National Aeronautics and
Space Administration

SL-E-0002 - BOOK 3
VOLUME 1

Lyndon B. Johnson Space Center
Houston, Texas 77058

SPACE SHUTTLE

SPECIFICATION

ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS, REQUIREMENTS FOR EQUIPMENT

BOOK 3

NEW OR MODIFIED EQUIPMENT

AUGUST 10, 2001

REVISION LOG

REV LTR	CHANGE NO	DESCRIPTION	DATE
		BASELINE ISSUE (Reference PRCBD S061680, dated 6/25/01) also includes CAR S061680.	08/10/01

SL-E-0002 - Space Shuttle
Specification
Electromagnetic Interference
Characteristics, Requirements for Equipment
Book 3 - New or Modified Equipment

*Baseline Issue (Reference PRCBD No. S061680, dated 6/25/01 and CAR S061680, dated 8/2/01)

LIST OF EFFECTIVE PAGES

August 10, 2001

The current status of all pages in this document is as shown below:

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i - xiv	Baseline	*	August 10, 2001
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2-1 - 2-6	Baseline	*	August 10, 2001
3-1 - 3-2	Baseline	*	August 10, 2001
4-1 - 4-28	Baseline	*	August 10, 2001
5-1 - 5-88	Baseline	*	August 10, 2001
6-1 - 6-2	Baseline	*	August 10, 2001
A-1 - A-6	Baseline	*	August 10, 2001
B-1 - B-88	Baseline	*	August 10, 2001

SL-E-0002 - BOOK 3
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SPECIFICATION ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS, REQUIREMENTS FOR EQUIPMENT

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FOREWORD

Efficient management of the Space Shuttle Program (SSP) dictates that effective control of program activities be established. Requirements, directives, procedures, interface agreements, and system capabilities shall be documented, baselined, and subsequently controlled by SSP management.

Program requirements controlled by the Manager, Space Shuttle Program, are documented in, attached to, or referenced from Volume I through XVIII of NSTS 07700.

SL-E-0002 contains three books applicable as defined below:

c. Book 1 is applicable to all hardware procurements prior to February 11, 1993.

d. Book 2 is applicable to all hardware procurements with an Authority to Proceed (ATP) after February 11, 1993 and before May 7, 2001.

e. Book 3 is applicable to all hardware procurements with an ATP on or after May 7, 2001.

For certifying modifications to hardware that was certified to the requirements contained in either Book 1 or Book 2, the choice of using SL-E-0002 - Book 3 or using SL-E-0002 - Book 1 or Book 2, respectively, is left to the discretion of the affected element project manager.

This book of SL-E-0002 has been prepared specifically to tailor the requirements of MIL-STD-461E, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, to Space Shuttle equipment level procurements. MIL-STD-461E, and thus this book, incorporates test requirements previously contained in MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of. MIL-STD-462 is a retired document.

All elements of the SSP must adhere to these baselined requirements. When it is considered by the Space Shuttle program element/project managers to be in the best interest of the SSP to change, waive or deviate from these requirements, an SSP Change Request (CR) shall be submitted to the Program Requirements Control Board (PRCB) Secretary. The CR must include a complete description of the change, waiver or deviation and the rationale to justify its consideration. All such requests will be processed in accordance with NSTS 07700, Volume IV - Book 1 and dispositioned by the Manager, Space Shuttle Program, on a Space Shuttle PRCB Directive (PRCBD).

R Dittemore

Ronald D. Dittemore
Manager, Space Shuttle Program

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1.0 INTRODUCTION

1.1 SCOPE

This specification (adapted from MIL-STD-461E, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment) establishes limits and associated test methods for the control of the Electromagnetic Interference (EMI) characteristics of electronic, electrical, and electromechanical equipment and subsystems designed or procured for use by NASA for use on the Space Shuttle Vehicle (SSV). Such equipment and subsystems may be used independently or as an integral part of other subsystems or systems. Data item requirements are also included (reference Paragraph 4.2).

The requirements of this specification are tailored for the SSV. Unforeseen cases may arise which necessitate further tailoring. When analyses reveal that the requirements in this specification are not appropriate for a procurement, the requirements may be tailored and incorporated into the request-for-proposal, specification, contract, order, and so forth. The test procedures contained in this document shall be adapted by the testing activity for each application. The adapted test procedures shall be documented in the EMI Test Procedures (EMITPs) (reference Paragraph 4.2.2).

1.1.1 Requirements

The requirements specified herein are established to:

a. Ensure that interference control is considered and incorporated into the design of equipment.

b. Enable compatible operation of the equipment in a complex electromagnetic environment.

1.1.2 Use

Unlike SL-E-0002 - Book 1, Specification Electromagnetic Interference Characteristics, Requirements for Equipment, Hardware Prior to February 11, 1993 and SL-E-0002 - Book 2, Specification Electromagnetic Interference Characteristics, Requirements for Equipment, Hardware After February 11, 1993 and Prior to May 7, 2001, this document does not require the use of MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of, or MIL-STD-463, Definition and Systems of Units, Electromagnetic Interference Technology. The test requirements previously specified in MIL-STD-462 are now directly incorporated in this document. The required definitions in MIL-STD-463 are either included herein or in the referenced document, American National Standards Institute (ANSI) C63.14, Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD).

1.1.3 Applicability

The requirements of this document are applicable to all new design NASA SSV hardware procurements with an authority to proceed dated on or after May 7, 2001. Modifications to NASA Space Shuttle hardware certified to either SL-E-0002 - Book 1 or Book 2 requirements may be certified to either the previously used requirements (i.e., SL-E-0002 - Book 1 or Book 2, respectively) or the requirements of this document (i.e., SL-E-0002 - Book 3).

1.1.4 Structure

The specification has two primary sections, the main body and Appendix B. The main body contains the limits and test methods of this specification. Appendix B is noncontractual and provides rationale for the requirements and guidance on their interpretation and use. The paragraph numbering scheme for the appendix parallels the numbering for the main body requirements. Occasionally, there are references in the main body to Appendix B material where an obvious need exists for the appendix information to be examined.

1.2 EMISSION AND SUSCEPTIBILITY DESIGNATIONS

The emissions and susceptibility and associated test procedure requirements in this specification are designated in accordance with an alphanumeric coding system. Each requirement is identified by a two letter combination followed by a three digit number. The number is for reference purposes only. The meaning of the individual letters is as follows:

C = Conducted
R = Radiated
E = Emission
S = Susceptibility
TT = Transient emission

a. Conducted Emissions (CEs) - requirements are designated by “CEXXX.”

b. Radiated Emissions (REs) - requirements are designated by “REXXX.”

c. Conducted Susceptibility (CS) - requirements are designated by “CSXXX.”

d. Radiated Susceptibility (RS) - requirements are designated by “RSXXX.”

e. Transient Test (TT) emissions - requirements are designated by “TTXXX.”

f. “XXX” - numerical order of requirement from 101 to 199

2.0 APPLICABLE DOCUMENTS

The following documents of the date and issue shown form a part of this document to extent specified herein. “(Current Issue)” is shown in place of a specific date and issue when the document is under Space Shuttle PRCB control. The current status of documents shown with “(Current Issue)” may be determined from NSTS 08102, Program Document Description and Status Report.

NSTS 07700 Volumes I - XVIII (Current Issue)	Program Definition and Requirements Ref. Foreword
NSTS 07700 Volume IV - Book 1 (Current Issue)	Configuration Management Requirements Ref. Foreword
SL-E-0002 Book 1 (Current Issue)	Specification Electromagnetic Interference Characteristics, Requirements for Equipment, Hardware Prior to February 11, 1993 Ref. Foreword, Para. 1.1.2, 1.1.3
SL-E-0002 Book 2 (Current Issue)	Specification Electromagnetic Interference Characteristics, Requirements for Equipment, Hardware After February 11, 1993 and Prior to May 7, 2001 Ref. Foreword, Para. 1.1.2, 1.1.3
AFSC DH 1-4	Electromagnetic Compatibility Ref. Apx. B
ANSI C63.2	Standard for Instrumentation Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz, Specifications Ref. Para. 4.3.10; Apx. B

ANSI C63.4	American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 406 GHz Ref. Apx. B
ANSI C63.12	American National Standard Recommended Practice for Electromagnetic Compatibility Limits Ref. Apx. B
ANSI C63.14	Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD) Ref. Para. 1.1.2, 3.0
ANSI/NCSL Z540-1	General Requirements for Calibration Laboratories and Measuring and Test Equipment Ref. Para. 4.3.11
ASTM E 380	Standard for Metric Practice (Department of Defense adopted) Ref. Para. 3.4
CFR Title 47 Part 2	Telecommunications, Frequency Allocations and Radio Treaty Matters; General Rules and Regulations Ref. Apx. B
CFR Title 47 Part 15	Telecommunications, Radio Frequency Devices Ref. Apx. B

CFR Title 47 Part 18	Telecommunications, Industrial, Scientific, and Medical Equipment Ref. Apx. B
CR-1999-209574	Specification, Measurement, and Control of Electrical Switching Transients Ref. Apx. B
CR-2000-209906	Investigation into the Effects of Microsecond Power Line Transients on Line-Connected Capacitors Ref. Apx. B
CISPR 16	Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods Ref. Para. 5.11.3.2, Fig. 5-28; Apx. B
DoDI 6055011	Protection of DoD Personnel from Exposure to Radiofrequency Radiation and Military Exempt Lasers Ref. Apx. B
IEEE C95.1-1991	IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE C95.1-1991 Ref. Para. 4.3.7.4
ISO 10012-1	Quality Assurance Requirements for Measuring Equipment Ref. Para. 4.3.11

MF0004-002	Electrical Design Requirements for Electrical Equipment Utilized on the Space Shuttle Vehicle Ref. Apx. B
MIL-HDBK-235	Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment, Subsystems and Systems Ref. Apx. B
MIL-HDBK-237	Guidance for Controlling Electromagnetic Environmental Effects or Platforms, Systems, and Equipment Ref. Apx. B
MIL-HDBK-241	Design Guide for Electromagnetic Interference (EMI) Reduction in Power Supplies Ref. Apx. B
MIL-HDBK-253	Guidance for the Design and Test of Systems Protected Against the Effects of Electromagnetic Energy Ref. Apx. B
MIL-HDBK-423	High-altitude Electromagnetic Pulse (HEMP) Protection for Fixed and Transportable Ground Based C4 1 Facilities Ref. Apx. B
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Ref. Apx. B

MIL-STD-461A	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Ref. Apx. B
MIL-STD-461D	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Ref. Apx. B
MIL-STD-461E	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Ref. Foreword, Para. 1.1
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of Ref. Foreword, Para. 1.1.2; Apx. B
MIL-STD-463	Definition and Systems of Units, Electromagnetic Interference Technology Ref. Para. 1.1.2
MIL-STD-704	Aircraft Electric Power Characteristics Ref. Apx. B
MIL-STD-1275	Characteristics of 28 Volt DC Electrical Systems in Military Vehicles Ref. Apx. B

MIL-STD-1399	Interface Standard for Shipboard Systems Ref. Apx. B
MIL-STD-1539	Electrical Power, Direct Current, Space Vehicle Design Requirements Ref. Apx. B
RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Equipment Ref. Apx. B
SAE ARP 958	Electromagnetic Interference Measurement Antennas, Standard Calibration Requirements and Methods Ref. Para. 4.3.11.2; Apx. B
SAE ARP 1972	Recommended Measurement Practices and Procedures for EMC Testing Ref. Apx. B
SL-E-0001 (Current Issue)	Specification Electromagnetic Compatibility Requirement Ref. Para. 5.13.2; Table 5.2; Apx. B

2.2 ORDER OF PRECEDENCE

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

3.0 DEFINITIONS

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

3.1 EXTERNAL INSTALLATION

An equipment location on the SSV which is exposed to the external electromagnetic environment, such as the payload bay when the doors are open, which does not use electrically conductive treatments on the canopy or windscreen.

3.2 FLIGHT-LINE EQUIPMENT

Any support equipment that is attached to or used next to the SSV during preflight or post-flight operations, such as uploading or downloading data, maintenance diagnostics, or equipment functional testing.

3.3 INTERNAL INSTALLATION

An equipment location on the SSV which is totally inside an electrically conductive structure, such as an avionics bay internal to the Orbiter.

3.4 METRIC UNITS

Metric units are a system of basic measures which are defined by the International System of Units based on “Le System International d’Unites (SI)”, of the International Bureau of Weights and Measures. These units are described in ASTM E 380, Standard for Metric Practice (Department of Defense adopted).

3.5 NON-DEVELOPMENTAL ITEM

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

3.6 SAFETY CRITICAL

A category of subsystems and equipment whose degraded performance could result in loss of life or loss of vehicle or platform.

3.7 TEST SETUP BOUNDARY

The test setup boundary includes all enclosures of the Equipment Under Test (EUT) and the two meters of exposed interconnecting leads (except for leads, which are shorter in the actual installation) and power leads required by Paragraph 4.3.8.6.

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4.0 GENERAL REQUIREMENTS

4.1 APPLICATION OF SPECIFICATION

The requirements of this specification shall be applied to electronic, electrical and electromechanical equipment as indicated hereinafter.

The applicability of the emission and susceptibility requirements is dependent upon the types of equipment or subsystems and their intended installations as specified herein. Table 4.1 shows individual requirements application based on equipment type or function. Table 4.1 and notes thereto shall be used as a guide for test selection. For each procurement, the activity shall specify the applicable tests from Table 4.1.

TABLE 4.1

REQUIREMENT APPLICABILITY

Requirement/Test Method →	CE102	CE106	CS101	CS103	CS104	CS105	CS106	CS114	CS116	RE102	RE103	RS103	TT101
↓ Equipment type ↓ Note→		1		2	2	2		3	3, 6	4	1		5
Antenna-connected electronics, battery powered		X		X	X	X		X	X	X	X	X	
Antenna-connected electronics connected to Shuttle primary power source	X	X	X	X	X	X	X	X	X	X	X	X	X
Non-antenna connected electronics, battery powered								X	X	X		X	
Non-antenna connected electronics, connected to Shuttle primary power source	X		X				X	X	X	X		X	X
Electrical loads connected to Shuttle primary power without intermediate power conversion													X

NOTES: (1) Either CE106 or RE103 applies, but not both. RE103 is performed when CE106 is not practical, as when the antenna cannot be disconnected from the transmitter/receiver, or when transmit power is too high to filter directly.

(2) Applies to Radio Frequency (RF) receivers and RF components between receiver and antenna (e.g., RF preamplifiers and down converters).

(3) Applies to cables connected to EUT only including power lines.

(4) RE102 includes a Bulk Current Emission (BCE) test, a measure of common mode currents on interconnect and power line wiring.

(5) TT101 applies to 28 Volts Direct Current (VDC) loads.

(6) Applicable for equipment that will not be lightning tested. Tailoring of requirements. Not applicable to Criticality 1 equipment that has been subjected to lightning transient testing.

4.1.1 Subsystems

Units or equipment within a single procurement subcontract shall be tested as a subsystem. Tests on individual units of the subsystem are not required unless directed by the procuring activity. (For this purpose, a subsystem would not normally be considered to be a spacecraft, launch vehicles or ground communication-electronic shelter.)

4.1.2 Government Furnished Equipment (GFE)

Equipment furnished by the government to a contractor may, unless the test data is furnished by the government, require testing by the contractor for conformance to the equipment item class and limit requirements. Application of suppression measures to meet the requirements shall be detailed in the EMI Control Procedure (EMICP) (reference Paragraph 4.2.1).

4.1.3 Commercial Off-the-Shelf (COTS) Equipment

When COTS equipment is selected by the contractor, all applicable tests shall be performed and the test data submitted to the procuring activity to determine the EMI/EMC compliance in the end item configuration. The EMI/EMC compliance shall be covered in the EMICP (reference Paragraph 4.2.1).

4.1.4 Other EMI Requirements

4.1.4.1 Certification to Another EMI Requirements Document

Equipment qualified to other EMI specifications may be qualified to the requirements of this specification by a combination of analysis and/or test, as required to verify that the equipment meets the requirements of this document.

4.1.4.2 Additional Production

All equipment, other than communication-electronic equipment, produced by a manufacturer, which are identical to those previously produced by the same manufacturer, tested in accordance with this specification and found satisfactory shall require minimal testing, as indicated in the approved test plan, to ascertain conformance with this specification. A copy of the previous test report shall be forwarded with the new test report for comparison and evaluation.

4.1.5 Short-duration Interference

Short-duration interference is not exempt from the requirements of this specification, unless specifically indicated in the individual equipment specification.

4.1.6 Self-compatibility

The operational performance of an equipment or subsystem shall not be degraded, nor shall it malfunction, when all of the units or devices in the equipment or subsystem are operating together at their designed levels of efficiency or their design capability.

4.2 DOCUMENTATION REQUIREMENTS

4.2.1 EMI Control Procedure

An EMICP shall be prepared if specified by the procuring authority. The EMICP shall contain the following:

a. Management. The EMICP shall address the following management areas:

   14. Specific organizational responsibilities, lines of authority and control, and program planning, including milestones and schedules.
   15. Detailed EMI requirements imposed on subcontractors.
   16. Role in program of GFE and subcontractor items.
   17. Description of the equipment or subsystem, its function, characteristics, and intended installation.
   18. Plans and procedures for identifying and resolving potential EMI problems, implementing solutions, and verifying solutions through analysis and testing.
   19. Point of contact for EMI technical issues.

b. Design techniques and procedures. The EMICP shall describe the specific design techniques and procedures used to meet each emission and susceptibility requirement, including the following:

   1. Spectrum management techniques.
   2. EMI mechanical design, including the following:
      (a) Type of metals, casting, finishes, and hardware employed in the design.
      (b) Construction techniques, such as isolated compartments; filter mounting, isolation of other parts; treatment of openings (ventilation ports, access hatches, windows, metal faces and control shafts), and attenuation characteristics of RF gaskets used on mating surfaces.

        (c) Shielding provisions and techniques used for determining shielding effectiveness.

        (d) Corrosion control procedures.

        (e) Methods of bonding mating surfaces, such as surface preparation and gaskets.

    3. Electrical wiring design, including cable types or characteristics, cable routing, cable separation, grounding philosophy, and cable shielding types and termination methods.

    4. Electrical and electronic circuit design, including the following:

        (a) Filtering techniques, technical reasons for selecting types of filters, and associated filter characteristics, including attenuation and line-to-ground capacitance values of Alternating Current (AC) and Direct Current (DC) power line filters.

        (b) Part location and separation for reducing EMI.

        (c) Location, shielding, and isolation of critical circuits.

c. Analysis. The EMICP shall provide analysis results demonstrating how each applicable requirement is going to be met.

d. Developmental testing. The EMICP shall include a discussion of testing to be performed during development (such as evaluations of breadboards, prototypes, and engineering models).

4.2.2 EMI Test Procedures

An EMITP shall be prepared. The EMITP shall contain the following:

a. Introduction. The introduction of the EMITP shall include the following:

    1. A table describing all the tests to be performed, the applicable section within the EMITP, and the corresponding test procedure from SL-E-0002.

    2. Description of the EUT, including its function, characteristics, intended installation, and power usage.

    3. Approved exceptions or deviations from contractual test requirements, if any.

b. Applicable documents. Applicable documents shall be listed as follows:

   1. NASA (such as standards and specifications)
   2. Military (such as standards and specifications).
   3. Company (such as in-house documents used for calibration or quality assurance).
   4. Other government or industry standards, specifications, and documents.

c. Test site. A description of the test site shall be provided covering the following:

   1. Test facility and shielded enclosure or anechoic chamber, including size, characteristics, and placement of RF absorbers.
   2. Ground plane (size and type) and methods of grounding or bonding the EUT to the ground plane to simulate actual equipment installation.
   3. Implementation of test precautions required by Paragraph 4.3.7.

d. Test instrumentation. Test instrumentation to be used shall be described as follows:

   1. Equipment nomenclature.
   2. Characteristics of coupling transformers and band-reject filters.
   3. Antenna factors of specified antennas, transfer impedances of current probes, and impedance of Line Impedance Stabilization Networks (LISN).
   4. Description of the operations being directed by computer programs/software for computer-controlled receivers, the verification techniques used to demonstrate proper performance of the software, and the specific versions of the software to be used.
   5. Bandwidth (BW) (resolution and video) and scanning speeds of measurement receivers.

e. EUT setup. A description of the EUT test setup for each test shall cover the following:

   1. Physical layout of the cables and EUT.
   2. Cable types, characteristics, and construction details (see Paragraph 4.3.8.6)
   3. Position of the LISNs on the ground plane.
   4. Use of bond straps and loads.

   5. Test simulation and monitoring equipment.
   6. The version of the software and firmware loaded into the EUT.

f. EUT operation. A description of the EUT operation shall cover the following:

   1. Modes of operation for each test, including operating frequencies (where applicable), and rationale for selection.
   2. Control settings on the EUT.
   3. Control settings on any test stimulation and monitoring equipment and characteristics of input signals.
   4. Operating frequencies (such as oscillator and clock frequencies) which may be expected to approach limits.
   5. Performance checks initiated to designate the equipment as meeting minimal working standard requirements.
   6. Enumeration of circuits, outputs, or displays to be monitored during susceptibility testing, as well as the criteria for determining degradation of performance.

g. Measurements. The following shall be described for each test.

   1. Block diagram depicting test setup, including all pertinent dimensions.
   2. Step-by-step procedures.
   3. Test equipment used in performance of the test and the methods of grounding, bonding, or achieving electrical isolation of the measurement instrumentation.
   4. Selection of measurement frequencies.
   5. Information to be recorded during the test, including frequency and units of recorded information. Sample data sheets, test logs and graphs, including test limits, may be shown.
   6. Modulation characteristics and scan rates of the susceptibility test signals, if applicable.

4.2.3 EMI Test Report (EMITR)

An EMITR shall be prepared. The EMITR shall contain the following:

a. Administrative data. The EMITR shall contain an administrative section covering the following:

1. Contract number.
2. Authentication and certification of performance of the tests by a qualified representative of the procuring activity.
3. Disposition of the EUT.
4. Description of the EUT, including its function, characteristics, intended installation, actual cable types (characteristics and construction details - reference Paragraph 4.3.8.6), and electrical current usage on each power input line.
5. List of tests performed with pass/fail indications.
6. Any approved deviations from contractual test procedures or limits previously authorized.
7. Identification of COTS and GFE that may be part of the EUT.
8. Traceability of test equipment calibration.
9. A reference to the approved EMITP.

b. Detailed results. A separate appendix shall be prepared for each test. If deviations from an approved test procedure occurred during the test program, an additional appendix shall be provided with the as run procedures showing all redlines and procuring activity concurrence. A separate appendix shall be provided for log sheets. Each test appendix shall contain the following factual data:

1. Test equipment nomenclature, serial numbers, version of software used (if any), and calibration due date.
2. Photographs or diagrams of the actual test set up and EUT, with identification.
3. Transfer impedance of current probes.
4. Antenna factors.
5. Impedance values of LISN.
6. Identification of any suppression devices used to meet the contractual requirements, including schematics, performance data, and drawings.
7. Sample calculations, such as conversions of measured levels for comparison against the applicable limit.

8. The ambient radiated and conducted electromagnetic emission profile of the test facility, when necessary.
9. Data, and data presentation, as specified in the “data presentation” sections of the individual test procedures of specification.
10. Scan speeds.
11. Measurement receiver BWs.
12. Antenna polarization.
13. Power line voltages, frequencies, and power factor.
14. Low-noise amplifiers compression points.
15. Any thresholds of susceptibility that were determined.

c. Conclusions and recommendations. Conclusions and recommendations shall be provided, including results of the tests in brief narrative form, a discussion of any remedial actions already initiated, and proposed corrective measures required (if necessary) to assure compliance of the equipment or subsystem with the contractual EMI requirements.

4.3 VERIFICATION REQUIREMENTS

The general requirements related to test procedures, test facilities, and equipment stated below, together with the detailed test procedures included in Section 5.0, shall be used to determine compliance with the applicable emission and susceptibility requirements of this specification.

Any procuring activity approved exceptions or deviations from these general requirements shall be documented in the EMITP (reference Paragraph 4.2.2). Equipments that are intended to be operated as a subsystem shall be tested as such to the applicable EMI requirements whenever practical. Formal testing is not to commence without approval of the EMITP by the designated approving authority. Data that is gathered as a result of performing tests in one electromagnetic discipline may be sufficient to satisfy requirements in another. Therefore, to avoid unnecessary duplication, a single test program should be established with tests for similar requirements conducted concurrently whenever possible.

4.3.1 Measurement Tolerances

Unless otherwise stated for a particular measurement, the tolerance shall be as follows:

a. Distance: ±5%

b. Frequency: ±2%

c. Amplitude, measurement receiver: ±2 decibel (dB)

d. Amplitude, measurement system (includes measurement receivers, transducers, cables, and so forth): ±3 dB

e. Time (waveforms): ±5%

f. Resistors: ±5%

g. Capacitors: ±20%

4.3.2 Shielded Enclosures

To prevent interaction between the EUT and the outside environment, shielded enclosures will usually be required for testing. These enclosures prevent external environment signals from contaminating emission measurements and susceptibility test signals from interfering with electrical and electronic items in the vicinity of the test facility. Shielded enclosures must have adequate attenuation such that the ambient requirements of Paragraph 4.3.4 are satisfied. The enclosures must be sufficiently large such that the EUT arrangement requirements of Paragraph 4.3.8 and antenna positioning requirements described in the individual test procedures are satisfied.

4.3.2.1 RF Absorber Material

RF absorber material (carbon impregnated foam pyramids, ferrite tiles, and so forth) shall be used when performing electric field REs or RS testing inside a shielded enclosure to reduce reflections of electromagnetic energy and to improve accuracy and repeatability. The RF absorber shall be placed above, behind, and on both sides of the EUT, and behind the radiating or receiving antenna as shown in Figure 4-1. Minimum performance of the material shall be as specified in Table 4.2. The manufacturer’s certification of their RF absorber material (basic material only, not installed) is acceptable.

TABLE 4.2

ABSORPTION AT NORMAL INCIDENCE

Frequency	Minimum Absorption
80 MHz - 250 MHz	6 dB
Above 250 MHz	10 dB

4.3.3 Other Test Sites

If other test sites are used, the ambient requirements of Paragraph 4.3.4 shall be met.

4.3.4 Ambient Electromagnetic Level

During testing, the ambient electromagnetic level measured with the EUT de-energized and all auxiliary equipment turned on shall be at least 6 dB below the allowable specified limits when the tests are performed in a shielded enclosure. Ambient conducted levels on power leads shall be measured with the leads disconnected from the EUT and connected to a resistive load which draws the same rated current as the EUT. When tests are performed in a shielded enclosure and the EUT is in compliance with required limits, the ambient profile need not be recorded in the EMITR. However, if the ambient profile is recorded it should be include in the EMITR. When measurements are made outside a shielded enclosure, the tests shall be performed during times and conditions when the ambient is at its lowest level. The ambient shall be recorded in the EMITR and shall not compromise the test results.

4.3.5 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 2.25 square meters or larger in area with the smaller side no less than 76 centimeters (cm). When a ground plane is not present in the EUT installation, the EUT shall be placed on a non-conductive table.

4.3.5.1 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 4-2 through Figure 4-5 shall be electrically bonded to the floor or wall of the basic shielded room structure at least once every 1 meter. The metallic bond straps shall be solid and maintain a 5-to-1 ratio or less in length to width. Metallic ground planes used outside a shielded enclosure shall extend at least 1.5 meters beyond the test setup boundary in each direction.

4.3.5.2 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.

4.3.6 Power Source Impedance

The impedance of power sources providing input power to the EUT shall be controlled by LISNs for all measurement procedures of this document unless otherwise stated in a particular test procedure. LISNs shall not be used on output power leads. The LISNs shall be located at the power source end of the exposed length of power leads specified in Paragraph 4.3.8.6.2. Two different LISNs are required in this specification. The LISN circuit for all tests except TT101 shall be in accordance with the schematic shown in Figure 4-6. The LISN impedance characteristics of the Figure 4-6 LISN shall be in accordance with Figure 4-7. The LISN impedance shall be measured at least annually under the following conditions:

a. The impedance shall be measured between the power output lead on the load side of the LISN and the metal enclosure of the LISN.

b. The signal output port of the LISN shall be terminated in 50 ohms.

c. The power input terminal on the power source side of the LISN shall be unterminated.

Impedance characteristics and circuitry for the TT101 LISN is described in that test section. Impedance is verified as follows:

a. The impedance shall be measured between the positive and negative power output leads on the load side of the LISN.

b. The positive and negative power input terminals on the power source side of the LISN shall be shorted together.

The impedance measurement results shall be provided in the EMITR.

4.3.7 General Test Precautions

4.3.7.1 Accessory Equipment

Accessory equipment used in conjunction with measurement receivers shall not degrade measurement integrity.

4.3.7.2 Excess Personnel and Equipment

The test area shall be kept free of unnecessary personnel, equipment, cable racks, and desks. Only the equipment essential to the test being performed shall be in the test area or enclosure. Only personnel actively involved in the test shall be permitted in the enclosure.

4.3.7.3 Overload Precautions

Measurement receivers and transducers are subject to overload, especially receivers without preselectors and active transducers. Periodic checks shall be performed to assure that an overload condition does not exist. Instrumentation changes shall be implemented to correct any overload condition.

4.3.7.4 RF Hazards

Some tests in this specification will result in electromagnetic fields which are potentially dangerous to personnel. The permissible exposure levels in IEEE C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 Gigahertz (GHz), shall not be exceeded in areas where personnel are present. Safety procedures and devices shall be used to prevent accidental exposure of personnel to RF hazards.

4.3.7.5 Shock Hazards

Some of the tests require potentially hazardous voltages to be present. Extreme caution must be taken by all personnel to assure that all safety precautions are observed.

4.3.7.6 Federal Communications Commission (FCC) Restrictions

All planned open site radiation tests (i.e., outside of shielded enclosures) shall be precoordinated and approved by the National Telecommunications and Information Administration (NTIA) and/or the FCC, whichever is applicable, regardless of the level of signals used. Authorization shall be secured prior to conducting the test readiness review. Test sponsor(s) and test facility personnel shall contact the respective NASA Field Center Spectrum Manager at the earliest possible stage of the test planning with all pertinent RF systems parameters and configuration data to facilitate the authorization process.

4.3.8 EUT Test Configurations

The EUT shall be configured as shown in the general test setups of Figure 4-1 through Figure 4-5, as applicable. These setups shall be maintained during all testing unless other direction is given for a particular test procedure.

4.3.8.1 EUT Design Status

EUT hardware, software, and firmware shall be representative of production. Software may be supplemented with additional code that provides diagnostic capability to assess performance.

4.3.8.2 Bonding of EUT

Only the provisions included in the design of the EUT shall be used to bond units such as equipment case and mounting bases together, or to the ground plane. When bonding straps are required, they shall be identical to those specified in the installation drawings.

4.3.8.3 Shock and Vibration Isolators

EUTs shall be secured to mounting bases having shock or vibration isolators if such mounting bases are used in the installation. The bonding straps furnished with the mounting base shall be connected to the ground plane. When mounting bases do not have bonding straps, bonding straps shall not be used in the test setup.

4.3.8.4 Safety Grounds

When external terminals, connector pins, or equipment grounding conductors are available for safety ground connections and are used in the actual installation, they shall be connected to the ground plane. Arrangement and length shall be in accordance with Paragraph 4.3.8.6.1.

4.3.8.5 Orientation of EUTs

EUTs shall be oriented such that surfaces which produce maximum REs and respond most readily to radiated signals face the measurement antennas. Bench mounted EUTs shall be located 10 ±2 cm from the front edge of the ground plane subject to allowances for providing adequate room for cable arrangement as specified below.

4.3.8.6 Construction and Arrangement of EUT Cables

Electrical cable assemblies shall simulate actual installation and usage. Shielded cables or shielded leads (including power leads and wire grounds) within cables shall be used only if they have been specified in installation requirements. Cables shall be checked against installation requirements to verify proper construction techniques such as use of twisted pairs, shielding, and shield terminations. Details on the cable construction, such as wire types, lengths, pigtail lengths, shield termination, lengths of ground wires, and ground locations, used for testing shall be included in the EMITP.

4.3.8.6.1 Interconnecting Leads and Cables

Individual leads shall be grouped into cables in the same manner as in the actual installation. Interconnecting cable lengths in the test setup shall represent the actual lengths in the SSV, unless the actual vehicle lengths are less than that allowed to meet the following conditions. Cable lengths, when not specified for the installation, shall be sufficiently long to achieve a two meter run along the ground plane edge. At least the first two meters of each interconnecting cable associated with each enclosure of the

EUT shall be run parallel to the front boundary of the setup. Remaining cable lengths shall be routed to the back of the setup and shall be placed in a zig-zagged arrangement. When the setup includes more than one cable, individual cables shall be separated by two centimeters measured from their outer circumference. For bench top setups using ground planes, cables shall be placed within the first ten centimeters from the front edge of the ground plane. All cables shall be supported five centimeters above the ground plane.

4.3.8.6.2 Input Power Leads

Two meters of input power leads, including neutrals and returns, shall be routed parallel to the front edge of the setup in the same manner as the interconnecting leads. Each input power lead, including neutrals and returns, shall be connected to a LISN (reference Paragraph 4.3.6). Power leads that are bundled as part of an interconnecting cable in the actual installation shall be configured in the same fashion for the 2 meter exposed length and then shall be separated from the bundle and routed to the LISNs. After the 2 meter exposed length, the power leads shall be terminated at the LISNs in as short a distance as possible. The total length of power lead from the EUT electrical connector to the LISNs shall not exceed 2.5 meters. All power leads shall be supported 5 cm above the ground plane. If the power leads are twisted in the actual installation, they shall be twisted up to the LISNs.

4.3.8.7 Electrical and Mechanical Interfaces

All electrical input and output interfaces shall be terminated with either the actual equipment from the platform installation or loads external to the EUT which simulate the electrical properties (impedance, grounding, balance, and so forth) present in the actual installation. Signal inputs shall be applied to all applicable electrical interfaces to exercise EUT circuitry. EUTs with mechanical outputs shall be suitably loaded. When variable electrical or mechanical loading is present in the actual installation, testing shall be performed under expected worst case conditions. When active electrical loading (such as a test set) is used, precautions shall be taken to insure the active load meets the ambient requirements of Paragraph 4.3.4 when connected to the setup, and that the active load does not respond to susceptibility signals. Antenna ports on the EUT shall be terminated with shielded, matched loads.

4.3.9 Operation of EUT

During emission measurements, the EUT shall be placed in an operating mode which produces maximum emissions. During susceptibility testing, the EUT shall be placed in its most susceptible operating mode. For EUTs with several available modes, including software controlled operational modes, a sufficient number of modes shall be tested for emissions and susceptibility such that all circuitry is evaluated. If production software or firmware is not available, justification that the software or firmware used for the test is able to activate or exercise the EUT in a manner equivalent to production software or firmware shall be shown. The rationale for modes selected shall be included in the EMITP. A functional test of the EUT shall be performed as a minimum before and after the entire test series.

4.3.9.1 Operating Frequencies for Tunable RF Equipment

Measurements shall be performed with the EUT tuned to not less than three frequencies within each tuning band, tuning unit, or range of fixed channels, consisting of one mid-band frequency and a frequency within ±5 percent from each end of each band or range of channels.

4.3.9.2 Operating Frequencies for Spread Spectrum Equipment

Operating frequency requirements for two major types of spread spectrum equipment shall be as follows:

a. Frequency hopping. Measurements shall be performed with the EUT utilizing a hop set which contains a minimum of 30% of the total possible frequencies. This hop set shall be divided equally into three segments at the low, mid, and high end of the EUT’s operational frequency range.

b. Direct sequence. Measurements shall be performed with the EUT processing data at the highest possible data transfer rate.

4.3.9.3 Susceptibility Monitoring

The EUT shall be monitored during susceptibility testing for indications of degradation or malfunction. This monitoring is normally accomplished through the use of built-in-test, visual displays, aural outputs, and other measurements of signal outputs and interfaces. Monitoring of EUT performance through installation of special circuitry in the EUT is permissible; however, these modifications shall not influence test results.

4.3.10 Use of Measurement Equipment

Measurement equipment shall be as specified in the individual test procedures of this specification. Any frequency selective measurement receiver may be used for performing the testing described in this specification provided that the receiver characteristics (that is, sensitivity, selection of BWs, detector functions, dynamic range, and frequency of operation) meet the constraints specified in this specification and are sufficient to demonstrate compliance with the applicable limits. Typical instrumentation characteristics may be found in ANSI C63.2, Standard for Instrumentation Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz, Specifications.

4.3.10.1 Detector

A peak detector shall be used for all frequency domain emission and susceptibility measurements. This device detects the peak value of the modulation envelope in the receiver bandpass. Measurement receivers are calibrated in terms of an equivalent Root Mean Square (RMS) value of a sine wave that produces the same peak value. When other measurement devices such as oscilloscopes, non-selective voltmeters, or broadband field strength sensors are used for susceptibility testing, correction factors shall be applied for test signals to adjust the reading to equivalent RMS values under the peak of the modulation envelope.

4.3.10.2 Computer-controlled Receivers

A description of the operations being directed by software for computer-controlled receivers shall be included in the EMITP. Verification techniques used to demonstrate proper performance of the software shall also be included.

4.3.10.3 Emission Testing

4.3.10.3.1 Bandwidths

The measurement receiver BWs listed in Table 4.3 shall be used for emission testing. These BWs are specified at the 6 dB down points for the overall selectivity curve of the receivers. Video filtering shall not be used to BW limit the receiver response. If a controlled video BW is available on the measurement receiver, it shall be set to its greatest value. Larger receiver BWs may be used; however, they may result in higher measured emission levels.

NOTE: No BW correction factors shall be applied to test data due to the use of larger BWs.

TABLE 4.3

BW AND MEASUREMENT TIME

Frequency Range	6 dB BW	Dwell Time	Minimum Measurement Time Analog Measurement Receiver
30 Hz - 1 kHz	10 Hz	0.15 sec	0.015 sec/Hz
1 kHz - 10 kHz	100 Hz	0.015 sec	0.15 sec/kHz
10 kHz - 150 kHz	1 kHz	0.015 sec	0.015 sec/kHz
150 kHz - 30 MHz	10 kHz	0.015 sec	1.5 sec/MHz
30 MHz - 1 GHz	100 kHz	0.015 sec	0.15 sec/MHz
Above 1 GHz	1 MHz	0.015 sec	15 sec/GHz

4.3.10.3.2 Emission Identification

All emissions, regardless of characteristics, shall be measured with the measurement receiver BWs specified in Table 4.3 and compared against the applicable limits. Identification of emissions with regard to narrowband or broadband categorization is not applicable.

4.3.10.3.3 Frequency Scanning

For emission measurements, the entire frequency range for each applicable test shall be scanned. Minimum measurement time for analog measurement receivers during emission testing shall be as specified in Table 4.3. Synthesized measurement receivers shall step in one-half BW increments or less, and the measurement dwell time shall be as specified in Table 4.3. For equipment that operates such that potential emissions are produced at only infrequent intervals, times for frequency scanning shall be increased as necessary to capture any emissions. For equipment which operates for very short durations, or which has a limited life, scan times may be reduced. Justification for such reduction will be presented in the EMITP, and approved by the designated approving authority prior to test.

4.3.10.3.4 Emission Data Presentation

Amplitude versus frequency profiles of emission data shall be automatically generated and displayed at the time of test and shall be continuous. The displayed information shall account for all applicable correction factors (transducers, attenuators, cable loss, and the like) and shall include the applicable limit. Manually gathered data is not acceptable except for verification of the validity of the output. Plots of the displayed data shall provide a minimum frequency resolution of 1% or twice the measurement receiver BW, whichever is less stringent, and minimum amplitude resolution of 1 dB. The above resolution requirements shall be maintained in the reported results of the EMITR.

4.3.10.4 Susceptibility Testing

4.3.10.4.1 Frequency Scanning

For susceptibility measurements, the entire frequency range for each applicable test shall be scanned. For swept frequency susceptibility testing, frequency scan rates and frequency step sizes of signal sources shall not exceed the values listed in Table 4.4. The rates and step sizes are specified in terms of a multiplier of the tuned frequency (f_o) of the signal source. Analog scans refer to signal sources, which are continuously tuned. Stepped scans refer to signal sources, which are sequentially tuned to discrete frequencies. Stepped scans shall dwell at each tuned frequency for the greater of three seconds or the EUT response time. Scan rates and step sizes shall be decreased when necessary to permit observation of a response.

TABLE 4.4

SUSCEPTIBILITY SCANNING

Frequency Range	Analog Scans Maximum Scan Rates	Stepped Scans Maximum Step Size
30 Hz - 1 MHz	0.0333f_o/sec	0.05 f_o
1 MHz - 30 MHz	0.00667 f_o/sec	0.01 f_o
30 MHz - 1 GHz	0.00333 f_o/sec	0.005 f_o
1 GHz - 8 GHz	0.000667 f_o/sec	0.001 f_o
8 GHz - 40 GHz	0.000333 f_o/sec	0.0005 f_o

4.3.10.4.2 Modulation of Susceptibility Signals

Susceptibility modulation requirements are located with the susceptibility requirement. If pulse modulation is not available below 1 GHz, amplitude modulation at 99% depth shall be substituted. With this option, care shall be exercised that the peak of the modulation envelope corresponds to the limit level stress.

4.3.10.4.3 Thresholds of Susceptibility

When susceptibility indications are noted in EUT operation, a threshold level shall be determined where the susceptible condition is no longer present. Thresholds of susceptibility shall be determined as follows and described in the EMITR:

a. When a susceptibility condition is detected, reduce the interference signal until the EUT recovers.

b. Reduce the interference signal by an additional 6 dB.

c. Gradually increase the interference signal until the susceptibility condition reoccurs. The resulting level is the threshold of susceptibility.

d. Record this level, frequency range of occurrence, frequency and level of greatest susceptibility, and other test parameters, as applicable.

4.3.11 Calibration of Measuring Equipment

Test equipment and accessories required for measurement in accordance with this specification shall be calibrated in accordance with ANSI/NCSL Z540-1, General Requirements for Calibration Laboratories and Measuring and Test Equipment, or ISO 10012-1, Quality Assurance Requirements for Measuring Equipment, or under an approved calibration program traceable to the National Institute for Standards and Technology. In particular, measurement antennas, current probes, field sensors, and other devices used in the measurement loop shall be calibrated at least every two years unless otherwise specified by the procuring activity, or when damage is apparent.

4.3.11.1 Measurement System Test

At the start of each emission test, the complete test system (including measurement receivers, cables, attenuators, couplers, and so forth) shall be verified by injecting a known signal, as stated in the individual test procedure, while monitoring system output for the proper indication. When the emission test involves an uninterrupted set of repeated measurements (such as evaluating different operating modes of the EUT) using the same measurement equipment, the measurement system test needs to be accomplished only one time.

4.3.11.2 Antenna Factors

Factors for test antennas shall be determined in accordance with SAE ARP-958, Electromagnetic Interference Measurement Antennas, Standard Calibration Requirements and Methods.

FIGURE 4-1

RF ABSORBER LOADING DIAGRAM

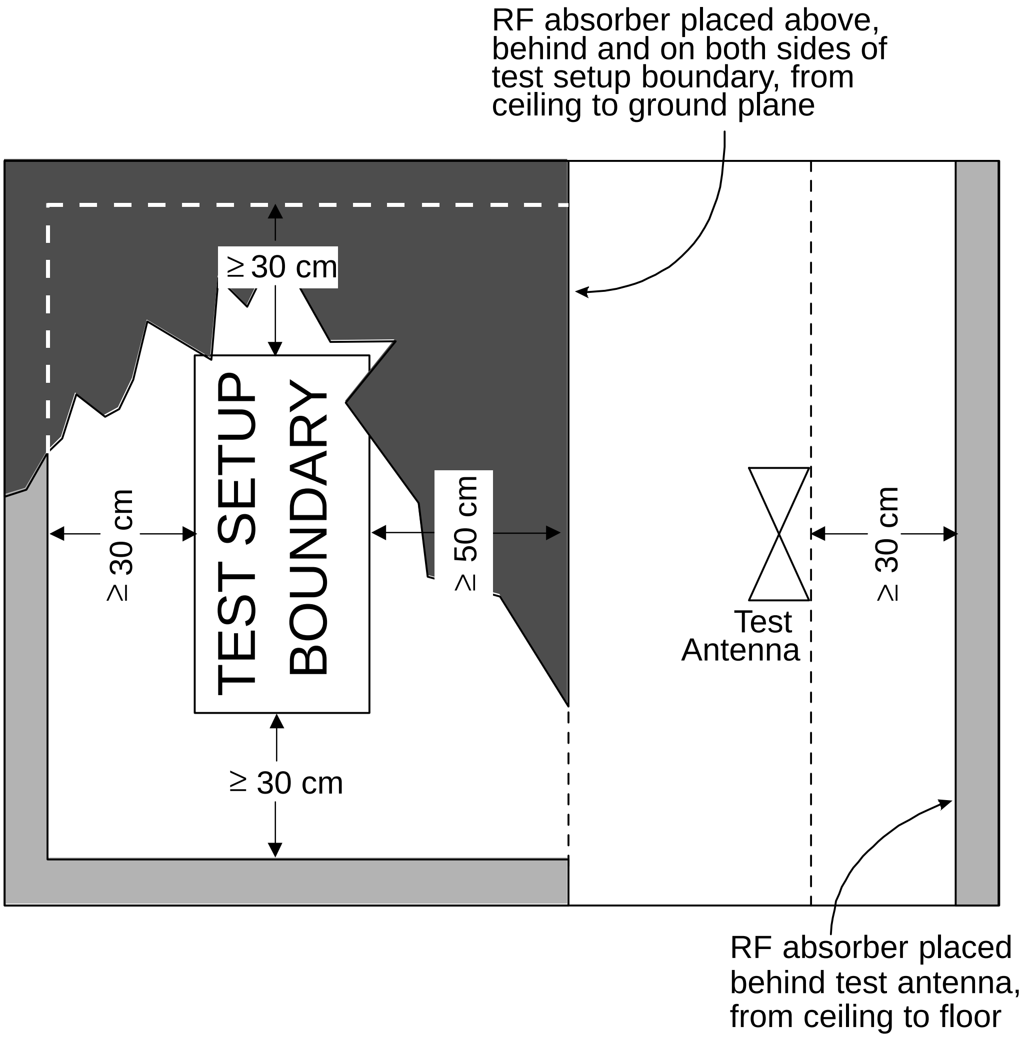


FIGURE 4-2

GENERAL TEST SETUP

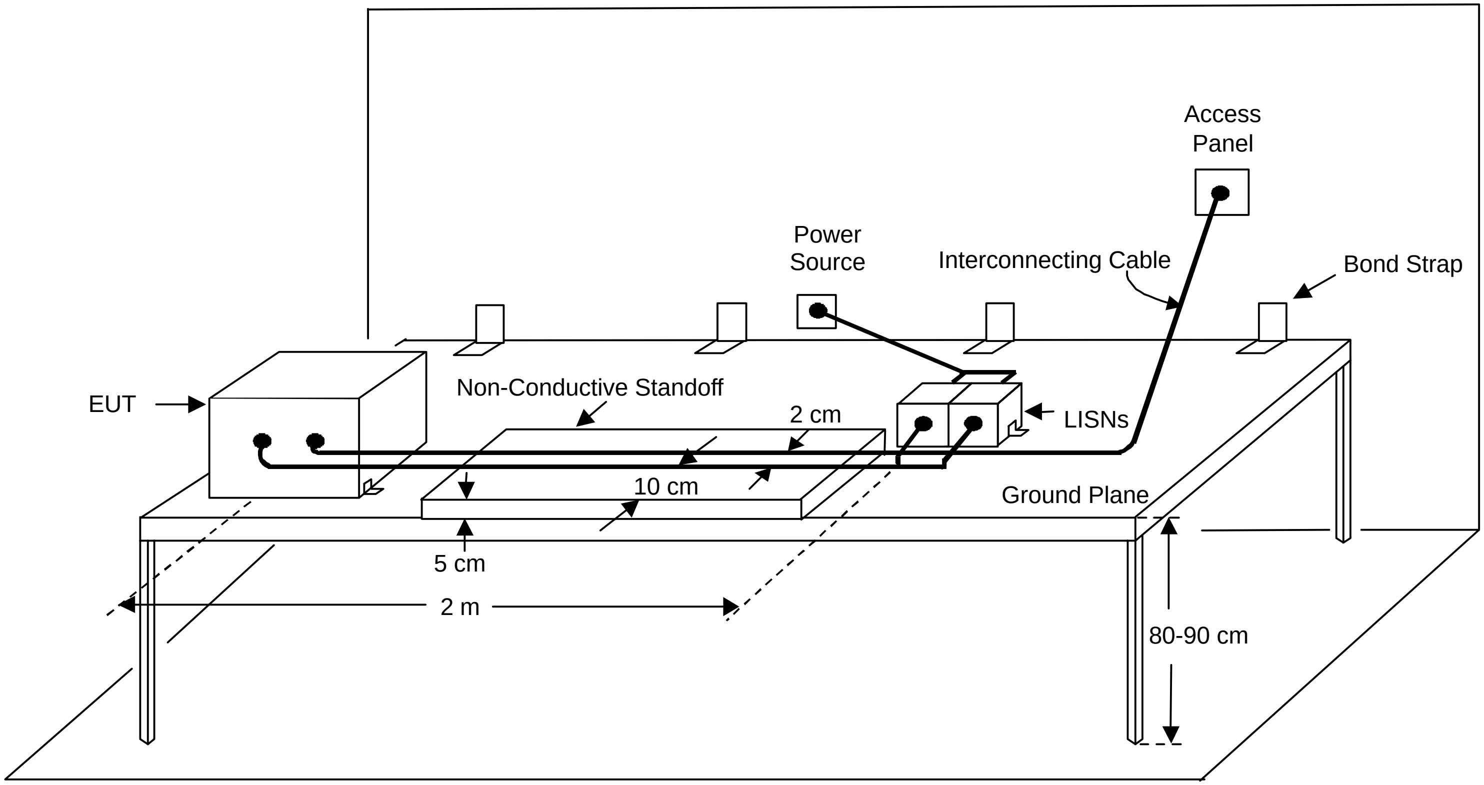


FIGURE 4-3

TEST SETUP FOR NON-CONDUCTIVE SURFACE MOUNTED EUT

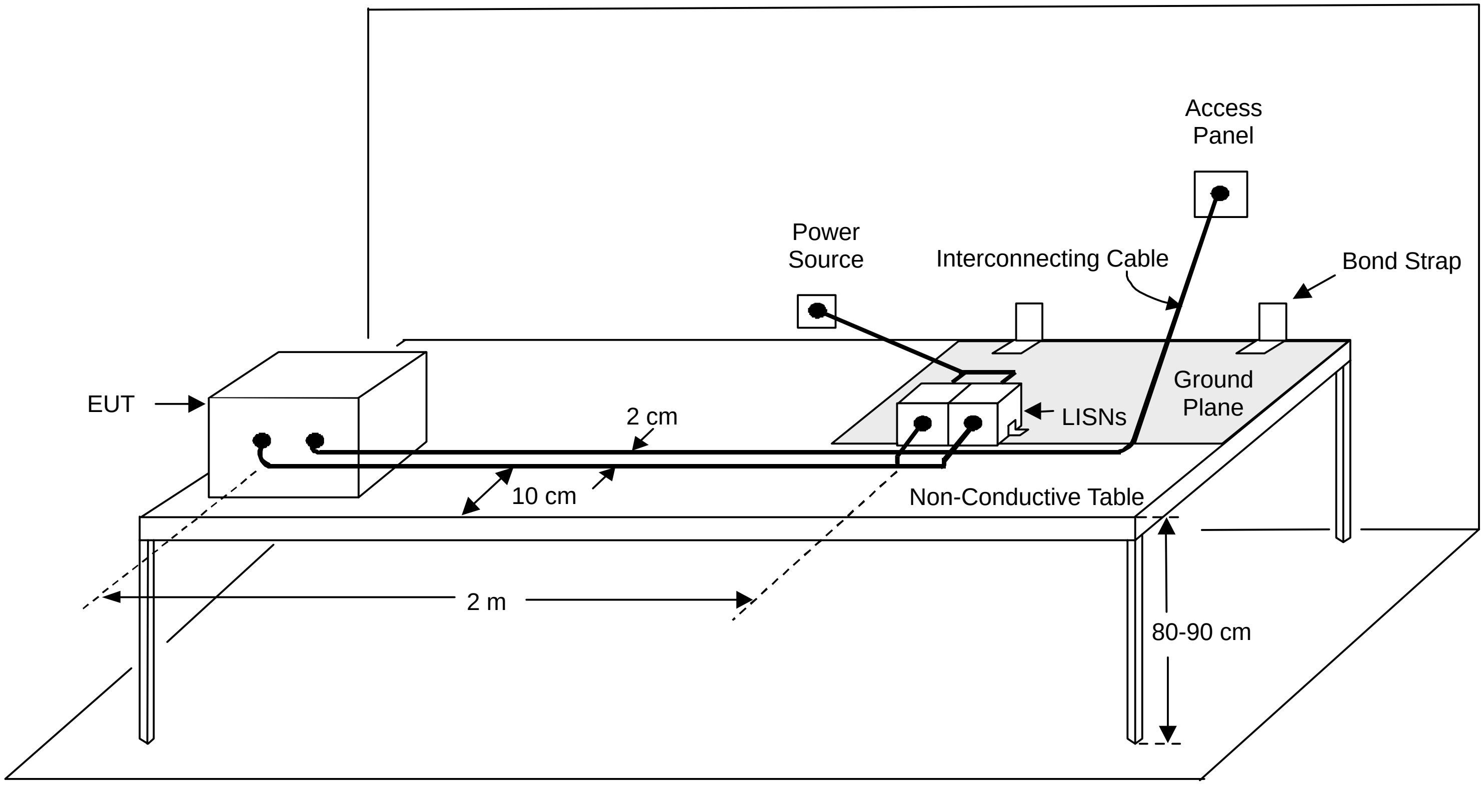


FIGURE 4-4

TEST SETUP FOR FREE STANDING EUT IN SHIELDED ENCLOSURE

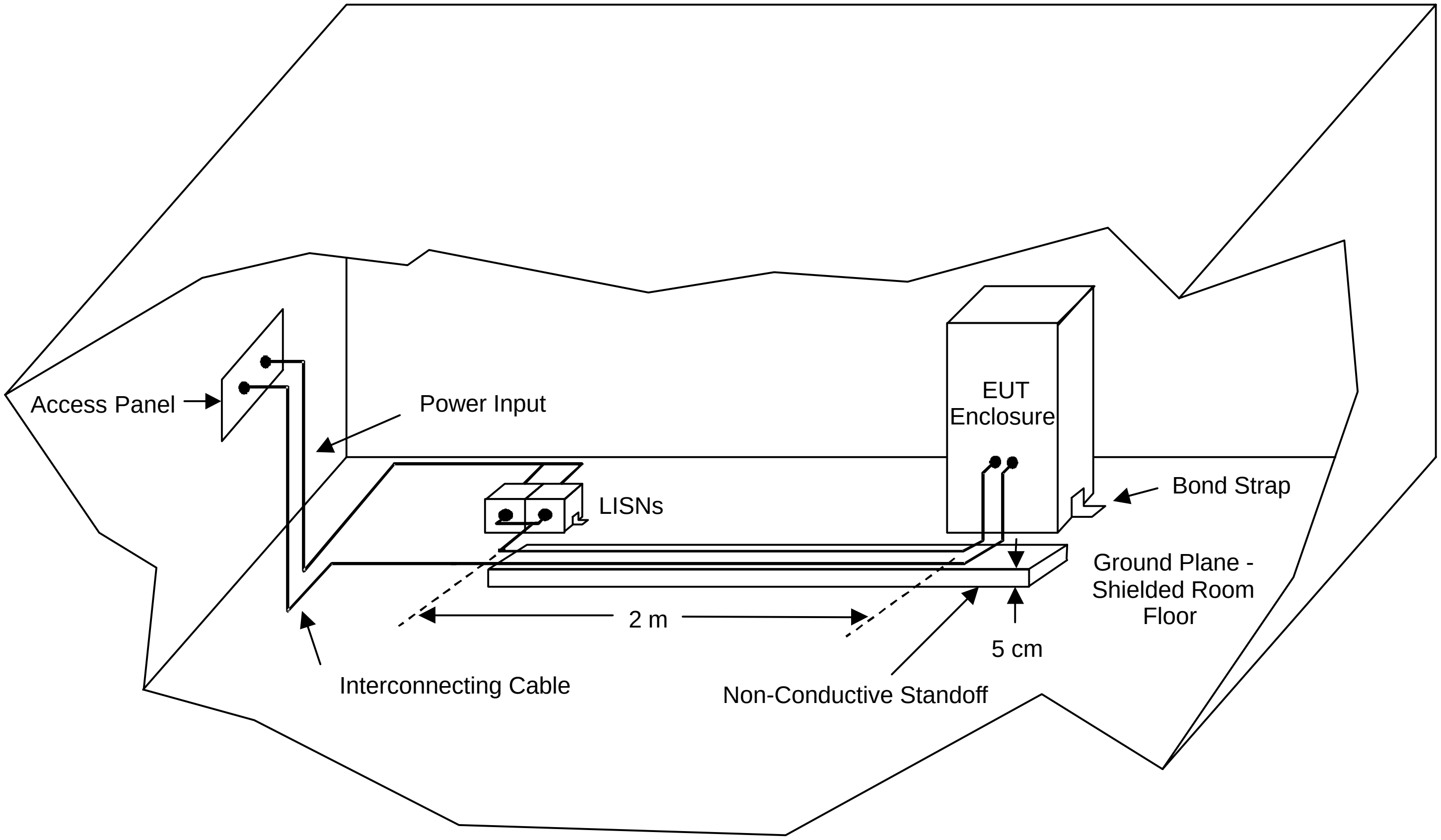


FIGURE 4-5

TEST SETUP FOR FREE STANDING EUT

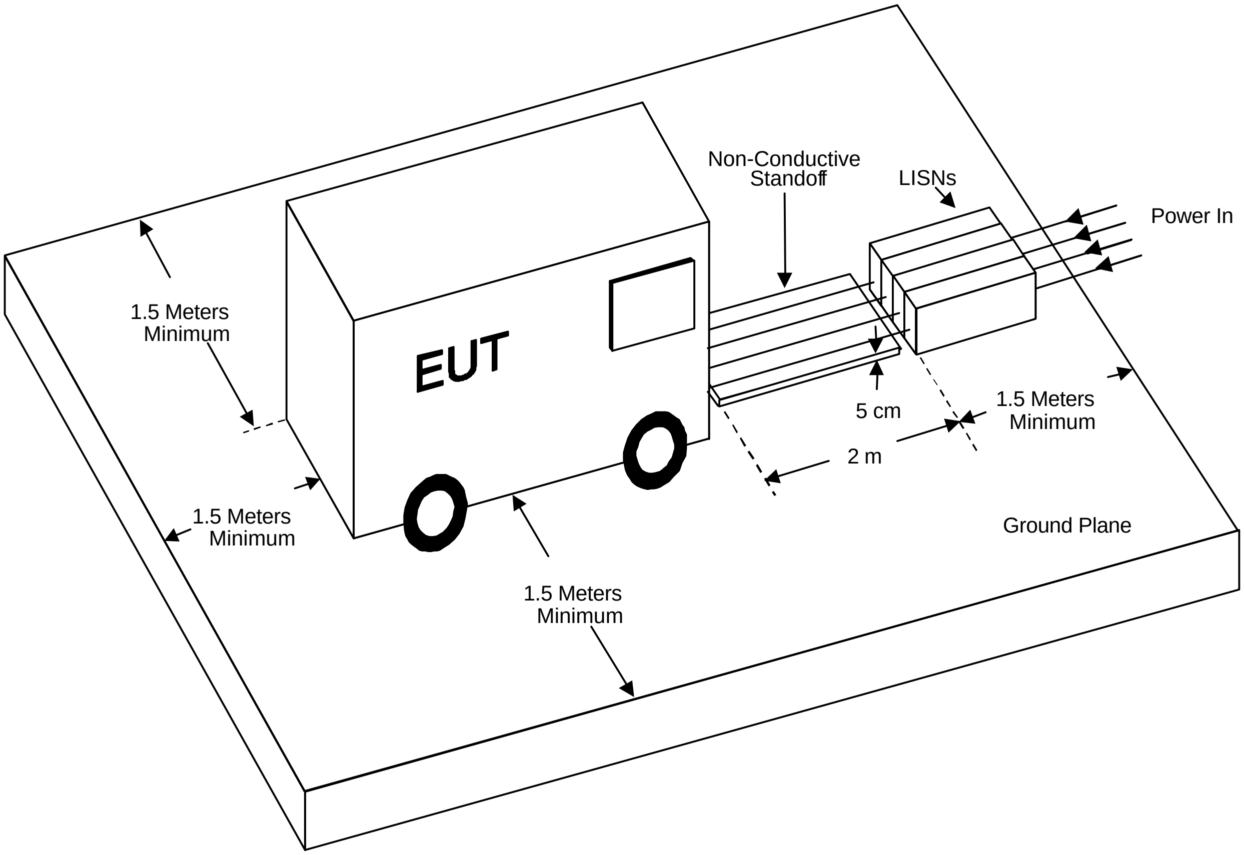


FIGURE 4-6

LISN SCHEMATIC

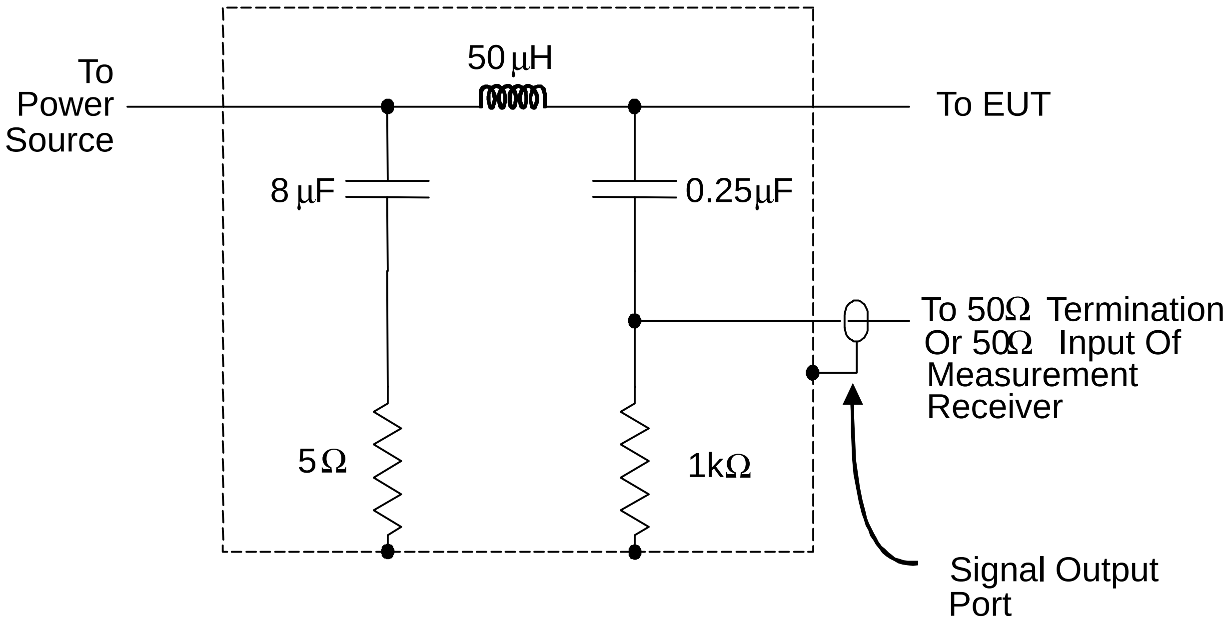
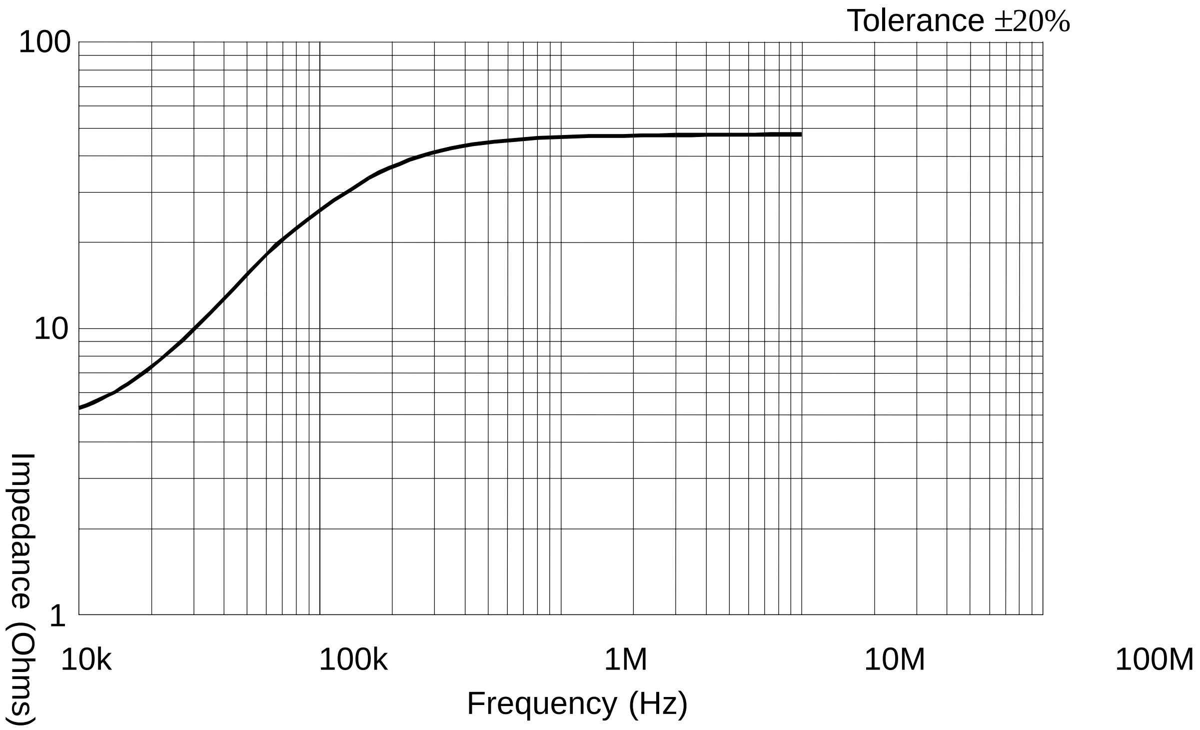


FIGURE 4-7

LISN IMPEDANCE



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5.0 DETAILED REQUIREMENTS

5.1 GENERAL

This section specifies detailed emissions and susceptibility requirements and the associated test procedures. Table 5.1 is a list of the specific requirements established by this standard identified by requirement number and title. General test procedures are included in this section. Specific test procedures are implemented by the approved EMITP. All results of tests performed to demonstrate compliance with the requirements are to be documented in the EMITR and forwarded to the designated authority for evaluation prior to acceptance of the equipment or subsystem. Design procedures and techniques for the control of EMI shall be described in the EMICP. Approval of design procedures and techniques described in the EMICP does not relieve the supplier of the responsibility of meeting the contractual emission, susceptibility, and design requirements.

5.1.1 Units of Frequency Domain Measurements

All frequency domain limits are expressed in terms of equivalent RMS value of a sine wave as would be indicated by the output of a measurement receiver using peak envelope detection (reference Paragraph 4.3.10.1).

TABLE 5.1

EMISSION AND SUSCEPTIBILITY REQUIREMENTS

Requirement	Description
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106	Conducted Emissions, Antenna Terminal, 100 MHz to 18 GHz
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 18 GHz
CS105	Conducted Susceptibility, Antenna Port, Cross Modulation, 30 Hz to 18 GHz
CS106	Conducted Susceptibility, Power-line Switching Transients
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 10 MHz
RE102	Radiated Emissions, Electric Field, 150 kHz to 18 GHz
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 100 MHz to 18 GHz
RS103	Radiated Susceptibility, Electric Field, 30 MHz to 18 GHz
TT101	Conducted Emission, Time Domain, DC Power Leads, Transient and Steady-state

5.2 CE102, CONDUCTED EMISSIONS, POWER LEADS, 10 KILOHERTZ (kHz) TO 10 MEGAHERTZ (MHz)

5.2.1 CE102 Applicability

This requirement is applicable from 10 kHz to 10 MHz for all power leads, including returns, that obtain power from primary sources.

5.2.2 CE102 Limits

CEs on power leads shall not exceed the applicable values shown on Figure 5-1.

5.2.3 CE102 Test Procedure

5.2.3.1 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.

5.2.3.2 Test Equipment

The test equipment shall be as follows:

a. Measurement receiver

b. Data recording device

c. Signal generator

d. Attenuator, 20 dB, 50 ohm

e. Oscilloscope

f. LISNs

5.2.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8.

b. Calibration.

    1. Configure the test setup for the measurement system check as shown in Figure 5-2. Ensure that the EUT power source is turned off.

    2. Connect the measurement receiver to the 20 dB attenuator on the signal output port of the LISN.

c. EUT testing.

    1. Configure the test setup for compliance testing of the EUT as shown in Figure 5-3.

    2. Connect the measurement receiver to the 20 dB attenuator on the signal output port of the LISN.

5.2.3.4 Procedures

The test procedures shall be as follows:

a. Calibration. Perform the measurement system check using the measurement system check setup of Figure 5-2.

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

2. Apply a signal level that is at least 6 dB below the limit at 10 kHz, 100 kHz, 2 MHz and 10 MHz to the power output terminal of the LISN. At 10 kHz and 100 kHz, use an oscilloscope to calibrate the signal level and verify that it is sinusoidal. At 2 MHz and 10 MHz, use a calibrated output level directly from a 50 ohm signal generator.

3. 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. Correction factors shall be applied for the 20 dB attenuator and the voltage drop due to the LISN 0.25 microfarad coupling capacitor.

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.

5. Repeat Items 2 through 4 (above) for each LISN.

b. EUT testing. Perform emission data scans using the measurement setup of Figure 5-3.

   1. Turn on the EUT and allow a sufficient time for stabilization.

   2. Select an appropriate lead for testing.

   3. Scan the measurement receiver over the applicable frequency range, using the BWs and minimum measurement times in Table 4.3.

   4. Repeat Items 2 and 3 (above) for each power lead.

5.2.3.5 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.

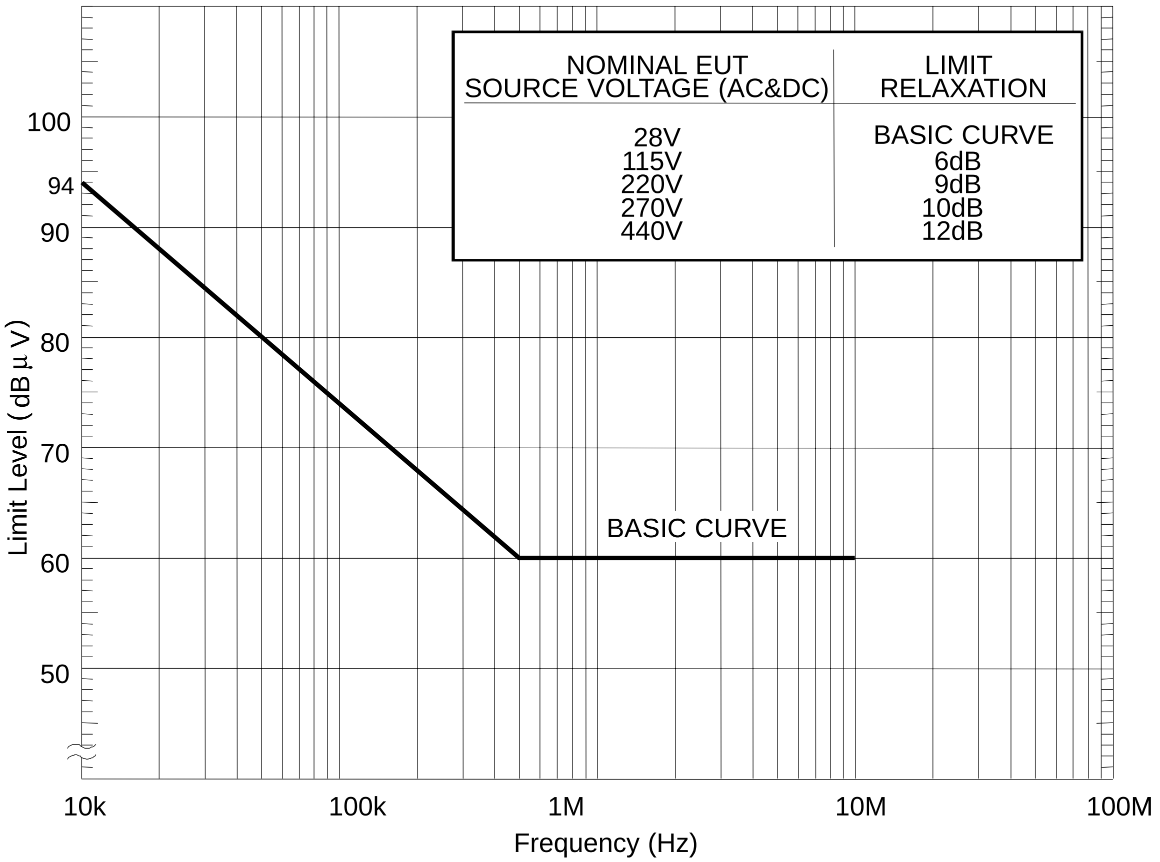
b. Display the applicable limit on each plot.

c. Provide a minimum frequency resolution of 1% or twice the measurement receiver BW, whichever is less stringent, and a minimum amplitude resolution of 1 dB for each plot.

d. Provide plots for both the measurement system check and measurement portions of the procedure.

FIGURE 5-1

(CE102-1) CE102 LIMIT (EUT POWER LEADS, AC AND DC) FOR ALL APPLICATIONS



NOMINAL EUT SOURCE VOLTAGE (AC&DC)	LIMIT RELAXATION
28V	BASIC CURVE
115V	6dB
220V	9dB
270V	10dB
440V	12dB

FIGURE 5-2

(CE102-2) MEASUREMENT SYSTEM CHECK SETUP

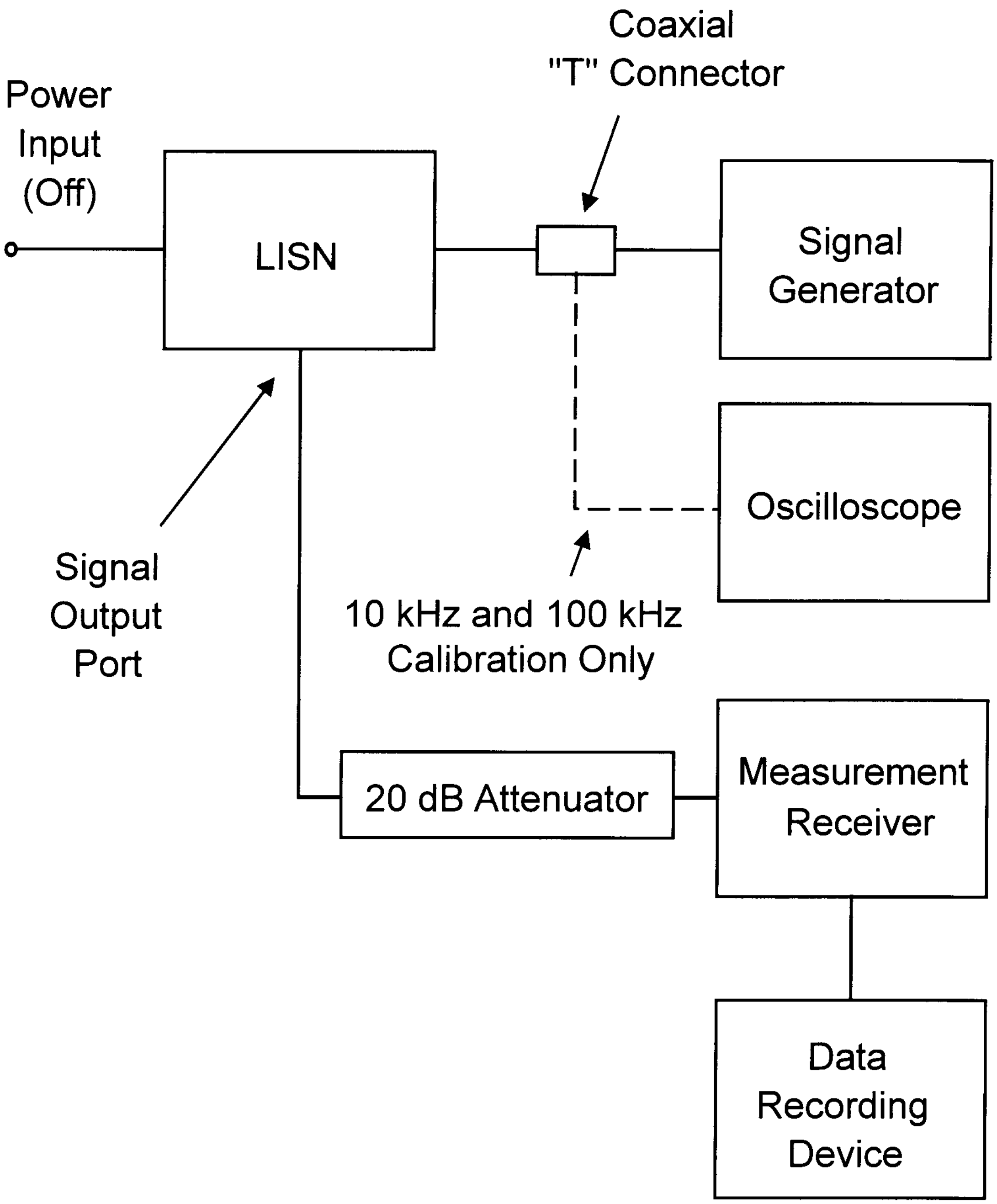
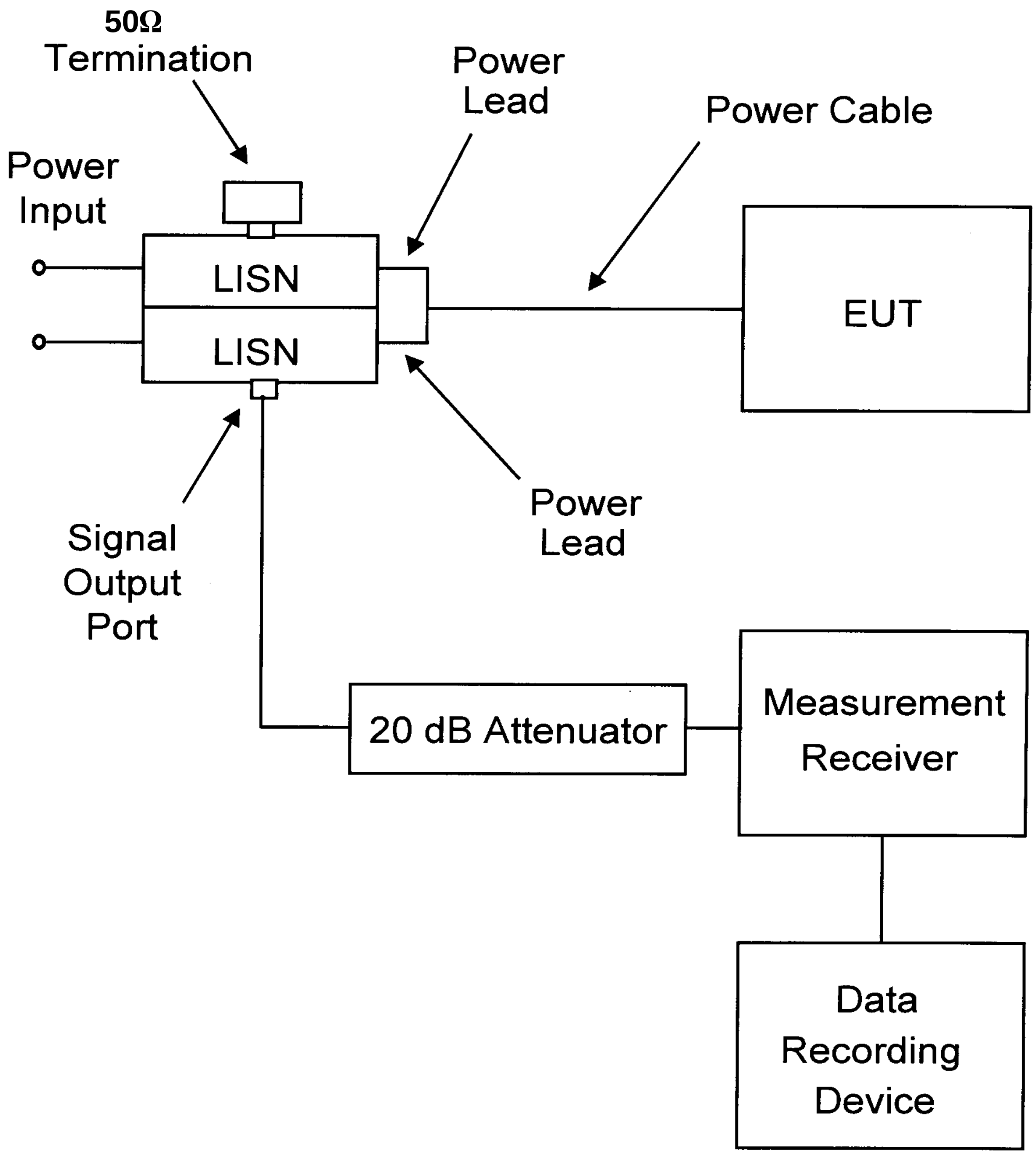


FIGURE 5-3

(CE102-3) MEASUREMENT SETUP



5.3 CE106, CONDUCTED EMISSIONS, ANTENNA TERMINAL, 100 MHz TO 18 GHz

5.3.1 CE106 Applicability

This requirement is applicable to the antenna terminals 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 EUT necessary BW and within ±5 percent of the fundamental frequency. The start frequency of the test is 100 MHz for all EUT operating frequency ranges. The end frequency of the test is 18 GHz or twenty times the highest generated or received frequency within the EUT, 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. RE102 is applicable for emissions from antennas in the receive and standby modes for equipment designed with antennas permanently mounted to the EUT.

5.3.2 CE106 Limits

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

a. Receivers: 34 decibel microvolts (dBμV)

b. Transmitters and amplifiers (standby mode): 34 dBμV

c. Transmitters and amplifiers (transmit mode): Harmonics, except the second and third, and all other spurious emissions shall be at least 80 dB 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 80 dB, whichever requires less suppression.

5.3.3 CE106 Test Procedure

5.3.3.1 Purpose

This test procedure is used to verify that CEs appearing at the antenna terminal of the EUT do not exceed specified requirements.

5.3.3.2 Test Equipment

The test equipment shall be as follows:

a. Measurement receiver.

b. Attenuators, 50 ohm.

c. Rejection networks.

d. Directional couplers.

e. Dummy loads, 50 ohm.

f. Signal generators. For amplifier testing, a signal generator is required to drive the amplifier that provides the modulation used in the intended application and that has spurious and harmonic outputs that are down at least 6 dB greater than the applicable limit.

g. Data recording device.

5.3.3.3 Setup

It is not necessary to maintain the basic test setup for the EUT as shown and described in Figure 4-2 through Figure 4-5 and Paragraph 4.3.8. The test setup shall be as follows:

a. Calibration. Configure the test setup for the signal generator path shown in Figure 5-1 through Figure 5-3, as applicable. The choice of Figure 5-1 or Figure 5-2 is dependent upon the capability of the measuring equipment to handle the transmitter power.

b. EUT Testing. Configure the test setup for the EUT path shown in Figure 5-1 through Figure 5-3, as applicable. The choice of Figure 5-1 or Figure 5-2 is dependent upon the capability of the measuring equipment to handle the transmitter power.

5.3.3.4 Procedures

5.3.3.4.1 Transmit Mode for Transmitters and Amplifiers

The test procedure shall be as follows:

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

b. Calibration.

    1. Apply a known calibrated signal level from the signal generator through the system check path at a mid-band fundamental frequency (f_o).

    2. Scan the measurement receiver in the same manner as a normal data scan. Verify the measurement receiver detects a level within ±3 dB of the expected signal.

3. 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 test.

4. Repeat Items 1 through 3 (above) at the end points of the frequency range of test.

c. EUT Testing.

1. Turn on the EUT and allow sufficient time for stabilization.

2. For transmitters, tune the EUT to the desired test frequency and apply the appropriate modulation for the EUT as indicated in the equipment specification. For amplifiers, apply an input signal to the EUT that has the appropriate frequency, power level, and modulation as indicated in the equipment specification. For transmitters and amplifiers for which these parameters vary, test parameters shall be chosen such that the worst case emissions spectrum will result.

3. Use the measurement path to complete the rest of this procedure.

4. Tune the test equipment to the operating frequency (f_o) of the EUT and adjust for maximum indication.

5. Record the power level of the fundamental frequency (f_o) and the measurement receiver BW.

6. Insert the fundamental frequency rejection network, when applicable.

7. Scan the frequency range of interest and record the level of all harmonics and spurious emissions. Add all correction factors for cable loss, attenuators and rejection networks. Maintain the same measurement receiver BW used to measure the power level of the fundamental frequency (f_o) in Step c, Item 5 (above).

8. Verify spurious outputs are from the EUT and not spurious responses of the measurement system.

9. Repeat Items 2 through 8 (above) for other frequencies as required by Paragraph 4.3.9.1 and Paragraph 4.3.9.2.

10. Determine measurement path losses at each spurious frequency as follows:

    (a) Replace the EUT with a signal generator.

  - (b) Retain all couplers and rejection networks in the measurement path.
  - (c) Determine the losses through the measurement path. The value of attenuators may be reduced to facilitate the end-to-end check with a low level signal generator.

5.3.3.4.2 Recievers and Stand-by Mode for Transmitters and Amplifiers

The test procedure shall be as follows:

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

b. Calibration.

   1. Apply a calibrated signal level, which is 6 dB below the applicable limit, from the signal generator through the system check path at a midpoint test frequency.
   2. Scan the measurement receiver in the same manner as a normal data scan. Verify the measurement receiver detects a level within ±3 dB of the injected signal.
   3. 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 test.
   4. Repeat Items 1 through 3 (above) at the end points of the frequency range of test.

c. EUT Testing.

   1. Turn on the EUT and allow sufficient time for stabilization.
   2. Tune the EUT to the desired test frequency and use the measurement path to complete the rest of this procedure.
   3. Scan the measurement receiver over the applicable frequency range, using the BWs and minimum measurement times of Table 4.3.
   4. Repeat Items 2 and 3 (above) for other frequencies as required by Paragraph 4.3.9.1 and Paragraph 4.3.9.2.

5.3.3.5 Data Presentation

5.3.3.5.1 Transmit Mode for Transmitters and Amplifiers

The data presentation shall be as follows:

a. Continuously and automatically plot amplitude versus frequency profiles for each tuned frequency. Manually gathered data is not acceptable except for plot verification.

b. Provide a minimum frequency resolution of 1% or twice the measurement receiver BW, whichever is less stringent, and a minimum amplitude resolution of 1 dB for each plot

c. Provide tabular data showing f_o and frequencies of all harmonics and spurious emissions measured, power level of the fundamental and all harmonics and spurious emissions, dB down level, and all correction factors including cable loss, attenuator pads, and insertion loss of rejection networks.

d. The relative dB down level is determined by subtracting the level in Paragraph 5.3.3.4.1, Step c, Item 7, from that obtained in Paragraph 5.3.3.4.1, Step c, Item 5.

5.3.3.5.2 Receivers and Stand-by Mode for Transmitters and Amplifiers

The data presentation shall be as follows:

a. Continuously and automatically plot amplitude versus frequency profiles for each tuned frequency. 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 BW, 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.

FIGURE 5-4

(CE106-1) SETUP FOR LOW POWER TRANSMITTERS AND AMPLIFIERS

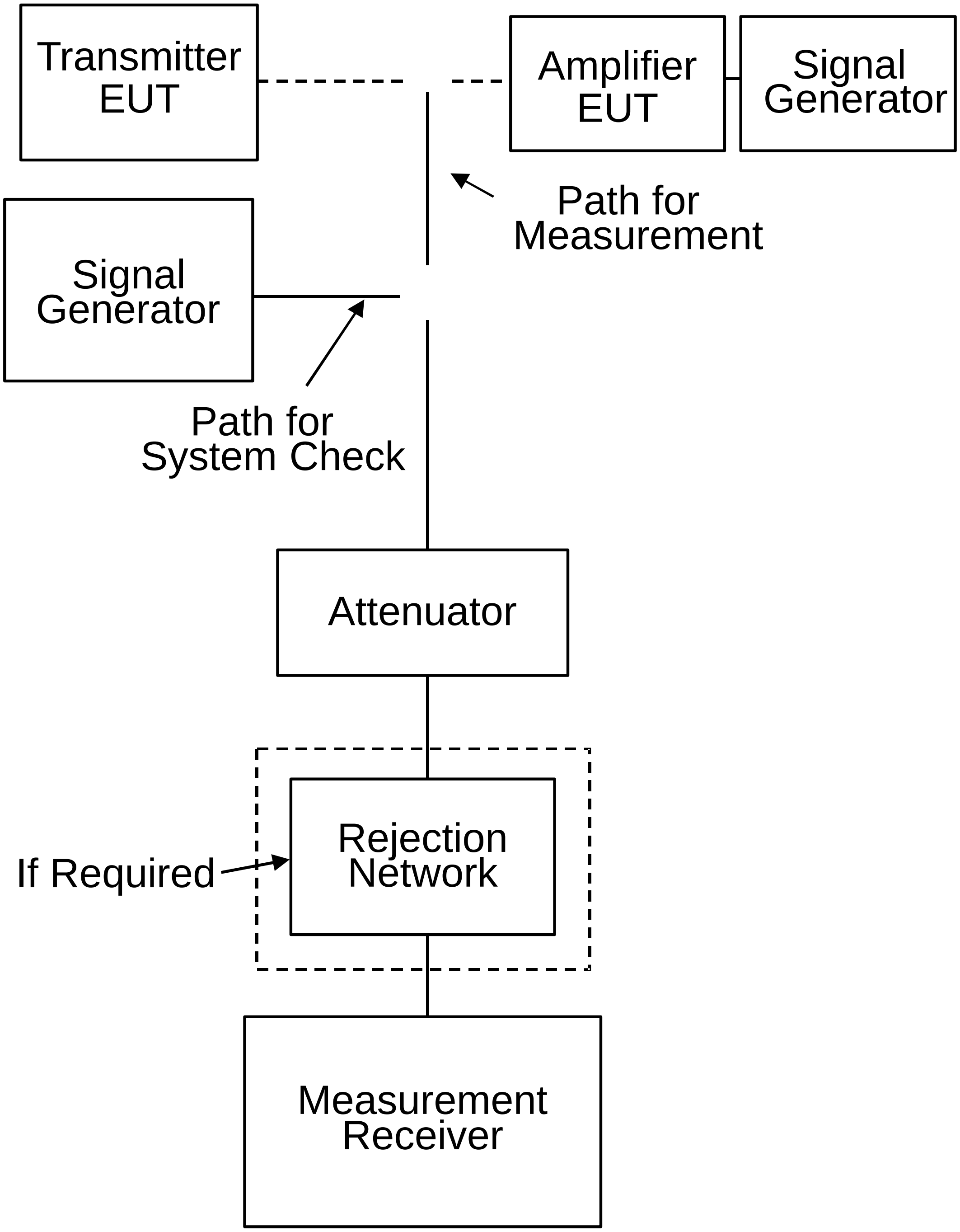


FIGURE 5-5

(CE106-2) SETUP FOR HIGH POWER TRANSMITTERS AND AMPLIFIERS

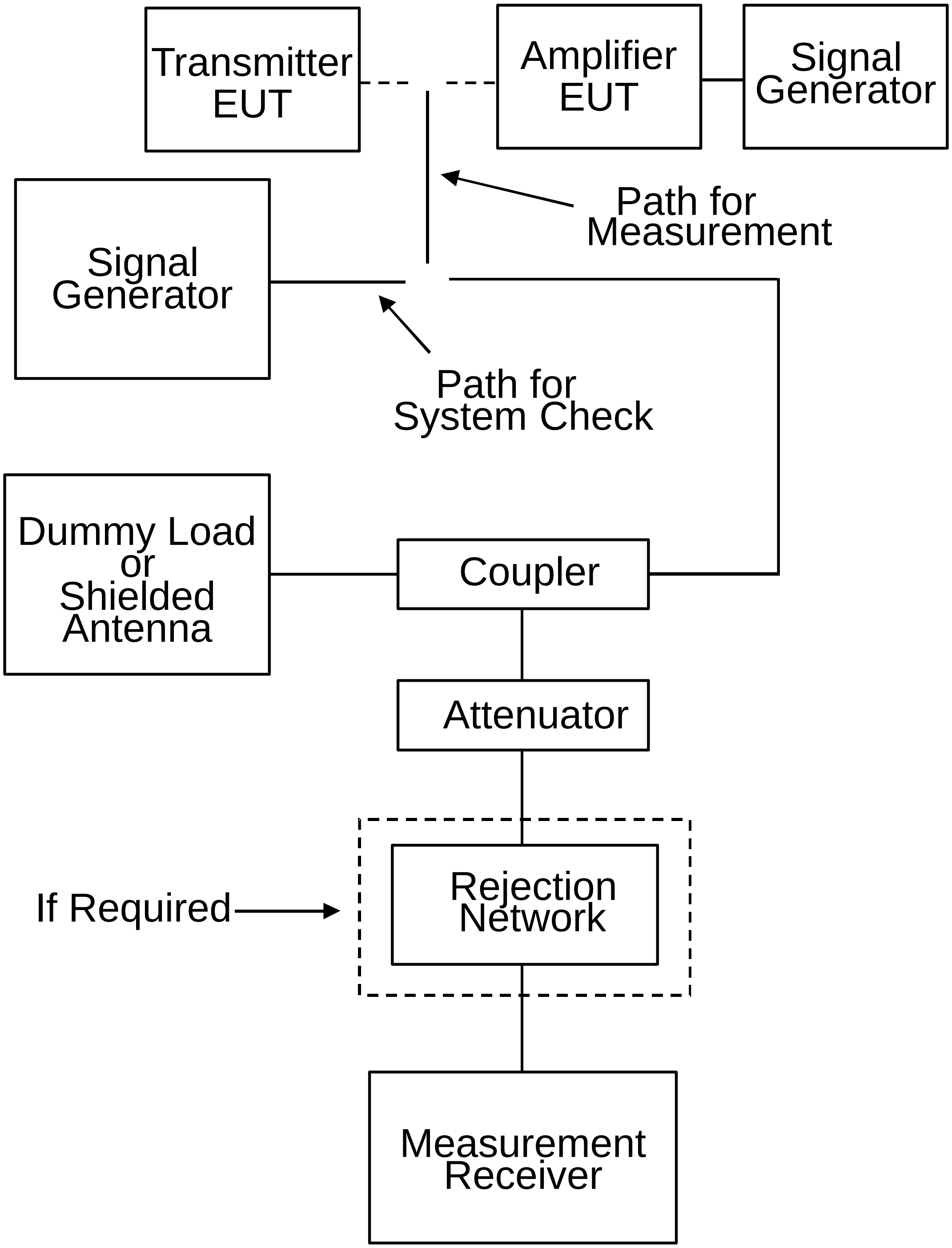
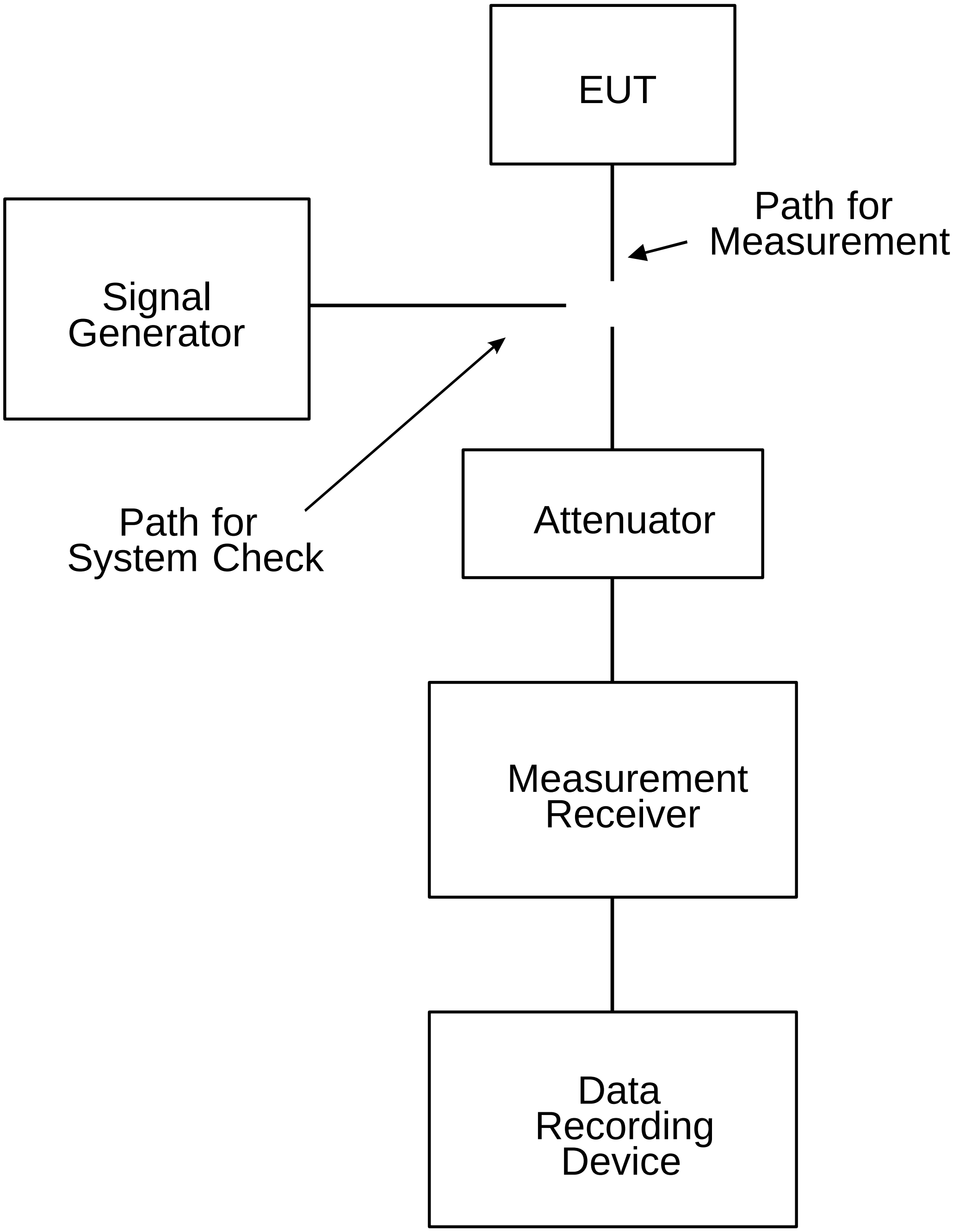


FIGURE 5-6

(CE106-3) SETUP FOR RECEIVERS AND STAND-BY MODE FOR TRANSMITTERS AND AMPLIFIERS



5.4 CS101, CONDUCTED SUSCEPTIBILITY, POWER LEADS, 30 HERTZ (Hz) TO 150 kHz

5.4.1 CS101 Applicability

This requirement is applicable to equipment and subsystem AC and DC input power leads, not including returns. If the EUT is DC operated, this requirement is applicable over the frequency range of 30 Hz to 150 kHz. If the EUT is AC operated, this requirement is applicable starting from the second harmonic of the EUT power frequency and extending to 150 kHz.

5.4.2 CS101 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 a test signal with voltage levels as specified in Figure 5-7 for these voltage levels. The requirement is also met when the power source is adjusted to dissipate the power level shown in Figure 5-8 in a 0.5 ohm load and the EUT is not susceptible.

Additional CS101 Test - Any EUT meeting all the criteria defined below shall perform an additional susceptibility test to determine whether the equipment performance is adversely affected by the following waveform:

> Ripple amplitude of 14 Volts (V) peak-to-peak with a 500 - 700 Hz sawtooth ripple for a duration of 250 milliseconds

This waveform is representative of the worst case noise generated on the aft power busses when the hydraulic circulation pumps are powered on. Test of EUT response to such ripple levels shall follow the CS101 test techniques defined below. When the EUT fails to function within performance, the ripple amplitude at which the EUT fails (i.e., susceptibility threshold) shall be determined and the test results shall be submitted to the procuring authority.

Criteria for performing additional CS101 test:

a. The EUT is classified as EMC critical equipment.
b. The EUT operates from an aft cargo bay 28 VDC power bus.
c. The EUT has a non-redundant power interface to a single power bus.
d. The EUT is operated on-orbit.

5.4.3 CS101 Test Procedure

5.4.3.1 Purpose

This test procedure is used to verify the ability of the EUT to withstand signals coupled onto input power leads.

5.4.3.2 Test Equipment

The test equipment shall be as follows:

a. Signal generator

b. Power amplifier

c. Oscilloscope

d. Coupling transformer

e. Capacitor, 10 µF

f. Isolation transformer

g. Resistor, 0.5 ohm

h. LISNs

5.4.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8.

b. Calibration. Configure the test equipment in accordance with Figure 5-9. Set up the oscilloscope to monitor the voltage across the 0.5 ohm resistor.

c. EUT testing.

   1. For DC or single-phase AC power, configure the test equipment as shown in Figure 5-10.

   2. For three-phase ungrounded power, configure the test setup as shown in Figure 5-11.

   3. For three-phase wye power (four power leads), configure the test setup as shown in Figure 5-12.

5.4.3.4 Procedures

The test procedures shall be as follows:

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

b. Calibration.

   1. Set the signal generator to the lowest test frequency.

2. Increase the applied signal until the oscilloscope indicates the voltage level corresponding to the maximum required power level specified for the limit. Verify the output waveform is sinusoidal.
3. Record the setting of the signal source.
4. Scan the required frequency range for testing and record the signal source setting needed to maintain the required power level.

c. EUT Testing.

1. Turn on the EUT and allow sufficient time for stabilization.

   CAUTION: Exercise care when performing this test since the “safety ground” of the oscilloscope is disconnected due to the isolation transformer and a shock hazard may be present.

2. Set the signal generator to the lowest test frequency. Increase the signal level until the required voltage or power level is reached on the power lead.

   NOTE: Power is limited to the level calibrated in Step b, Item 2 (above).

3. While maintaining at least the required signal level, scan through the required frequency range at a rate no greater than specified in Table 4.4.
4. Susceptibility evaluation.
   (a) Monitor the EUT for degradation of performance.
   (b) If susceptibility is noted, determine the threshold level in accordance with Paragraph 4.3.10.4.3 and verify that it is above the limit.
5. Repeat Items 2 through 4 (above) for each power lead, as required. For three-phase ungrounded power, the measurements shall be made according to the following:

Coupling Transformer in Line	Voltage Measurement From
A	A to B
B	B to C
C	C to A

For three-phase wye power (four leads) the measurements shall be made according to the following:

Coupling Transformer in Line	Voltage Measurement From
A	A to Neutral
B	B to Neutral
C	C to Neutral

5.4.3.5 Data Presentation

Data presentation shall be as follows:

a. Provide graphical and tabular data showing the frequencies and amplitudes at which the test was conducted for each lead.

b. Provide data on any susceptibility thresholds and the associated frequencies that were determined for each power lead.

c. Provide indications of compliance with the applicable requirements for the susceptibility evaluation specified in Paragraph 4.3.4, Step c, for each lead.

FIGURE 5-7

(CS101-1) CS101 LIMIT FOR DC AND AC PRIMARY POWER BUSES

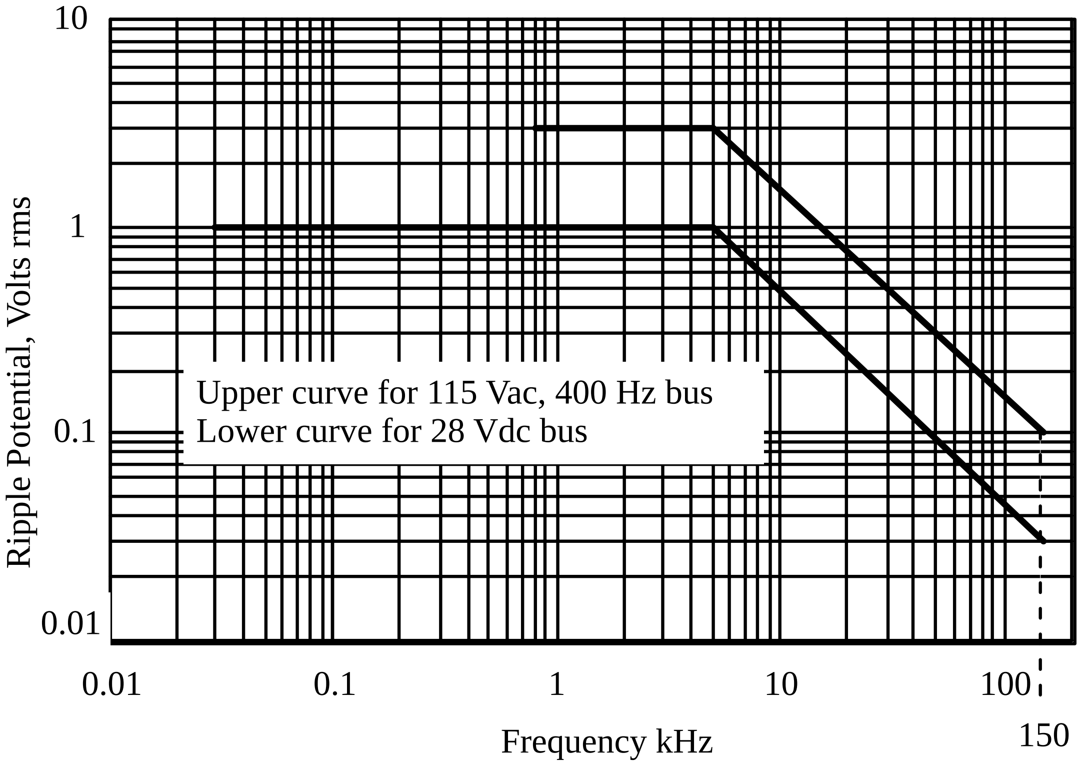


FIGURE 5-8

(CS101-2) CS101 POWER LIMIT FOR ALL APPLICATIONS

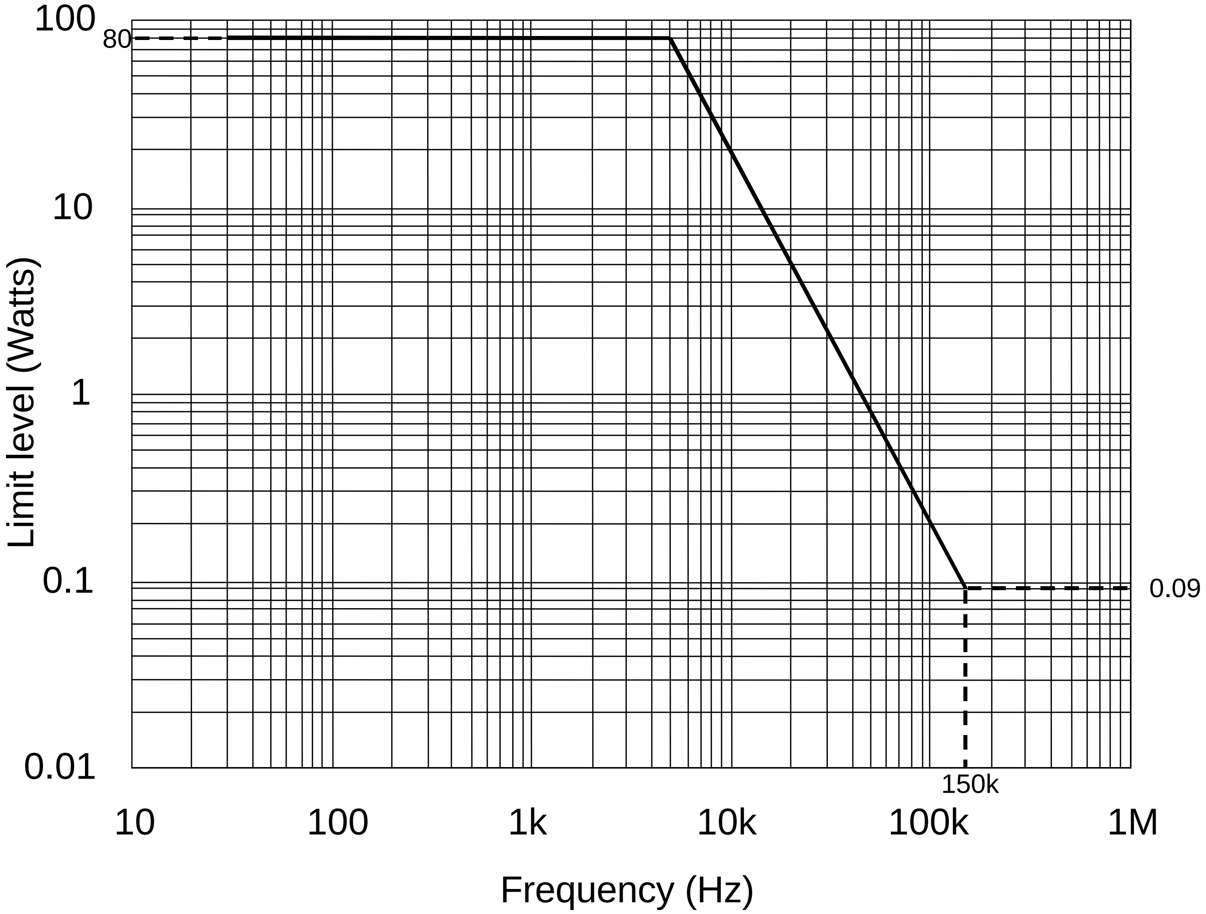


FIGURE 5-9

(CS101-3) CALIBRATION

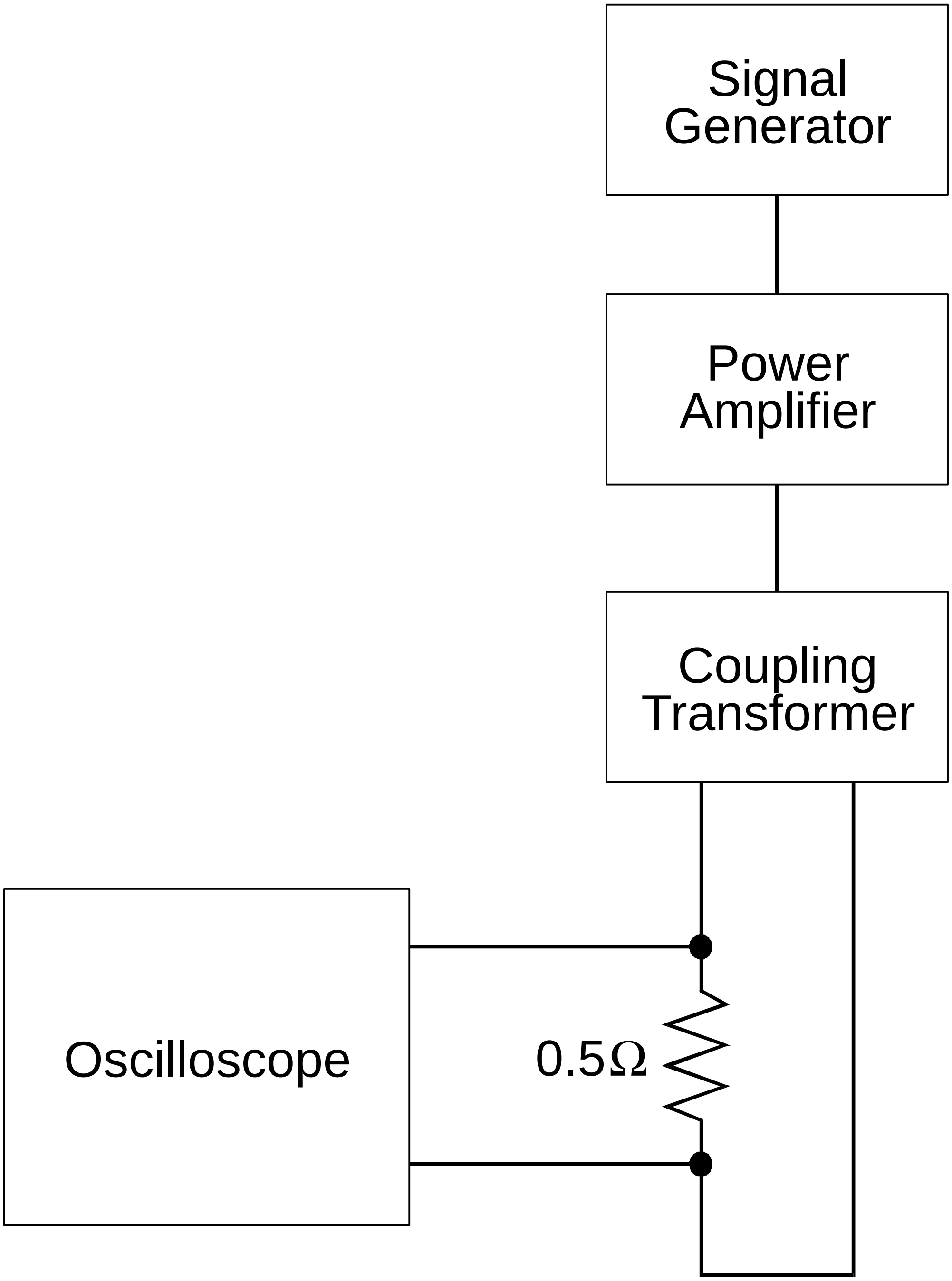


FIGURE 5-10

(CS101-4) SIGNAL INJECTION, DC OR SINGLE PHASE AC

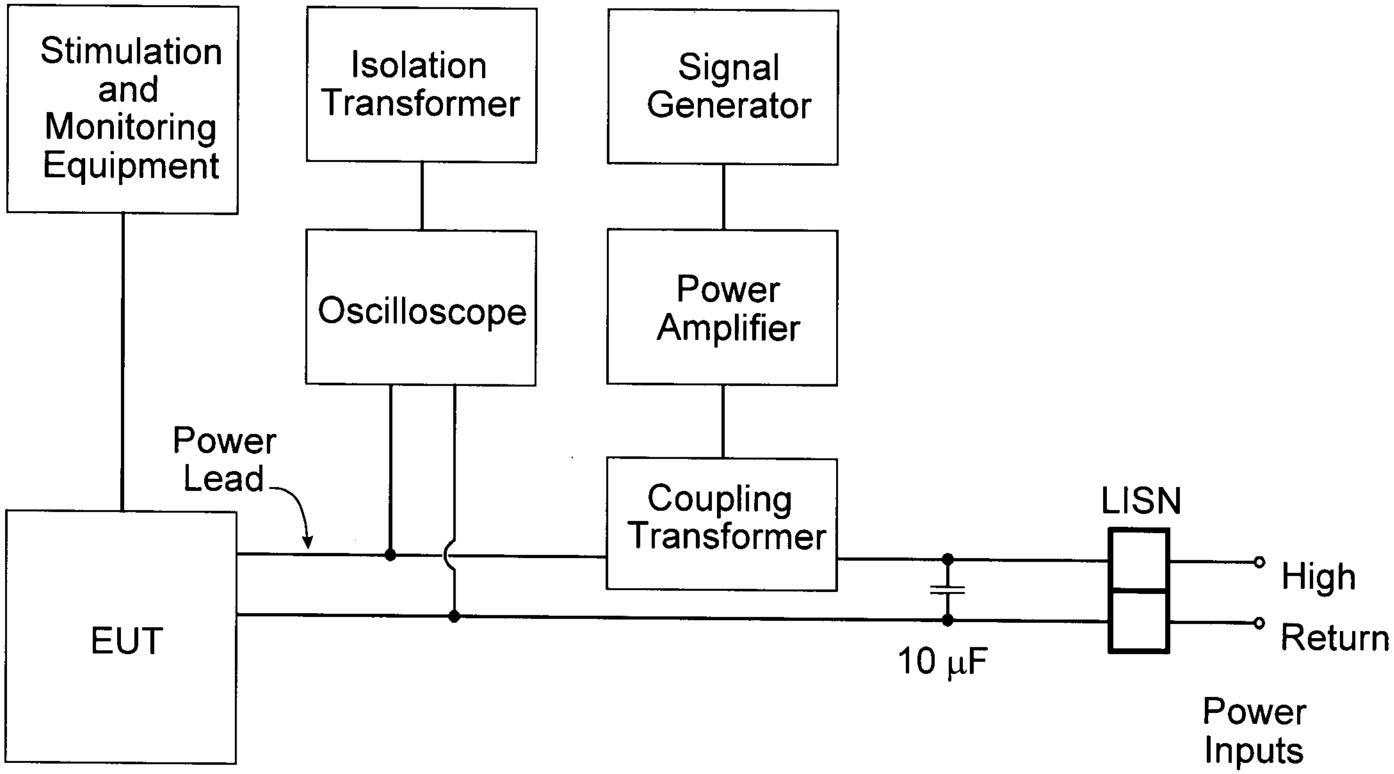


FIGURE 5-11

(CS101-5) SIGNAL INJECTION, 3-PHASE UNGROUNDED

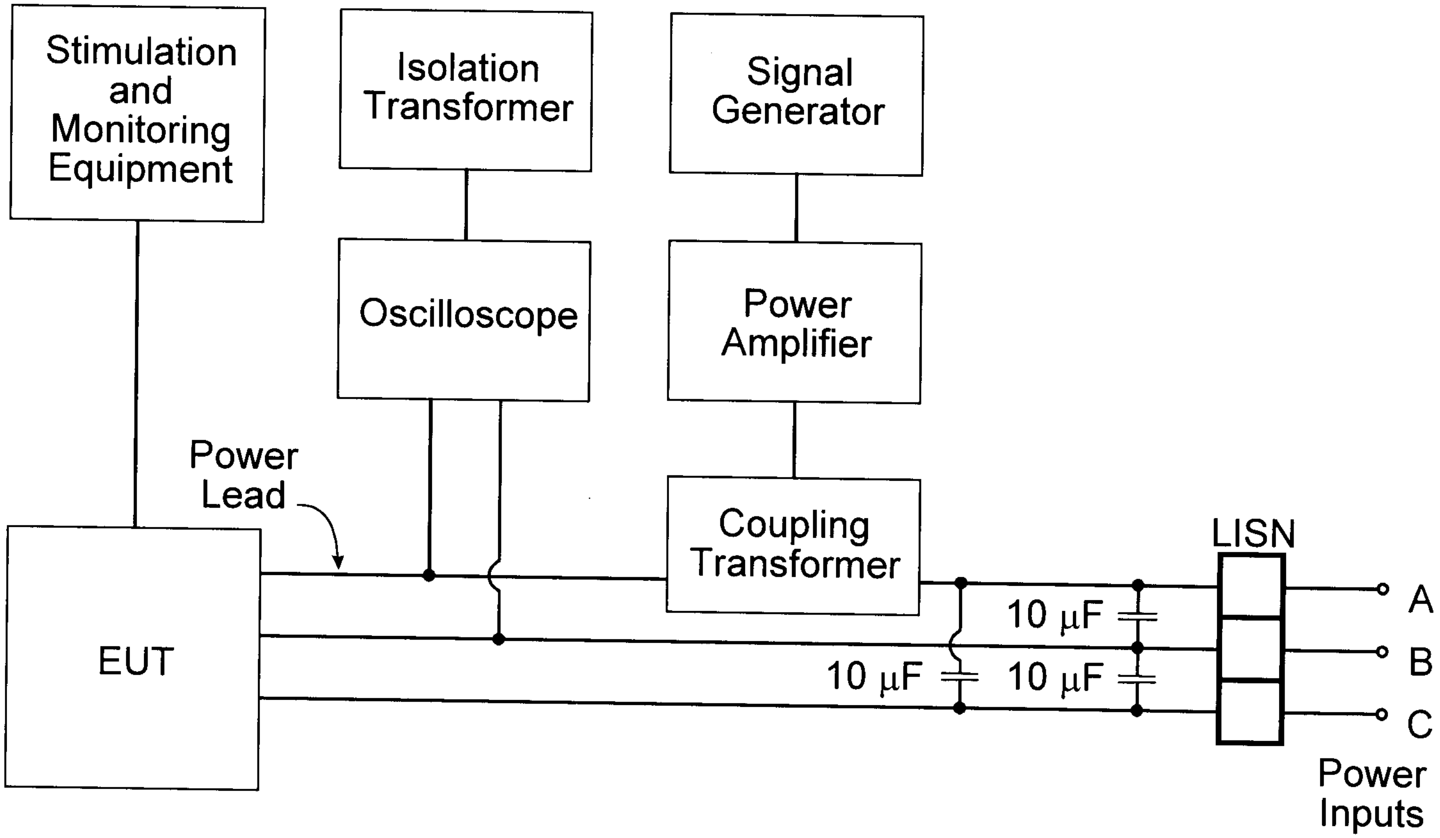
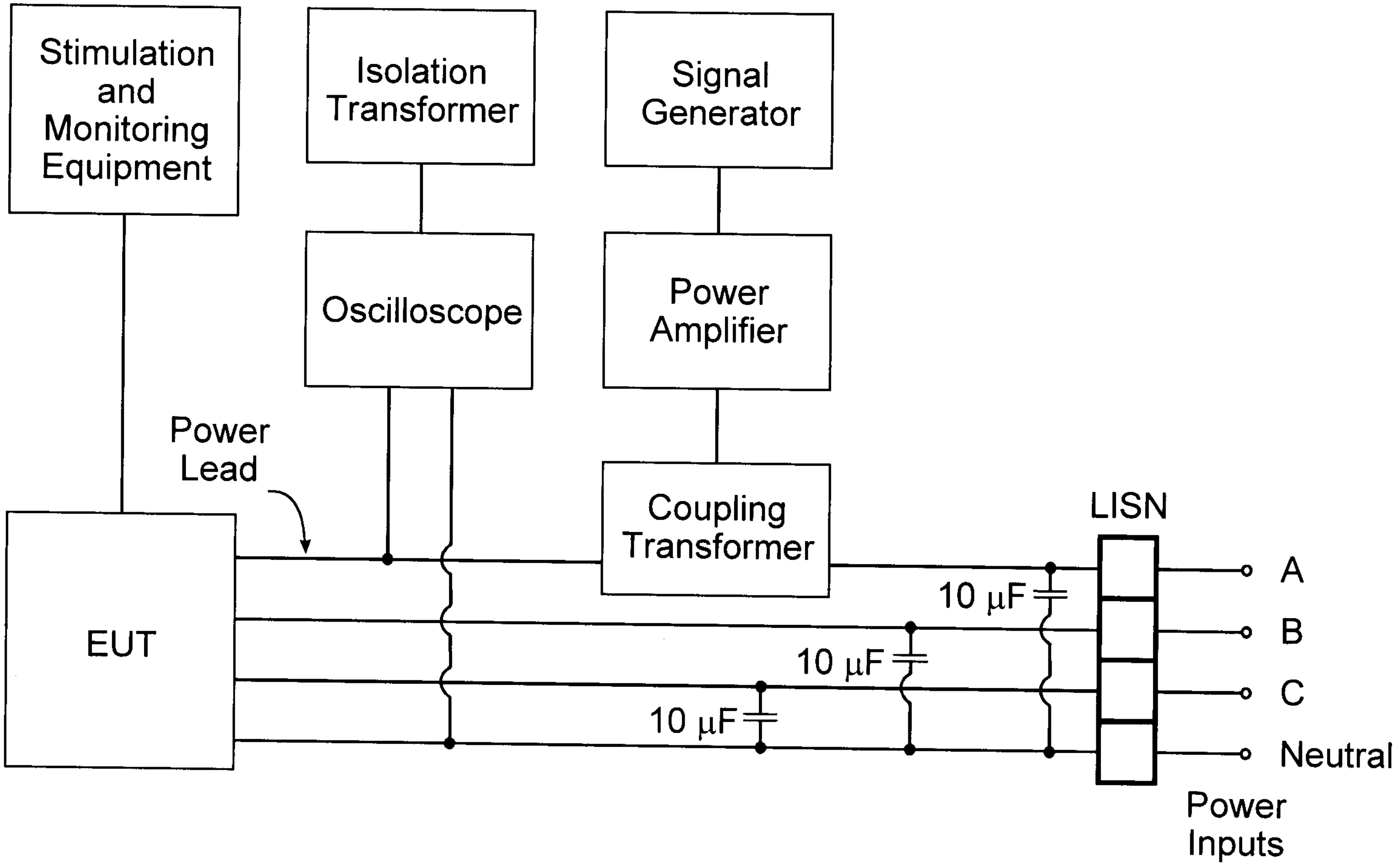


FIGURE 5-12

(CS101-6) SIGNAL INJECTION, 3-PHASE WYE



5.5 CS103, CONDUCTED SUSCEPTIBILITY, ANTENNA PORT, INTERMODULATION, 15 kHz TO 10 GHz

5.5.1 CS103 Applicability

This receiver front-end susceptibility requirement is applicable to equipment and subsystems, such as communications receivers, RF amplifiers, transceivers, radar receivers, acoustic receivers, and electronic warfare receivers as specified in the individual procurement specification.

5.5.2 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.

5.5.3 CS103 Test Procedures

5.5.3.1 Purpose

This test procedure is used to determine the presence of intermodulation products that may be caused by undesired signals at the EUT antenna input terminals.

5.5.3.2 Test Requirements

The required test equipment, setup, procedures, and data presentation shall be determined on a case-by-case basis in accordance with the guidance provided in Appendix B, Paragraph 5.5.

5.6 CS104, CONDUCTED SUSCEPTIBILITY, ANTENNA PORT, REJECTION OF UNDESIRED SIGNALS, 30 Hz TO 18 GHz

5.6.1 CS104 Applicability

This receiver front-end susceptibility requirement is applicable to equipment and subsystems, such as communications receivers, RF amplifiers, transceivers, radar receivers, acoustic receivers, and electronic warfare receivers as specified in the individual procurement specification.

5.6.2 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.

5.6.3 CS104 Test Procedures

5.6.3.1 Purpose

This test procedure is used to determine the presence of spurious responses that may be caused by undesired signals at the EUT antenna input terminals.

5.6.3.2 Test Requirements

The required test equipment, setup, procedures, and data presentation shall be determined on a case-by-case basis in accordance with the guidance provided in Appendix B, Paragraph 5.6 of this document.

5.7 CS106, CONDUCTED SUSCEPTIBILITY, ANTENNA PORT, CROSS MODULATION, 30 Hz TO 18 GHz

5.7.1 CS105 Applicability

This receiver front-end susceptibility requirement is applicable only to receivers that normally process amplitude-modulated RF signals, as specified in the individual procurement specification.

5.7.2 CS105 Limit

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

5.7.3 CS105 Test Procedures

5.7.3.1 Purpose

This test procedure is used to determine the presence of cross-modulation products that may be caused by undesired signals at the EUT antenna terminals.

5.7.3.2 Test Requirements

The required test equipment, setup, procedures, and data presentation shall be determined in accordance with the guidance provided in Appendix B, Paragraph 5.7.

5.8 CS106, CONDUCTED SUSCEPTIBILITY, POWER-LINE SWITCHING TRANSIENTS

5.8.1 CS106 Applicability

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

5.8.2 CS106 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 subsystems specification, when subjected to a pre-calibrated transient having pulse width and amplitude as specified in Figure 5-13 at a 1 Hz rate for 1 minute.

5.8.3 CS106 Test Procedures

5.8.3.1 Purpose

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

5.8.3.2 Test Equipment

The test equipment shall be as follows:

a. Switching transient generator

b. Oscilloscope, 50 ohm input impedance

c. 50 microHenry (µH), 50 ohm line-to-ground LISNs, one in each power conductor

d. 50 µf capacitor rated above 28 working volts DC (nominal capacitor value)

e. 4 ohm, 1 W resistor (nominal resistance value)

5.8.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8.

b. Calibration. Configure the test equipment in accordance with Figure 5-14 for calibrating the switching transient.

   Set transient generator for “turn-on” (negative polarity) transient. Set pulse rate to nominal 1 Hz rate.

c. EUT Testing. Configure per Figure 5-14 calibration, except that the EUT is now connected to power.

5.8.3.4 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 5-13.

    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 one minute in negative polarity mode. Verify proper operation of EUT. Shut down transient generator.

        (b) Whenever susceptibility is noted, determine the threshold level in accordance with Paragraph 4.3.10.4.3 and verify that it is above the limit. Transient duration is modified by changing switched capacitor and/or resistor value. 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).

        (c) Record samples of transients injected into EUT. These waveforms may differ from those pre-calibrated.

5.8.3.5 Data Presentation

Data presentation shall be as follows:

a. Oscilloscope traces for pre-calibrated transients.

b. Oscilloscope traces for EUT-injected transients.

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

FIGURE 5-13

(CS106-1) TRANSIENTS ENVELOPE: 28 VDC BUS, 4//50μF LOAD

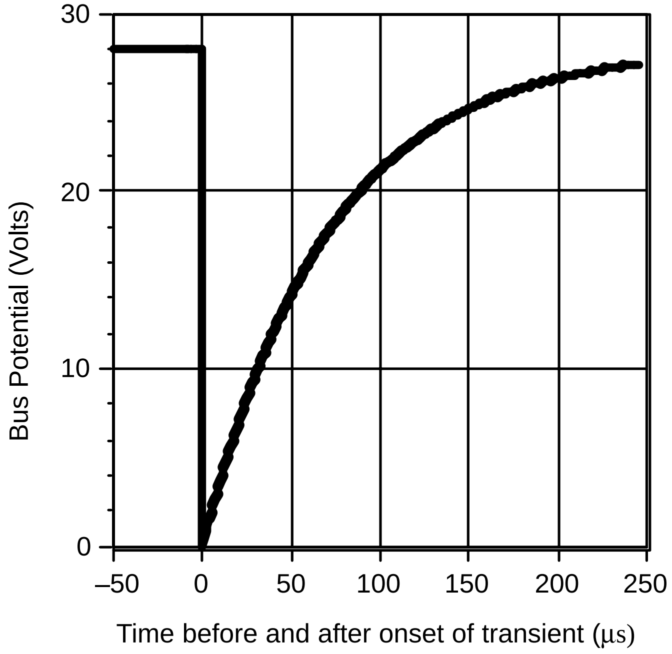
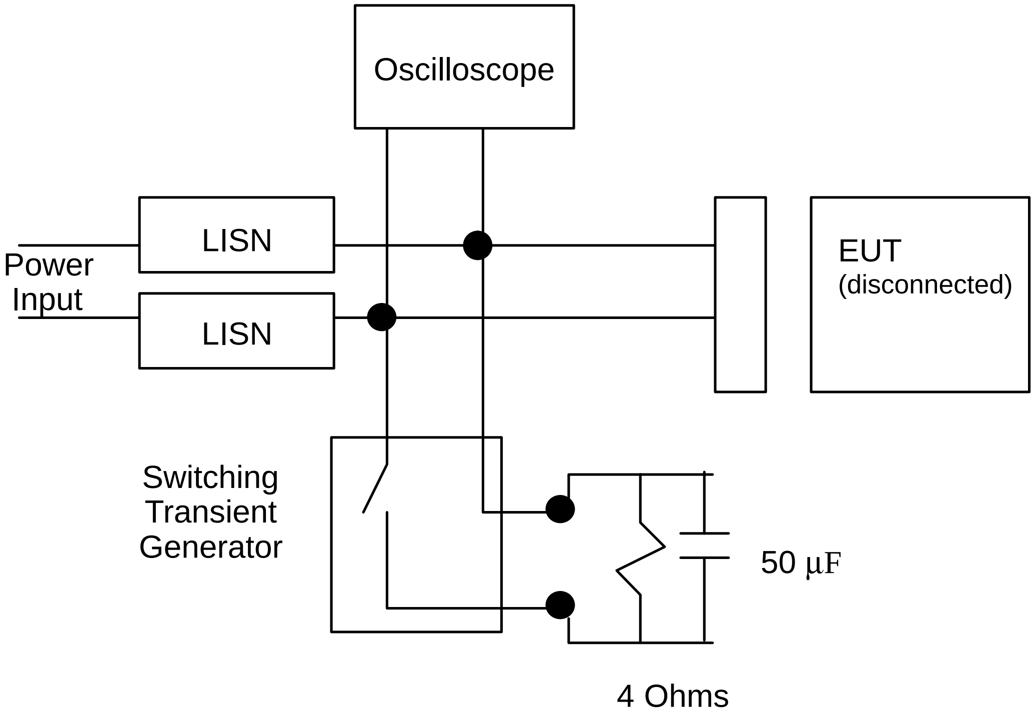


FIGURE 5-14

(CS106-2) CALIBRATION SETUP



5.9 CS114, CONDUCTED SUSCEPTIBILITY, BULK CABLE INJECTION, 10 kHz TO 200 MHz

5.9.1 CS114 Applicability

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

5.9.2 CS114 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 current limit shown in Figure 5-15 and is modulated as specified below. Requirements are also met if the EUT is not susceptible at forward power levels sensed by the coupler that are below those determined during calibration provided that the actual current induced in the cable under test is 6 dB or greater than the calibration limit.

5.9.3 CS114 Test Procedures

5.9.3.1 Purpose

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

5.9.3.2 Test Equipment

The test equipment shall be as follows:

a. Measurement receivers.

b. Current injection probes (maximum insertion loss shown in Figure 5-16, minimum insertion loss is recommended, not required).

c. Current probes.

d. Calibration fixture: coaxial transmission line with 50 ohm characteristic impedance, coaxial connections on both ends, and space for an injection probe around the center conductor.

e. Directional couplers.

f. Signal generators.

g. Plotter.

h. Attenuators, 50 ohm.

i. Coaxial loads, 50 ohm.

j. Power amplifiers.

k. LISNs.

5.9.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8.

b. Calibration. Configure the test equipment in accordance with Figure 5-17 for calibrating injection probes.

   1. Place the injection probe around the center conductor of the calibration fixture.

   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 in Figure 5-18 for testing of the EUT.

   1. Place the injection and monitor probes around a cable bundle interfacing with an EUT connector.

   2. Locate the monitor probe 5 cm from the connector. If the overall length of the connector and backshell exceeds 5 cm, position the monitor probe as close to the connector’s backshell as possible.

   3. Position the injection probe 5 cm from the monitor probe.

5.9.3.4 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 10 kHz, unmodulated.

2. Increase the applied signal until measurement receiver A indicates the current level specified in the applicable limit is flowing in the center conductor of the calibration fixture.

3. Record the forward power to the injection probe indicated on measurement receiver B.

4. Scan the frequency band from 10 kHz to 200 MHz and record the forward power needed to maintain the required current amplitude.

c. EUT Testing. Perform the following procedures on each cable bundle interfacing with each electrical connector on the EUT including complete power cables (high sides and returns). Also perform the procedures on power cables with the power returns and chassis grounds (green wires) excluded from the cable bundle. For connectors which include both interconnecting leads and power, perform the procedures on the entire bundle, on the power leads (including returns and grounds) grouped separately, and on the power leads grouped with the returns and grounds removed.

1. Turn on the EUT and allow sufficient time for stabilization.

2. Susceptibility evaluation.

   (a) Set the signal generator to 10 kHz with 1 kHz pulse modulation, 50% duty cycle.

   (b) Apply the forward power level determined under Step b, Item 4 (above) to the injection probe while monitoring the induced current.

   (c) Scan the required frequency range in accordance with Paragraph 4.3.10.4.1 and Table 4.4 while maintaining the forward power level at the calibration level determined under Step b, Item 4, 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 Paragraph 4.3.10.4.3 and verify that it is above the applicable requirement.

   (f) For EUTs with redundant cabling for safety critical reasons such as multiple data buses, use simultaneous multi-cable injection techniques.

5.9.3.5 Data Presentation

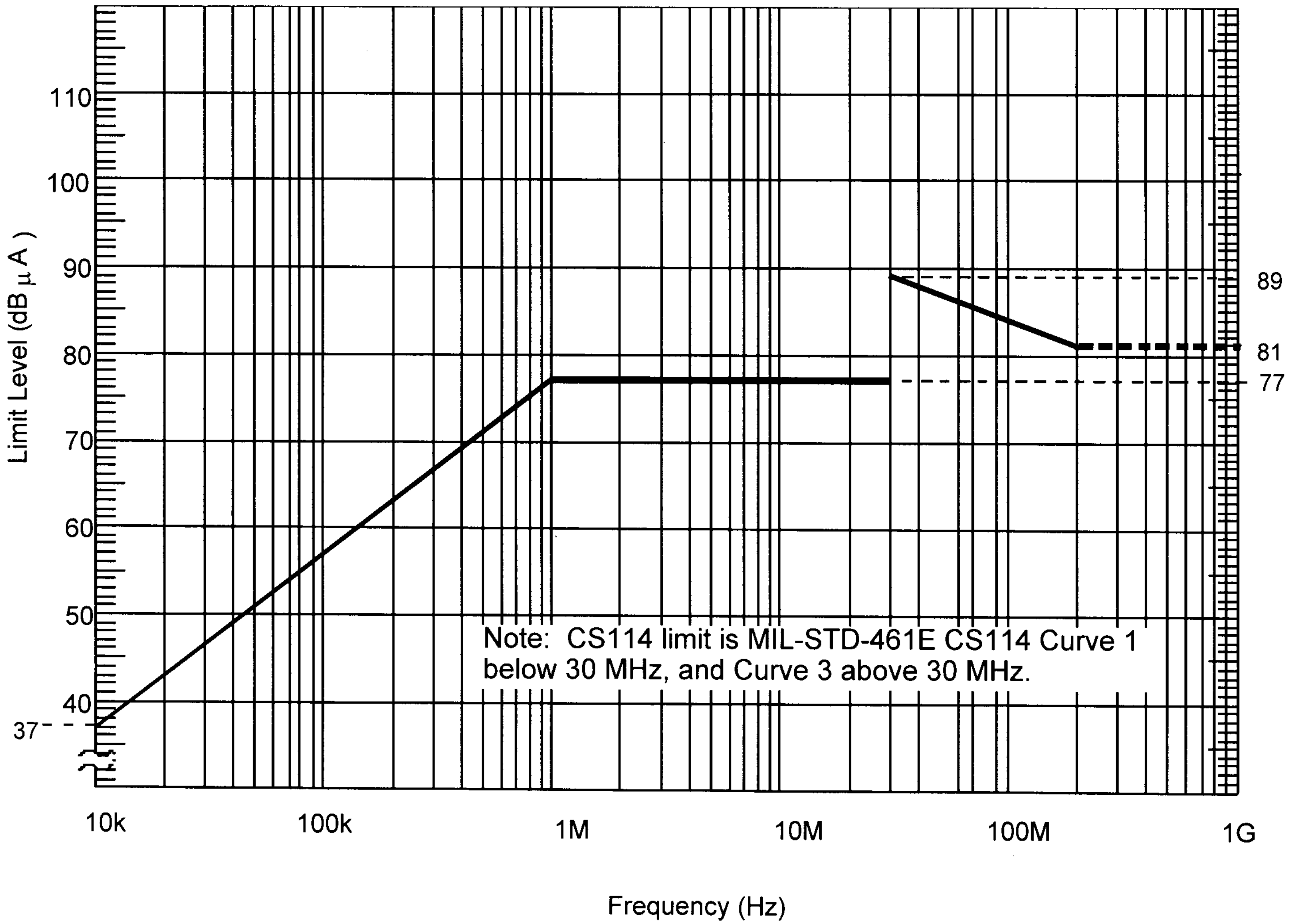
Data presentation shall be as follows:

a. Provide amplitude versus frequency plots for the forward power levels required to obtain the calibration level as determined in Paragraph 5.9.3.4, Step b, Item 4.

b. Provide tables showing scanned frequency ranges and statements of compliance with the requirements for the susceptibility evaluation of Paragraph 5.9.3.4, Step c, Item 2, for each interface connector. Provide any susceptibility thresholds that were determined, along with their associated frequencies.

FIGURE 5-15

(CS114-1) CS114 CALIBRATION LIMIT



Note: CS114 limit is MIL-STD-461E CS114 Curve 1 below 30 MHz, and Curve 3 above 30 MHz.

FIGURE 5-16

(CS114-2) MAXIMUM INSERTION LOSS FOR INJECTION PROBES

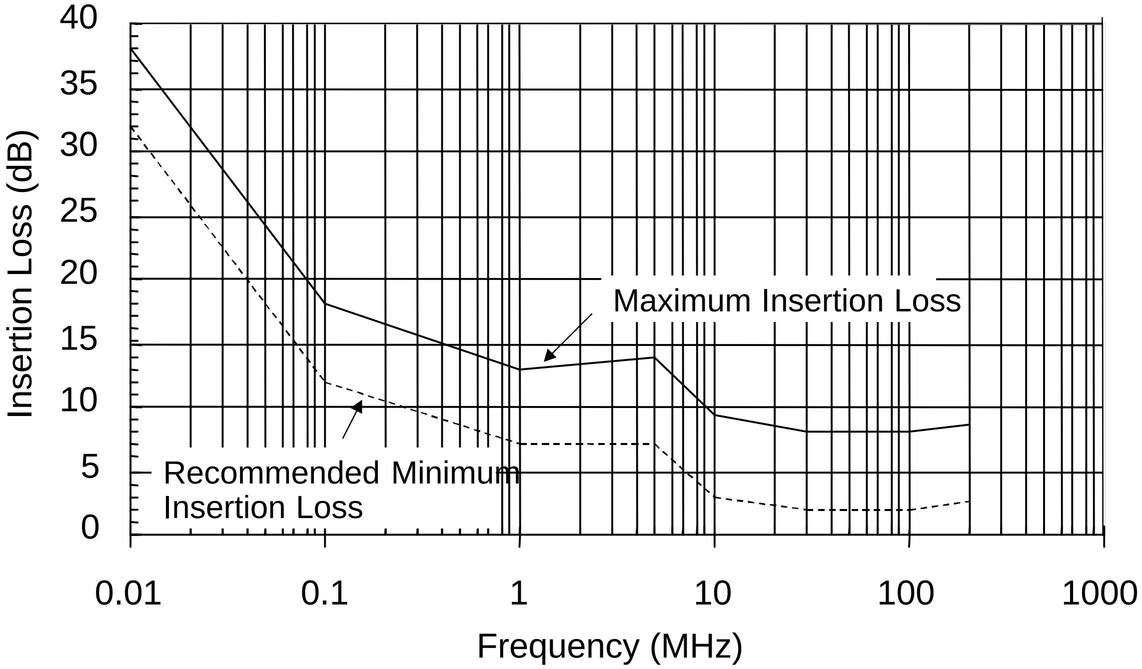


FIGURE 5-17

(CS114-3) CALIBRATION SETUP

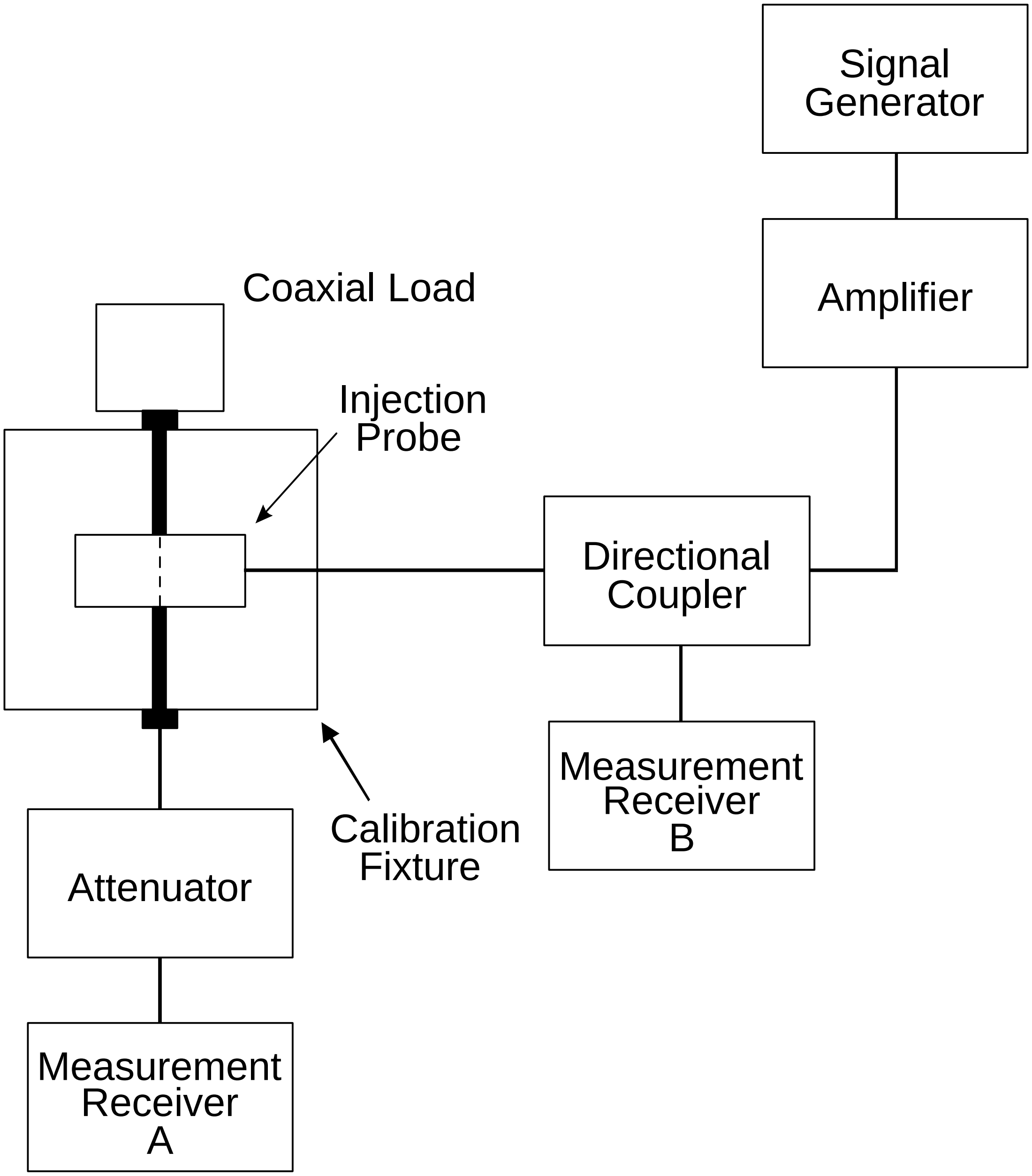
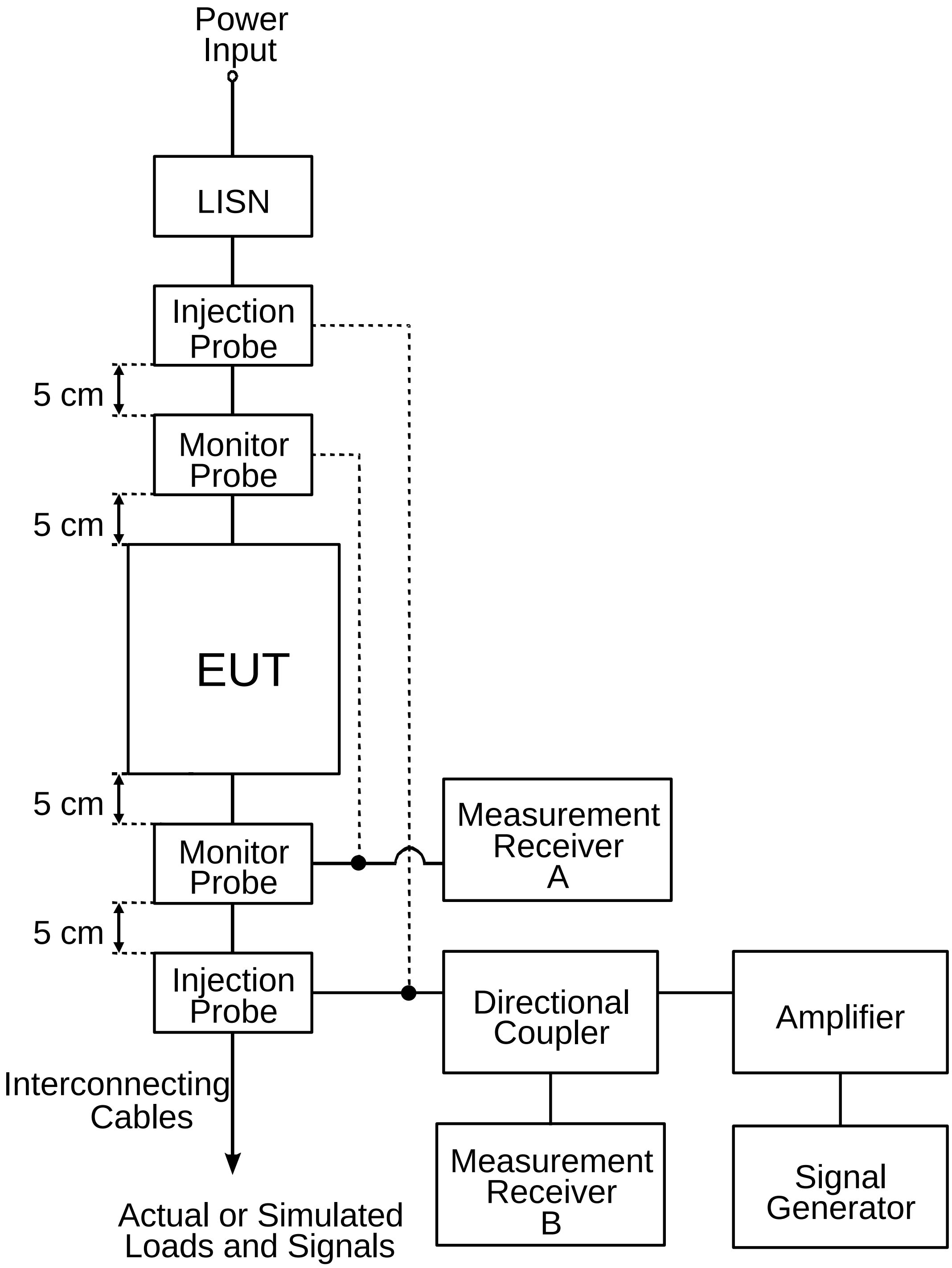


FIGURE 5-18

(CS114-4) BULK CABLE INJECTION EVALUATION



5.10 CS116, CONDUCTED SUSCEPTIBILITY, DAMPED SINUSOIDAL TRANSIENTS, CABLES AND POWER LEADS, 10 kHz TO 10 MHz

5.10.1 CS116 Applicability

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.

5.10.2 CS116 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 a signal having the waveform shown in Figure 5-19 and having a maximum current as specified in Figure 5-20. 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, and 10 MHz. 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 (pps) and no less than one pulse every two seconds. The pulses shall be applied for a period of five minutes.

5.10.3 CS116 Test Procedures

5.10.3.1 Purpose

This test procedure is used to verify the ability of the EUT to withstand damped sinusoidal transients coupled onto EUT associated cables and power leads.

5.10.3.2 Test Equipment

The test equipment shall be as follows:

a. Damped sinusoid transient generator, three 100 ohm output impedance.

b. Current injection probe.

c. Oscilloscope, 50 ohm input impedance.

d. Calibration fixture: Coaxial transmission line with 50 ohm characteristic impedance, coaxial connections on both ends, and space for an injection probe around the center conductor.

e. Current probes.

f. Waveform recording device.

g. Attenuators, 50 ohm.

h. Measurement receivers.

i. Power amplifiers.

j. Coaxial loads, 50 ohm.

k. Signal generators.

l. Directional couplers.

m. LISNs.

5.10.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8.

b. Calibration. Configure the test equipment in accordance with Figure 5-20 for verification of the waveform.

c. EUT Testing:

   1. Configure the test equipment as shown in Figure 5-21.

   2. Place the injection and monitor probes around a cable bundle interfacing an EUT connector.

   3. Locate the monitor probe 5 cm from the connector. If the overall length of the connector and backshell exceeds 5 cm, position the monitor probe as close to the connector’s backshell as possible.

   4. Position the injection probe 5 cm from the monitor probe.

5.10.3.4 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 for waveform verification.

1. Set the frequency of the damped sine generator at 10 kHz.
2. Adjust the amplitude of the signal from the damped sine generator to the level specified in the requirement.
3. Record the damped sine generator settings.
4. Verify that the waveform complies with the requirements.
5. Repeat Items 2 through 4 (above) for each frequency specified in the requirement and those identified in Step c, Item 2 (below).

c. EUT testing. Perform the following procedures, using the EUT test setup on each cable bundle interfacing with each connector on the EUT including complete power cables. Also perform tests on each individual high side power lead (individual power returns and neutrals are not required to be tested).

   1. Turn on the EUT and measurement equipment to allow sufficient time for stabilization.
   2. Set the damped sine generator to a test frequency.
   3. Apply the test signals to each cable or power lead of the EUT sequentially. Slowly increase the damped sinewave generator output level to provide the specified current, but not exceeding the precalibrated generator output level. Record the peak current obtained.
   4. Monitor the EUT for degradation of performance.
   5. If susceptibility is noted, determine the threshold level in accordance with Paragraph 4.3.10.4.3 and verify that it is above the specified requirements.
   6. Repeat Items 2 through 5 (above) for each test frequency as specified in the requirement. Repeat testing in Step c for the power-off condition.

5.10.3.5 Data Presentation

Data presentation shall be as follows:

a. Provide a list of the frequencies and amplitudes at which the test was conducted for each cable and lead.

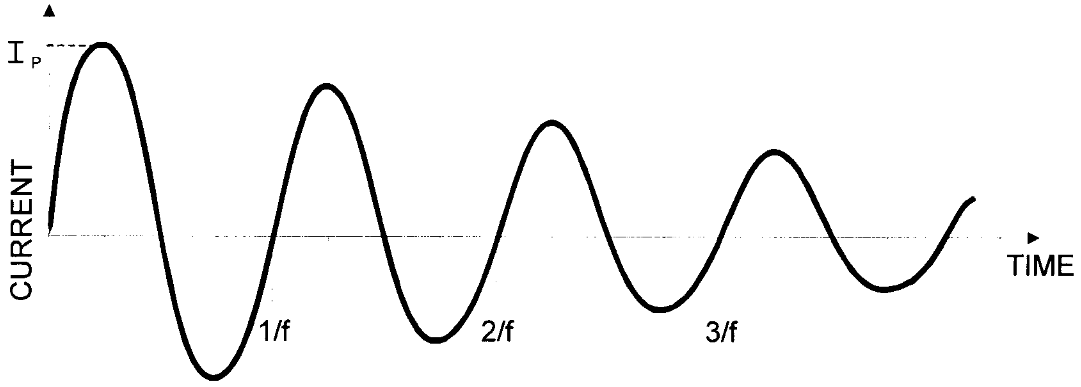
b. Provide data on any susceptibility thresholds and the associated frequencies that were determined for each connector and power lead.

c. Provide indications of compliance with the requirements for the susceptibility evaluation specified in Paragraph 5.10.3.4, Step c, for each interface connector.

d. Provide oscilloscope photographs of injected waveforms with test data.

FIGURE 5-19

(CS116-1) TYPICAL CS116 DAMPED SINUSOIDAL WAVEFORM



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

Where:
f = Frequency (Hz)
t = Time (sec)
Q = Damping factor, 15 ± 5

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

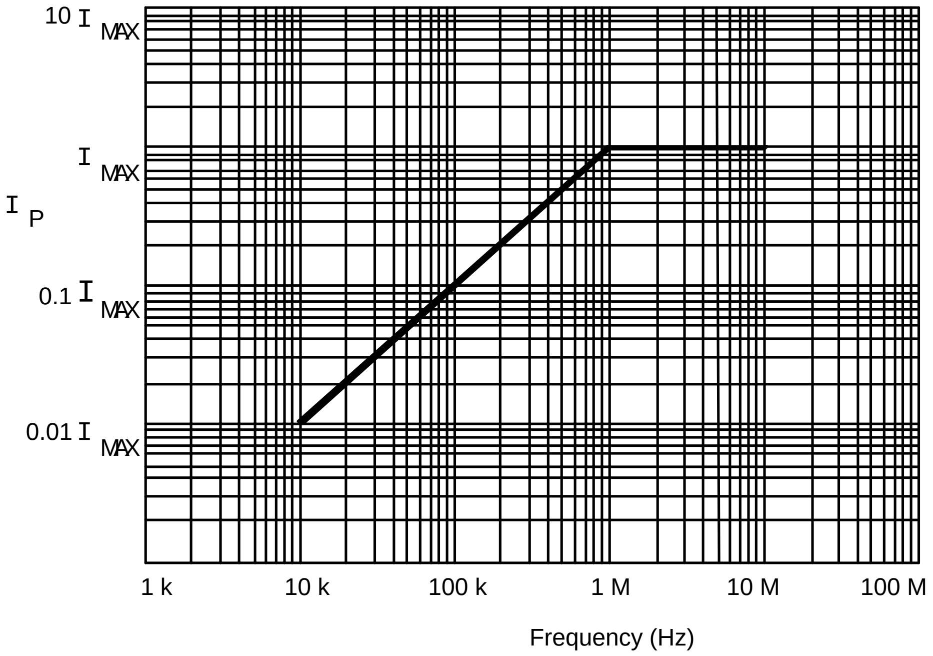
$$Q = \frac{\pi(N - 1)}{\ln(I_P/I_N)}$$

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 CS116-2

FIGURE 5-20

(CS116-2) CS116 LIMIT FOR ALL APPLICATIONS



I max = 0.5 Amp

FIGURE 5-21

(CS116-3) TYPICAL TEST SETUP FOR CALIBRATION OF TEST WAVEFORM

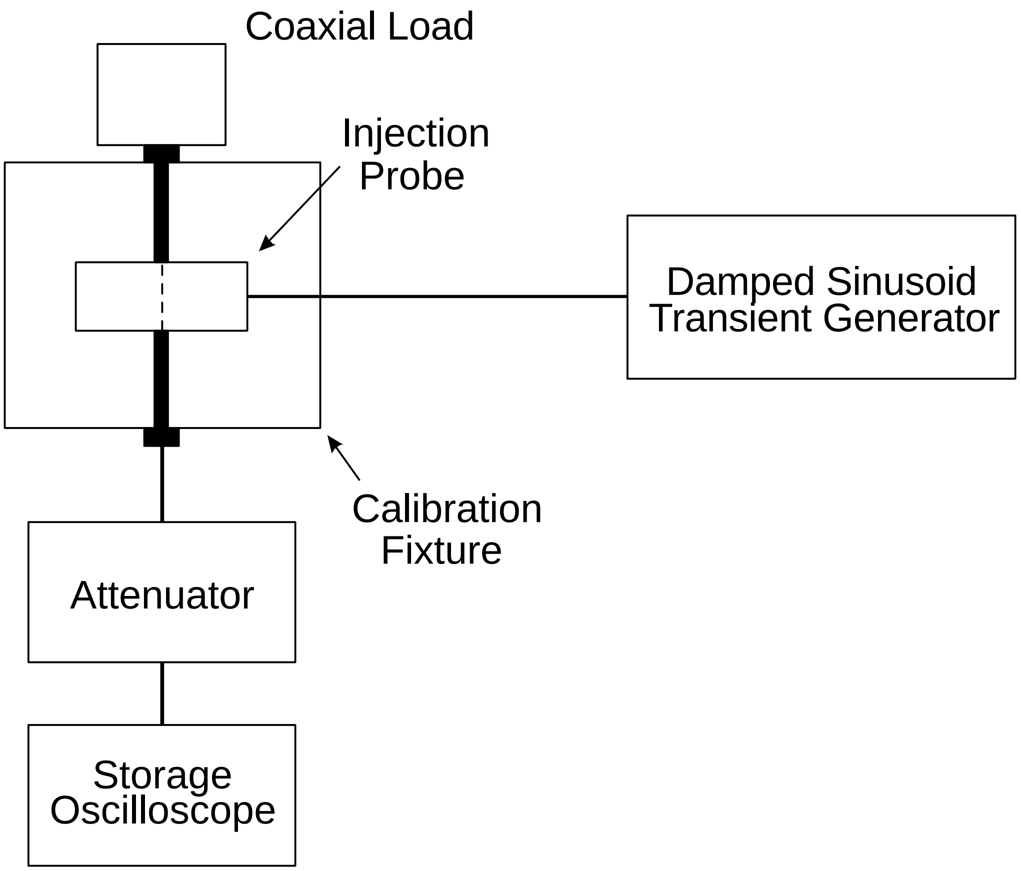
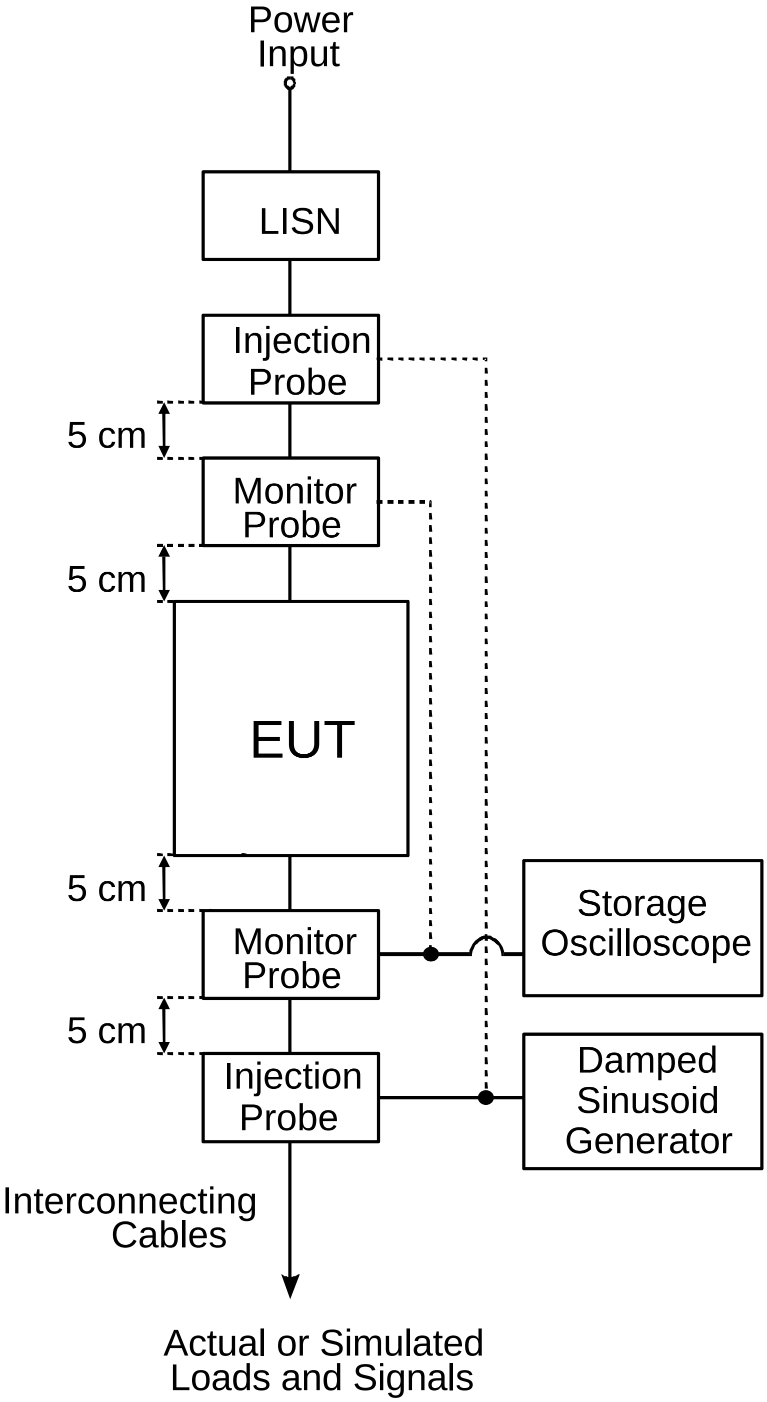


FIGURE 5-22
(CS116-4) TYPICAL SET UP FOR BULK CABLE INJECTION OF DAMPED SINUSOIDAL TRANSIENTS



5.11 RE102, RADIATED EMISSIONS, ELECTRIC FIELD, 150 kHz TO 18 GHz

5.11.1 RE102, Applicability

This requirement is applicable for REs from equipment and subsystem enclosures, all interconnecting cables including power leads, and antennas designed to be permanently mounted to EUTs (receivers and transmitters in standby mode). The requirement does not apply at the transmitter fundamental frequencies. The requirement is applicable as follows:

a. Space Shuttle BCE - 150 kHz to 200 MHz

b. Space Shuttle (including ground support equipment) REs - 200 MHz - 18 GHz*

*Testing is required up to 1 GHz or 10 times the highest intentionally generated frequency within the EUT, whichever is greater. Measurements beyond 18 GHz are not required.

5.11.2 RE102 Limits

Electric field emissions shall not be radiated in excess of those shown in Figure 5-23 through Figure 5-26 as defined in the following subsections. Above 200 MHz, the limits shall be met for both horizontally and vertically polarized fields, when the receive antenna is polarized. Circularly polarized antennas are also acceptable. For Space Shuttle applications, the RE102 limits of Figure 5-23 through Figure 5-25 are applicable as define above 200 MHz as specified in the following sections. The RE limit below 200 MHz is defined by Figure 5-26 for all applications.

5.11.2.1 Internal Equipment Installation Limits

Equipment located internal to the SSV shall meet the limit depicted in Figure 5-23.

Equipment that meets all of the following criteria may use the limit depicted in Figure 5-24.

a. The equipment is located internal to the SSV.

b. The equipment is designated as Criticality 3 or non-critical allowing it to be turned off if interference arises from its operation.

c. The equipment is not operated on the flight deck during launch and entry operational phases.

d. The equipment is not permanently manifested.

Reference Appendix B, Paragraph 5.11 for a discussion as to why the limit depicted in Figure 5-24 is acceptable only for equipment that meets all the defined criteria.

5.11.2.2 External Equipment Installation Limits

Equipment installed externally to the SSV shall meet the limit depicted in Figure 5-25 (reference definition in Paragraph 3.1).

5.11.3 RE102 Test Procedures

5.11.3.1 Purpose

This test procedure is used to verify that electric field emissions from the EUT and its associated cabling do not exceed specified requirements. The BCE portion of the requirement for Space Shuttle protects against cable-to-cable crosstalk out of band to Shuttle radio receivers.

5.11.3.2 Test Equipment

The test equipment shall be as follows:

a. Measurement receivers

b. Data recording device

c. Antennas

    1. 200 MHz to 1 GHz, logconical, logperiodic, or -double ridge horn, 69.0 by 94.5 cm opening

    2. One GHz to 18 GHz, double ridge horn, 24.2 by 13.6 cm opening

    3. One GHz to 10 GHz, logconical may be used in this band, if desired

d. Signal generators

e. Stub radiator

f. LISNs

g. Absorbing clamp (per CISPR 16, Specification for radio disturbance and immunity measuring apparatus and methods)

NOTE: Absorbing clamp must be calibrated as a current probe, not per CISPR 16.

5.11.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8. Ensure that the EUT is oriented such that the surface that produces the maximum REs is toward the front edge of the test setup boundary.

b. Calibration. For radiated calibration, configure the test equipment as shown in Figure 5-27. For BCE testing, configure per Figure 5-28.

c. EUT testing.

  1. Antenna positioning.

    (a) Determine the test setup boundary of the EUT and associated cabling for use in positioning of antennas.

    (b) Use the physical reference points on the antennas shown in Figure 5-30 for measuring heights of the antennas and distances of the antennas from the test setup boundary.

      (1) Position antennas 1 meter from the front edge of the test setup boundary for all setups.

      (2) Position antennas 120 cm above the floor ground plane.

      (3) Ensure that no part of any antenna is closer than 1 meter from the walls and 0.5 meter from the ceiling of the shielded enclosure.

      (4) For test setups using bench tops, additional positioning requirements for the antenna and distance above the bench ground plane are shown in Figure 5-30.

  2. The number of required antenna positions depends on the size of the test setup boundary and the number of enclosures included in the setup (reference Figure 5-31).

    (a) For testing from 200 MHz up to 1 GHz, place the antenna in a sufficient number of positions such that the entire width of each EUT enclosure and the first 35 cm of cables and leads interfacing with the EUT enclosure are within the 3 dB beamwidth of the antenna.

    (b) For testing at 1 GHz and above, place the antenna in a sufficient number of positions such that the entire width of each EUT enclosure and the first 7 cm of cables and leads interfacing with the EUT enclosure are within the 3 dB beamwidth of the antenna.

5.11.3.4 Procedures

The test procedures shall be as follows:

a. Verify that the ambient requirements specified in Paragraph 4.3.4 are met. Take plots of the ambient when required by the referenced paragraph.

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

c. Using the system check path of Figure 5-27, perform the following evaluation of the overall measurement system from each antenna to the data output device at the highest measurement frequency of the antenna.

   1. Apply a calibrated signal level, which is at least 6 dB below the limit (limit minus antenna factor), to the coaxial cable at the antenna connection point. For the BCE calibration, set signal generator to a potential which will yield a current flow at 6 dB below the limit at 150 kHz, 10 MHz, and 200 MHz.

   2. Scan the measurement receiver in the same manner as a normal data scan. Verify that the data recording device indicates a level within ±3 dB of the injected signal level.

   3. 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.

d. Using the measurement path of Figure 5-27, perform the following evaluation for each antenna to demonstrate that there is electrical continuity through the antenna.

   1. Radiate a signal using an antenna or stub radiator at the highest measurement frequency of each antenna.

   2. Tune the measurement receiver to the frequency of the applied signal and verify that a received signal of appropriate amplitude is present.

   NOTE: This evaluation is intended to provide a coarse indication that the antenna is functioning properly. There is no requirement to accurately measure the signal level.

e. Turn on the EUT and allow sufficient time for stabilization.

f. Using the measurement path of Figure 5-27, determine the REs from the EUT and its associated cabling. Using the setup of Figure 5-29, measure common mode emissions on all EUT attached cables (both power and signal).

NOTE: Both power conductors are tested together to ensure that only common mode power-line CEs are measured.

   1. Scan the measurement receiver for each applicable frequency range, using the BWs and minimum measurement times in Table 4.3.

2. Orient antennas for both horizontally and vertically polarized fields.
3. Take measurements for each antenna position determined under Paragraph 5.11.3.3, Step 3, Item b (above).

5.11.3.5 Data Presentation

Data presentation shall be as follows:

a. Continuously and automatically plot amplitude versus frequency profiles. Manually gathered data is not acceptable except for plot verification. Vertical and horizontal data for a particular frequency range shall be presented on separate plots or shall be clearly distinguishable in black or white format for a common plot.

b. Display the applicable limit on each plot.

c. Provide a minimum frequency resolution of 1% or twice the measurement receiver BW, 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.

e. Provide a statement verifying the electrical continuity of the measurement antennas as determined in Paragraph 5.11.3.4, Step d.

FIGURE 5-23

(RE102-1A) RE102 LIMIT FOR INTERNAL EQUIPMENT

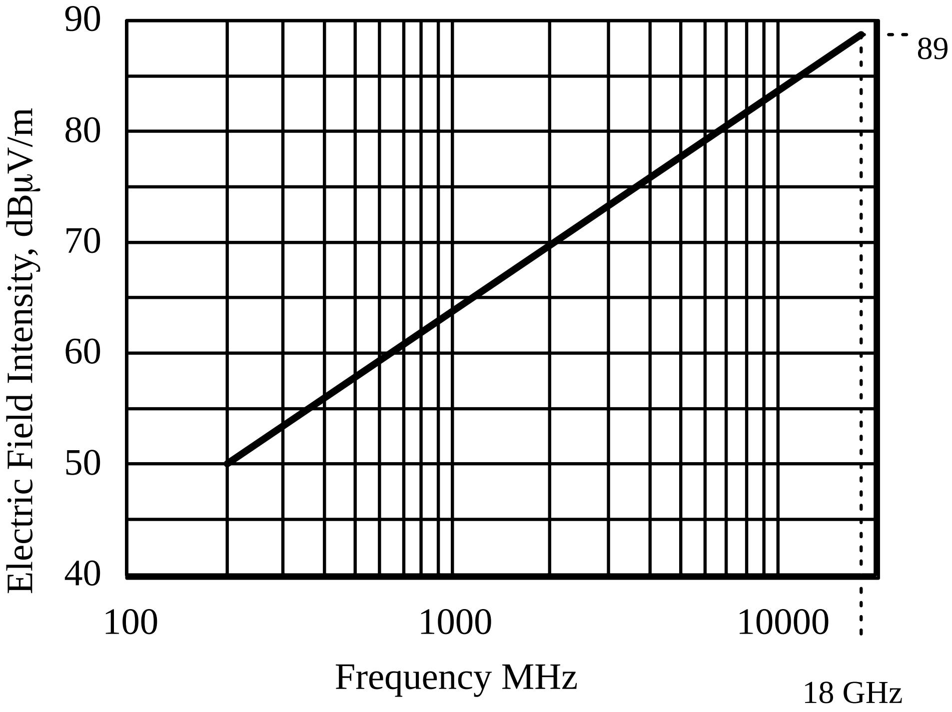


FIGURE 5-24

(RE102-1B) RE102 LIMIT FOR INTERNAL EQUIPMENT THAT MEETS ALL THE CRITERIA OF SECTION 5.11.2.1

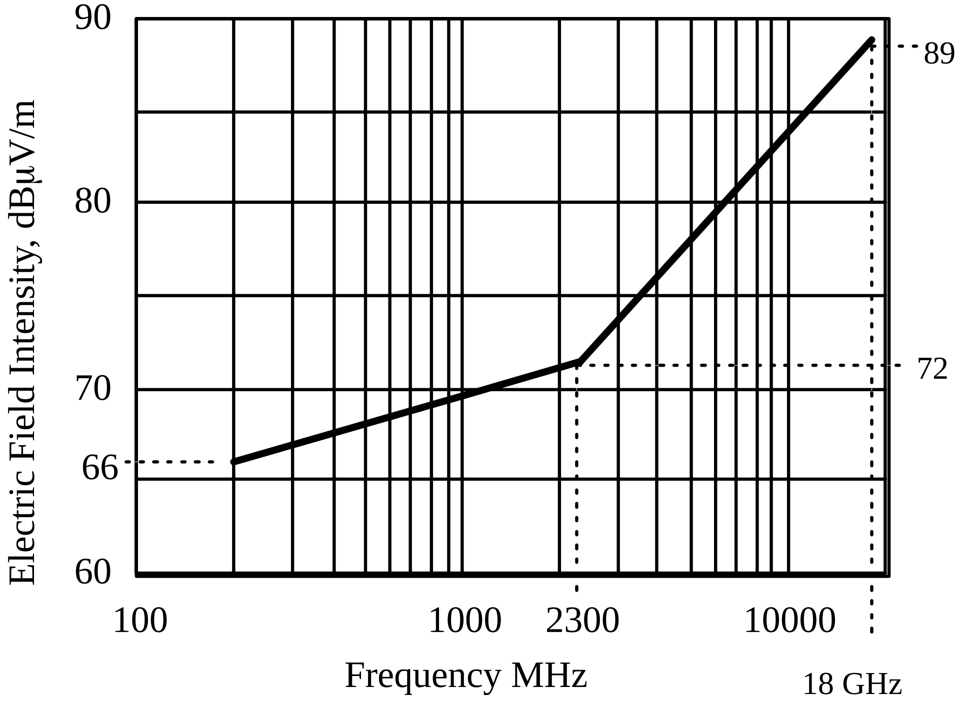


FIGURE 5-25

(RE102-1C) RE102 LIMIT FOR EXTERNAL EQUIPMENT

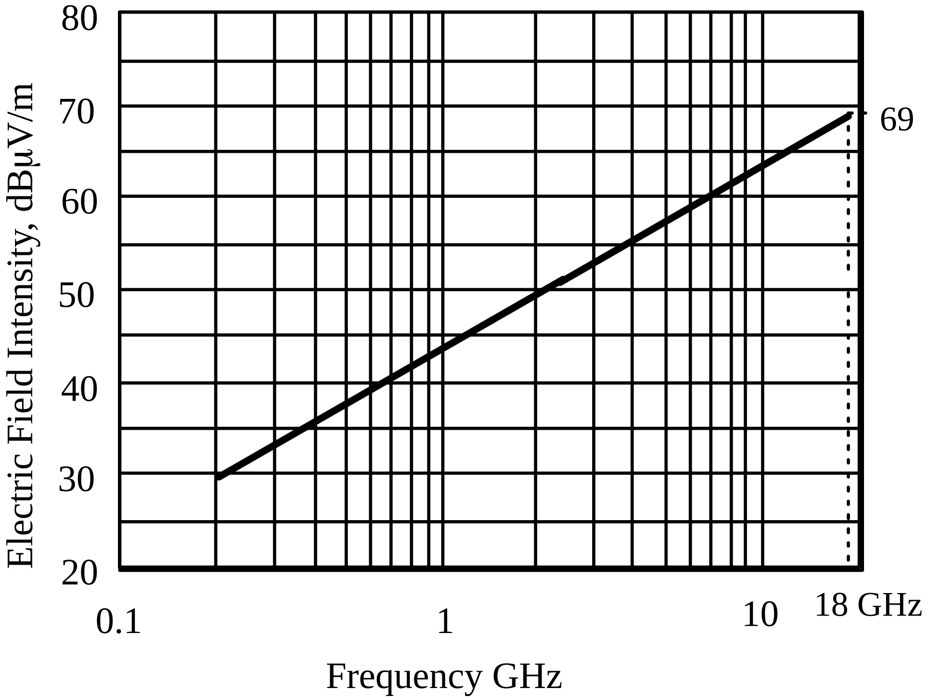


FIGURE 5-26

(RE102-1D) BCE LIMIT FOR SPACE SHUTTLE APPLICATIONS

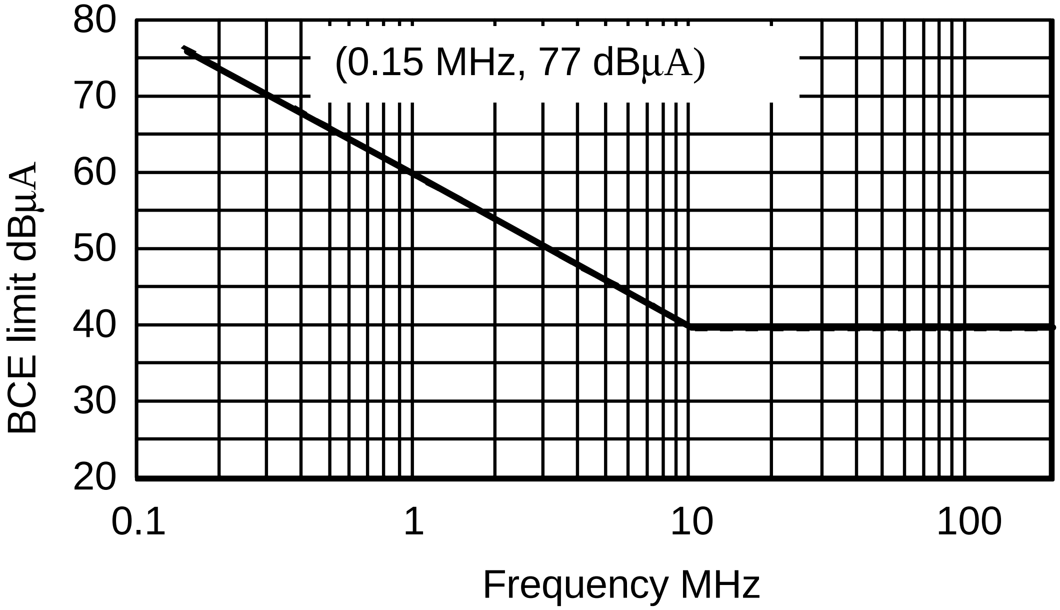


FIGURE 5-27

(RE102-2) BASIC TEST SETUP

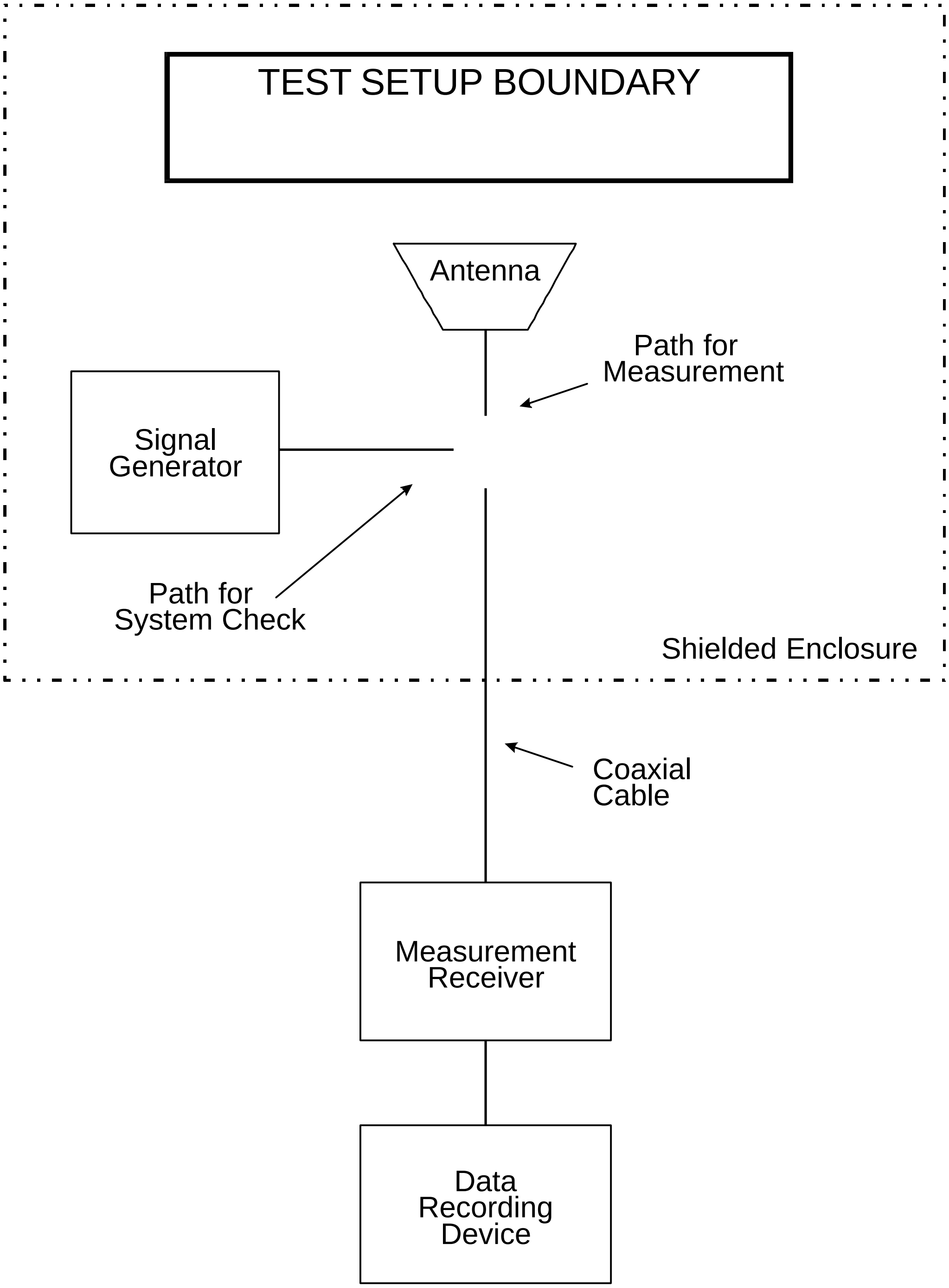


FIGURE 5-28

(RE102-2A) BASIC BCE CALIBRATION TEST SETUP

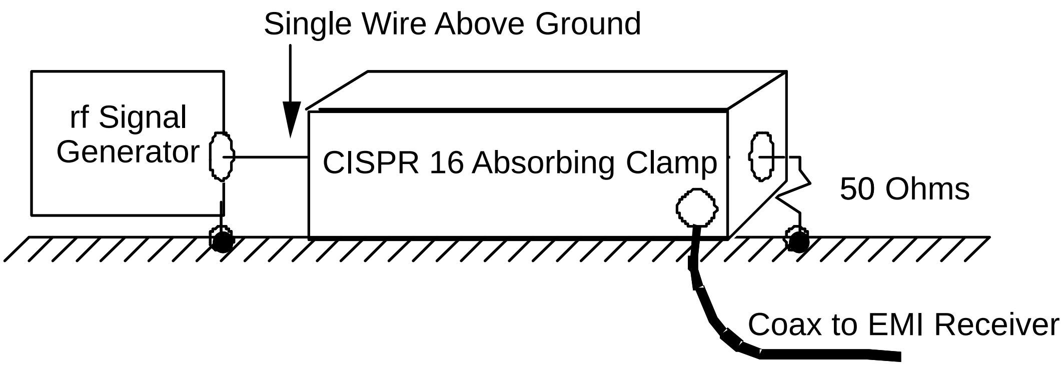


FIGURE 5-29

(RE102-2B) BCE TEST SETUP

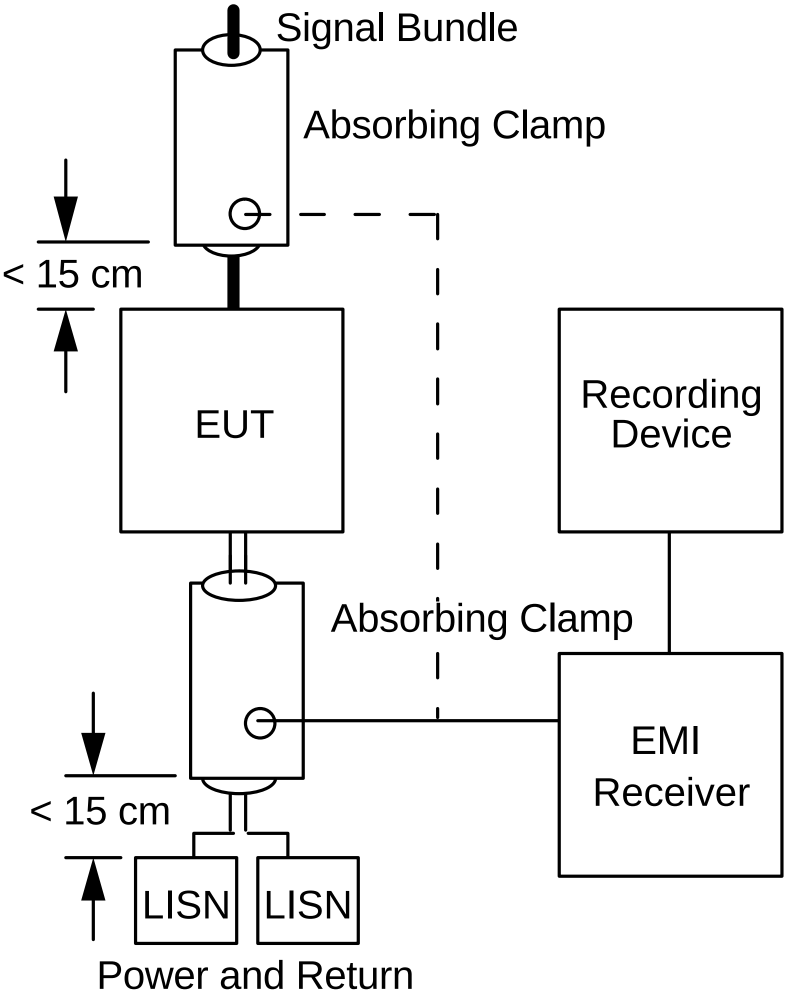


FIGURE 5-30

(RE102-3) ANTENNA POSITIONING

NOTE: The rod and biconical antenna configurations are not required for SSV testing.

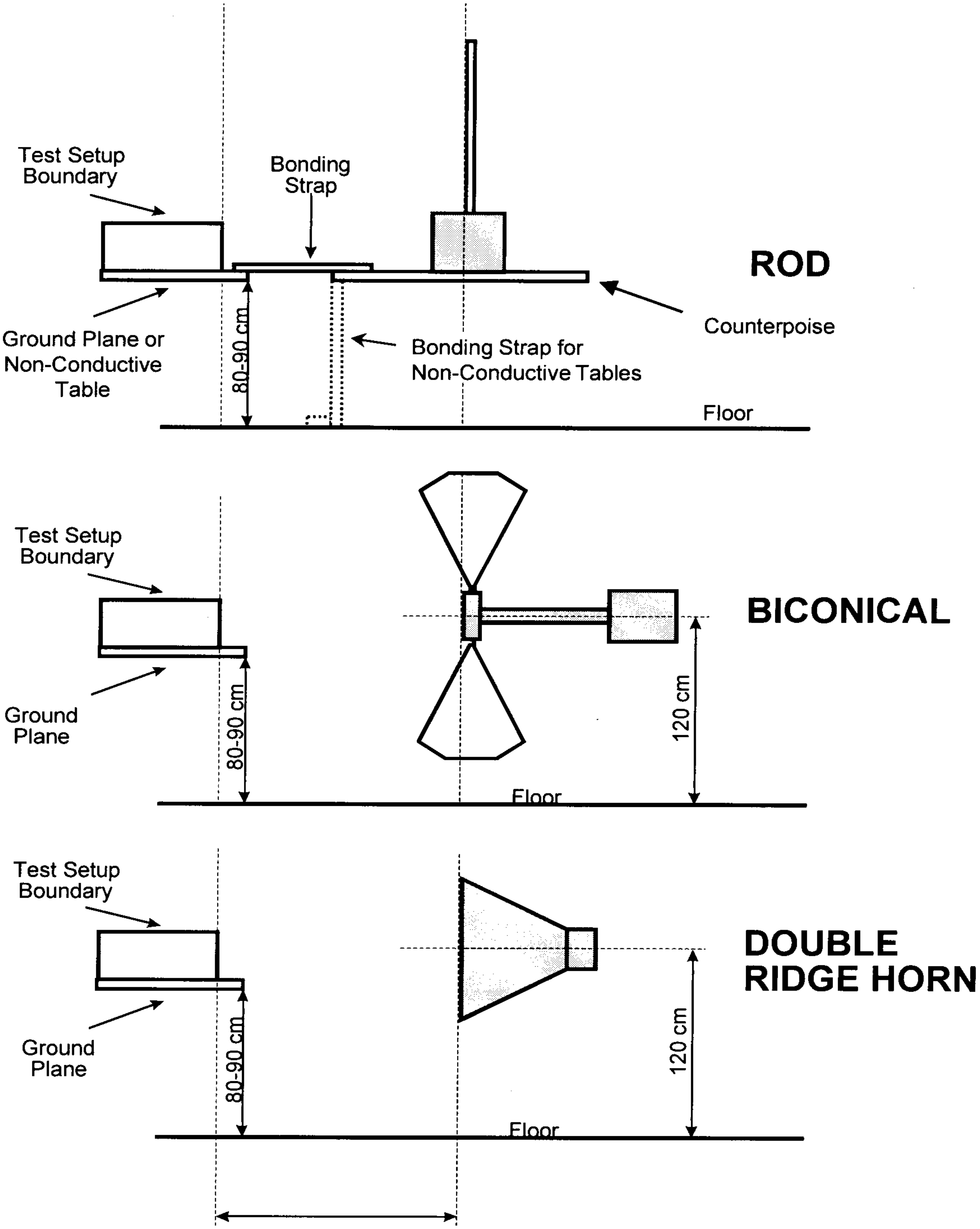
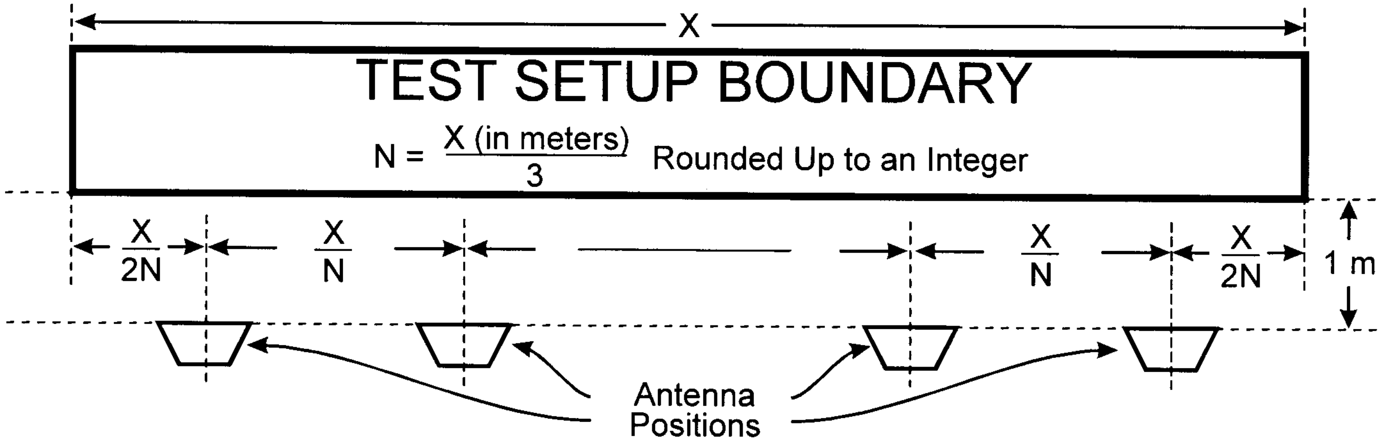
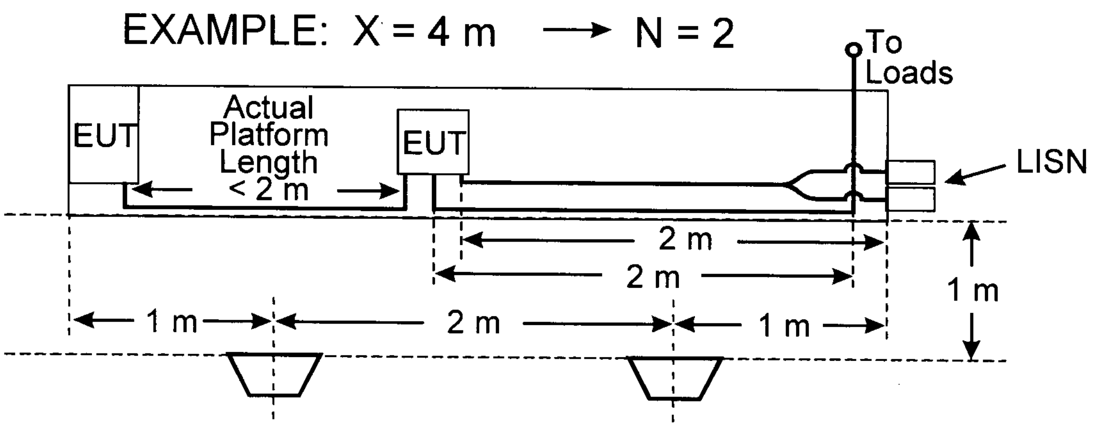


FIGURE 5-31

(RE102-4) MULTIPLE ANTENNA POSITIONS





5.12 RE103, RADIATED EMISSIONS, ANTENNA SPURIOUS AND HARMONIC OUTPUTS, 100 MHz TO 18 GHz

5.12.1 RE103 Applicability

This requirement may be used as an alternative for CE106 when testing transmitters with their intended antennas. The requirement is not applicable within the EUT necessary BW and within ±5 percent of the fundamental frequency. Depending on the operating frequency range of the EUT, the start frequency is 100 MHz for all EUT operating frequency ranges. The end frequency of the test is 18 GHz or twenty times the highest generated frequency within the EUT, whichever is less. For equipment using waveguide, the requirement does not apply below eight-tenths of the waveguide's cutoff frequency.

5.12.2 RE103 Limits

Harmonics, except the second and third, and all other spurious emissions shall be at least 80 dB 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 80 dB, whichever requires less suppression.

5.12.3 RE103 Test Procedures

5.12.3.1 Purpose

This test procedure is used to verify that radiated spurious and harmonic emissions from transmitters do not exceed the specified requirements.

5.12.3.2 Test Equipment

The test equipment shall be as follows:

a. Measurement receiver

b. Attenuators, 50 ohm

c. Antennas

d. Rejection networks

e. Signal generators

f. Power monitor

5.12.3.3 Setup

It is not necessary to maintain the basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8. The test setup shall be as follows:

a. Calibration. Configure the test setup for the signal check path shown in Figure 5-32 or Figure 5-33, as applicable.

b. EUT Testing. Configure the test setup for the measurement path shown in Figure 5-32 or Figure 5-33, as applicable.

5.12.3.4 Procedures

The test procedures shall be as follows:

a. The measurements must be performed in the far-field of the transmitting frequency. Consequently, the far-field test distance must be calculated prior to performing the test using the relationships below:

R = distance between transmitter antenna and receiver antenna.

D = maximum physical dimension of transmitter antenna.

d = maximum physical dimension of receiver antenna.

λ = wavelength of frequency of the transmitter.

All dimensions are in meters.

For transmitter frequencies less than or equal to 1.24 GHz, the greater distance of the following relationships shall be used:

$R = 2D^2/\lambda \qquad R = 3\lambda$

For transmitter frequencies greater than 1.24 GHz, the separation distance shall be calculated as follows:

For $2.5\,D < d$ use $R = 2D^2/\lambda$

For $2.5\,D \geq d$ use $R = (D+d)^2/\lambda$

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

c. Calibration.

1. Apply a known calibrated signal level from the signal generator through the system check path at a midband fundamental frequency (f_o).
2. Scan the measurement receiver in the same manner as a normal data scan. Verify the measurement receiver detects a level within ±3 dB of the expected signal.
3. 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 test.
4. Repeat Items 1 through 4 (above) for two other frequencies over the frequency range of test.

d. EUT Testing.

1. Turn on the EUT and allow a sufficient time for stabilization.
2. Tune the EUT to the desired test frequency and use the measurement path to complete the rest of this procedure.
3. Tune the test equipment to the measurement frequency (f_o) of the EUT and adjust for maximum indication.
4. For transmitters where a power monitor can be inserted, measure the modulated transmitter power output P, using a power monitor while keying the transmitter. Convert this power level to units of dB relative to 1 watt (decible watt [dBW]). Calculate the Effective Radiated Power (ERP) by adding the EUT antenna gain to this value. Record the resulting level for comparison with that obtained in Item 6 (below).
5. Key the transmitter with desired modulation. Tune the measurement receiver for maximum output indication at the transmitted frequency. If either or both of the antennas have directivity, align both in elevation and azimuth for maximum indication. Verbal communication between sites via radiotelephone will facilitate this process. Record the resulting maximum receiver meter reading and the measurement receiver BW.
6. Calculate the transmitter ERP in dBW, based on the receiver meter reading V, using the following equation:

$$\mathrm{ERP} = V + 20 \log R + AF - 135$$

where:

V = reading on the measurement receiver in dBμV

R = distance between transmitter and receiver antennas in meters

AF = antenna factor of receiver antenna in dB (1/m)

Compare this calculated level to the measured level recorded in Item 4 (above). The compared results should agree within ±3 dB. If the difference exceeds ±3 dB, check the test setup for errors in measurement distance, amplitude calibration, power monitoring of the transmitter, frequency tuning or drift and antenna boresight alignment. Assuming that the results are within the ±3 dB tolerance, the ERP becomes the reference for which amplitudes of spurious and harmonics will be compared to determine compliance with standard limits.

7. With the rejection network filter connected and tuned to f_o, scan the measurement receiver over the frequency range of test to locate spurious and

harmonic transmitted outputs. It may be necessary to move the measuring system antenna in elevation and azimuth at each spurious and harmonic output to assure maximum levels are recorded. Maintain the same measurement receiver BW used to measure the fundamental frequency in Item 5 (above).

8. Verify that spurious outputs are from the EUT and not spurious responses of the measurement system or the test site ambient.
9. Calculate the ERP of each spurious output. Include all correction factors for cable loss, amplifier gains, filter loss, and attenuator factors.
10. Repeat Items 2 through 9 (above) for other f_o of the EUT.

5.12.3.5 Data Presentation

Data presentation shall be as follows:

Provide tabular data showing fundamental frequency (f_o) and frequency of all harmonics and spurious emissions measured, the measured power monitor level and the calculated ERP of the fundamental frequency, the ERP of all spurious and harmonics emissions measured, dB down levels, and all correction factors including cable loss, attenuator pads, amplifier gains, insertion loss of rejection networks and antenna gains.

The relative dB down level is determined by subtracting the level in Paragraph 5.12.4, Step d, Item 6, from that recorded in Paragraph 5.12.4, Step d, Item 9.

FIGURE 5-32

(RE103-1) CALIBRATION AND TEST SETUP FOR RADIATED HARMONICS AND SPURIOUS EMISSIONS, 100 MHz TO 1 GHz

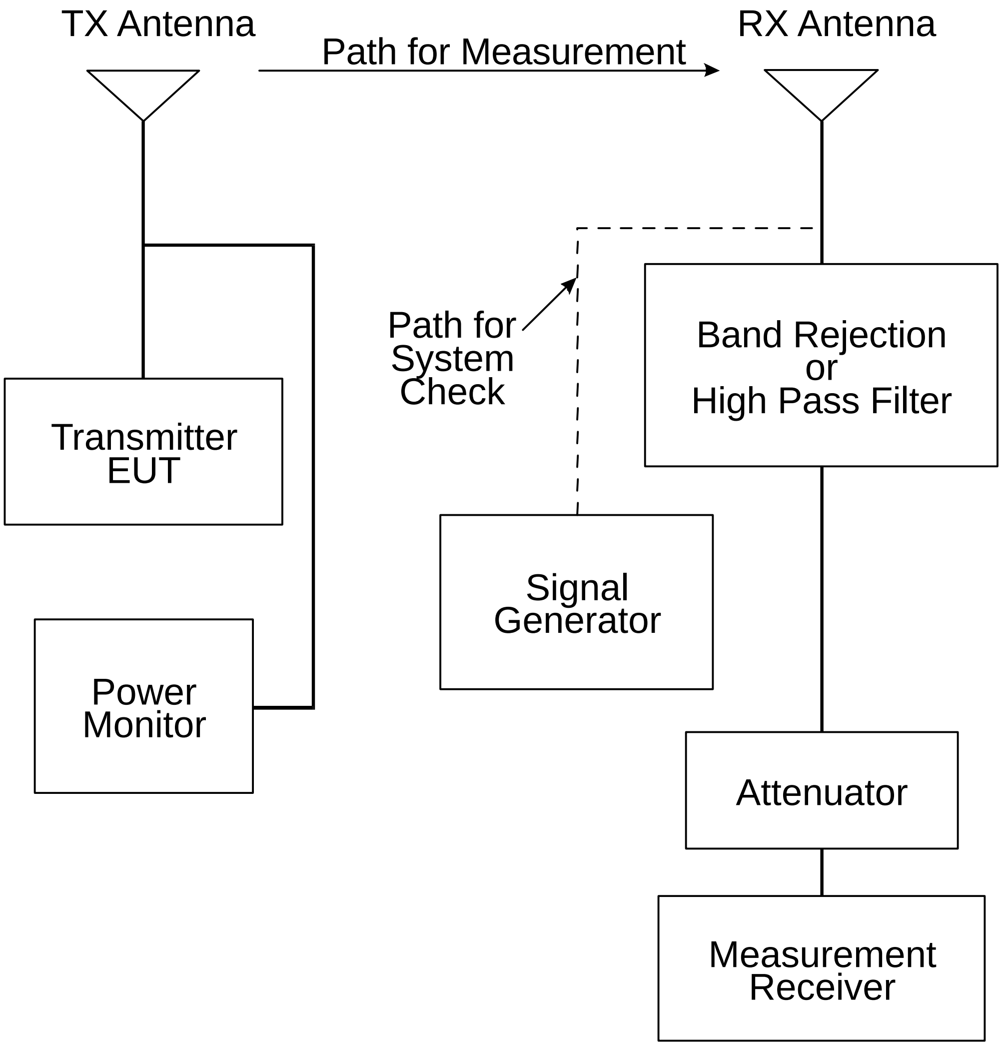
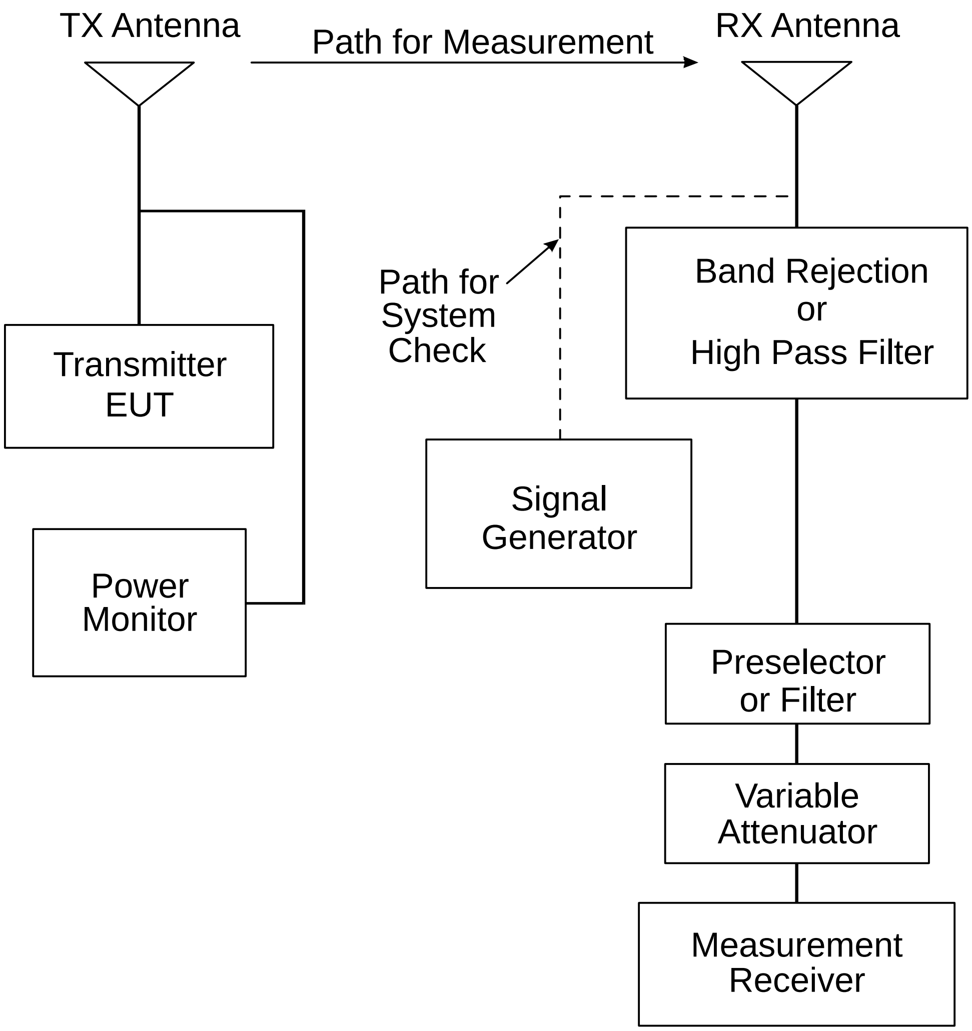


FIGURE 5-33

(RE103-2) CALIBRATION AND TEST SETUP FOR RADIATED HARMONICS AND SPURIOUS EMISSIONS, 1 GHz TO 18 GHz



5.13 RS103, RS, ELECTRIC FIELD, 30 MHz TO 18 GHz

5.13.1 RS103 Applicability

This requirement is applicable to equipment and subsystem enclosures and all interconnecting cables. The requirement is applicable as follows:

a. 30 MHz to 18 GHz

b. 18 GHz to 40 GHz - optional*

*Required only if specified in the procurement specification

The requirement at the tuned frequency of an antenna-connected receiver is 20 dB above the RE102 limit associated with the particular platform application, with the antenna port dummy loaded and shielded.

5.13.2 RS103 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 the radiated electric fields listed in Table 5.1 or Table 5.2 (as applicable) and modulated as specified below the tables. EMC critical equipment is defined in SL-E-0001, Specification Electromagnetic Compatibility Requirement. The requirement shall be met for both horizontally and vertically polarized fields. Circularly polarized fields are not acceptable.

TABLE 5.2

(RS103-1) RS103 LIMITS FOR EMC CRITICAL EQUIPMENT (AS DEFINED IN SL-E-0001)

Frequency	Test Level (V/m) Square Wave Modulation	Test Level (V/m) Low prf Pulse Modulation
30 MHz - 1 GHz	20	N/A
1 - 18 GHz	N/A	200

TABLE 5.3

(RS103-2) RS103 LIMITS FOR NON-EMC CRITICAL EQUIPMENT

Frequency	Test Level (V/m) Square Wave Modulation	Test Level (V/m) Low prf Pulse Modulation
30 MHz - 18 GHz	20	N/A

50% duty cycle pulse or amplitude modulation: use 1 kHz, 50% duty cycle pulse modulation with at least 40 dB on/off ratio, or square wave amplitude modulation with at least 99% depth.

Low pulse repetition frequency (prf) pulse modulation: use a 4 microsecond pulse at a 1 kHz prf from 1 to 18 GHz.

5.13.3 RS103 Test Procedures

5.13.3.1 Purpose

This test procedure is used to verify the ability of the EUT and associated cabling to withstand electric fields.

5.13.3.2 Test Equipment

The test equipment shall be as follows:

a. Signal generators

b. Power amplifiers

c. Receive antennas

    1. 1 GHz to 10 GHz, double ridge horns

    2. 10 GHz to 40 GHz, other antennas as approved by the procuring activity

d. Transmit antennas

e. Electric field sensors (physically small - electrically short)

f. Measurement receiver

g. Power meter

h. Directional coupler

i. Attenuator

j. Data recording device

k. LISNs

5.13.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8.

b. For electric field calibration, electric field sensors are required from 100 MHz to 1 GHz. Either field sensors or receive antennas may be used above 1 GHz (reference Paragraph 5.13.3.2, Step c and Step e).

c. Configure test equipment as shown in Figure 5-34.

d. Calibration.

    1. Placement of electric field sensors (reference Step b [above]). Position sensors 1 meter from, and directly opposite, the transmit antenna as shown in Figure 5-35 and Figure 5-36 and a minimum of 30 cm above the ground plane. Do not place sensors directly at corners or edges of EUT components.

    2. Placement of receive antennas (reference Step b [above]). Prior to placement of the EUT, position the receive antenna, as shown in Figure 5-37, on a dielectric stand at the position and height above the ground plane where the center of the EUT will be located.

e. EUT testing.

    1. Placement of transmit antennas. Antennas shall be placed 1 meter from the test setup boundary as follows:

        (a) 30 MHz to 200 MHz

            (1) Test setup boundaries ≤ 3 meters. Center the antenna between the edges of the test setup boundary. The boundary includes all enclosures of the EUT and the 2 meters of exposed interconnecting and power leads required in Paragraph 4.3.8.6. Interconnecting leads shorter than 2 meters are acceptable when they represent the actual platform installation.

            (2) Test setup boundaries > 3 meters. Use multiple antenna positions (N) at spacings as shown in Figure 5-36. The number of antenna positions (N) shall be determined by dividing the edge-to-edge boundary distance (in meters) by 3 and rounding up to an integer.

(b) 200 MHz and above. Multiple antenna positions may be required as shown in Figure 5-35. Determine the number of antenna positions (N) as follows:

(1) For testing from 200 MHz up to 1 GHz, place the antenna in a sufficient number of positions such that the entire width of each EUT enclosure and the first 35 cm of cables and leads interfacing with the EUT enclosure are within the 3 dB beamwidth of the antenna.

(2) For testing at 1 GHz and above, place the antenna in a sufficient number of positions such that the entire width of each EUT enclosure and the first 7 cm of cables and leads interfacing with the EUT enclosure are within the 3 dB beamwidth of the antenna.

2. Maintain the placement of electric field sensors as specified in Step d, Item 1 (above).

5.13.3.4 Procedures

The test procedures shall be as follows:

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

b. Assess the test area for potential RF hazards and take necessary precautionary steps to assure safety of test personnel.

c. Calibration.

1. Electric field sensor procedure. Record the amplitude shown on the electric field sensor display unit due to EUT ambient. Reposition the sensor, as necessary, until this level is < 10% of the applicable field strength to be used for testing.

2. Receive antenna procedure (> 1 GHz).

(a) Connect a signal generator to the coaxial cable at the receive antenna connection point (antenna removed). Set the signal source to an output level of 0 decibel milliWatt (dBm) at the highest frequency to be used in the present test setup. Tune the measurement receiver to the frequency of the signal source.

(b) Verify that the output indication is within ±3 dB of the applied signal, considering all appropriate losses. If larger deviations are found, locate the source of the error and correct the deficiency before proceeding.

(c) Connect the receive antenna to the coaxial cable as shown in Figure 5-37. Set the signal source to the applicable modulation noted in Table 5.1 or Table 5.2. Using an appropriate transmit antenna and amplifier, establish an electric field at the test start frequency. Gradually increase the electric field level until it reaches the applicable limit.

(d) Scan the test frequency range and record the required input power levels to the transmit antenna to maintain the required field.

(e) Repeat procedures Step c, Item 2a through Step c, Item 2d (above) whenever the test setup is modified or an antenna is changed.

3. EUT Testing.

   (a) E-Field sensor procedure.

      (1) Set the signal source to the applicable modulation as noted in Table 5.1 or Table 5.2 and using appropriate amplifier and transmit antenna, establish an electric field at the test start frequency. Gradually increase the electric field level until it reaches the applicable limit.

      (2) Scan the required frequency ranges in accordance with the rates and durations specified in Table 4.4. Maintain field strength levels in accordance with the applicable limit. Monitor EUT performance for susceptibility effects.

   (b) Receive antenna procedure.

      (1) Remove the receive antenna and reposition the EUT in conformance with Paragraph 5.13.3.3, Step a.

      (2) Set the signal source to the applicable modulation noted in Table 5.1 or Table 5.2. Using an appropriate amplifier and transmit antenna, establish an electric field at the test start frequency. Gradually increase the input power level until it corresponds to the applicable level recorded during the calibration routine.

      (3) Scan the required frequency range in accordance with the rates and durations specified in Table 4.4 while assuring the correct transmitter input power is adjusted in accordance with the calibration data collected. Constantly monitor the EUT for susceptibility conditions.

   (c) If susceptibility is noted, determine the threshold level in accordance with Paragraph 4.3.10.4.3 and verify that it is above the limit.

(d) Perform testing over the required frequency range with the transmit antenna vertically polarized. Repeat the testing with the transmit antenna horizontally polarized.

(e) Repeat Step d (above) for each transmit antenna position required by Paragraph 5.13.3.3, Step e.

5.13.3.5 Data Presentation

Data presentation shall be as follows:

a. Provide graphical and tabular data showing frequency ranges and field strength levels tested.

b. Provide graphical and tabular data listing (antenna procedure only) all calibration data collected to include input power requirements used versus frequency, and results of system check in Paragraph 5.13.3.4, Step c, Item 2c and Item 2d.

c. Provide the correction factors necessary to adjust sensor output readings for equivalent peak detection of modulated waveforms.

d. Provide graphs or tables listing any susceptibility thresholds that were determined along with their associated frequencies.

e. Provide diagrams or photographs showing actual equipment setup and the associated dimensions.

5.13.4 RS103 Alternative Test Procedures - Reverberation Chamber (mode-tuned)

These procedures may be substituted for the Paragraph 5.13.3 procedures over the frequency range of 200 MHz to 40 GHz. The lower frequency limit is dependent on chamber size. To determine the lower frequency limit for a given chamber, use the following formula to determine the number of possible modes (N) which can exist at a given frequency. If, for a given frequency, N is less than 100 then the chamber should not be used at or below that frequency.

$$N = \frac{8\pi}{3} abd \frac{f^3}{c^3}$$

where: a, b, and d are the chamber internal dimensions in meters
f is the operation frequency in Hz
c is the speed of propagation (3×10^8 m/s)

5.13.4.1 Purpose

This test procedure is an alternative technique used to verify the ability of the EUT and associated cabling to withstand electric fields.

5.13.4.2 Test Equipment

The test equipment shall be as follows:

a. Signal generators

b. Power amplifiers

c. Receive antennas

   1. 200 MHz to 1 GHz, log periodic or double ridge horns

   2. 1 GHz to 18 GHz, double ridge horns

   3. 18 GHz to 40 GHz, other antennas as approved by the procuring activity

d. Transmit antennas

e. Electric field sensors (physically small - electrically short), each axis independently displayed

f. Measurement receiver

g. Power meter

h. Directional coupler

i. Attenuator, 50 ohm

j. Data recording device

k. LISNs

5.13.4.3 Setup

The test setup shall be as follows:

a. Install the EUT in a reverberation chamber using the basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8. The EUT shall be at least 1.0 meter from the chamber walls, the tuner, and antennas.

b. For electric field calibration, electric field sensors (Paragraph 5.13.4.2, Step e) are required from 200 MHz to 1 GHz. Either field sensors or receive antennas may be used above 1 GHz (reference Paragraph 5.13.4.2, Step c and Step e).

c. Configure the test equipment as shown in Figure 5-38 and Figure 5-39. The same configuration is used for both calibration and EUT testing. Both the transmit and receive antennas shall be present in the chamber for all calibration and EUT testing, including for the electric-field probe technique. Unused receive antennas shall be terminated in 50 ohms.

5.13.4.4 Procedures

The test procedures shall be as follows:

a. Calibration. Use the following procedure to determine the electric field strength that will be created inside the chamber when a fixed amount of RF energy is injected into the chamber.

  1. Receive antenna procedure.

    (a) Adjust the RF source to inject an appropriate forward power (unmodulated) into the chamber at the start frequency of the test.

    (b) Measure the level at the receive antenna using the measurement receiver.

    (c) Rotate the tuner 360 degrees using the minimum number of steps required from Table 5.3. Allow the paddle wheel to dwell at each position for a period corresponding to a minimum of 1.5 times the response time of the measurement receiver.

    (d) Record the maximum amplitude of the signal received and use the following formula to derive a calibration factor for the field strength created inside the chamber. ($P_{r\text{-max}}$ and $P_{forward}$ in watts; λ in meters).

$$\text{Calibration factor} = \frac{8\pi}{\lambda}\sqrt{5\left(\frac{P_{r-\max}}{P_{forward}}\right)} \quad \text{V/m (for one watt)}$$

    (e) Repeat the procedure in frequency steps no greater than 2% of the preceding frequency until 1.1 times the start frequency is reached. Continue the procedure in frequency steps no greater than 10% of the preceding frequency, thereafter.

  2. Electric field probe procedure.

    (a) Adjust the RF source to inject an appropriate forward power ($P_{forward}$) (unmodulated) into the chamber at the start frequency of the test.

    (b) Rotate the tuner 360 degrees using the minimum number of steps required from Table 5.3. Allow the tuner to dwell at each position for a period corresponding to a minimum of 1.5 times the probe response time.

(c) Record the maximum amplitude from the receive antenna ($P_{r\text{-}max}$) and from each element of the probe and use the following formula to derive a calibration factor for the field strength created inside the chamber. (Probe reading in V/m and $P_{forward}$ in watts).

$$\text{Calibrationfactor} = \sqrt{\left(\frac{E_{x-\max}+E_{y-\max}+E_{z-\max}}{3}\right)^2 \Big/ P_{forward}} \quad \text{V/m (for one watt)}$$

(d) Repeat the procedure in frequency steps no greater than 2% of the preceding frequency until 1.1 times the start frequency is reached. Continue the procedure in frequency steps no greater than 10% of the preceding frequency, thereafter.

3. EUT testing. The same antennas used for calibration shall be used for EUT testing.

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

(b) Set the RF source to the start frequency of the test with the applicable modulation as noted in Table 5.1 or Table 5.2.

(c) Calculate the amount of RF power needed to create the desired field strength by determining the difference (in dB - decibel differences are the same for both field strength and power, there is a square law relationship between field strength and power in real numbers) between the desired field strength and the field strength obtained during the calibration. Adjust the chamber peak forward power to this value. Interpolation between calibration points is required.

(d) Adjust the measurement receiver to display the received signal at the receive antenna to verify that an electric field is present.

(e) Rotate the tuner 360 degrees using the minimum of steps shown in Table 5.3. Allow the tuner to dwell at each position for the duration specified in Table 4.4. As the tuner rotates, maintain the forward power required to produce field levels at the applicable limit as determined from the calibration.

(f) Scan the required frequency range in accordance with the maximum frequency step sizes and durations specified in Table 4.4. Monitor EUT performance for susceptibility effects.

(g) If susceptibility is noted, determine the threshold level in accordance with Paragraph 4.3.10.4.3 and verify that it is above the limit.

5.13.4.5 Data Presentation

Data presentation shall be as follows:

a. Provide graphical and tabular data showing frequency ranges and field strength levels tested.

b. Provide and tabular data listing of all calibration data collected to include input power requirements used versus frequency and results of calibration in Paragraph 5.13.4.4, Step a, Item 1d and Step a, Item 2c.

c. Provide the correction factors necessary to adjust sensor output readings for equivalent peak detection of modulated waveforms.

d. Provide graphs or tables listing any susceptibility thresholds that were determined along with their associated frequencies.

e. Provide diagrams or photographs showing the actual equipment setup and the associated dimensions.

f. Provide the data certifying the baseline performance of the shielded room as a properly functioning reverberation chamber over a defined frequency range.

TABLE 5.4

(RS103-3) REQUIRED NUMBER OF TUNER POSITIONS FOR A REVERBERATION CHAMBER

Frequency Range (MHz)	Tuner Positions
200 - 300	50
300 - 400	20
400 - 600	16
Above 600	12

FIGURE 5-34

(RS103-1) TEST EQUIPMENT CONFIGURATION

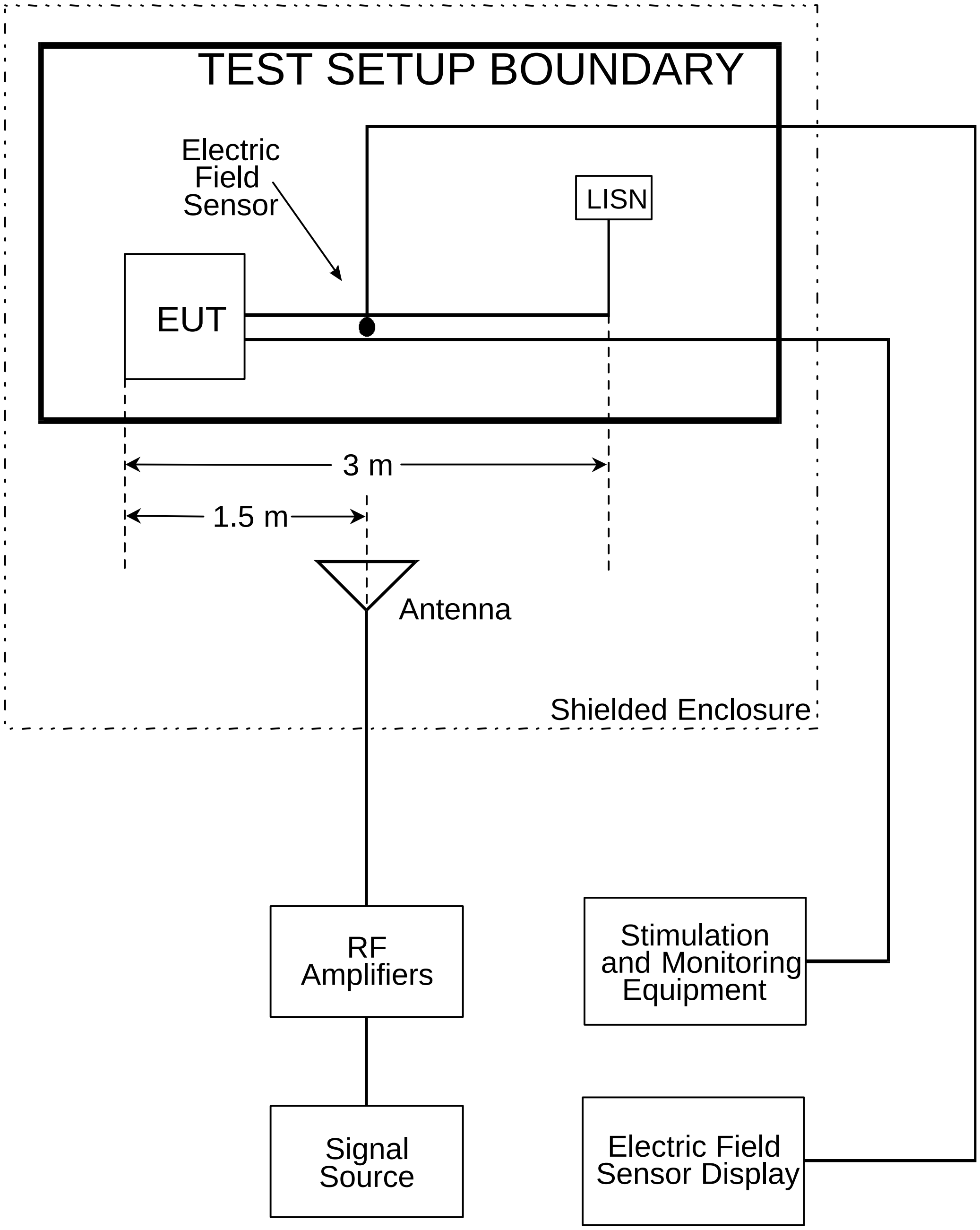


FIGURE 5-35

(RS103-2) MULTIPLE TEST ANTENNA LOCATIONS FOR FREQUENCY >200 MHz

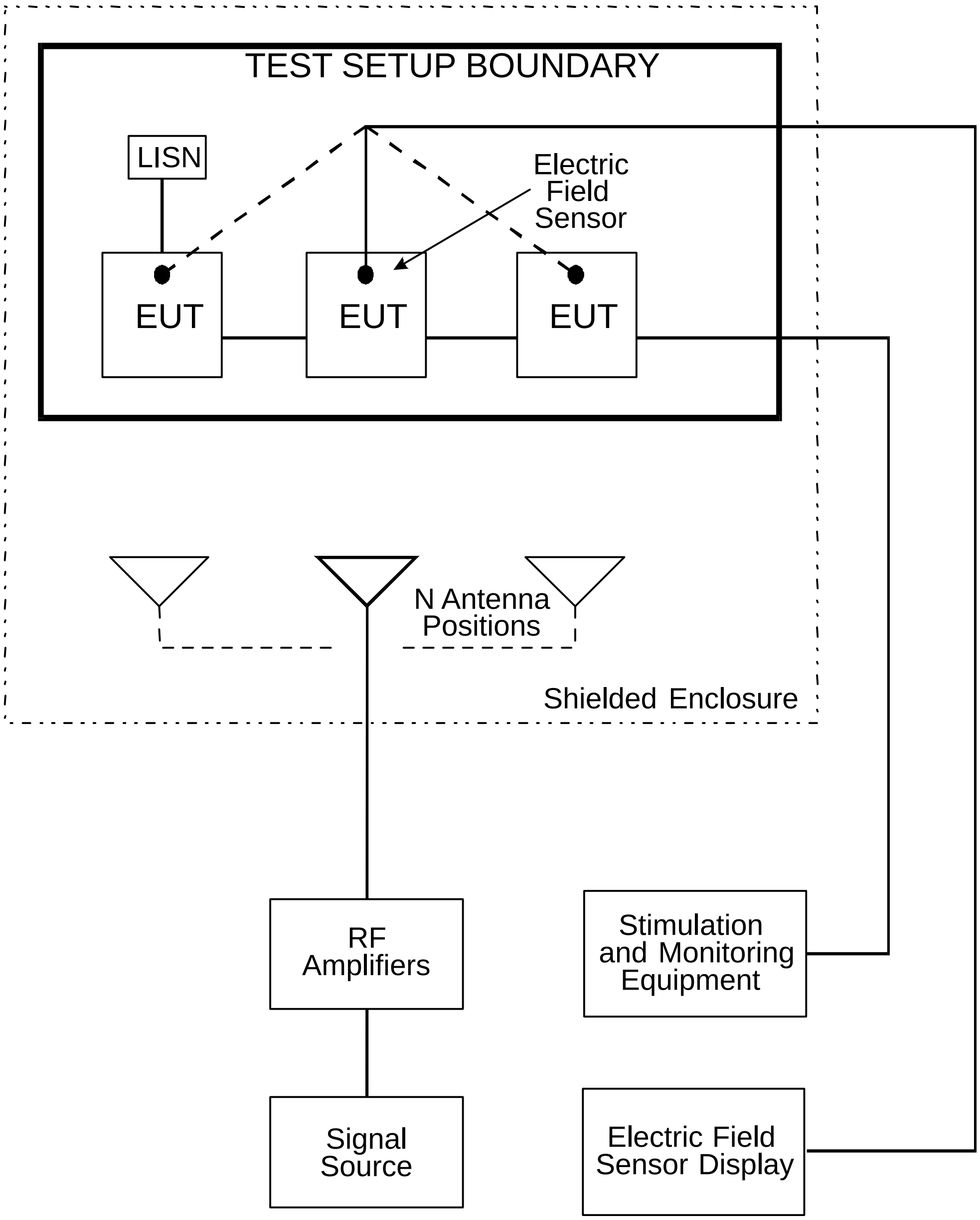


FIGURE 5-36

(RS103-3) MULTIPLE TEST ANTENNA LOCATIONS FOR N POSITIONS, D>3 METERS

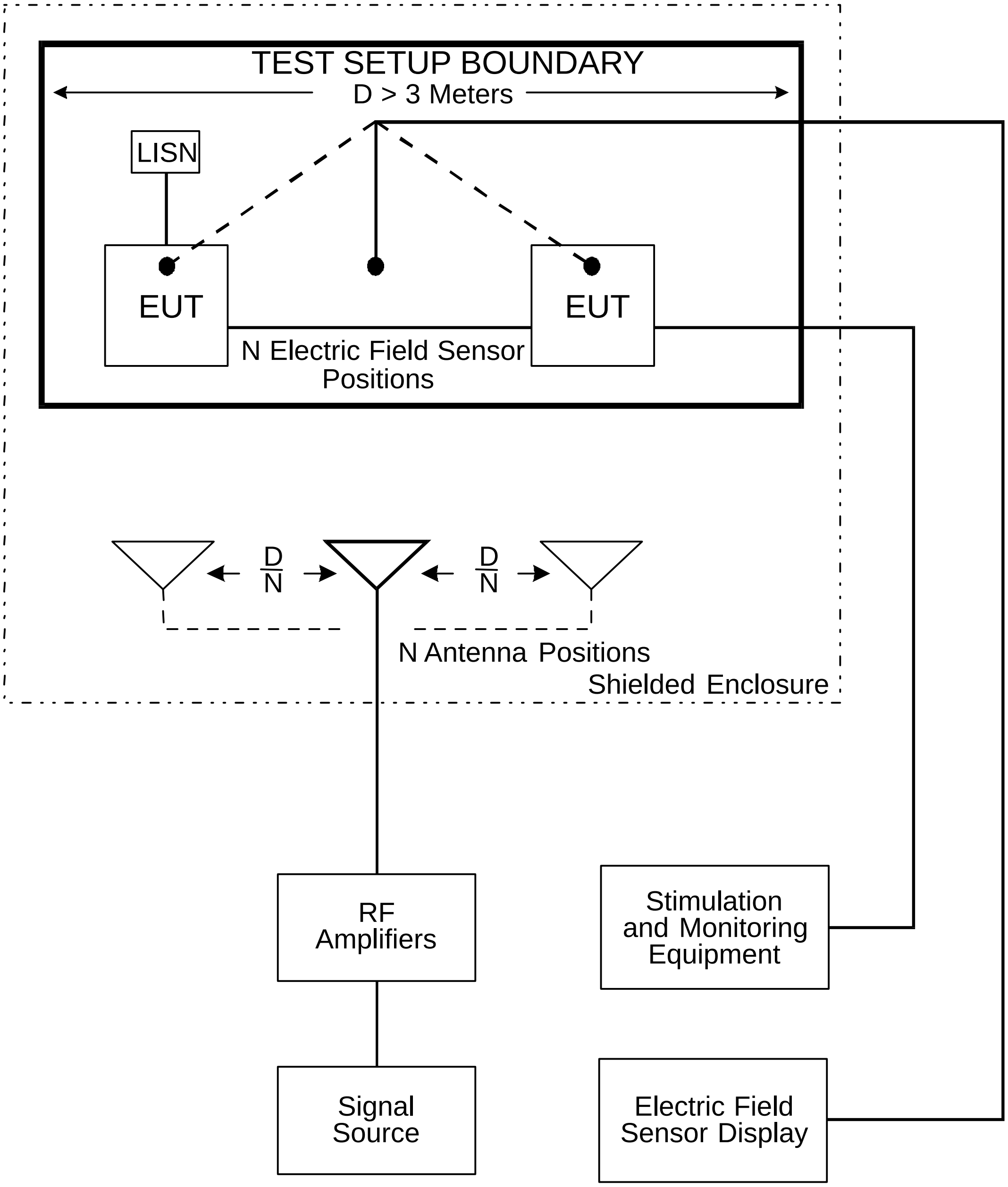


FIGURE 5-37

(RS103-4) RECEIVE ANTENNA PROCEDURE

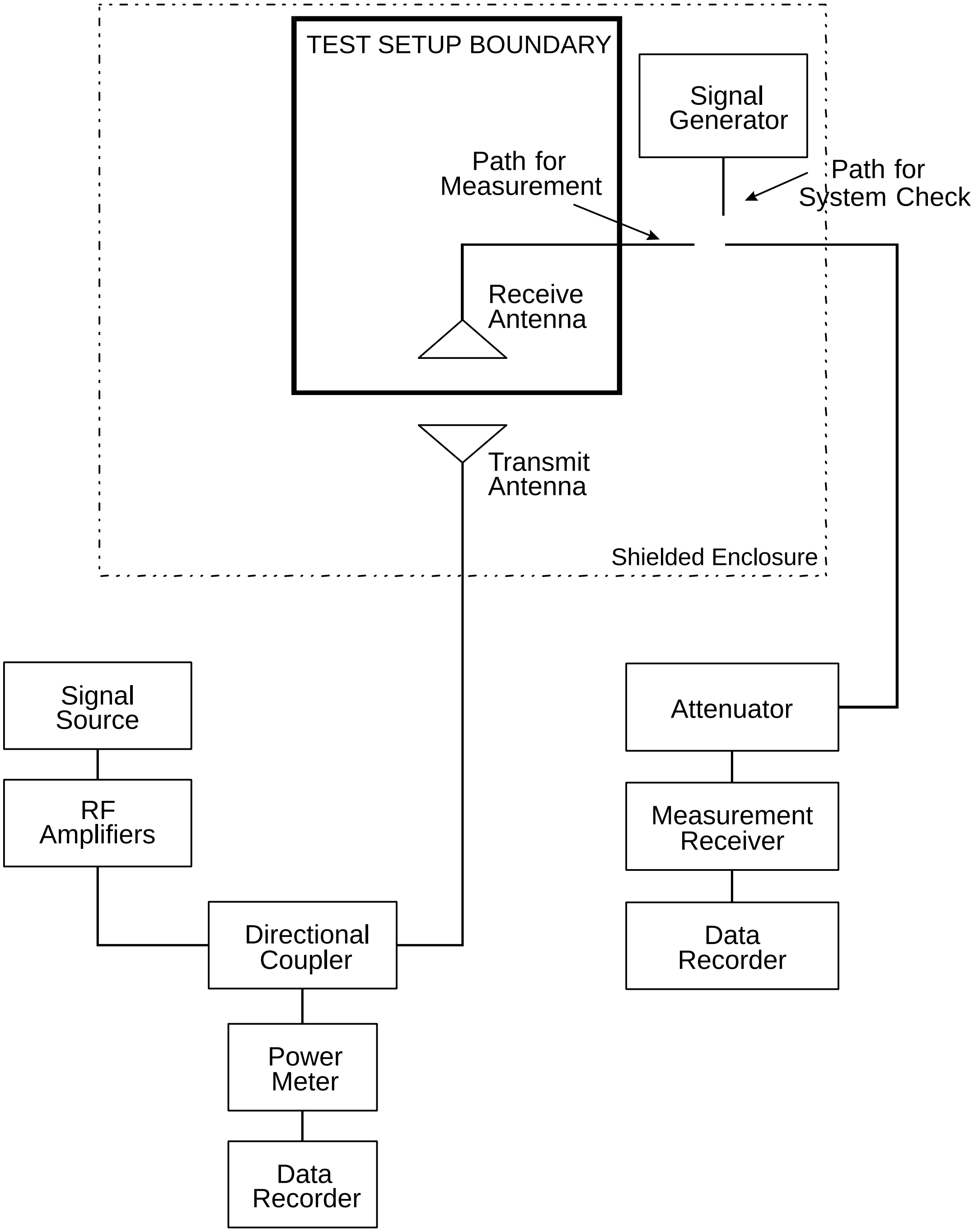


FIGURE 5-38
(RS103-5) REVERBERATION CHAMBER SETUP

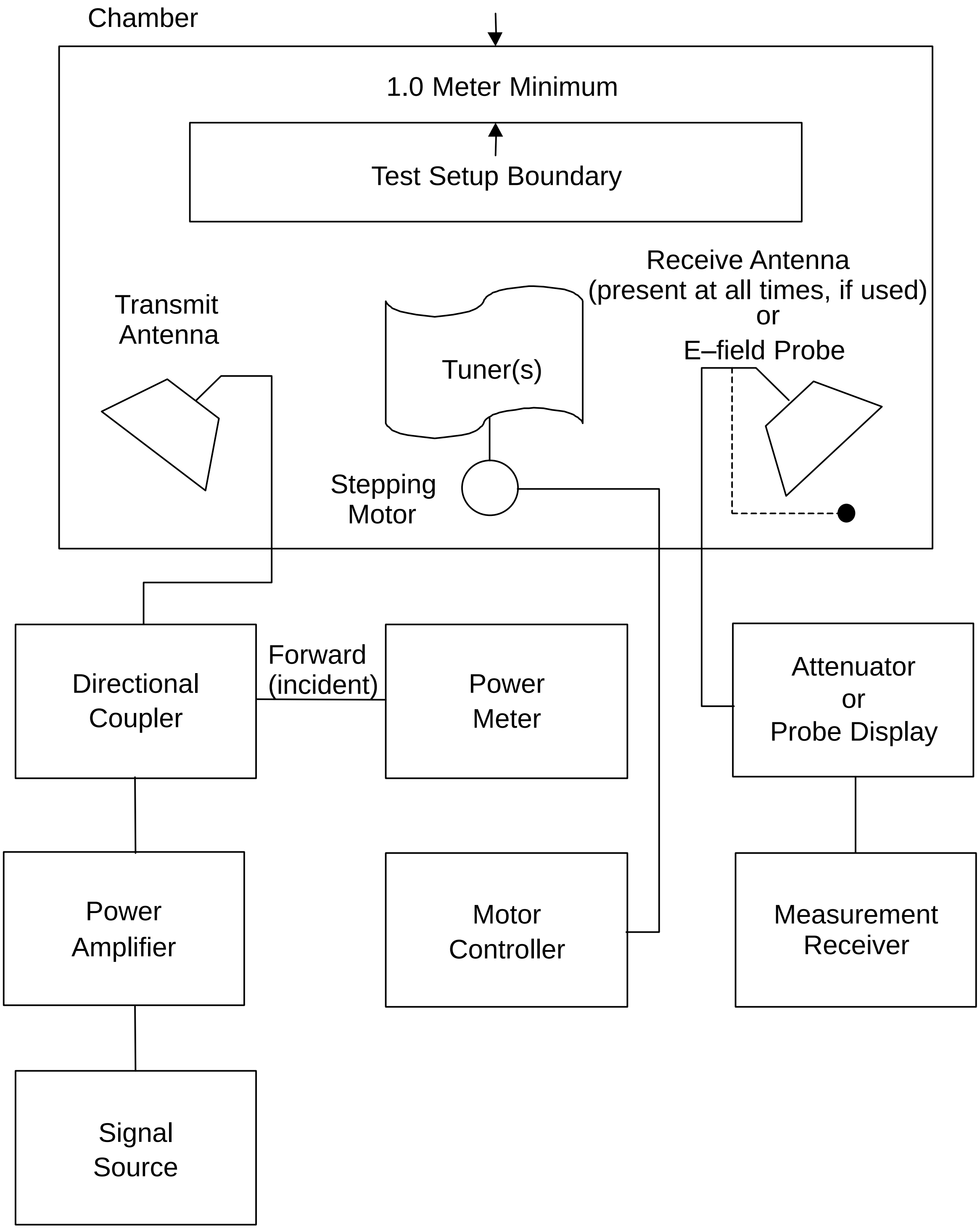
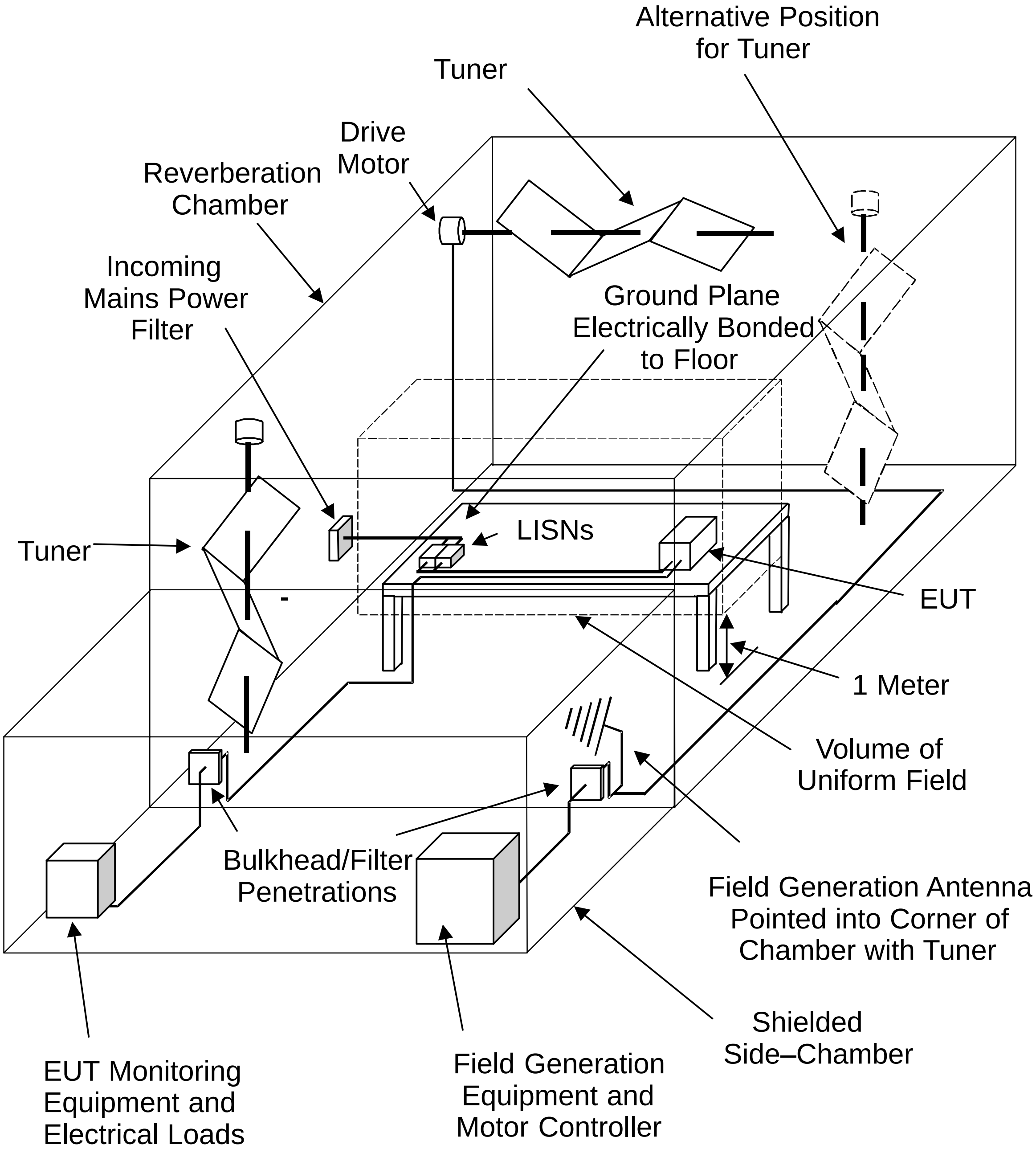


FIGURE 5-39
(RS103-6) REVERBERATION CHAMBER OVERVIEW



5.14 TT101, CONDUCTED EMISSIONS, TIME DOMAIN, DC POWER LEADS, TRANSIENT AND STEADY-STATE

5.14.1 TT101 Applicability

The requirement is applicable for measurement of all turn-on and mode-switching transients.

5.14.2 TT101 Limits

Transient emissions on power leads shall not exceed the applicable values shown on Figure 5-40.

For electrical loads connected to Shuttle primary power without intermediate power conversion, the steady-state ripple voltage in the time domain shall not exceed ±0.45 volts line-to-line, starting approximately one second after the transient.

5.14.3 TT101 Test Procedure

5.14.3.1 Purpose

The purpose of this test method is to measure, in the time domain, the load induced effect on power bus voltage caused by cycling the EUT on, as well as through any and all of its various modes of operation which might reasonably be expected to affect line voltage significantly, that is, in a manner approaching limits set forth in the governing power quality specification.

5.14.3.2 Test Equipment

The test equipment shall be as follows:

a. LISN (8 μH/50 ohm, per Figure 5-40)

b. Data recording device

c. Solid-state switch (to energize/de-energize EUT)

d. Digital storage oscilloscope (10 MHz single event BW)

e. Resistive load for verifying test set-up and measurement accuracy

5.14.3.3 Setup

The test setup shall be as follows:

a. Maintain a basic test setup for the EUT as shown and described in Figure 4-1 through Figure 4-5 and Paragraph 4.3.8.

b. Calibration.

   Configure the test setup for the measurement system check as shown in Figure 5-41. The resistor “R_{load}” in Figure 5-41 shall have a value that draws the same steady-state current as the EUT.

c. EUT testing.

   Configure the test setup for compliance testing of the EUT as shown in Figure 5-42.

5.14.3.4 Procedures

The test procedures shall be as follows:

a. Calibration. Perform the measurement system check using the measurement system check setup of Figure 5-41.

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

   2. For turn-on transient: Set time per division to bracket expected L/R time constant. Use 5 or 10 V/division sensitivity. Set up trigger to look for a negative-going transient. Set threshold to a few Volts below V_{oc}. Set up a single trace acquisition (acquire and hold).

   3. Use oscilloscope to verify that transient waveforms are as shown in Figure 5-41.

b. EUT testing. Perform transient measurement using the setup of Figure 5-42.

   1. Apply power to LISN. Wait at least one second after EUT has been de-energized before measuring a turn-on transient event.

   2. Configure oscilloscope for turn-on transient measurement per Step a, Item 2 (above) except that transient waveform will typically be longer than that calibrated, and time per division will have to be empirically determined.

   3. Measure and record turn-on transient as switch is closed. Configure oscilloscope for steady-state measurement per Step a, Item 3 (above).

   4. For steady-state measurement, set time per division to 1 microsecond. Use a vertical sensitivity of 100 mV/division, using either AC coupling or a

DC offset to keep trace at mid-screen. Repeat with a 100 microsecond per division time-base. Measure with a time per division setting commensurate with time period associated with EUT current draw. Record steady-state ripple using a max or peak hold function. Record data for the greater of one second or the longest cyclic period associated with EUT operation.

5.14.3.5 Data Presentation

Data presentation shall be as follows:

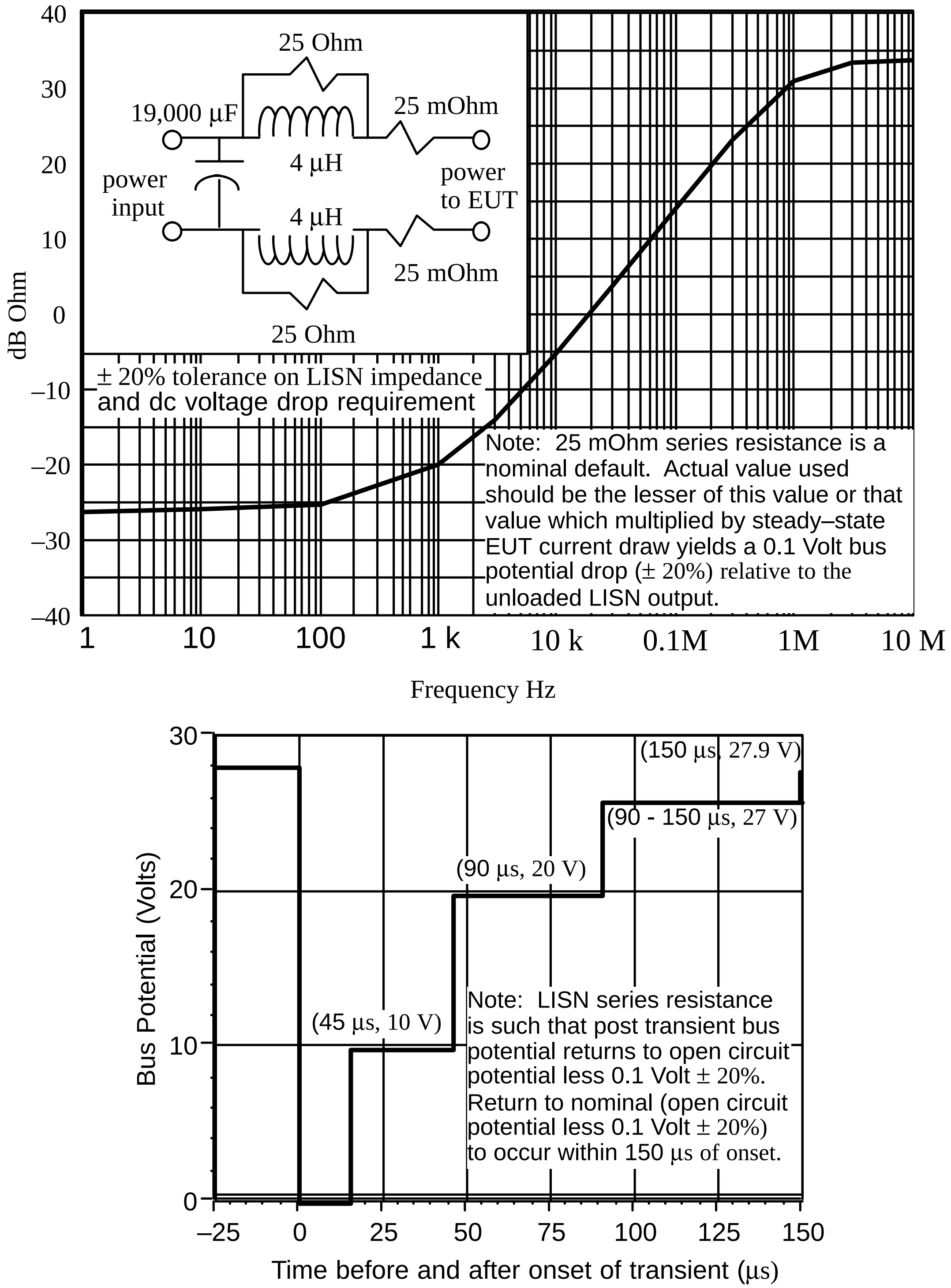
a. Oscillograph of transient waveform, including all axis and unit labels necessary for proper interpretation.

b. Display the applicable limit on each plot.

c. Provide plots for both the measurement system check and measurement portions of the procedure.

FIGURE 5-40

(TT101-1) TT101 POWER SOURCE IMPEDANCE AND TRANSIENT EXCURSION LIMIT



± 20% tolerance on LISN impedance and dc voltage drop requirement

Note: 25 mOhm series resistance is a nominal default. Actual value used should be the lesser of this value or that value which multiplied by steady–state EUT current draw yields a 0.1 Volt bus potential drop (± 20%) relative to the unloaded LISN output.

Note: LISN series resistance is such that post transient bus potential returns to open circuit potential less 0.1 Volt ± 20%. Return to nominal (open circuit potential less 0.1 Volt ± 20%) to occur within 150 µs of onset.

FIGURE 5-41

(TT101-2) MEASUREMENT SYSTEM CHECK SETUP

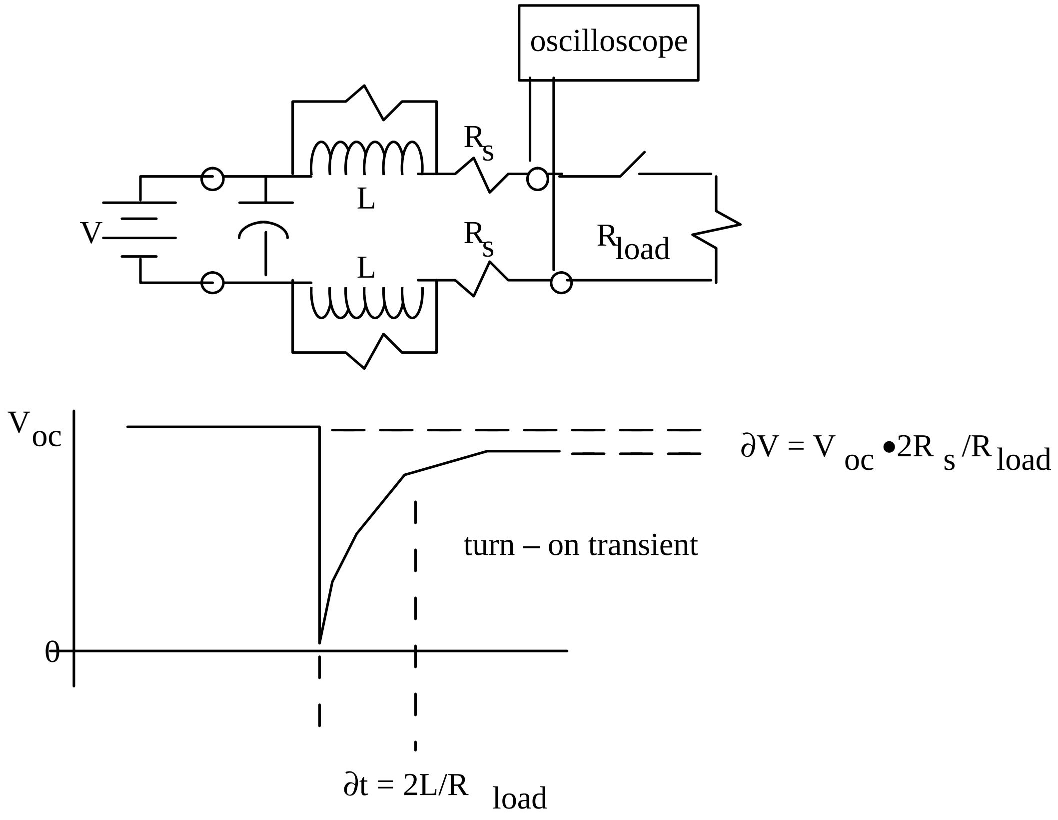
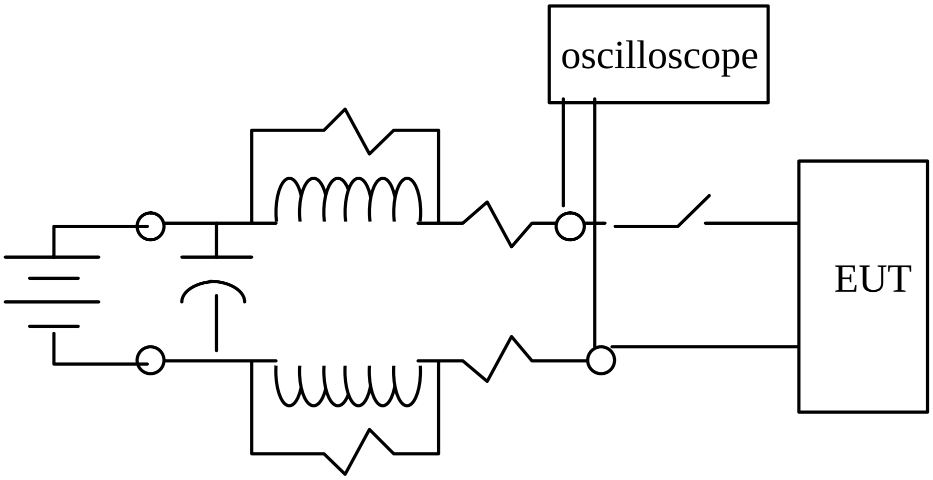


FIGURE 5-42

(TT101-3) MEASUREMENT SETUP



6.0 NOTES

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

6.1 INTENDED USE

This standard is intended for use in the acquisition cycle of equipment and subsystems to specify the electromagnetic emission and susceptibility requirements for the control of EMI.

6.2 TAILORING GUIDANCE

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

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APPENDIX A

ACRONYMS AND ABBREVIATIONS

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APPENDIX A

ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
AM	Amplitude Modulation
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
ATP	Authority to Proceed
BCE	Bulk Current Emission
BW	Bandwidth
CE	Conducted Emission
CISPR	International Special Committee on Radio Interference
cm	centimeter
COTS	Commercial Off-the-Shelf
CS	Conducted Susceptibility
CUT	Cable-under-test
CW	Continuous Wave
dB	decibel
dBm	decibel milliWatt
dBμV	decibel microvolts
dBW	decibel watts
DC	Direct Current
dso	digital oscilloscope
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMICP	EMI Control Procedure
EMITP	EMI Test Procedures
EMITR	EMI Test Report
EMP	Electromagnetic Pulse
ERP	Effective Radiated Power
ESD	Electrostatic Discharge
EUT	Equipment Under Test
FCC	Federal Communications Commission
FM	Frequency Modulation
f_o	frequency_o

GFE	Government Furnished Equipment
GHz	Gigahertz
GPI	Ground Plane Interference
HF	High Frequency
Hz	Hertz
IF	Intermediate Frequency
kHz	Kilohertz
LISN	Line Impedance Stabilization Network
MHz	Megahertz
NTIA	National Telecommunications and Information Administration
pps	pulse per second
prf	pulse repetition frequency
Q	quality factor
RC	Resistor/Capacitor
RE	Radiated Emission
RF	Radio Frequency
RMS	Root Mean Square
RS	Radiated Susceptibility
SAE	Society of Automotive Engineers
sec	second(s)
SI	System International
SSV	Space Shuttle Vehicle
TT	Transient Test
UHF	Ultrahigh Frequency
V	Volt
VDC	Volts Direct Current

VHF	Very High Frequency
Vrms	Volts root mean square
VSWR	Voltage Standing Wave Ratio

SYMBOLS

μH	microHenry

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APPENDIX B

APPLICATION GUIDE

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APPENDIX B

APPLICATION GUIDE

1.1 SCOPE

This appendix provides background information for each EMI limit or test level and associated test procedure contained in the main body of SL-E-0002 - Book 3. This information includes rationale for requirements, guidance in applying the requirements, and lessons learned from platform and laboratory experience. This information should help users understand the intent behind the requirements, should aid the procuring activity in EMI requirements as necessary for particular applications, and should help users develop detailed test procedures based on the general test procedures in this document. This appendix is provided for guidance purposes and, as such, should not be interpreted as providing contractual requirements.

1.1.4 Structure

This appendix follows the same general format as the main body of the specification. A "Discussion" paragraph is provided for each requirement if deemed necessary. For Section 5, discussion paragraphs on "Applicability and Limits" and "Test Procedures" are included.

4.1 APPLICATION OF SPECIFICATION

Discussion: The requirements in this section are universally applicable to all subsystems and equipment. Separate EMI requirements that are structured to address specific concerns with various classes of subsystems and equipment are contained in other portions of this specification.

This document is concerned only with specifying technical requirements for controlling EMI at the subsystem and equipment-level. The requirements in this document are not intended to be directly applied to subassemblies of equipment such as modules or circuit cards. The basic concepts can be implemented at the subassembly level; however, significant tailoring needs to be accomplished for the particular application. The requirements included herein are intended to be used as a baseline. Placement of MIL-STD-461E limits is based on demonstrated performance typically required for use on existing military platforms in order to achieve EMC. These have been tailored in some instances to better reflect SSV concerns. SSV system-level requirements dealing with integration of subsystems and equipment are contained in SL-E-0001. SL-E-0001 requirements include intra-system compatibility within the system, inter-system compatibility with external RF environments, lightning protection, and hazards of electromagnetic radiation to ordnance. The procuring activity and system contractors should review the requirements contained herein for possible tailoring based on system design and expected operational environments. NTIA “Manual of Regulations and Procedures for Federal Radio Frequency Management” provides requirements for complying with laws governing use of the RF spectrum by federal agencies.

Guidance and techniques which are helpful in meeting the requirements of this specification are contained in MIL-HDBK-241, Design Guide for Electromagnetic Interference (EMI) Reduction in Power Supplies, MIL-HDBK-253, Guidance for the Design and Test of Systems Protected Against the Effects of Electromagnetic Energy, MIL-HDBK-423, High-altitude Electromagnetic Pulse (HEMP) Protection for Fixed and Transportable Ground Based C4 1 Facilities, AFSC DH 1-4, Electromagnetic Compatibility, and AMC Pamphlet 706-410. MIL-HDBK-237, Guidance for Controlling Electromagnetic Environmental Effects on Platforms, Systems, and Equipment, provides guidance for management of EMC efforts. MIL-HDBK-235, Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment, Subsystems and Systems, provides information on land, air, and sea based RF emitters, both hostile and friendly, which contribute to the overall electromagnetic environment.

The qualification status of equipment and subsystems becomes uncertain when hardware or software changes are incorporated due to equipment updates or test failures, including failures from testing to requirements other than EMI. To maintain certification to SL-E-0002 after changes are implemented, either an analysis showing no substantive impact needs to be issued or continued compliance needs to be demonstrated by limited testing deemed to be appropriate to evaluate the changes. The approach used to maintain continued certification and the results of analysis and testing are normally subject to procuring activity approval.

4.1.3 COTS Equipment

Discussion: The use of COTS equipment presents a dilemma between the need for EMI control with appropriate design measures implemented and the desire to take advantage of existing designs which may exhibit undesirable EMI characteristics.

For some applications of commercially developed products, such as commercial transport aircraft, EMI requirements similar to those in this specification are usually imposed on equipment. Most commercial aircraft equipment is required to meet the EMI requirements in RTCA DO-160, Environmental Conditions and Test Procedures for Airborne Equipment, or an equivalent contractor in-house document. Recent revisions to RTCA DO-160 are making the document more compatible with this specification. Equipment qualified to RTCA DO-160, Revisions C and D is often suitable for military aircraft applications.

EMI requirements on most commercial equipment are more varied and sometimes nonexistent. The FCC is responsible for regulating non-licensed RF devices in the commercial and residential environment to control interference to radio reception. Requirements are imposed in FCC CFR Title 47, Telecommunications, Part 2, Frequency Allocations and Radio Treaty Matters; General Rules and Regulations, Part 15, Radio Frequency Devices, and Part 18, Industrial, Scientific, and Medical Equipment. The FCC does not control susceptibility (referred to as immunity in the commercial community) characteristics of equipment. The most widely applied requirement is Part 15 which requires that any digital device comply with the following conducted and RE limits for commercial environments (Class A) and residential environments (Class B).

Conducted Emissions

Frequency (MHz)	Class A (dBμV)	Class B (dBμV)
0.45 - 1.705	60	48
1.705 - 30	70	48

Radiated Emissions

Frequency (MHz)	Class A (dBμV/m at 10 meters)	Class B (dBμV/m at 3 meters)
30 - 88	39	40
88 - 216	44	44
216 - 960	46	46
Above 960	50	54

These requirements are typically less stringent than military requirements of a similar type. Also, there is difficulty in comparing levels between commercial and military testing due to differences in measurement distances, different types of antennas, and near-field conditions.

The commercial community is moving toward immunity standards. The basis for immunity requirements is given in ANSI C63.12, American National Standard Recommended Practice for Electromagnetic Compatibility Limits. There is also activity in the international area. The European Union is imposing mandatory standards and the International Electrotechnical Commission is working on standards.

4.1.4.1 Certification to Another EMI Requirements Document

Discussion: In general, the government expects configuration controls to be exercised in the manufacturing process of equipment and subsystems to ensure that produced items continue to meet the particular EMI requirements to which the design was qualified. This specification reflects the most up-to-date environments and concerns. Since the original EMI requirements may be substantially different than those in this specification, they may not be adequate to assess the suitability of the item in a particular installation. This situation most often occurs for equipment susceptibility tests related to the radiated electromagnetic environment. Procuring activities need to consider imposing additional test requirements on the contractor to gather additional data to permit adequate evaluation.

Testing of production items has shown degraded performance of the equipment from that previously demonstrated during development. One problem area is engineering changes implemented for ease of manufacturing which are not adequately reviewed for potential effects on EMI control design measures. Specific problems have been related to treatment of cable and enclosure shields, electrical grounding and bonding, and substitution of new component parts due to obsolescence.

4.1.6 Self-compatibility

Discussion: The EMI controls imposed by this specification apply to subsystem-level hardware with the purpose of ensuring compatibility when various subsystems are integrated into a system platform. In a parallel sense, a subsystem can be considered to be an integration of various assemblies, circuit cards, and electronics boxes. While specific requirements could be imposed to control the interference characteristics of these individual items, this specification is concerned only with the overall performance characteristics of the subsystem after integration. Therefore, the subsystem itself must exhibit compatibility among its various component parts and assemblies.

4.3 VERIFICATION REQUIREMENTS

Discussion: This portion of the document specifies general requirements that are applicable to a variety of test procedures applicable for individual EMI requirements. The detailed test procedures for each EMI requirement include procedures that are unique to that requirement. Other sources of information dealing with electromagnetic interference testing are available in industry documents such as RTCA DO-160 and SAE ARP 1972, Recommended Measurement Practices and Procedures for EMC Testing.

Electromagnetic disciplines (EMC, EMP, lightning, RF compatibility, frequency allocation, etc.) are integrated to differing levels in various government and contractor organizations. There is often a common base of requirements among the disciplines. It is more efficient to have unified requirements and complete and concise testing. For example, the EMC, EMP and lightning areas all pertain to electronic hardness to transients. The transient requirements in this specification should satisfy most concerns or should be adapted as necessary to do so.

Testing integrated equipment at the subsystem-level is advantageous because the actual electrical interfaces are in place rather than electrical load or test equipment simulations. When simulations are used, there is always doubt regarding the integrity of the simulation and questions arise whether emission and susceptibility problems are due to the EUT or the simulation.

Contractor generated test procedures provide a mechanism to interpret and adapt SL-E-0002 as it is applicable to a particular subsystem or equipment and to detail the test agency’s facilities and instrumentation and their use. It is important that the procedures are available to the procuring activity early so that the procuring activity can approve the test procedures prior to the start of testing. Agreement needs to exist between the procuring activity and the contractor on the interpretation of test requirements and procedures, thereby minimizing the possible need for retesting.

When testing large equipment, equipment that requires special handling provision or high power equipment, deviations from the standard testing procedures may be required. Large equipment may not fit through the typical shielded room door or may be so heavy that it would crush the floor. Other equipment has large movable arms or turrets or equipment that requires special heating or cooling facilities. This equipment may have to be tested at the manufacturer’s facilities or at the final installation. The following examples are for guidance. Sound engineering practices should be used and explained in detail in the EMITP when deviating from the standard test procedures due to EUT characteristics. The design of the tests is of primary importance and the data recorded during the testing must reflect the final installation characteristics as closely as possible.

For equipment which requires high input current (for example: > 200 A), commercial LISNs may not be available. For CE102, the voltage probe called out in ANSI C63.4, American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz, may be substituted. The construction of the probe is shown in Figure B-1. A direct connection to the power lines is required and care must be taken to establish a reference ground for the measurements. It may be necessary to perform repeated measurements over a suitable period of time to determine the variation in the power line impedance and the impact on the measured emissions from the EUT. Alternatively, a current-based limit could be analytically derived in such a case and the test performed with current probes, as per earlier version of this specification.

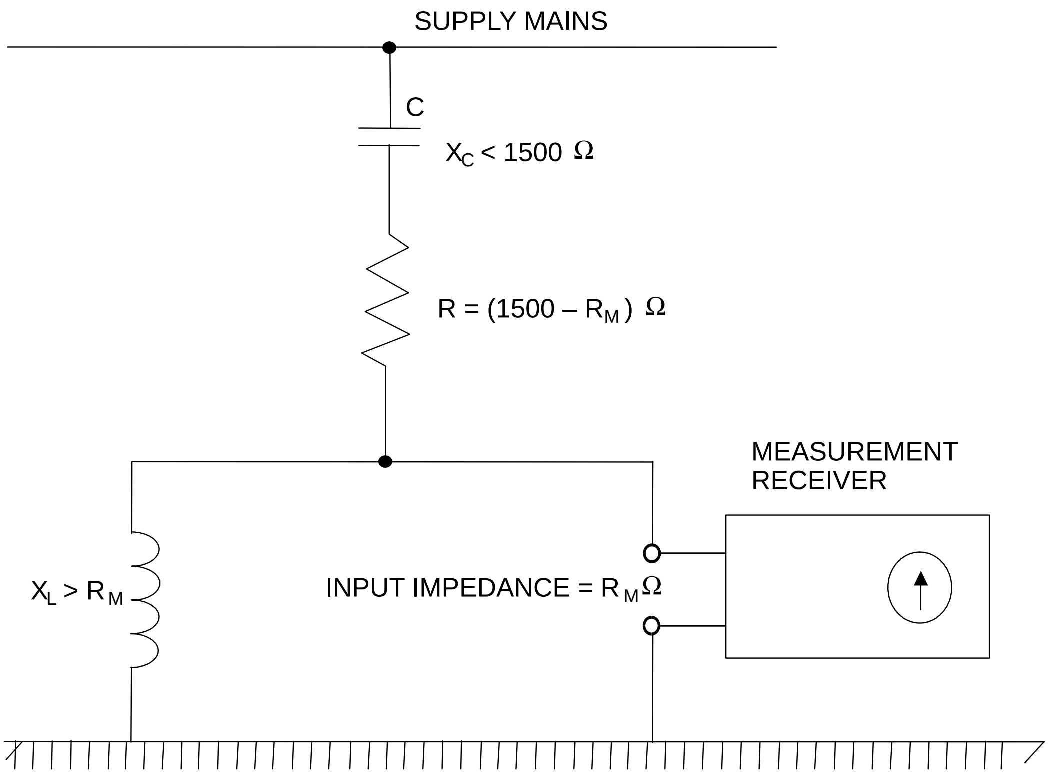
The measurements are made between each current-carrying conductor in the supply mains and the ground conductor with a blocking capacitor C and resistor R, as shown in Figure B-1, so that the total resistance between the line under test and ground is 1500 ohm. The probe attenuates the voltage so calibration factors are required. The measurement point (probe's position on the cables) must be identified in all test setups.

When equipment is too large or requires special provisions (loads, drives, water, emission of toxic fumes and such), testing in a typical semi-anechoic room may not be feasible. Temporary screen rooms consisting of hardware cloth can be built around the test area to reduce the ambient for RE testing and to contain the RF field during RS testing. Since the room may be highly reflective, care must be taken to identify any resonances. Several antenna positions may be required in order to reduce the effect of the resonances, or stirring may be employed.

Equipment which produces high power RF output may be required to be tested on an open area test site. Additionally, equipment that needs to have a communication link to the outside world must be tested in the open. FCC approval may be required in order to generate the RF fields for the RS103 test requirement. If the communication link can be simulated, then the test can be performed in a shielded room. In this case, special dummy loads may be required, since the high power RF radiation could damage the anechoic material due to heating.

FIGURE B-1

VOLTAGE PROBE FOR TESTS AT USER'S INSTALLATION



Imposition of EMI requirements on large equipment has become essential to prevent EMI problems. Therefore, EMI requirements should not be waived simply because of special handling problems or equipment size. Typical military equipment and subsystems for which these special provisions have been applied are as follows:

- a. Air handling units (heating, ventilating, and air conditioning)
- b. Large uninterruptible power supplies
- c. Equipment vans/motorized vehicles
- d. Desalinization units
- e. Large motors/generators/drives/power distribution systems
- f. Large radars
- g. Rail guns and their power sources
- h. Catapults and their power sources
- i. Multiple console subsystems

An issue unique to space applications is that the EUT is often the flight unit. Special care must be exercised in these cases. Some types of test items are designed for limited lifetimes, and/or are built to operate in microgravity or vacuum. Operation of such equipment during a test program may affect useful lifetime. Special EMI test designs may be required. One technique for reducing test time is to limit RE testing to receiver passbands. All such measures should be described in detail in the EMI test plan, and presented for approval by the designated approving authority well in advance of testing.

4.3.1 Measurement Tolerances

Discussion: Tolerances are necessary to maintain reasonable controls for obtaining consistent measurements. Paragraph 4.3.1, Step b through Step d, are in agreement with ANSI C 63.2 for electromagnetic noise instrumentation.

4.3.2 Shielded Enclosures

Discussion: Potential accuracy problems introduced by shielded enclosure resonances are well documented and recognized; however, shielded enclosures are usually a necessity for testing of military equipment to the requirements of this specification. Most test agencies are at locations where ambient levels outside of the enclosures are significantly above the limits in this specification and would interfere with the ability to obtain meaningful data.

Electrical interfaces with military or space equipment are often complex and require sophisticated test equipment to simulate and evaluate the interface. This equipment usually must be located outside of the shielded enclosure to achieve sufficient isolation and prevent it from contaminating the ambient and responding to susceptibility signals.

The shielded enclosure also prevents radiation of applied susceptibility signals from interfering with local antenna-connected receivers. The most obvious potential offender is the RS103 test. However, other susceptibility tests can result in substantial radiated energy that may violate FCC rules.

4.3.2.1 RF Absorber Material

Discussion: Accuracy problems with making measurements in untreated shielded enclosures due to reflections of electromagnetic energy have been widely recognized and documented. The values of RF absorption required by Table B.1 are considered to be sufficient to substantially improve the integrity of the measurements without unduly impacting test facilities. The minimum placement provisions for the material are specified to handle the predominant reflections. The use of additional material is desirable, where possible. It is intended that the values in Table B.1 can be met with available ferrite tile material or standard 24 inch (0.61 meters) pyramidal absorber material.

TABLE B.1

ABSORPTION AT NORMAL INCIDENCE

Frequency	Minimum Absorption
80 MHz - 250 MHz	6 dB
Above 250 MHz	10 dB

4.3.3 Other Test Sites

Discussion: For certain types of EUTs, testing in a shielded enclosure may not be practical. Examples are EUTs, which are extremely large, require high electrical power levels or motor drives to function, emit toxic fumes, or are too heavy for normal floor loading (reference Paragraph 4.3, Discussion, for additional information). There is a serious concern with ambient levels contaminating data when testing is performed outside of a shielded enclosure. Therefore, special attention is given to this testing under Paragraph 4.3.4. All cases, where testing is performed outside a shielded enclosure, should be justified in detail in the EMI test plan, including typical profiles of expected ambient levels.

If it is necessary to operate EUTs that include RF transmitters outside of a shielded enclosure, spectrum certification and a frequency assignment must first be obtained through the spectrum management process.

An option in emission testing is the use of an open area test site in accordance with ANSI C63.4. These sites are specifically designed to enhance accuracy and repeatability. Due to differences between ANSI C63.4 and this specification in areas such as antenna selection, measurement distances, and specified frequency ranges, the EMITP should detail the techniques for using the open area test site and relating the test results to the requirements of this specification.

4.3.4 Ambient Electromagnetic Level

Discussion: Controlling ambient levels is critical to maintaining the integrity of the gathered data. High ambients present difficulties distinguishing between EUT emissions and ambient levels. Even when specific signals are known to be ambient related, they may mask EUT emissions that are above the limits of this specification.

The requirement that the ambient be at least 6 dB below the limit ensures that the combination of the EUT emissions and ambient does not unduly affect the indicated magnitude of the emission. If a sinusoidal noise signal is at the limit and the ambient is 6 dB below the limit, the indicated level would be approximately 3 dB above the limit.

Similarly, if the ambient were allowed to be equal to the limit for the same true emission level, the indicated level would be approximately 5 dB above the limit. Conversely, a flat noise floor level indicates that any signals present are at least 6 dB below the noise floor, or the noise floor would be elevated. This is useful when very sensitive receivers drive RE limits which are challenging to meet with off-the-shelf test equipment.

A resistive load is specified to be used for conducted ambients on power leads. However, under certain conditions actual ambient levels may be higher than indicated with a resistive load. The most likely reason is the presence of capacitance at the power interface of the EUT that will lower the input impedance at higher frequencies and increase the current. This capacitance should be determined and ambient measurements repeated with the capacitance in place. There is also the possibility of resonance conditions with shielded room filtering, EUT filtering, and powerline inductance. These types of conditions may need to be investigated if unexpected emission levels are observed.

Testing outside of a shielded enclosure often must be performed at night to minimize influences of the ambient. A prevalent problem with the ambient is that it continuously changes with time as various emitters are turned on and off and as amplitudes fluctuate. A useful tool for improving the flow of testing is to thoroughly analyze the EUT circuitry prior to testing and identify frequencies where emissions may be expected to be present.

An option to improve overall measurement accuracy is to make preliminary measurements inside a shielded enclosure and accurately determine frequencies where emissions are present. Testing can be continued outside the shielded enclosure with measurements being repeated at the selected frequencies. The 6 dB margin between the ambient and limits must then be observed only at the selected frequencies.

4.3.5 Ground Plane

Discussion: Generally, the REs and RSs of equipment are due to coupling from and to the interconnecting cables and not via the case of the EUT. Emissions and susceptibility levels are directly related to the placement of the cable with respect to the ground plane and to the electrical conductivity of the ground plane. Thus, the ground plane plays an important role in obtaining the most realistic test results.

When the EUT is too large to be installed on a conventional ground plane on a bench, the actual installation should be duplicated. For example, a large radar antenna may need to be installed on a test stand and the test stand bonded to the floor of the shielded enclosure. Ground planes need to be placed on the floor of shielded rooms with floor surfaces such as tiles that are not electrically conductive.

The use of ground planes is also applicable for testing outside of a shielded enclosure. These ground planes will need to be referenced to earth as necessary to meet the electrical safety requirements of the National Electrical Code. Where possible, these ground planes should be electrically bonded to other accessible grounded reference surfaces such as the outside structure of a shielded enclosure.

The minimum dimensions for a ground plane of 2.25 square meter with 76 cm on the smallest side will be adequate only for setups involving a limited number of EUT enclosures with few electrical interfaces. The ground plane must be large enough to allow for the requirements included in Paragraph 4.3.8 on positioning and arrangement of the EUT and associated cables to be met.

4.3.5.1 Metallic Ground Plane

Discussion: For the metallic ground plane, a copper ground plane with a thickness of 0.25 millimeters has been commonly used and satisfies the surface resistance requirements. Other metallic materials of the proper size and thickness needed to achieve the resistivity can be substituted.

For metallic ground planes, the surface resistance can be calculated by dividing the bulk resistivity by the thickness. For example, copper has a bulk resistivity of 1.75×10^{-8} ohm-meters. For a 0.25 millimeter thick ground plane as noted above, the surface resistance is $1.7 \times 10^{-8} / 2.5 \times 10^{-4} = 6.8 \times 10^{-5}$ ohms per square = 0.068 milliohms per square. The requirement is 0.1 milliohms per square.

4.3.5.2 Composite Ground Plane

Discussion: A copper ground plane has typically been used for all testing in the past. For most instances, this has been adequate. However, with the increasing use of composites, the appropriate ground plane will play a bigger role in the test results. Limited testing on both copper and conductive composite ground planes has shown some differences in electromagnetic coupling test results, thus the need exists to duplicate the actual installation, if possible. In some cases, it may be necessary to include several ground planes in the same test setup if different units of the same EUT are installed on different materials in the installation.

With the numerous different composite materials being used in installations, it is not possible to specify a general resistivity value. The typical resistivity of carbon composite is about 2,000 times that of aluminum. The actual resistivity needs to be obtained from the installation contractor and used for testing.

4.3.6 Power Source Impedance

Discussion: The impedance of the 50 μH, 50 Ω line-to-ground LISN is standardized to represent expected impedances in actual installations and to ensure consistent results between different test agencies. The impedance of the 8 μH, 50 ohm line-to-line LISN, is tailored specifically for SSV. Versions of MIL-STD-462 (previously contained test procedures for MIL-STD-461, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, requirements) in the past used 10 microfarad feedthrough capacitors on the power leads. The intent of these devices was to determine the current generator portion of a Norton current source model. If the impedance of the interference source was also known, the interference potential of the source could be analytically determined for particular circumstances in the installation. A requirement was never established for measuring the impedance portion of the source model. More importantly, concerns arose over the test configuration influencing the design of powerline filtering. Optimized filters are designed based on knowledge of both source and load impedances. Significantly different filter designs will result for the 10 microfarad capacitor loading versus the impedance loading shown in Figure 4-7.

LISNs are not used on output power leads. Emission measurements using LISNs are performed on input power leads because the EUT is using a power source common to many other equipment items and the EUT must not degrade the quality of the power. When the EUT is the source of power, the issue is completely different since the electrical characteristics of the power required are controlled by the defined power quality requirements. Output power leads should be terminated with appropriate electrical loading that produces potentially worst case emission and susceptibility characteristics.

The particular configuration of the line-to-ground LISN is specified for several reasons. A number of experiments were performed to evaluate typical power line impedances present in a shielded room on various power input types both with and without power line filters and to assess the possible methods of controlling the impedance. An approach was considered for MIL-STD-461E to simply specify an impedance curve from 30 Hz to 100 MHz and to allow the test agency to meet the impedance using whatever means the agency found suitable. The experiments showed that there were no straightforward techniques to maintain desired controls over the entire frequency range.

A specific 50 microhenry LISN (reference ANSI C63.4) was selected to maintain a standardized control on the impedance as low as 10 kHz. Five microhenry LISNs used commonly in the past provide little control below 100 kHz. Impedance control below 10 kHz is difficult. From evaluations of several 50 microhenry LISN configurations, the one specified demonstrated the best overall performance for various shielded room filtering variations. Near 10 kHz, the reactances of the 50 microhenry inductor and 8 microfarad capacitor cancel and the LISN is effectively a 5 ohm resistive load across the power line.

Using a common LISN is important for standardization reasons. However, the use of alternative LISNs may be desirable in certain application where the characteristics of the LISN may not be representative of the actual installation and the design of EUT circuitry is being adversely affected. For example, there are issues with switching power supply stability and the power source impedance seen by the power supply. The 50 microhenry inductor in the LISN represents the inductance of power distribution wiring running for approximately 50 meters. For a large platform, such as a ship or cargo aircraft, this value is quite representative of the actual installation. However, for smaller platforms such as fighter aircraft, inductance values may be substantially lower than 50 microhenries. If alternative LISN designs are used, certain issues need to be addressed such as the frequency range over which effective impedance control is present and where voltage versus current measurements are appropriate.

Caution needs to be exercised in using the LISN for 400 Hz power systems. Some existing LISNs may not have components sufficient to handle the power dissipation requirements. At 115 volts, 400 Hz, the 8 microfarad capacitor and 5 ohm resistor will pass approximately 2.3 amperes which results in 26.5 watts being dissipated in the resistor.

The SSV-specific LISN is used to measure time-domain phenomena. Measured events are transient deviations from nominal conditions. Limits are levied as to the length of the transient event. Therefore, the LISN must be defined to have a DC resistance as well as an AC impedance, in order to accurately measure the transient return to nominal conditions. This results in the requirement for series impedance in the LISN. The value used, and how to tailor it for different EUT load currents, is discussed in the appendix for the TT101 test section.

4.3.7 General Test Precautions

Discussion: The requirements included in Paragraph 4.3.7 cover important areas related to improving test integrity and safety that need special attention. There are many other areas where test difficulties may develop. Some are described here.

It is common for shields to become loose or broken at connectors on coaxial cables resulting in incorrect readings. There also are cases where center conductors of coaxial cables break or separate. Periodic tests should be performed to ensure cable integrity. Special low loss cables may be required when testing at higher frequencies.

Caution needs to be exercised when performing emission testing at frequencies below approximately 10 kHz to avoid ground loops in the instrumentation which may introduce faulty readings. A single-point ground often needs to be maintained. It is usually necessary to use isolation transformers at the measurement receiver and accessory equipment. The single-point ground is normally established at the access (feedthrough) panel for the shielded enclosure. However, if a transducer is being used which requires an electrical bond to the enclosure (such as the rod antenna counterpoise), the coaxial cable will need to be routed through the enclosure access panel without being grounded. Since the shielded room integrity will then be compromised, a normal multiple point grounded setup needs to be re-established as low in frequency as possible.

Rather than routing the coaxial cable through the enclosure access panel without grounding it to the enclosure, a 50-ohm video isolation transformer may be connected to the grounded RF connector at the access panel inside the room. Normal connection of the measuring receiver is made to the grounded connector at the panel outside the room. This technique effectively breaks the ground loop without sacrificing the room's shielding integrity. The losses of the video isolation transformer must be accounted for in the measurement data. These devices are typically useful up to approximately 10 MHz.

If isolation transformers are found to be necessary in certain setups, problems may exist with items powered by switching power supplies. A solution is to use transformers that are rated at approximately five times the current rating of the item.

Solid state instrumentation power sources have been found to be susceptible to radiated fields even to the extent of being shut down. It is best to keep these items outside of the shielded enclosure.

4.3.7.1 Accessory Equipment

Discussion: Measurement receivers are generally designed to meet the limits of this specification so they do not contaminate the ambient for emission testing when they are used inside the shielded enclosure. However, accessory equipment such as computers, oscilloscopes, plotters, or other instruments used to control the receiver or monitor its outputs can cause problems. They may compromise the integrity of the receiver by radiating signals conducted out of the receiver from improperly treated electrical interfaces or may produce interference themselves and raise the ambient. Even passive devices such as headsets have been known to impact the test results.

It is best to locate all of the test equipment outside of the shielded enclosure with the obvious exception of the transducer (antenna or current probe). Proper equipment location will ensure that the emissions being measured are being generated in the EUT only and will help ensure that the ambient requirements of Paragraph 4.3.4 are met. If the equipment must be used inside the enclosure or if testing is being conducted outside of an enclosure, the measurement receiver and accessory equipment should be located as far away from the transducers as practical to minimize any impact.

4.3.7.2 Excess Personnel and Equipment

Discussion: Excess personnel and both electronic and mechanical equipment such as desks or cable racks in the enclosure can affect the test results. During radiated emission testing in particular, all nonessential personnel and equipment need to be removed from the test site. Any object in the enclosure can significantly influence or introduce standing waves in the enclosure and thus alter the test results. The requirement to use RF absorber material will help to mitigate these effects. However, material performance is not defined below 80 MHz for practical reasons and standing waves continue to be a concern.

4.3.7.3 Overload Precautions

Discussion: Overloads can easily go unnoticed if there is not an awareness of the possibility of an overload or active monitoring for the condition. The usual result is a leveling of the output indication of the receiver.

Two types of overloads are possible. A narrowband signal, such as a sinusoid, can saturate any receiver or active transducer. Typical procedures for selecting attenuation settings for measurement receivers place detected voltages corresponding to emission limits well within the dynamic range of the receiver. Saturation problems for narrowband type signals will normally only appear for a properly configured receiver if emissions are significantly above the limits. Saturation can occur more readily when receivers are used to monitor susceptibility signals due to the larger voltages involved.

Overload from impulsive type signals with broad frequency content can be much more deceptive. This condition is most likely to occur with devices without a tuneable bandpass feature in the first stage of the signal input. Examples are preamplified rod antennas and spectrum analyzers without preselectors. The input circuitry is exposed to energy over a large portion of the frequency spectrum. Preselectors include a tuneable tracking filter which BW limits the energy applied to the receiver front end circuitry.

Measurement receiver overload to both narrowband and impulsive type signals can be evaluated by applying 10 dB additional attenuation in the first stage of the receiver (before mixer circuitry) or external to the receiver. If overload is not present, the observed output will uniformly decrease by 10 dB.

Overload conditions for active antennas are normally published as part of the literature supplied with the antenna. For narrowband signals, the indicated level in the data can be reviewed with respect to the literature to evaluate overload. Levels are also published for impulsive type signals; however, these levels are not very useful since they usually assume that a flat field exists across the useable range of the antenna. In reality, the impulsive field will vary significantly with frequency and the antenna circuitry sees the integration of the spectral content of this field over its bandpass. The primary active antenna used is an active rod antenna. Overload can be evaluated by collapsing the rod and observing the change in indication. If overload is not present, the indicated level should drop approximately 8 dB (rod at 30% of its original height). The actual change for any particular manufacturer's product will depend on the telescoping design and can be determined by radiating a signal to the antenna that is within its linear range.

4.3.7.4 RF Hazards

Discussion: During some RS and RE testing, fields may exceed the permissible exposure levels in DoDI 6055011, Protection of DoD Personnel from Exposure to Radiofrequency Radiation and Military Exempt Lasers. During these tests, precautions must be implemented to avoid inadvertent exposure of personnel. Monitoring of the EUT during testing may require special techniques such as remotely connected displays external to the enclosure or closed circuit television to adequately protect personnel.

4.3.7.5 Shock Hazard

Discussion: A safety plan and training of test personnel are normally required to assure that accidents are minimized. Test equipment manufacturers' precautions need to be followed, if specified. If these are not available, the test laboratory should establish adequate safety precautions and train all test personnel.

4.3.7.6 FCC Restrictions

Discussion: RS RS103 testing and possibly other tests will produce signals above FCC authorizations. This situation is one of the reasons that shielded enclosures are normally required.

4.3.8 EUT Test Configurations

Discussion: Emphasis is placed on maintaining the specified setup for all testing unless a particular test procedure directs otherwise. Confusion has resulted from previous versions of the standard regarding consistency of setups between individual requirements in areas such as lead lengths and placement of 10 uF capacitors on power leads. In this version of the specification, any changes from the general test setup are specifically stated in the individual test procedure.

4.3.8.1 EUT Design Status

Discussion: It is important that the hardware and software being tested is the same as the production equipment. Sometimes equipment is tested which is pre-production and contains circuit boards that do not include the final layout or software that is not the final version. Questions inevitably arise concerning the effects of the differences between the tested equipment and production configurations on the qualification status of the equipment. Analytically determining the impact is usually very difficult.

4.3.8.2 Bonding of EUT

Discussion: Electrical bonding provisions for equipment are an important aspect of platform installation design. Adequacy of bonding is usually one of the first areas reviewed when platform problems develop. Electrical bonding controls common mode voltages that develop between the equipment enclosures and the ground plane. Voltages potentially affecting the equipment will appear across the bonding interface when RF stresses are applied during susceptibility testing. Voltages will also develop due to internal circuit operation and will contribute to RE profiles. Therefore, it is important that the test setup use actual bonding provisions so that test results are representative of the intended installation.

4.3.8.3 Shock and Vibration Isolators

Discussion: Including shock and vibration isolators in the setup when they represent the platform installation is important. The discussion above for Paragraph 4.3.8.2 is also applicable to shock and vibration isolators; however, the potential effect on test results is even greater. Hard mounting of the equipment enclosures to the ground plane can produce a low impedance path across the bonding interface over most of the frequency range of interest. The bonding straps associated with isolators will typically represent significant impedances at frequencies as low as tens of kHz. The common mode voltages associated with these impedances will generally be greater than the hard mounted situation. Therefore, the influence on test results can be substantial.

4.3.8.4 Safety Grounds

Discussion: Safety grounds used in equipment enclosures have been the source of problems during EMI testing. Since they are connected to the equipment enclosure, they would be expected to be at a very low potential with respect to the ground plane and a non-contributor to test results. However, the wire lengths within enclosures are often sufficiently long that coupling to them results from noisy circuits. Also, safety grounds can conduct induced signals from external sources and reradiate within the equipment enclosure. Therefore, they must be treated similarly to other wiring.

4.3.8.5 Orientation of EUTs

Discussion: Determination of appropriate surfaces is usually straightforward. Seams on enclosures that have metal-to-metal contact or contain EMI gaskets rarely contribute and should be considered low priority items. Prime candidates are displays such as video screens, ventilation openings, and cable penetrations. In some cases, it may be necessary to probe the surfaces with a sensor and measurement receiver to decide on EUT orientation.

MIL-STD-462, superseded by this specification, specifically required probing with a loop antenna to determine localized areas producing maximum emissions or susceptibility for radiated electric field testing. The test antennas were to be placed one meter from the identified areas. The requirement was not included in this specification due to difficulties in applying the requirement and the result that probing was often not performed. Probing implies both scanning in frequency and physical movement of the probe. These two actions cannot be performed in a manner to cover all physical locations at all frequencies. A complete frequency scan can be performed at particular probe locations and movement of the probe over the entire test setup can be performed at particular frequencies. The detailed requirements on the use of multiple antenna positions and specific requirements on the placement of the antennas in test procedures for RE102 and RS103 minimize concerns with the need to probe.

4.3.8.6 Construction and Arrangement of EUT Cables

Discussion: For most EUTs, electrical interface requirements are covered in interface control or similar documents. Coordination between equipment manufacturers and system integration organizations is necessary to ensure a compatible installation from both functional and EMI standpoints. For general purpose EUTs, which may be used in many different installations, either the equipment specifications cover the interface requirements or the manufacturers publish recommendations in the documentation associated with the equipment.

Equipment manufacturers sometimes contend that failures during EMI testing are not due to their equipment and can be cured simply by placing overall shields on the interface cabling. High level emissions are often caused by electronic circuits within EUT enclosures coupling onto cables simulating the installation which interface with the EUT. Overall shielding of the cabling is certainly permissible if it is present in the installation. However, the use of overall shielding that is not representative of the installation would result in test data that is useless. Also, overall shielding of cabling in some installations is not a feasible option due to weight and maintenance penalties. The presence of platform structure between cabling and antennas on a platform is not an acceptable reason for using overall shields on cables for testing in accordance with this specification. The presence of some platform shielding is a basic assumption.

An issue that arises with power leads concerns the use of shielding. It is unusual for power leads to be shielded in the actual installation. If they come directly off a prime power bus, shielding can only be effective if the entire bus is shielded end-to-end. Since buses normally distribute power to many locations, it is not practical to shield them. An exception to this situation is when power is derived from an intermediate source that contains filtering. Shielding between the intermediate source and the EUT will then be effective. When it is proposed that shielded power leads be used in the test setup, the configuration needs to be researched to ensure that it is correct. There may be instances when published interface information is not available. In this case, overall shielding is not to be used. Individual circuits are to be treated as they typically would for that type of interface with shielding not used in questionable cases.

For some testing performed in the past using bulk cable drive techniques, overall cable shields were routinely removed and the injected signal was applied to the core wiring within the shield. The intent of this specification is to test cables as they are configured in the installation. If the cable uses an overall shield, the test signal is applied to the overall shielded cable. If the procuring agency desires that the test be performed on the core wiring, specific wording needs to be included in contractual documentation.

4.3.8.6.1 Interconnecting Leads and Cables

Discussion: Actual lengths of cables used in installations are necessary for several reasons. At frequencies below resonance, coupling is generally proportional to cable length. Resonance conditions will be representative of the actual installation. Also, distortion and attenuation of intentional signals due strictly to cable characteristics will be present and potential susceptibility of interface circuits to induced signals will therefore be similar to the actual installation.

Zig-zagging of long cables is accomplished by first placing a length of cable in an open area and then reversing the direction of the cable run by 180 degrees each time a change of direction is required. Each subsequent segment is farther from the first. Individual segments of the cable are parallel and should be kept 2 cm apart. The zig-zagging of long cables rather than coiling is to control excess inductance. A 2 cm spacing between cables is required to expose all cabling to the test antennas and limit coupling of signals between cables. The 10 cm dimension for cables along the front edge of the ground plane ensures that there is both sufficient ground plane surface below the first cable to be effective, and that the cables are near enough the edge to simulate radiation as when they are installed along the front edge of an equipment rack. The 5 cm standoffs standardize loop areas available for coupling and capacitance to the ground plane. The standoffs represent routing and clamping of cables in actual installations a fixed distance from structure.

The requirement that the first two meters of each interconnecting cable associated with each enclosure of the EUT be routed parallel to the front boundary of the setup is intended to ensure that REs and susceptibility testing properly assesses the performance of the EUT. Noise signals developed within the EUT and conducted outside on electrical interfaces will tend to be attenuated as they travel along interconnecting cables, particularly at frequencies where the associated wavelength is becoming short compared with the cable length. Similarly, induced signals on interconnecting cables from RS fields will be attenuated as they travel along the cable. Requiring that the first two meters of the cabling be exposed therefore maximizes the effects of potential radiated coupling. When extension cables must be built, it is advantageous if the connection can be made at the bulkhead feedthrough point between test and control chambers. Especially if the individual signals are shielded, and/or there is an overshield, a bulkhead feedthrough connector is extremely effective in limiting noise pollution from support equipment in control chamber from polluting the test chamber ambient.

In some military applications, there can be over 2,000 cables associated with a subsystem. In most cases where large numbers of cables are involved, there will be many identical cable interfaces connected to identical circuitry. Testing of every cable interface is not necessary in this situation. The EMITP should document instances where these circumstances exist and should propose which cables are to be included in the setup and to be tested.

4.3.8.6.2 Input Power Leads

Discussion: Appropriate power lead length is a trade-off between ensuring sufficient length for efficient coupling of radiated signals and maintaining the impedance of the LISNs. To keep a constant setup, it is undesirable to change the power lead length for different test procedures. Requiring a 2 meter exposed length is consistent with treatment of interconnecting leads for radiated concerns. Wiring inductance 5 cm from a ground plane is approximately 1 μH/meter. At 1 MHz this inductance has an impedance of approximately 13 ohms which is significant with respect to the LISN requirement.

While it is common to require that neutrals and returns be isolated from equipment chassis within equipment enclosures, there are some cases where the neutral or return is tied directly to chassis. If the equipment is electrically bonded to metallic system structure in the installation and the system power source neutral or return is also tied to system structure, power return currents will flow primarily through system structure rather than through wiring. For this case, a LISN should normally be used only on the high side of the power. There are other installations, such as many types of aircraft, where returns and neutrals are isolated within the equipment, but they are often connected to system structure outside of the equipment enclosure. This practice allows for the flexibility of using a wired return, if necessary. For this situation, LISNs should normally be used on neutrals and returns to test for the wired return configuration.

The LISN requirement standardizes impedance for power leads. While signal and control circuits are usually terminated in specified impedances, power circuit impedances are not usually well defined. The LISN requirement applies to all input prime power leads. The LISN requirement does not apply to output power leads. These leads should be terminated after the two meter exposed length in a load representing worst-case conditions. This load would normally draw the maximum current allowed for the power source.

The construction of the power cable between the EUT and the LISNs must be in accordance with the requirements of Paragraph 4.3.8.6. For example, if a twisted triplet is used to distribute three-phase ungrounded power in the actual installation, the same construction should be used in the test setup. The normal construction must be interrupted over a sufficient length to permit connection to the LISNs.

4.3.8.7 Electrical and Mechanical Interfaces

Discussion: The application of signals to exercise the electrical interface is necessary to effectively evaluate performance. Most electronic subsystems on platforms are highly integrated with large amounts of digital and analog data being transferred between equipment. The use of actual platform equipment for the interfacing eliminates concerns regarding proper simulation of the interface. The interfaces must function properly in the presence of induced levels from susceptibility signals. Required isolation may be obtained by filtering the interface leads at the active load and either shielding the load or placing it outside of the shielded enclosure. The filtering should be selected to minimize the influence on the interface electrical properties specified above. For proper simulation, filtering at the loads should be outside the necessary BW of the interface circuitry.

Antenna ports are terminated in loads for general setup conditions. Specific test procedures address electromagnetic characteristics of antenna ports and required modifications to the test setup.

4.3.9 Operation of EUT

Discussion: The particular modes selected may vary for different test procedures. Considerations for maximum emissions include conditions which cause the EUT to draw maximum prime power current, result in greatest activity in interface circuit operation, and generate the largest current drain on internal digital clock signals. Settings for a radar could be adjusted such that an output waveform results which has the highest available average power. Data bus interfaces could be queried frequently to cause constant bus traffic flow. Any modes of the EUT that are considered mission critical in the installation should be evaluated during susceptibility testing.

A primary consideration for maximum susceptibility is placing the EUT in its most sensitive state for reception of intentional signals (maximum gain). An imaging sensor would normally be evaluated with a scene meeting the most stringent specifications for the sensor. RF receivers are normally evaluated using an input signal at the minimum signal to noise specification of the receiver. However, mission profiles must be kept in mind. If a particular threat transmission originated from the same source as a signal to be received, then it is unlikely that the signal would be received near the receiver's noise floor when the threat is at 200 V/m. Judgment must be used, and rationale supplied in the EMITP. An additional consideration is ensuring that all electrical interfaces that intentionally receive data are exercised frequently to monitor for potential responses.

4.3.9.1 Operating Frequencies for Tunable RF Equipment

Discussion: Tuned circuits and frequency synthesis circuitry inside RF equipment typically vary in characteristics such as response, rejection, and spectral content of emissions as they are set to different frequencies. Several test frequencies are required simply to obtain a sampling of the performance of the EUT across its operating range.

RF equipment that operates in several frequency bands or performs multiple functions is becoming more common. One example is a radio transceiver with Very High Frequency (VHF)-Frequency Modulation (FM), VHF-Amplitude Modulation (AM), and Ultrahigh Frequency (UHF)-AM capability. Other devices are adaptive over large frequency ranges and can be programmed to perform different functions as the need arises. To meet the intent of the requirement to perform measurements at three frequencies within each tuning band, tuning unit, or range of fixed channels, each of the three functions of the radio in the example should be treated as separate bands, even if they are adjacent in frequency. Similarly, each function of adaptive RF equipment needs to be separately assessed.

The “value added” of performing all required tests at three frequencies within each band needs to be weighed against the added cost and schedule. The specific equipment design and intended function needs to be evaluated for each case.

For example, performing CS101 on a VHF-FM, VHF-AM, and UHF-AM combined receiver-transmitter would require that the test be performed a minimum of 18 times (3 frequencies • 3 bands • 2 modes). Since CS101 performance generally is related to the power supply design and load rather than the specific tuned frequency, doing the test for more than a few conditions may not add much value. If there is a problem, a typical result is “hum” on the secondary power outputs that is transmitted with the RF or that appears on the output audio of the receiver portion of the equipment. An appropriate approach for this particular requirement might be to test at one mid-band frequency for each of the three functions for both transmit and receive (6 tests - 3 frequencies • 2 modes).

Other requirements need to be evaluated similarly. Since CE102 emissions are mainly caused by power supply characteristics, testing at a mid-band frequency for each band just in the transmit mode might be adequate. For requirements with frequency coverage that extends into the operating frequency range of the equipment, such as RE102, CE106, and RS103, testing at three frequencies per band may be necessary.

4.3.9.2 Operating Frequencies for Spread Spectrum Equipment

Discussion: During testing it is necessary to operate equipment at levels that they will experience during normal field operations to allow for a realistic representation of the emission profile of the EUT during radiated and conducted testing and to provide realistic loading and simulation of the EUT during radiated and CS testing.

Frequency hopping - Utilization of a hopset that is distributed across the entire operational spectrum of the EUT will help assure that internal circuitry dependent on the exact EUT transmit frequency being used is active intermittently during processing of the entire pseudo random stream. The fast operating times of hopping receivers/transmitters versus the allowable measurement times of the measurement receivers being used (reference Paragraph 4.3.10.3) will allow a representative EUT emission signature to be captured.

Direct sequence - Requiring the utilization of the highest data transfer rate used in actual operation of the EUT should provide a representative worst-case radiated and CE profile. Internal circuitry will operate at its highest processing rate when integrating the data entering the transmitter, and then resolving (disintegrating) the data back once again on the receiver end. Additionally, the data rate will need to be an area of concentration during all susceptibility testing.

4.3.9.3 Susceptibility Monitoring

Discussion: Most EUTs can be adequately monitored through normal visual and aural outputs, self diagnostics, and electrical interfaces. The addition of special circuitry for monitoring can present questions related to its influence on the validity of the test results and may serve as an entry or exit point for electromagnetic energy.

The monitoring procedure needs to be specified in the EMITP and needs to include allowances for possible weaknesses in the monitoring process to assure the highest probability of finding regions of susceptibility. Monitoring techniques should allow for realtime susceptibility evaluation, and should facilitate easy discovery of degradation. Inspecting data at the end of a susceptibility test or at the end of a frequency band sweep to determine pass/fail criteria can lead to very long tests if failures are found. One workaround is to accurately time stamp both frequency sweeps and EUT data output so that faults and frequencies can be time-correlated. Asking a human operator to examine large blocks of hexadecimal data words looking for errors is not as likely to find faults as a program which compares data to expected values and provides an alarm for an error condition.

4.3.10 Use of Measurement Equipment

Discussion: Questions frequently arise concerning the acceptability for use of measurement receivers other than instruments that are specifically designated “field intensity meters” or “EMI receivers.” Most questions are directed toward the use of spectrum analyzers. These instruments are generally acceptable for use. However, depending on the type, they can present difficulties that are not usually encountered with the other receivers. Sensitivity may not be adequate in some frequency bands requiring that a low noise preamplifier be inserted before the analyzer input. Impulse type signals from the EUT with broad spectral content may overload the basic receiver or preamplifier. The precautions of Paragraph 4.3.7.3 must be observed. Both of these concerns can usually be adequately addressed by the use of a preselector with the analyzer. These devices typically consist of a tunable filter which tracks the analyzer followed by a preamplifier.

ANSI C63.2 represents a coordinated position from industry on required characteristics of instrumentation receivers. This document can be consulted when assessing the performance of a particular receiver.

Many of the test procedures require non-specialized instrumentation that is used for many other purposes. The test facility is responsible for selecting instrumentation that has characteristics capable of satisfying the requirements of a particular test procedure.

Current probes used for EMI testing are more specialized instrumentation. These devices are current transformers with the circuit under test forming a single turn primary. They are designed to be terminated in 50 ohms. Current probes are calibrated using transfer impedance that is the ratio of the voltage output of the probe across 50 ohms to the current through the probe. Probes with higher transfer impedance provide better sensitivity. However, these probes also result in more series impedance added to the circuit with a greater potential to affect the electrical current level. The series impedance added by the probe is the transfer impedance divided by the number of turns in the secondary winding on the probe. Typical transfer impedances are 5 ohms or less. Typical added series impedance is 1 ohm or less.

4.3.10.1 Detector

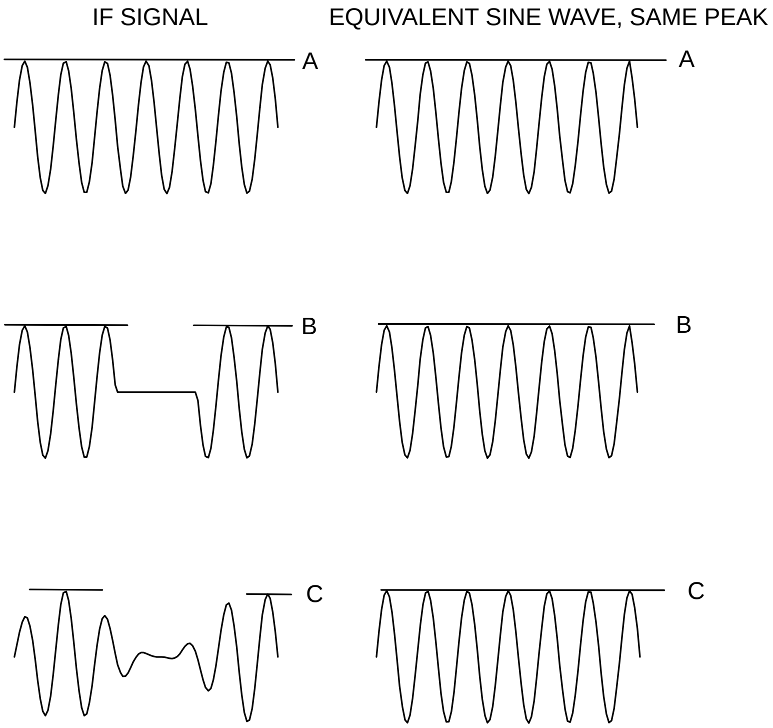
Discussion: The function of the peak detector and the meaning of the output indication on the measurement receiver are often confusing. Although there may appear to be an inherent discrepancy in the use of the terms “peak” and “RMS” together, there is no contradiction. All detector functions (that is peak, carrier, field intensity, and quasi-peak) process the envelope of the signal present in the receiver Intermediate Frequency (IF) section. All outputs are calibrated in terms of an equivalent RMS value. For a sine wave input to the receiver, the signal envelope in the IF section is a DC level and all detectors produce the same indicated RMS output. Calibration in terms of RMS is necessary for consistency. Signal sources are calibrated in terms of RMS. If a 0 dBm (107 dBμV) unmodulated signal is applied to the receiver, the receiver must indicate 0 dBm (107 dBμV).

If there is modulation present on the signal applied to the receiver, the detectors respond differently. The IF section of the receiver sees the portion of the applied signal within the BW limits of the IF. The peak detector senses the largest level of the signal envelope in the IF and displays an output equal to the RMS value of a sine wave with the same peak. The specification of a peak detector ensures that the worst case condition for emission data is obtained. A carrier detector averages the modulation envelope based on selected charge and discharge time constants.

Figure B-2 shows the peak detector output for several modulation waveforms. An item of interest is that for a square wave modulated signal, which can be considered a pulse type modulation, the receiver can be considered to be displaying the RMS value of the pulse when it is on. Pulsed signals are often specified in terms of peak power. The RMS value of a signal is derived from the concept of power, and a receiver using a peak detector correctly displays the peak power.

FIGURE B-2

PEAK DETECTOR RESPONSE



RECEIVER OUTPUT INDICATION WILL BE $\frac{A}{\sqrt{2}}$, $\frac{B}{\sqrt{2}}$, $\frac{C}{\sqrt{2}}$, RESPECTIVELY

All frequency domain measurements are standardized with respect to the response that a measurement receiver using a peak detector would provide. Therefore, when instrumentation is used which does not use peak detection, correction factors must be applied for certain signals. For an oscilloscope, the maximum amplitude of the modulated sine wave measured from the level is divided by 1.414 (square root of 2) to determine the RMS value at the peak of the modulation envelope.

Correction factors for other devices are determined by evaluating the response of the instrumentation to signals with the same peak level with and without modulation. For example, a correction factor for a broadband field sensor can be determined as follows. Place the sensor in an unmodulated field and note the reading. Apply the required modulation to the field ensuring that the peak value of the field is the same as the unmodulated field. For pulse type modulation, most signal sources will output the same peak value when modulation is applied. Amplitude modulation increases the peak amplitude of the signal and caution must be observed. Note the new reading. The correction factor is simply the reading with the unmodulated field divided by the reading with the modulated field. If the meter read 10 volts/meter without modulation and 5 volts/meter with modulation, the correction factor is 2. The evaluation should be tried at several frequencies and levels to ensure that a consistent value is obtained. When subsequently using the sensor for measurements with the evaluated modulation, the indicated reading is multiplied by the correction factor to obtain the correct reading for peak detection.

4.3.10.2 Computer-controlled Receivers

Discussion: Computer software obviously provides excellent opportunities for automating testing. However, it also can lead to errors in testing if not properly used or if incorrect code is present. It is essential that users of the software understand the functions it is executing, know how to modify parameters (such as transducer or sweep variables) as necessary, and perform sanity checks to ensure that the overall system performs as expected.

4.3.10.3 Emission Testing

4.3.10.3.1 Bandwidths

Discussion: The BWs specified in Table 4.3 are defaults consistent with the recommended available BWs and the BW specification technique for receivers contained in ANSI C63.2. If an SSV receiver has a BW significantly different than those listed in Table 4.3, consideration to tailoring the measurement bandwidth in that band should be considered. Existing receivers have BWs specified in a number of different ways. Some are given in terms of 3 dB down points. The 6 dB BWs are usually about 40% greater than the 3 dB values. Impulse BWs are usually very similar to the 6 dB BWs. For gaussian shaped bandpasses, the actual value is 6.8 dB.

The frequency break point between using a 1 kHz and 10 kHz BW was modified from 250 kHz to 150 kHz in this version of the specification to harmonize with commercial EMI standards.

In order not to restrict the use of presently available receivers that do not have the specified BWs, larger BWs are permitted. The use of larger BWs can produce higher detected levels for wide BW signals. The prohibition against the use of correction factors is included to avoid any attempts to classify signals. MIL-STD-461D, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, eliminated the concept of classification of emissions as broadband or narrowband in favor of fixed BWs and single limits. Emission classification was a controversial area often poorly understood and handled inconsistently among different facilities.

The sensitivity of a particular receiver is an important factor in its suitability for use in making measurements for a particular requirement. RE102 is usually the most demanding requirement. The sensitivity of a receiver at room temperature can be calculated as follows:

Sensitivity in dBm = -114 dBm/MHz + BW (dBMHz) + noise figure (dB)

As noted in the equation, reducing the noise figure is the only way (cryogenic cooling is not practical) to improve sensitivity for a specified BW. The noise figure of receivers can vary substantially depending on the front end design. System noise figure can be improved through the use of low noise preamplifiers. The resulting noise figure of a preamplifier/receiver combination can be calculated from the following. All numbers are real numbers. Conversion to dB (10 log) is necessary to determine the resulting sensitivity in the formula, which is an approximation valid in those cases when receiver noise figure or gain are large with respect to one:

System noise figure = preamp noise figure + (receiver noise figure)/(preamp gain)

Since preamplifiers are broadband devices, issues of potential overload need to be addressed. Separate preselectors, which are available for some spectrum analyzers, usually combine a tracking filter with a low noise preamplifier to eliminate overload. Preselection is an integral part of many receivers.

4.3.10.3.2 Emission Identification

Discussion: Requirements for specific BWs and the use of single limits are intended to resolve a number of problems. Versions of MIL-STD-461 and MIL-STD-462 prior to the “D” revision and of SL-E-0002 prior to the “F” revision had no controls on required BWs and provided both narrowband and broadband limits over much of the frequency range for most emission requirements. The significance of the particular BWs chosen for use by a test facility were addressed by classification of the appearance of the emissions with respect to the chosen BWs. Emissions considered to be broadband had to be normalized to equivalent levels in a 1 MHz BW. The BWs and classification techniques used by various facilities were very inconsistent and resulted in a lack of standardization. The basic issue of emission classification was often poorly understood and implemented. Requiring specific bandwidths with a single limit eliminates any need to classify emissions.

An additional problem is that emission profiles from modern electronics are often quite complex. Some emission signatures have frequency ranges where the emissions exhibit white noise characteristics. Normalization to a 1 MHz BW using spectral amplitude assumptions based on impulse noise characteristics is not technically correct. Requiring specific BWs eliminates normalization and this discrepancy.

4.3.10.3.3 Frequency Scanning

Discussion: For each emission test, the entire frequency range as specified for the applicable requirement must be scanned to ensure that all emissions are measured.

Continuous frequency coverage is required for emission testing. Testing at discrete frequencies is not acceptable unless otherwise stated in a particular test procedure. The minimum scan times listed in Table 4.3 are based on two considerations. The first consideration is the response time of a particular BW to an applied signal. This time is 1/(filter BW). The second consideration is the potential rates (that is modulation, cycling, and processing) at which electronics operate and the need to detect the worst case emission amplitude. Emission profiles usually vary with time. Some signals are present only at certain intervals and others vary in amplitude. For example, signals commonly present in emission profiles are harmonics of microprocessor clocks. These harmonics are very stable in frequency; however, their amplitude tends to change as various circuitry is exercised and current distribution changes.

The first entry in the table for analog measurement receivers of 0.015 sec/Hz for a BW of 10 Hz is the only one limited by the response time of the measurement receiver bandpass. The response time is 1/BW = 1/10 Hz = 0.1 seconds. Therefore, as the receiver tunes, the receiver bandpass must include any particular frequency for 0.1 seconds implying that the minimum scan time = 0.1 seconds/10 Hz = 0.01 seconds/Hz. The value in the table has been increased to 0.015 seconds/Hz to ensure adequate time. This increase by a multiplication factor of 1.5 results in the analog receiver having a frequency in its bandpass for 0.15 seconds as it scans. This value is the dwell time specified in the table for synthesized receivers for 10 Hz BWs. Since synthesized receivers are required to step in one-half BW increments or less and dwell for 0.15 seconds, test time for synthesized receivers will be greater than analog receivers.

The measurement times for other table entries are controlled by the requirement that the receiver bandpass include any specific frequency for a minimum of 15 milliseconds (dwell time in table), which is associated with a potential rate of variation of approximately 60 Hz. As the receiver tunes, the receiver bandpass is required to include any particular frequency for the 15 milliseconds. For the fourth entry in the table of 1.5 seconds/MHz for a 10 kHz BW, the minimum measurement time is 0.015 seconds/0.01 MHz = 1.5 seconds/MHz. A calculation based on the response time of the receiver would yield a response time of 1/BW = 1/10 kHz = 0.0001 seconds and a minimum measurement time of 0.0001 seconds/0.01 MHz = 0.01 seconds/MHz. The longer measurement time of 1.5 seconds/MHz is specified in the table. If the specified measurement times are not adequate to capture the maximum amplitude of the EUT emissions, longer measurement times should be implemented.

Caution must be observed in applying the measurement times. The specified parameters are not directly available on measurement receiver controls and must be interpreted for each particular receiver. Also, the specified measurement times may be too fast for some data gathering devices such as realtime X-Y recording. Measurement receiver peak hold times must be sufficiently long for the mechanical pen drive on X-Y recorders to reach the detected peak value. In addition, the scan speed must be sufficiently slow to allow the detector to discharge after the signal is detuned so that the frequency resolution requirements of Paragraph 4.3.10.3.4 are satisfied.

For measurement receivers with a “maximum hold” feature that retains maximum detected levels after multiple scans over a particular frequency range, multiple faster sweeps that produce the same minimum test times as implied by Table 4.3 are acceptable. For the situation noted in the requirement concerning equipment that produces emissions at only infrequent intervals, using the multiple scan technique will usually provide a higher probability of capturing intermittent data than using one slower scan.

Tailoring to shorten these sweep times is reasonable for equipment whose emission profile is time invariant. This is especially useful when the EUT must be exercised for short time periods only. Any such tailoring should be described and justified in the EMITP.

4.3.10.3.4 Emission Data Presentation

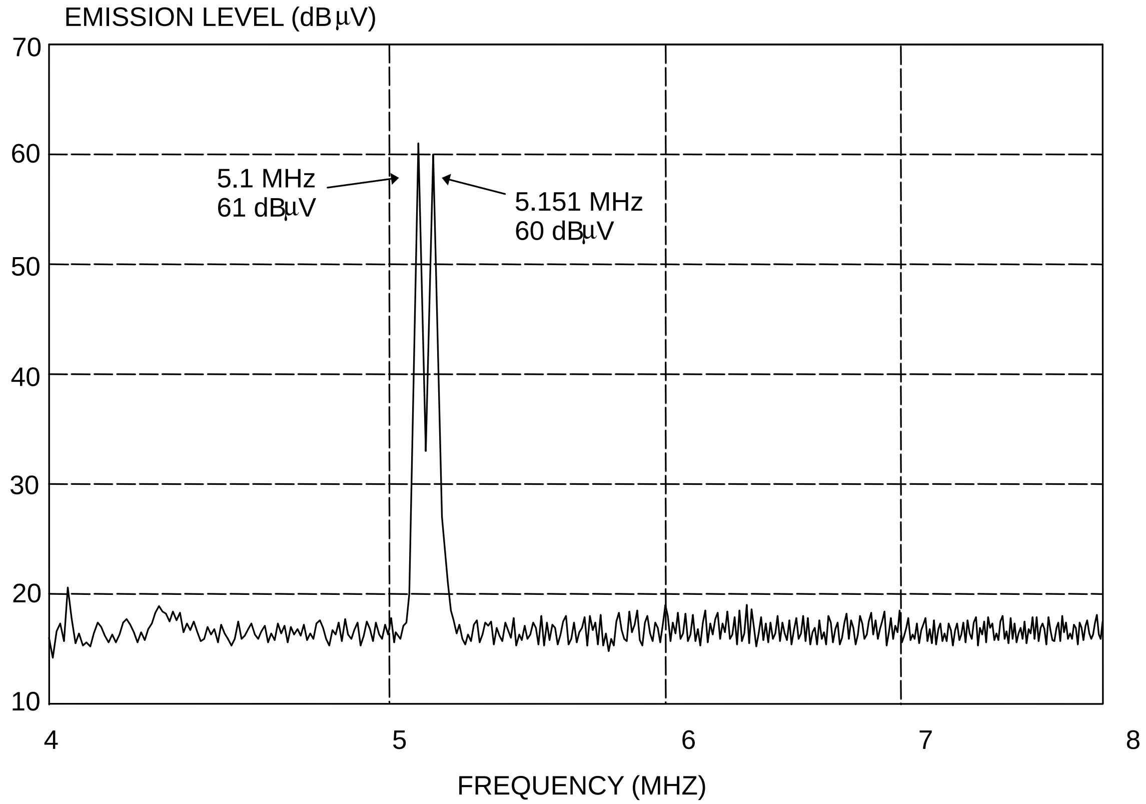
Discussion: Versions of MIL-STD-462 prior to the “D” revision permitted data to be taken at the three frequencies per octave for the highest amplitude emissions. This approach is no longer acceptable. Continuous displays of amplitude versus frequency are required. This information can be generated in a number of ways. The data can be plotted realtime as the receiver scans. The data can be stored in computer memory and later dumped to a plotter. Photographs of video displays are acceptable; however, it is generally more difficult to meet resolution requirements and to reproduce data in this form for submittal in an EMITR.

Placement of limits can be done in several ways. Data may be displayed with respect to actual limit dimensions (such as dBμV/m) with transducer, attenuation, and cable loss corrections made to the data. An alternative is to plot the raw data in dBμv (or dBm) and convert the limit to equivalent dBμv (or dBm) dimensions using the correction factors. This second technique has the advantage of displaying the proper use of the correction factors. Since both the emission level and the required limit are known, a second party can verify proper placement. Since the actual level of the raw data is not available for the first case, this verification is not possible.

An example of adequate frequency and amplitude resolution is shown in Figure B-3. One percent frequency resolution means that two sinusoidal signals of the same amplitude separated by 1% of the tuned frequency are resolved in the output display so that they both can be seen. As shown in the figure, 1% of the measurement frequency of 5.1 MHz is 0.051 MHz and a second signal at 5.151 MHz (1 dB different in amplitude on the graph) is easily resolved in the display. The “2 times the measurement receiver BW” criteria means that two sinusoidal signals of the same amplitude separated by twice the measurement receiver BW are resolved. For the example, shown in Figure B-3, the BW is 0.01 MHz and 2 times this value is 0.02 MHz. Therefore, the 1% criterion is less stringent and is applicable. 1 dB amplitude resolution means that the amplitude of the displayed signal can be read within 1 dB. As shown in the figure, the reviewer can determine whether the signal amplitude is 60 dBμV or 61 dBμV.

FIGURE B-3

EXAMPLE OF DATA PRESENTATION RESOLUTION



The difference between resolution and accuracy is sometimes confusing. Paragraph 4.3.1 of the specification requires 3 dB measurement system accuracy for amplitude while Paragraph 4.3.10.3.4 of the specification requires 1 dB amplitude resolution. Accuracy is an indication how precisely a value needs to be known while resolution is an indication of the ability to discriminate between two values. A useful analogy is reading time from a watch. A watch typically indicates the time within one second (resolution) but may be 30 seconds different than the absolute correct time (accuracy).

4.3.10.4 Susceptibility Testing

4.3.10.4.1 Frequency Scanning

Discussion: For any susceptibility test performed in the frequency domain, the entire frequency range as specified in the applicable requirement must be scanned to ensure that all potentially susceptible frequencies are evaluated.

The scan rates and step sizes in Table 4.4 are structured to allow for a continuous change in value with frequency for flexibility. Computerized test systems could be programmed to change values very frequently. A more likely application is to block off selected bands for scanning and to base selections of scan rate or step size on the lowest frequency. For example, if 1 - 2 GHz were selected, the maximum scan rate would be (0.000667 X 1 GHz)/sec which equals 0.667 MHz/sec and the maximum step size would be 0.001 X 1 GHz which equals 1 MHz. Both automatic and manual scanning are permitted.

The two primary areas of concern for frequency scanning for susceptibility testing are response times for EUTs to react to stimuli and how sharply the responses tune with frequency, normally expressed as quality factor (Q). Both of these items have been considered in the determination of the scan rates and step sizes in Table 4.4. The table entries are generally based on the assumption of a maximum EUT response time of three seconds and Q values of 10, 50, 100, 500, and 1000 (increasing values as frequency increases in Table 4.4). Since EUT responses are more likely to occur in approximately the 1 to 200 MHz range due to efficient cable coupling based on wavelength considerations, Q values have been increased somewhat to slow the scan and allow additional time for observation of EUT responses. More detailed discussions on these items follow.

The assumption of a maximum response time of three seconds is considered to be appropriate for a large percentage of possible cases. There are several considerations. While the electronics processing the interfering signal may respond quickly, the output display may take some time to react. Outputs that require mechanical motion such as meter movements or servo driven devices will generally take longer to show degradation effects than electronic displays such as video screens. Another concern is that some EUTs will only be in particularly susceptible states periodically. For example, sensors feeding information to a microprocessor are typically sampled at specific time intervals. It is important that the susceptibility stimuli be located at any critical frequencies when the sensor is sampled. The time intervals between steps and sweep rates in Table 4.4 may need to be modified for EUTs with unusually long response times.

Some concern has been expressed on the susceptibility scan rates and the impact that they would have on the length of time required to conduct a susceptibility test. The criteria of Table 4.4 allow the susceptibility scan rate to be adjusted continually as the frequency is increased; however, as a practical matter, the rate would most likely only be changed once every octave or decade. As an example, Table B.2 splits the frequency spectrum up into ranges varying from octaves to decades and lists the minimum time required to conduct a susceptibility test for an analog scan. The scan rate for each range is calculated based on the start frequency for the range. The total test time to run RS103 from 1 MHz to 18 GHz is 177 minutes. A similar calculation for a stepped scan results in a total test time which is 2 times this value or 353 minutes. It must be emphasized that the scan speeds should be slowed down if the EUT response time or Q are more critical than those used to establish the values in Table 4.4.

Q is expressed as f_o/BW where f_o is the tuned frequency and BW is the width in frequency of the response at the 3 dB down points. For example, if a response occurred at 1 MHz at a susceptibility level of 1 volt and the same response required 1.414 volts (3 dB higher in required drive) at 0.95 and 1.05 MHz, the Q would be 1 MHz/(1.05 - 0.95 MHz) or 10. Q is primarily influenced by resonances in filters, interconnecting cabling, physical structure, and cavities. The assumed Q values are based on observations from various types of testing. The step sizes in Table 4.4 are one half of the 3 dB BWs of the assumed value of Q ensuring that test frequencies will lie within the resonant responses.

Below approximately 200 MHz, the predominant contributors are cable and interface filter resonances. There is loading associated with these resonances which dampens the responses and limits most values of Q to less than 50. Above 200 MHz, structural resonances of enclosures and housings start playing a role and have higher values of Q due to less dampening. Above approximately 1 GHz, aperture coupling with excitation of cavities will be become dominant. Values of Q are dependent on frequency and on the amount of material contained in the cavity. Larger values of Q result when there is less material in the volume. A densely packaged electronics enclosure will exhibit significantly lower values of Q than an enclosure with a higher percentage of empty volume. Q is proportional to volume/(surface area X skin depth). The value of Q also tends to increase with frequency as the associated wavelength becomes smaller. EUT designs with unusual configurations that result in high Q characteristics may require that the scan rates and step sizes in Table 4.4 be decreased for valid testing.

TABLE B.2

SUSCEPTIBILITY TESTING TIMES

Frequency Range	Maximum Scan Rate	Actual Scan Time
30 Hz - 100 Hz	1.0 Hz/sec	1.2 min
100 Hz - 1 kHz	3.33 Hz/sec	4.5 min
1 kHz - 10 kHz	33.3 Hz/sec	4.5 min
10 kHz - 100 kHz	333 Hz/sec	4.5 min
100 kHz - 1 MHz	33.3 kHz/sec	4.5 min
1 MHz - 5 MHz	6.67 kHz/sec	10 min
5 MHz - 30 MHz	33.3 kHz/sec	12.5 min
30 MHz - 100 MHz	100 kHz/sec	11.7 min
100 MHz - 200 MHz	333 kHz/sec	5.0 min
200 MHz - 400 MHz	667 kHz/sec	5.0 min
400 MHz - 1 GHz	1.33 MHz/sec	7.5 min
1 GHz - 2 GHz	0.667 MHz/sec	25.0 min
2 GHz - 4 GHz	1.33 MHz/sec	25.0 min
4 GHz - 8 GHz	2.67 MHz/sec	25.0 min
8 GHz - 12 GHz	2.67 MHz/sec	25.0 min
12 GHz - 18 GHz	4 MHz/sec	25.0 min
18 GHz - 30 GHz	6 MHz/sec	33.3 min
30 GHz - 40 GHz	10 MHz/sec	16.7 min

RF processing equipment presents a special case requiring unique treatment. Intentionally tuned circuits for processing RF can have very high values of Q. For example, a circuit operating at 1 GHz with a BW of 100 kHz has a Q of 1 GHz/100 kHz or 10,000.

Automatic leveling used to stabilize the amplitude of a test signal for stepped scans may require longer dwell times than one second at discrete frequencies. The signal will take time to settle and any EUT responses during the leveling process should be ignored.

For SSV, susceptibility tests other than CS103, 104, and 105 may use 1% frequency steps throughout, except at frequencies approaching passbands of receivers or other sharply tuned circuits.

4.3.10.4.2 Modulation of Susceptibility Signals

Discussion: CS114 and RS103 specify pulse modulation at a 1 kHz rate, 50% duty cycle, (alternately termed 1 kHz square wave modulation) for several reasons. One kHz is within the bandpass of most analog circuits such as audio or video. The fast rise and fall times of the pulse causes the signal to have significant harmonic content high in frequency and can be detrimental to digital circuits. Response of electronics has been associated with energy present and a square wave results in high average power. The modulation encompasses many signal modulations encountered in actual use. The square wave is a severe form of amplitude modulation used in communications and broadcasting. It also is a high duty cycle form of pulse modulation representative of radars.

RS103 also specifies a low duty cycle pulse modulation in the microwave bands for EMC critical equipments which are subjected to a 200 V/m peak field intensity above 1 GHz. Equipments which are deemed flight or safety critical (flight and engine controls) typically have small BWs and hence are likely to respond to average rather than peak power. Imposing the square wave modulation in bands where the threats are mainly low duty-cycle radars is deemed overly restrictive.

Modulation is usually the effect that degrades EUT performance. The wavelengths of the RF signal cause efficient coupling to electrical cables and through apertures (at higher frequencies). Non-linearities in the circuit elements detect the modulation on the carrier. The circuits may then respond to the modulation depending upon detected levels, circuit bandpass characteristics, and processing features.

Care needs to be taken in implementing 1 kHz, 50% duty cycle, pulse modulation (on/off ratio of 40 dB) using some signal sources. Most higher frequency signal sources have either internal pulse modulation or an external port for pulse modulation. This function switches the output on and off without affecting the amplitude of the unmodulated signal, provided that the strength of the modulation signal is adequate. For other signal sources, particularly at lower frequencies, the external AM port needs to be driven to a minimum of 99% depth of modulation (equivalent to 40 dB on/off ratio) to simulate pulse modulation. The output signal will essentially double in amplitude compared to an unmodulated signal for this type of input. Depending on the type of testing being performed and the technique of monitoring applied signals, this effect may or may not influence the results. Use of an AM port can be substantially more involved than using a pulse modulation port. The amplitude of the input signal directly influences the depth of modulation. There is a potential of exceeding 100% depth of modulation, which will result in signal distortion. Since the on/off ratio requirement is stringent, it is necessary to view the output signal on an oscilloscope to set the appropriate depth of modulation. Another complication is that the BW of AM ports is usually less than pulse ports. Driving the port with a pulse shape may result in difficulty in setting the source for a minimum of 99%.

MIL-STD-461A, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, required that the worst case modulation for the EUT be used. Worst case modulation usually was not known or determined. Also, worst case modulation may not be related to modulations seen in actual use or may be very specialized. The most typical modulations used below approximately 400 MHz have been amplitude modulation at either 400 or 1000 Hz (30 to 80%) or pulse modulation, 50% duty cycle, at 400 or 1000 Hz. These same modulations have been used above 400 MHz together with pulse modulation at various pulse widths and pulse repetition frequencies. Continuous Wave ([CW] - no modulation) has also occasionally been used. CW typically produces a detected DC level in the circuitry and affects certain types of circuits. In general, experience has shown that modulation is more likely to cause degradation. CW should be included as an additional requirement when assessing circuits that respond only to heat such as electroexplosive devices. CW should not normally be used as the only condition.

Consideration should be given to applying a secondary 1 Hz modulation (where the normal 1 kHz square wave modulated waveform is completely turned on and off every 500 milliseconds) for certain subsystems with low frequency response characteristics, such as aircraft flight control subsystems. This modulation simulates characteristics of some transmitters such as High Frequency (HF) radios in single sideband operation (no carrier), where a transmitted voice signal will cause the RF to be present only when a word is spoken. The dilemma with using this modulation is that the potential response of some subsystems may be enhanced, while others may be less responsive. In the latter case, the 500 millisecond “off” period allows the subsystem to recover from effects introduced during the “on” period.

For SSV purposes, if a particularly severe threat source has a known modulation characteristic, that modulation may be substituted for the default modulation. This is particularly useful if the modulation is FM, phase-shifted Tracking and Data Relay Satellite System, or very narrow low duty cycle pulses (radar). The typical EUT is less susceptible to these types of modulation than to the default 1 kHz waveform.

4.3.10.4.3 Thresholds of Susceptibility

Discussion: It is usually necessary to test at levels above the limits to ensure that the test signal is at least at the required level. Determination of a threshold of susceptibility is necessary when degradation is present to assess whether requirements are met. This information should be included in the EMITR. Threshold levels below limits are unacceptable.

The specified steps to determine thresholds of susceptibility standardize a particular technique. An alternative procedure sometimes utilized in the past was to use the value of the applied signal where the EUT recovers (reference Section 4, Paragraph 4.3.10.4.3, Thresholds of Susceptibility, Step a, in the general requirements section) as the threshold. Hysteresis type effects are often present where different values are obtained for the two procedures.

Distortion of sinusoidal susceptibility signals caused by non-linear effects in power amplifiers can lead to erroneous interpretation of results. When distortion is present, the EUT may actually respond to a harmonic of the intended susceptibility frequency, where the required limit may be lower. When frequency selective receivers are used to monitor the injected level, distortion itself does not prevent a valid susceptibility signal level from being verified at the intended frequency. However, harmonic levels should be checked when susceptibility is present to determine if they are influencing the results. When broadband sensors are being used, such as in portions of RS103, distortion can result in the sensor incorrectly displaying the required signal level at the intended frequency. In this case, distortion needs to be controlled such that correct levels are measured.

4.3.11 Calibration of Measuring Equipment

Discussion: Calibration is typically required for any measurement device whose characteristics are not verified through use of another calibrated item during testing. For example, it is not possible during testing to determine whether an antenna used to measure REs is exhibiting correct gain characteristics. Therefore, these antennas require periodic calibration. Conversely, a power amplifier used during RS testing often will not require calibration since application of the proper signal level is verified through the use of a separate calibrated field sensing device. Other amplifier applications such as the use of a signal pre-amplifier in front of a measurement receiver would require calibration of the amplifier characteristics since the specific gain versus frequency response is critical and is not separately verified.

4.3.11.1 Measurement System Test

Discussion: The end-to-end system check prior to emission testing is valuable in demonstrating that the overall measurement system is working properly. It evaluates many factors including proper implementation of transducer factors and cable attenuation, general condition and setting of the measurement receiver, damaged RF cables or attenuators, and proper operation of software. Details on implementation are included in the individual test procedures.

4.3.11.2 Antenna Factors

Discussion: SAE ARP-958 provides a standard basis for determining antenna factors emission testing. A caution needs to be observed in trying to apply these factors in applications other than EMI testing. The two antenna technique for antennas such as the biconical and double ridge horns is based on far field assumptions which are not met over much of the frequency range. Although the factors produce standardized results, the true value of the electric field is not necessarily being provided through the use of the factor. Different measuring sensors need to be used when the true electric field must be known.

5.1 GENERAL

Discussion: The applicability of individual requirements in Table 5.1 for a particular equipment or subsystem is dependent upon the platforms where the item will be used. The electromagnetic environments present on a platform together with potential degradation modes of electronic equipment items play a major role regarding which requirements are critical to an application. For example, emissions requirements are tied to protecting antenna-connected receivers on platforms. The operating frequency ranges and sensitivities of the particular receivers on-board a platform, therefore, influence the need for certain requirements.

The EMI control plan, EMITPs, and EMITR are important elements in documenting design efforts for meeting the requirements of this specification, testing approaches which interpret the generalized test procedures in this specification, and reporting of the results of testing. The EMI control plan is a mechanism instituted to help ensure that contractors analyze equipment design for EMI implications and include necessary measures in the design for compliance with requirements. Approval of the document does not indicate that the procuring activity agrees that all the necessary effort is stated in the document. It is simply a recognition that the design effort is addressing the correct issues.

The susceptibility limits are the upper bound on the range of values for which compliance is required. The EUT must also provide required performance at any stress level below the limit. For example, if the limit for RS to electric fields is 20 volts/meter, the EUT must also meet its performance requirements at 10 volts/meter or any other field less than or equal to 20 volts/meter. There have been cases documented where equipment (such as equipment with automatic gain control circuitry) was not susceptible to radiated electric fields at given frequencies at the limit level but was susceptible to the environment at the same frequencies when exposed to fields below the limit level.

5.1.1 Units of Frequency Domain Measurements

Discussion: A detailed discussion is provided on peak envelope detection in Paragraph 4.3.10.1. A summary of output of the detector for several input waveforms is as follows.

For an unmodulated sine wave, the output simply corresponds to the RMS value of the sine wave. For a modulated sine wave, the output is the RMS value of an unmodulated sine wave with the same absolute peak value. For a signal with a BW greater than the BW of the measurement receiver, the output is the RMS value of an unmodulated sine wave with the same absolute peak value as the waveform developed in the receiver bandpass.

5.2 CE102, CONDUCTED EMISSIONS, POWER LEADS, 10 kHz TO 10 MHz

Applicability and Limits: The requirements are applicable to leads that obtain power from sources that are not part of the EUT. There is no requirement on output leads from power sources.

The basic concept in the lower frequency portion of the requirement is to ensure that the EUT does not corrupt the power quality (allowable voltage distortion) on the power buses present on the platform. Examples of power quality documents are MIL-STD-704, Aircraft Electric Power Characteristics, for aircraft, MIL-STD-1399, Interface Standard for Shipboard Systems, for ships, MIL-STD-1539, Electrical Power, Direct Current, Space Vehicle Design Requirements, for space systems, and MIL-STD-1275, Characteristics of 28 Volt DC Electrical Systems in Military Vehicles, for military vehicles. Electrical power quality for the Space Shuttle is described in MF-0004-02, Electrical Design Requirements for Electrical Equipment Utilized on the Space Shuttle Vehicle. The military standards described above differ in one important respect from Shuttle power quality. The source of Shuttle DC power is a fuel cell, which, loaded in a time independent manner produces pure DC power with no inherent ripple. Therefore limiting load-induced effects is the only control necessary or exerted to control steady-state power bus ripple. While the CE102 28 VDC limit is not specifically tailored for Shuttle use, it is considered to be sufficient to adequately control load-induced ripple. The CE102 curve for 115 VAC power is also sufficient for control of load-induced ripple on the 400 Hz bus as well. Unlike aircraft, where 28 VDC is either transformed and rectified 400 Hz power, or directly derived from rotating machinery, the reverse is true for the Shuttle, with the 400 Hz bus emanating from a low power inverter. Thus, there are relatively few loads on the AC bus, and the majority of these tend to be insensitive to ripple (electrical versus electronic loads).

Since power quality standards govern allowable distortion on output power, there is no need for separate EMI requirements on output leads. The output power leads are treated no differently than any other electrical interface. This specification does not directly control the spectral content of signals present on electrical interfaces. Waveform definitions and distortion limits are specified in documents such as interface control documents. In the case of output power, the quality of the power must be specified over an appropriate frequency range so that the user of the power can properly design for its characteristics. This situation is true whether the power source is a primary source such as 115 volts, 400 Hz, or a ± 15 VDC low current supply. A significant indirect control on spectral content exists in the RE102 limits which essentially require that appropriate waveform control and signal transmission techniques be used to prevent unacceptable radiation (see discussion on CE102 limit placement and RE102 relationship below).

Since voltage distortion is the basis for establishing power quality requirements, the CE102 limit is in terms of voltage. The use of a standardized line impedance over the frequency range of this test provides for the convenient measurement of the voltage as developed across this impedance. In previous versions of MIL-STD-461, a current measurement into a 10 microfarad feedthrough capacitor was specified. The intent of the capacitor was to provide an RF short of the power lead to the ground plane. It was difficult to interpret the significance of the current limit with respect to platform applications. The presence of a standardized impedance is considered to reflect more closely the electrical characteristics of the power buses in platforms.

Of the power quality documents reviewed, MIL-STD-704 is the only one with a curve specifying an amplitude versus frequency relationship for the allowable distortion. The CE102 limits require that amplitude decays with increasing frequency similar to the requirements of MIL-STD-704. Common requirements are specified for all applications since the concerns are the same for all platforms.

The basic limit curve for 28 volts is placed approximately 20 dB below the power quality curve in MIL-STD-704. There are several reasons for the placement. One reason is that a number of interference sources present in different subsystems and equipments on a platform may be contributing to the net interference voltage present at a given location on the power bus. Assuming that the interference sources are not phase coherent, the net voltage will be the square root of the sum of the squares of the voltages from the individual sources. A second reason is that the actual impedance in an installation will vary from the control impedance with actual voltages being somewhat higher or lower than that measured during the test. Therefore, some conservatism needs to be included in the limit.

The relaxation for other higher voltage power sources is based on the relative levels of the power quality curves on ripple for different operating voltages.

At higher frequencies, the CE102 limit serves as a separate control from RE102 on potential radiation from power leads that may couple into sensitive antenna-connected receivers. The CE102 limits have been placed to ensure that there is no conflict with the RE102 limit. Emissions at the CE102 limit should not radiate above the RE102 limit. Laboratory experiments on coupling from a 2.5 meter power lead connected to a LISN have shown that the electric field detected by the RE102 rod antenna is flat with frequency up to approximately 10 MHz and is approximately equal to (x-40) dBμV/m, where “x” is the voltage expressed in dBμV. For example, if there is a signal level of 60 dBμV on the lead, the detected electric field level is approximately 20 dBμV/m.

Tailoring of the requirements in contractual documents may be desirable by the procuring activity. Adjusting the limit line to more closely emulate a spectral curve for a particular power quality standard is one possibility. Contributions from multiple interference sources need to be considered as noted above. If antenna-connected receivers are not present on the platform at the higher frequencies, tailoring of the upper frequency of the requirement is another possibility. The requirement is limited to an upper frequency of 10 MHz due to the allowable 2.5 meter length of power lead in the test setup approaching resonance. Any conducted measurements become less meaningful above this frequency. If tailoring is done to impose the requirement at higher frequencies, the test setup should be modified for CE102 to shorten the allowable length of the power leads. Tailoring for Space Shuttle use might take into account the above HF concerns, and also low frequency relaxations for extremely high current loads with a low impedance connection (relative to the 50 μH LISNs) to the fuel cell. In such a case, the limit might be retained but another LISN (e.g., 5 μH, 50 Ω) used, or the low current limit might be relaxed using the MIL-STD-461E LISN.

Test procedures: Emission levels are determined by measuring the voltage present at the output port on the LISN.

The power source impedance control provided by the LISN is a critical element of this test. This control is imposed due to wide variances in characteristics of shielded room filters and power line impedances among various test agencies and to provide repeatability through standardization. The LISN standardizes this impedance. The impedance present at the EUT electrical interface is influenced by the circuit characteristics of the power lead wires to the LISNs. The predominant characteristic is inductance. The impedance starts to deviate noticeably at approximately 1 MHz where the lead inductance is about 13 ohms.

A correction factor must be included in the data reduction to account for the 20 dB attenuator and for voltage drops across the coupling capacitor. This capacitor is in series with a parallel combination of the 50 ohm measurement receiver and the 1 kilo ohm LISN resistor. The two parallel resistances are equivalent to 47.6 ohms. The correction factor equals:

$$20 \log_{10} (1 + 5.60\text{x}10^{-9}f^2)^{1/2}/(7.48\text{x}10^{-5}f)$$

where f is the frequency of interest expressed in Hz. This equation is plotted in Figure B-4. The correction factor is 4.45 dB at 10 kHz and drops rapidly with frequency.

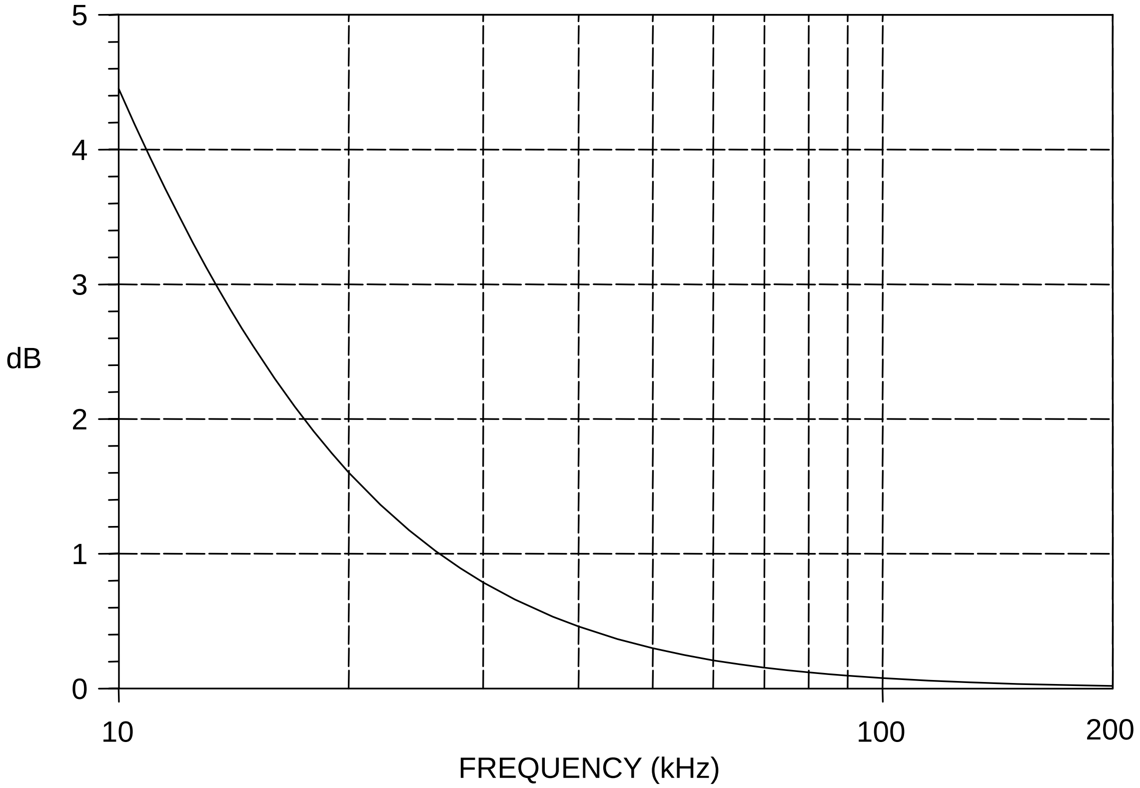
The upper measurement frequency is limited to 10 MHz because of resonance conditions with respect to the length of the power leads between the EUT and LISN. As noted in Paragraph 4.3.8.6.2 of the main body of the specification, these leads are between 2.0 and 2.5 meters long. Laboratory experimentation and theory show a quarter-wave resonance close to 25 MHz for a 2.5 meter lead. In the laboratory experiment, the impedance of the power lead starts to rise significantly at 10 MHz and peaks at several thousand ohms at approximately 25 MHz. Voltage measurements at the LISN become largely irrelevant above 10 MHz.

The 0.25 microfarad coupling capacitor in the LISN allows approximately 3.6 volts to be developed across the 50 ohm termination on the signal port for 115 volt, 400 Hz, power sources. The 20 dB attenuator is specified in the test procedure to protect the measurement receiver and to prevent overload. Sources of 60 Hz pose less of a concern.

An oscilloscope is necessary for the measurement system check in Figure 5-1 to ensure that the actual applied voltage is measured accurately at 10 kHz and 100 kHz and maintains a sinusoidal shape. The LISN presents a 50 ohm load impedance to a 50 ohm signal generator only for frequencies of approximately 300 kHz or higher (reference Figure 4-7). Since a 50 ohm signal generator is essentially an ideal voltage source in series with 50 ohms, the amplitude display setting of the generator is correct only when it is terminated in a matched impedance of 50 ohms. Under this condition the voltage splits between the two 50 ohm resistances. If the output is measured directly with a high impedance instrument, such as an oscilloscope, the indicated voltage is twice the amplitude setting. The load seen by the signal generator varies with frequency and the voltage at the LISN will also vary.

FIGURE B-4

CORRECTION FACTOR FOR LISN CAPACITOR



An area of concern for this test procedure is the potential to overload the measurement receiver due to the line voltage at the power frequency. Overload precautions are discussed in Paragraph 4.3.7.3 of this specification. When an overload condition is predicted or encountered, a rejection filter can be used to attenuate the power frequency. A correction factor must be then included in the emission data to account for the filter loss with respect to frequency.

5.3 CE106, CONDUCTED EMISSIONS, ANTENNA TERMINAL, 100 MHz TO 18 GHz

Applicability and Limits: The requirement is applicable for transmitters, receivers and amplifiers. The basic concern is to protect antenna-connected receivers both on and off the platform from being degraded due to radiated interference from the antenna associated with the EUT. The limit for transmitters in the transmit mode is placed primarily at levels which are considered to be reasonably obtainable for most types of equipment. Suppression levels that are required to eliminate all potential electromagnetic compatibility situations are often much more severe and could result in significant design penalties. The limit for receivers and transmitters in standby is placed at a level that provides reasonable assurance of compatibility with other equipment. Common requirements are specified for all applications since the concerns are the same for all platforms.

As an example of an antenna coupling situation, consider a 10 watt VHF-AM transmitter operating at 150 MHz and a UHF-AM receiver with a sensitivity of -100 dBm tuned to 300 MHz with isotropic antennas located 10 meters apart. The requirement is that the transmitter second harmonic at 300 MHz must be down 50 + 10 log 10 = 60 dB. The free space loss equation. $P_R/P_T = (\lambda^2 G_T G_R)/(4\pi R)^2$ indicates an isolation of 42 dB between the two antennas.

P_R = Received Power	G_R = Receive Antenna Gain = 1
P_T = Transmitted Power	G_T = Transmitter Antenna Gain = 1
λ = Wavelength = 1 meter	R = Distance between Antennas = 10 meters

A second harmonic at the limit would be 60 + 42 = 102 dB down at the receiver. 102 dB below 10 Watts (40 dBm) is -62 dBm which is still 38 dB above the receiver sensitivity. The level that is actually required not to cause any degradation in the receiver is -123 dBm. This value results because the worst-case situation occurs when the interfering signal is competing with the sidebands of the intentional signal with a signal amplitude at the receiver sensitivity. For a standard tone of 30% AM used to verify sensitivity, the sidebands are 13 dB down from the carrier and a 10 dB signal-to-noise ratio is normally specified. To avoid problems, the interfering signal must, therefore, be 13 + 10 = 23 dB below -100 dBm or -123 dBm. This criterion would require the second harmonic to be 121 dB down from the transmitter carrier that could be a difficult task. Harmonic relationships can sometimes be addressed through frequency management actions to avoid problems.

Assessing the 34 dBμV (-73 dBm) requirement for standby, the level at the receiver would be -115 dBm which could cause some minimal degradation in the presence of a marginal intentional signal.

Greater antenna separation or antenna placement not involving direct line of sight would improve the situation. Also, the VHF antenna may be poorer than isotropic in the UHF band. CE106 does not take into account any suppression associated with frequency response characteristics of antennas; however, the results of the case cited are not unusual. RE103, which is a RE control on spurious and harmonic outputs, includes assessment of antenna characteristics.

Since the free space loss equation indicates that isolation is proportional to the wavelength squared, isolation values improve rapidly as frequency increases. Also, antennas are generally more directional in the GHz region and receivers tend to be less sensitive due to larger BWs.

The procuring activity may consider tailoring contractual documents by establishing suppression levels based on antenna-to-antenna coupling studies on the particular platform where the equipment will be used. Another area could be relaxation of requirements for high power transmitters. The standard suppression levels may result in significant design penalties. For example, filtering for a 10,000 watt HF transmitter may be excessively heavy and substantially attenuate the fundamental frequency. Engineering trade-offs may be necessary.

Test procedures: Since the test procedures measure emissions present on a controlled impedance, shielded, transmission line, the measurement results should be largely independent of the test setup configuration. Therefore, it is not necessary to maintain the basic test setup described in the main body of this specification.

The CE106 procedure uses a direct coupled technique and does not consider the effect that the antenna system characteristics will have on actual radiated levels.

The selection of modulation for transmitters and frequency, input power levels, and modulation for amplifiers can influence the results. The procedure requires that parameters that produce the worst case emission spectrum be used. The most complicated modulation will typically produce the worst case spectrum. The highest allowable drive level for amplifiers usually produces the worst harmonics and spurious outputs. However, some amplifiers with automatic gain controls may produce higher distortion with drive signals set to the lowest allowable input due to the amplifier producing the highest gain levels. The details of the analysis on the selection of test parameters should be included in the EMITPs.

Figure 5-6 is used for receivers and transmitters in the stand-by mode. The purpose of the attenuator pad in Figure 5-6 is to establish a low Voltage Standing Wave Ratio (VSWR) for more accurate measurements. Its nominal value is 10 dB, but it can be smaller, if necessary, to maintain measurement sensitivity.

The setup in Figure 5-4 is used for low power transmitters in which the highest intentionally generated frequency does not exceed 40 GHz. The attenuator pad should be approximately 20 dB or large enough to reduce the output level of the transmitter sufficiently so that it does not damage or overload the measurement receiver. The rejection network in the figure is tuned to the fundamental frequency of the EUT and is intended to reduce the transmitter power to a level that will not desensitize or induce spurious responses in the measurement receiver. Both the rejection network and RF pad losses must be adjusted to maintain adequate measurement system sensitivity. The total power reaching the measurement receiver input should not exceed the maximum allowable level specified by the manufacturer. All rejection and filter networks must be calibrated over the frequency range of measurement.

The setup of Figure 5-5 is for transmitters with high average power. For transmitters with an integral antenna, it is usually necessary to measure the spurious emissions by the radiated procedures of RE103.

Some caution needs to be exercised in applying Table 4.3. For spurious and harmonic emissions of equipment in the transmit mode, it is generally desirable for the measurement receiver BW to be sufficiently large to include at least 90% of the power of the signal present at a tuned frequency. This condition is required if a comparison is being made to a power requirement in a specification. Spurious and harmonic outputs generally have the same modulation characteristics as the fundamental. Since this procedure measures relative levels of spurious and harmonic signal with respect to the fundamental, it is not necessary for the measurement receiver to meet the above receiver BW to signal BW criterion. However, if the measurement receiver BW does not meet the criterion and spurious and harmonic outputs are located in frequency ranges where this specification specifies a BW different than that used for the fundamental, the measurement receiver BW should be changed to that used at the fundamental to obtain a proper measurement.

For EUTs having waveguide transmission lines, the measurement receiver needs to be coupled to the waveguide by a waveguide to coaxial transition. Since the waveguide acts as a high-pass filter, measurements are not necessary at frequencies less than 0.8 f_{co}, where f_{co} is the waveguide cut-off frequency.

5.4 CS101, CONDUCTED SUSCEPTIBILITY, POWER LEADS, 30 Hz TO 150 kHz

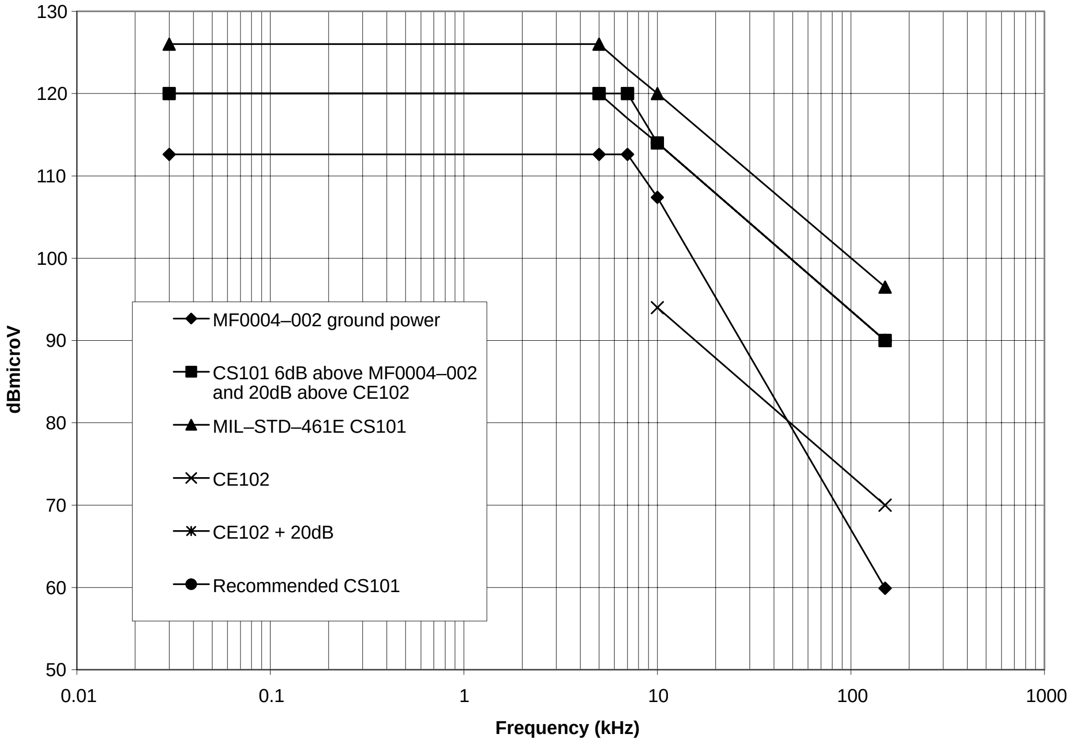
Applicability and Limits: The requirement is applicable to EUT primary power input leads (28 VDC and 115 VAC 400 Hz). There is no requirement on power output leads. The basic concern is to ensure that equipment performance is not degraded from ripple voltages associated with allowable distortion of power source voltage waveforms.

The required signal is applicable only to the high sides on the basis that the concern is developing a differential voltage across the power input leads to the EUT. The series injection technique in the test procedure results in the voltage dropping across the impedance of the EUT power input circuitry. The impedance of the power return wiring is normally insignificant with respect to the power input over most of the required frequency range. Common mode voltages evaluations are addressed by other susceptibility tests such as CS114 and RS103. Injection on a power return will result in the same differential voltage across the power input; however, the unrealistic condition will result in a large voltage at the return connection to the EUT with respect to the ground plane.

The CS101 limit for 28 VDC loads is derived from ripple descriptions in MF0004-002, Electrical Design Requirements for Electrical Equipment Utilized on the Space Shuttle Vehicle, and CE102. The CS101 limit was placed 6 dB higher than the MF0004-002 ripple guarantee below about 5 kHz. Above 10 kHz, the CS101 limit is placed 20 dB higher than CE102 which was adopted without change from MIL-STD-461E. Since CE102 allows more ripple on an individual EUT basis than MF0004-002 reports for the entire bus, it was felt that some relaxation from CE102 would be more conservative and realistic than the very tight MF0004-002 levels. Between 5 and 10 kHz, a straight line was drawn connecting the two points, one being the end point of 6 dB above MF-0004-02 at 5 kHz, and the other being the start point at 10 kHz 20 dB above CE102. The 20 dB separation should not be viewed as a margin. It is based on the same considerations which placed the MIL-STD-461E CE102 limit 20 dB below MIL-STD-704 ripple, the allowance for additive effects. The resultant CS101 curve shown below is 6 dB below the MIL-STD-461E CS101 curve for 28 VDC loads.

FIGURE B-5

CS101 LIMIT DERIVATION FOR 28 VDC LOADS

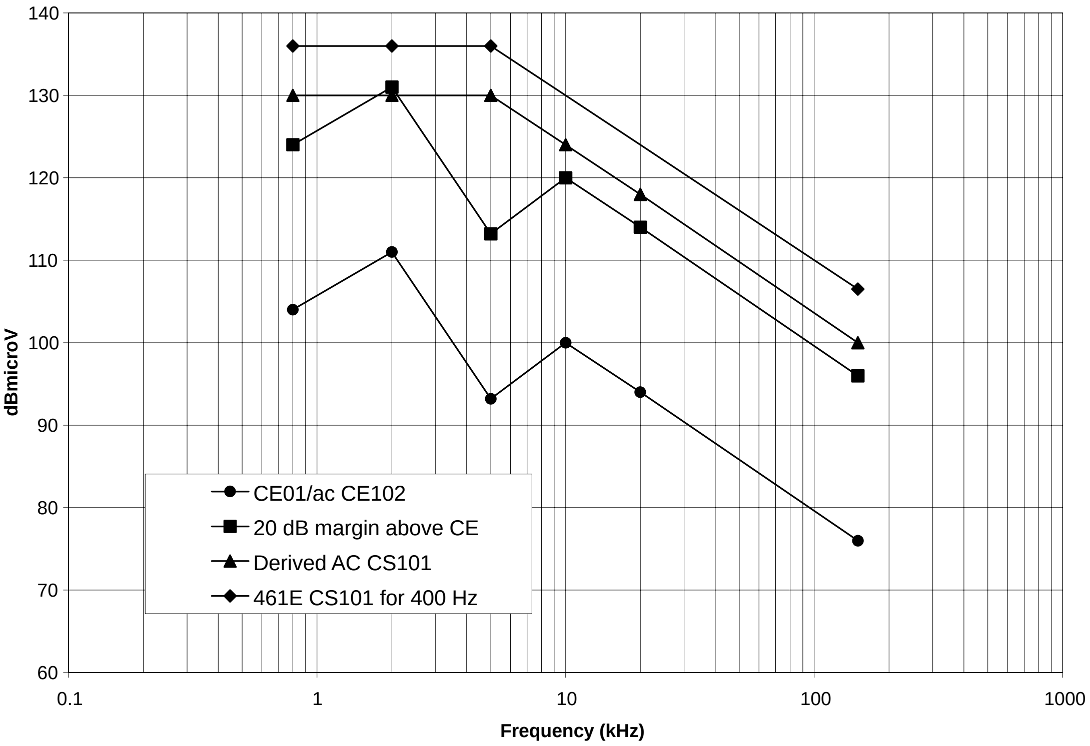


Tailoring of this limit would take into consideration EUT location on the power bus. A very high power load with a short low impedance connection to the fuel cell is unlikely to see significant ripple potentials. Indeed, the highest current capacity CS101 injection transformer is limited to carrying 100 Amps of power current in its secondary winding. Another consideration is a relatively high impedance connection at some distance from the fuel cell and adjacent to a noisy load. The CS101 limit already has special requirements for loads powered towards the aft of the cargo bay.

The CS101 limit for 400 Hz AC loads is derived solely from the old CE01 limit and CE102. The derivation placed the AC CS101 limit roughly 20 dB above CE01 (adjusted for bus impedance in that frequency range) and the MIL-STD-461E CE102 AC limit, which was adopted without change for Shuttle usage. The 20 dB separation should not be viewed as a margin. It is based on the same considerations which placed the MIL-STD-461E CE102 limit 20 dB below MIL-STD-704 ripple, the allowance for additive effects. The resultant CS101 curve shown below is 6 dB below the MIL-STD-461E CS101 curve for 115 VAC, 400 Hz loads.

FIGURE B-6

CS101 LIMIT DERIVATION FOR 115 VAC, 400 Hz LOADS



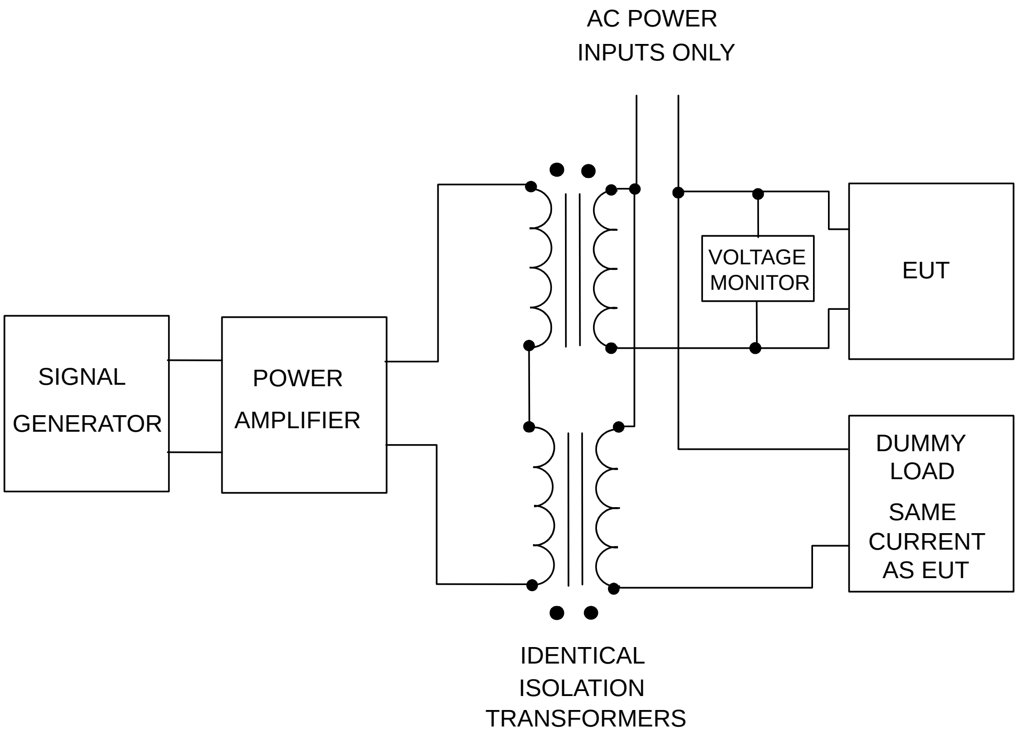
Test procedures: Since the applied voltage is coupled in series using a transformer, Kirchoff’s voltage law requires that the voltage appearing across the transformer output terminals must drop around the circuit loop formed by the EUT input and the power source impedance. The voltage level specified in the limit is measured across the EUT input because part of the transformer induced voltage can be expected to drop across the source impedance.

Earlier EMI standards introduced a circuit for a phase shift network which was intended to cancel out AC power waveforms and allow direct measurement of the ripple present across the EUT. While these devices very effectively cancel the power waveform, they return the incorrect value of the ripple and are not acceptable for use. The networks use the principle of inverting the phase of the input power waveform, adding it to the waveform (input power plus ripple) across the EUT, and presumably producing only the ripple as an output. For a clean power waveform, the network would perform properly. However, the portion of the ripple that drops across the power source impedance contaminates the waveform and gets recombined with the ripple across the EUT resulting in an incorrect value.

Voltages will appear across the primary side of the injection transformer due to the EUT current load at the power frequency. Larger current loads will result in larger voltages and are the predominant concern. These voltages can cause potential problems with the power amplifier. The circuit arrangement in Figure B-7 will substantially reduce this voltage and provide protection for the amplifier. This effect is accomplished by using a dummy load equal to the EUT and wiring the additional transformer so that its induced voltage is equal to and 180 degrees out of phase with the induced voltage in the injection transformer. If possible, the dummy load should have the same power factor as the EUT.

FIGURE B-7

CS101 POWER AMPLIFIER PROTECTION



On initial turn on, DC to DC power switching converters can create large voltages on the primary side of the injection transformer that can damage the power amplifier. A precaution is to place a 5 ohm resistor across the primary and to disconnect the transformer during initial turn on.

The injected signal should be maintained as a sinusoid. Saturation of the power amplifier or coupling transformer may result in a distorted waveform.

If the return side of power is not connected to the shielded room ground, the oscilloscope may need to be electrically “floated” using an isolation transformer to correctly measure the injected voltage resulting in a potential shock hazard. Differential probe amplifiers are available which will convert a differential measurement between the high side and an isolated ground to a single-ended measurement where the measurement device can be grounded. These probes have an output that is suitable for measurement with either an oscilloscope or a high impedance, frequency selective, receiver (provided the receiver can tolerate the high input voltage).

The generic test setup drawing shows a 10 microfarad capacitor bypassing the power source impedance. That capacitor will alone draw 3 Amps of current from 115 VAC at 400 Hz and therefore is an upper limit on bypass capacitors for AC powered EUTs. However, that capacitor has no useful effect in terms of shorting out the power source below 10 kHz. For DC powered EUTs especially, the bypass capacitor may be increased essentially without bound. This is especially important when the 28 VDC power source is outside the test chamber and fed into the chamber through EMI filters. Such filters are low pass devices with stop bands starting at 14 kHz and 100 dB of attenuation. The pass band is 400 Hz and below. In between these filters will resonate and provide quite high power source impedances. Often in such cases it will appear that the precalibrated power limit will have been reached prior to achieving the specification level ripple potential across the EUT power input. In fact what is happening is that a significant fraction of the transformer injected ripple is dropping across the power source, not the EUT. Use of a large bypass capacitor (on the order of one millifarad) will alleviate this situation.

5.5 CS103, CONDUCTED SUSCEPTIBILITY, ANTENNA PORT, INTERMODULATION, 15 kHz TO 10 GHz

Applicability and Limits: The intent of this requirement is to control the response of antenna-connected receiving subsystems to in-band signals resulting from potential intermodulation products of two signals outside of the intentional passband of the subsystem produced by non-linearities in the subsystem. The requirement can be applied to receivers, transceivers, amplifiers, and the like. Due to the wide diversity of subsystem designs being developed, the applicability of this type of requirement and appropriate limits need to be determined for each procurement. Also, requirements need to be specified that are consistent with the signal processing characteristics of the subsystem and the particular test procedures to be used to verify the requirement.

One approach for determining levels required for the out-of-band signals is from an analysis of the electromagnetic environments present and characteristics of receiving antennas. However, levels calculated by this means will often place unreasonable design penalties on the receiver. For example, if an external environment of 200 volts/meter is imposed on a system, an isotropic antenna at 300 MHz will deliver 39 dBm to the receiver. This level represents a severe design requirement to many receivers. An alternative approach is to simply specify levels that are within the state-of-the-art for the particular receiver design.

This requirement is most applicable to fixed frequency, tunable, superheterodyne receivers. Previous versions of this specification required normal system performance with the two out-of-band signals to be 66 dB above the level required to obtain the standard reference output for the receiver. One signal was raised to 80 dB above the reference in the 2 to 25 MHz and 200 to 400 MHz bands to account for transmissions from HF and UHF communication equipment. Maximum levels for both signals were limited to 10 dBm. As an example, conventional communication receivers commonly have sensitivities on the order of -100 dBm. For this case, the 66 dB above reference signal is at -34 dBm and the 80 dB above reference signal is at -20 dBm. Both are substantially below the 10 dBm maximum used in the past.

For other types of receivers, application of this requirement is often less straightforward and care must be taken to ensure that any applied requirements are properly specified. Many receivers are designed to be interference or jam resistant and this feature may make application of this requirement difficult or inappropriate.

One complicating factor is that one of the out-of-band signals typically is modulated with a waveform normally used by the receiver. For receivers that process a very specific modulation, the issue exists whether an out-of-band signal can reasonably be expected to contain that modulation. Another complicating factor is related to the potential intermodulation products resulting from two signals. Responses from intermodulation products can be predicted to occur when $f_o = mf_1 \pm nf_2$ where f_o is the operating frequency of the receiver, m and n are integers, and f_1 and f_2 are the out-of-band signals. For receivers which continuously change frequency (such as frequency agile or frequency hopping), the relationship will be true only for a portion of the operating time of the receiver, unless the out-band-signals are also continuously tuned or the receiver operating characteristics are modified for the purpose of evaluation.

Test procedures: No test procedures are provided in the main body of this specification for this requirement. Because of the large variety of receiver designs being developed, the requirements for the specific operational characteristics of a receiver must be established before meaningful test procedures can be developed. Only general testing techniques are discussed in this appendix.

Intermodulation testing can be applied to a variety of receiving subsystems such as receivers, RF amplifiers, transceivers and transponders.

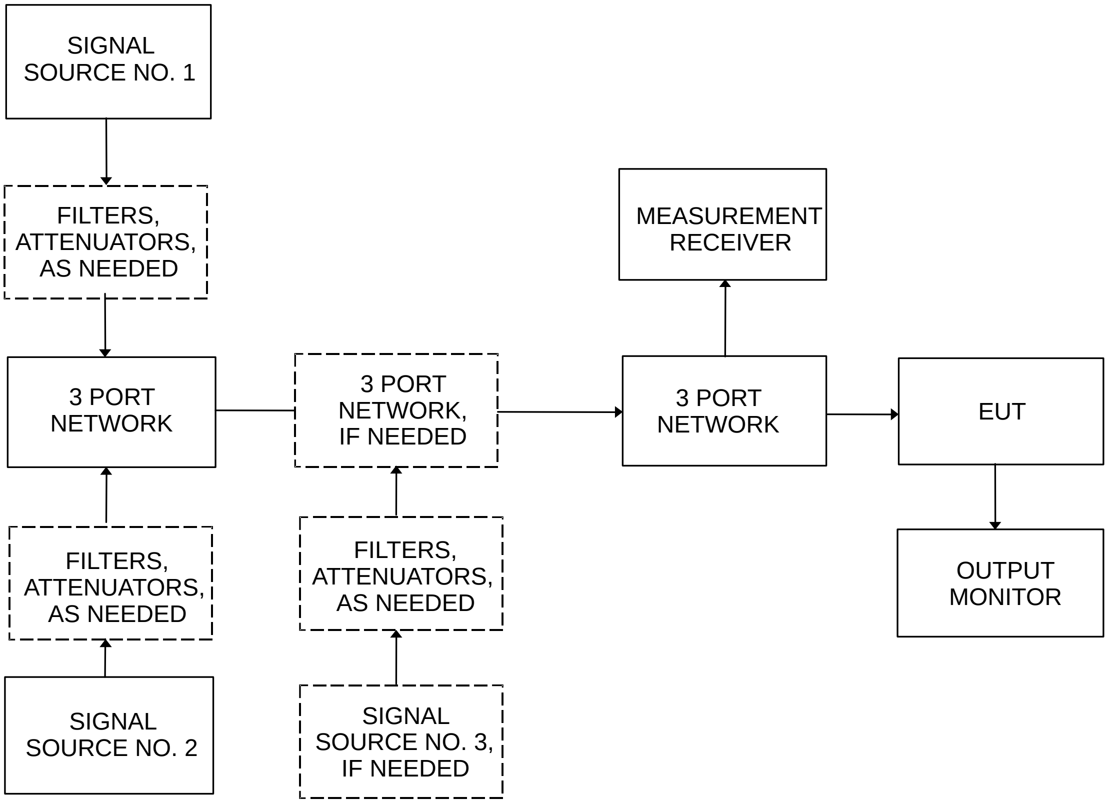
Several receiver front-end characteristics must be known for proper testing for intermodulation responses. These characteristics generally should be determined by test. The maximum signal input that the receiver can tolerate without overload needs to be known to ensure that the test levels are reasonable and that the test truly is evaluating intermodulation effects. The bandpass characteristics of the receiver are important for determining frequencies near the receiver fundamental f_o that will be excluded from test. Requirements for this test are generally expressed in terms of a relative degree of rejection by specifying the difference in level between potentially interfering signals and the established sensitivity of the receiver under test. Therefore, determination of the sensitivity of the receiver is a key portion of the test.

The basic concept with this test is to combine two out-of-band signals and apply them to the antenna port of the receiver while monitoring the receiver for an undesired response. One of the out-of-band signals is normally modulated with the modulation expected by the receiver. The second signal is normally CW. Figure B-8 shows a general setup for this test. For applications where the receiver would not provide an indication of interference without a receive signal being present, a third signal can be used at the fundamental. This arrangement may also be suitable for some receivers that process a very specialized type of modulation which would never be expected on an out-of-band signal. An option is for the two out-of-band signals to be CW for this application.

The frequency of the two out-of-band signals should be set such that $f_o = 2f_1 - f_2$ where f_o is the tuned frequency of the receiver and f_1 and f_2 are the frequencies of the signal sources. This equation represents a third order intermodulation product, which is the most common response observed in receivers. f_1 and f_2 should be swept or stepped over the desired frequency range while maintaining the relationship in the equation. It is important to verify that any responses noted during this test are due to intermodulation responses. Responses can result from simply lack of rejection to one of the applied signals or from harmonics of one of the signal sources. Turning off each signal source in turn and noting whether the response remains can demonstrate the source of the response.

FIGURE B-8

CS103 GENERAL TEST SETUP



For receivers with front-end mixing and filtering in an antenna module, the test may need to be designed to be performed on a radiated basis. All signals would need to be radiated and assurances provided that any observed intermodulation products are due to the receiver and not caused by items in the test area. The EMITPs would need to address antenna types, antenna locations, antenna polarizations and field measurement techniques. This test would probably need to be performed in an anechoic chamber.

For frequency hopping receivers, one possible approach is choose an f_o within the hop set and set up the signals sources as described above. The performance of the receiver could then be evaluated as the receiver hops. If the frequency hopping receiver has a mode of operation using just one fixed frequency, this mode should also be tested.

A common error made in performing this test procedure is attributing failures to the EUT which are actually harmonics of the signal source or intermodulation products generated in the test setup. Therefore, it is important to verify that the signals appearing at the EUT antenna port are only the intended signals through the use of a measurement receiver as shown in Figure B-8. Damaged, corroded, and faulty components can cause signal distortion resulting in misleading results. Monitoring will also identify path losses caused by filters, attenuators, couplers, and cables.

Typical data for this test procedure for the EMITR are the sensitivity of the receiver, the levels of the signal sources, frequency ranges swept, operating frequencies of the receivers, and frequencies and threshold levels associated with any responses.

5.6 CS104, CONDUCTED SUSCEPTIBILITY, ANTENNA PORT, REJECTION OF UNDESIRED SIGNALS, 30 Hz TO 18 GHz

Applicability and Limits: The intent of this requirement is to control the response of antenna-connected receiving subsystems to signals outside of the intentional passband of the subsystem. The requirement can be applied to receivers, transceivers, amplifiers, and the like. Due to the wide diversity of subsystem designs being developed, the applicability of this type of requirement and appropriate limits need to be determined for each procurement. Also, requirements need to be specified that are consistent with the signal processing characteristics of the subsystem and the particular test procedures to be used to verify the requirement.

One approach for determining levels required for the out-of-band signal can be determined from an analysis of the electromagnetic environments present and characteristics of receiving antennas. However, levels calculated by this means will often place unreasonable design penalties on the receiver. For example, if an external environment of 200 volts/meter is imposed on a system, an isotropic antenna at 300 MHz will deliver 39 dBm to the receiver. This level represents a severe design requirement to many receivers. An alternative approach is to simply specify levels that are within the state-of-the-art for the particular receiver design.

This requirement is most applicable to fixed frequency, tunable, superheterodyne receivers. Previous versions of this specification required normal system performance for a 0 dBm signal outside of the tuning range of the receiver and a signal 80 dB above the level producing the standard reference output within the tuning range (excluding the receiver passband within the 80 dB points on the selectivity curve). As an example, a conventional UHF communication receiver operating from 225 MHz to 400 MHz commonly has a sensitivity on the order of -100 dBm. For this case, the 0 dBm level applies below 225 MHz and above 400 MHz. Between 225 MHz and 400 MHz (excluding the passband), the required level is -20 dBm.

For other types of receivers, application of this requirement is often less straightforward and care must be taken to ensure that any applied requirements are properly specified.

Many receivers are designed to be interference or jam resistant and this feature may make application of this requirement difficult or inappropriate.

This requirement is usually specified using either one or two signals. With the one signal requirement, the signal is out-of-band to the receiver and is modulated with a waveform normally used by the receiver. No in-band signal is used. For receivers that process a very specific modulation, the issue exists whether an out-of-band signal can reasonably be expected to contain that modulation. An alternative is to specify the requirement for two signals. An in-band signal can be specified which contains the normal receiver modulation. The out-of-band signal can be modulated or unmodulated with the criterion being that no degradation in reception of the intentional signal is allowed.

Test procedures: No test procedures are provided in the main body of this specification for this requirement. Because of the large variety of receiver designs being developed, the requirements for the specific operational characteristics of a receiver must be established before meaningful test procedures can be developed. Only general testing techniques are discussed in this appendix.

Front-end rejection testing can be applied to a variety of receiving subsystems such as receivers, RF amplifiers, transceivers, and transponders.

Several receiver front-end characteristics must be known for proper testing. These characteristics generally should be determined by test. The maximum signal input that the receiver can tolerate without overload needs to be known to ensure that the test levels are reasonable. The bandpass characteristics of the receiver are important for determining frequencies near the receiver fundamental that will be excluded from testing. Requirements for this test are often expressed in terms of a relative degree of rejection by specifying the difference in level between a potentially interfering signal and the established sensitivity of the receiver under test. Therefore, determination of the sensitivity of the receiver is a key portion of the test.

The basic concept with this test procedure is to apply out-of-band signals to the antenna port of the receiver while monitoring the receiver for degradation. Figure B-9 shows a general test setup for this test. There are two common techniques used for performing this test using either one or two signal sources. For the one signal source procedure, the signal source is modulated with the modulation expected by the receiver. It is then swept over the appropriate frequency ranges while the receiver is monitored for unintended responses. With the two signal source procedure, a signal appropriately modulated for the receiver is applied at the tuned frequency of the receiver. The level of this signal is normally specified to be close to the sensitivity of the receiver. The second signal is unmodulated and is swept over the appropriate frequency ranges while the receiver is monitored for any change in its response to the intentional signal.

The two signal source procedure is more appropriate for most receivers. The one signal source procedure may be more appropriate for receivers that search for a signal to capture since they may respond differently once a signal has been captured. Some receivers may need to be evaluated using both procedures to be completely characterized.

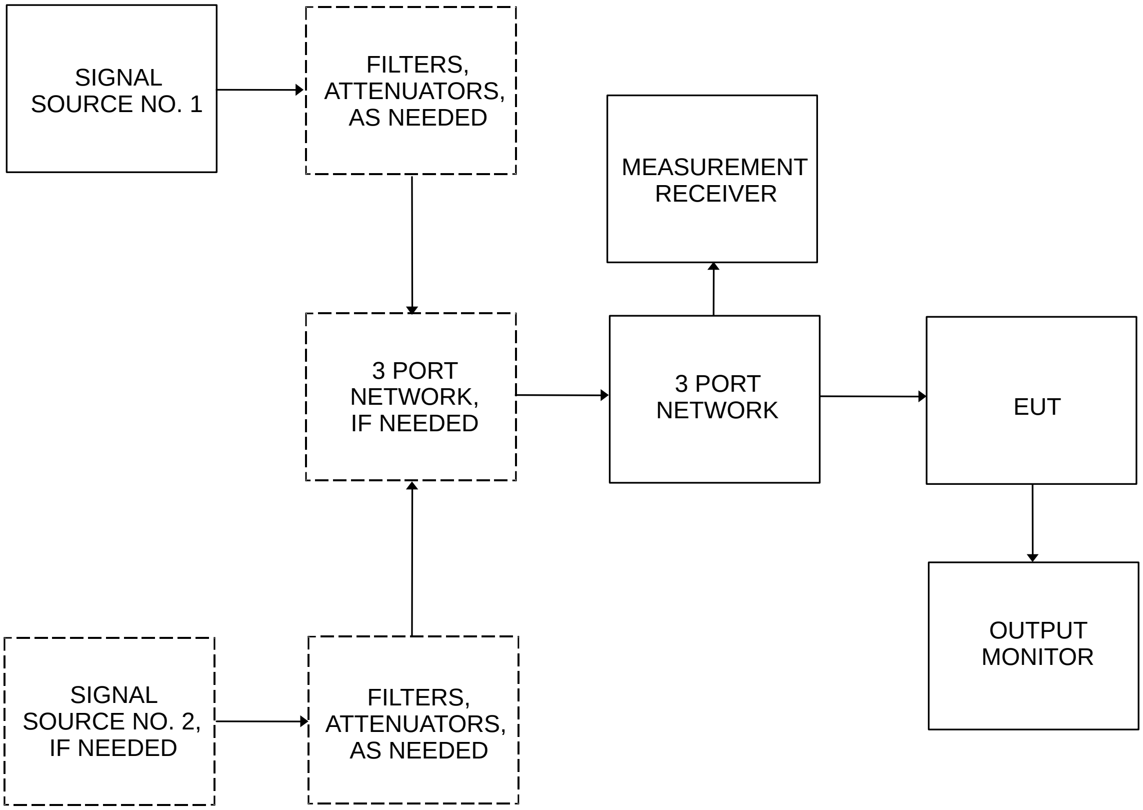
For frequency hopping receivers, one possible approach is to use a one signal procedure as if the EUT did not have a tuned frequency (include frequency scanning across the hop set) to evaluate the jamming/interference resistance of the receiver. If a frequency hopping receiver has a mode of operation using just one fixed frequency, this mode should also be tested.

For receivers with front-end mixing and filtering in an antenna module, the test may need to be designed to be performed on a radiated basis. All signals would need to be radiated and assurances provided that any observed responses are due to the receiver and not caused by items in the test area. The EMITPs would need to address antenna types, antenna locations, antenna polarizations, and field measurement techniques. This test would probably need to be performed in an anechoic chamber.

A common error made in performing this test procedure is attributing failures to the EUT which are actually harmonics or spurious outputs of the signal source. Therefore, it is important to verify that the signals appearing at the EUT antenna port are only the intended signals through the use of a measurement receiver as shown in Figure B-9. Damaged, corroded, and faulty components can cause signal distortion resulting in misleading results. Monitoring will also identify path losses caused by filters, attenuators, couplers, and cables.

FIGURE B-9

CS104 GENERAL TEST SETUP



Typical data for this test procedure for the EMITR are the sensitivity of the receiver, the levels of the signal sources, frequency ranges swept, operating frequencies of the receivers, degree of rejection (dB), and frequencies and threshold levels associated with any responses.

5.7 CS105, CONDUCTED SUSCEPTIBILITY, ANTENNA PORT, CROSS MODULATION, 30 Hz TO 18 GHz

Applicability and Limits: The intent of this requirement is to control the response of antenna-connected receiving subsystems to modulation being transferred from an out-of-band signal to an in-band signal. This effect results from a strong, out-of-band signal near the operating frequency of the receiver that modulates the gain in the front-end of the receiver and adds amplitude varying information to the desired signal. The requirement should be considered only for receivers, transceivers, amplifiers, and the like, which extract information from the amplitude modulation of a carrier. Due to the wide diversity of subsystem designs being developed, the applicability of this type of requirement and appropriate limits need to be determined for each procurement. Also, requirements need to be specified that are consistent with the signal processing characteristics of the subsystem and the particular test procedure to be used to verify the requirement.

One approach for determining levels required for the out-of-band signal can be determined from an analysis of the electromagnetic environments present and characteristics of receiving antennas. However, levels calculated by this means will often place unreasonable design penalties on the receiver. For example, if an external environment of 200 volts/meter is imposed on a system, an isotropic antenna at 300 MHz will deliver 39 dBm to the receiver. This level represents a severe design requirement to many receivers. An alternative approach is to simply specify levels that are within the state-of-the-art for the particular receiver design.

This requirement is most applicable to fixed frequency, tunable, superheterodyne receivers. Previous versions of this specification required normal system performance with an out-of-band signal to be 66 dB above the level required to obtain the standard reference output for the receiver. The maximum level for the signal was limited to 10 dBm. As an example, conventional communication receivers commonly have sensitivities on the order of -100 dBm. For this example, the 66 dB above reference signal is at -34 dBm that is substantially below the 10 dBm maximum used in the past.

For other types of receivers, application of this requirement is often less straightforward and care must be taken to ensure that any applied requirements are properly specified. Many receivers are designed to be interference or jam resistant and this feature may make application of this requirement difficult or inappropriate.

One complicating factor is that one of the out-of-band signals typically is modulated with a waveform normally used by the receiver. For receivers that process a very specific modulation, the issue exists whether an out-of-band signal can reasonably be expected to contain that modulation. Another factor is that the out-of-band signal is normally specified to be close to the receiver operating frequency. For receivers that continuously change frequency (such as frequency agile or frequency hopping), an appropriate relationship may exist for only short periods for a fixed frequency out-of-band signal.

Test procedures: No test procedures are provided in the main body of this specification for this requirement. Because of the large variety of receiver designs being developed, the requirements for the specific operational characteristics of a receiver must be established before meaningful test procedures can be developed. Only general testing techniques are discussed in this appendix.

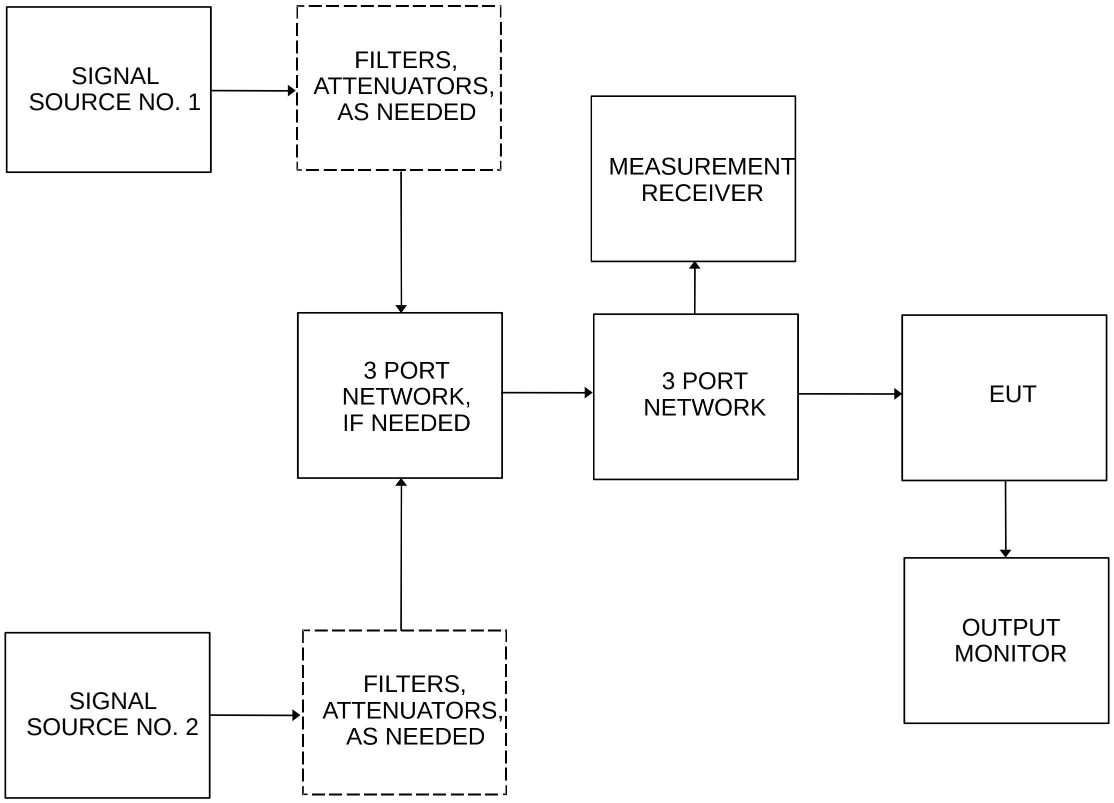
Cross modulation testing should be applied only to receiving subsystems such as receivers, RF amplifiers, transceivers and transponders which extract information from the amplitude modulation of a carrier.

Several receiver front-end characteristics must be known for proper testing for cross modulation responses. These characteristics generally should be determined by test. The maximum signal input that the receiver can tolerate without overload needs to be known to ensure that the test levels are reasonable. The bandpass characteristics of the receiver are important for determining frequencies near the receiver fundamental that will be excluded from test. Requirements for this test are generally expressed in terms of a relative degree of rejection by specifying the difference in level between potentially interfering signals and the established sensitivity of the receiver under test. Therefore, determination of the sensitivity of the receiver is a key portion of the test.

The basic concept with this test is to apply a modulated signal out-of-band to the receiver and to determine whether the modulation is transferred to an unmodulated signal at the receiver's tuned frequency resulting in an undesired response. There may be cases where the in-band signal needs to be modulated if the receiver characteristics so dictate. The level of the in-band signal is normally adjusted to be close to the receiver's sensitivity. The out-of-band signal is modulated with the modulation expected by the receiver. It is then swept over the appropriate frequency ranges while the receiver is monitored for unintended responses. Testing has typically been performed over a frequency range ± the receiver IF centered on the receiver's tuned frequency. Figure B-10 shows a general setup for this test.

FIGURE B-10

CS105 GENERAL TEST SETUP



For receivers with front-end mixing and filtering in an antenna module, the test may need to be designed to be performed on a radiated basis. All signals would need to be radiated and assurances provided that any responses are due to the receiver and not caused by items in the test area. The EMITPs would need to address antenna types, antenna locations, antenna polarizations and field measurement techniques. This test would probably need to be performed in an anechoic chamber.

For frequency hopping receivers, one possible approach is choose an f_o within the hop set and set up the signals sources as described above. The performance of the receiver could then be evaluated as the receiver hops. If the frequency hopping receiver has a mode of operation using just one fixed frequency, this mode should also be tested.

It is important to verify that the signals appearing at the EUT antenna port are only the intended signals through the use of a measurement receiver as shown in Figure B-10. Damaged, corroded, and faulty components can cause signal distortion resulting in misleading results. Monitoring will also identify path losses caused by filters, attenuators, couplers, and cables.

Typical data for this test procedure for the EMITR are the sensitivity of the receiver, the levels of the signal sources, frequency ranges swept, operating frequencies of the receivers, and frequencies and threshold levels associated with any responses.

5.8 CS106, CONDUCTED SUSCEPTIBILITY, POWER-LINE SWITCHING TRANSIENTS

Applicability and Limits: The requirement is applicable to 28 VDC primary power inputs to the EUT, excluding grounds (the transient is induced differentially between power input and power return). The basic concern is to protect equipment from normal transients which result from the connection or disconnection of other loads on the same power bus. The requirement is intended to replace the obsolete CS06 requirement of MIL-STD-461 (all revisions through C) and MIL-STD-462. CS106 is a highly accurate simulation of load-induced power-line switching transients.

The susceptibility transient waveform is intended to last longer (negative polarity) than that allowed by the transient emission limit, TT101. In this way, a “margin” between the spike emission and susceptibility requirements is maintained. There were cases of Shuttle equipment qualified to CS06 which exhibited susceptibility to longer duration transients of lesser amplitude. This requirement is intended to protect against that eventuality.

A turn-off (positive polarity) transient would be high source impedance (100 ohm), of microsecond duration, and would be significantly loaded by the EUT. Further, such transients are easily filtered by even a small capacitor, and do not damage capacitors, even though they might appear to apply a potential above the capacitor’s rating. See NASA publication CR-2000-209906, Investigation into the Effects of Microsecond Power Line Transients on Line-Connected Capacitors, on this subject, available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 703/487-4650

or:

NASA Center for AeroSpace Information
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
Phone: 301/621-0390

For these reasons, it was decided that demonstrating immunity from turn-off transients was unnecessary. The requirement is to demonstrate operation through a sag in power bus potential only.

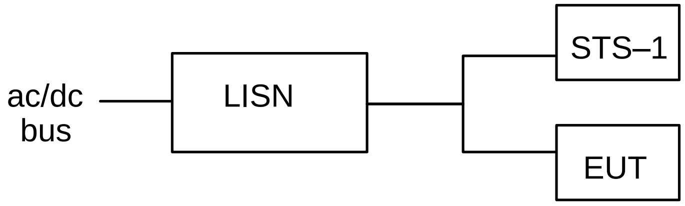
A detailed description of the entire test, including the physics of switching transients, as well as a detailed description of the test equipment and test technique is available in the NASA publication CR-1999-209574, Specification, Measurement, and Control of Electrical Switching Transients, available from the above listed offices.

The test equipment is commercially available.

Test preparation: The switching transient simulator (designated below as STS-1) injects simulated switching transients between power feeders supplying the EUT. The switching transient simulator utilizes a LISN as a common source impedance between power source, switching transient simulator and EUT (reference Figure B-11).

FIGURE B-11

SWITCHING TRANSIENT TEST SETUP

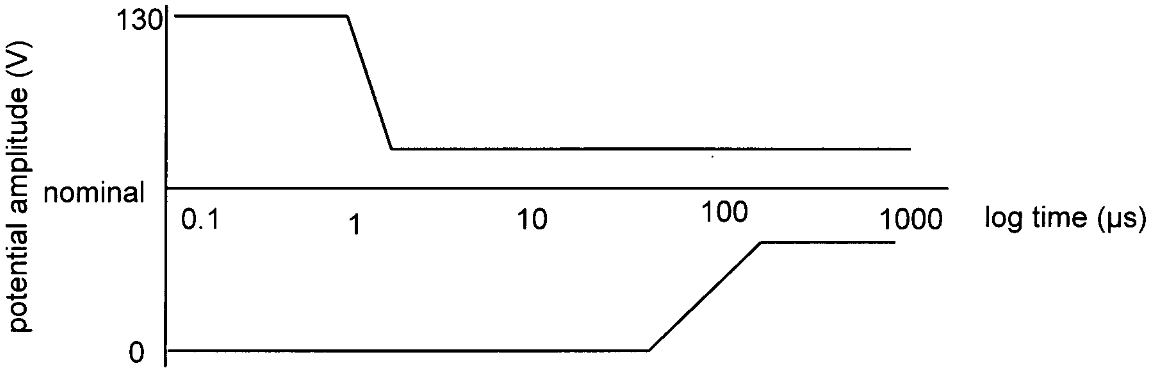


The switching transient simulator switches a user selectable RC load on and off the power bus in an accurate repeatable fashion. The RC combination is chosen to yield the specified or desired power quality or EMI specification transient envelopes.

The R value will be representative of the worst case load which might be rapidly switched on or off the bus. The C value will be that which yields a suitable margin above a reasonable hold-up time constant in parallel with the chosen R value, and working against the LISN inductance. Figure B-12 represents an illustrative specification for switching transients (except that it realistically portrays the positive transient rather than making it the mirror image of the turn-on transient.)

FIGURE B-12

REPRESENTATIVE SWITCHING TRANSIENT ENVELOPE SPECIFICATION



Once R has been chosen, it is easy to choose C to provide the negative going transient envelope. The time constant is v(LC), where L is the LISN inductance (100 µH for two MIL-STD-461E LISNs), and C is the load capacitor. In the case of Figure B-12, the time constant is about 70 µs. Using 100 µH for L, the C-value would be 50 µF. Note that if a margin is desired between this susceptibility waveform and the TT101 limit, it can only be in terms of time duration; the spike amplitude cannot be driven negative.

Test Setup:

<u>WARNING</u>

When connecting an oscilloscope across a power bus, precautions must be made. Never connect neutral or return to the scope ground unless that return or neutral is chassis grounded on the EUT side of the LISN unless the scope itself has a floating ground (this last highly recommended for this type of measurement). Another option is to float the scope - however, in this case make sure oscilloscope ground is connected to EUT power return before applying power to the oscilloscope, so that the oscilloscope chassis has a safety ground at all times. Also, regardless of whether the scope has a floating ground or not, no other connection from the scope to anywhere should be made.

Having chosen appropriate switched RC values for the switching transient simulator, it can now be connected into the EMI test setup (reference Figure B-11). Actual connections from the LISN are provided on the switching transient simulator and are so labeled (LISN HOT and LISN RTN OR GROUND). The RC values are connected across the panel terminals so labeled. If the capacitor is polarized, be careful to connect the positive side to the red terminal. If the switched bus potential is considered a safety hazard, mount the R&C in an enclosed housing, again noting proper polarity.

The EUT is powered from the same LISN output power port(s) as the switching transient simulator. EUT and STS-1 both look back into the LISN as a common source impedance.

Test Procedures: Once setup is complete, switching transient simulator panel controls may be properly adjusted. One knob adjusts the number of transients per unit time. Range is from under one pps to just over 10 pps. The “BUS” switch should be set to DC. “PHASE ANGLE” only applies to AC buses. The knob labeled “TRANSIENT MODE” selects three types of transients. “ON” selects series of the relatively long negative going transients. This simulates many loads being brought on-line sequentially. “OFF” selects a series of the short duration positive spikes. This simulates many loads being turned off sequentially. “ON/OFF” selects a series of alternately appearing negative and positive spikes. “AC POLARITY” only applies to AC buses. The “PULSE ENABLE” switch actually commands switching to occur. Actual switching rate may be monitored before switching is commanded on at the front panel Bayonet Connector labeled pps. It is easy to record the transient, even though it is a short duration, low duty cycle phenomenon. Use a digital oscilloscope (dso) (20 MHz single-event BW - Nyquist criteria - is sufficient). Trigger on a level either above or below nominal with suitable slope, as appropriate. Use a time per division near the expected transient duration. This will be on the order of 100 μs/division for the negative going transient.

NASA CR-1999-209574 includes test data illustrating the technique with some prototype switching transient simulators.

5.9 CS114, CONDUCTED SUSCEPTIBILITY, BULK CABLE INJECTION, 10 kHz TO 200 MHz

Applicability and Limits: The requirements are applicable to all electrical cables interfacing with the EUT enclosures. The basic concept is to simulate currents that will be developed on platform cabling from electromagnetic fields generated by antenna transmissions both on and off the platform.

An advantage of this type of requirement is that it provides data that can be directly related to induced current levels measured during platform-level evaluations. An increasingly popular technique is to illuminate the platform with a low level, relatively uniform field while monitoring induced levels on cables. Then, either laboratory data can be reviewed or current injection done at the platform with the measured currents scaled to the full threat level. This same philosophy has been applied to lightning and EMP testing.

Due to size constraints and available field patterns during RS testing (such as RS103), it has long been recognized that cabling cannot be properly excited to simulate platform effects at lower frequencies. The most notable example of this situation is experience with HF (2 - 30 MHz) radio transmissions. HF fields have caused numerous problems in platforms through cable coupling. However, equipment items rarely exhibit problems in this frequency range during laboratory testing.

The limits are primarily derived from testing on aircraft that were not designed to have intentionally shielded volumes. The basic structure is electrically conductive; however, there was no attempt to ensure continuous electrical bonding between structure members or to close all apertures. The shape of the limit reflects the physics of the coupling with regard to resonant conditions, and the cable length with respect to the interfering frequency wavelength. At frequencies below resonance, coupling is proportional to frequency (20 dB/decade slope). Above resonance, coupled levels are cyclic with frequency with a flat maximum value. The 10 dB/decade decrease in the limit level at the upper frequency portion is based on actual induced levels in the aircraft testing data base when worst-case measurements for the various aircraft are plotted together. From coupling theory for a specific cable, the decrease would be expected to be cyclic with frequency with an envelope slope of 40 dB/decade.

The basic relationship for the limit level in the resonance (flat) portion of the curve is 1.5 milliamperes per volt/meter that is derived from worst-case measurements on aircraft. For example, 110 dBμA corresponds to 200 volts/meter. At resonance, the effective shielding effectiveness of the aircraft can be zero. Application of these results to other platforms is reasonable.

The frequency range of 10 kHz to 200 MHz is now standardized for all applications. The optional frequency range of 200 MHz to 400 MHz is deleted because of the questionable validity of performing bulk cable measurements at higher frequencies.

Possible tailoring by the procuring activity for contractual documents is a curve amplitude based on the expected field intensity for the installation and a breakpoint for the curve based on the lowest resonance associated with the platform. Tailoring of the frequency of application can be done based on the operating frequencies of antenna-radiating equipment. Tailoring should also include transmitters that are not part of the platform. For equipment used in benign environments, the requirement may not be necessary.

Test procedures: This type of test is often considered as a bulk current test since current is the parameter measured. However, it is important to note that the test signal is inductively coupled and that Faraday’s law predicts an induced voltage in a circuit loop with the resultant current flow and voltage distribution dependent on the various impedances present.

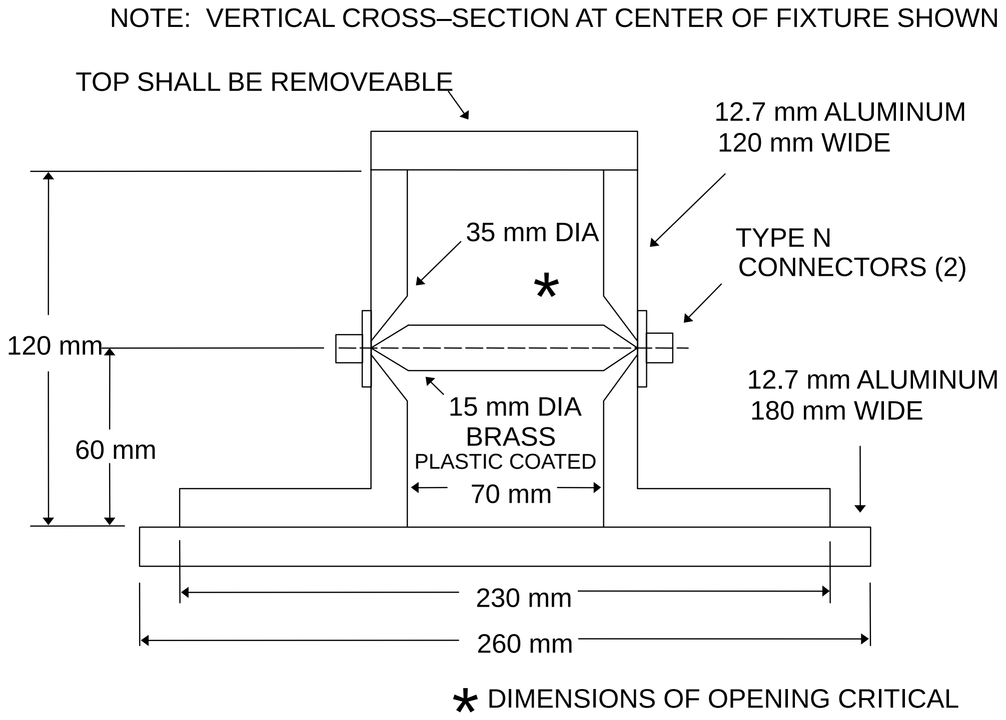
The calibration fixture with terminations is a 50 ohm transmission line. Since the injection probe is around the center conductor within the fixture, a signal is being induced in the loop formed by the center conductor, the two 50 ohm loads, and the structure of the fixture to which the 50 ohm loads are terminated. From a loop circuit standpoint, the two 50 ohm loads are in series, providing a total loop impedance of 100 ohms. Because of the transmission line configuration, inductance effects are minimized. Measurement of induced current levels is performed by measuring a corresponding voltage across one of the 50 ohm loads. Since the 50 ohm loads are in series for the induced signal, the total drive voltage is actually two times that being measured.

The actual current that appears on a tested cable from the pre-calibrated drive signal depends on the loop impedance associated with the cable and the source impedance characteristics of the drive probe and amplifier. If the loop impedance is low, such as would often result with an overall shielded cable, currents greater than those the calibration fixture will result. The maximum required current is limited to 6 dB above the pre-calibration level.

Versions of MIL-STD-462 (superseded by this specification) prior to the “D” revision included a test procedure CS02 which specified capacitive coupling of a voltage onto individual power leads. As is the case for this test procedure, CS02 assessed the effect of voltages induced from electromagnetic fields. CS114 improves on CS02 by inducing levels on all wires at a connector interface simultaneously (common mode) which better simulates actual platform use. Also, a deficiency existed with CS02 since the RF signals were induced only on power leads. This test procedure is applicable to all EUT cabling.

FIGURE B-13

TYPICAL CS114 CALIBRATION FIXTURE



The requirement to generate loop circuit characterization data has been removed from this version of the specification. The information was not being used as it was originally envisioned.

A commonly used calibration fixture is shown in Figure B-13. Other designs are available. The top is removable to permit the lower frequency probes to physically fit. The calibration fixture can be scaled to accommodate larger injection probes. Figure B-14 displays the maximum VSWR that this calibration fixture should exhibit when measured without a current probe installed in the fixture. The presence of a probe will usually improve the VSWR of the fixture.

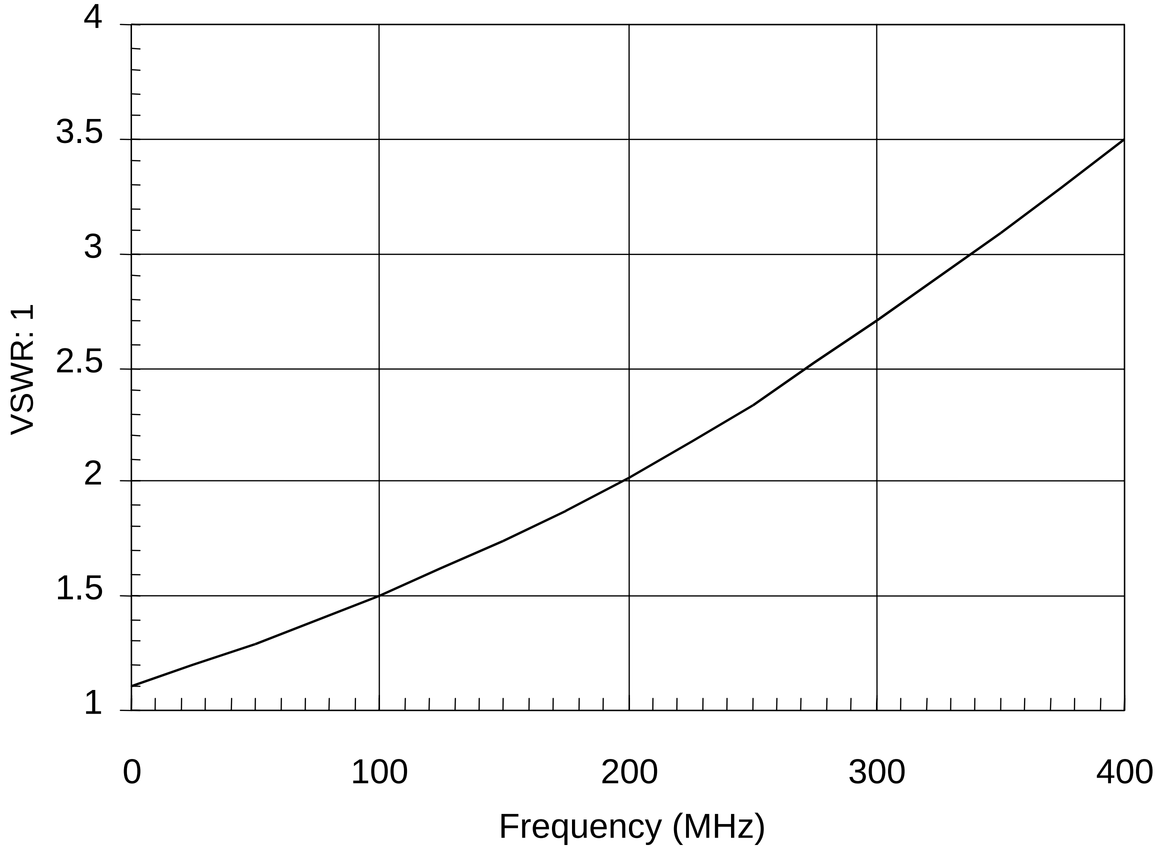
An advantage of this type of conducted testing as compared to RS testing is that voltage and current levels can be more easily induced on the interfaces that are comparable to those present in installations. The physical dimensions of the EUT cabling in a test setup are often not large enough compared to the installation for efficient coupling at lower frequencies.

In the past, some platform-level problems on Navy aircraft could not be duplicated in the laboratory using the standard test procedures in earlier versions of MIL-STD-461.

It was determined that differences between the aircraft installation and laboratory setups regarding the laboratory ground plane and avionics (aircraft electronics) mounting and electrical bonding practices were responsible. Most avionics are mounted in racks and on mounting brackets. At RF, the impedances to general aircraft structure for the various mounting schemes can be significantly different than they are with the avionics mounted on a laboratory ground plane. In the laboratory, it is not always possible to produce a reasonable simulation of the installation. A Ground Plane Interference (GPI) test was developed to detect potential failures due to the higher impedance. In the GPI test, each enclosure of the EUT, in turn, is electrically isolated above the ground plane and a voltage is applied between the enclosure and the ground plane to simulate potential differences that may exist in the installation. Since CS114 provides similar common mode stresses at electrical interfaces as the GPI, the GPI is not included in this specification.

FIGURE B-14

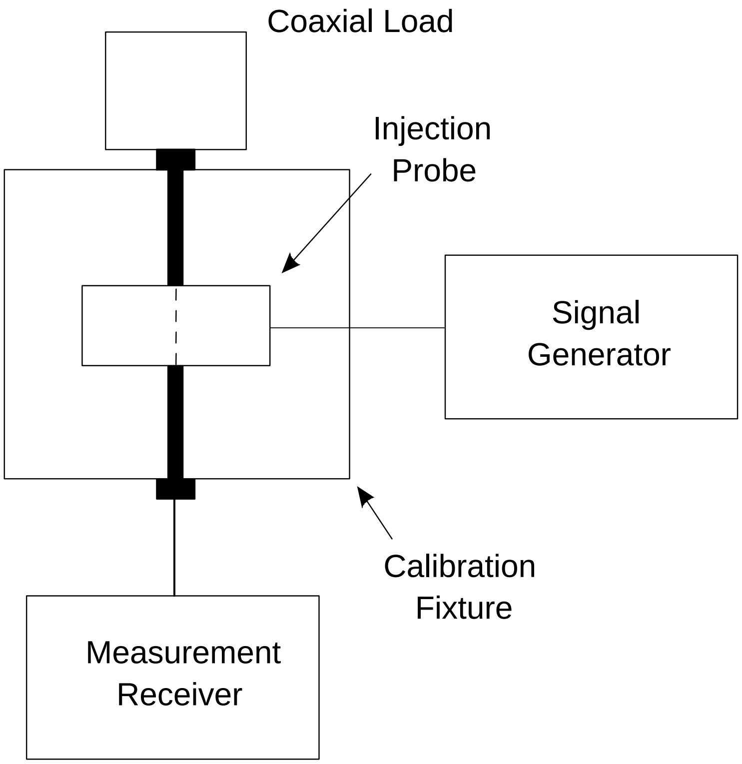
MAXIMUM VSWR OF CALIBRATION FIXTURE



CS114 has several advantages over the GPI as a general evaluation procedure. The GPI often results in significant current flow with little voltage developed at lower frequencies. CS114 is a controlled current test. A concern with the GPI test, which is not associated with CS114, is that the performance of interface filtering can be altered due to isolation of the enclosure from the ground plane. The results of CS114 are more useful since the controlled current can be compared with current levels present in the actual installation induced from fields. This technique has commonly been used in the past for certification of aircraft as safe to fly.

FIGURE B-15

INSERTION LOSS MEASUREMENT



Testing is required on both entire power cables and power cables with the returns removed to evaluate common mode coupling to configurations that may be present in different installations. In some installations, the power returns are routed with the high side wiring. In other installations, power returns are tied to system structure near the utilization equipment with system structure being used as the power return path.

Insertion loss characteristics of injection probes are specified in Figure 5-16 of the test procedure. A control on insertion loss has been found to be necessary to obtain consistency in test results. Insertion loss is measured as shown in Figure B-15. It is the difference in dB of the power applied to the probe installed in the calibration fixture and the power level detected by the measurement receiver. Lower insertion loss indicates more efficient coupling. Since the signal level that is induced in the calibration fixture is equally divided between the 50 ohm coaxial load and the measurement receiver, the lowest possible loss is 3 dB. The use of a network analyzer or measurement receiver that includes a tracking generator can simplify the measurement.

Techniques using network analyzers or spectrum analyzers with tracking generators can simplify the measurements for both Paragraph 5.9.3.4, Step b, calibration and Paragraph 5.9.3.4, Step c, EUT testing portions of the procedure. For example, the output signal can first be set to a predetermined value such as one milliwatt and the flatness of the signal with frequency can be separately verified through a direct connection to the receiver. With this same signal then applied to the directional coupler, the induced level in the calibration fixture can be directly plotted.

5.10 CS116, CONDUCTED SUSCEPTIBILITY, DAMPED SINUSOID TRANSIENTS, CABLES AND POWER LEADS, 10 kHz TO 10 MHz

Applicability and Limits: The requirements are applicable to all electrical cables interfacing with each EUT enclosure and also individually on each power lead. The basic concept is completely different than the MIL-STD-461E original. For Shuttle usage, this requirement is meant to replace the HF aspects of the obsolete CS06 from the previous revisions of SL-E-0002. The combination of the CS106 requirement and CS116 as modified for SL-E-0002 is felt to provide adequate simulation of all fast transients likely to occur on the Shuttle (fast meaning of shorter duration than specified in power quality specifications).

The levels and frequency range have been vastly reduced for Shuttle usage from the MIL-STD-461E levels. The requirement levels for this test in MIL-STD-461E could in some cases cause damage to insufficiently protected equipment. The levels for Shuttle usage have been reduced to be commensurate with the obsolete CS06.

A limited set of damped sine waves is specified to address a sampling of the various ringing frequencies that may be present in the platform. An advantage of using a set of damped sine waves is that different circuit types are evaluated for various waveform attributes that may cause worst-case effects. Some circuits may respond to peak amplitude while others may respond to total energy or rate of rise.

Test procedures: The calibration fixture with terminations is a 50 ohm transmission line. Since the injection probe is around the center conductor within the fixture, a signal is being induced in the loop formed by the center conductor, the two 50 ohm loads, and the structure of the fixture to which the 50 ohm loads are terminated. From a loop circuit standpoint, the two 50 ohm loads are in series, providing a total loop impedance of 100 ohms. Because of the transmission line configuration, inductance effects are minimized. Measurement of induced current levels is performed by measuring a corresponding voltage across one of the 50 ohm loads. Since the 50 ohm loads are in series for the induced signal, the total drive voltage is actually two times that being measured.

Prior to the “D” revision, MIL-STD-462 (superseded by MIL-STD-461E) included test procedures CS10, CS11, CS12, and CS13, which addressed various types of damped sine testing on both cables and individual circuits or connector pins. This test procedure is a single replacement for all those procedures. CS116 addresses testing of cables (interconnecting including power) and individual power leads. The common mode cable portion of the test is the best simulation of the type of condition present on platforms from electromagnetic field excitation. The individual power lead test addresses differential type signals present on platforms from switching functions occurring in the power system.

As necessary, the test can be applied in a straightforward manner to wires on individual pins on an EUT connector or to individual circuits (twisted pairs, coaxial cables, and so forth).

Since the Q of the damped sine signal results in both positive and negative peaks of significant value regardless of the polarity of the first peak, there is no requirement to switch the polarity of the injected signal.

The common mode injection technique used in this procedure and other procedures such as CS114 is a partial simulation of the actual coupling mechanism on platforms. The magnetic field in the injection device is present at the physical location of the core of the injection device. In the platform, the electromagnetic field will be distributed in space. The injection probe induces a voltage in the circuit loops present with the voltage dropping and current flowing based on impedances present in the loop. There is a complex coupling relationship among the various individual circuits within the cable bundle. The injection probe is required to be close to the EUT connector for standardization reasons to minimize variations particularly for higher frequencies where the shorter wavelengths could affect current distribution.

For measurement of Q of the injected waveform, Figure 5-19 specifies the use of the peak of the first half-sine wave and the associated peak closest to being 50% down in amplitude. Some facilities use a damped cosine waveform rather than a damped sine. Since this waveform is more severe than the damped sine because of the fast risetime on the leading edge, there is no prohibition from using it. Because of potential distortion caused by leading edge effects, the first peak should not be used to determine Q for damped cosine waveforms. The next half peak (negative going) should be used together with the associated negative peak closest to 50% down. Equipment may exhibit failures with this waveform that would not be present with the damped sine.

5.11 RE102, RADIATED EMISSIONS, ELECTRIC FIELD, 150 kHz TO 18 GHz

Applicability and Limits: The rationale for an antenna-measured RE requirement controlling electric field emissions is to protect sensitive receivers from interference coupled through platform antennas connected to platform receivers. Many tuned receivers have sensitivities on the order of one microvolt and are connected to an intentional aperture (the antenna) which are constructed for efficient reception of energy in the operating range of the receiver. The potential for degradation requires relatively stringent requirements to prevent platform problems.

The limits used for the SSV are based on the following criteria:

a. The internal equipment limit depicted in Figure 5-23 is selected to be the same as MIL-STD-461E limit for internal equipment located in metallic aircraft of length greater than 25 meters beginning at 200 MHz. This limit is a slight relaxation of the previously applied limit. The start frequency was based on no known SSV receivers below 200 MHz.

b. The external equipment limit depicted in Figure 5-25 is selected to be the same limit as MIL-STD-461E for equipment located external on an aircraft beginning at 200 MHz. This limit is more restrictive than the internal equipment limit since external equipment may have a more direct line of sight to SSV receiving antennas during critical flight phases.

c. The internal RE limit depicted in Figure 5-24 is the previously titled alternate limit” from past revisions of this specification (i.e., prior to Revision F). This limit is also in agreement with the payload ICD crew compartment limit. This relaxed internal limit is deemed acceptable for non-critical equipment because the equipment can be turned off without affecting mission success if the equipment is found to interfere with Orbiter systems (e.g., wireless crew communications system). It is very important that this limit only be applied to equipment that does not operate during ascent and entry since interference with vehicle communication systems during these flight phases could be catastrophic. The use of this limit may need to be reconsidered when new RF communication systems are operated inside the vehicle (e.g., wireless networks).

Since the SSV does not use the electromagnetic spectrum below 200 MHz for the purpose of receiving RF signals, there is no reason to impose the stringent RE102 limit below that frequency. Instead, a limit on cable common mode CEs is imposed from 150 kHz to 200 MHz. The purpose is to control cable-to-cable crosstalk while at the same time eliminating the paperwork associated with waivers against an inapplicable RE102 limit. Part of the rationale for imposing such a limit is that the SSV often flies quite sensitive payloads. These payloads are not as sensitive as the aforementioned radio receivers, but they are orders of magnitude more sensitive than ordinary avionics. An example is a crystal growth furnace facility, with control electronics remote from the furnace. Thermocouple sensors mounted within the furnace send signals back to the remote controller. Furnace temperature control requirements often dictate that the thermocouple reading be accurate to within less than one hundred microvolts.

The BCE limit imposed was designed to limit inductively coupled crosstalk to 1 mV over a frequency range of 150 kHz to 200 MHz. Any victim signal susceptible to millivolt or sub-millivolt level crosstalk will be shielded and the shield may be counted on to provide necessary protection to signals whose accuracy requirement is less than 1 mV. Imposing cable common mode potential control in addition to current conducted emissions was considered. For the purpose of minimizing requirements and extra test equipment, this extra method was not included. The current CE requirement should suffice in the vast majority of cases. If a high potential, high impedance common mode culprit is suspected, extra wire separation requirements may need to be taken.

There is no implied relationship between this requirement and RS103 that addresses RS to electric fields. Attempts have been made quite frequently in the past to compare electric field RE and susceptibility type requirements as a justification for deviations and waivers. While RE102 is concerned with potential effects with antenna-connected receivers, RS103 simulates fields resulting from antenna-connected transmitters.

Often, the same equipment item will be involved in influencing both requirements. A 30 watt VHF-AM radio with a typical blade antenna operating at 150 MHz can easily detect a 40 dBμV/m electric field (approximately -81 dBm developed at receiver input) while in the receive mode. When this same piece of equipment transmits at the same 150 MHz frequency, it will produce a field of approximately 150 dBμV/m (32 volts/meter) at a 1 meter distance. The two field levels are 110 dB apart.

Test procedures: Specific antennas are required by this test procedure for standardization reasons. The intent is to obtain consistent results between different test facilities.

In order for adequate signal levels to be available to drive the measurement receivers, physically large antennas are necessary. Due to shielded room measurements, the antennas are required to be relatively close to the EUT, and the radiated field is not uniform across the antenna aperture. For electric field measurements below several hundred MHz, the antennas do not measure the true electric field.

The biconical and double ridged horn antennas are calibrated using far-field assumptions at a 1 meter distance. This technique produces standardized readings. However, the true electric field is obtained only above approximately 1 GHz where a far field condition exists for practical purposes.

Antenna factors are determined using the procedures of SAE ARP-958. They are used to convert the voltage at the measurement receiver to the field strength at the antenna.

Any RF cable loss and attenuator values must be added to determine the total correction to be applied.

Previous versions of this specification specified conical log spiral antennas. These antennas were convenient since they did not need to be rotated to measure both polarizations of the radiated field. The double ridged horn is considered to be better for standardization for several reasons. At some frequencies, the antenna pattern of the conical log spiral is not centered on the antenna axis. The double ridged horn does not have this problem. The circular polarization of the conical log spiral creates confusion in its proper application. Electric fields from EUTs would rarely be circularly polarized. Therefore, questions are raised concerning the need for 3 dB correction factors to account for linearly polarized signals. The same issue is present when spiral conical antennas are used for RS testing. If a second spiral conical is used to calibrate the field correctly for a circularly polarized wave, the question arises whether a 3 dB higher field should be used since the EUT will respond more readily to linearly polarized fields of the same magnitude.

Other linearly polarized antennas such as log periodic antennas are not to be used. It is recognized that these types of antennas have sometimes been used in the past; however, they will not necessarily produce the same results as the double ridged horn because of field variations across the antenna apertures and far field/near field issues. Uniform use of the double ridge horn is required for standardization purposes to obtain consistent results among different test facilities.

The stub radiator required by the procedure is simply a short wire (approximately 10 cm) connected to the center conductor of a coaxial cable that protrudes from the end of the cable.

The antenna positioning requirements in this procedure are based on likely points of radiation and antenna patterns. The wavelengths above 200 MHz will result in radiation from EUT apertures and portions of cabling close to EUT interfaces. The requirements for antenna positioning above 200 MHz are based on including EUT apertures and lengths of cabling at least one quarter wavelength.

All the specified antennas are linearly polarized. Above 30 MHz, measurements must be performed to measure both horizontal and vertical components of the radiated field.

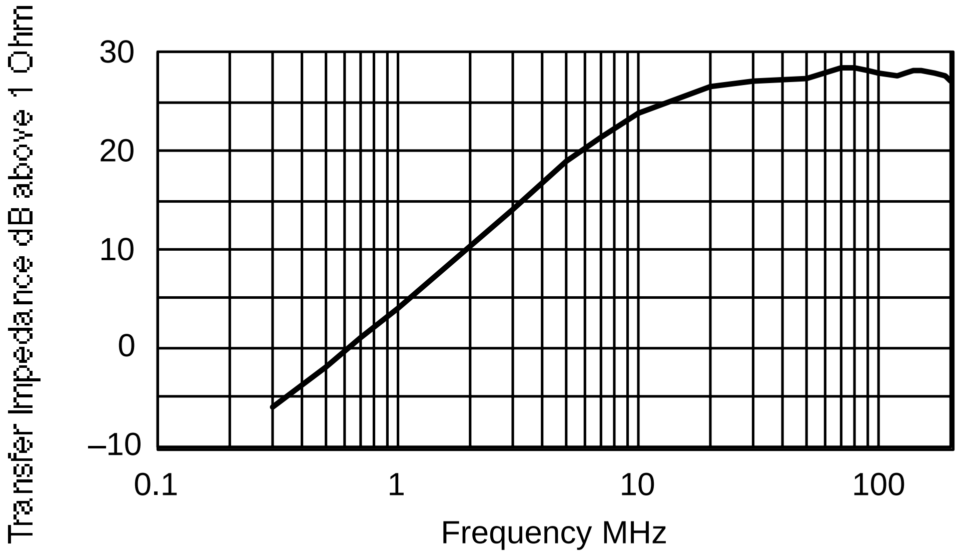
For equipment or subsystems that have enclosures or cabling in various parts of a platform, data may need to be taken for more than one configuration. For example, in an aircraft installation where a pod is located outside of aircraft structure and its associated cabling is internal to structure, two different limits may be applicable. Different sets of data may need to be generated to isolate different emissions from the pod housing and from cabling. The non-relevant portion of the equipment would need to be protected with appropriate shielding during each evaluation.

Additional commentary relative to the added Space Shuttle BCE requirement:

The test procedure is similar to that for CE101 of MIL-STD-461E, except that signal bundles are also tested, and the power cable as a whole (power input and return) are both fed through the absorbing clamp to ensure that only common mode emissions are measured. The absorbing clamp (fully described in CISPR 16) is a current probe followed by a series of ferrite ring absorber elements. These act to isolate the rest of the cable, minimizing the standing waves associated with signals on an electrically long mismatched transmission line. If a traditional current probe were used for this test instead of an absorbing clamp, then at frequencies above which the Cable-under-test (CUT) were greater than one-tenth wavelength long, it would be necessary to physically scan the probe the length of the CUT in order to find a peak. Since a 2 meter cable is one-tenth wavelength at 15 MHz, this would entail a convolution of frequency and physical scanning over a wide frequency range which would result in a long test which could not use automated scanning. Use of the absorbing clamp provides repeatable results using automated test techniques. In order to use the absorbing clamp for this test, with the current CE limit of this requirement, 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. Calibration is done as per the figure showing measurement validation. Instead of a calibration fixture, as described in the CS114 section, a wire must be connected between signal generator and 50 ohm dummy load. The return path is a ground plane connected between signal generator return and dummy load return. The wire should be as short as possible. Since the absorbing clamp is built per CISPR drawings, and its loss factor as defined in CISPR 16 is fixed, its transfer impedance should also be fixed and be nominally as shown in Figure B-16.

FIGURE B-16

NOMINAL TRANSFER IMPEDANCE FCISPR 16 ABSORBING CLAMP



In development tests, the absorbing clamp was found to reduce standing wave peaks about 20 dB from that measured with a traditional current probe. Further, when testing on a shielded cable with well-terminated shields, the absorbing clamp reduced conducted emissions by 20 dB even at frequencies where the cable was electrically short. To account for this 20 dB difference between absorbing clamp and traditional current probe results, the limit was reduced 20 dB from that resulting from the criterion of limiting crosstalk to one millivolt. It is likely that this 20 dB effect would not be present when measuring BCE on a power cable, because it is not shielded and has a relatively high impedance at the lower frequencies. However, in this case, higher current conducted emissions would translate into higher cable common mode potentials, so there is good rationale for imposing the 20 dB safety factor in this case as well.

NOTE: In order to get the full value of the absorbing clamp, it must be placed as close as possible to the EUT. One-tenth wavelength at 200 MHz is 15 cm. This should be an outer bound on absorber clamp-EUT separation.

5.12 RE103, RADIATED EMISSIONS, ANTENNA SPURIOUS AND HARMONIC OUTPUTS, 10 kHz TO 18 GHz

Applicability and Limits: The requirements are essentially identical with CE106 for transmitters in the transmit mode. There are no requirements for receivers or transmitters in the standby mode. Most of the discussion under CE106 also applies to RE103. A distinction between the requirements is that RE103 testing includes effects due to antenna characteristics. The test itself is considerably more difficult.

Test procedures: Since the test procedure measures emissions radiating from an antenna connected to a controlled impedance, shielded, transmission line, the measurement results should be largely independent of the test setup configuration. Therefore, it is not necessary to maintain the basic test setup described in the main body of this specification.

The test procedure is laborious and will require a large open area to meet antenna separation distances. Equations in the test procedure specify minimum acceptable antenna separations based on antenna size and operating frequency of the EUT. Antenna pattern searches in both azimuth and elevation are required at the spurious and harmonic emissions to maximize the level of the detected signal and account for antenna characteristics.

Sensitivity of the measurement system may need enhancement by use of preamplifiers and the entire test needs to be coordinated with local frequency allocation authorities. All recorded data has to be corrected for space loss and antenna gain before comparisons to the limit.

As shown in Figure 5-32 and Figure 5-33, shielding might be necessary around the measurement system and associated RF components to prevent the generation of spurious responses in the measurement receiver. The need for such shielding can be verified by comparing measurement runs with the input connector of the measurement receiver terminated in its characteristic impedance and with the EUT in both transmitting and stand-by modes or with the EUT turned off. Also, the receiving or transmit antenna may be replaced with a dummy load to determine if any significant effects are occurring through cable coupling.

The RF cable from the receive antenna to the measurement receiver should be kept as short as possible to minimize signal loss and signal pick-up.

The band-rejection filters and networks shown in Figure 5-32 and Figure 5-33 are needed to block the transmitter fundamental and thus reduce the tendency of the measurement receiver to generate spurious responses or exhibit suppression effects because of the presence of strong out-of-band signals. These rejection networks and filters require calibration over the frequency range of test.

Some caution needs to be exercised in applying Table 4.3 of the main body of this specification. In Paragraph 5.12.3.4, Step d, Item 4, of the test procedure, a power monitor is used to measure the output power of the EUT. In conjunction with the antenna gain, this value is used to calculate the ERP of the equipment. In Paragraph 5.12.3.4, Step d, Item 5, of the test procedure, the measurement receiver is used to measure the power from a receiving antenna. This result is also used to calculate an ERP. For the two measurements to be comparable, the measurement receiver BW needs to be sufficiently large to include at least 90% of the power of the signal present at the tuned frequency. If the BW in Table 4.3 of the main body of the specification is not appropriate, a suitable measurement receiver BW should be proposed in the EMITPs.

For measurement of the magnitude of harmonic and spurious emissions with respect of the fundamental, the BWs of Table 4.3 will normally produce acceptable results, regardless of whether the BW is large enough to process 90% of the power. Since the signal BW of harmonic and spurious emissions is usually the same as the fundamental, use of a common BW for measuring both the fundamental and the emissions will provide a correct relative reading of the amplitudes.

5.13 RS103, RS, ELECTRIC FIELD, 10 kHz TO 18 GHz

Applicability and Limits: The requirements are applicable to both the EUT enclosures and EUT associated cabling. The basic concern is to ensure that equipment will operate without degradation in the presence of electromagnetic fields generated by antenna transmissions both onboard and external to the platform.

There is no implied relationship between this requirement and RE102. The RE102 limit is placed primarily to protect antenna-connected receivers while RS103 simulates fields resulting from antenna transmissions.

Using circularly polarized fields is not allowed due to problems with using the spiral conical antennas specified in versions of MIL-STD-462 (superseded by this specification) prior to the “D” revision. Circularly polarized fields were convenient since they avoided the need to rotate a linearly polarized antenna to obtain both polarizations of the radiated field. However, problems existed with this antenna. At some frequencies, the antenna pattern of the conical log spiral is not centered on the antenna axis. Also, the circular polarization of the conical log spiral creates confusion in its proper application. The EUT and associated cabling can be expected to respond more readily to linearly polarized fields. If a second spiral conical were used to calibrate the field radiated from the first spiral conical antenna, it would indicate an electric field 3 dB higher than a linearly polarized antenna. The question arises whether a 3 dB higher field should be used for a spiral conical transmit antenna to obtain response characteristics similar to a linearly polarized field. Similarly, if a spiral conical antenna were used to calibrate a linearly polarized field, the indication would be 3 dB below the true electric field strength.

Test procedures: Test facilities are permitted to select appropriate electric field generating apparatus. Any electric field generating device such as antenna, long wire, transverse electromagnetic cell, reverberating chamber (using mode tuned techniques) or parallel strip line capable of generating the required electric field may be used. Fields should be maintained as uniform as possible over the test setup boundary. Both horizontally and vertically polarized fields must be generated. This requirement may limit the use of certain types of apparatus.

Monitoring requirements emphasize measuring true electric field. While emission testing for radiated electric fields does not always measure true electric field, sensors with adequate sensitivity are available for field levels generated for susceptibility testing. Physically small and electrically short sensors are required so that the electric field does not vary substantially over the pickup element resulting in the measurement of a localized field. Broadband sensors not requiring tuning are available.

The use of more than one sensor is acceptable provided all sensors are within the beamwidth of the transmit antenna. The effective field is determined by taking the average of the readings. For example, if the readings of three sensors are 30, 22, and 35 volts/meter, the effective electric field level is (30 + 22 + 35)/3 = 29 volts/meter.

Different sensors may use various techniques to measure the field. At frequencies where far-field conditions do not exist, sensors must be selected which have electric field sensing elements. Sensors that detect magnetic field or power density and convert to electric field are not acceptable. Under far-field conditions, all sensors will produce the same result. Correction factors must be applied for modulated test signals for equivalent peak detection as discussed under Paragraph 4.3.10.1. A typical procedure for determining the correction factor for these sensors is as follows:

a. Generate a field at a selected frequency using an unmodulated source.

b. Adjust the field to obtain a reading on the sensor display near full scale and note the value.

c. Modulate the field as required (normally 1 kHz pulse, 50% duty cycle) and ensure the field has the same peak value. A measurement receiver with the peak detector selected and receiving antenna can be used to make this determination.

d. Note the reading on the sensor display.

e. Divide the first reading by the second reading to determine the correction factor (Subtract the two readings if the field is displayed in terms of dB).

f. Repeat the procedure at several frequencies to verify the consistency of the technique.

Above 1 GHz, radiated fields usually exhibit far-field characteristics for test purposes due to the size of typical transmit antennas, antenna patterns, and distances to the EUT. Therefore, a double ridged horn together with a measurement receiver will provide true electric field. Similarly, the particular sensing element in an isotropic sensor is not critical, and acceptable conversions to electric field can be made.

For equipment or subsystems that have enclosures or cabling in various parts of a platform, data may need to be taken for more than one configuration. For example, in an aircraft installation where a pod is located outside of aircraft structure and its associated cabling is internal to structure, two different limits may be applicable. Different sets of data may need to be generated to evaluate potential pod susceptibility due to coupling through the housing versus coupling from cabling. The non-relevant portion of the equipment would need to be protected with appropriate shielding.

Reverberating chambers, using mode tuned techniques, have been popular for performing shielded effectiveness evaluations and, in some cases, have been used for RS testing of equipment and subsystems. The concept used in reverberating chambers is to excite available electromagnetic wave propagation modes to set up variable standing wave patterns in the chamber. A transmit antenna is used to launch a electromagnetic wave. An irregular shaped tuner is rotated to excite the different modes and modify the standing wave pattern in the chamber. Any physical location in the chamber will achieve same peak field strength at some position of the paddle wheel.

Reverberation chambers have the advantage of producing relatively higher fields than other techniques for a particular power input. Also, the orientation of EUT enclosures is less critical since the all portions of the EUT will be exposed to the same peak field at some paddle wheel position. The performance of a particular reverberation chamber is dependent upon a number of factors including dimensions, Q of the chamber, number of available propagation modes, and frequency range of use.

Some issues with reverberation chambers are as follows. The field polarization and distribution with respect to the EUT layout are generally unknown at a point in time. If a problem is noted, the point of entry into the EUT may not be apparent.

Reverberation chambers are sometimes treated as a good tool to determine potential problem frequencies with conventional antenna procedures being used to evaluate areas of concern.

The performance of each chamber must be reviewed to determine the suitability of its use for reverberation testing over a particular frequency range.

Reverberation chambers should be constructed in accordance with the following guidance in order to function properly.

a. A tuner should be constructed of metal and installed with appropriate positioning equipment to allow the tuner to be rotated 360 degrees in at least 200 evenly spaced increments. The tuner should be constructed to be asymmetric with the smallest dimension of the tuner being at least $\lambda/3$ of lowest frequency to be tested and the longest dimension of the tuner being approximately 75% of the smallest chamber dimension.

b. The enclosure should be free of any materials that might exhibit absorptive properties such as tables, chairs, wood floors, sub-floors, shelves, and such. Support structures should be constructed from high density foam.

c. Transmit and receive antennas should be at least 1.0 meter ($\lambda/3$ is the actual limitation) from any wall or object and should be positioned to prevent direct alignment between the main lobes of the two antennas or between the EUT and the main lobe of either antenna.

d. The lower frequency limit is dependent on chamber size. To determine the lower frequency limit for a given chamber, use one of the following methods:

1. Using the following formula, determine the number of possible modes (N) which can exist at a given frequency. If, for a given frequency, N is less than 100, then the chamber should not be used at or below that frequency.

$$N = \frac{8\pi}{3} abd \, \frac{f^3}{c^3}$$

where: a, b, and d are the chamber internal dimensions in meters
f is the operation frequency in Hz
c is the speed of propagation (3×10^8 m/s)

2. Use the methods detailed in RTCA DO-160, Section 20.6, for determining the lowest useable frequency based on field uniformity.

e. In order to assure that the time response of the chamber is fast enough to accommodate pulsed waveform testing (other than the 1 kHz, 50% duty cycle, waveform specified), determination of the chamber time constant must be accomplished using the following procedure:

1. Calculate the chamber Q using:

$$Q = \left(\frac{16\pi^2 V}{\eta_{Tx}\eta_{Rx}\lambda^3} \right) \left(\frac{P_{ave\ rec}}{P_{forward}} \right)$$

where η_{Tx} and η_{Rx} are the antenna efficiency factors for the Tx and Rx antennas respectively and can be assumed to be 0.75 for a log periodic antenna and 0.9 for a horn antenna, V is the chamber volume (m^3), λ is the free space wavelength (m) at the specific frequency, $P_{ave\ rec}$ is the average received power over one tuner rotation, and $P_{forward}$ is the forward power input to the chamber over the tuner rotation at which $P_{ave\ rec}$ was measured.

2. Calculate the chamber time constant, τ, using:

$$\tau = \frac{Q}{2\pi f}$$

where Q is the value calculated above, and f is the frequency (Hz)

3. If the chamber time constant is greater than 0.4 of the pulse width of the modulation waveform, absorber material must be added to the chamber or the pulse width must be increased. If absorber material is added, repeat the measurement and the Q calculation until the time constant requirement is satisfied with the least possible absorber material. A new *CLF*(f) must be defined if absorber material is required.

f. Prior to using the chamber, the effectiveness of the tuner should be evaluated at the upper and lower frequencies to be used and at points between the end-points not to exceed 1 GHz spacing. To evaluate the stirring effectiveness, inject a CW signal into the chamber at the desired frequency and record the net received power at 200 positions of the tuner evenly spaced over a 360 degree rotation of the tuner. Determine the correlation coefficient between the original set of received power and subsequent sets obtained by rotating the last data point of the original set to the position of the first point and then shifting all the other points to the right as depicted below.

Original data	D1, D2, D3, D4, D5, . . . D200
Shifted data (1)	D200, D1, D2, D3, D4, . . . D199
Shifted data (2)	D199, D200, D1, D2, D3, . . . D198
Shifted data (3)	D198, D199, D200, D1, D2, . . . D197
Shifted data (4)	D197, D198, D199, D200, D1, . . . D196
Shifted data (5)	D196, D197, D198, D199, D200, D1, . . . D195

The correlation coefficient should drop to below 0.36 within five shifts of the data. This will ensure that the tuner is operating properly. If the tuner fails this test, then the tuner needs to be made either larger or more complex, or both.

g. National Bureau of Standards Technical Note 1092, “Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/ Vulnerability Measurements” and National Institute of Standards and Technology Technical Note 1508, “Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility,” should be used as a guide in preparing a shielded room for reverberation measurements.

5.14 TT101, CONDUCTED EMISSIONS, TIME DOMAIN, DC POWER LEADS, TRANSIENT AND STEADY-STATE

Applicability and Limits: Several issues are potentially of interest when cycling loads on/off a power bus. This method addresses voltage transients on the bus due transmission line characteristics of power bus wiring. Another issue is inrush current, which is an important consideration on some types of loads and also when power source is current limited, such as on the Shuttle 400 Hz bus. The Shuttle DC bus is powered from a fuel cell, which is a very low resistance (stiff) source of power. Loading the fuel cell itself is not an issue. Reactive and resistive effects of a long distributed power bus is the concern. There have been several cases noted where energizing certain equipment has dropped bus potentials for durations of the order of 100 µs, causing other equipment to malfunction.

There are also a few cases where high current loads generate periodic spikes on the power bus, such as hydraulic pumps near the aft end of the cargo bay. The steady-state ripple requirement is imposed to limit such spikes.

For a detailed discussion of the physics of switching transients, see NASA CR-1999-209574.[1] Considering the nature of a power bus, it is impossible for a transient to cause line voltage to cross zero from whatever polarity the nominal line voltage happened to be at instant of turn-on. There is no justification for a DC limit below zero. In essence there is no justification for an amplitude-based safety margin. Margins must be based on duration only. For a turn-off transient, the only limit is the characteristic impedance of the LISN multiplied by the switched current. The duration is fixed by choice of LISN. Hence, picking a limit comes down to deciding how much DC load current can be switched off at once.

The steady-state limit of 0.7 Volt peak departure from nominal bus potential in a 10 MHz BW was picked to provide a 0.5 Volts root mean square (Vrms) sine wave equivalent time domain ripple. In practice, the rms equivalent will be much less. The 0.5 Vrms number provides reasonable margin with respect to imposed susceptibility requirements.

Test procedures: The LISN defined herein for the purpose of this test is different than the LISN defined for CE102. Whereas the CE102 LISN provides a defined impedance between power conductor and ground, the TT101 LISN provides a defined impedance between each 28 VDC power conductor. Impedance to ground is uncontrolled. Necessarily, the measurement is made line-to-line, which imposes certain restrictions on how

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[1] NASA Center for AeroSpace Information, 800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934 301/621-0390 or National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 703/487-4650

the oscilloscope is used, which is discussed below. In this revision of SL-E-0002, the default series resistance of the LISN has been reduced an order of magnitude, to 25 mΩ in each leg, to more correctly reflect the character of the transient where it is of most interest, at the point where the transient is impressed on other victim loads. Other things equal, a transient waveform will return to nominal much more quickly with the lower bus resistance. Users of commercially procured LISNs should be aware they were likely built to older revisions and will require modification for testing to the newer standard. The default resistance value of 25 mΩ is reasonable for EUTs which present a light load to the power bus. In general, the total series resistance (sum of resistances in both LISN conductors) should be such that EUT current causes a 0.1 Volt steady-state drop across the LISN series resistance.

A solid-state switch to energize/de-energize EUT is a necessity in order to avoid the inevitable bouncing and/or arcing associated with mechanical switching. Instructions on how to build such a switch may be found in NASA CR-1999-209574.

A digital storage oscilloscope (10 MHz single event BW) is highly desirable for both transient and steady-state measurements. It is necessary to record transient waveforms such that undisturbed line voltage is displayed before and after the transient event. A dso is the most convenient method of capturing the waveform. The advantage of a dso for this measurement is in ease of triggering. A digital oscilloscope's triggering function is almost opposite in function to that of an analog oscilloscope, in that an analog oscilloscope does not record data until the specified trigger event occurs. The dso, by contrast, can be set to continually record data to memory until the trigger event occurs. When the trigger event occurs, the dso ceases to take data once its memory has filled. Thus, data taken prior to trigger event can be recorded, assuring a complete record of the transient event leading edge. A dso also has the capability to record continuously in a max or peak hold mode, which is what is needed for the steady-state measurement.

Because the LISN inserts impedances in both 28 VDC power conductors, it is essential that the oscilloscope measurement not ground the low side conductor. With a grounded chassis dso, this means a differential measurement (channel A - channel B) must be made. A better solution is to use a portable isolated chassis dso, in which the ground side of the oscilloscope probe is floating.

The switch should be placed between LISN and EUT. There is often confusion about this. The switch cannot be placed on the power input side of the LISN or else all that is measured is the filtering effect of the LISN on a switched input. The purpose of the test is to measure bus voltage transients when a load is switched on or off the bus as modeled by the LISN itself.

Calibration is extremely important for the transient measurement. If triggering is incorrectly set up, no emission will be found. A resistive load drawing the same DC current as the EUT will normally provide a smaller turn-on transient than the EUT itself, hence the ability to measure the transient associated with that resistor indicates a proper test set up.

The transient limit allows that once a load is turned on and drawing a DC current, that the turn-on transient does not return to the open circuit voltage which appeared at the output of the LISN prior to turn-on, but rather returns to a loaded potential which is the open circuit potential less the DC resistance of the LISN multiplied by the EUT load current. However, if the transient waveform does not return to this level, or takes excessive time to do so, it may mean there are other sources of DC or AC impedances between power source and LISN. If an EUT fails to meet the turn-on transient limit due to excessive time to return to nominal, troubleshooting the test set up should precede redesign of the EUT. Measure the transient waveform on the power input side of the LISN. It should be non-existent or small enough it does not contribute to the non-compliance. If such is not the case, steps must be taken to lower the power source impedance. The most obvious technique is to shorten the length of power leads between power supply and LISN. This can be especially effective if power source is outside of a shield room with filtered power, and providing power from within the room bypasses those filters.

The major source of the transient voltage drop and duration is the charging of a bulk capacitor in the EUT. If this capacitor is partially charged, the measured transient is smaller than if the capacitor is completely discharged. A one second period should be allowed after EUT has been de-energized before measuring a turn-on transient, in order to ensure complete discharge of bulk capacitor.

The steady-state limit measures departures from nominal bus potential. The issue of how long to test is based on EUT cycle times. If the EUT performs different functions at different times, then it is necessary to lengthen the acquisition time to cover the total cycle. In the event that only one portion of the cycle generates above limit emissions, it may be useful to note that fact when considering how to address the problem.