applicable to equipment designed with antennas permanently mounted to the EUT. The transmit mode portion of this requirement is not applicable within the bandwidth of the EUT transmitted signal or within ± 5 percent of the fundamental frequency, whichever is larger.

The equipment shall be tested to an upper frequency limit based on the highest frequency generated or received by the EUT. For systems with the frequencies generated or received less than 1 GHz, the upper frequency limit shall be 20 times the highest frequency or 20 GHz, whichever is greater. For systems with frequencies generated or received greater than or equal to 1 GHz, the upper frequency limit shall be 10 times the highest frequency or 40 GHz, whichever is less. For equipment using waveguide, the requirement does not apply below eight-tenths of the waveguide's cutoff frequency. RE103 may be used as an alternative for CE106 for testing transmitters with their operational antennas.

Note: The end frequency of the test is 40GHz or 20 times the highest generated or received frequency within the EUT, whichever is less. For equipment using

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waveguide, the requirement does not apply below eight-tenths of the waveguide's cutoff frequency. Radiated Emission RE103 may be used as an alternative for CE106 for testing transmitters with their operational antennas. RE102 is applicable for emissions from antennas in receive and standby modes and designed with antennas permanently mounted to the EUT.

3.3.1.1.3.1 CE106 Limits

Conducted emissions at the EUT antenna terminal shall not exceed the values given below.

- a. Receivers: 34 Decibel microvolts (dBµV).
- b. Transmitters and amplifiers (standby mode): 34dBµV.
- c. Transmitters and amplifiers (transmit mode): Harmonics and all other spurious emissions, except the second and third harmonics, shall be at least 80dB down from the level at the fundamental. The second and third harmonics shall be suppressed to a level of -20 decibels to one milliwatt (dBm) or 80dB below the fundamental, whichever requires less suppression.

3.3.1.2 Radiated Emissions (RE)

3.3.1.2.1 Radiated Emissions, Time Varying Magnetic Field (RE101A)

This requirement is applicable from 30Hz to 50kHz for radiated emissions from equipment and subsystem enclosures, including electrical cable interfaces. The requirement does not apply to radiation from antennas.

3.3.1.2.1.1 RE101A Limits

Magnetic field emissions shall not exceed the limits shown on Figure 6, when measured at 7cm.

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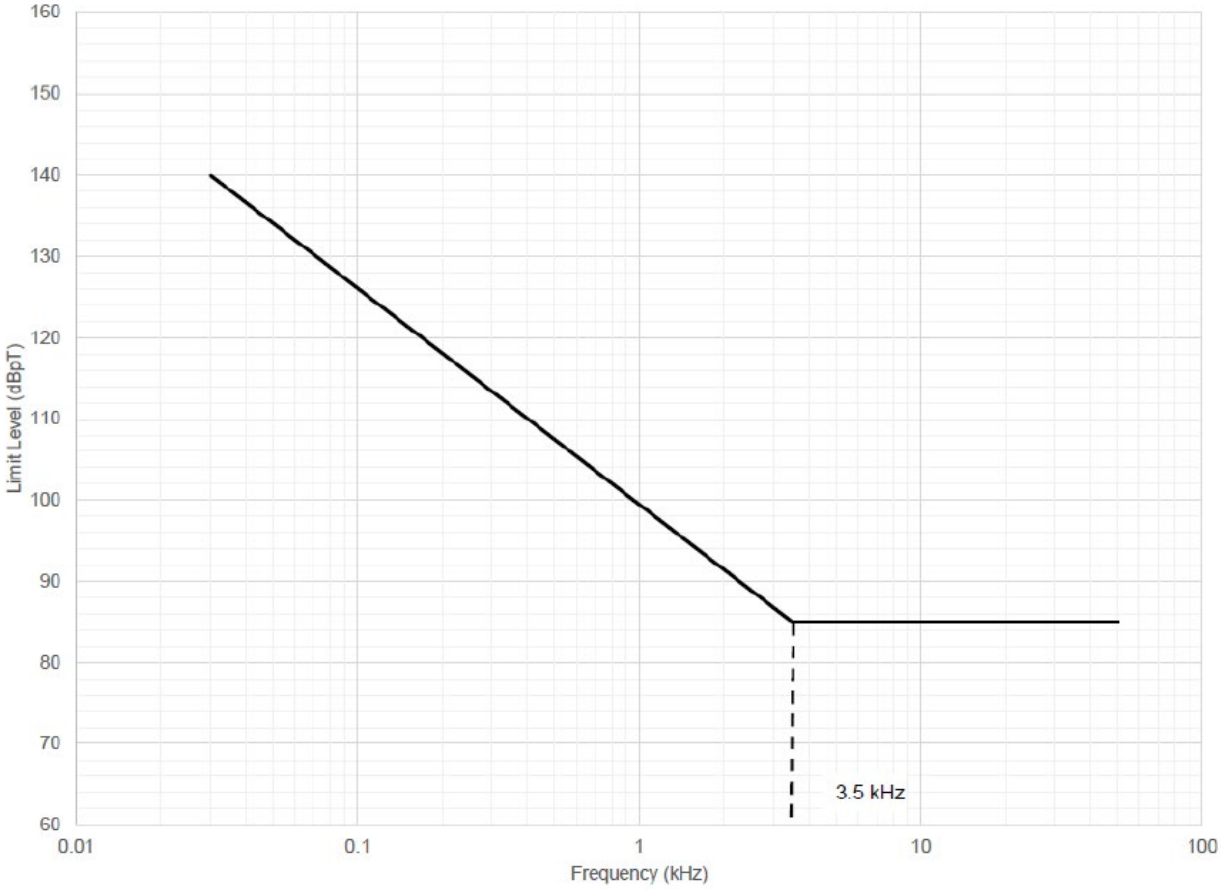


Figure 6. RE101A Limit

3.3.1.2.2 Radiated Emissions, Static Magnetic Field (RE101D)

This requirement is applicable for radiated emissions from equipment and subsystem enclosures, including permanent magnets. This requirement is not applicable to solenoid valves, solenoid relays, and electric motors with current of less than 1 Ampere.

3.3.1.2.2.1 RE101D Limits

Magnetic field emissions shall not be more than 170dBpT when measured at a distance of 7cm.

3.3.1.2.3 Radiated Emissions, Electric Field (RE102)

This requirement is applicable for radiated emissions from equipment and subsystem enclosures, all interconnecting cables, and antennas designed to be permanently mounted to EUTs (receivers

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and transmitters in standby mode). The requirement does not apply at the transmitter fundamental frequencies. The requirement is applicable between 200MHz to 40GHz. *

** Testing is required up to 18 GHz or ten times the highest intentionally generated frequency within the EUT, whichever is greater. Measurements beyond 40 GHz are not required.*

3.3.1.2.3.1 RE102 Limits

Electric field emissions shall not exceed the limits shown in Figure 7. The limits shall be met for both horizontally and vertically polarized fields.

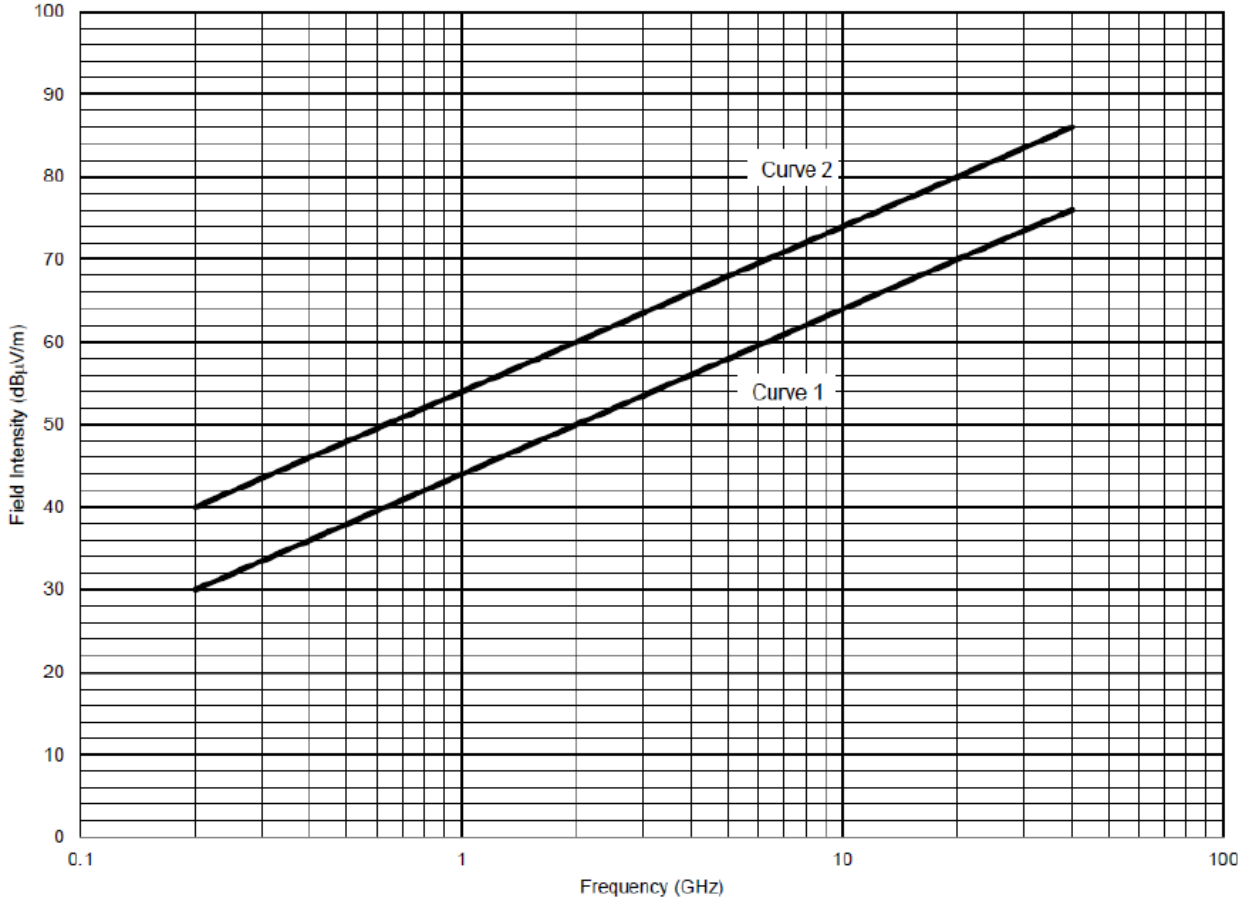


Figure 7. RE102 Limit for All Applications

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Note: Curve 1 is for equipment mounted outside the pressurized element. Curve 1 also applies to equipment mounted internal to the pressurized element in bands, where the spectrum is used intentionally, internal to the pressurized element. Curve 2 is for equipment mounted internal to the pressurized element, out-of-band to internally used radio bands.

3.3.1.2.4 Radiated Emissions, Antenna Spurious and Harmonic Outputs (RE103)

This requirement may be used as an alternative for CE106 when testing transmitters with their intended antennas. This requirement is met if the emissions do not exceed the applicable RE102 limit in transmit mode. CE106 is the preferred requirement unless the equipment or subsystem design characteristics preclude its use. RE103 should be the preferred method for high power transmitters. Systems using active or non-detachable antennas should be evaluated per RE102, if possible. RE103 should be retained for high power transmitters when CE106 cannot be performed.

RE103 is applicable from 200 MHz to 40 GHz, and not applicable within the bandwidth of the EUT transmitted signal or within ± 5 percent of the fundamental frequency, whichever is larger. The equipment will be tested to an upper frequency limit based on the highest frequency generated or received by the EUT. For systems with the frequencies generated or received less than 1 GHz, the upper frequency limit will be 20 times the highest frequency or 20 GHz, whichever is greater. For systems with frequencies generated or received greater than or equal to 1 GHz, the upper frequency limit will be 10 times the highest frequency or 40 GHz, whichever is less. For equipment using waveguide, the requirement does not apply below eight-tenths of the waveguide's cutoff frequency.

3.3.1.2.4.1 RE103 Limits

Harmonics, except the second and third, and all other spurious emissions shall be at least 80dB down from the level at the fundamental. The second and third harmonics shall be suppressed $50 + 10 \log p$ (where p = peak power output in watts, at the fundamental) or 80dB, whichever requires less suppression.

3.3.2 Equipment Susceptibility

Equipment shall not malfunction or exhibit degraded performance beyond the tolerance given in the individual equipment specification when subjected to the following electromagnetic environment.

3.3.2.1 Conducted Susceptibility (CS)

3.3.2.1.1 Conducted Susceptibility, Power Leads (CS101)

This requirement is applicable to equipment and subsystem DC input power leads, not including returns. This requirement is applicable over the frequency range of 30Hz to 100kHz.

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3.3.2.1.1 CS101 Limits

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem specification, when subjected to a test signal with voltage levels as specified on Figure 8. The requirement is also met when the power source is adjusted to dissipate the power level shown in Figure 9.

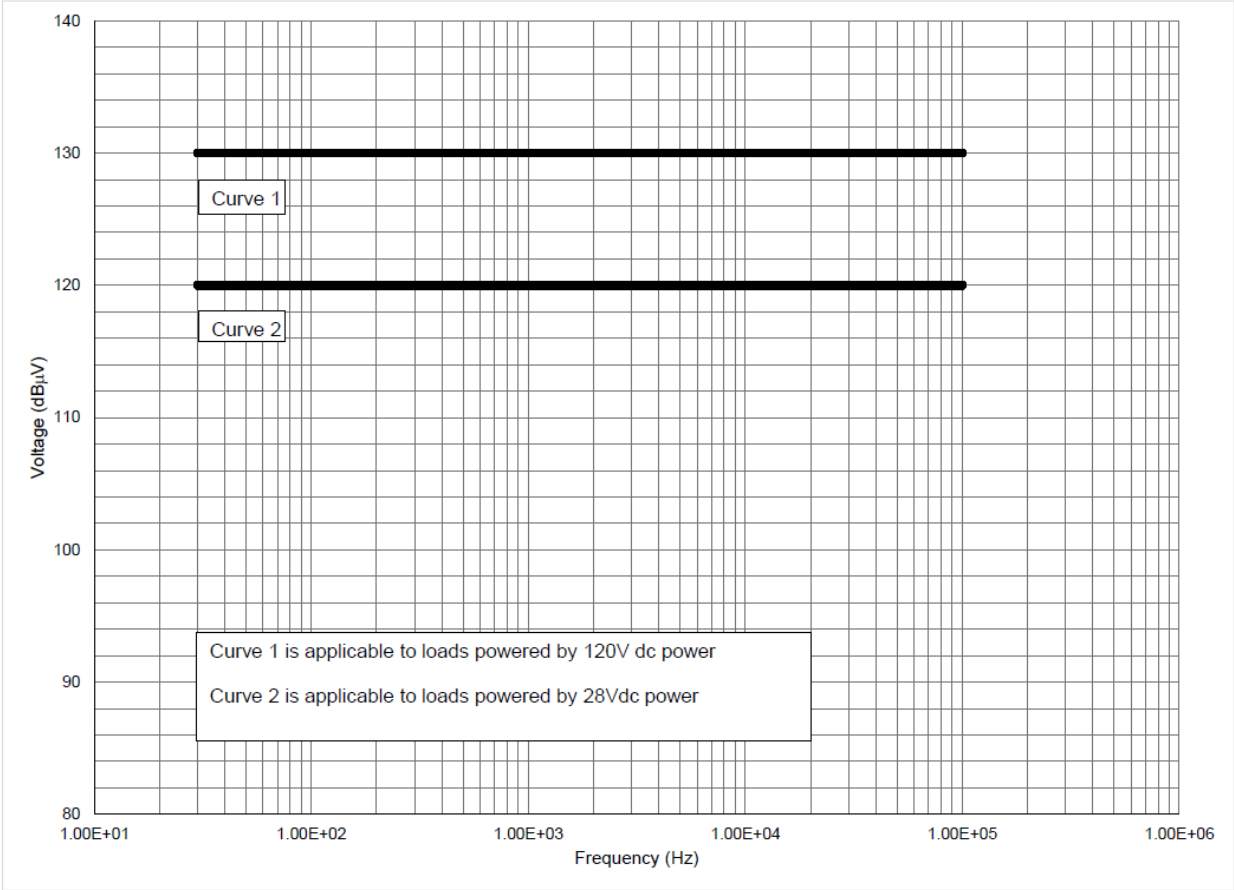


Figure 8. CS101 Voltage Limit for Interfaces

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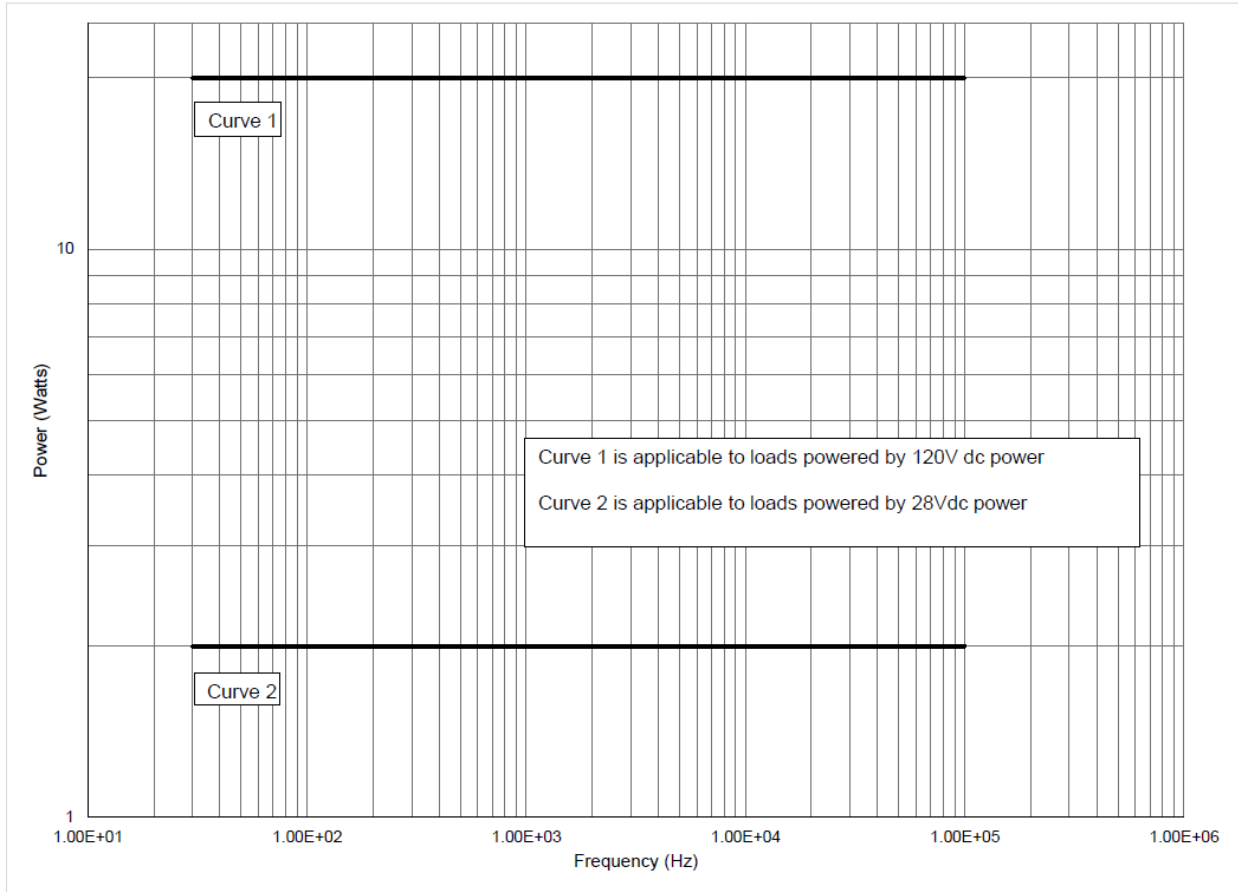


Figure 9. CS101 Power Limit for Interfaces

3.3.2.1.2 Conducted Susceptibility, Antenna Port, Intermodulation (CS103)

This receiver front-end susceptibility requirement is applicable from 200 MHz to 40 GHz for equipment and subsystems, such as communications receivers, RF amplifiers, transceivers, and radar receivers as specified in the individual procurement specification.

3.3.2.1.2.1 CS103 Limit

The EUT shall not exhibit any intermodulation products beyond specified tolerances when subjected to the limit requirement provided in the individual procurement specification.

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3.3.2.1.3 Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals (CS104)

This receiver front-end susceptibility requirement is applicable from 200 MHz to 40 GHz for equipment and subsystems, such as communications receivers, RF amplifiers, transceivers, radar receivers, and other receivers as specified in the individual procurement specification. The applicable frequencies are a function of the front-end design of the unit being evaluated.

3.3.2.1.3.1 CS104 Limit

The EUT shall not exhibit any undesired response beyond specified tolerances when subjected to the limit requirement provided in the individual procurement specification.

3.3.2.1.4 Conducted Susceptibility, Antenna Port, Cross-Correlation (CS105PN)

This requirement is applicable to direct sequence spread spectrum receivers that use Pseudo-Random (PN) codes to correlate and demodulate the incoming message or ranging information.

3.3.2.1.4.1 CS105PN Limit

The EUT shall exhibit a loss of lock (loss of acquired signal) when presented with an unassigned PN code and reacquire when presented with the assigned PN code.

3.3.2.1.5 Conducted Susceptibility, Negative Transients, Power Leads (CS106)

This requirement is applicable to equipment and subsystem DC input power leads, not including returns.

Note: This is not the same test as MIL-STD-461F CS106, which uses a different transient waveform and is not applicable for space applications.

3.3.2.1.5.1 CS106 Limits

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystems specification, when subjected to a pre-calibrated transient having pulse width and amplitude as specified in Figure 10 for 28VDC applications or Figure 11 for 120VDC applications at a 1Hz rate for 1 minute.

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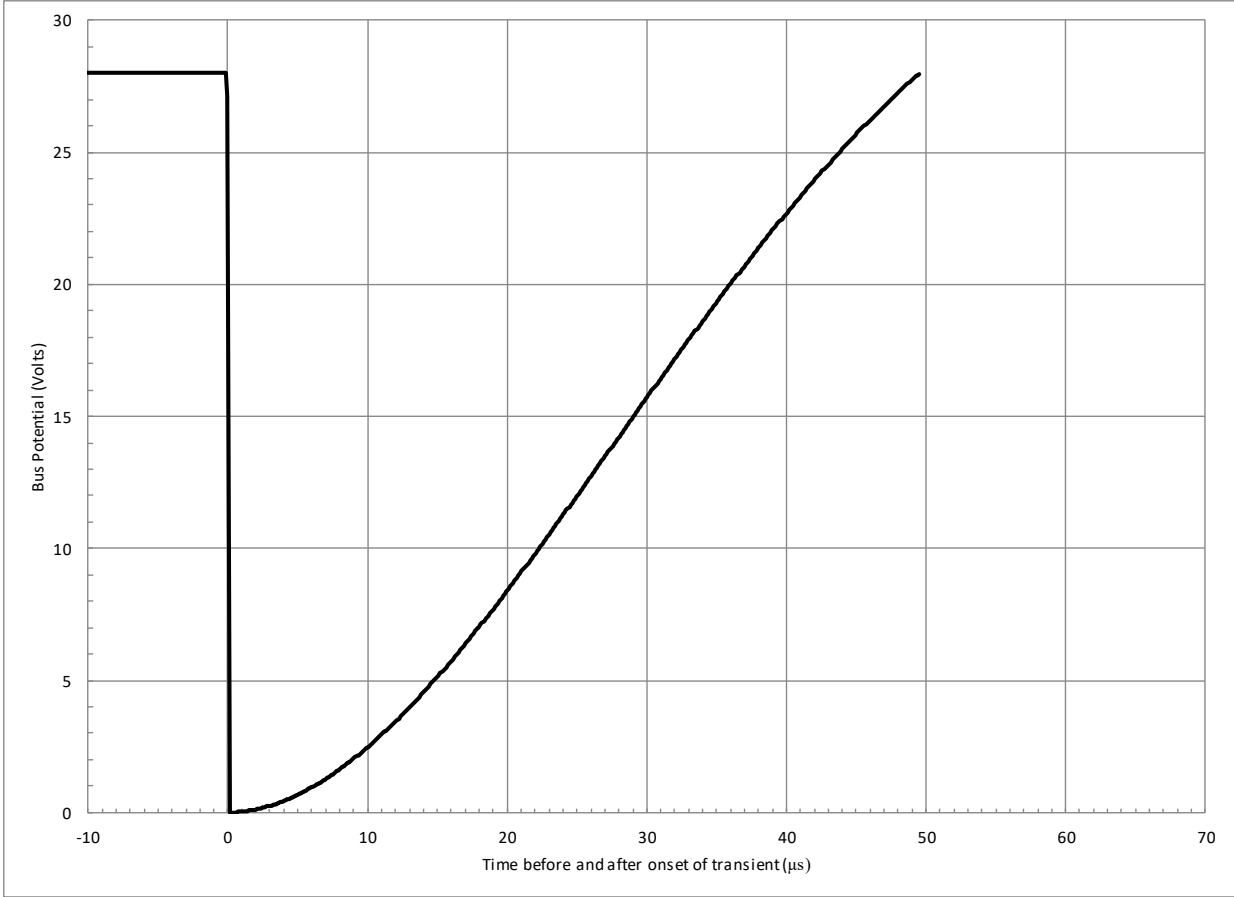


Figure 10. CS106 Transients Envelope for 28VDC Applications

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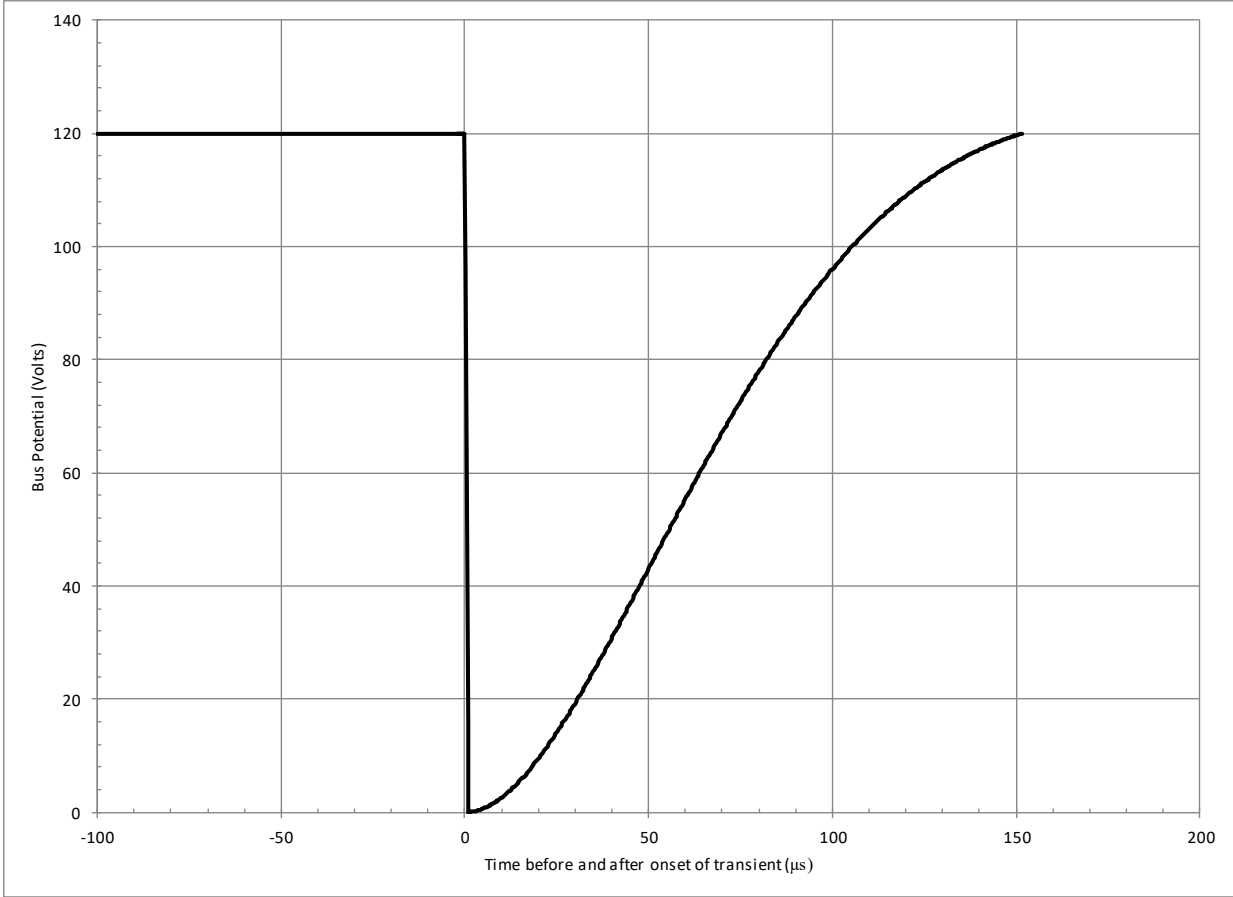


Figure 11. CS106 Transients Envelope for 120VDC Applications

3.3.2.1.6 Conducted Susceptibility, Bulk Cable Injection (CS114)

This requirement is applicable to all interconnecting cables, including power cables.

3.3.2.1.6.1 CS114 Differential Mode Limits

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications beyond the tolerances indicated in the individual equipment or subsystem specification, when the applied differential potential shown in Figure 12 from 100kHz to 10MHz or when subjected to an injection probe drive level which has been pre-calibrated to the differential mode current limit shown on Figure 13 and is modulated as specified below.

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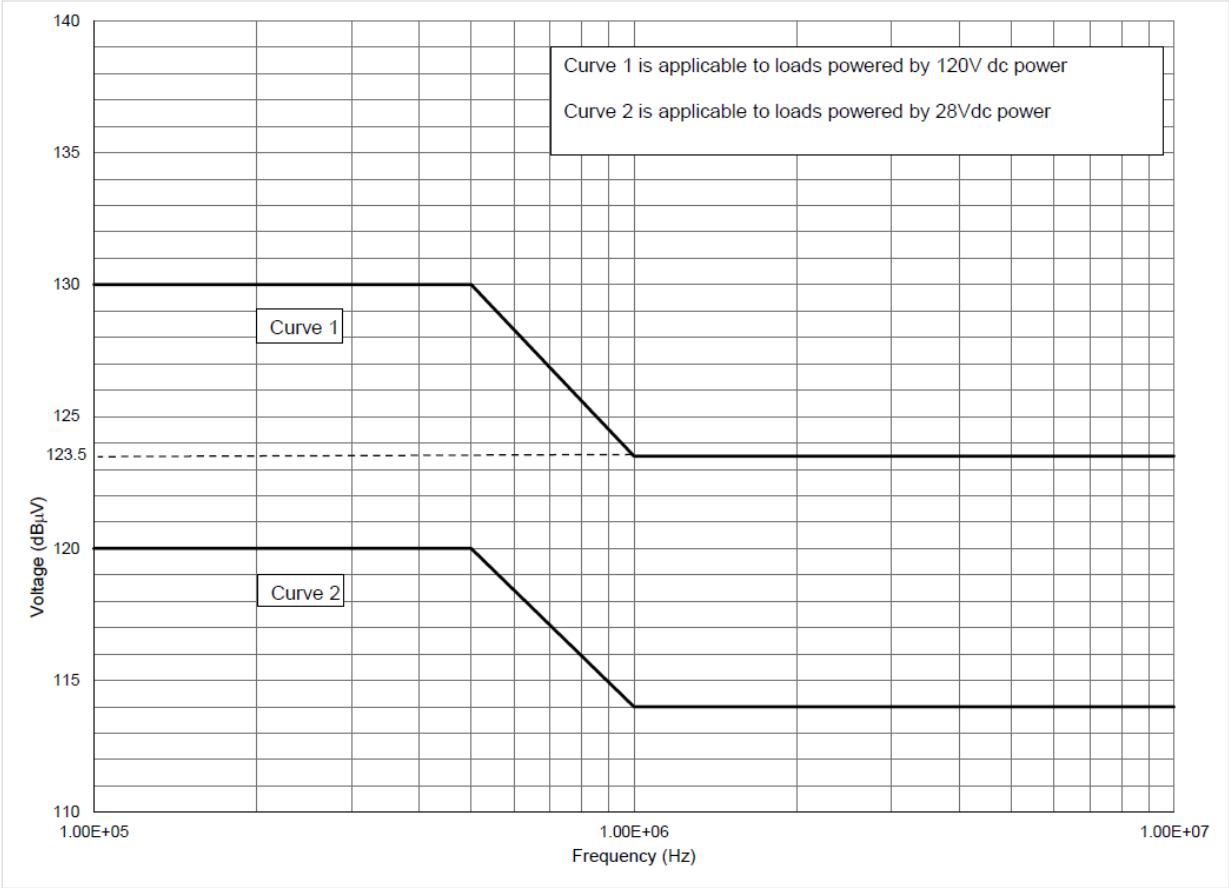


Figure 12. CS114 Voltage Limit Differential Mode Injection For 120V and 28V Applications

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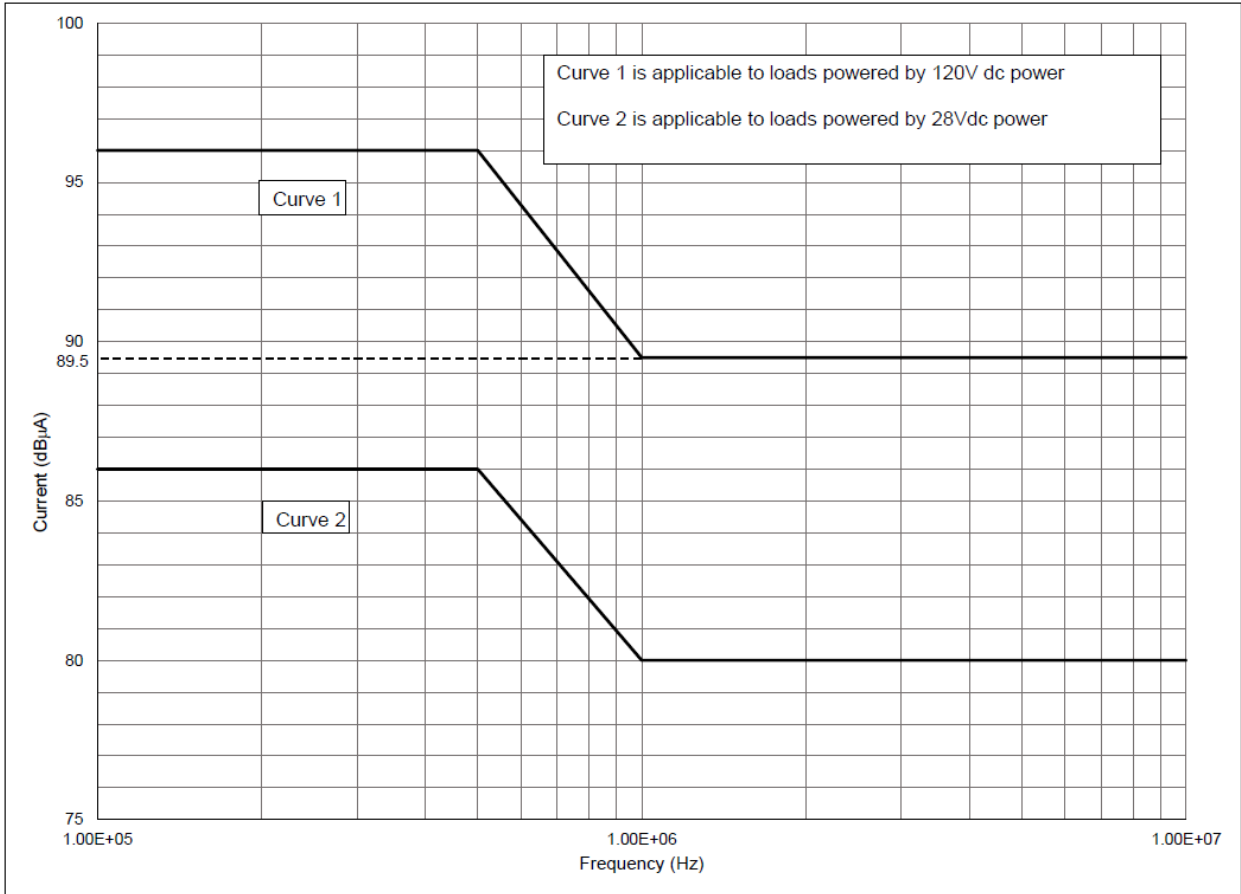


Figure 13. CS114 Calibration Limit Differential Mode Injection for Equipment Powered For 120V and 28V Applications

3.3.2.1.6.2 CS114 Common Mode Limit

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications beyond the tolerances indicated in the individual equipment or subsystem specification, when subjected to an injection probe drive level which has been pre-calibrated to the common mode current limit shown on Figure 14 from 150kHz to 200MHz and is modulated as specified below. Requirements are also met if the EUT is not susceptible at forward power levels sensed by the directional coupler that are below those determined during calibration, provided that the actual current induced in the cable under test is 6dB above the limit.

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The requirement is not applicable for coaxial cables to antenna ports of antenna-connected receivers.

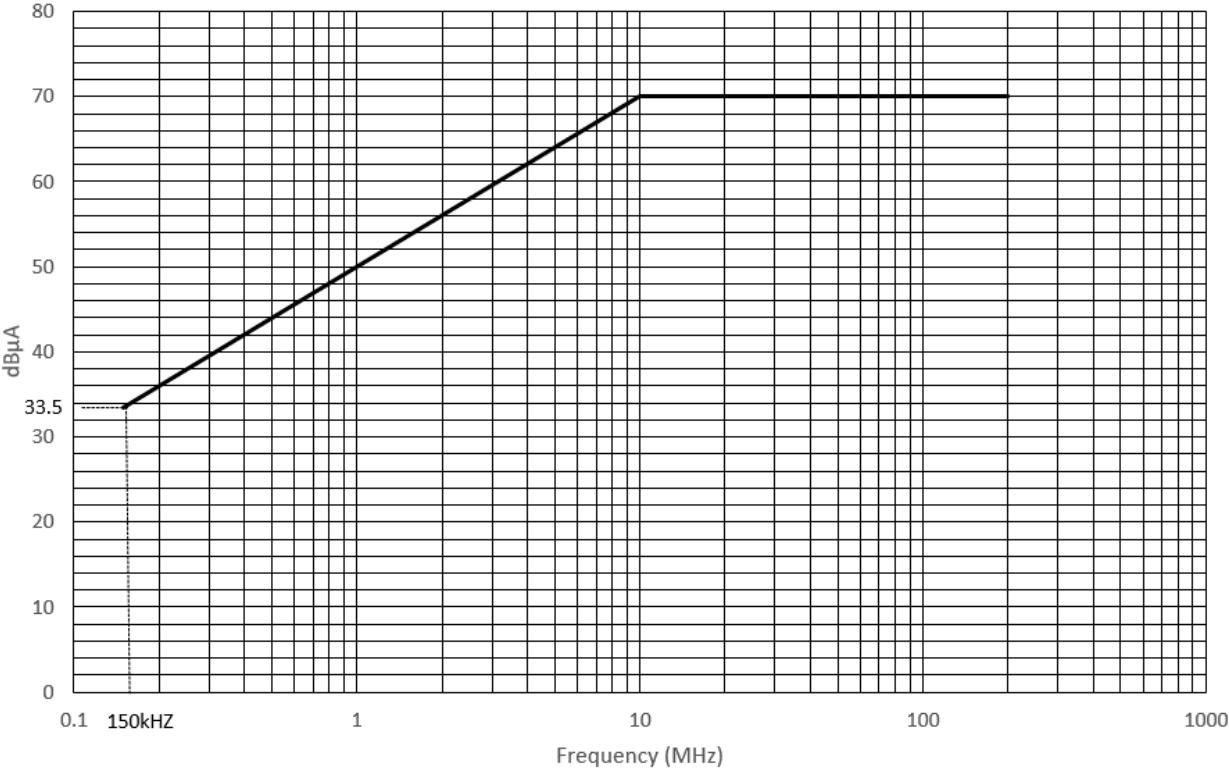


Figure 14. CS114 Calibration Limit Common Mode Injection

3.3.2.1.7 Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation (CS115)

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystems specification, when subjected to a pre-calibrated signal having rise and fall times, pulse width, and amplitude as specified on Figure 15 at a 30Hz rate for one minute. This test procedure is used to verify the ability of the EUT to withstand impulse signals coupled onto EUT associated cabling.

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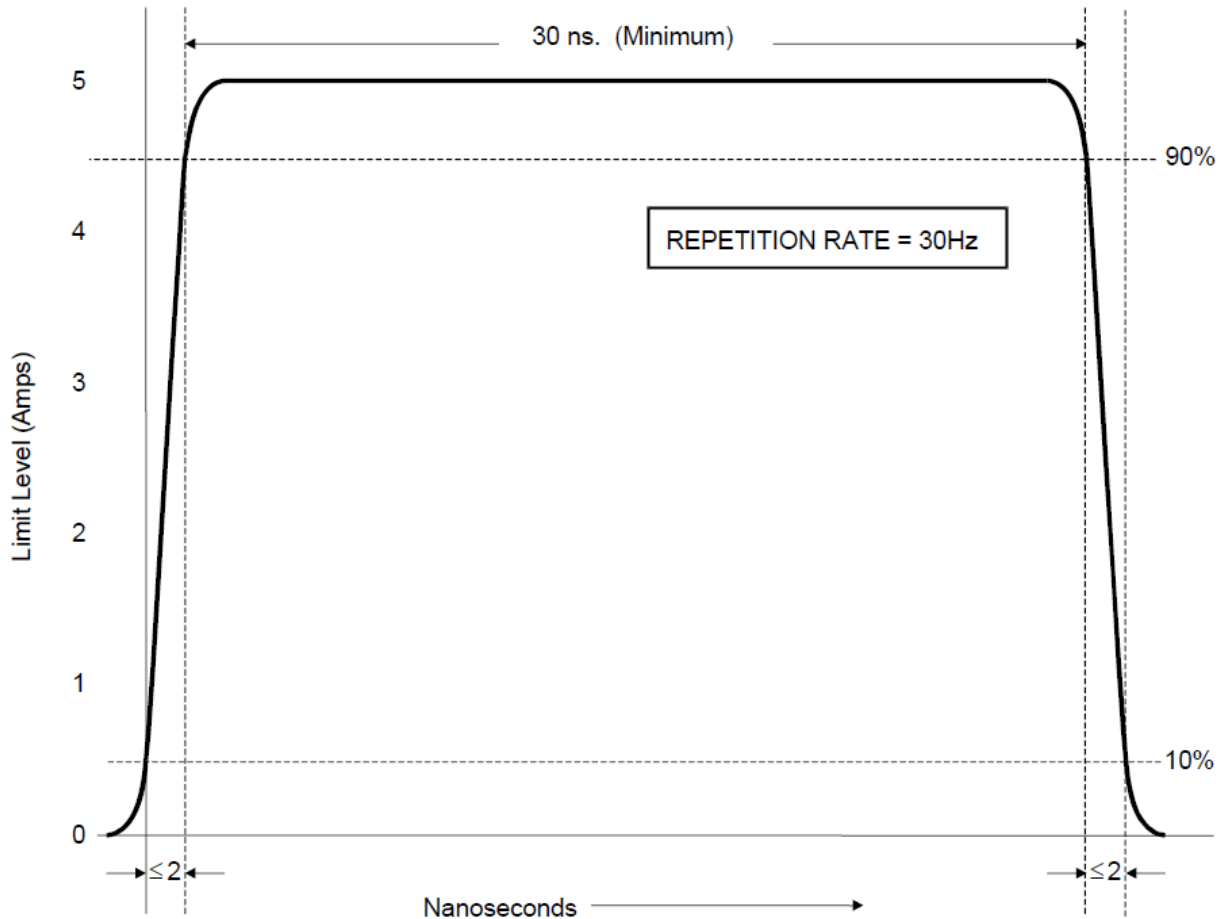


Figure 15. CS115 Signal Characteristics for All Applications

3.3.2.1.8 Conducted Susceptibility, Damped Sinusoid Transients, Cables and Power Leads (CS116)

This requirement is applicable to all interconnecting cables, including power cables, and individual high side power leads. Power returns and neutrals need not be tested individually.

Satellite payloads are exempted from this test.

3.3.2.1.8.1 CS116 Limits

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem

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specification, when subjected to a signal having the waveform shown in Figure 16 and having a maximum current as specified in Figure 17. The limit is applicable across the entire specified frequency range. As a minimum, compliance shall be demonstrated at the following frequencies: 0.01, 0.1, 1, 10, 30, and 100MHz. If there are other frequencies known to be critical to the equipment installation, such as platform resonances, compliance shall also be demonstrated at those frequencies. The test signal repetition rate shall be no greater than one pulse per second and no less than one pulse every two seconds. The pulses shall be applied for a period of five minutes.

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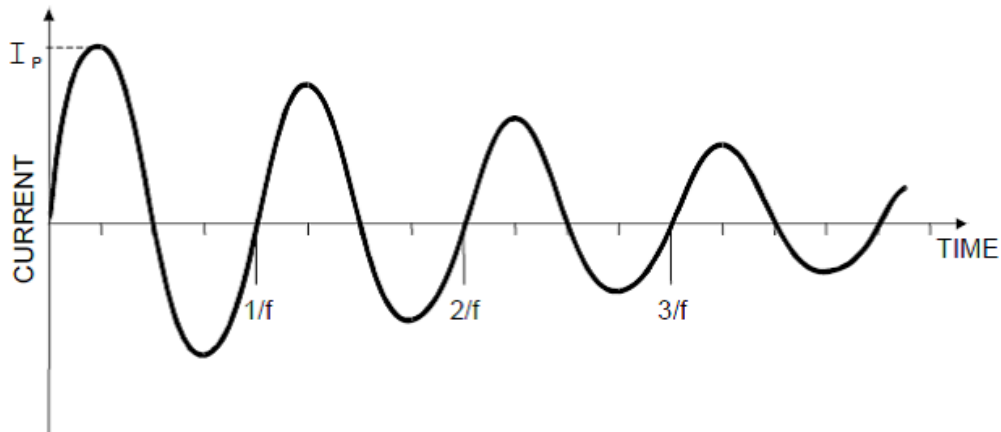


Figure 16. Typical CS116 Damped Sinusoidal Waveform

Figure 16 Notes:

1. Normalized waveform: $e^{-(\pi ft)/Q} \sin(2\pi ft)$

Where:

f = Frequency (Hz)

t = Time (sec)

Q = Damping factor, 15 ± 5

2. Damping factor (Q) shall be determined as follows:

$$Q = \frac{\pi(N - 1)}{\ln(I_P/I_N)}$$

Where:

Q = Damping factor

N = Cycle number (i.e., N = 2, 3, 4, 5...)

I_P = Peak current at 1st cycle

I_N = Peak current at cycle closest to 50% decay

ln = Natural log

3. I_P as specified in Figure 17.

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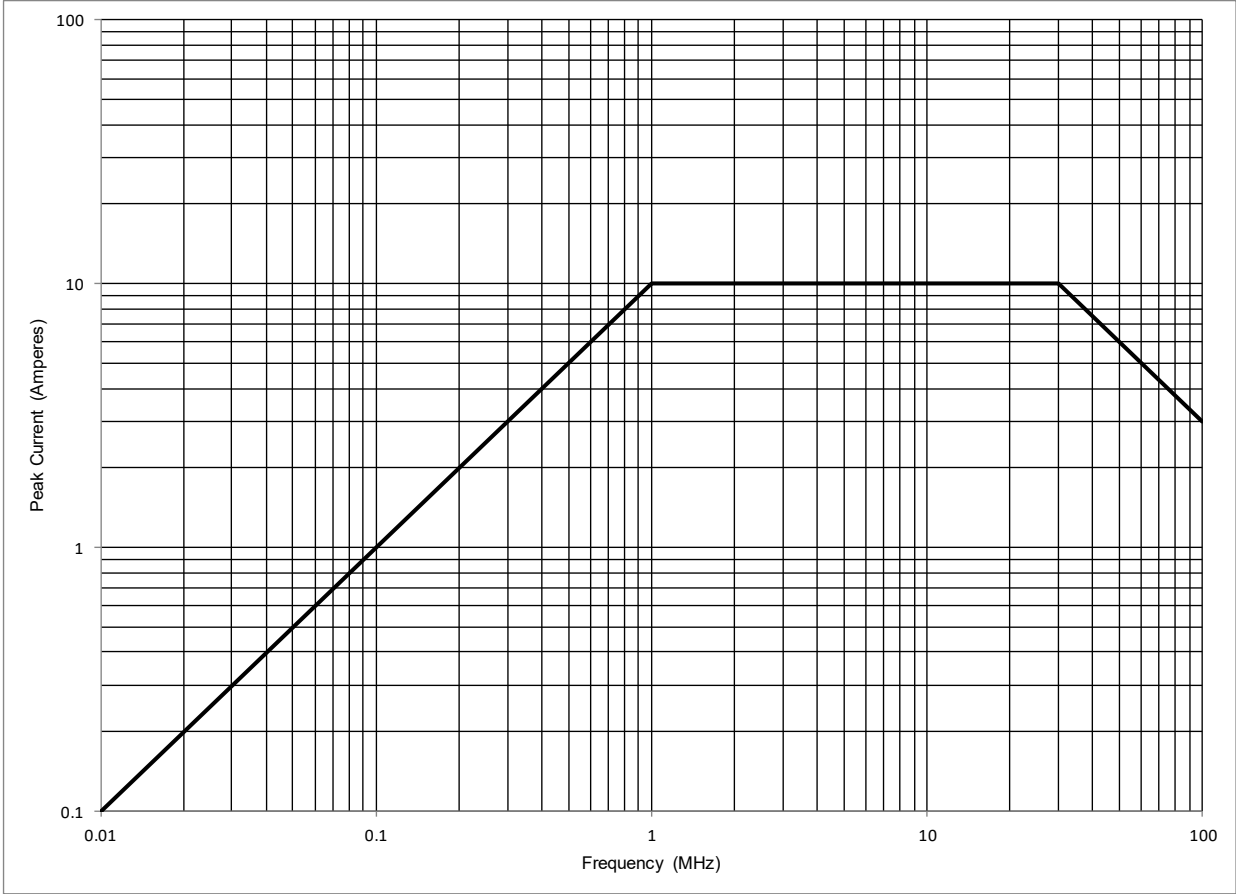


Figure 17. CS116 Limit

3.3.2.1.9 CS118, Personnel Borne Electrostatic Discharge

This requirement is applicable to electrical, electronic, and electromechanical subsystems and equipment that have a man-machine interface.

Note: It is not applicable to ordnance items. ESD for ordnance items should be covered under program-specific pyrotechnic requirements.

3.3.2.1.9.1 CS118 Limits

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem specification, when subjected to the values shown in Table 1 while discharging from a 150 picofarads (pF) capacitor through a 330 ohm resistor, with a circuit inductance not to exceed 5

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μH. Contact discharge at 8 kilovolts (kV) is required for conductive surfaces. Air discharge is only required where contact discharge cannot be applied.

Table 1. CS118 ESD Test Levels

Level	Test Voltage (kV)	Method
1	±2	Air
2	±4	Air
3	±8	Contact/Air
4	±15	Air

3.3.2.2 Radiated Susceptibility (RS)

3.3.2.2.1 Radiated Susceptibility, Magnetic Field (RS101)

This requirement is applicable to equipment and subsystem enclosures, including electrical cable interfaces. The requirement is not applicable for electromagnetic coupling via antennas.

3.3.2.2.1.1 RS101 Limits

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem specification, when subjected to the magnetic fields shown in Figure 18.

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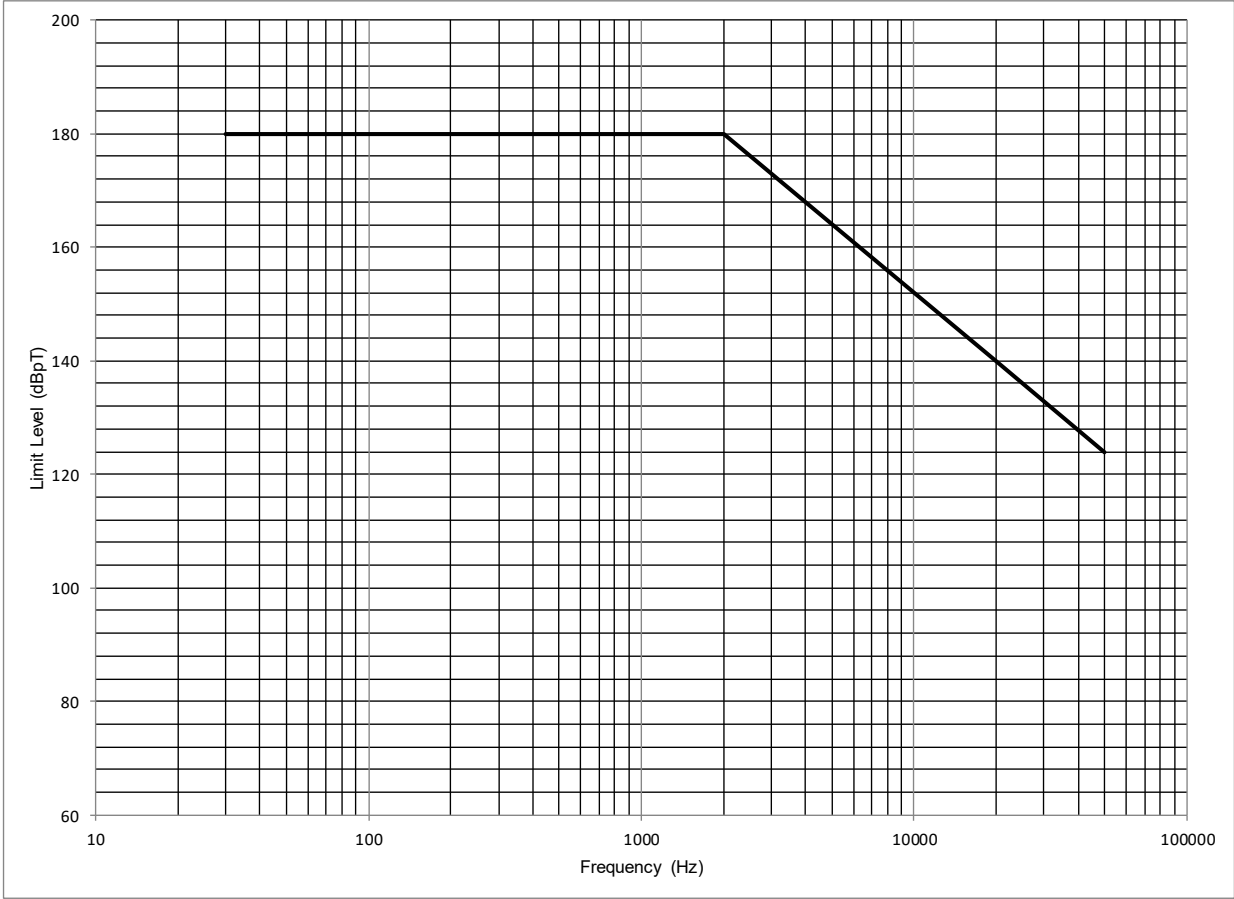


Figure 18. RS101 Test Limit for All Applications

3.3.2.2.2 Radiated Susceptibility, Electric Field (RS103)

This requirement is applicable to equipment and subsystem enclosures and all interconnecting cables.

Note: The requirement in the passband of an antenna-connected receiver is 20 dB above the RE102 limit associated with the particular platform application. The test should be performed with the antenna removed and antenna port terminated. Receivers with antennas permanently mounted to the EUT are exempt from testing in the receiver passband.

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3.3.2.2.2.1 RS103 Limits

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem specification, when subjected to the radiated electric fields listed in Table 2 and modulated as specified below. The requirement shall be met for both horizontally and vertically polarized fields.

Table 2. RS103 Limits

Frequency Range	Test Limit (V/m)	Applicability
200MHz – 1GHz 1GHz – 18GHz	100 200	Applicable when platform or vehicle on which equipment will be installed is unknown or equipment is mounted externally
100MHz – 1GHz 1GHz – 18GHz	32 63	Alternate test level. Applicable when platform or vehicle on which equipment will be installed provides greater than 10dB of attenuation from outside electromagnetic environment
18GHz – 40GHz	100	Applicable when platform or vehicle on which equipment will be installed utilizes transmitters operating above 18 GHz

4.0 VERIFICATION

4.1 General

This section identifies activities required to verify that the requirements of Section 3 have been satisfied.

4.2 Verification methods

Equipment and subsystems shall be verified by analysis, demonstration, inspection, test, validation of records or similarity (or a combination thereof) as specified herein to assure compliance with Section 3. Definitions of verification methods are from *MPR 7123.1*.

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4.2.1 Analysis

Analysis (A) involves the use of engineering analysis, qualitative assessment, computer modeling and/or simulations to ensure compliance to the requirement(s). Analysis is a method used in lieu of, or in addition to, testing.

4.2.2 Inspection

Inspection (I) is the physical evaluation to ensure that the requirement(s) has been incorporated or met. Inspection shall be used as the method on the product to satisfy such requirements as construction features, workmanship, dimensions, and physical conditions identified on the engineering documentation (e.g., drawings, Engineering Parts List).

4.2.3 Demonstration

Demonstration (D) is the “acting out” to ensure the requirement(s) has been incorporated or met. Demonstration shall be used as the method on the product to satisfy such requirements as accessibility, replace-ability, and human factors.

4.2.4 Test

Test (T) (e.g., functional, environmental) is the actual operation to ensure that the performance is in accordance with the requirement(s).

4.2.5 Validation of Records

Validation of records (VR) is the use of vendor-furnished/supplied manufacturing or processing records to ensure the requirement(s) has been incorporated or met. Validation of records shall be used as the method to satisfy incorporation of requirements for such items as commercial off-the-shelf products and products purchased to standards.

4.2.6 Similarity

Similarity (S) is the process of assessing prior data, configuration, processes, or applications and concluding that the item under assessment is similar or identical to another item that has previously been verified to equivalent or more stringent specifications or validated to an equivalent use or function. Similarity shall only be used when each of the following criteria is met:

1. Engineering evaluation(s) reveal(s) that design configurations between the item under assessment and the similar item would produce the same results if the verification/validation activity were performed on the item under assessment.
2. The similar item was designed for and verified/validated to equal or higher environmental (e.g., thermal, stress) levels than those required for the item under assessment.
3. The item under assessment was built by the same manufacturer using the same manufacturing processes and the same quality control procedures as the similar item.

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4. Similarity assessment shall undergo an independent evaluation by a technically qualified person or group other than the person(s) performing the assessment.

Similarity shall not be used when either of the following conditions exists:

1. The similar item used in the assessment was itself verified/validated using similarity as the method.
2. Items whose criticality is 1 or 1R (i.e., items whose failure or malfunction could result in loss of vehicle, life, or serious injury).

Table 3. Verification Methods

Requirement	Title	Method						Verification Method Comments	Verification Success Criteria
		A	I	D	T	V R	S		
3.1	System Compatibility							NA	
3.1.1	Functional Compatibility	X						Analysis	Verification is successful when analysis of all requirements are met and the vehicle is compatible with the RF environment. If any non-compliances are found, the waiver adjudication process ensure the non-compliances do

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Requirement	Title	Method						Verification Method	Verification
		A	I	D	T	V R	S	Comments	Success Criteria
									not interact with each other.
3.1.2	Margins	X			X			Test and/or analysis	Verification is successful when test and/or analysis results show that the critical circuit's threshold of susceptibility is 6dB or more (16.5dB for pyrotechnic circuits) above the equipment's intended operational electromagnetic environment
3.2	Design Requirements							NA	
3.2.1	Primary Power							NA	
3.2.1.1	System							NA	

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Requirement	Title	Method						Verification Method	Verification
		A	I	D	T	V R	S	Comments	Success Criteria
3.2.1.2	Equipment Power Ground Reference							NA	
3.2.1.2.1	Interface 1		X					Inspection of engineering documentation	Verification is successful when inspection shows the voltage source is referenced to ground and the grounding circuit is fully enclosed within the equipment chassis
3.2.1.2.2	Interface 2		X					Inspection of engineering documentation Inspection of workmanship test results Analysis may be required to show isolation in all operational modes	Verification is successful when inspection shows equipment maintains a 1MΩ isolation between primary power lines and chassis and between primary and secondary power lines

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Requirement	Title	Method						Verification Method	Verification
		A	I	D	T	V R	S	Comments	Success Criteria
3.2.1.2.3	Primary Power to Secondary Power Isolation		X					Inspection of engineering documentation Inspection of workmanship test results Analysis may be required to show isolation in all operational modes	Verification is successful when inspection shows equipment maintains a 1MΩ isolation between primary power lines and secondary power lines
3.2.1.3	Equipment/LRU Signals Grounding Considerations							NA	
3.2.1.3.1	Signal Grounding		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows equipment signal returns maintains a 1MΩ isolation except at the source end
3.2.1.3.2	Signal Returns		X					Inspection of engineering documentation	Verification is successful when inspection shows equipment signal, command,

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Requirement	Title	Method						Verification Method	Verification
		A	I	D	T	V R	S	Comments	Success Criteria
								Inspection of workmanship test results	control, and power circuits routed externally employ separate returns and returns maintains a 1MΩ isolation from harness shields
3.2.1.3.3	Balanced Differential Circuit Isolation		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows balanced differential circuits routed external to equipment has 6kΩ or greater isolation to chassis
3.2.1.3.4	Coaxial Shields		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows all frequency components of signals carried on coax is greater than 1MHz and coax interconnecting equipment using different power

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		A	I	D	T	V R	S	Comments	Success Criteria
									sources does not violated SPG
3.2.2	Enclosure Shielding							NA	
3.2.3	Electrical Bonding		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows the equipment has the necessary provisions for electrical bonding and the provisions, including the bond straps comply with the requirements for cleanliness, surface finish, and dimensions.
3.2.3.1	Bonding Provisions		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows the equipment has the necessary provisions for electrical bonding and the provisions

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		A	I	D	T	V R	S	Comments	Success Criteria
3.2.3.2	Bonding Contact Area		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows the equipment has the necessary bonding contact area
3.2.3.3	Bonding Area Preparation		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows the equipment has the necessary provisions for electrical bonding with respect to preparation
3.2.3.4	Bonding Straps		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows the equipment usage of bond strap meets the length-to-width ratio of 5:1
3.2.4	Circuit Classification		X					Inspection of engineering documentation	Verification is successful when inspection shows that wiring of different EMC classifications

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		A	I	D	T	V R	S	Comments	Success Criteria
								Inspection of workmanship test results	are separated by mechanical shielding (conduit, cable trays, etc.) or by a minimum of 5 cm
3.2.5	Wire Twisting		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows returns are twisted with the high side, signal and power circuits twisted with their respective return and multiple circuits using a common return are twisted as a group
3.2.5.1	Group Wire Twisting		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows returns are twisted with the high side, signal and power circuits twisted with their respective return

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		A	I	D	T	V R	S	Comments	Success Criteria
									and multiple circuits using a common return are twisted as a group
3.2.6	Wire Shielding		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection shows cable shields cover the twisted pair or group and shields do not intentionally carry current (except coax). Verification is successful when inspection also shows cable connectors used to terminate cable shields are installed to provide a low impedance path to case with the dc resistance not to exceed 2.5mΩ.
3.2.6.1	Shield Current		X					Inspection of engineering documentation	Verification is successful when inspection of

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Requirement	Title	Method						Verification Method	Verification
		A	I	D	T	V R	S	Comments	Success Criteria
								Inspection of workmanship test results	engineering documentation for implementation of single point ground for shielded cable circuits. (Coax cables utilizing frequencies above 1MHz are excluded)
3.2.6.2	Shield Termination		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection of cable documentation demonstrates that cable shielding is bonded to connector backshell at both ends of the cable
3.2.6.3	Shield Termination Bonding		X					Inspection of engineering documentation Inspection of workmanship test results	Verification is successful when inspection of cable documentation demonstrates that cable shielding is

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		A	I	D	T	V R	S	Comments	Success Criteria
									bonded to connector backshell at both ends of the cable with a Class R bond
3.3	Subsystem and Equipment Emission and Susceptibility Requirements							NA	
3.3.1	Equipment Produced Emission							NA	
3.3.1.1	Conducted Emissions (CE)							NA	
3.3.1.1.1	Conducted Emissions, Power Leads, Differential Mode, (CE101)							See Appendix B for test setup and procedure	
3.3.1.1.1.1	CE101 Limits				X				Conducted emissions on power leads shall not exceed the applicable limits

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		A	I	D	T	V R	S	Comments	Success Criteria
3.3.1.1.2	Conducted Emissions, Common-Mode Radio Frequency Current, Power and Signal Cables (CE104)							See Appendix B for test setup and procedure	
3.3.1.1.2.1	CE104 Limits				X				Conducted emissions on power leads shall not exceed the applicable limits
3.3.1.1.3	Conducted Emissions, Antenna Terminal (CE106)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.1.1.3.1	CE106 Limits				X				Conducted emissions at antenna terminals shall not exceed the applicable limits
3.3.1.2	Radiated Emissions (RE)							NA	

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		A	I	D	T	V R	S	Comments	
3.3.1.2.1	Radiated Emissions, Time Varying Magnetic Field (RE101A)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.1.2.1.1	RE101A Limits				X				Magnetic field emissions shall not be radiated in excess of those shown in the applicable Figures
3.3.1.2.2	Radiated Emissions, Static Magnetic Field (RE101D)							See Appendix B for test setup and procedure	
3.3.1.2.2.1	RE101D Limits				X				Magnetic field emissions shall not be radiated in excess of those shown in the applicable paragraphs
3.3.1.2.3	Radiated Emissions, Electric Field (RE102)							See <i>MIL-STD-461</i> for test setup and procedure	

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3.3.1.2.3.1	RE102 Limits				X				Electric field emissions shall not be radiated in excess of those shown in the applicable Figures
3.3.1.2.4	Radiated Emissions, Antenna Spurious and Harmonic Outputs (RE103)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.1.2.4.1	RE103 Limits				X				Harmonics except the second and third, and all other spurious emissions shall be at least 80dB down from the level at the fundamental.
3.3.2	Equipment Susceptibility							NA	
3.3.2.1	Conducted Susceptibility (CS)							NA	

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3.3.2.1.1	Conducted Susceptibility, Power Leads (CS101)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.2.1.1.1	CS101 Limits				X				The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when subject to the CS101 test limits
3.3.2.1.2	Conducted Susceptibility, Antenna Port, Intermodulation (CS103)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.2.1.2.1	CS103 Limit				X				The EUT shall not exhibit any intermodulation products beyond specified tolerances when subjected to the limit requirement provided in the individual procurement specification.

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3.3.2.1.3	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals (CS104)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.2.1.3.1	CS104 Limit				X				The EUT shall not exhibit any undesired response beyond specified tolerances when subjected to the limit requirement provided in the individual procurement specification.
3.3.2.1.4	Conducted Susceptibility, Antenna Port, Cross-Correlation (CS105PN)							See Appendix B for test setup and procedure	
3.3.2.1.4.1	CS105PN Limit				X				The EUT shall exhibit a loss of lock (loss of acquired signal) when presented with an

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		A	I	D	T	V R	S	Comments	Success Criteria
									unassigned PN code, and reacquire when presented with the assigned PN code.
3.3.2.1.5	Conducted Susceptibility, Negative Transients, Power Leads (CS106)							See Appendix B for test setup and procedure	
3.3.2.1.5.1	CS106 Limits				X				The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when subject to the CS106 test limits
3.3.2.1.6	Conducted Susceptibility, Bulk Cable Injection (CS114)							See Appendix B for test setup and procedure	
3.3.2.1.6.1	CS114 Differential Mode Limits				X				The EUT shall not exhibit any malfunction, degradation of

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Requirement	Title	Method						Verification Method Comments	Verification Success Criteria
		A	I	D	T	V R	S		
									performance, or deviation from specified indications when subject to the CS114 test limits
3.3.2.1.6.2	CS114 Common Mode Limits				X				The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when subject to the CS114 test limit
3.3.2.1.7	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation (CS115)				X			See <i>MIL-STD-461</i> for test setup and procedure	The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when subject to the CS115 test limit
3.3.2.1.8	Conducted Susceptibility, Damped Sinusoid Transients,							See <i>MIL-STD-461</i> for test setup and procedure	

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Requirement	Title	Method						Verification Method	Verification
		A	I	D	T	V R	S	Comments	Success Criteria
	Cables and Power Leads (CS116)								
3.3.2.1.8.1	CS116 Limits				X				The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when subject to the CS116 test limits
3.3.2.1.9	CS118, Personnel Borne Electrostatic Discharge							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.2.1.9.1	CS118 Limits				X				The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when subject to the CS118 discharges

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

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Requirement	Title	Method						Verification Method	Verification Success Criteria
		A	I	D	T	V R	S	Comments	
3.3.2.2	Radiated Susceptibility (RS)							NA	
3.3.2.2.1	Radiated Susceptibility, Magnetic Field (RS101)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.2.2.1.1	RS101 Limits				X				The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when subject to the RS101 test limits
3.3.2.2.2	Radiated Susceptibility, Electric Field (RS103)							See <i>MIL-STD-461</i> for test setup and procedure	
3.3.2.2.2.1	RS103 Limits				X				The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications when

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Requirement	Title	Method						Verification Method Comments	Verification Success Criteria
		A	I	D	T	V R	S		
									subject to the RS103 test limits

5.0 PACKAGING

Not Applicable.

6.0 NOTES

Not Applicable.

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APPENDIX A ACRONYMS AND ABBREVIATIONS

A	Ampere, Analysis
AC	Alternating Current
BCE	Bulk Cable Emission
C	Capacitance, capacitor
CE	Conducted Emission
CLDP	Commercial Low Earth Development Program
CLV	Crew Launch Vehicle
cm	Centimeter(s)
CS	Conducted Susceptibility
D	Demonstration
dB	Decibel
dBm	Decibels to one Milliwatt
dB μ A	Decibels to one Ampere
dB μ V	Decibels to one Microvolts
dBpT	Decibels to one Picotesla
DC	Direct Current
DE	Design and Development Engineering
DoD	Department of Defense
E3	Electromagnetic Environmental Effects
ED	Engineering Directorate
EIA	Electronics Industries Association
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EPS	Electrical Power System
EUT	Equipment Under Test
GHz	Gigahertz
Hz	Hertz

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HLS	Human Landing System
I	Inspection
ICD	Interface Control Document
ISS	International Space Station
JSC	Joint Spectrum Center
k Ω	Kilohm
kHz	Kilohertz
L	Inductance
LISN	Line Impedance Stabilization Network
LNA	Low-noise amplifiers
LRU	Line Replaceable Unit
m	Meter(s)
m ²	Square Meters
MHz	Megahertz
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
min	Minute
MPR	Marshall Procedural Requirements
MSFC	Marshall Space Flight Center
MSL	Material Science Laboratory
M Ω	Megaohms
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NDI	Non-Developmental Item
NPR	NASA Procedural Requirements
ns	Nanosecond(s)
NSTS	National Space Transportation System
RC	Resistor/Capacitor
RE	Radiated Emission
RF	Radio Frequency

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RMS	Root Mean Square
RS	Radiated Susceptibility
RTCA	Radio Technical Commission for Aeronautics
s	Second
S	Similarity
SI	International System of Units
SPG	Single Point Ground
SPEC	Specification
STD	Standard
T	Test
TOR	Technical Operating Report
UL	Underwriters Laboratories
V	Volt
V/m	Volts per Meter
VAC	Volts Alternating Current
VDC	Volts Direct Current
VR	Validation of Records
W	Watts
μF	Microfarad
μH	Microhenry
Ω	Ohm

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**APPENDIX B
TEST METHODOLOGIES**

B.1 Test Configuration Setups

B.1.1 Ground Plane

The EUT shall be installed on a ground plane that simulates the actual installation. If the actual installation is unknown or multiple installations are expected, then a metallic ground plane shall be used. Unless otherwise specified below, ground planes shall be 2.25m² or larger in area with the smaller side no less than 76cm. When a ground plane is not present in the EUT installation, the EUT shall be placed on a nonconductive table.

B.1.2 Metallic Ground Plane

When the EUT is installed on a metallic ground plane, the ground plane shall have a surface resistance no greater than 0.1 milliohms per square. The DC resistance between metallic ground planes and the shielded enclosure shall be 2.5 milliohms or less. The metallic ground planes shown in Figure 19, Figure 20, or Figure 21 shall be electrically bonded to the floor or wall of the basic shielded room structure at least once every 1m. The metallic bond straps shall be solid and maintain a five-to-one ratio or less in length to width. Metallic ground planes used outside a shielded enclosure shall extend at least 2.5m beyond the test setup boundary in each direction.

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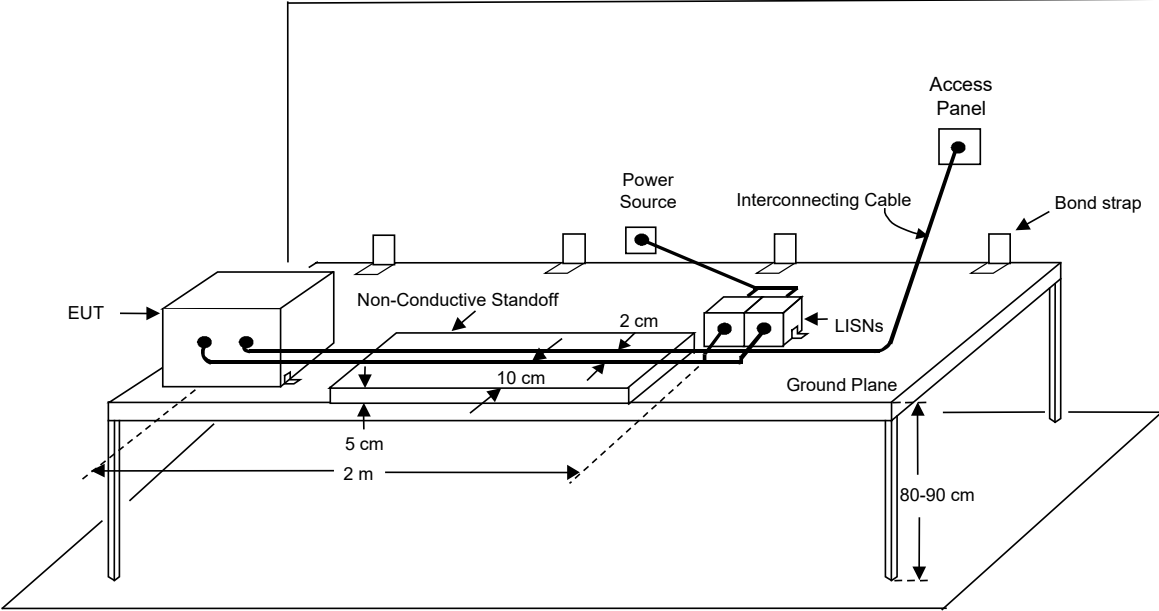


Figure 19. General test setup with a conductive ground plane

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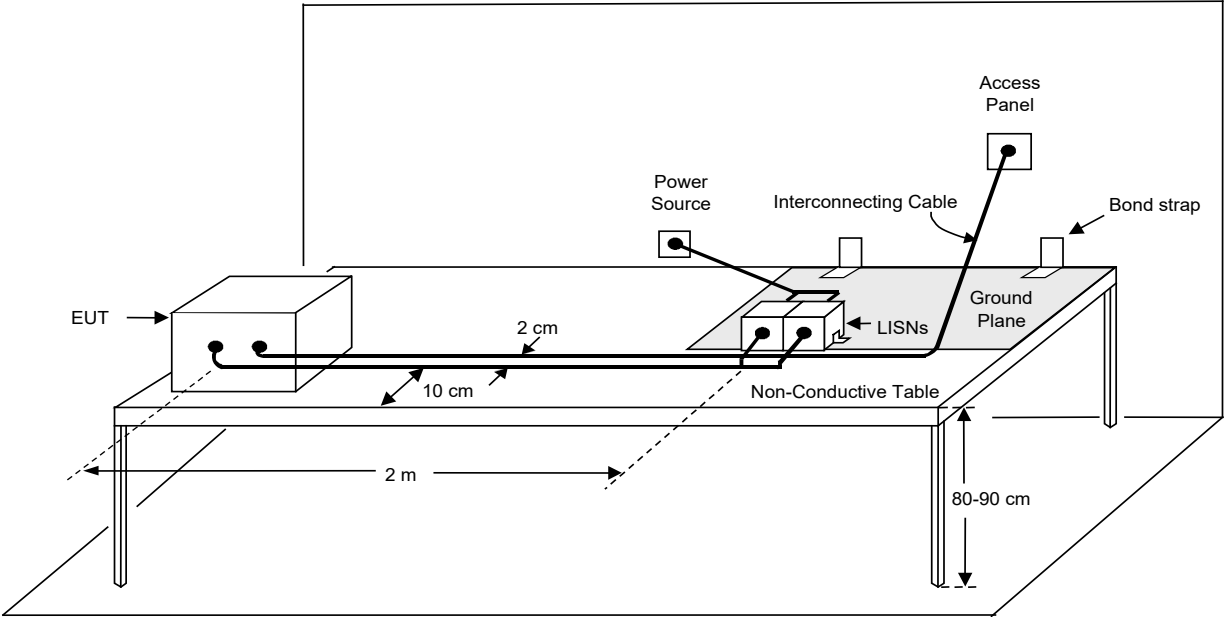


Figure 20. Test setup for nonconductive surface mounted EUT

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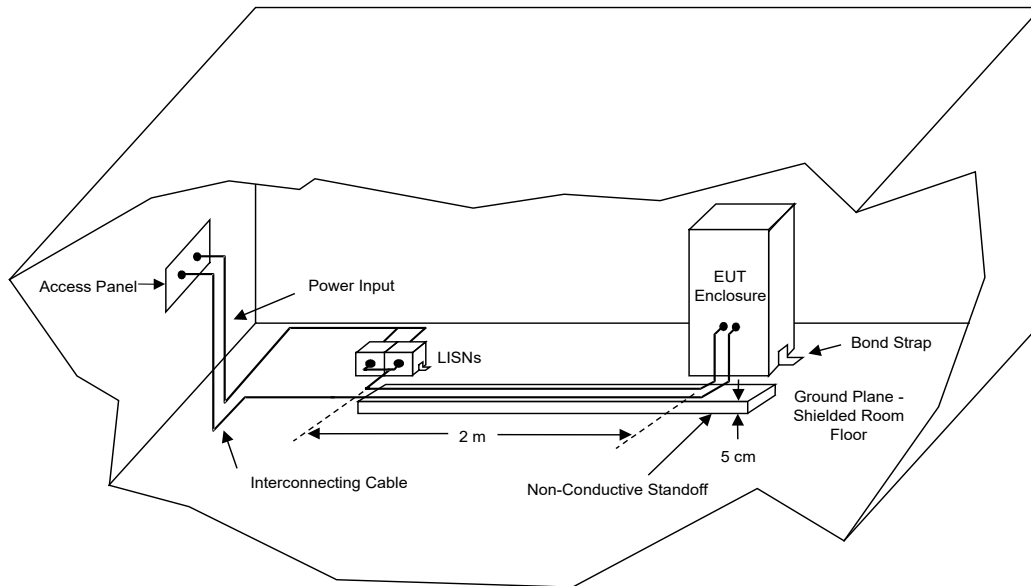


Figure 21. Test setup for freestanding EUT in shielded enclosure

B.1.3 Composite Ground Plane

When the EUT is installed on a conductive composite ground plane, the surface resistivity of the typical installation shall be used. Composite ground planes shall be electrically bonded to the enclosure with means suitable to the material.

B.1.4 General Test Requirements

Testing will comply with the general requirements of *MIL-STD-461*, Section 4.3, except the LISNs used will be as listed below.

B.1.5 Test Methodology

Test methods for showing compliance with the requirements of Section 3.3 will be those of *MIL-STD-461*. Requirements CE101, CE104, RE101D, CS106, and CS114 Differential Mode, (as specified herein) are not in *MIL-STD-461*. The test procedures for those requirements are listed below.

B.1.6 LISN

The LISNs used for EUT testing will be the five-microhenry LISNs defined in *RTCA DO-160, Environmental Conditions and Test Procedures for Airborne Equipment, Section 20, Radio*

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Frequency Susceptibility (Radiated and Conducted) and Section 21, Emission of Radio Frequency Energy for all tests. Ten-microfarad feed-through capacitors may be connected to the facility power input of the LISNs to minimize self-resonances of the LISNs.

During the CS106 test, additional line-to-line capacitance may be added at power input of the LISNs to minimize power source voltage drop. It is recommended to add line-to-line 10,000 microfarad electrolytic (or similar value) capacitor between hot and return, upstream (facility sde) of the two line-to-ground feedthrough caps. This will control the impedance down to 30Hz.

B.2 CE101, Conducted Emissions, Power Leads, Differential Mode

B.2.1 CE101 Test Procedures

B.2.1.1 Purpose

This test procedure is used to verify that electromagnetic emissions from the EUT do not exceed the specified requirements for power input leads including returns.

B.2.1.2 Setup

The test setup shall be as follows:

- a. Maintain a basic test setup for the EUT as shown and described on Figures 19, Figure 20, or Figure 21. The LISN may be removed or replaced with an alternative stabilization device when approved by the procuring activity.
- b. **Measurement system integrity check.** Configure the test setup for the measurement system check as shown on Figure 22.
- c. **EUT testing.**
 - 1. Configure the test setup for compliance testing of the EUT as shown on Figure 23.
 - 2. Position the current probe around both feeder and return to measure only differential mode current, as per Figure 23.

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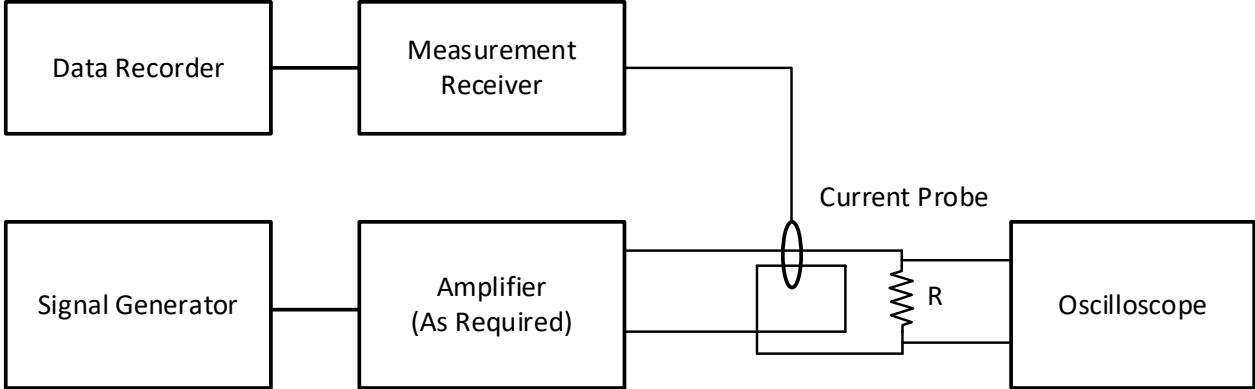


Figure 22. CE101 Measurement System Check

Note: At and above 150 kHz, the oscilloscope/resistor combination may be replaced with a 50ohm input spectrum analyzer, different from the measurement receiver.

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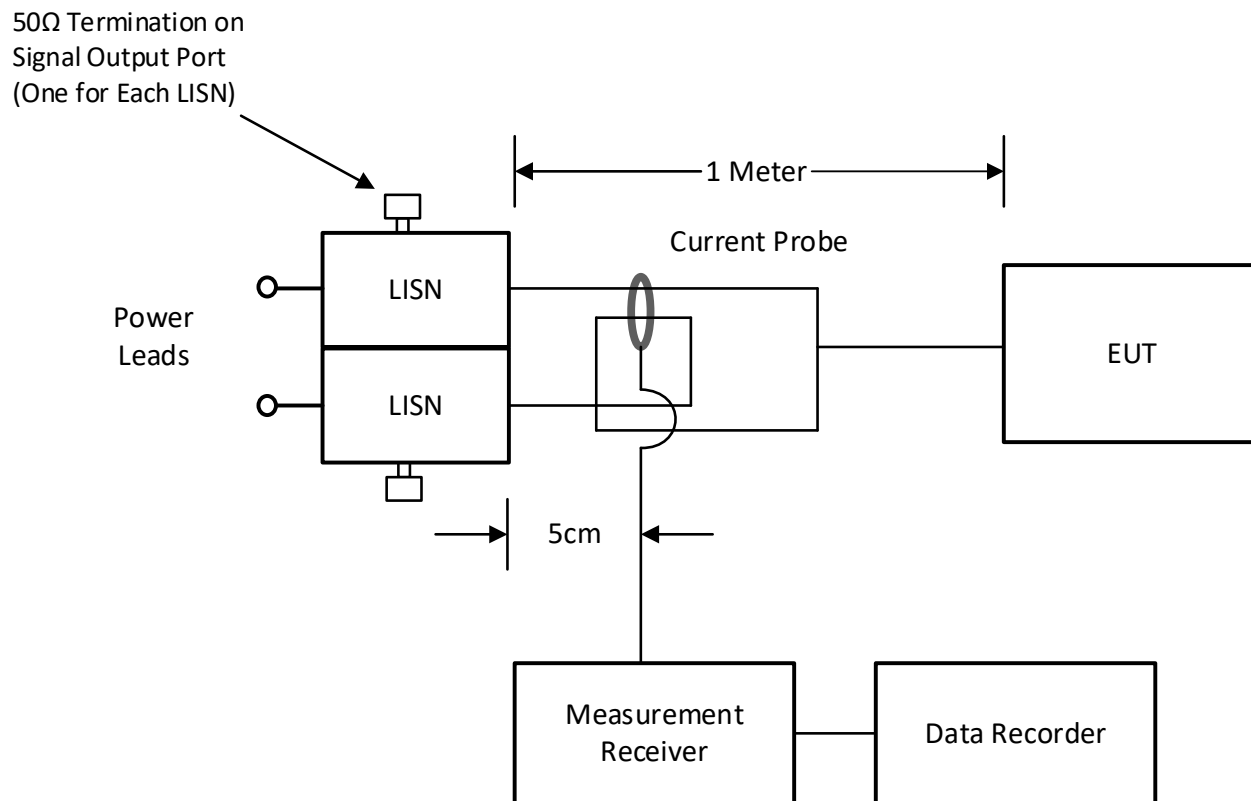


Figure 23. CE101 Measurement Setup

B.2.1.3 Procedure

The test procedures shall be as follows:

- a. Turn on the measurement equipment and allow a sufficient time for stabilization.
- b. **Measurement system integrity check.** Evaluate the overall measurement system from the current probe to the data output device.
 1. Apply a calibrated signal level, which is at least 6 dB below the applicable limit at 30 Hz, 3 kHz, 10 kHz, 150 kHz and 2 MHz, to the current probe.
 2. Verify the current level, using the oscilloscope and load resistor; also, verify that the current waveform is sinusoidal.
 3. Scan the measurement receiver for each frequency in the same manner as a normal data scan. Verify that the data recording device indicates a level within ± 3 dB of the injected

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level (*Note: Using the test setup of Figure 22, the current through the load resistor will be 6 dB below the level measured by the current probe*).

4. If readings are obtained which deviate by more than ± 3 dB, locate the source of the error and correct the deficiency prior to proceeding with the testing.
- c. **EUT testing.** Determine the conducted emissions from the EUT input power lead.
1. Turn on the EUT and allow sufficient time for stabilization.
 2. Clamp the current probe into the proper position to measure only differential mode current.
 3. Scan the measurement receiver over the applicable frequency range, using the bandwidths and minimum measurement times specified in *MIL-STD-461* Table II.

B.2.1.4 Data presentation

Data presentation shall be as follows:

- a. Continuously and automatically plot amplitude versus frequency profiles on X-Y axis outputs. Manually gathered data is not acceptable except for plot verification.
- b. Display the applicable limit on each plot.
- c. Provide a minimum frequency resolution of 1% or twice the measurement receiver bandwidth, whichever is less stringent, and a minimum amplitude resolution of 1 dB for each plot.
- d. Provide plots for both the measurement and system check portions of the procedure.

B.3 CE104, Conducted Emissions, Common Mode Radio Frequency Current, Power and Signal Cables

B.3.1 CE104 Test Procedures

B.3.1.1 Purpose

This test procedure is used to verify that electromagnetic emissions from the EUT do not exceed the specified requirements for EUT interconnecting cables.

B.3.1.2 Test Procedures

The test procedures shall be as follows:

- a. **Measurement system integrity check.** Perform the measurement system check using the measurement system check setup of Figure 24.
1. Turn on the measurement equipment and allow a sufficient time for stabilization.
 2. Connect the measurement receiver to the absorbing clamp current probe output.
 3. Apply a calibrated signal which is at least 6 dB below the applicable limit by setting the signal generator level such that the spectrum analyzer/EMI receiver connected to load end of the calibration fixture reads 78 dBuV (50 dBuA limit – 6 dB below limit + 34 dBΩ) at 150 kHz.

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4. Scan the measurement receiver for each frequency in the same manner as a normal data scan. Verify that the measurement receiver indicates a level within ± 3 dB of the injected level.
 5. If readings are obtained which deviate by more than ± 3 dB, locate the source of the error and correct the deficiency prior to proceeding with the testing.
 6. Repeat at 1 MHz, 10 MHz, 50 MHz, and 100 MHz.
- b. **EUT testing.** Perform emission data scans using the measurement setup of Figure 25.
1. Turn on the EUT and allow a sufficient time for stabilization.
 2. Select an appropriate cable for testing and place within absorbing clamp.
 3. Scan the measurement receiver over the applicable frequency range, using the bandwidths and minimum measurement times in the Table 3.3.10.3.1-1.
- Repeat Steps B.3.1.2.b step 2 and B.3.1.2.b step 3 for each EUT-attached cable, including power (common mode only).

B.3.1.3 Data Presentation

Data presentation shall be as follows:

- a. Continuously and automatically plot amplitude versus frequency profiles on X-Y axis outputs. Manually gathered data is not acceptable except for plot verification.
- b. Display the applicable limit on each plot.
- c. Provide emissions plot and over-limit tabular data per *MIL-STD-461* Paragraph 4.3.10.3.4. Provide plots for both the measurement system check and measurement portions of the procedure.

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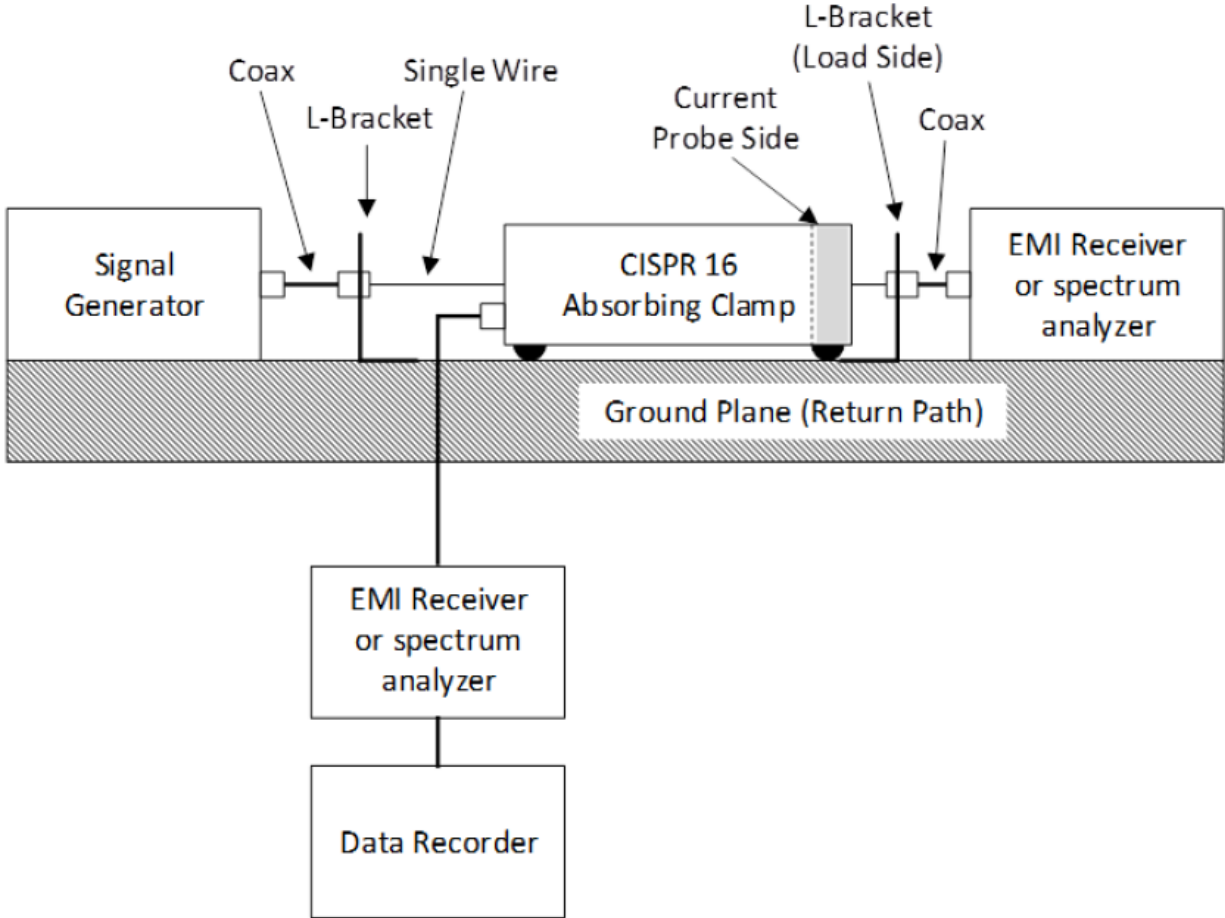


Figure 24. CE104 Measurement System Check Setup

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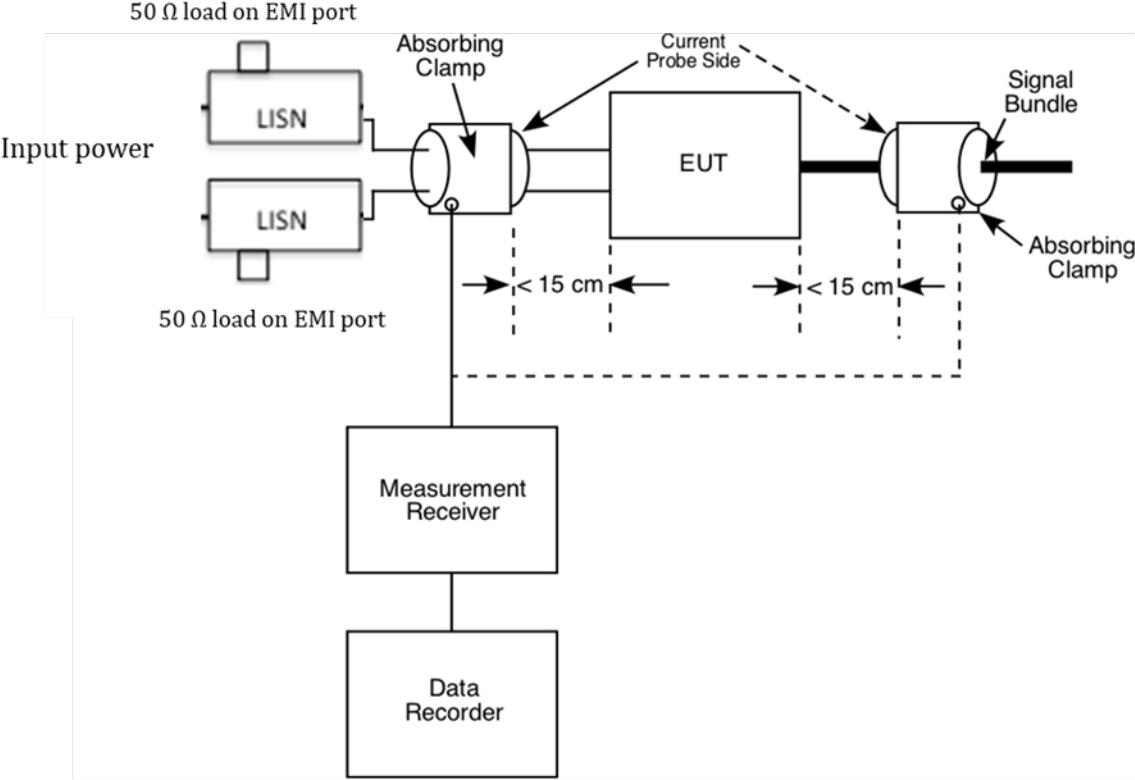


Figure 25. CE104 Measurement Setup

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B.4 RE101D, Radiated Emissions, Static Magnetic Field

B.4.1 RE101D Test Procedures

B.4.1.1 Purpose

This test procedure is used to verify that the magnetic field emissions from the EUT and its associated electrical interfaces do not exceed specified requirements.

B.4.1.2 Test Equipment

The test equipment shall be as follows:

1. Gaussmeter (Figure 26)
2. Zero flux chamber (Figure 27)
3. LISNs

B.4.1.3 Setup

The test setup shall be as follows:

1. Maintain a basic test setup for the EUT as shown and described in Figure 19, Figure 20, or Figure 21.
2. Calibration. Configure the test equipment as shown in Figure 28.
3. EUT Testing. Configure the test as shown in Figure 29.

B.4.1.4 Procedure

The test procedures shall be as follows:

Turn on the measurement equipment and allow sufficient time for stabilization.

a. **Calibration.** Perform the following procedures using the probe zero configuration of Figure 30.

1. Place the probe inside the zero flux chamber.
2. Perform a probe zero function on ALL channels.

b. **EUT Testing.**

1. Turn on the EUT and measurement equipment to allow sufficient time for stabilization.
2. Locate the sensor 7 cm from the EUT face or electrical interface connector being probed. Orient the plane of the probe perpendicular to the EUT faces.
3. Monitor the output of the gaussmeter while moving the probe (maintaining the 7 cm spacing) over the EUT face under test, keeping the probe perpendicular to the EUT face under test. Move the probe slowly enough for the gaussmeter to respond to changes in the DC field.
4. At 7 cm from the point of maximum radiation, record the value for each gaussmeter channel (X, Y, and Z). If using a single axis probe, then take the measurement with the probe oriented in each of the three axes.

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5. If any over-limit emission is observed, rescan the EUT face area with the highest emission, being sure that the probe is moved slowly enough to capture the maximum value. Repeat the measurement at 10 cm. If the emission exceeds the limit at 10 cm, make additional measurements in increasing 10 cm increments away from the surface until the emission is 6dB below the limit. Record the distance at which the emission is 6dB below the limit.
6. Repeat Steps EUT Testing B.4.1.4.b step 2 through EUT Testing B.4.1.4.b step 5 for each face of the EUT and for each EUT electrical connector.

B.4.1.5 Data Presentation

Data presentation shall be as follows:

1. Provide tabular listings of each mode of operation and the area(s) of each EUT face corresponding to maximum emission.



Figure 26. RE101D Probe



Figure 27. RE101D Zero Flux Chamber

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Figure 28. Probe Zero Flux Configuration

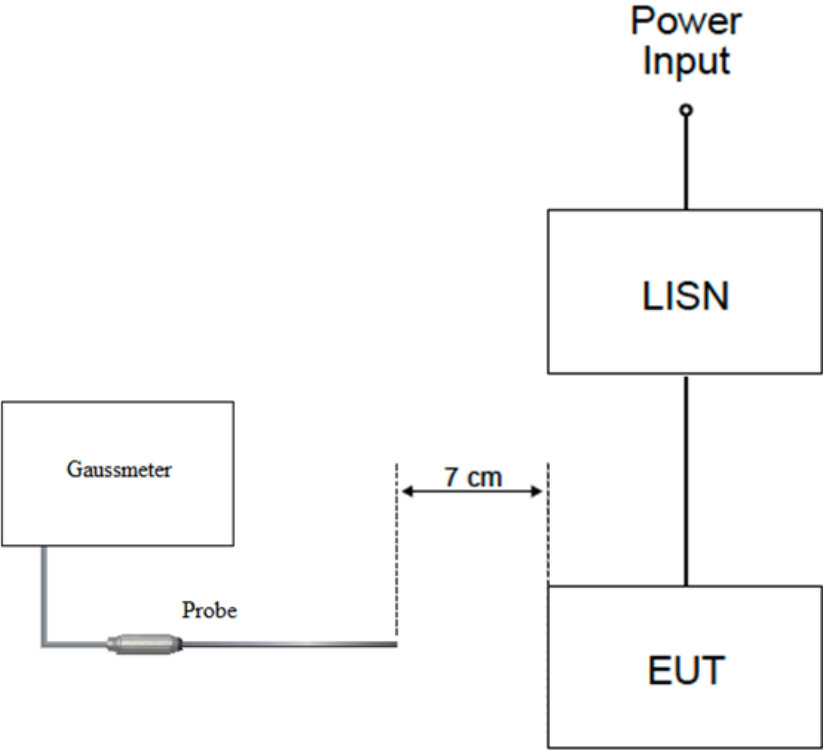


Figure 29. RE101D Basic Test Setup

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B.5 CS106, Negative Transients, Power Leads

B.5.1 CS106 Test Procedures

B.5.1.1 Purpose

This test procedure is used to verify the ability of the EUT to withstand power line load-induced switching transients.

B.5.1.2 Test Equipment

The test equipment shall be as follows:

- a. Switching transient generator.
- b. Oscilloscope, $\geq 1\text{M}\Omega$ input impedance.
- c. LISNs.
- d. $50\mu\text{F}$ capacitor rated above 28 working volts DC (nominal capacitor value) for 28VDC applications or $200\mu\text{F}$ capacitor rated above 120 working volts DC (nominal capacitor value).
- e. 4Ω , 1W resistor (nominal resistance value) for 28VDC applications or 10Ω , 1W resistor (nominal resistance value) for 120VDC applications.

B.5.1.3 Setup

The test setup shall be as follows:

- a. Maintain a basic test setup for the EUT as shown and described in Figure 19, Figure 20, or Figure 21.
- b. **Calibration.** Configure the test equipment in accordance with Figure 30 for calibrating the switching transient. Set transient generator for “turn-on” (negative polarity) transient. Set pulse rate to nominal 1Hz rate. Perform a differential oscilloscope measurement with the oscilloscope channels set to $1\text{M}\Omega$ input impedance.
- c. **EUT testing.** Configure per Figure 30 calibration, except that the EUT is now connected to power.

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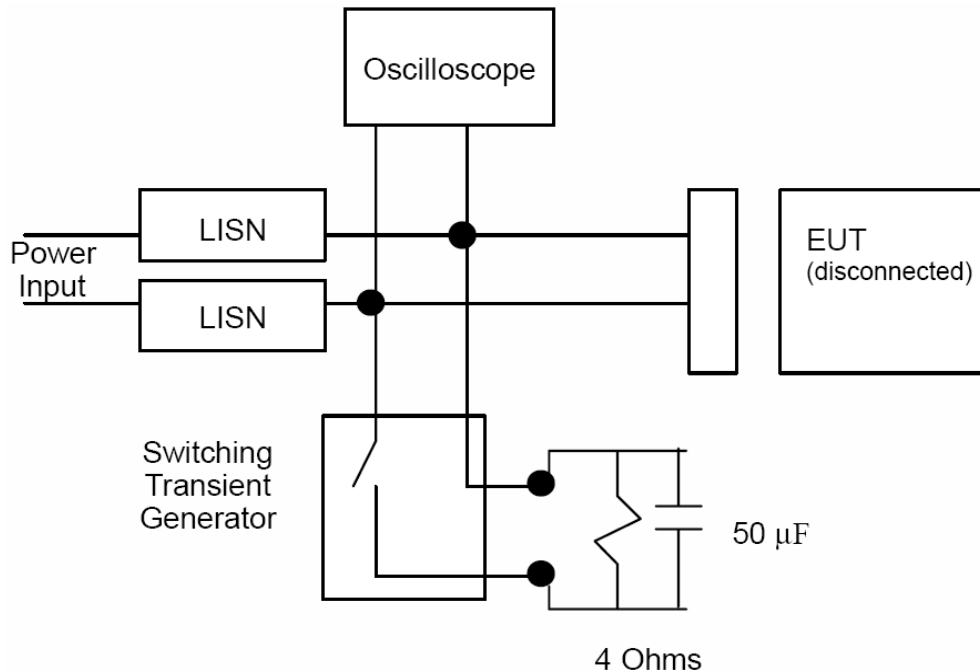


Figure 30. CS106 Calibration setup

Note: This shows the calibration for the 28VDC test limit. For calibrating the 120VDC test limit, replace the 50 μ F capacitor with a 200 μ F capacitor and replace the 4 Ω with a 10 Ω resistor.

B.5.1.4 Procedures

The test procedures shall be as follows:

- a. Turn on the measurement equipment (oscilloscope) and allow sufficient time for stabilization.
- b. **Calibration.** Perform the following procedures using the calibration setup.
 1. Verify that transient amplitude and duration are no less than shown in Figure 10 or Figure 11.
 2. After recording waveforms, shut off transient generator.
- c. **EUT testing.**
 1. Turn on the EUT and allow sufficient time for stabilization.
 2. Susceptibility evaluation.
 - a) Initiate transient generation. Operate for 1 min in negative polarity mode. Verify proper operation of EUT. Shut down transient generator.

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- b) Whenever susceptibility is noted, determine the threshold level in accordance with *MIL-STD-461* Paragraph 4.3.10.4.3 and verify that it is above the limit. The transient duration is to be modified by changing switched capacitor and/or resistor value. The amplitude cannot be changed. When a resistor/capacitor (RC) combination is found that yields the threshold of susceptibility, record the injected waveform as well as the waveform that combination yields in the pre-calibration setup (EUT disconnected). It is recommended to leave the 4Ω (or 10Ω) resistor in place and swap the capacitor to values of 100μF (120VDC testing only), 50μF (120VDC testing only), 22μF, 10μF, and 5μF.
- c) Record samples of transients injected into EUT. These waveforms may differ from those pre-calibrated.

B.5.1.5 Data Presentation

Data presentation shall be as follows:

- a. Oscilloscope traces for calibration transients.
- b. Oscilloscope traces for EUT-injected transients.

Provide any susceptibility thresholds and recorded waveforms thereof that were determined.

B.6 CS114 Conducted Susceptibility, Bulk Cable Injection

B.6.1 Test Procedure

This test procedure is used to verify the ability of the EUT to withstand RF signals coupled onto EUT associated cabling.

B.6.1.1 Setup

The test setup shall be as follows:

- a. Maintain a basic test setup for the EUT as shown and described on Figure 19, Figure 20, or Figure 21.
- b. **Calibration.** Configure the test equipment in accordance with Figure 32 for calibrating injection probes.
 - 1. Place the injection probe (maximum and recommended minimum insertion loss shown in Figure 31) around the center conductor of the calibration fixture and the monitor probe around a second fixture. Terminate the monitor probe with a 50 ohm load.
 - 2. Terminate one end of the calibration fixture with a 50 ohm load, and terminate the other end with an attenuator connected to measurement receiver A.
- c. **EUT testing.** Configure the test equipment as shown on Figure 34 or Figure 35 for testing of the EUT as detailed below.
 - 1. Place the injection and monitor probes around a cable bundle interfacing with EUT connector.

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2. To minimize errors, maintain the same signal circuit that was used for calibration between the attenuator at the calibration fixture (oscilloscope, coaxial cables, bulkhead connectors, additional attenuators, etc.) and connect the circuit to the monitor probe. Additional attenuation may be used, if necessary.
3. Locate the monitor probe 5 cm from the connector. If the overall length of the connector, backshell or backshell extension exceeds 5 cm, position the monitor probe as close to the connector's backshell or backshell extension as possible.
4. Position the injection probe 5 cm from the monitor probe. For differential mode injection, place the injection probe 15 cm from the connector.

B.6.1.2 Procedures

The test procedures shall be as follows:

- a. Turn on the measurement equipment and allow sufficient time for stabilization.
- b. **Calibration.** Perform the following procedures using the calibration setup.
 1. Set the signal generator to 150 kHz (100 kHz for differential mode injection), unmodulated.
 2. Increase the applied signal until measurement receiver A indicates the current level specified in the applicable limit exists in the center conductor of the calibration fixture.
 - (a) The calibration limit for Step B.6.1.2 step 2 is shown in Figure 13 for Differential Mode injection and Figure 14 for Common Mode injection
 3. Record the "forward power" to the injection probe indicated on measurement receiver B.
 4. For common mode injection testing, scan the frequency band from 150 kHz to 200 MHz and record the forward power needed to maintain the required current amplitude. For differential mode injection testing, scan the frequency band from 100 kHz to 1 MHz and record the forward power needed to maintain the required current amplitude.
- c. **Verification.** With the probes still in the calibration setup, configure the verification of the test system using Figure 33. Conduct a scan as though this is a test of an EUT cable.
 1. Set the signal generator to 150 kHz (modulation is optional and should not have an effect).
 2. Apply the forward power level determined under Step B.6.1.2.b step 2 to the injection probe while monitoring the induced current on the monitor probe.
 3. Scan the required frequency range with minimal dwell times and step sizes twice those in *MIL-STD-461* Table II while maintaining the forward power level at the calibrated level determined under Step B.6.1.2.b step 2. Verify that the forward power follows the calibration and that the developed current is within a 3 dB tolerance of the current test limit.

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- d. **EUT testing.** Configure the test as indicated on Figure 34 for common mode injection or Figure 35 for power line differential injection. Perform the following procedures on each signal cable bundle interfacing with each electrical connector on the EUT, including complete power cables (high sides and returns). Also inject differentially on power cables as shown in the Figure 35. For connectors which include both interconnecting leads and power, perform the procedures on the entire bundle common mode, on the power grouped separately and injected differentially.
1. Turn on the EUT and allow sufficient time for stabilization.
 2. Common mode susceptibility evaluation.
 - a) Set the signal generator to 150 kHz with 1 kHz pulse modulation, 50% duty cycle. Verify that the modulation is present on the drive signal for each signal generator/modulation source combination. Ensure that the modulation frequency, waveform, and depth (40 dB minimum from peak to baseline) are correct.
 - b) Apply the forward power level determined under Step B.6.1.2.b step 2 to the injection probe while monitoring the induced current. For shielded cables or low impedance circuits, it may be preferable to increase the signal gradually to limit the current.
 - c) Scan the required frequency range in accordance with MIL-STD-461 Table II while maintaining the forward power level at the calibration level determined under Step B.6.1.2.b step 2, or the maximum current level for the applicable limit, whichever is less stringent.
 - d) Monitor the EUT for degradation of performance during testing.
 - e) Whenever susceptibility is noted, determine the threshold level in accordance with MIL-STD-461 Paragraph 4.3.10.4.3. Also evaluate effect on susceptibility of removing modulation when the signal is at the limit.
 - f) For EUTs with redundant cabling for safety critical reasons, such as multiple data buses, use simultaneous multi-cable injection techniques.
 3. Differential mode susceptibility evaluation.
 - a) Set the signal generator to 100 kHz with no modulation, i.e., a continuous wave signal.
 - b) Apply the forward power level determined under Step B.6.1.2.b step 2 to the injection probe while monitoring the RF potential induced across the power input.
 - c) Scan the required frequency range in accordance with *MIL-STD-461* Table II while maintaining the induced RF potential shown in Figure 12, or the forward power level at the calibration level determined under Step B.6.1.2.b, whichever is less stringent.
 - d) Monitor the EUT for degradation of performance during testing.
 - e) Whenever susceptibility is noted, determine the threshold level in accordance with *MIL-STD-461* Paragraph 4.3.10.4.3.

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B.6.1.3 Data Presentation

Data presentation shall be as follows:

- a. Provide amplitude versus frequency plots for the forward power levels required to obtain the calibration level as determined in B.6.1.2.b.
- b. Provide tables showing scanned frequency ranges and statements of compliance with the requirements for the susceptibility evaluation of B.6.1.2.d step 2 for each interface connector. Provide any susceptibility thresholds that were determined, along with their associated frequencies.

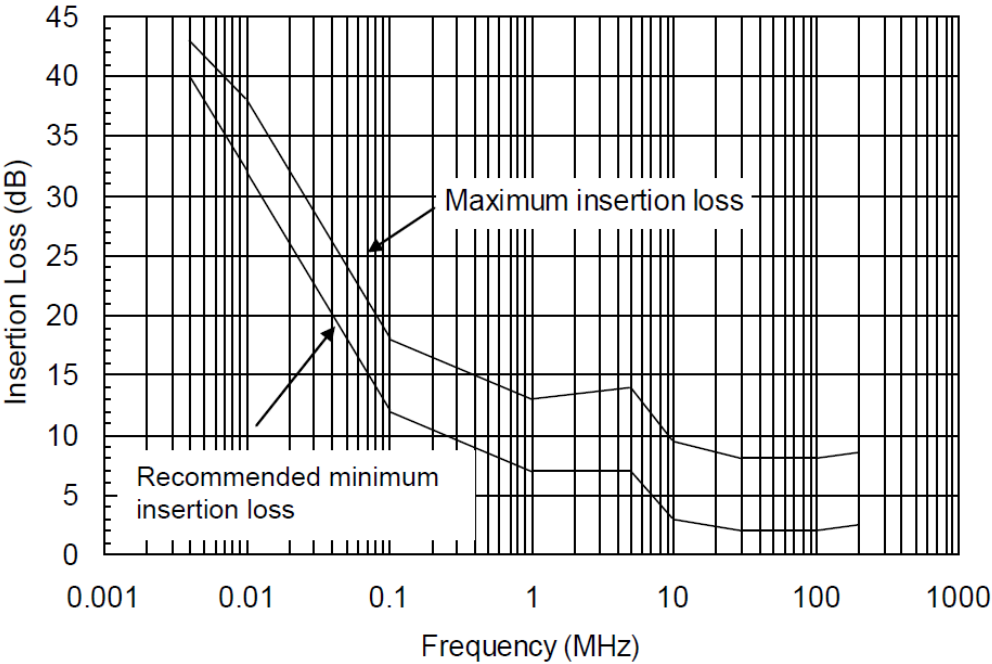


Figure 31. CS114 Insertion Loss for Injection Probes

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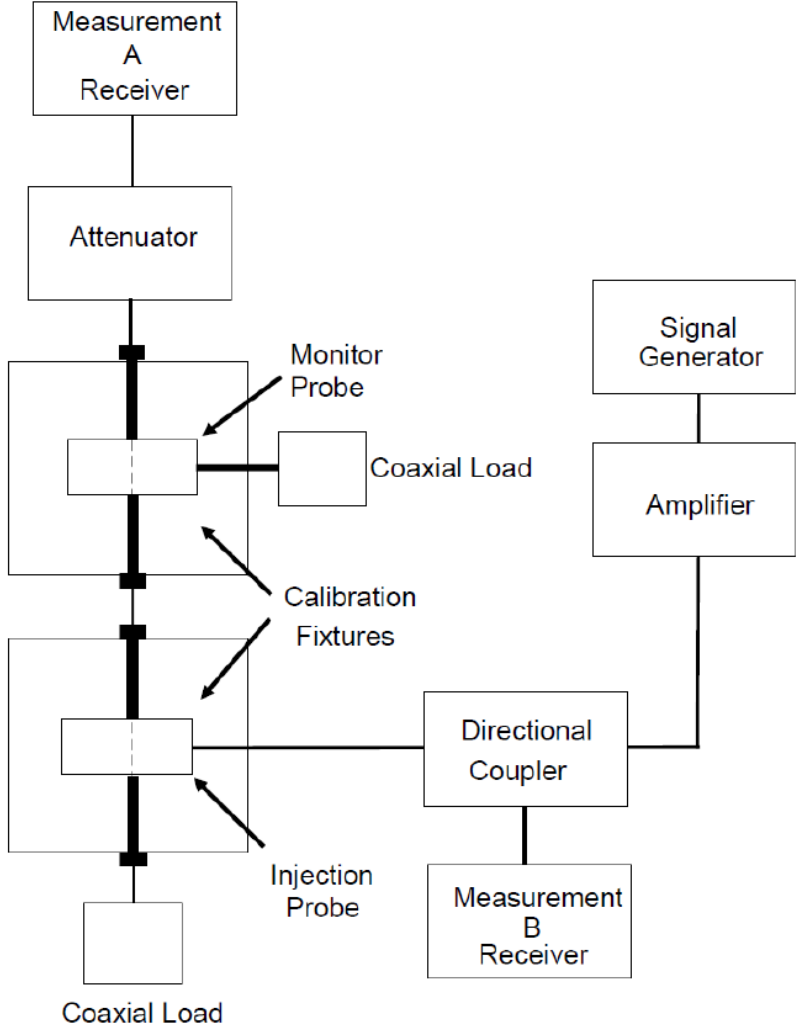


Figure 32. CS114 Calibration Setup

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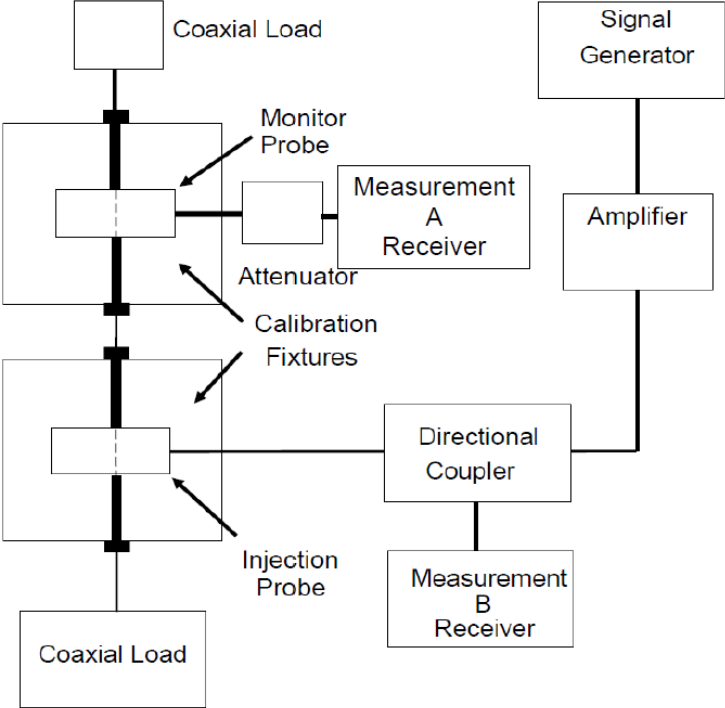


Figure 33. CS114 Verification Setup

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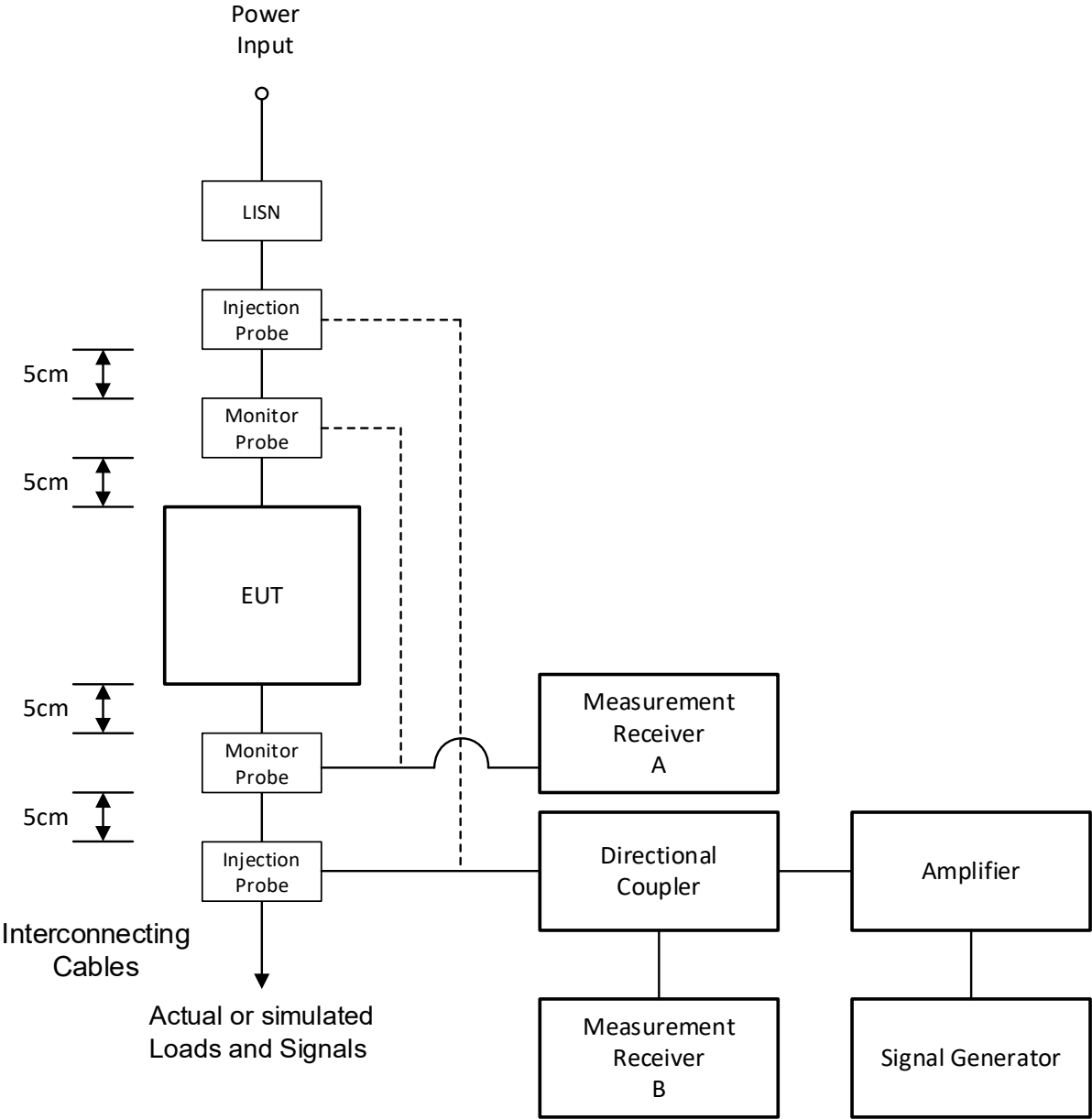


Figure 34. CS114 Bulk Cable Injection Evaluation, Common Mode

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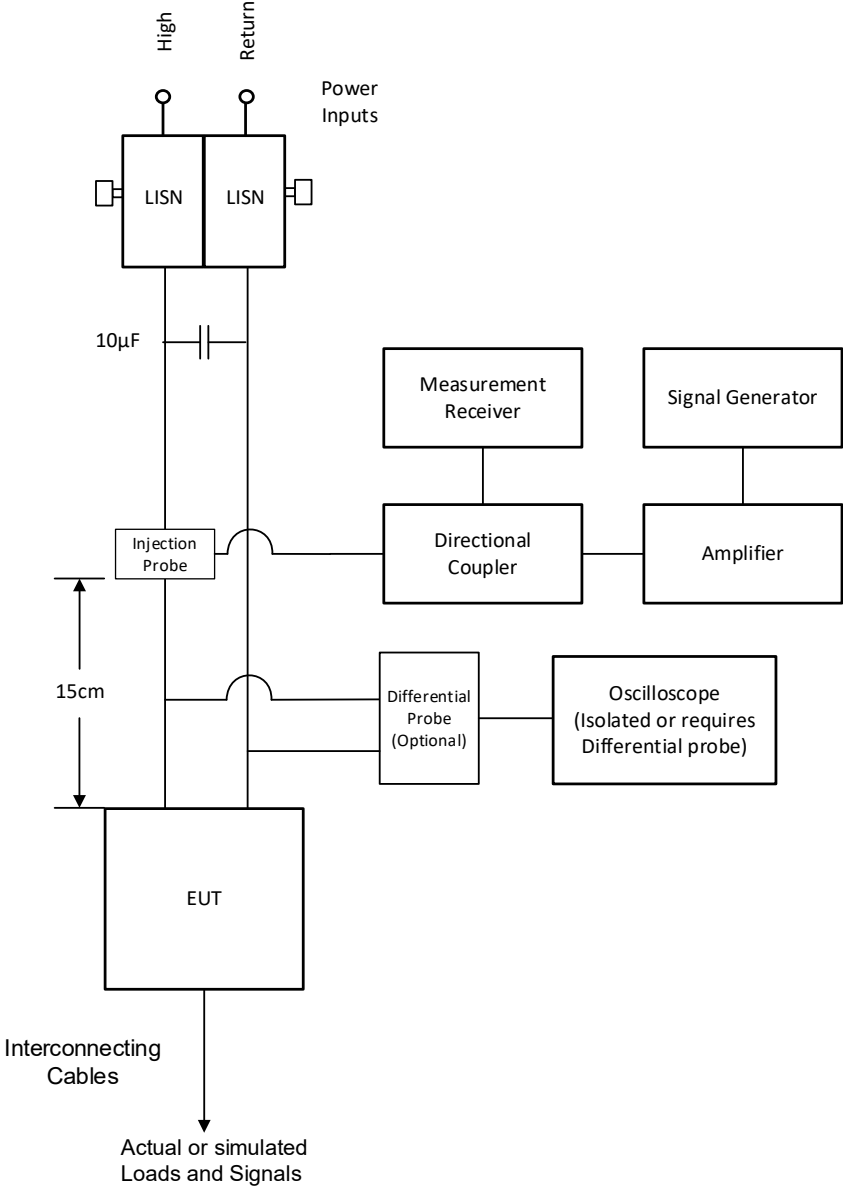


Figure 35. CS114 Bulk Cable Injection Evaluation, Differential Mode

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APPENDIX C
REQUIREMENTS BACKGROUND AND GUIDANCE

C.1 INTRODUCTION

This appendix provides background information for each emission and susceptibility requirement in the main body of the standard. This information includes rationale for requirements and guidance in applying the requirements. This information should help users understand the intent behind the requirements and should aid the procuring activity in tailoring emission and susceptibility requirements as necessary for particular applications. This appendix is provided for guidance purposes and, as such, should not be interpreted as providing contractual requirements.

This appendix follows the same general format as the main body of the specification.

C.2 DOCUMENTS

See section 2.0 for Applicable Documents, Reference Documents, and Order of Precedence.

C.3 REQUIREMENTS

C.3.1 System Compatibility

C.3.1.1 Functional Compatibility

This document provides a set of requirements for equipment and subsystems. The equipment must be self-compatible and compatible with other platform or carrier subsystems and the operational environment.

Equipment must comply with the emissions requirements contained in this specification and any non-compliance must be evaluated against the other equipment and subsystems on the platform. The equipment must also comply with susceptibility requirements contained herein and non-compliances must be evaluated against platform or carrier environment, including that generated by the platform or carrier and its operational environment.

While compliance with the requirements of this specification does not guarantee EMC, it does provide risk mitigation against interference and incompatibilities.

C.3.1.2 Margins

In order to prevent critical or catastrophic hazards, equipment containing critical circuits must demonstrate that circuit thresholds of susceptibility are 6dB (16.5dB for pyrotechnic circuits) or more above the expected environment.

The use of margins simply recognizes that there is variability in manufacturing and that requirement verification has uncertainties.

Margins may be demonstrated in a number of ways. Simply doubling the susceptibility test levels contained in this specification is not recommended. Doing so may lead to over-testing or,

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in some cases, test failure and damage. During verification planning, it is recommended the E3 subject matter experts be brought into the planning process in order to help identify the most expeditious method of margin demonstration.

C.3.2 Design Requirements

C.3.2.1 Primary Power

Typically, primary power is vehicle or platform generated power that is distributed to the various loads. Secondary power may be distributed to other loads, but secondary power distribution is usually, but not always limited in scope. For example, the Space Shuttle Orbiter provided 28V primary power, sourced by the fuel cells, but also provided a secondary, inverter generated AC power for some loads. On the International Space Station, however, primary power is the DC power, generated by the solar arrays. The 120VDC secondary power is widely distributed.

Interface 1 is defined as the distribution point and includes the common bus and source. Using this definition, CE101 requirements were defined to allow compliance with the power quality requirements based off of the *Gateway Program GP 10009, Gateway Electrical Power Quality Specification Requirements for 120 VDC*, which specifies a ripple voltage requirement of 1.5Vrms.

C.3.2.1.1 System

The grounding requirements contained in this specification assume that the equipment or subsystem will be powered by a source that is referenced to vehicle or platform structure. Therefore, it is important to maintain isolation at the loads to prevent currents from returning through structure. *NASA Reference Publication 1368 Marshall Space Flight Center Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook*, has more information concerning electrical grounding and a distributed single point ground concept.

C.3.2.1.2 Equipment Power Ground Reference

C.3.2.1.2.1 Interface 1

Equipment that provides a voltage source should reference the source to ground to allow for electrical fault clearing and enhance operability and safety. Equipment ground references should not be brought outside the equipment chassis but should be connected as close to the source as possible to prevent noise currents and voltages from creating common mode voltages in the power circuit.

C.3.2.1.2.2 Interface 2

DC Power consumers/converters/conditioners/distributors/etc. connected to primary power must maintain at least 1 M Ω dc isolation between both the high and return lines and chassis to prevent SPG violation and the isolation should be maintained during all operational modes to prevent sneak circuits.

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Isolation between primary and secondary lines is required to prevent violation of SPG in circuitry utilizing secondary power.

C.3.2.1.2.3 Primary Power to Secondary Power Isolation

Isolation between primary and secondary is best achieved through the use of transformers. If secondary power is not further referenced to structure (i.e., floating output), then no SPG violation occurs and the intent of the requirement is met.

C.3.2.1.3 Equipment/LRU Signals Grounding Considerations

C.3.2.1.3.1 Signal Grounding

This requirement applies only to signals that are routed outside of the equipment to other equipment or subsystems.

C.3.2.1.3.2 Signal Returns

This requirement applies only to signals that are routed outside of the equipment to other equipment or subsystems. The use of separate returns minimizes common impedance coupling, cross talk, and allows for twisting to minimize coupling area.

C.3.2.1.3.3 Balanced Differential Circuit Isolation

Balanced differential circuits provide a high degree of common mode isolation. However, commercially available digital driver and receiver integrated circuits may have a DC resistance as low as 6kΩ between the input or output pins and the ground pin.

C.3.2.1.3.4 Coaxial Shields

Coax is frequently used to carry video signals. However, video signals have components well below 1MHz. As such, the low frequency components will not remain on the inner surface of the coax shield but will flow through all conductors in the shield. This can be a source of unintentional radiated emissions or radiated susceptibility coupling path.

Typically, coax shields are terminated through connector backshells to equipment enclosures. Using coax as interconnects between equipment utilizing different power sources may violate SPG.

C.3.2.2 Enclosure Shielding

A metallic shielding material thick enough to support itself usually provides good electric field shielding at all frequencies. However, apertures and discontinuities degrade the shielding effectiveness of an equipment enclosure. *NASA RP 1368* has more information concerning enclosure shielding.

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C.3.2.3 Electrical Bonding

Equipment must have the necessary provisions so it can be electrically bonded to the vehicle or platform. The bonding requirements of this specification are in line with those of *NASA-STD-4003*.

C.3.2.3.1 Bonding Provisions

Equipment must have the necessary provisions so it can be electrically bonded to the vehicle or platform. This includes planning for metal-to-metal bonding, surface preparation, or if bonding straps are used.

C.3.2.3.2 Bonding Contact Area

Equipment must have the necessary contact area to ensure the electrical bond can carry the expected electrical currents, whether common mode currents or hazard fault currents.

C.3.2.3.3 Bonding Area Preparation

For the bonding process, the faying surface area shall be prepared such that it is clean and free of paint or any type of non-conductive conversion coating. This is done to ensure that the faying surface bond impedance path is minimal.

C.3.2.3.4 Bonding Straps

If bond straps are used, the length to width ratio needs to be followed to ensure a low impedance path for common mode electrical currents to flow.

C.3.2.4 Circuit Classification

Power and signal cables may act as both transmitting and receiving antennas for radiated EMI and conduits for conducted EMI. Because cables are usually routed to accommodate practical routing paths and equipment location, it is almost impossible to predict and quantify the EMI environment associated with these cables. One way of controlling crosstalk from cables and wiring is to separate cables and wiring of dissimilar classes.

C.3.2.5 Wire Twisting

Wire twisting minimizes coupling loop areas, aiding the designer in meeting both radiated emissions and radiated susceptibility requirements.

C.3.2.5.1 Group Wire Twisting

Wire twisting minimizes coupling loop areas, aiding the designer in meeting both radiated emissions and radiated susceptibility requirements.

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C.3.2.6 Wire Shielding

Unshielded or improperly shielded cables are a primary source for radiated emissions and an entry point for the external RF environment. Shield terminations must provide low impedances paths for noise currents. *NASA RP 1368* has more information concerning wire shielding.

C.3.2.6.1 Shield Current

Electrical cable shield shall not be used to intentionally carry electrical current except for RF signals on coax cable (frequency content above 1MHz).

C.3.2.6.2 Shield Termination

Electrical cable shields should be terminated to conductive backshells, 360 degrees. This provides an electrical “Faraday” cage to minimize emissions and susceptibility. If no conductive backshell is present, the shield may be terminated to chassis through a “pigtail”. This type of termination only limits radiated emissions up to 1MHz. If used, the EMI test needs to represent this “flight-like” cable connector configuration.

C.3.2.6.3 Shield Termination Bonding

Electrical cable shields need to be bonding to vehicle structure with a low impedance bond path in order to provide a low impedance path for common mode currents to flow.

C.3.3 Subsystem and Equipment Emission and Susceptibility Requirements

The basis for the emission and susceptibility requirements is primarily *MIL-STD-461*, with six requirements based from *Gateway Program, GP 11461, Gateway Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*.

C.3.3.1 Equipment Produced Emission

C.3.3.1.1 Conducted Emissions (CE)

C.3.3.1.1.1 Conducted Emissions, Power Leads, Differential Mode (CE101)

This requirement is applicable from 30Hz to 10MHz for all primary power leads, including returns, which obtain power from other sources not part of the EUT. There is no requirement on output leads from power sources. Since power quality requirements are normally used to govern the characteristics of output power, this specification does not impose separate EMI requirements on output leads.

C.3.3.1.1.1.1 CE101 Limits

These limits for both 120 Vdc and 28 Vdc loads are derived from *GP 10009* requirements, using the impedance of the 5µH LISN as the source impedance (see *MIL-STD-461*, Appendix A for a discussion on the use of the 5µH LISN). In most cases, the platform or vehicle power bus impedance will not approach this value so the CE101 limits are moderately conservative. The

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limit may be relaxed based on the current draw of the load. This limit was derived from a power quality voltage ripple requirement of 1.5 Vrms (*GP 10009*).

C.3.3.1.1.2 Conducted Emissions, Common-Mode Radio Frequency Current, Power and Signal Cables (CE104)

This requirement is applicable from 150kHz to 200MHz for all cables.

C.3.3.1.1.2.1 CE104 Current Clamp Calibration/Verification Procedure

Conducted emissions levels are determined by measuring the common mode current or Bulk Current Emissions (BCEs) present on each individual cable, including the power harness consisting of both feeder and return. The test procedure is similar to the obsolete CE04 from *MIL-STD-461A*, hence the requirement nomenclature. During the latter part of the Space Shuttle Program, low frequency radiated emissions measurements were replaced with a BCE-similar BCE requirement.

A CISPR 16-1 absorbing clamp is preferred over a traditional current probe, because the frequency range of the test covers electrically long cables. Most cables contain shields whose low impedance terminations at each end act as mismatches. Constructive and destructive interference will result in very high peak currents and very deep nulls. Neither of these are useful; and while it might seem conservative to scan a current probe looking for and recording peaks, this is time consuming and in fact degrades the value of the requirement. It is in fact the average current which is proportional to crosstalk due to inductive coupling to a shielded victim and recording peaks, which can be 20dB – 30dB higher than the average current, dilutes the value of the relaxation in common mode current allowed by substituting a crosstalk requirement for the traditional control of radiated emissions. Average current is the metric of interest because we assume any circuit that might be a victim of crosstalk will be shielded, and the coupling mechanism is shield currents coupling through the shield transfer impedance. Current induced on the victim shield by inductive coupling from the culprit is a distributed phenomenon. The familiar concepts of near-end and far-end crosstalk evaluated in printed circuit board design are not useful when evaluating interface cable crosstalk.

The CISPR 16-1 absorbing clamp consists of a current transformer (current probe) and a stack of ferrite cores that act to damp (absorb) reflections due to their primarily resistive inserted impedance. Because the CISPR standards utilizing the absorbing clamp employ power limits, their calibration of the absorbing clamp does not work for a limit that directly controls current. That means the absorbing clamp must be calibrated for the purpose of CE104 as a current probe, as follows.

Absorbing Clamp Calibration Procedure:

To use the absorbing clamp for CE104, it must be calibrated as a current probe, not as an absorbing clamp per CISPR 16. The manufacturer may be requested to do this, or it can be done in-house using the general setup shown in Figures 36, Figure 37, Figure 38, and Figure 40.

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A network analyzer is most easily employed to make this measurement, but it can be replaced by a spectrum analyzer with tracking generator, or a spectrum analyzer and stand-alone signal generator.

If necessary, a low power amplifier may be connected in series with the signal source output to raise the level of the injected signal level. This may be necessary to obtain an accurate measurement at and above 30MHz, where the absorbing clamp decoupling factor reduces the signal getting through the clamp. Decoupling factor is identical to loss in a coaxial transmission line; it affects what gets through the clamp without impacting the impedance the clamp presents to the cable around which it is clamped.

The general procedure is as follows:

1. Two L-brackets with bulkhead mount BNC or N-type connectors are bonded to the ground plane on either side of the CISPR 16 absorbing clamp. The center pins of the L-bracket coaxial connectors are connected by a thick conductor (\geq AWG 12), approximately one meter in length. A signal source (network analyzer source output) drives one end of the fixture, while an analyzer (network analyzer reference port) measures the received power at the load end. The absorbing clamp is placed around the wire, with the current probe side of the clamp (at opposite end of the clamp from the RF connector) as close as possible to the fixture load end, but in no case more than 15cm away from the fixture load end.
2. Connect the current probe output of the absorbing clamp to the network analyzer test port. Analyzer configured to display T/R, in dB vs. log frequency.
3. Sweep from 150kHz to 200MHz.
4. The absorbing clamp transfer impedance is the measured T/R ratio less 34dB.
5. Verify that the measured transfer impedance closely approximates the transfer impedance given by the curve in Figure 39.

The general procedure is as follows for a 2 Port Vector Network Analyzer:

1. Bond two L-brackets with bulkhead mount BNC or N-type connectors to the ground plane on either side of the CISPR 16 absorbing clamp. Connect the center pins of the L-bracket coaxial connectors with a thick conductor (\geq AWG 12), approximately one meter in length. Place the absorbing clamp around the wire as close as possible to the fixture load end, but in no case more than 15cm from the load end.
2. Calibrate the network analyzer for an S21 (insertion loss) measurement over the 150kHz – 200MHz frequency range using manufacturer recommended calibration procedures.
3. Connect the S1 port of the network analyzer to the end of the fixture nearest the current probe.
4. Connect the S2 port of the network analyzer to the current probe output of the absorbing clamp.
5. Configure the analyzer to display S21 in dB vs log frequency format and sweep from 150kHz – 200MHz.

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6. The absorbing clamp transfer impedance is the measured S21 less 34dB.
7. Verify the measured transfer impedance closely approximates the transfer impedance given the curve in Figure 39.

The general procedure is as follows for using two Spectrum Analyzers or EMI Receivers:

1. Bond two L-brackets with bulkhead mount BNC or N-type connectors to the ground plane on either side of the CISPR 16 absorbing clamp. Connect the center pins of the L-bracket coaxial connectors with a thick conductor (\geq AWG 12), approximately one meter in length. Place the absorbing clamp around the wire as close as possible to the fixture load end, but in no case more than 15 cm from the load end.
2. Connect the first spectrum analyzer or EMI receiver (SA1) to the end of the fixture nearest the current probe.
3. Connect the second spectrum analyzer or EMI receiver (SA2) to the current probe output of the absorbing clamp.
4. Connect the signal generator to the other fixture and configure the analyzer to sweep from 150kHz – 200MHz.
5. The absorbing clamp transfer impedance is the level (in dB μ V) measured by SA2 minus the level measured by SA1 less 34dB.
6. Verify the measured transfer impedance closely approximates the transfer impedance given the curve in Figure 39.

The general procedure is as follows for using one Spectrum Analyzer or EMI Receiver:

1. Bond two L-brackets with bulkhead mount BNC or N-type connectors to the ground plane on either side of the CISPR 16 absorbing clamp. Connect the center pins of the L-bracket coaxial connectors with a thick conductor (\geq AWG 12), approximately one meter in length. Place the absorbing clamp around the wire as close as possible to the fixture load end but in no case more than 15cm from the load end.
2. Connect the spectrum analyzer or EMI receiver to the end of the fixture nearest the current probe.
3. Connect a 50 Ω termination to the current probe output of the absorbing clamp.
4. Connect the signal generator to the other fixture and configure the analyzer to sweep from 150kHz – 200MHz.
5. Record the signal level measured by the spectrum analyzer or EMI receiver. This is the Reference Signal (R).
6. Connect the spectrum analyzer or EMI receiver to the current probe output of the absorbing clamp.
7. Connect the 50 Ω termination to the end of the fixture nearest the current probe.
8. Using the same signal generator amplitude setting as in Step e, repeat the sweep from 150kHz – 200MHz.
9. Record the signal level measured by the spectrum analyzer or EMI receiver. This is the Test Signal (T).

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- 10. The absorbing clamp transfer impedance is T/R less 34dB.
- 11. Verify the measured transfer impedance closely approximates the transfer impedance given the curve in Figure 39.

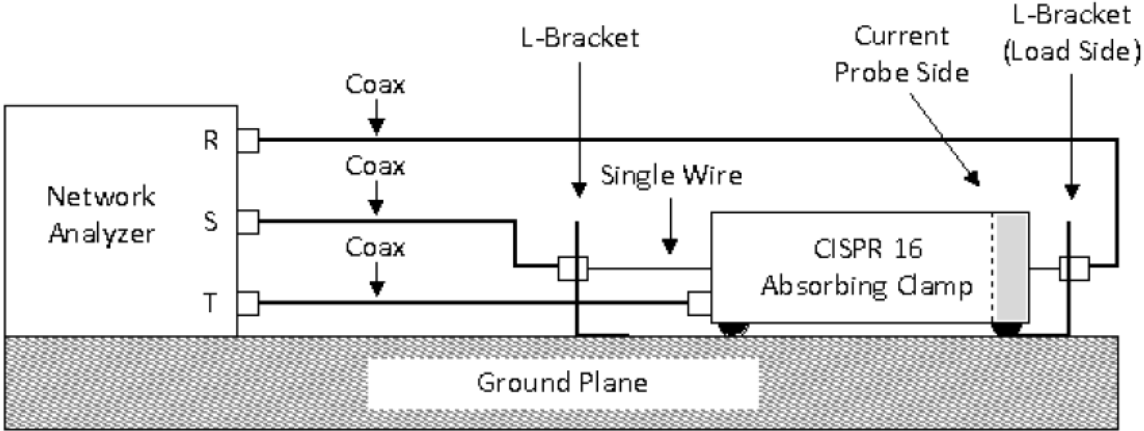


Figure 36. Basic Common Mode Conducted Emissions Calibration Setup

Note: A low power amplifier (~ 1 W output) may be necessary to complete measurement.

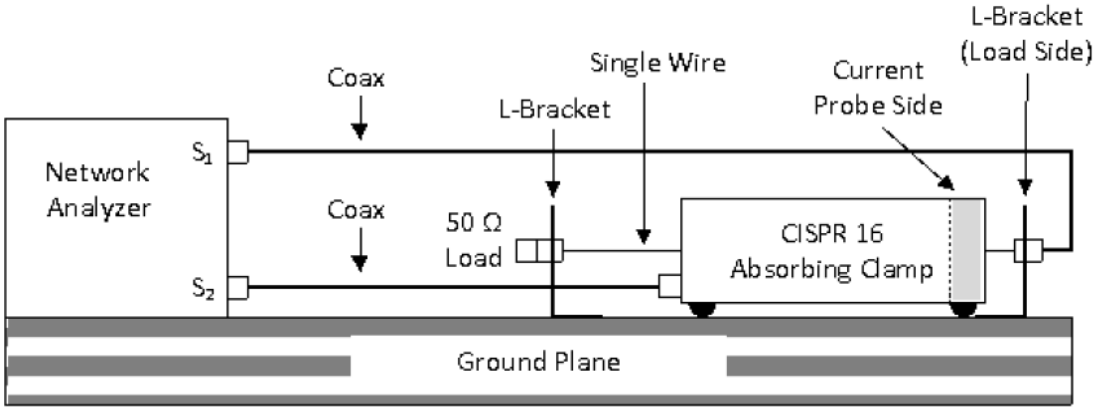


Figure 37. Basic Common Mode Conducted Emissions Calibration Setup, 2 Port Analyzer

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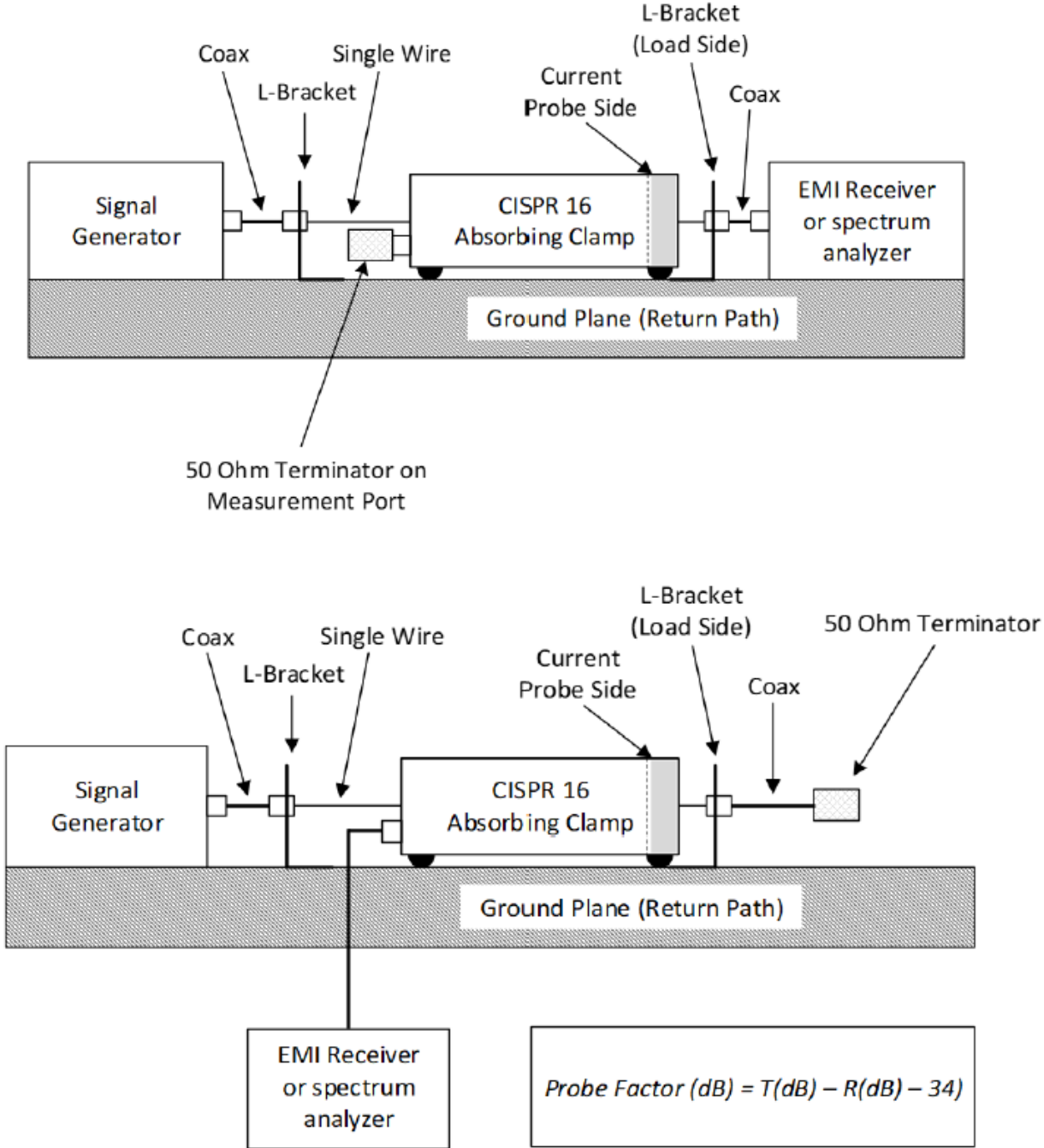


Figure 38. Basic Common Mode Conducted Emissions Calibration Setup, 1 Spectrum Analyzer or EMI Receiver Method

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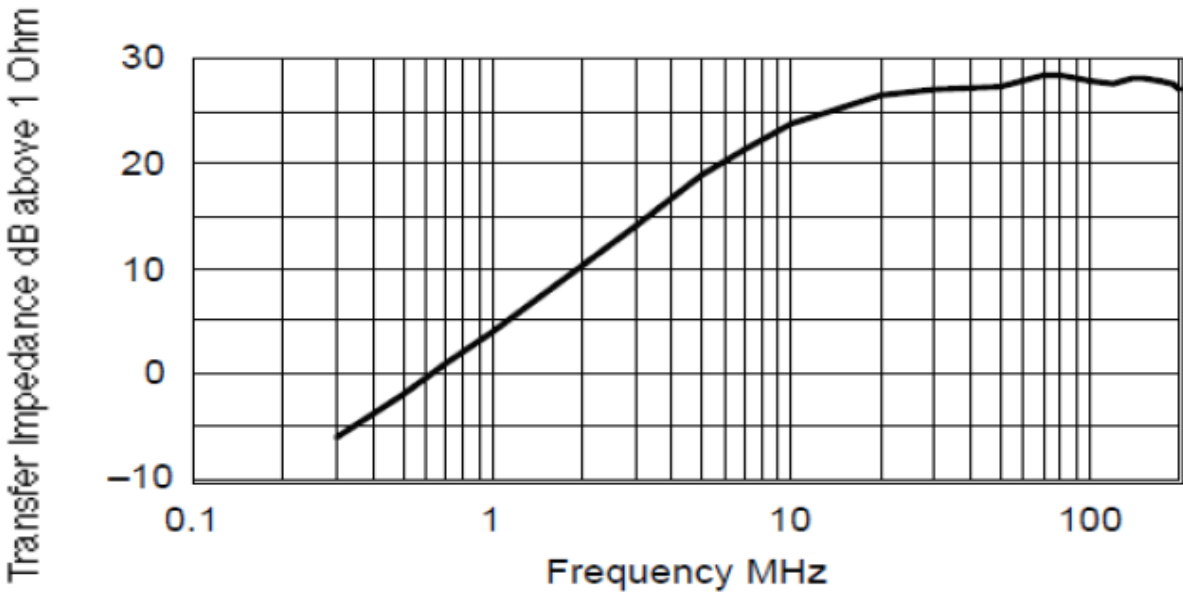


Figure 39. Nominal Transfer Impedance of CISPR 16 Absorbing Clamp

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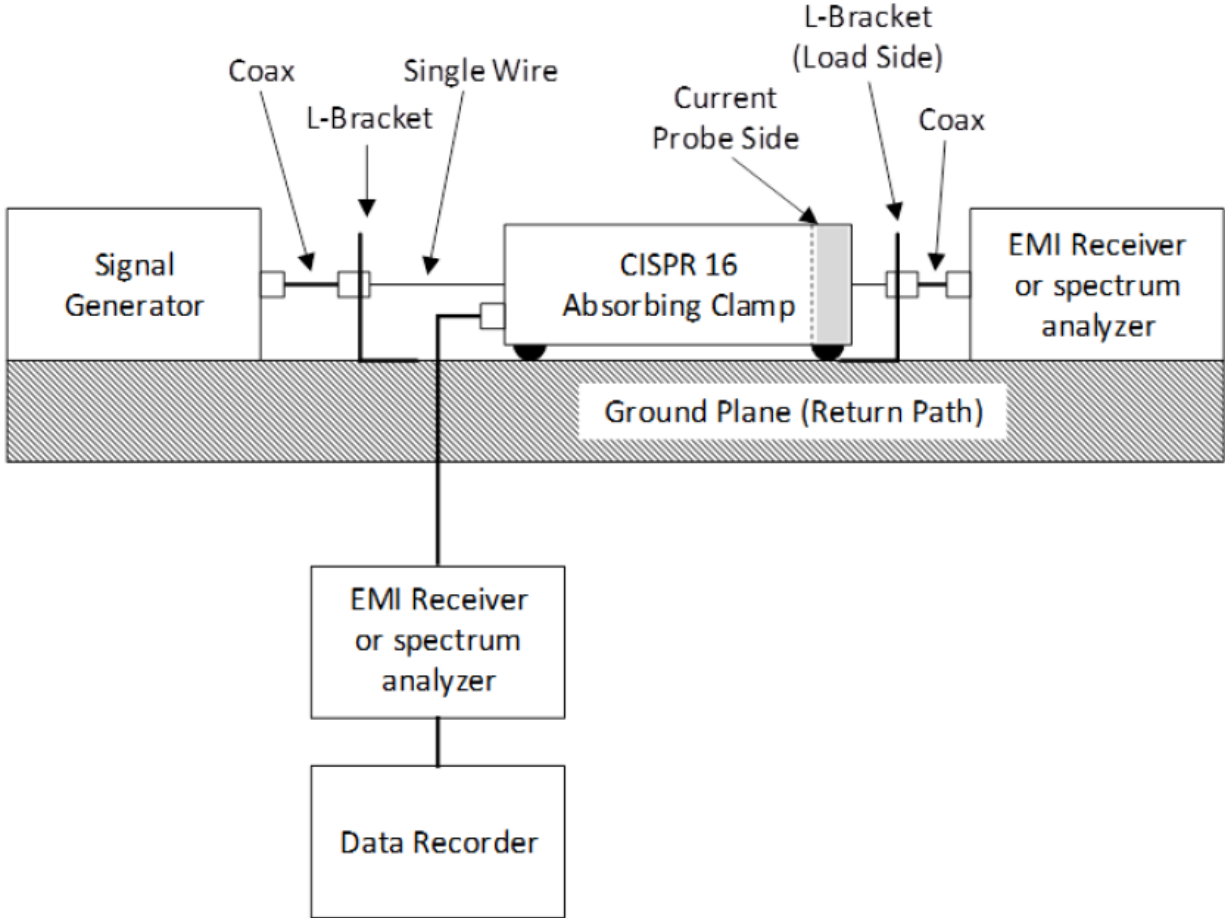


Figure 40. CE104 Basic Common Mode Conducted Emissions Calibration Setup, 2 Spectrum Analyzer or EMI Receiver Method/CE104 Measurement System Check Setup

C.3.3.1.1.2.2 CE104 Limits

Conducted emissions on power and signal cables shall not exceed the applicable values shown on Figure 4. This limit (compared to the common mode current control required to meet MIL-STD-461 radiated emission limits) works in concert with a 70 dBuA CS114 limit to form a duo of control over cable crosstalk. Only cables that fail one or more of these requirements by very large margins need be considered for any sort of cable separation requirements. The relaxation inherent in this crosstalk limit may be judged by comparison to the 60 dBuV CE102 limit above.

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500 kHz. That limit protects the RE102 limit at the same frequency, and is equivalent to about 20 dBuA, so that the 50 dBuA limit represents a 30 dB relaxation.

C.3.3.1.1.3 Conducted Emissions, Antenna Terminal (CE106)

This requirement is applicable to the antenna terminals of transmitters, receivers, and amplifiers. If the equipment or subsystem does not contain transmitter, receiver, or amplifier, this requirement is not applicable and no verification is required.

C.3.3.1.1.3.1 CE106 Limits

The CE106 limits in this specification are the same as those in *MIL-STD-461*.

C.3.3.1.2 Radiated Emissions (RE)

C.3.3.1.2.1 Radiated Emissions, Magnetic Field (RE101A)

This requirement is specialized and is intended primarily to control magnetic fields for applications where equipment is present in the installation that is potentially sensitive to magnetic induction at lower frequencies. Most equipment is insensitive to the low levels defined in this limit unless the equipment specifically uses, senses, or measures low-frequency magnetic fields. Due to the time-consuming nature of the testing, this requirement should be imposed on the equipment only when necessary to protect magnetically sensitive equipment that may reside on the platform or vehicle.

C.3.3.1.2.1.1 RE101A Limits

The RE101 limits contained in this specification are derived from those imposed in ISS payloads.

C.3.3.1.2.2 Radiated Emissions, Static Magnetic Field (RE101D)

This requirement is specialized and is intended primarily to control static (dc) magnetic fields for applications where equipment is present in the installation which is potentially sensitive to magnetic fields. The most common examples are magnetometers and scientific payloads. The limit is the same as that used for ISS hardware and derived jointly by NASA and the European Space Agency.

C.3.3.1.2.2.1 RE101D Limits

Measurements are now required for each point of maximum radiation which exceeds the RE101D limit at 7 cm. These measurements are performed by increasing the measurement distance until the emission falls below the specified limit. The fall-off measurement data is intended to assist the equipment designer in determining the source of the magnetic field emissions and in the development of appropriate mitigation techniques. It should be noted the EUT is required to comply with the applicable RE101D limit at 7cm; this is not a change to the RE101D limit or measurement distance.

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Note: Limits are not applicable to solenoid valves, solenoid relays, and electrical motors with current draw less than 1 ampere.

C.3.3.1.2.3 Radiated Emissions, Electric Field (RE102)

This requirement is to protect antenna connected receivers from interference due to equipment generated unintentional radiated emissions. It is not complimentary to the RS103 limit.

C.3.3.1.2.3.1 RE102 Limits

The RE102 limit contained in this specification is a tailored version of the *MIL-STD-461* RE102 limit for US Army and US Navy fixed-wing and rotary-wing aircraft. While that limit extends to 10kHz, the limit in this specification begins at 200MHz due to the fact that NASA vehicles and platforms do not use the electromagnetic spectrum below 200MHz for the purpose of receiving RF signals.

C.3.3.1.2.4 Radiated Emissions, Antenna Spurious and Harmonic Outputs (RE103)

This requirement may be used as an alternative for CE106.

C.3.3.1.2.4.1 RE103 Limits

The RE103 limits contained in this specification are the same as those in *MIL-STD-461*.

C.3.3.2 Equipment Susceptibility

The purpose of the susceptibility requirements is to determine the immunity of the equipment to the electromagnetic environment. During test planning, the hardware provider must determine susceptibility criteria to be used during testing. When the equipment exhibits susceptibilities during testing, it is important to determine the threshold of susceptibility.

C.3.3.2.1 Conducted Susceptibility (CS)

C.3.3.2.1.1 Conducted Susceptibility, Power Leads (CS101)

C.3.3.2.1.1.1 CS101 Limits

This requirement is derived from *Gateway Program, GP 10009* ripple voltage requirements and is intended to prove equipment immunity against power bus ripple voltages generated by the source and other loads. This is complementary to the CS101 test limit in this document.

C.3.3.2.1.2 Conducted Susceptibility, Antenna Port, Intermodulation (CS103)

The CS103 requirement is to ensure that the equipment under test will not exhibit any intermodulation products beyond specified tolerances when subjected to the limit requirement provided in the individual procurement specification.

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C.3.3.2.1.3 Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals (CS104)

The CS104 requirement is to ensure that the equipment under test will exhibit any undesired response beyond specified tolerances when subjected to the limit requirement provided in the individual procurement specification.

C.3.3.2.1.4 Conducted Susceptibility, Antenna Port, Cross-Correlation (CS105PN)

C.3.3.2.1.4.1 CS105PN Notional Test Setup General Guidance

The receiver is presented with a signal level that meets the minimum signal to noise ration or bit error rate of the receiver. The signal has the correct PN code modulation and the receiver is monitored to ensure it acquires the signal. A PN code not assigned to the receiver is then applied to the signal. The receiver should be monitored to ensure loss of acquisition at this point. It may be necessary to monitor the receiver telemetry output to determine if the receiver attempts to correlate the incorrect PN code, resulting in a false lock. The receiver is then presented with the correct PN code and monitored to ensure reacquisition.

Figure 41 shows a notional test setup. The signal source and modulators may be replaced by a specialized test set capable of generating both the correct and incorrect PN codes, as well as the proper message signal. The spectrum analyzer monitors the power provided to the receiver achieve the minimum signal to noise ratio or bit error rate required by the receiver. A test set or some system is required to monitor receiver performance.

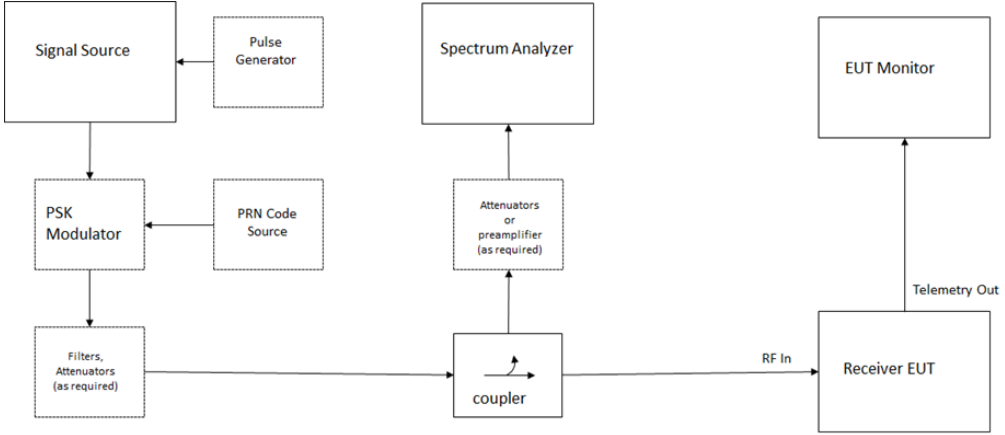


Figure 41. CS105PN Notional Test Setup

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C.3.3.2.1.4.2 CS105 PN Applicability and Limits

This receiver requirement is applicable to direct-sequence spread spectrum receivers that use Pseudo-Random (PN) codes to correlate and demodulate the incoming message or ranging information. During operations, a forward link from a Visiting Vehicle or other communications system may overpower the receiver and lock out the assigned link. It is possible that the receiver could attempt to correlate the incorrect PN code, thus preventing acquisition of the correct signal.

C.3.3.2.1.5 Conducted Susceptibility, Negative Transients, Power Leads (CS106)

C.3.3.2.1.5.1 CS106 Limits

This requirement is not the same as the MIL-STD-461F, CS106 requirement. The purpose of this requirement is to determine the immunity of the equipment against power bus voltage drops due to turn-on transients generated by other loads. The test limit simulates the turn-on transient of a 28VDC, 200W load with 50µF of bulk capacitance or a 120VDC, 1.44kW load with 200µF of bulk capacitance.

C.3.3.2.1.6 Conducted Susceptibility, Bulk Cable Injection (CS114)

This requirement is applicable to all interconnecting cables, including power cables. Due to size constraints and available antenna field patterns during RS103 testing, it is recognized that cabling cannot be properly excited to simulate platform effects at lower frequencies. The common mode injection technique replaced low frequency radiated susceptibility testing starting with *MIL-STD-461F*.

C.3.3.2.1.6.1 CS114 Limit Differential Mode Limit

The differential mode current limit controlling load-induced ripple is based on how much current the mandated 300 mV ripple will induce in the 100 ohm CS114 calibration fixture. The 70 dBuA limit, together with 10 uF capacitor bypassing the LISNs acts to provide a 10 dB margin between total load-induced ripple and the susceptibility requirement. While a 6 dB margin usually suffices in such cases, it should be noted that the CE101 limit controls load-induced effects to the same level as the power quality standard allows for a resistively loaded bus. Thus, purely theoretically, there could be 3 dB more total bus ripple from the sum total of inherent bus ripple and load-induced effects, which brings the net margin down to 7 dB.

C.3.3.2.1.6.2 CS114 Limit Common Mode Limit

The common mode limit doubles as a crosstalk control and simulates the coupling of a 2 V/m electromagnetic field. As a crosstalk control, the level is 20 dB higher than the 50 dBuA CMCE limit of CE104. The roll-off below 10 MHz is based on a cable with maximum length 15 meters, and is not in conflict with CE104 limit at low frequencies, because if a signal might be susceptible to crosstalk, the cable will be shielded and the calibration fixture current in Figure 14 will be flat at 70 dBuA down to 150 kHz for a low impedance cable (shield terminated to ground at both ends).

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C.3.3.2.1.7 Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation (CS115)

CS115 used as the indirect coupling of an ESD to a short cable. As such, if a susceptibility is found at the full 5 ampere limit, it is not only incumbent to find the threshold of susceptibility as a function of the amplitude, but also the repetition rate, because ESD phenomena, especially due to spacecraft charging, are very intermittent compared to the default 30 Hz rate of CS115.

C.3.3.2.1.7.1 CS115 Limits

The limits contained in this specification are the same as those found in *MIL-STD-461*.

C.3.3.2.1.8 Conducted Susceptibility, Damped Sinusoid Transients, Cables and Power Leads (CS116)

C.3.3.2.1.8.1 CS116 Limits

The damped sine waveforms can be induced in equipment and subsystems by external stimuli such as lightning or electromagnetic pulse or from electrical switching phenomena. The limits contained in this specification are the same as those found in *MIL-STD-461*.

C.3.3.2.1.9 Conducted Susceptibility, Personnel Borne Electrostatic Discharge (CS118)

The requirement is applicable to electrical, electronic, and electromechanical subsystems and equipment which does not interface with or control pyrotechnic devices. This requirement addresses the effects of electrostatic discharging on electrical and electronic equipment caused by human ESD. ESD requirements for other NASA Programs, such as ISS, focused on damage tolerance to ESD events during ground handling or on orbit installation, when the equipment is most vulnerable. The underlying assumption of this requirement is that ground operations will employ ESD protective measures such as those outlined in *ANSI/ESD S20.20* during assembly, installation, cable mating, etc. It also assumes the crew will implement ESD protective measures such as ESD-dissipative wrist straps, during remove and replace or cable mating. The equipment provider is not relieved of the responsibility for assuring that proper ESD protective procedures are transmitted to flight operations planners who develop installation and assembly procedures for crew operations.

C.3.3.2.1.9.1 CS118 Limits

The limits for this test are contained in Table 1 of this document.

C.3.3.2.2 Radiated Susceptibility (RS)

C.3.3.2.2.1 Radiated Susceptibility, Magnetic Field (RS101)

C.3.3.2.2.1.1 RS101 Limits

This requirement has limited application and is intended to ensure that the equipment is immune to intentionally-generated, low frequency magnetic fields. For equipment and subsystems flying

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on platforms that do not have high field devices such as magnetic furnaces or high-power transformers, the applicability of this requirement should be evaluated.

C.3.3.2.2.2 Radiated Susceptibility, Electric Field (RS103)

The purpose of this requirement to show immunity of equipment and subsystems to intentional transmitters located on the platform and on the ground. It is not complimentary to RE102 and there is implied relationship between the two requirements.

C.3.3.2.2.2.1 RS103 Limits

The test limit in Table 2 encompasses the worst-case ground environment described in *Technical Operating Report (TOR)-2022-01686-Rev C, Cape Canaveral Radio Frequency Environment: Eastern Range*; the on-orbit environment described in *Joint Spectrum Center (JSC)-CR-06070, Space Vehicle RF Environments*; and data received from the Joint Spectrum Center to MSFC in 2020. If the equipment or subsystem is installed on a vehicle or platform that provides 20 dB or more attenuation from external RF environment, the attenuated limit may be used.

Equipment and subsystems flying on platforms or vehicles with intentional transmitters operating above 18 GHz should perform the RS103 testing in the 18GHz – 40GHz range. Platforms and vehicles that operate in low earth, high inclination (52° or greater) orbits will be exposed to RF fields generated by ground sources in the 18GHz – 40GHz range. Equipment and subsystems mounted externally to platforms or vehicles operating in this region should perform the RS103 testing in the 18GHz – 40GHz range.