DEFENSE INFORMATION SYSTEMS AGENCY
The IT Combat Support Agency

Department of Defense Interface Standard MIL-STD-461G Overview

Joint Spectrum Center
E3 & Spectrum Engineering Division, OS35
Tony Keys

Who Are We

Defense Information System Agency (DISA) Mission

- To conduct DODIN operations for the joint warfighter to enable lethality across all warfighting domains in defense of our Nation.

Defense Spectrum Organization (DSO) Mission

- Deliver tools, capabilities, and expertise to empower DOD to solve tomorrow's electromagnetic spectrum challenges today.

Joint Spectrum Center (JSC) Mission

- Provides direct support to the JCS, CCMDs, and MILDEPs to enable trusted, efficient and effective use of the Electromagnetic Spectrum Enterprise (operations, services, data, tools/capabilities), Applied Engineering, Acquisition and Analysis, and the mitigation of Electromagnetic Environmental Effects (E3) in support of national security and military objectives.

Disclaimer

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Instructor Bio

Welcome to "MIL-STD-461G Overview"

Tony Keys, President of EMC Analytical Services (EMCAS)

Over 28 years of E3 engineering experience from a wide variety of organizational aspects including DoD employee, DoD support service contractor, defense contractor system developer…

Education:
- BS Degree in Physics
- MS Degree in Systems Engineering

Professional Certifications:
- NARTE Certified EMC Engineer
- IEEE EMCS Member

Telephone Number: **603-488-5171**
Email: **tony@e3as.com**
Link to Instructor's web site: **www.e3as.com**

MIL-STD-461 Introduction

- **Applicability**
- **Purpose**
- **Definitions**
- **Notes**

METRIC

MIL-STD-461G
11 December 2015

SUPERSEDING
MIL-STD-461F
10 December 2007

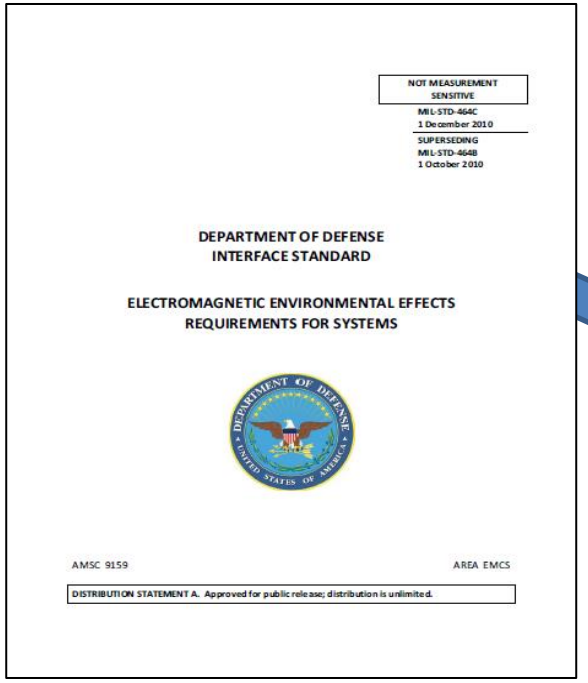
DEPARTMENT OF DEFENSE INTERFACE STANDARD

REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT

AMSC 9618 AREA EMCS

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

MIL-STD-461G


NOT MEASUREMENT SENSITIVE
MIL-STD-464C
1 December 2010
SUPERSEDING
MIL-STD-464B
1 October 2010

DEPARTMENT OF DEFENSE
INTERFACE STANDARD

ELECTROMAGNETIC ENVIRONMENTAL EFFECTS
REQUIREMENTS FOR SYSTEMS

AMSC 9159 AREA EMCS

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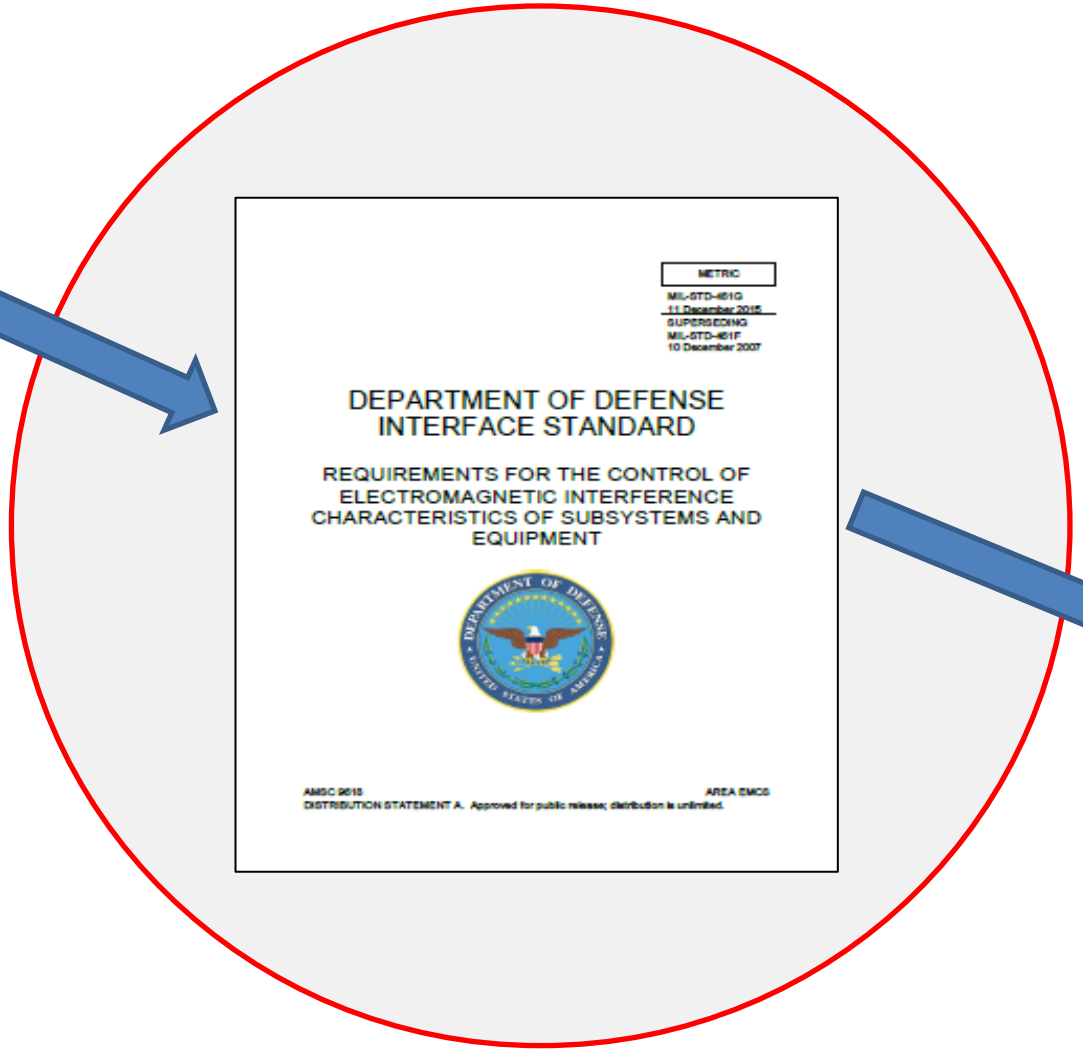
METRIC
MIL-STD-461G
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SUPERSEDING
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DEPARTMENT OF DEFENSE
INTERFACE STANDARD

REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT

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Subsystem Performance Specs

MIL-STD-461G

- **Applies to Equipment and Subsystems**
  - Not appropriate for platform level
  - Not appropriate for module level
- **Conducted and Radiated Emissions and Susceptibility (CE, CS, RE, RS) Requirements and Test Procedures**
- **Requirements Tailored to Equipment Characteristics and Installation**
- **Main Body**
- **Appendix**
- **DIDs**

MIL-STD-461G

- **The purpose of MIL-STD-461G**
  - "…to provide reasonable confidence that a particular subsystem or equipment complying with these requirements will function within their designated design tolerances when operating in their intended electromagnetic environment (EME)."
- **What this does not state**
  - Passing 461 testing ensures platform level EMC
  - Failing 461 testing guarantees platform level EMI

Notes

- **Associated Data Item Descriptions (DIDs)**
  - DI-EMCS-80199 Electromagnetic Interference Control Procedures (EMICP)
  - DI-EMCS-80201 Electromagnetic Interference Test Procedures (EMITP)
  - DI-EMCS-80200 Electromagnetic Interference Test Report (EMITR)
- **Tailoring guidance for contractual application**
- **Keywords**
- **International standardization agreement implementation**
- **Technical POCs**

Definitions

- **Above deck** - All shipboard areas, outside the skin of the ship or submarine, which are continuously exposed to the external electromagnetic environment.
- **Antenna port** - Any connector, terminal or waveguide of a transmitter, receiver or amplifier which is employed in the transmission and/or reception of RF energy. The antenna port can be either directly connected to an antenna or indirectly connected to an antenna, such as through an antenna coupler, power divider, amplifier, etc.
- **Below deck** - Areas in ships that are surrounded by a metallic structure such as the hull or superstructure of metallic surface ships, the shielded areas or rooms of non-metallic ships, the shielded areas of ships utilizing a combination of metallic/non-metallic material for hull and superstructure or a deck mounted metallic shelter. This also includes inside the pressure hull of submarines.
- **Cable bundle** - All wires and shields associated with a specific equipment under test (EUT) connector.

Definitions (cont.)

- **Exposed below deck** - Areas within the skin of the ship that have electrically large openings which when open expose the equipment and cables in those spaces to the external electromagnetic environment. This can also include spaces that are surrounded by material that does not have at least as much shielding effectiveness as the structure. Examples of these areas may include the bridge, hangar, boat bay, within the superstructure but outside the pressure hull of submarines, mooring stations, intakes, and uptake trunks.
- **External installation** - An equipment location on a platform which is exposed to the external electromagnetic environment (EME), such as an aircraft cockpit which does not use electrically conductive treatments on the canopy or windscreen or electronic systems mounted outside of a tactical ground platform.
- **Internal installation** - An equipment location on a platform which is totally inside an electrically conductive structure, such as a typical avionics bay in aluminum skin aircraft or metallic hull of a tactical ground platform.

Definitions (cont.)

- **Safety critical** - Unless otherwise defined in the procurement specification, a term applied to a condition, event, operation, process, or item whose proper recognition, control, performance, or tolerance is essential to safe system operation or use; for example, safety critical function, safety critical path, or safety critical component. A term also used when a failure or malfunction of a system or subsystem can cause death or serious injury to personnel.
- **Test setup boundary** - The test setup boundary includes all enclosures of the EUT, exposed interconnecting leads and power leads required by 4.3.8.6.

General Requirements

- Interface
- Verification
- Test Setup Configurations

General

Electronic, electrical, and electromechanical equipment and subsystems shall comply with the applicable general interface requirements in 4.2. General requirements for verification shall be in accordance with 4.3. These general requirements are in addition to the applicable detailed emission and susceptibility requirements and associated test procedures defined in 5.

- **Provides guidance for:**
  - **Interface requirements**
  - **Verification requirements**
    - Measurement tolerances
    - Shielded enclosures
    - Ambient electromagnetic level
    - Ground plane
    - Power source impedance
    - General test precautions
    - EUT test configurations
    - Operation of EUT
    - Use of measurement equipment
    - Calibration of measuring equipment

Measurement Tolerances

Distance: ±5%

Frequency: ±2%

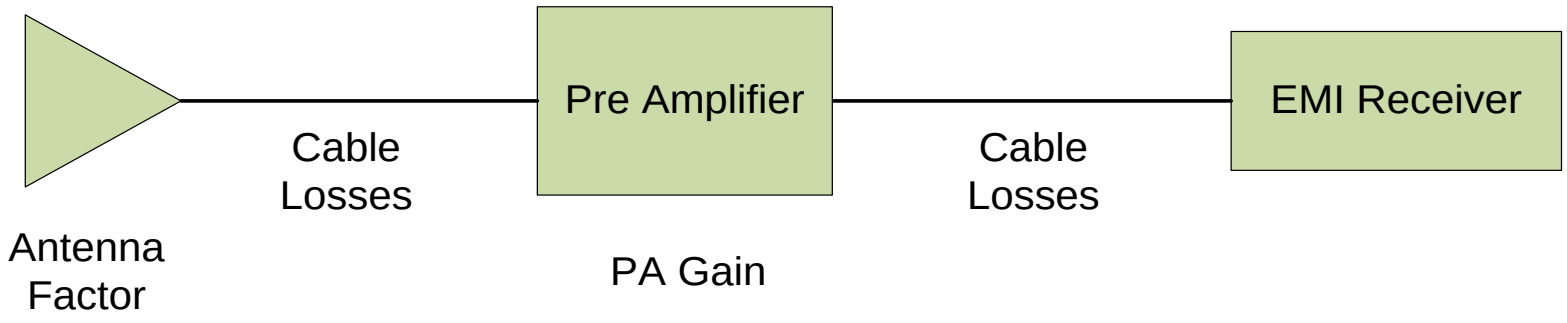
Amplitude, measurement receiver: ±2 dB

Time (waveforms): ±5%

Resistors: ±5%

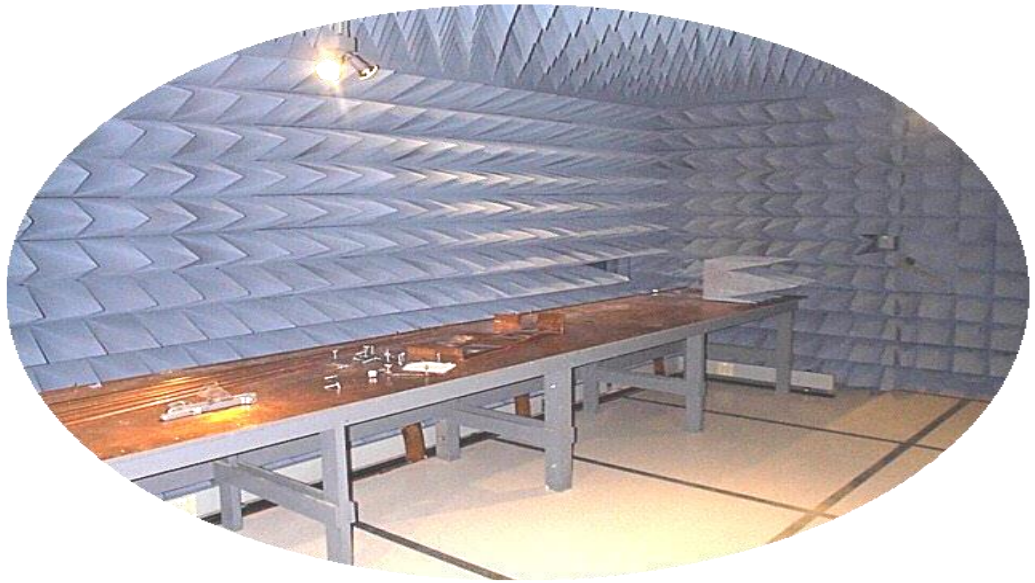
Capacitors: ±20%

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



Shielded Enclosures

Shielded enclosures are usually required to 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.



RF absorber placed above, behind, and on both sides of the EUT, and behind the radiating or receiving antenna.

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

Ambient Level

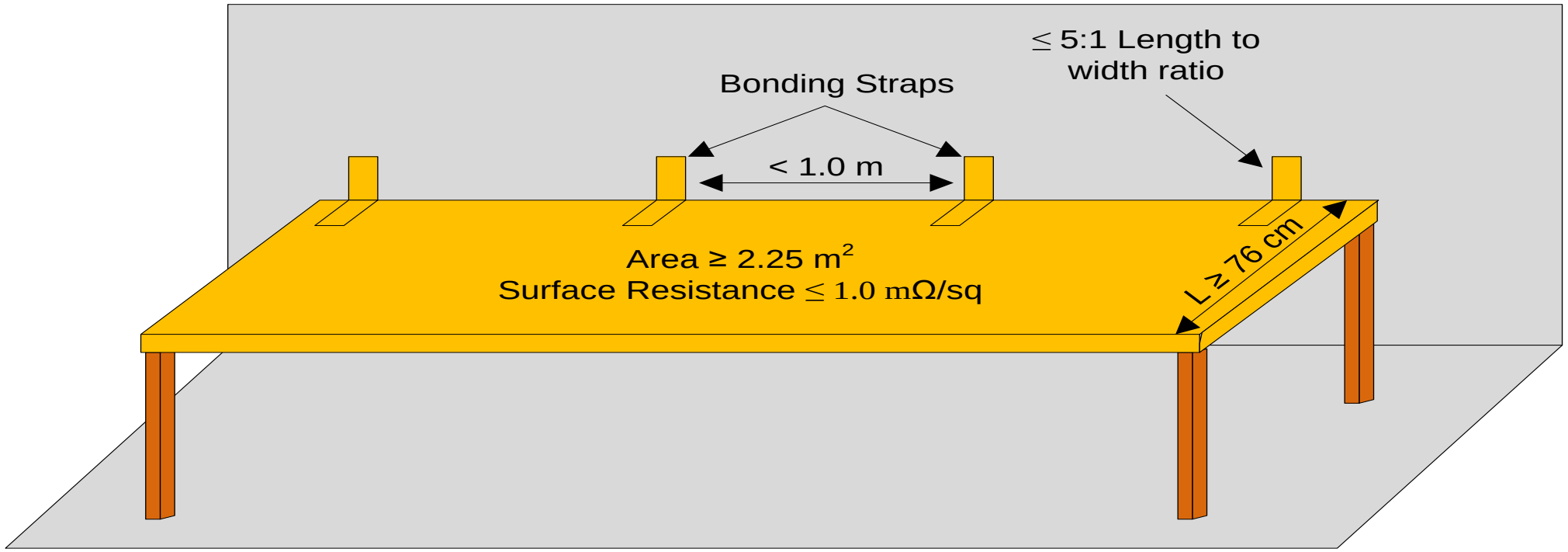
- **During testing, the ambient electromagnetic level measured with the EUT de-energized, and all auxiliary equipment turned on shall be at least 6 dB below the allowable specified limits when the tests are performed in a shielded enclosure.**
- **Radiated emissions testing at Open Area Test Sites (OATS) poses enormous challenges due to high level ambient HF, VHF and UHF transmissions.**
- **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.**
  - Ambient measurements for conducted emissions are sometimes ommitted!

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.

When a ground plane is not present in the EUT installation, the EUT shall be placed on a non-conductive table.

For conductive composite ground planes, the surface resistivity of the typical installation shall be used.

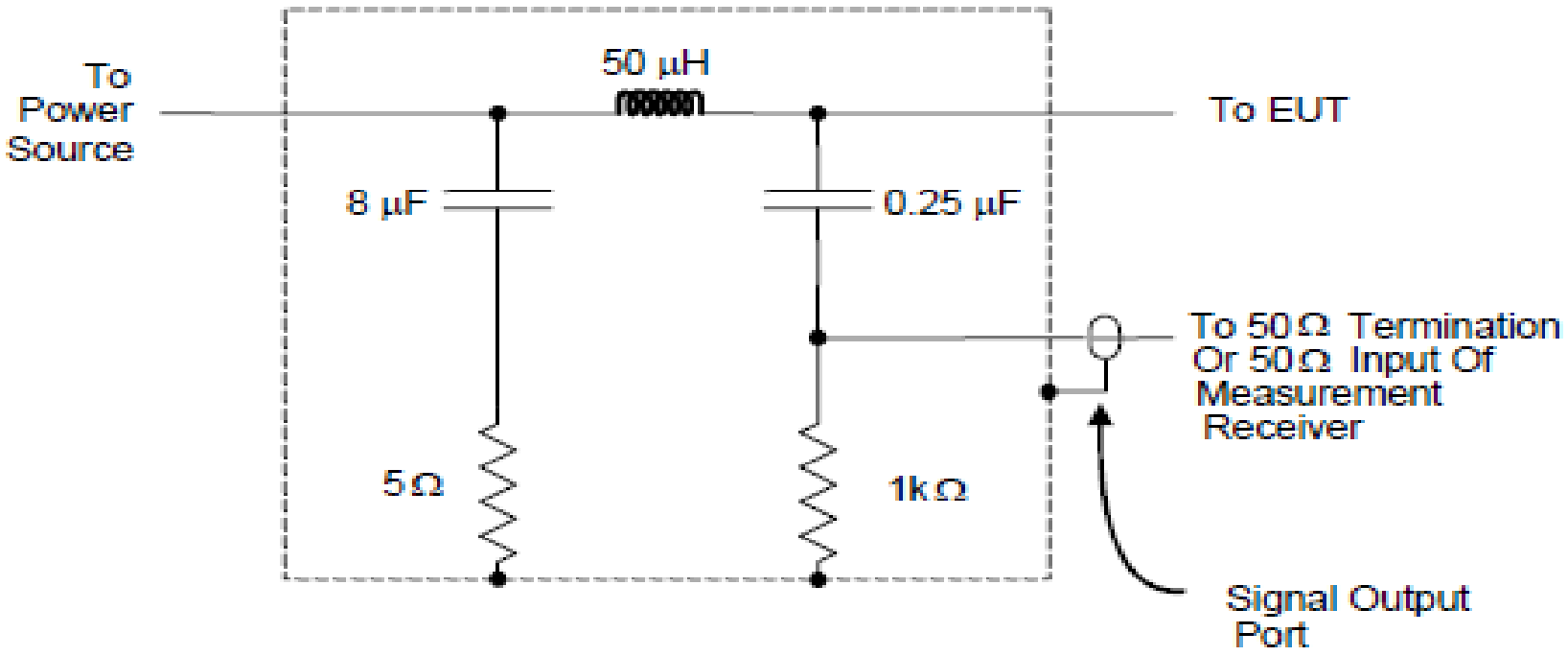


Power Source Impedance

- The impedance of power sources providing input power to the EUT shall be controlled by Line Impedance Stabilization Networks (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 4.3.8.6.2.
- LISNs shall be electrically bonded to the test ground plane or facility ground as required and the bond resistance shall not exceed 2.5 milliohms.

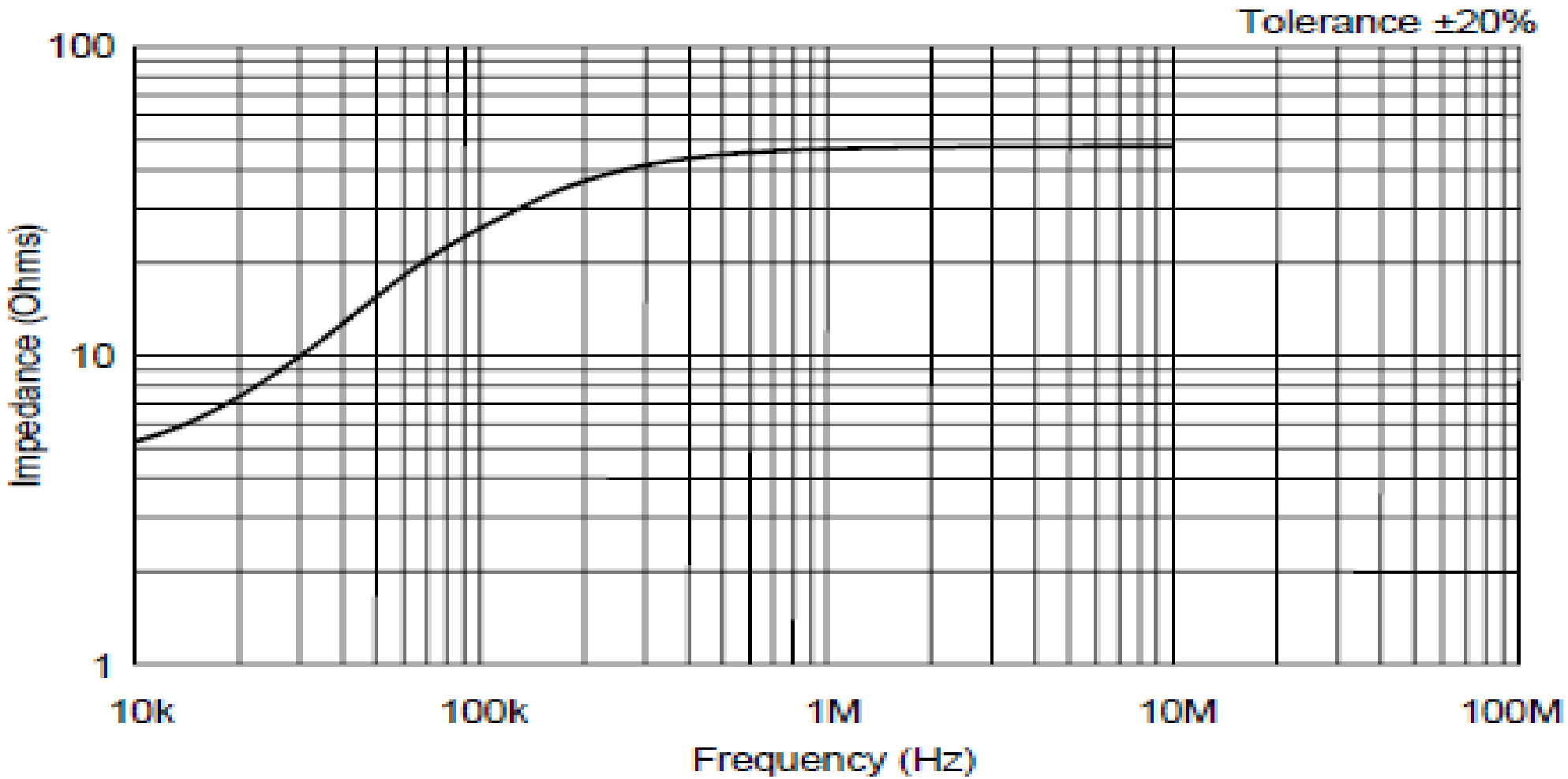
Specific LISNs required by MIL-STD-461G

LISNs


To
Power
Source
50 µH
To EUT
8 µF
0.25 µF
To 50Ω Termination
Or 50Ω Input Of
Measurement
Receiver
5Ω
1kΩ
Signal Output
Port


LOAD

LISN Impedance

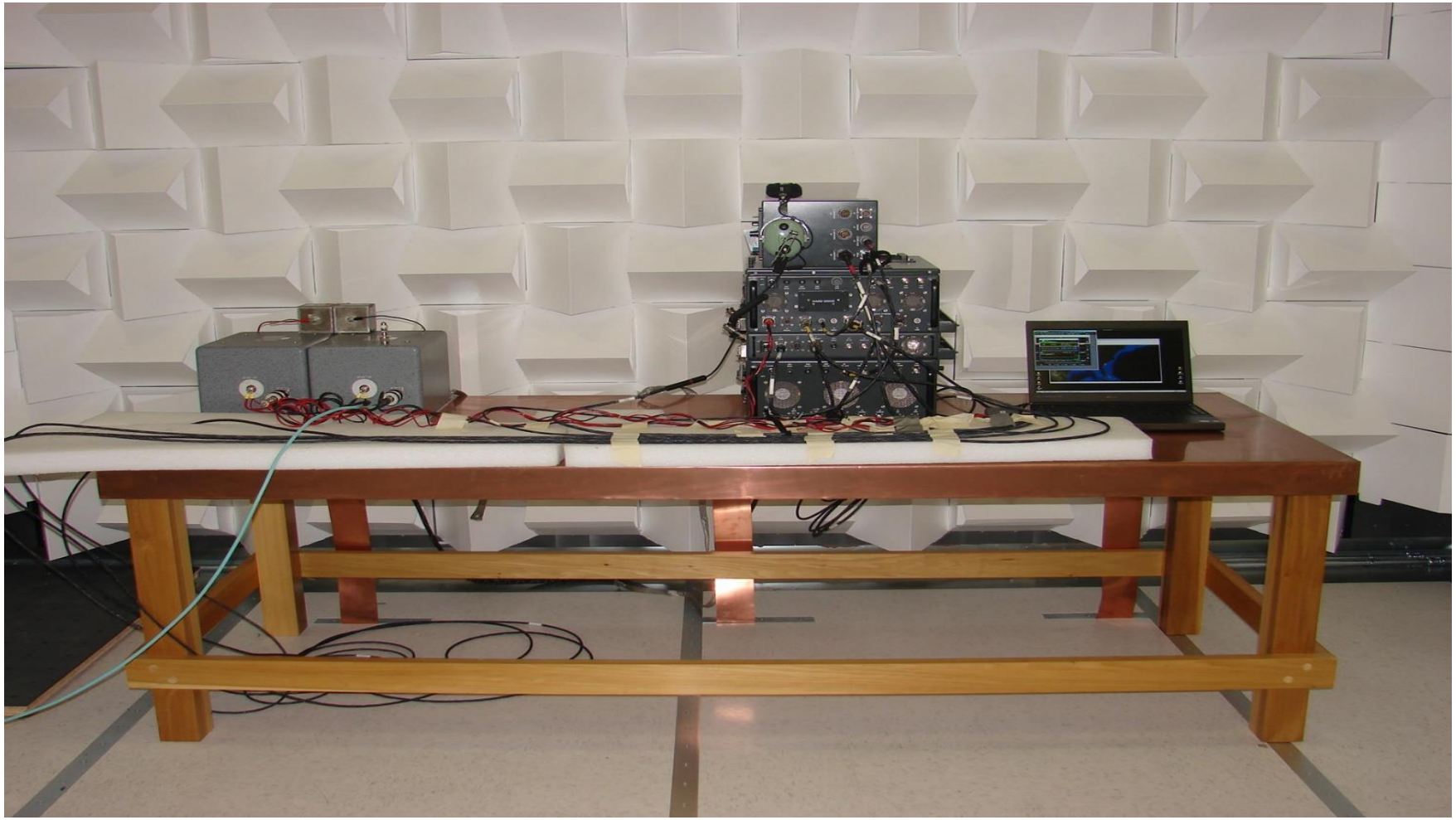


EUT Test Configurations

- **EUT Design Status**
  - Must be production representative including HW, SW and FW!!
- **Bonding of the 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.
  - Bonding of the EUT to the ground plane shall be verified to be in accordance with the installation drawings or equipment specification before connecting cables and EMI testing.
- **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.
- **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.
- **Orientation of the EUTs**
  - EUTs shall be oriented such that surfaces which produce maximum radiated emissions and respond most readily to radiated signals face the measurement antennas.

EUT Cables

Specific guidance on construction, length and arrangement of power and interconnecting leads and cables.



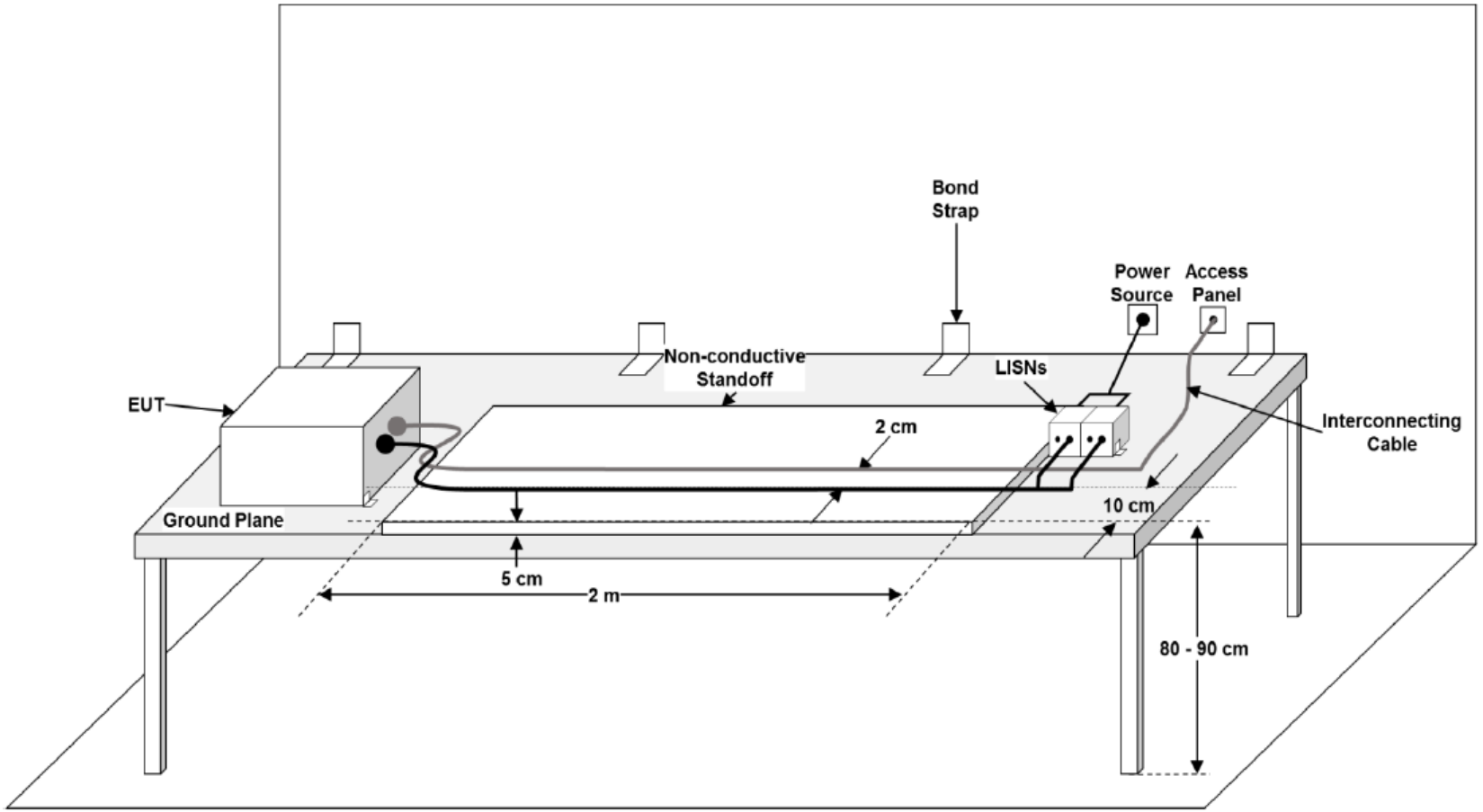
Cable construction and arrangements during testing are critical!

EUT Cables (cont)

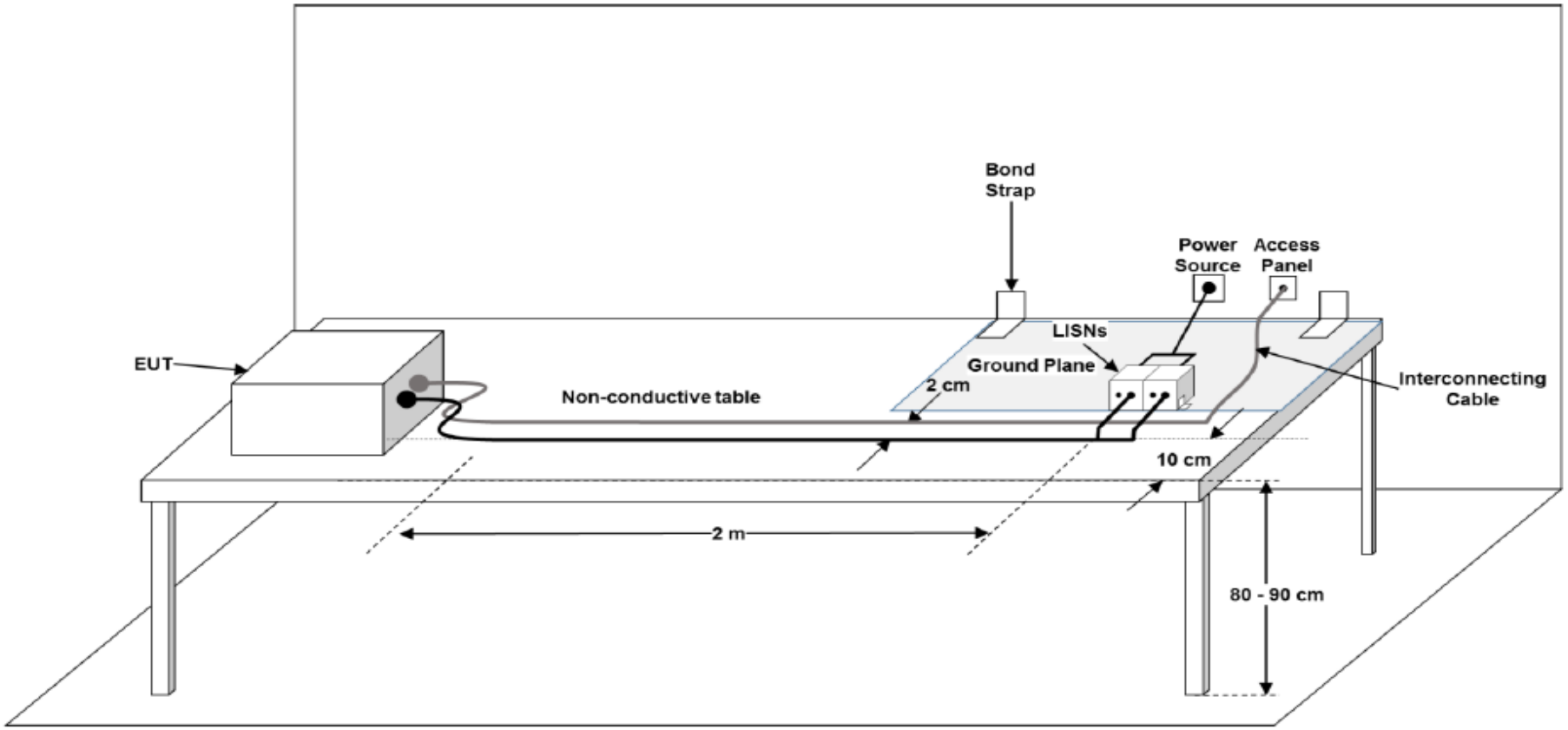
- **Must simulate actual installation and usage.**
- **Input (primary) power leads, returns, and wire grounds shall not be shielded.**
- **Interconnecting Leads and Cables**
  - Addresses length, routing, placement in the test setup etc…
  - 461G now addresses interconnecting cables for floor standing EUTs - Not addressed in 461F.
- **Input Power Leads**
  - Addresses length, routing, placement in the test setup etc…
  - 461G now addresses power cables for floor standing EUTs - Not addressed in 461F.
- **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 which simulate the electrical properties (impedance, grounding, balance, and so forth) present in the actual installation.

Cables shall be checked against installation requirements to verify proper construction.

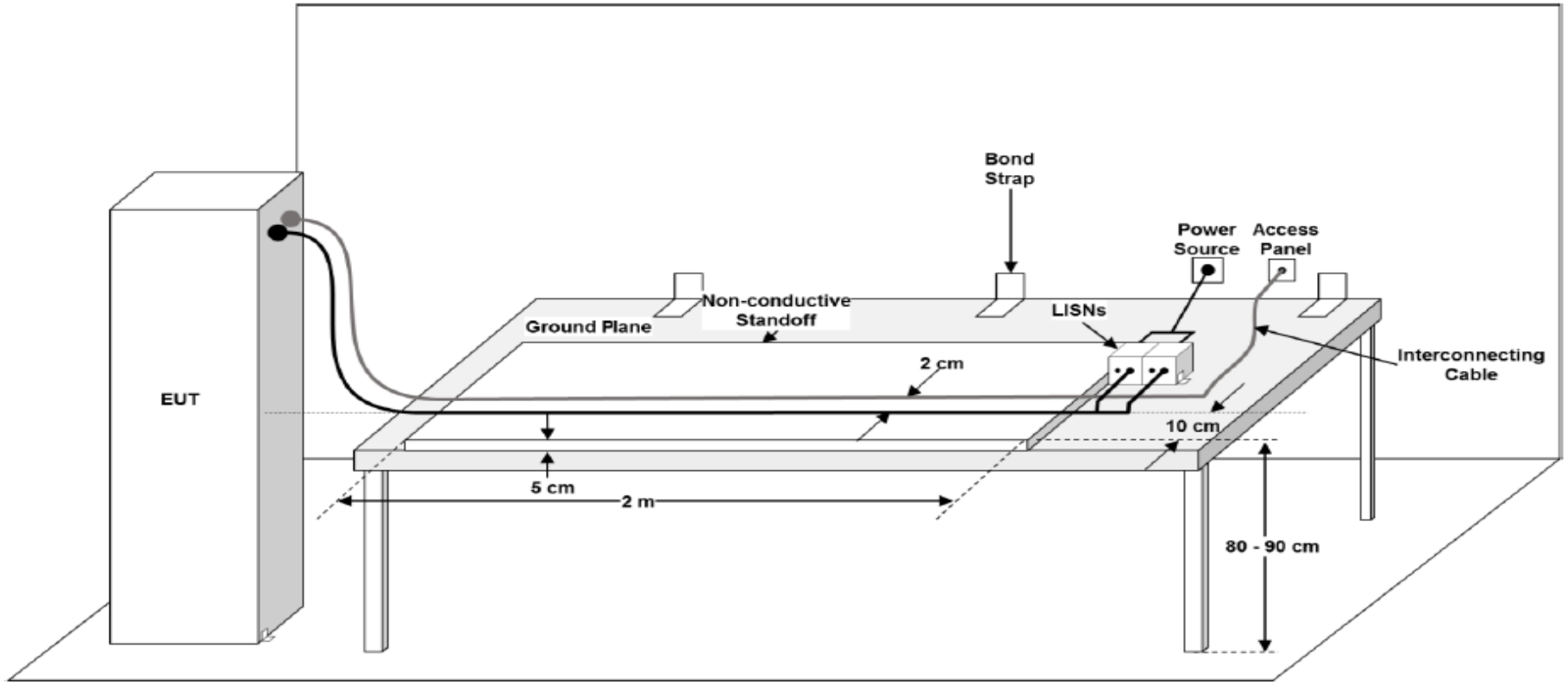
General Test Setup



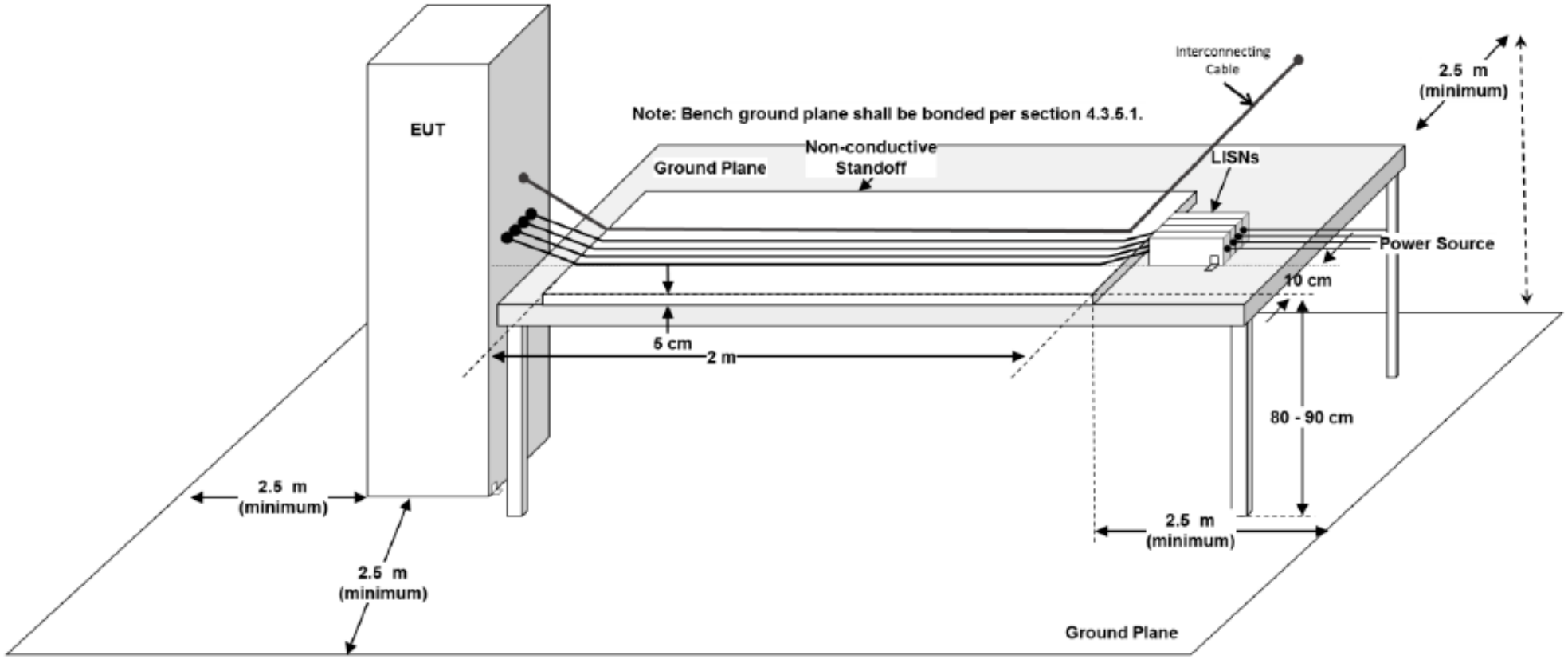
Non-Conductive Surface Mounted EUT



Free Standing – Shielded Enclosure



Free Standing – No Shielded Enclosure



Operation of the EUT

- **Operation of the EUT**
  - Operational modes for testing should be based on maximum emissions expected during emissions testing and most susceptible modes for susceptibility testing
  - Engineering judgement often needed to balance cost and technical aspects
- **Operating Frequencies for Tunable RF Equipment**
- **Operating Frequencies for Spread Spectrum Equipment**
  - Frequency Hopping and Direct Sequence
- **Susceptibility Monitoring**
  - BIT, visual display, test benches etc.

Combined Effort Between System and E3 Engineers

Use of Measurement Equipment

- **Detector**
  - A peak detector shall be used for all frequency domain emission and susceptibility measurements
- **Computer-Controlled Instrumentation**
  - SW controlled instrumentation must be documented in the EMITP. Including demonstration of proper performance. All SW documentation should be included in the EMITP (manufacturer, model, and revision).
  - **Locally developed SW must be validated and well documented.**

Configuration Management for ALL SW Should Be Maintained!

Emissions Testing

- **Specific guidance on emissions measurements**
  - Bandwidth
  - Measurement time
  - Step size based on frequency range
  - Sweep rates based on frequency range

Emissions Testing (cont.)

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

Step size is 1/2 of the 6 dB BW. For example:

Between 10 MHz and 30 MHz, the step size will be 1/2 of 10 kHz or 5 kHz

FFT Receiver Information

- **New for MIL-STD-461G**
  - FFT receivers time sample a portion of the frequency spectrum and use digital signal processing techniques to display frequency data in a manner similar to conventional spectrum analyzers.
  - FFT operation must be in accordance with ANSI C63.2, and Table II parameters must be directly addressable.
  - May be used to capture frequency agile signals.
  - Potential to saturate sooner than a conventional receiver at lower signal levels when detecting broadband signals (with respect to the receiver band-pass)
    - Due to the larger measurement FFT bandwidths used.
- **An additional concern exists (with any type of receiver) where low repetition rate signals can be totally missed if the dwell time is shorter than the pulse repetition interval of the emission. This can be remedied simply by increasing the FFT measurement dwell time, or with a traditional receiver, performing as per the note to Table II, which gives the same result, if enough time is taken.**

Susceptibility Testing

Specific guidance on measurement scan rates, sweep times, dwell time and step size based on frequency range.

Frequency Range	Analog Scans Maximum Scan Rates	Stepped Scans Maximum Step Size
30 Hz – 1 MHz	$0.0333f_0$/sec	$0.05\ f_0$
1 MHz – 30 MHz	$0.00667\ f_0$/sec	$0.01\ f_0$
30 MHz – 1 GHz	$0.00333f_0$/sec	$0.005\ f_0$
1 GHz – 40 GHz	$0.00167f_0$/sec	$0.0025\ f_0$

- **Susceptibility test signals for CS114 and RS103 shall be pulse modulated (on/off ratio of 40 dB minimum) at a 1 kHz rate with a 50% duty cycle. Modulation must be verified.**
- **Stepped scans shall dwell at each tuned frequency for the greater of 3 seconds or EUT response time.**
- **When susceptibility indications are noted in EUT operation, a threshold level shall be determined where the susceptible condition is no longer present.**

461G requires identification of the worst-case failure frequency

Equipment Calibration

- Section 4.3.11 only requires routine NIST traceable calibration for devices such as EMI receivers, spectrum analyzers, oscilloscopes, and electric field strength meters.
- Passive devices and even items like low noise preamplifiers and rod antenna electronics can be verified by the measurement system integrity check and the test facility can verify proper operation in accordance with SAE AIR 6236.
- “After the initial calibration, passive devices such as measurement antennas, current probes, and LISNs, require no further formal calibration unless the device is repaired. The measurement system integrity check in the procedures is sufficient to determine acceptability of passive devices.”

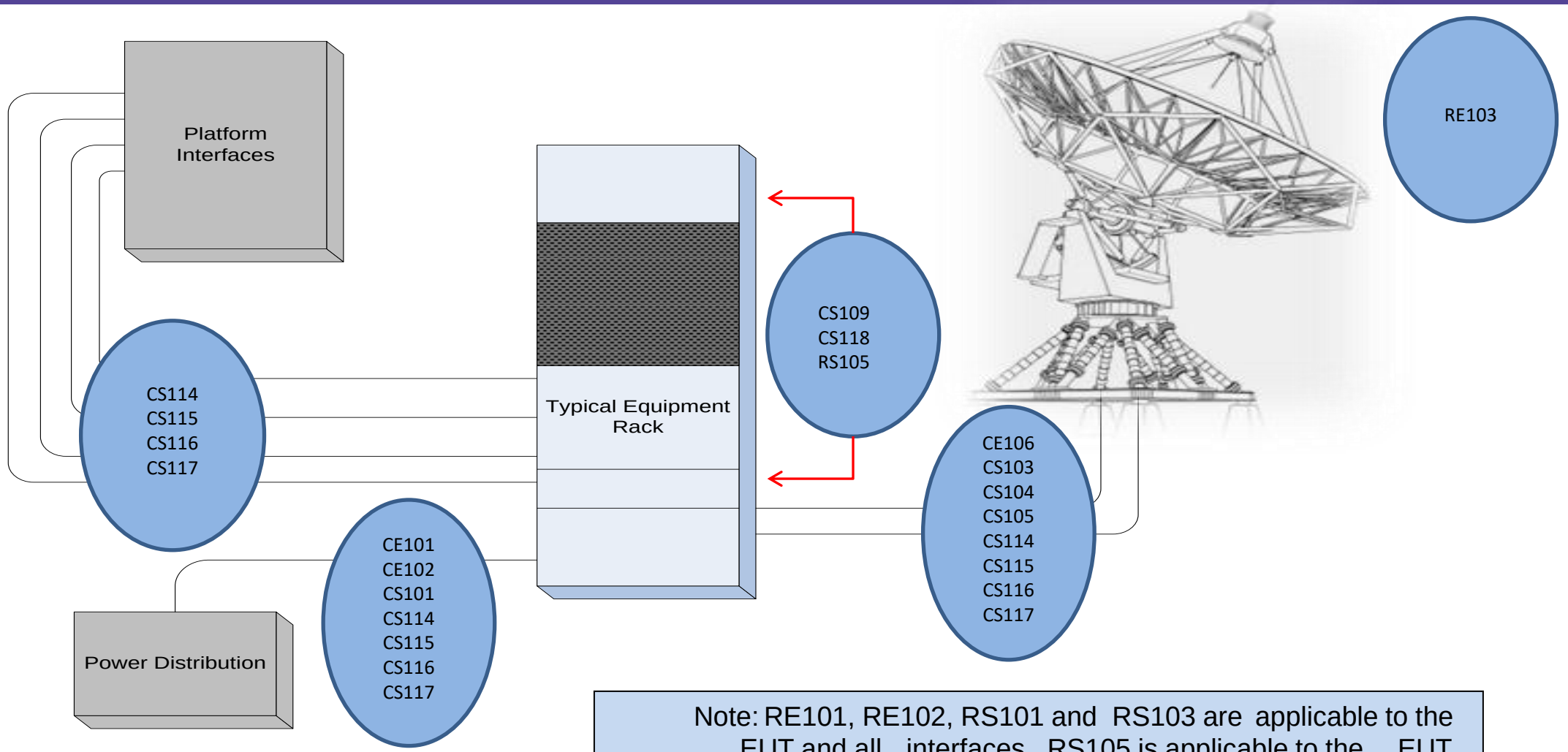
Detailed Requirements

- Conducted Emissions
- Conducted Susceptibility
- Radiated Emissions
- Radiated Susceptibility

Requirements

Requirement	Description
CE101	Conducted Emissions, Audio Frequency Currents, Power Leads
CE102	Conducted Emissions, Radio Frequency Potentials, Power Leads
CE106	Conducted Emissions, Antenna Port
CS101	Conducted Susceptibility, Power Leads
CS103	Conducted Susceptibility, Antenna Port, Intermodulation
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation
CS106	**Conducted Susceptibility, Transients, Power Leads - REMOVED**
CS109	Conducted Susceptibility, Structure Current
CS114	Conducted Susceptibility, Bulk Cable Injection
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads
CS117	**Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads**
CS118	**Conducted Susceptibility, Personnel Borne Electrostatic Discharge**
RE101	Radiated Emissions, Magnetic Field
RE102	Radiated Emissions, Electric Field
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs
RS101	Radiated Susceptibility, Magnetic Field
RS103	Radiated Susceptibility, Electric Field
RS105	Radiated Susceptibility, Transient Electromagnetic Field

Equipment Applicability



Note: RE101, RE102, RS101 and RS103 are applicable to the EUT and all interfaces. RS105 is applicable to the EUT enclosure only.

Application Specific

Equipment and Subsystems Installed In, On, or Launched From the Following Platforms or Installations	Requirement Applicability																		
	CE101	CE102	CE106	CS101	CS103	CS104	CS105	CS109	CS114	CS115	CS116	CS117	CS118	RE101	RE102	RE103	RS101	RS103	RS105
Surface Ships	A	A	L	A	S	L	S	L	A	S	A	L	S	A	A	L	L	A	L
Submarines	A	A	L	A	S	L	S	L	A	S	L	S	S	A	A	L	L	A	L
Aircraft, Army, Including Flight Line	A	A	L	A	S	S	S		A	A	A	L	A	A	A	L	A	A	L
Aircraft, Navy	L	A	L	A	S	S	S		A	A	A	L	A	L	A	L	L	A	L
Aircraft, Air Force		A	L	A	S	S	S		A	A	A	L	A		A	L		A	
Space Systems, Including Launch Vehicles		A	L	A	S	S	S		A	A	A	L			A	L		A	
Ground, Army		A	L	A	S	S	S		A	A	A	S	A		A	L	L	A	
Ground, Navy		A	L	A	S	S	S		A	A	A	S	A		A	L	L	A	L
Ground, Air Force		A	L	A	S	S	S		A	A	A		A		A	L		A	

A Applicable

L Limited as specified in the individual sections of this standard

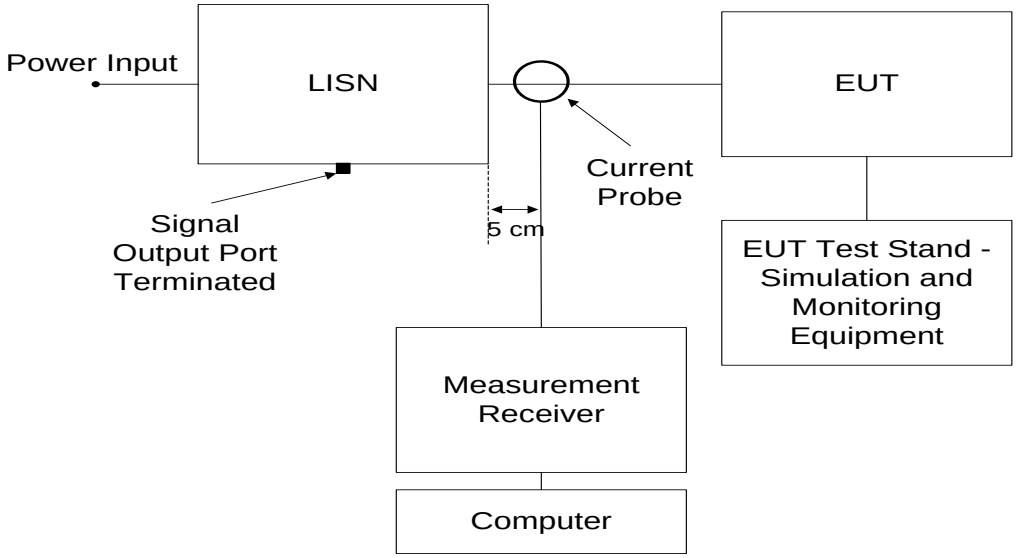
S Procuring activity must specify in procurement documentation

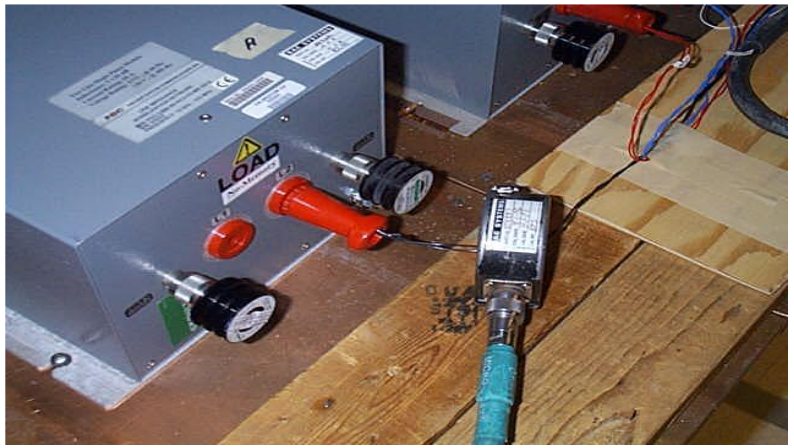
Detailed Requirements

- **Conducted Emissions, Audio Frequency Currents, Power Leads - CE101**

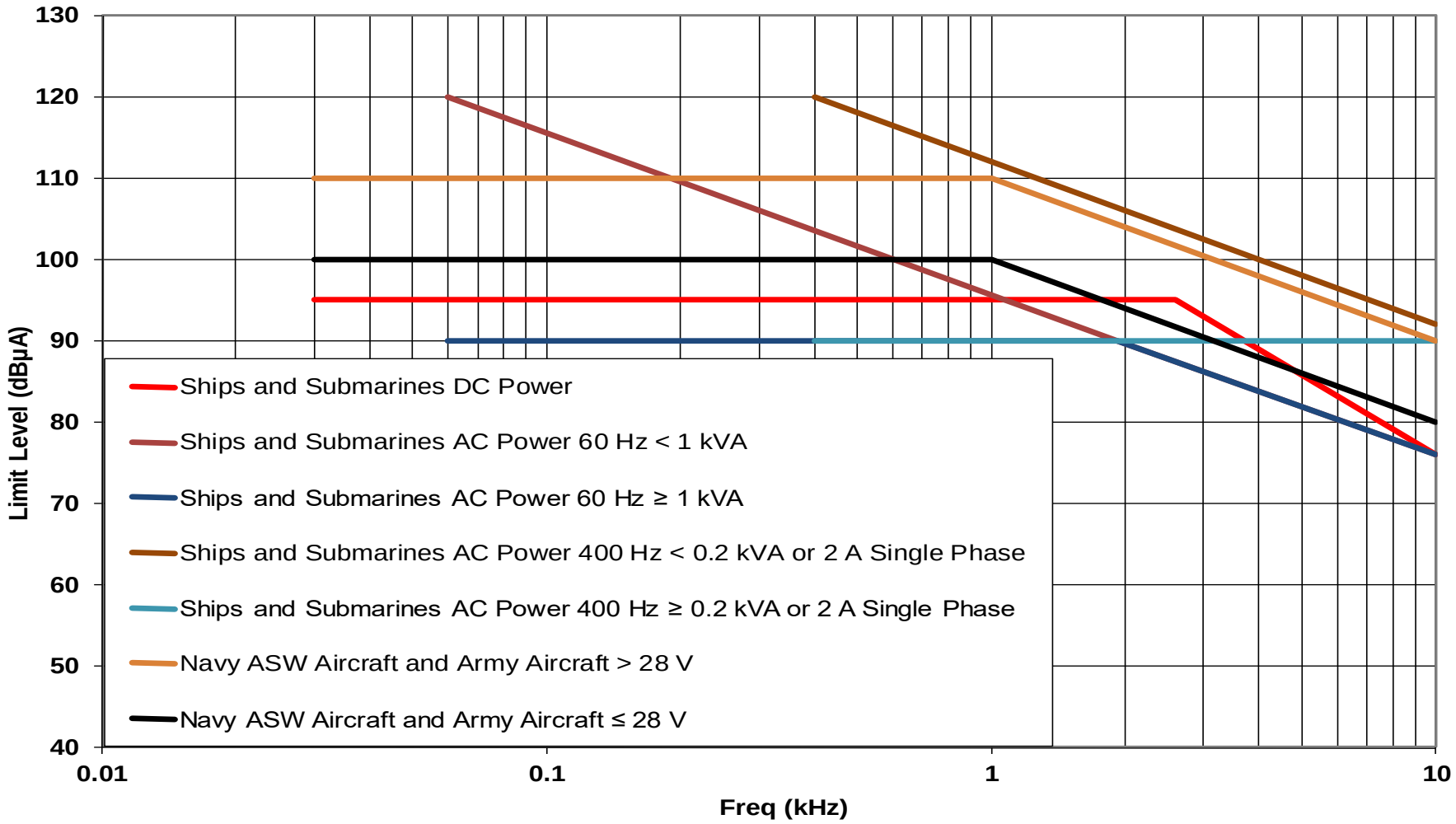
CE101

- Applicable to leads that obtain power from sources that are not part of the EUT from 30 Hz to 10 kHz. There is no requirement on output leads from power sources.
- Emission levels are determined by measuring the current present on each power lead.
- For surface ships and submarines, the intent is to control the effects of conducted emissions peculiar to the shipboard power distribution system.
- For Army aircraft, the concern is to ensure that the EUT does not corrupt the power quality on platform power buses
- Navy aircraft applicable for installations using anti-submarine warfare (ASW) equipment which operate between 30 Hz and 10 kHz.



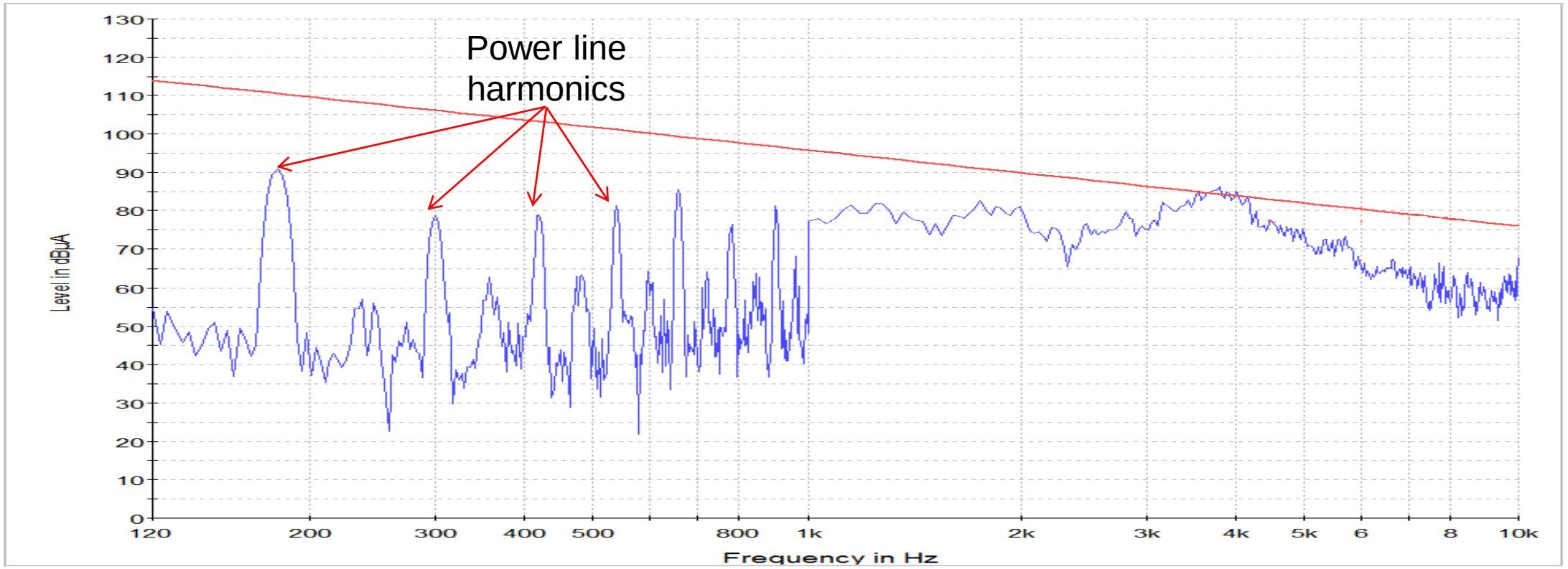


CE101 Limits



Limits based on application, input voltage, frequency, power and current.

CE101 Sample Data



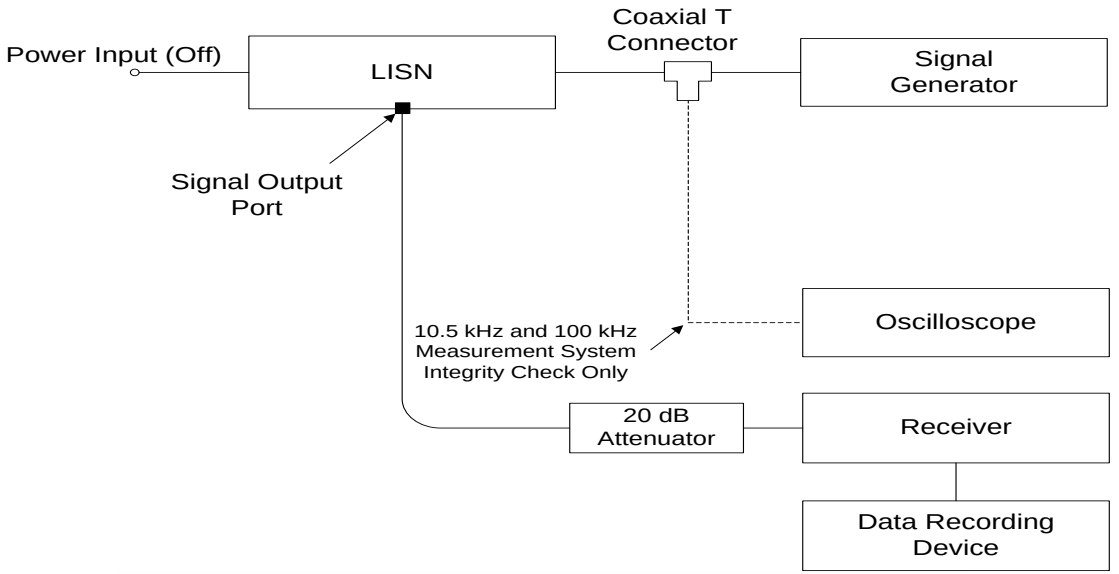
One common problem area is rectifier noise at power line harmonic frequencies.

Detailed Requirements

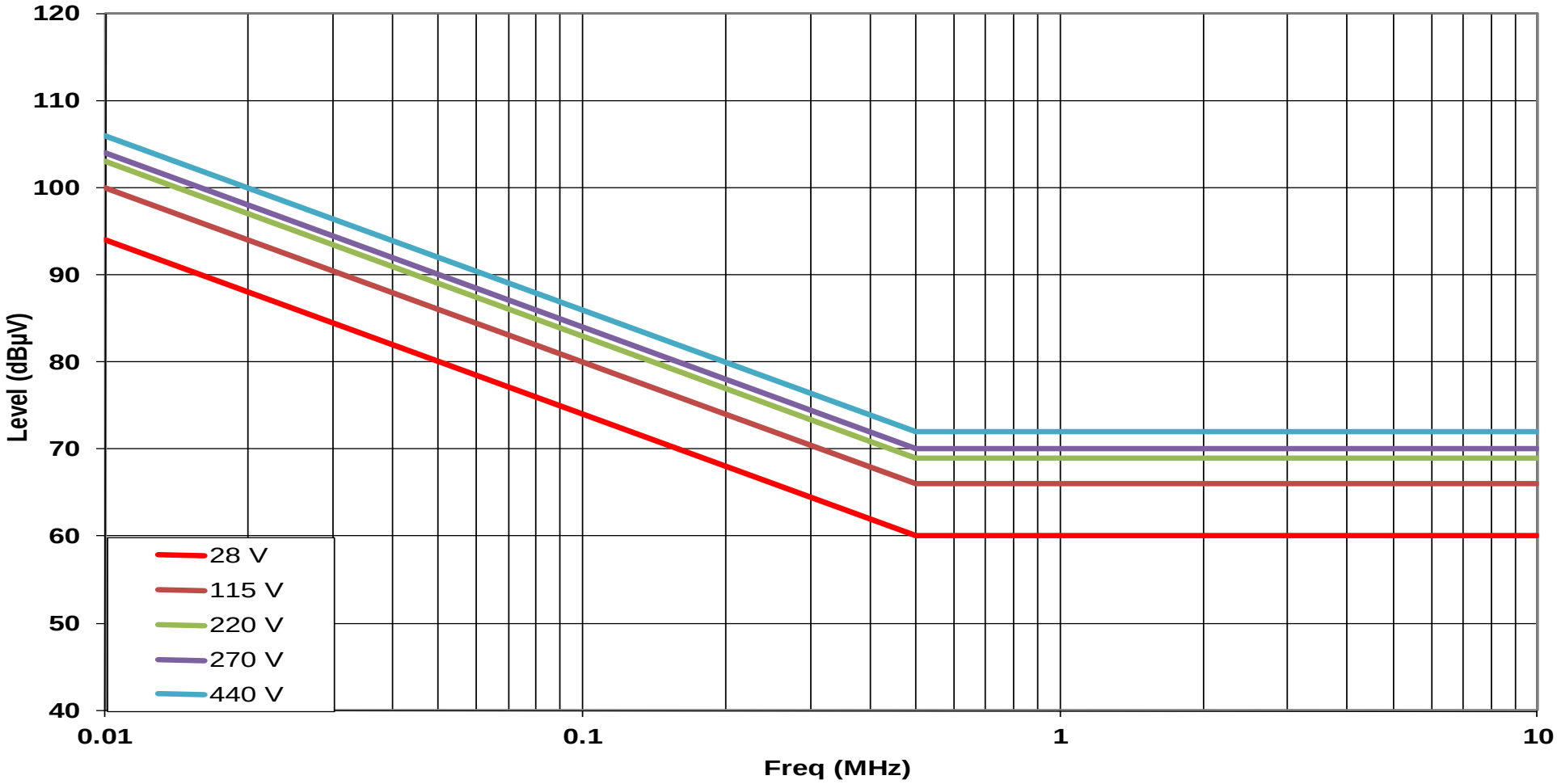
- **Conducted Emissions, Radio Frequency Potential, Power Leads - CE102**

CE102

- The requirements are applicable to leads that obtain power from sources that are not part of the EUT from 10 kHz to 10 MHz. There is no requirement on output leads from power sources.
- Lower frequency portion is to ensure EUT does not corrupt the power quality (allowable voltage distortion) on platform power buses.
- Voltage distortion is the basis for power quality so CE102 limit is in terms of voltage.
- Emission levels determined by measuring voltage present at the signal output port of the LISN.

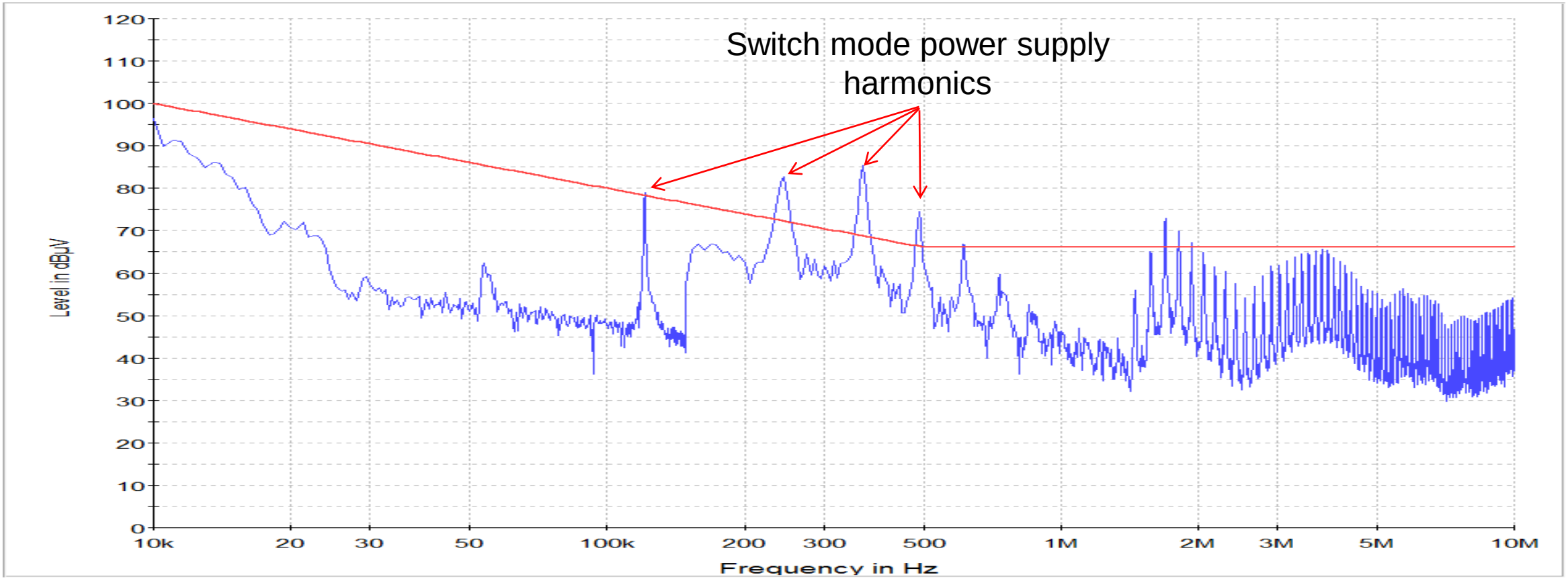


CE102 Limits



Limits based on input voltage only

CE102 Sample Data



Common problems include switching regulators and harmonics.

Detailed Requirements

- **Conducted Emissions, Antenna Port - CE106**

CE106

- **CE106 is applicable to the antenna terminals of transmitters, receivers, and amplifiers to protect receivers on and off the platform from being degraded by antenna radiation from the EUT.**
- **Not applicable for permanently mounted antennas.**
- **For Navy shipboard applications with peak transmitter power greater than 1 kW, the 5% frequency exclusion will be increased by an additional 0.1% of the fundamental frequency for each dB above 1 kW of peak power.**
- **Frequency Exclusion = ± f (0.05 + (0.001/dB)(P_{tPk} [dBm] – 60 [dBm]))**
- **Upper Test Frequency:**
  - For systems with the frequencies < 1 GHz, the upper frequency limit will be 20 times the highest frequency or 18 GHz whichever is greater. For systems with frequencies ≥ 1 GHz, the upper frequency limit will be 10 times the highest frequency or 40 GHz whichever is less. For equipment using waveguide, the requirement does not apply below eight-tenths of the waveguide's cutoff frequency.

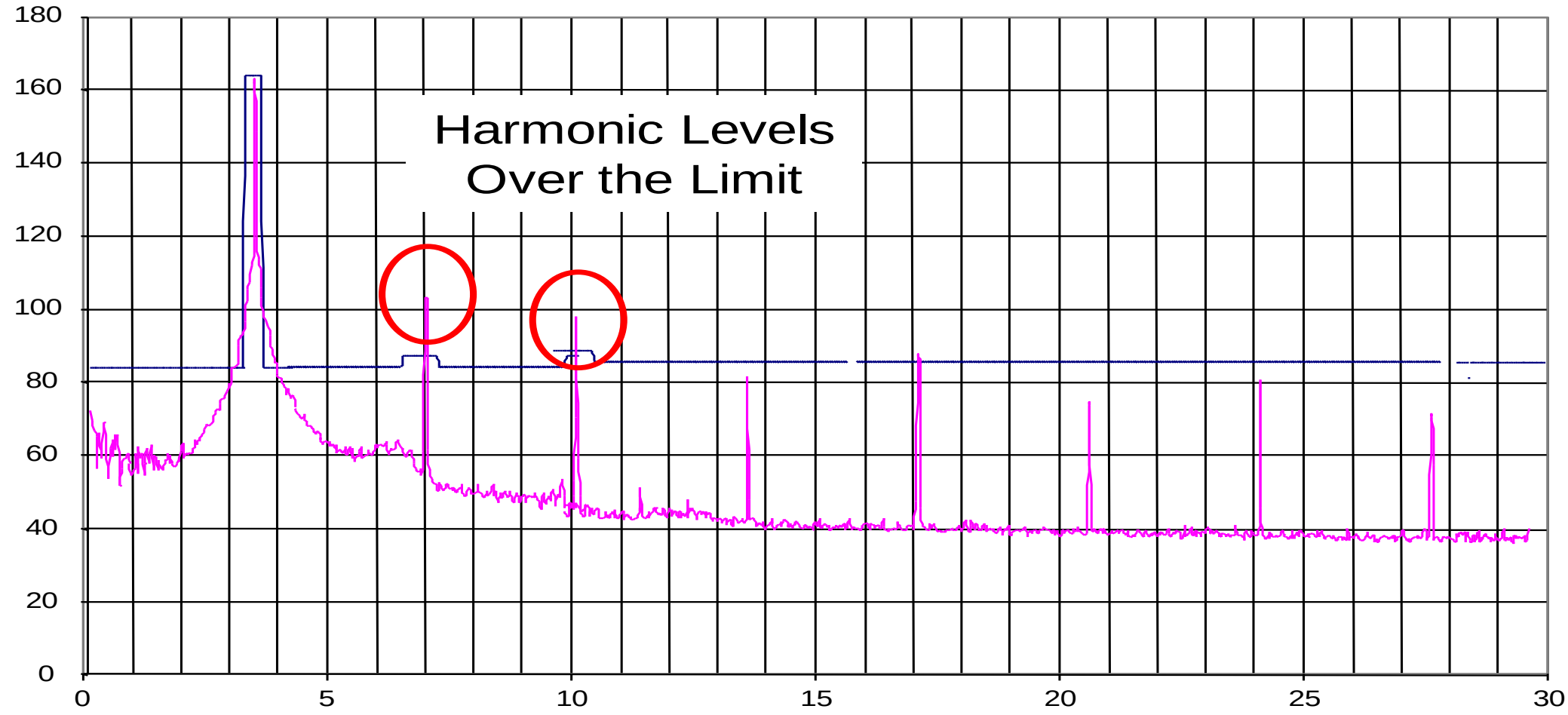
Suppression to meet requirements can result in significant design penalties.

CE106 Limits

- **Receivers:**
  - 34 dBµV
- **Transmitters and amplifiers (standby mode):**
  - 34 dBµV
- **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 to a level of -20 dBm or 80 dB below the fundamental, whichever requires less suppression. For Navy shipboard applications, the second and third harmonics will be suppressed to a level of -20 dBm and all other harmonics and spurious emissions shall be suppressed to -40 dBm, except if the duty cycle of the emissions are less than 0.2%, then the limit may be relaxed to 0 dBm.
- **Tailoring of this requirement and limits may be needed… Consider a broadband jammer**
- **Test setup varies with EUT.**

CE106 limits for transmit mode operation may disagree with the system performance specification!

CE106 Sample Data



Harmonic levels from high power transmitters are hard to suppress.

CE106 – More Thoughts

- **Transmitter modulation and amplifier frequency, input power, and modulation influences the results and thus worst-case emission spectrum must be used with the most complicated modulation.**
- **Non-removable antennas**
  - RE103 for transmitters
  - 461F allowed for verification using RE102 for receive and standby modes for permanently mounted antennas.
    - Not allowed in 461G
- **CE106 requirements for transmitters often disagree with system performance specifications.**
  - Often driven by subsystem requirements
  - Current state of the art technology
  - COTS

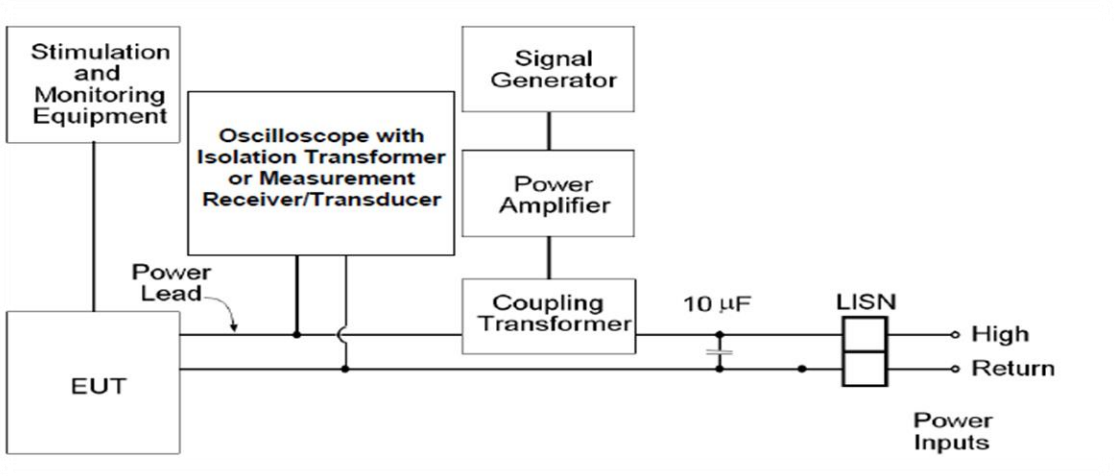
Harmonic and spurious requirements usually not located in the E3 sections of performance specifications!

Detailed Requirements

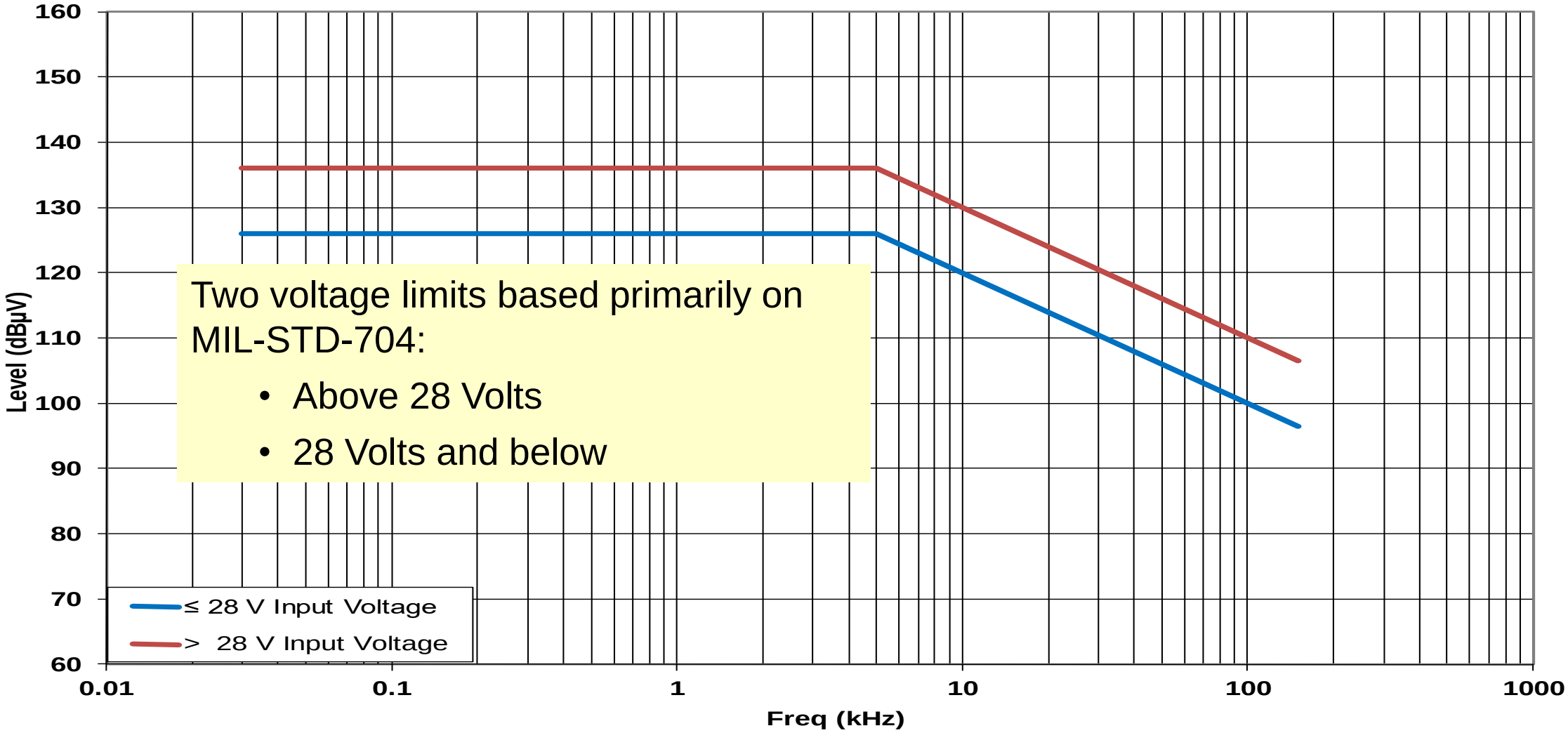
- **Conducted Susceptibility, Power Leads - CS101**

CS101

- Applicable to equipment and subsystem AC, limited to current draws ≤ 30 amperes per phase, and DC input power leads, not including returns.
- Applicable for current draws > 30 amperes for operating frequencies < 150 kHz and sensitivity < 1 µV.
- If the EUT is DC operated, requirement applicable over frequency range 30 Hz to 150 kHz.
- If the EUT is AC operated, requirement is applicable from the second harmonic of the EUT power frequency and extending to 150 kHz.
- Ensures that performance is not degraded from ripple voltages on power source waveforms.



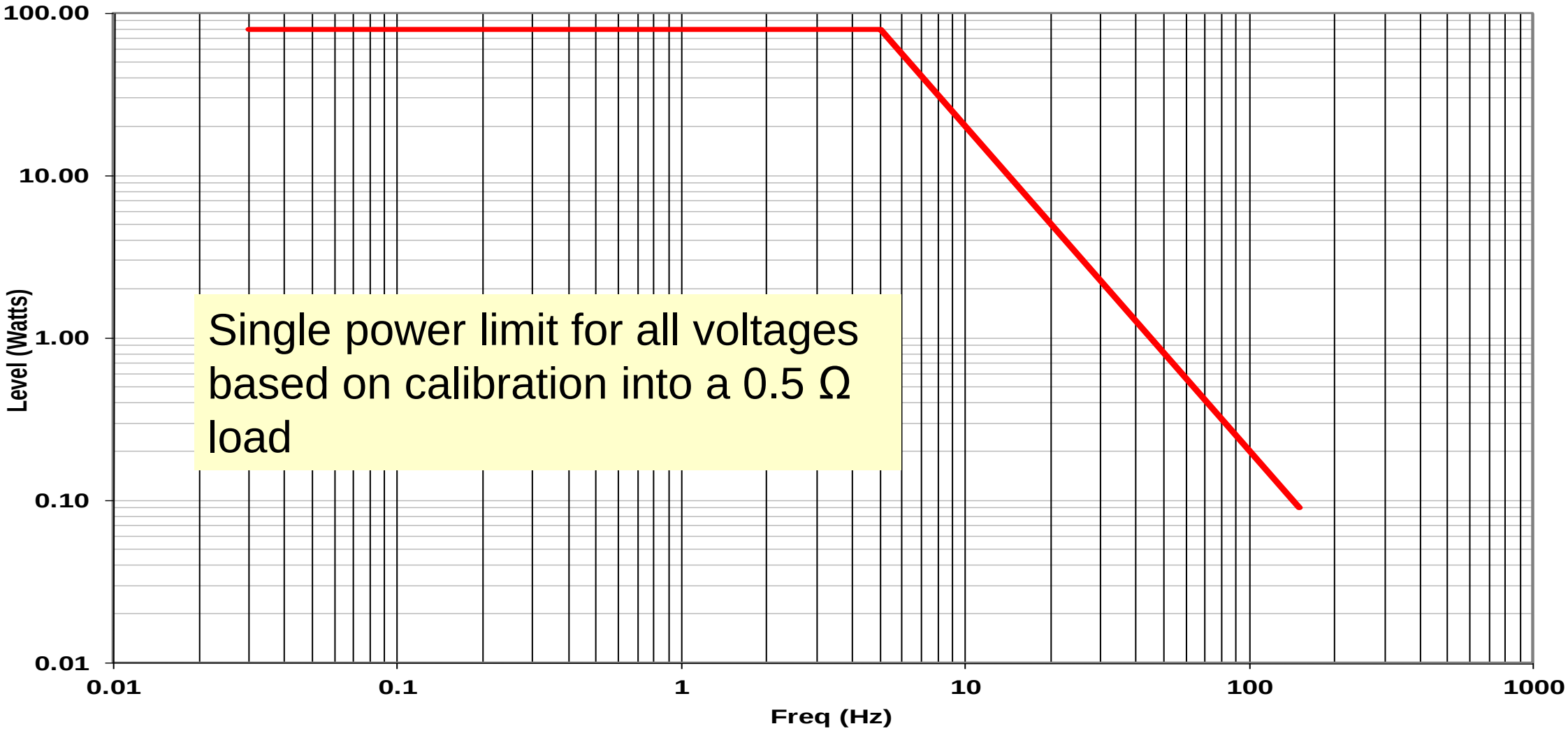
CS101 Limits



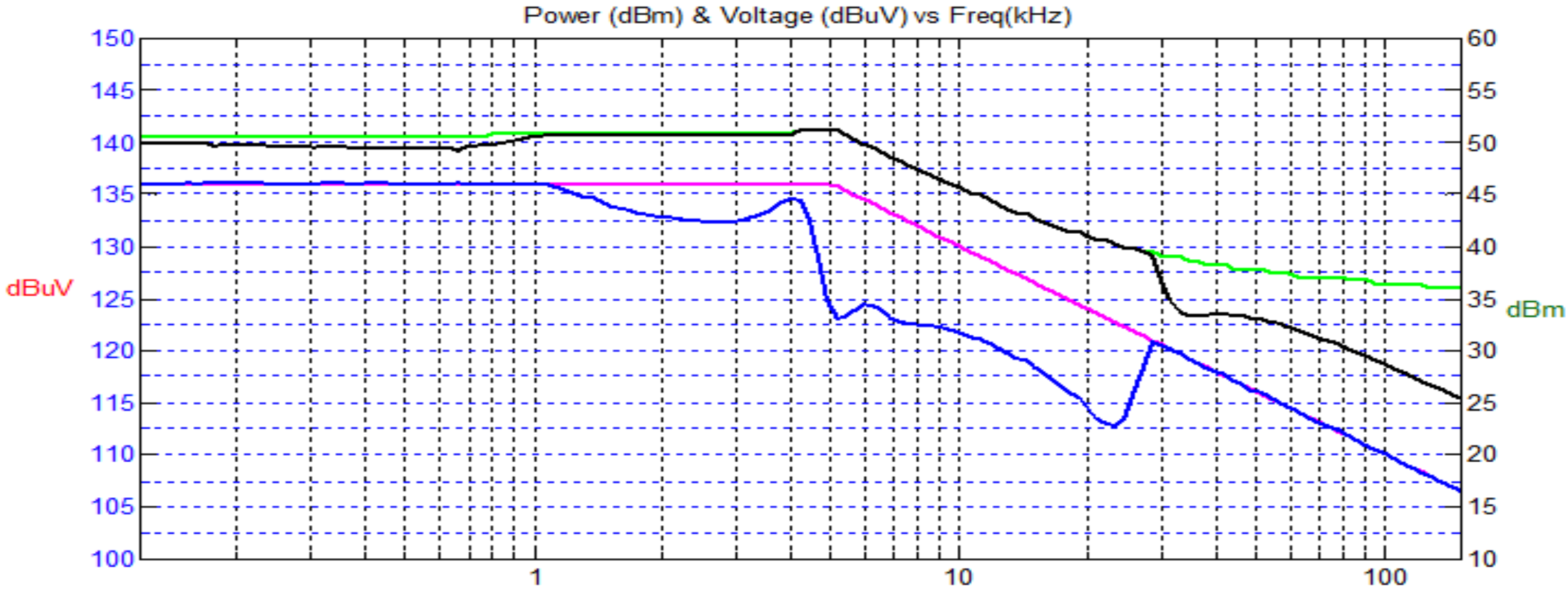
Two voltage limits based primarily on MIL-STD-704:

- Above 28 Volts
- 28 Volts and below

CS101 Limits



CS101 Sample Data



Voltage Limit

Test Voltage

Power Limit

Test Power

Detailed Requirements

- **Conducted Susceptibility, Antenna Port**
  - **Intermodulation - CS103**
  - **Rejection of Undesired Signals - CS104**
  - **Cross-modulation - CS105**

Receiver Front End Tests

CS103 - Intermodulation

CS104 - Rejection of Undesired Signals

CS105 - Cross Modulation

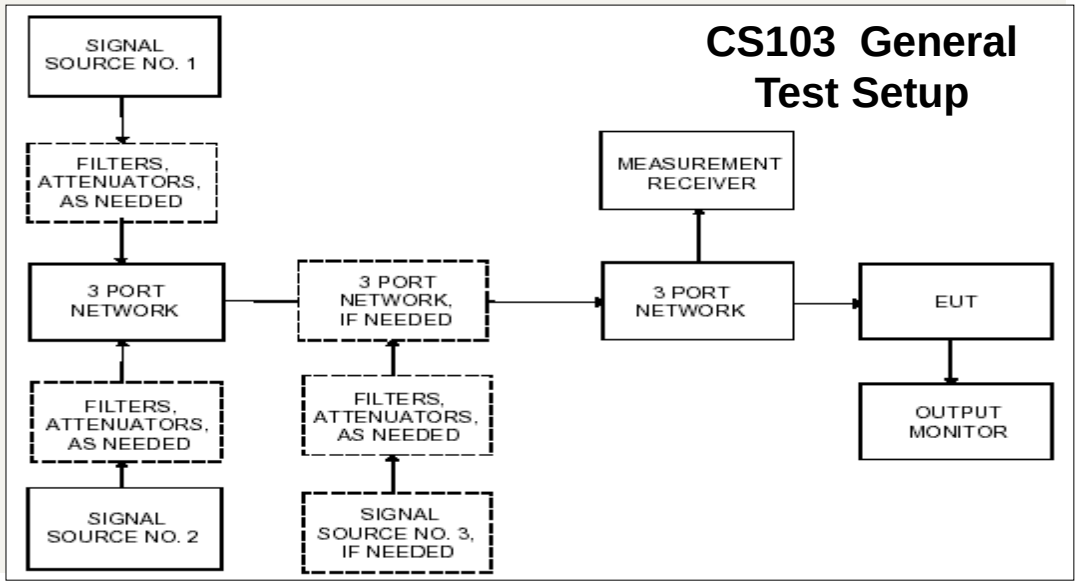
- **No real guidance given in 461G**
- **Originally based on superheterodyne systems**
- **Should be based on system performance specs**
- **Each system is unique**
  - Frequency Range
  - Amplitude
  - Modulation
  - Test Setups
- **Proper evaluation will require a combined engineering effort between E3**

Allow significant time and funding to plan and execute!

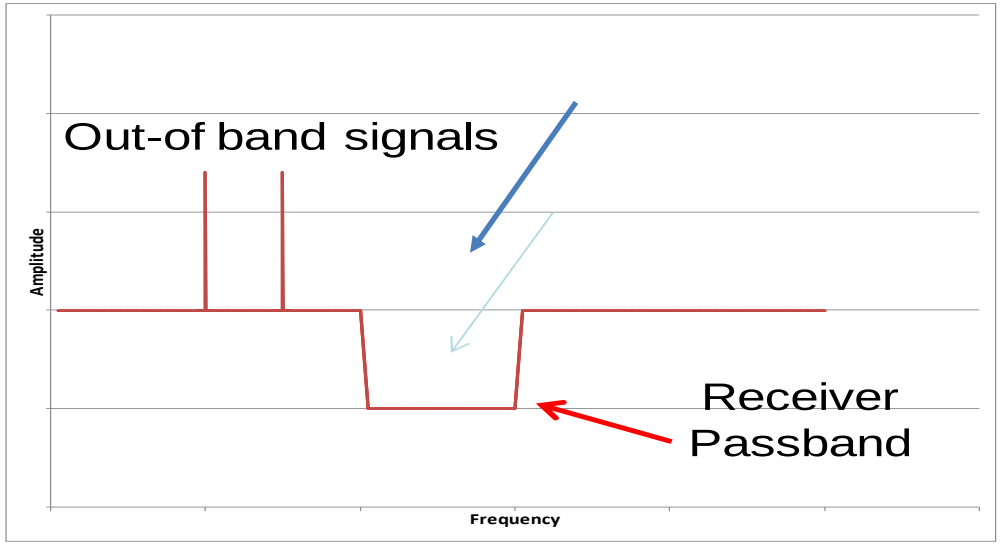
CS103

Intent 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.

Most applicable to fixed frequency, tunable, superheterodyne receivers.



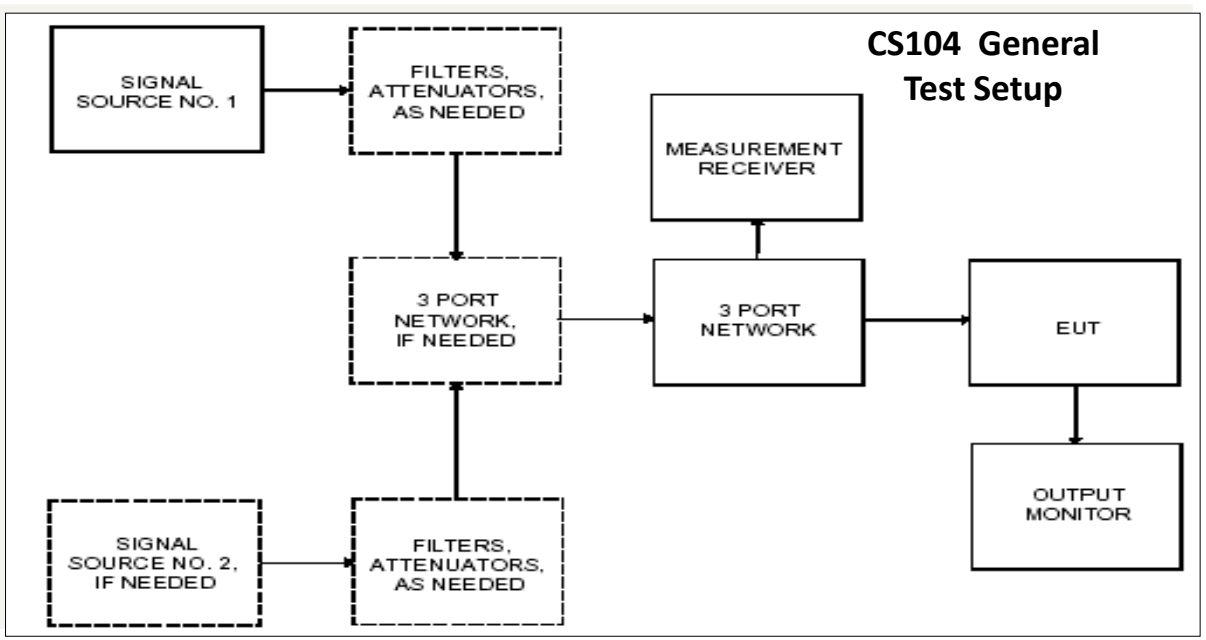
The basic concept is to combine two out-of-band signals (one modulated and one CW) and apply to the antenna port of receiver while monitoring it for an undesired response.



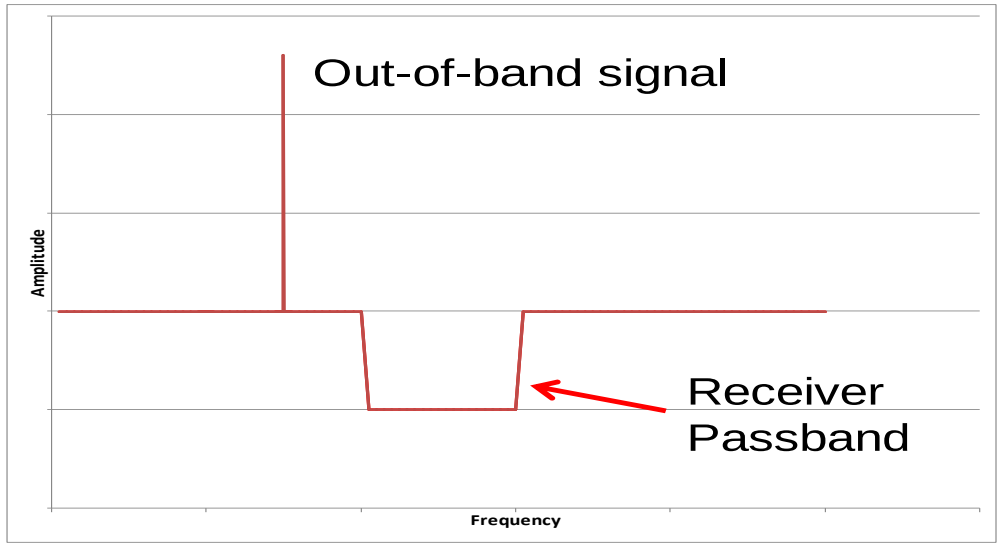
CS104

Intent of CS104 is to control response of antenna connected receiving subsystems to signals outside intentional passband of the subsystem.

Most applicable to fixed frequency, tunable, superheterodyne receivers.



The basic concept is to apply out-of-band signals to the antenna port of the receiver while monitoring the receiver for degradation.

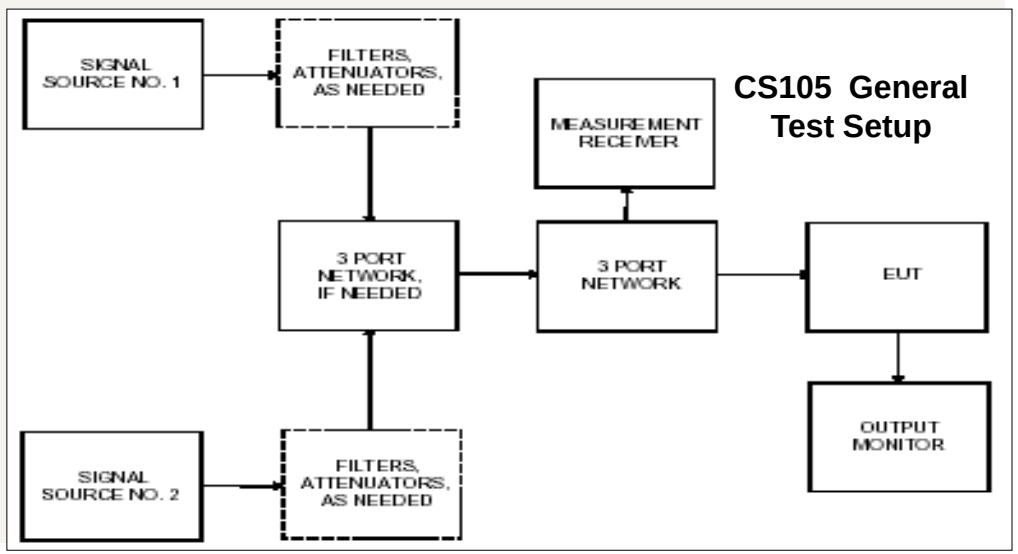


CS105

Intent 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.

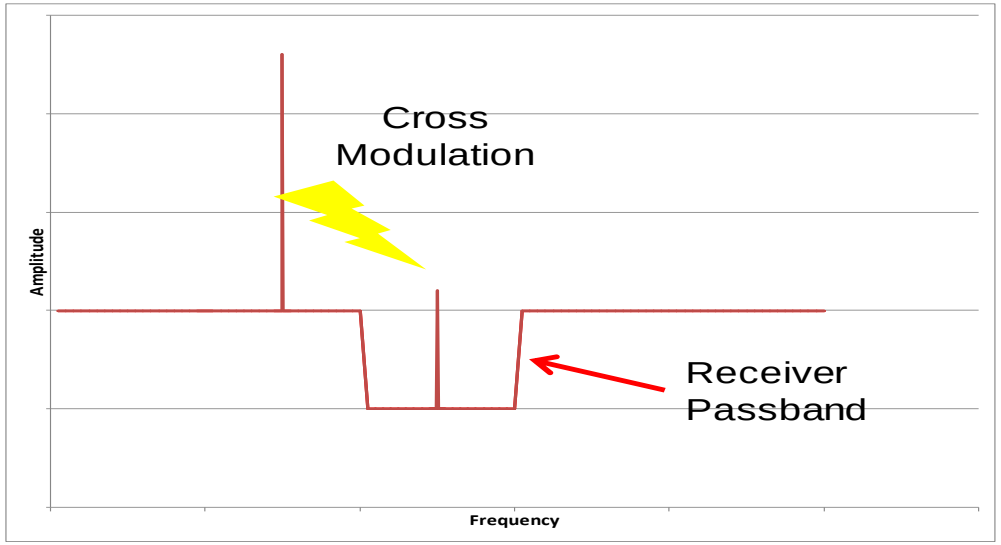
Results from a strong, out-of-band signal near the operating frequency of the receiver.

Should be considered only for receivers, transceivers, amplifiers, and the like, which extract information from the amplitude modulation of a carrier.



CS105 General Test Setup

The basic concept of 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.

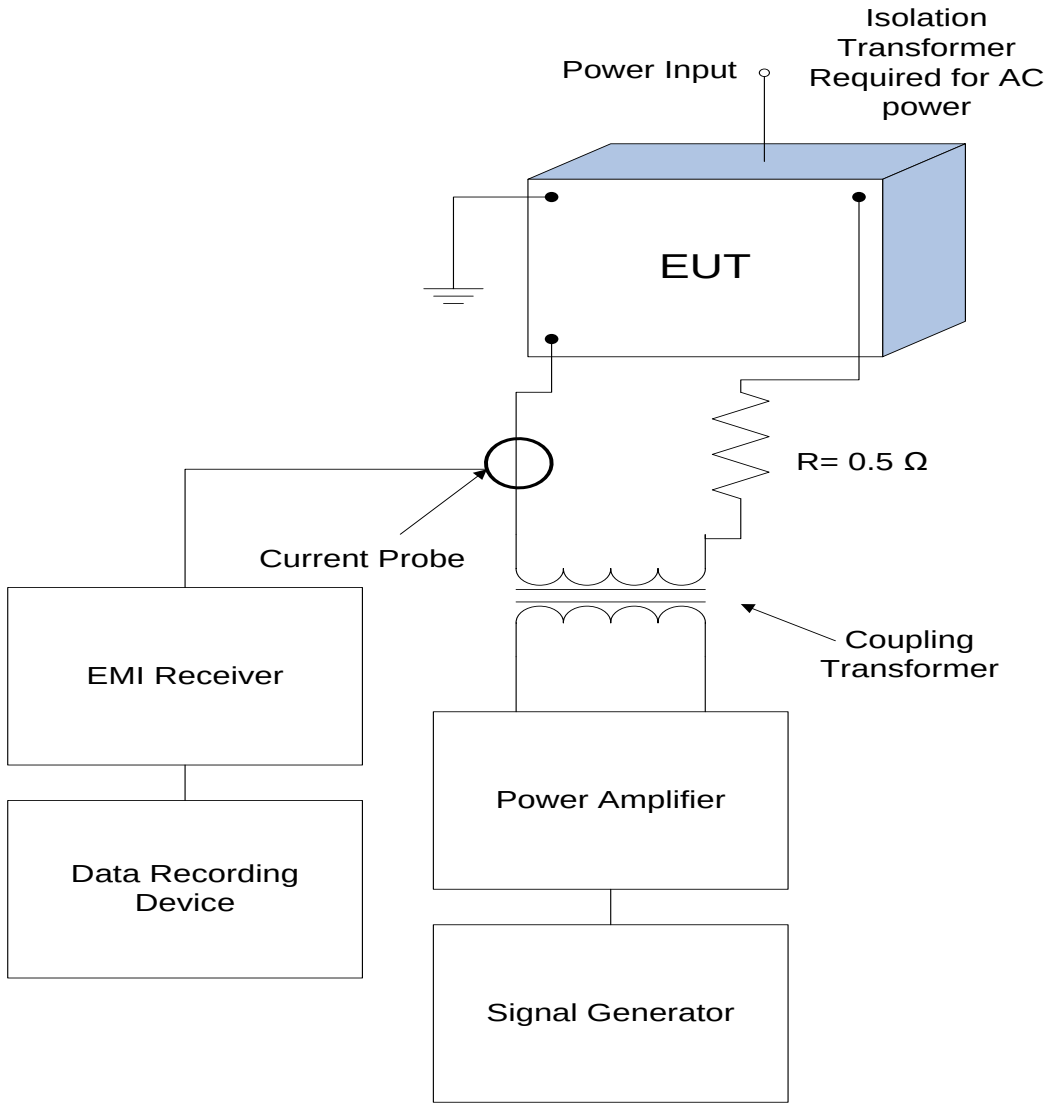


Detailed Requirements

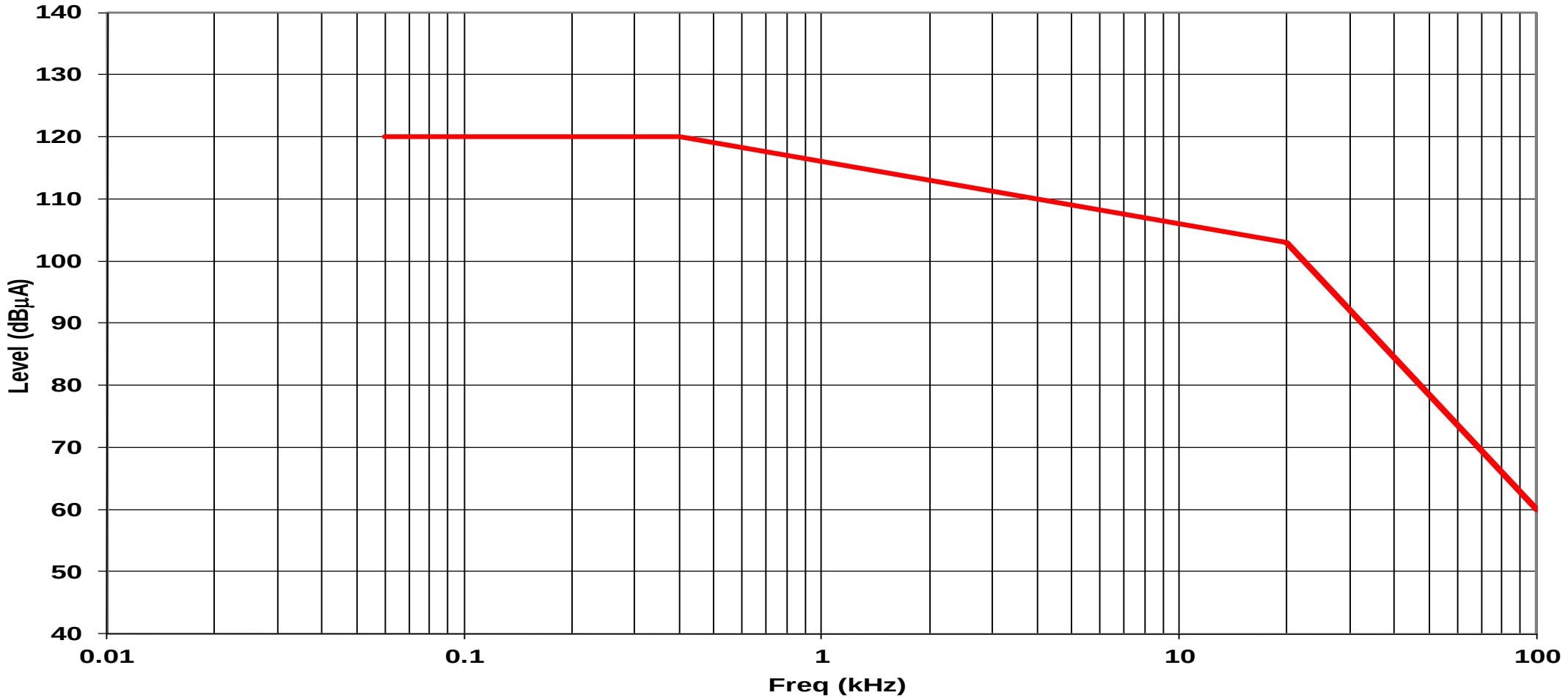
- **Conducted Susceptibility, Structure Current - CS109**

CS109

- Specialized test intended for very sensitive equipment (1 uV or better) such as tuned receivers operating over the frequency range of the test.
- Handheld equipment is exempt.
- Intent is to ensure that equipment does not respond to magnetic fields caused by currents flowing in platform structure.
- A current is imposed across the surface of the EUT to verify its ability to withstand structure currents.



CS109 Limit



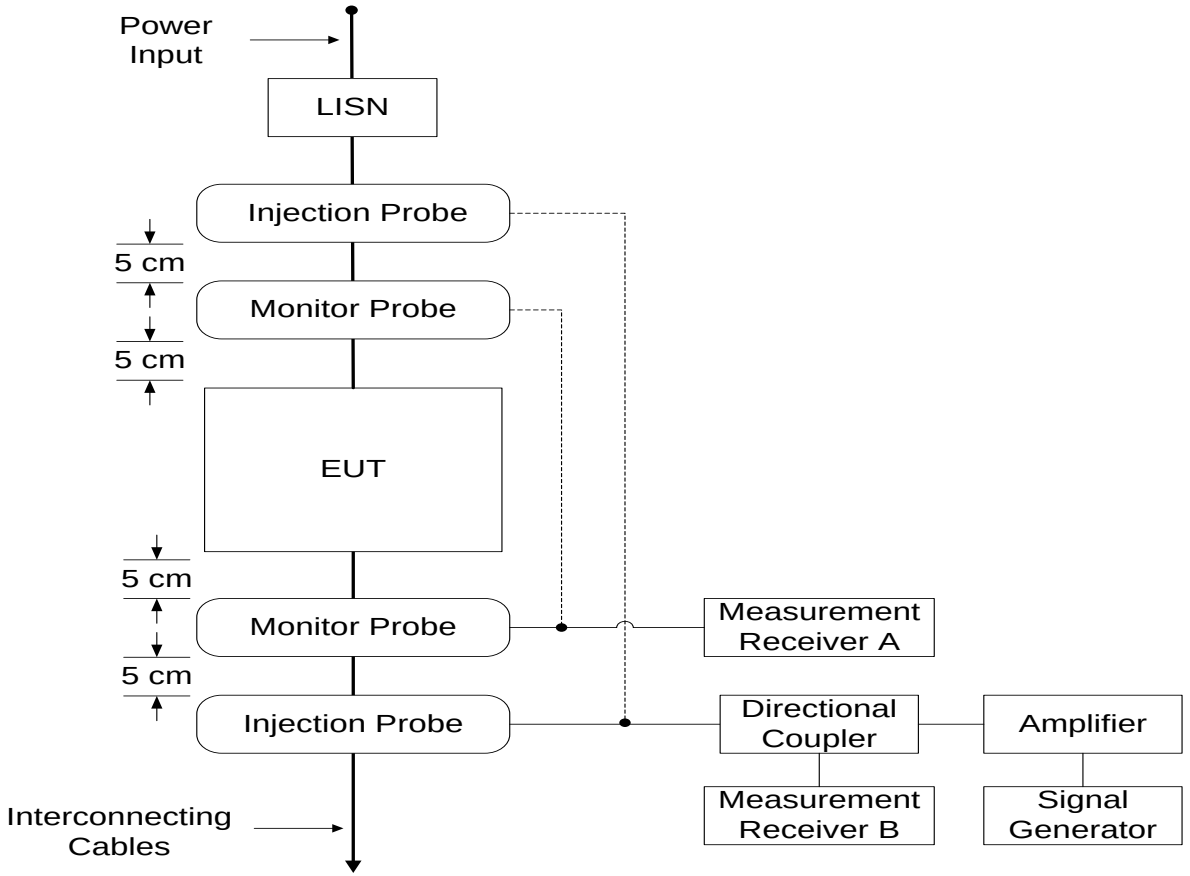
The limit is derived from operational problems due to current conducted on equipment cabinets and laboratory measurements of response characteristics of selected receivers.

Detailed Requirements

- **Conducted Susceptibility, Bulk Cable Injection - CS114**

CS114

- Applicable to all electrical cables interfacing with the EUT enclosures from 10 kHz to 200 MHz.
- Concept is to simulate currents developed on platform cabling from electromagnetic fields generated by antenna transmissions both on and off the platform.
- Aircraft carrier hangar deck EME test data from 9 aircraft carriers showed significant HF electric field levels are present.
- Not applicable for coaxial cables to antenna ports of antenna-connected receivers except for surface ships and submarines.

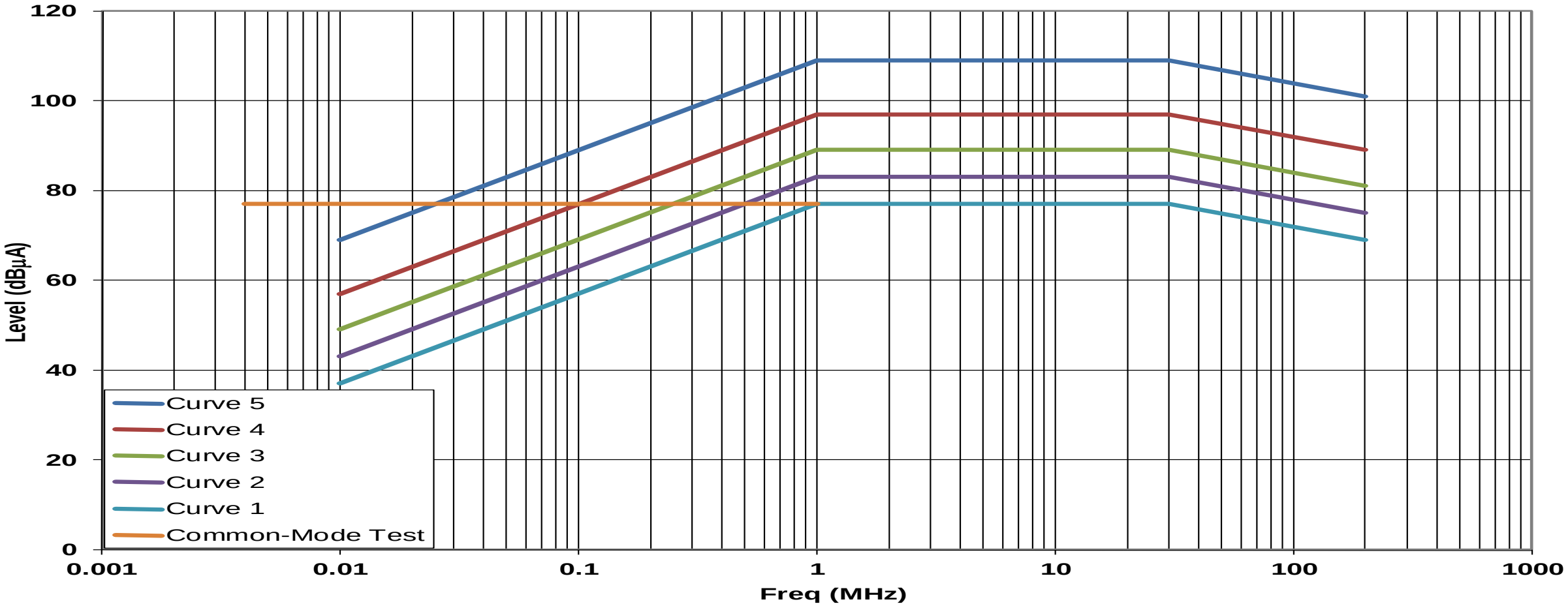


CS114 Applications

Frequency Range-	Platform	A/C (Ext. Or Safety Critical)	A/C Int.	All Ships (Above Decks) & Exposed Below Decks And Submarines (External) *	Ships (Metallic) (Below Decks)	Ships (Non-Metallic) (Below Decks) **	Submarine (Internal)	Ground	Space
4 kHz To 1 MHz	Navy	-	-	77 dBµA	77 dBµA	77 dBµA	77 dBµA	-	-
10 kHz To 2 MHz	Army	5	5	2	2	2	1	3	3
	Navy	5	3	2	2	2	1	2	3
	Air Force	5	3	-	-	-	-	2	3
2 MHz To 30 MHz	Army	5	5	5	2	4	1	4	3
	Navy	5	5	5	2	4	1	2	3
	Air Force	5	3	-	-	-	-	2	3
30 MHz To 200 MHz	Army	5	5	5	2	2	2	4	3
	Navy	5	5	5	2	2	2	2	3
	Air Force	5	3	-	-	-	-	2	3

* For equipment located external to the pressure hull of a submarine but within the superstructure, use Ships (Metallic) (Below Decks)
** For equipment located in the hanger deck of Aircraft Carriers

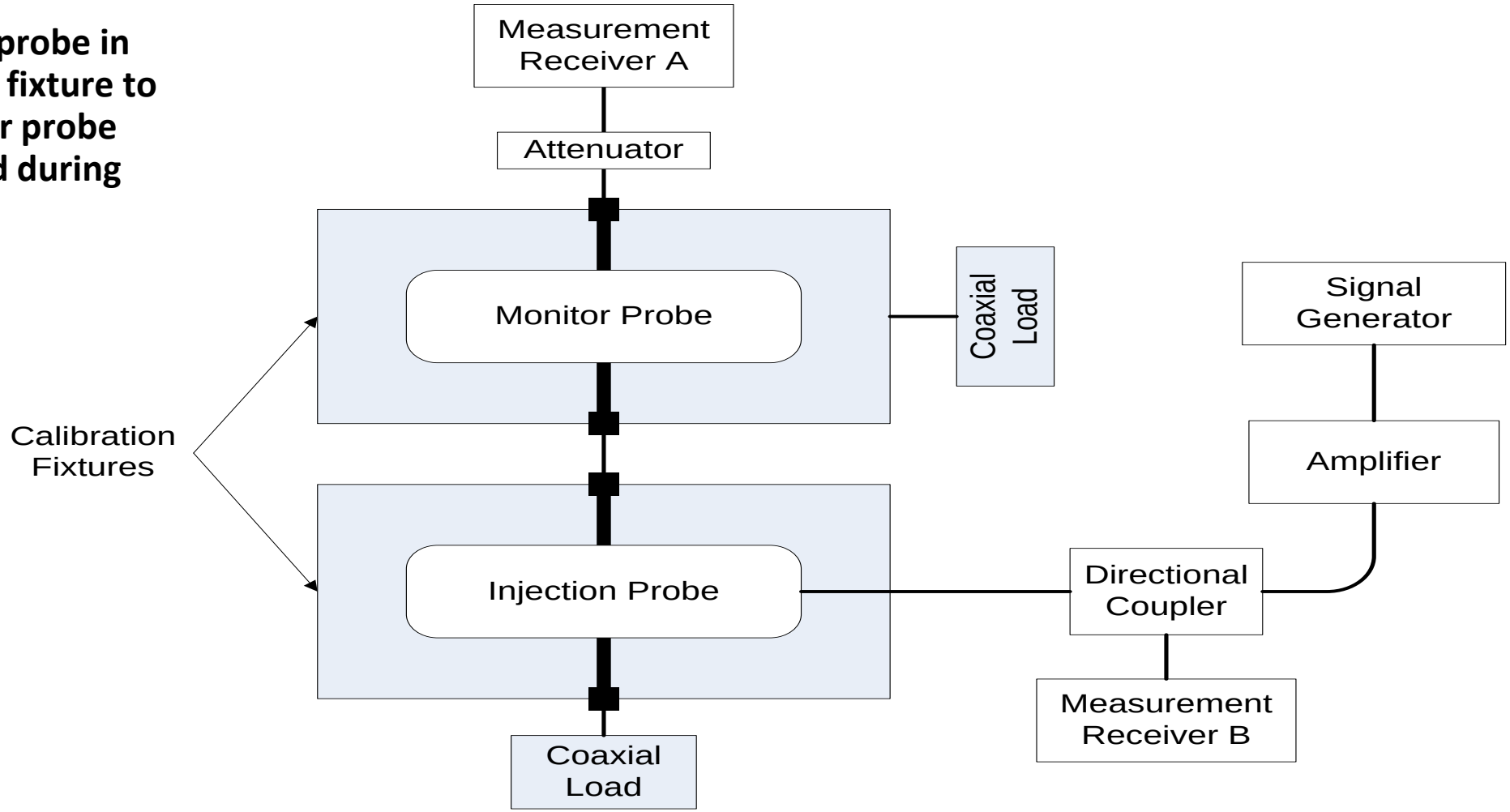
CS114 Calibration Limits



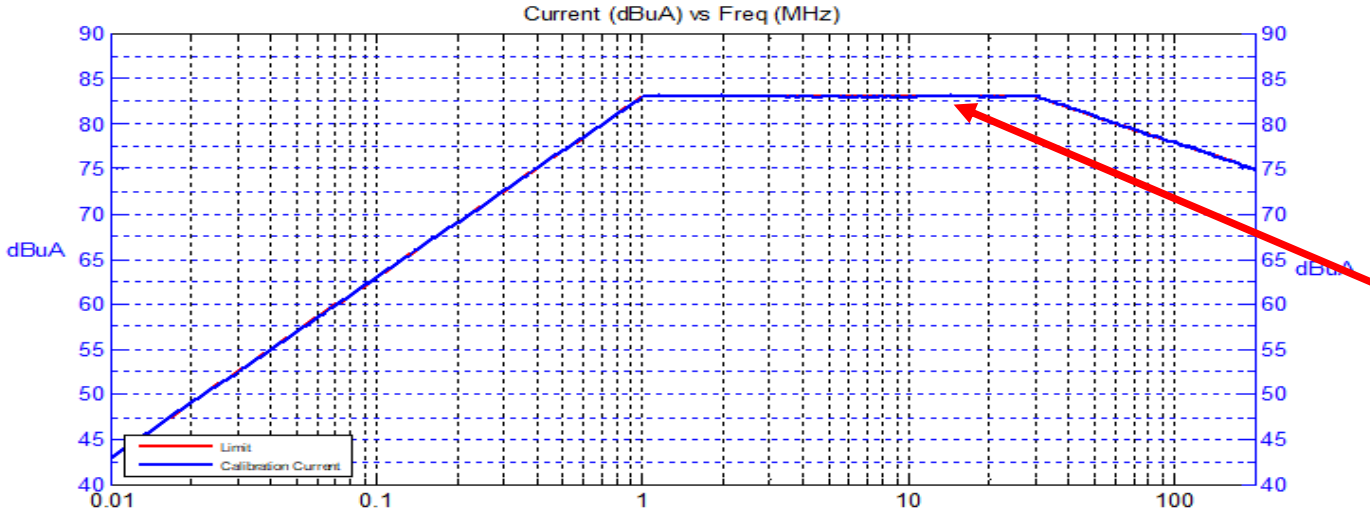
Multiple limits based on application
Common mode power line limit for ships and submarines only.

CS114 – Calibration

Calibrate with the monitor probe in place within the calibration fixture to compensate for the monitor probe loading effects encountered during EUT testing.

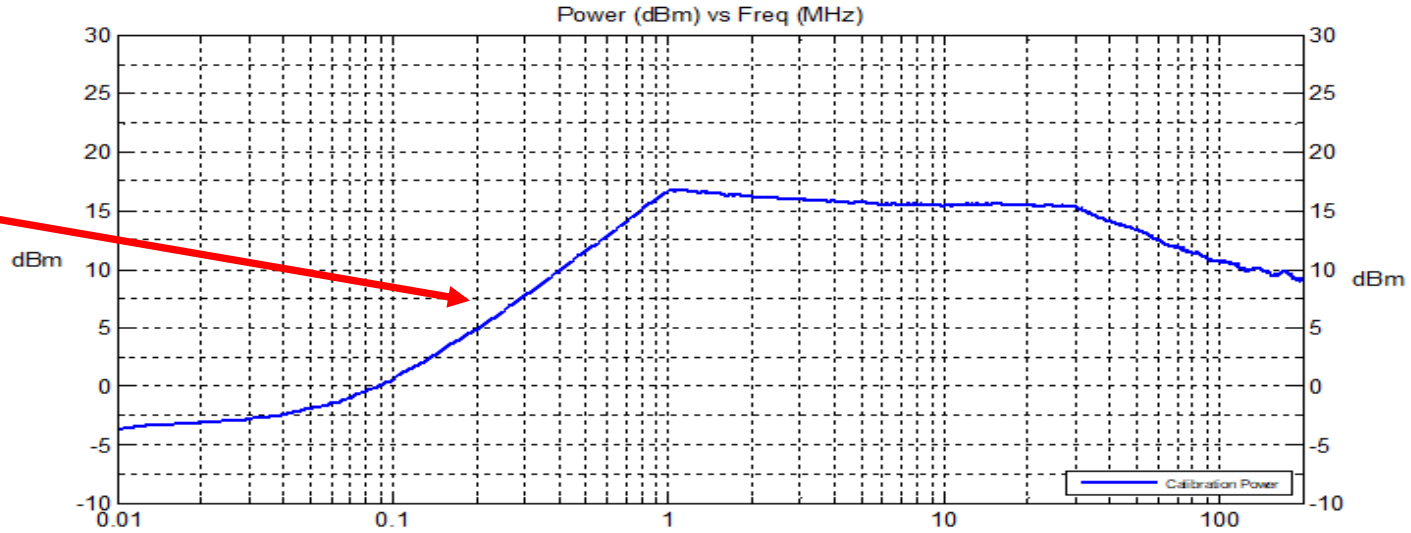


CS114 – Calibration Data

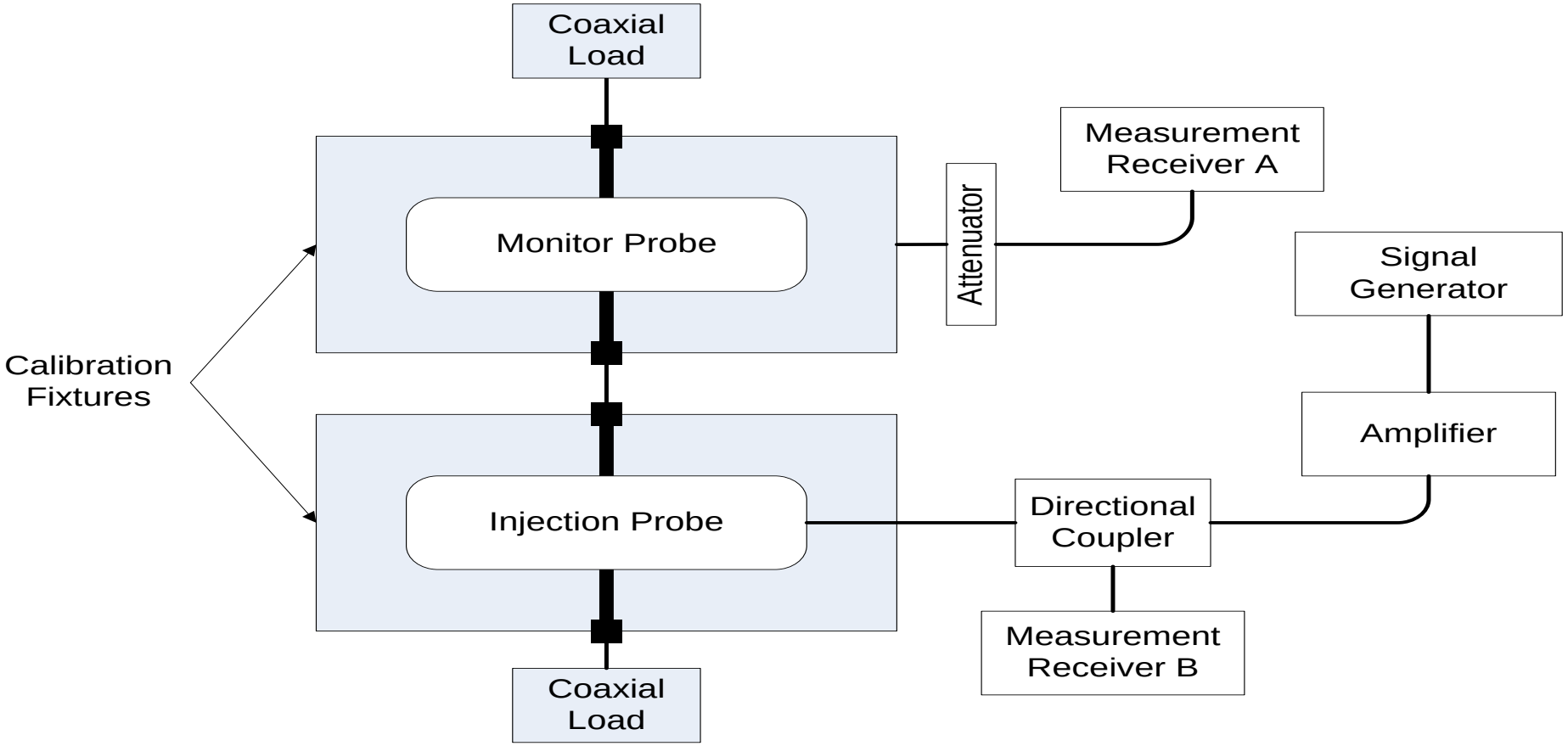


Signal generator drive set to induce the required currents into the calibration fixture.

Signal generator output settings recorded as not to exceed levels during test.



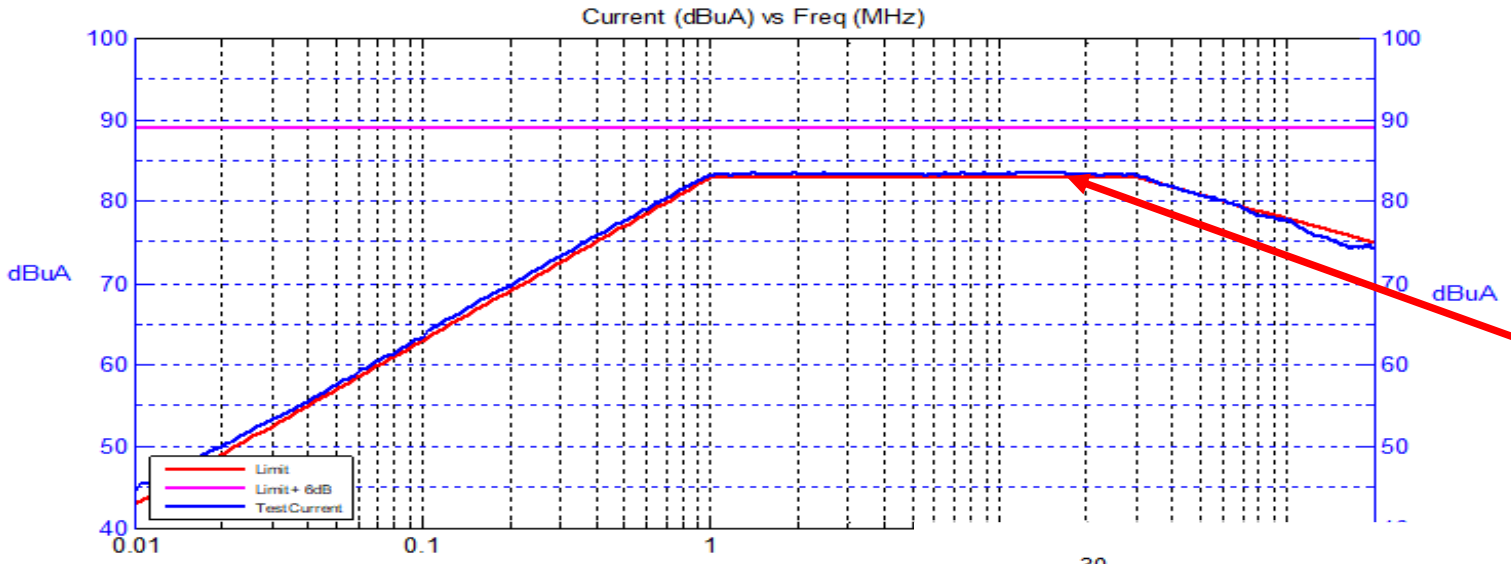
CS114 – Verification



Verification performed with minimal dwell times and step sizes up to twice the size of used during actual testing.

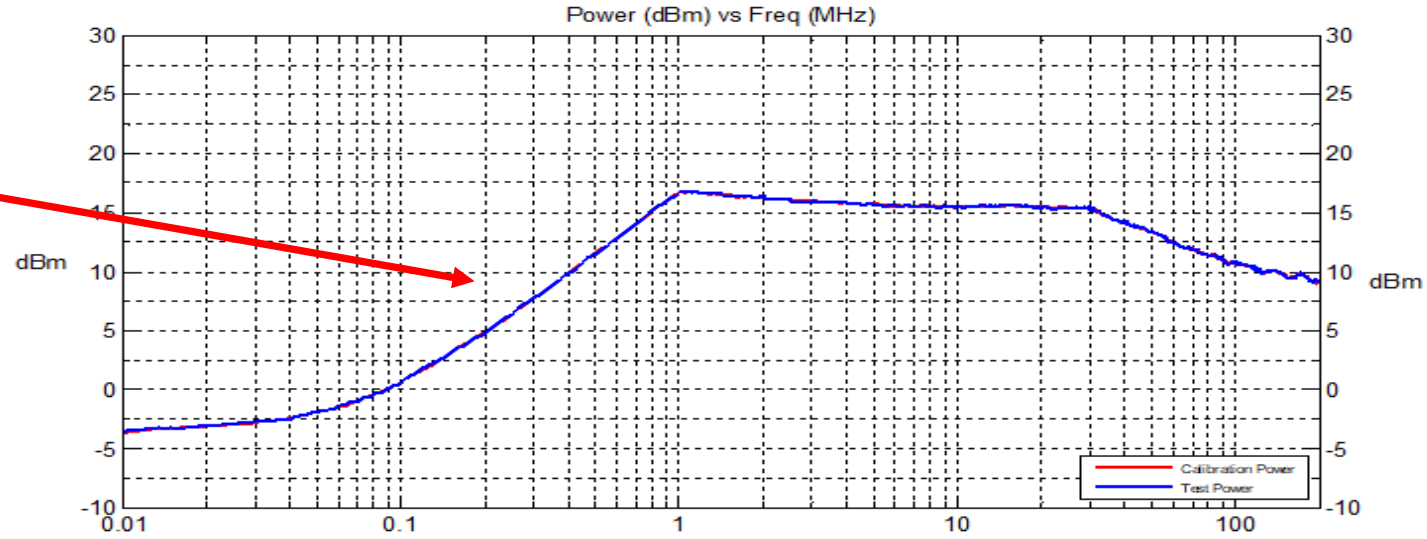
MIL-STD-461G requires a verification check to ensure that the forward power follows the calibration and that the developed current is within a 3 dB tolerance of the current test limit.

CS114 – Calibration Verification

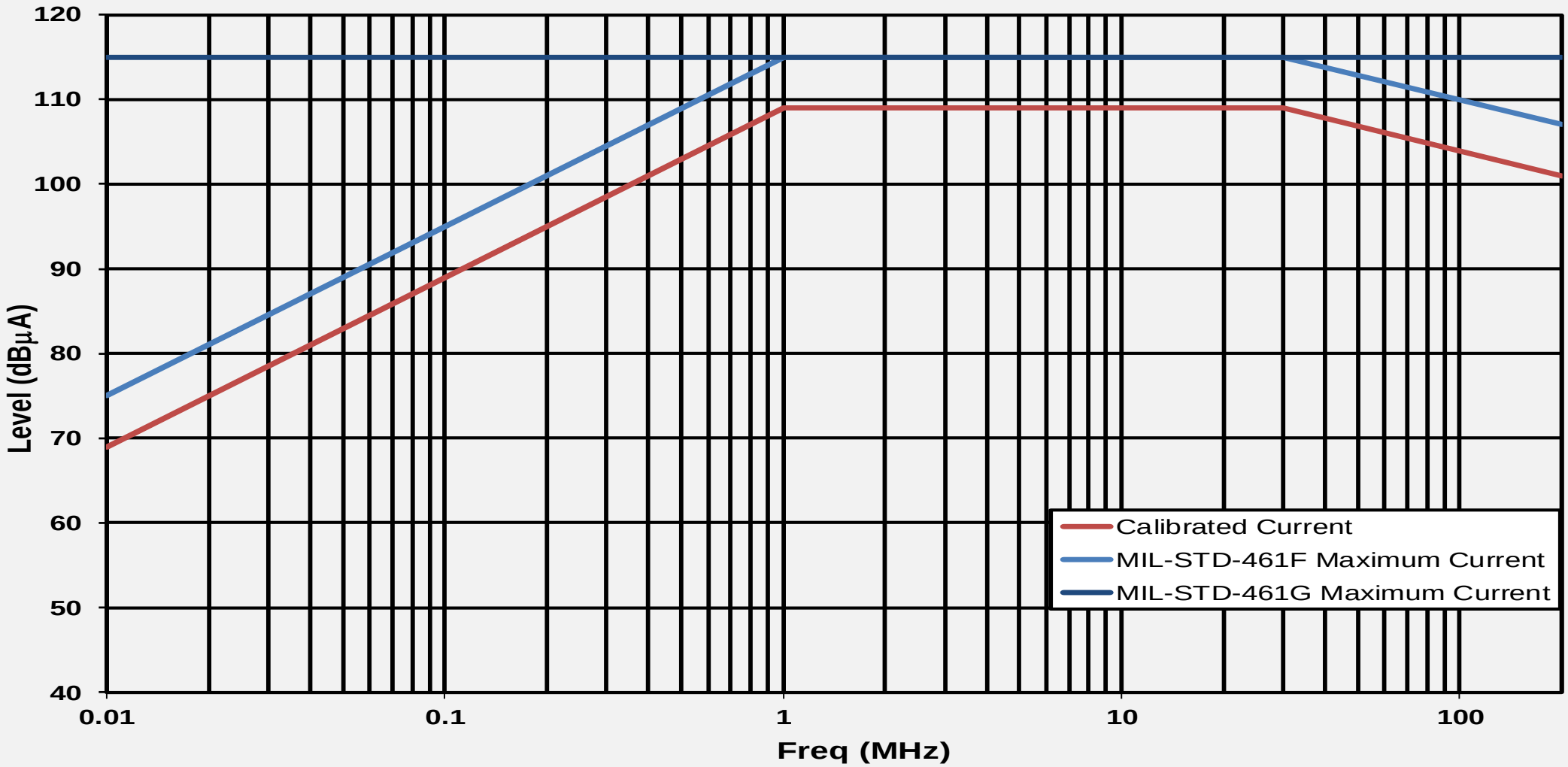


Test current maps to calibration curve.

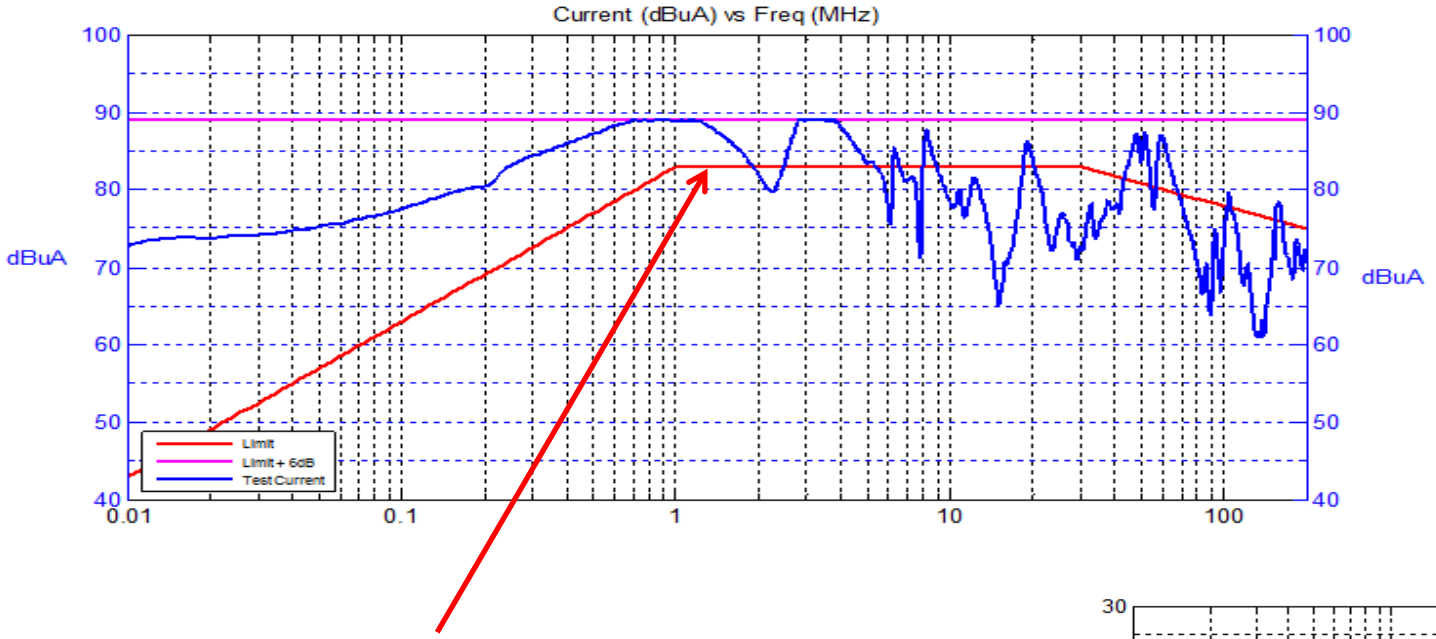
Signal generator output maps to calibrated level.



Test Limits in MIL-STD-461G



CS114 – Example Data

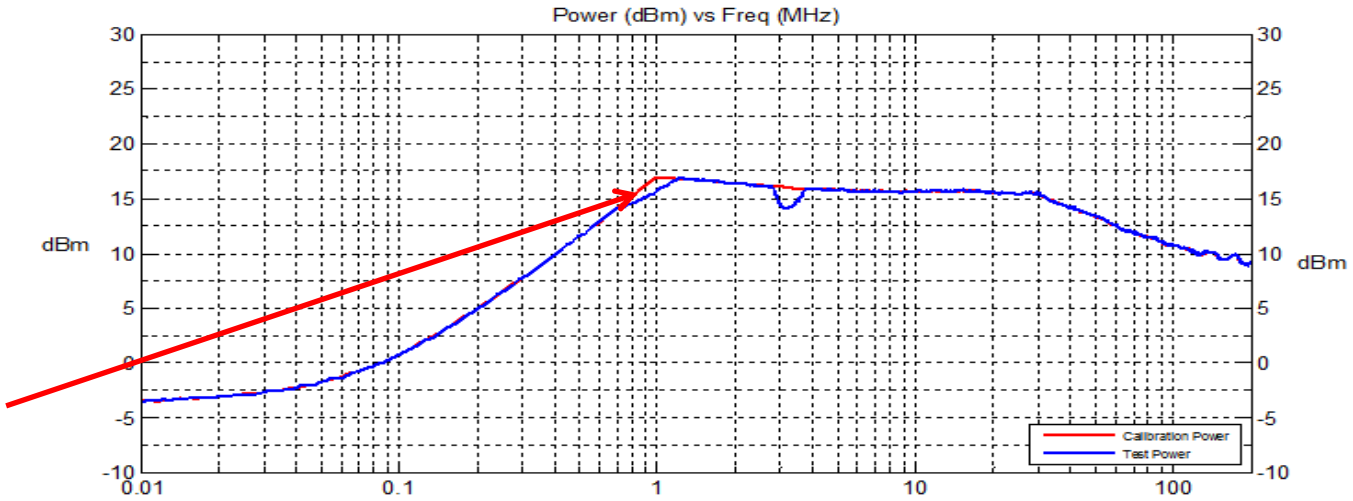


Due to impedance variations in the cable under test, the current injected may exceed the calibrated levels. To protect against severe over testing, the maximum injected current is limited.

Note that testing is actually performed at a level 6 dB above the flat portion of the calibrated current

OR

The power determined during calibration.

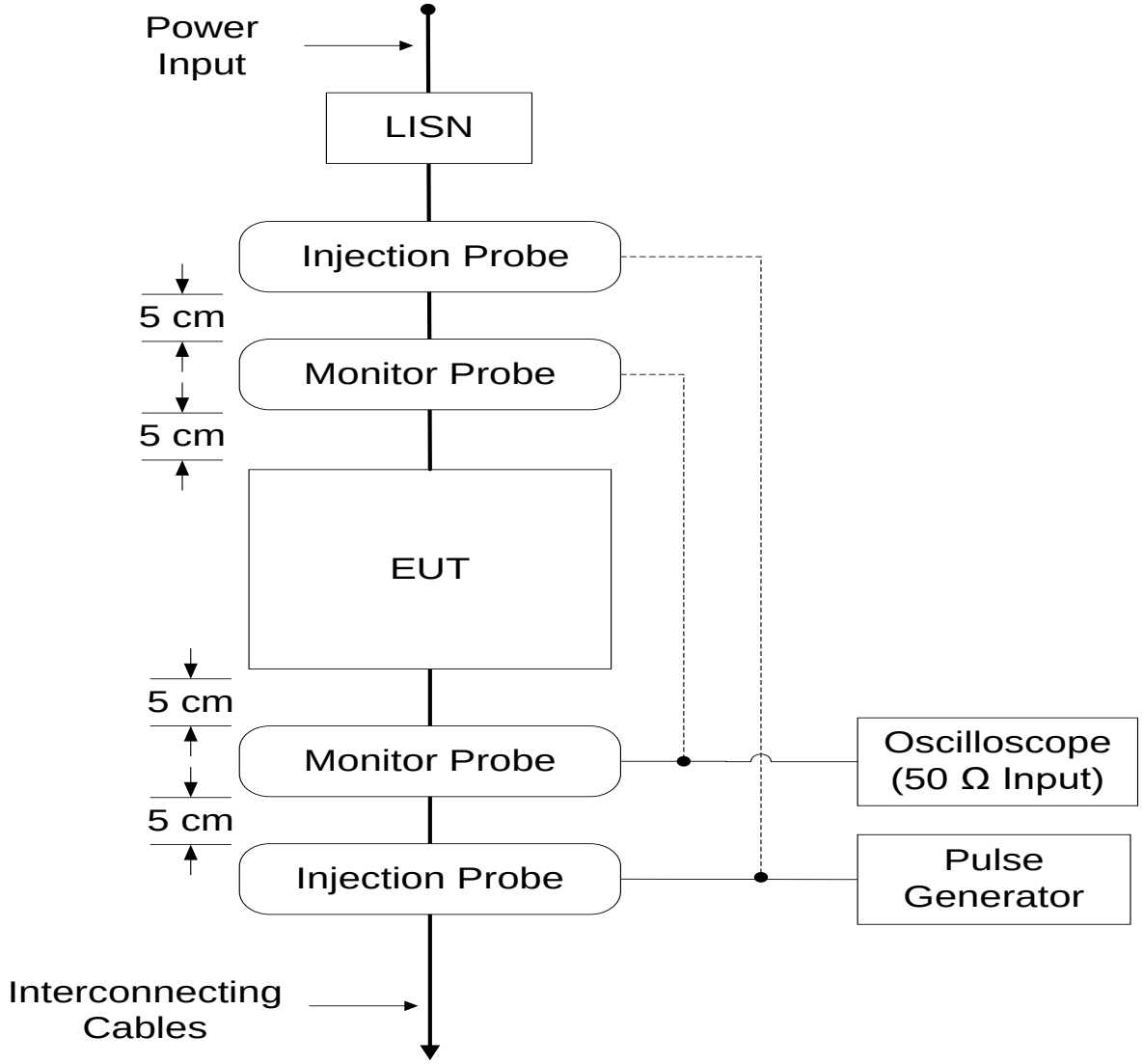


Detailed Requirements

- **Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation - CS115**

CS115

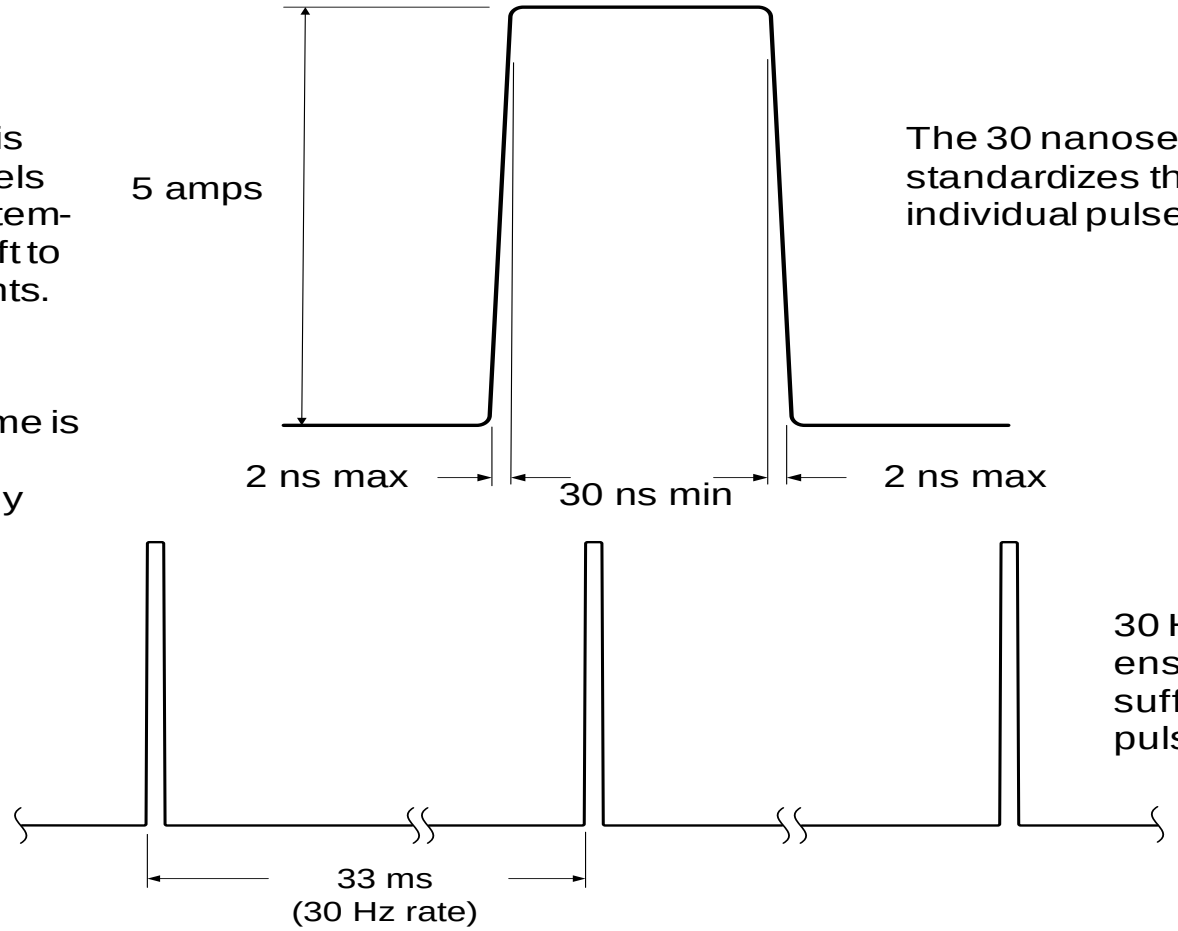
- Applicable to all electrical cables interfacing with EUT enclosures.
- Concern is to protect equipment from fast rise and fall time transients that may be present due to platform switching operations and external transient environments such as lightning and electromagnetic pulse.
- Replaces "chattering relay" type requirements (RS06 in MIL-STD-461C).
- The excitation waveform from the generator is a trapezoidal pulse.



CS115 Pulse

5 ampere amplitude is representative of levels observed during system-level testing of aircraft to transient environments.

2 nanosecond rise time is consistent with waveforms created by inductive device switching action.

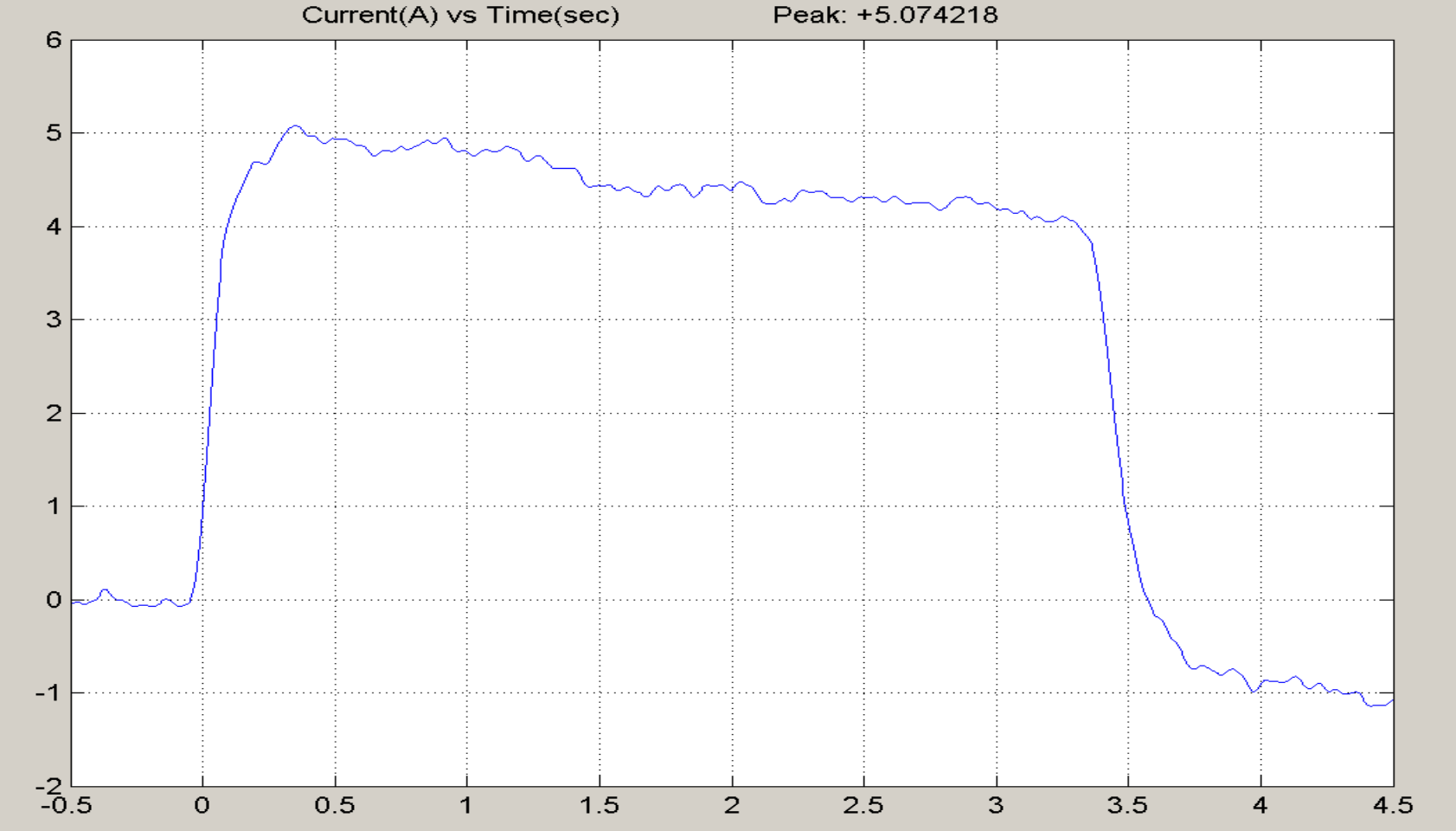


The 30 nanosecond pulse width standardizes the energy in individual pulses.

30 Hz pulse rate ensures that a sufficient number of pulses are applied.

Single set of pulse parameters regardless of application

CS115 Test Pulse Example



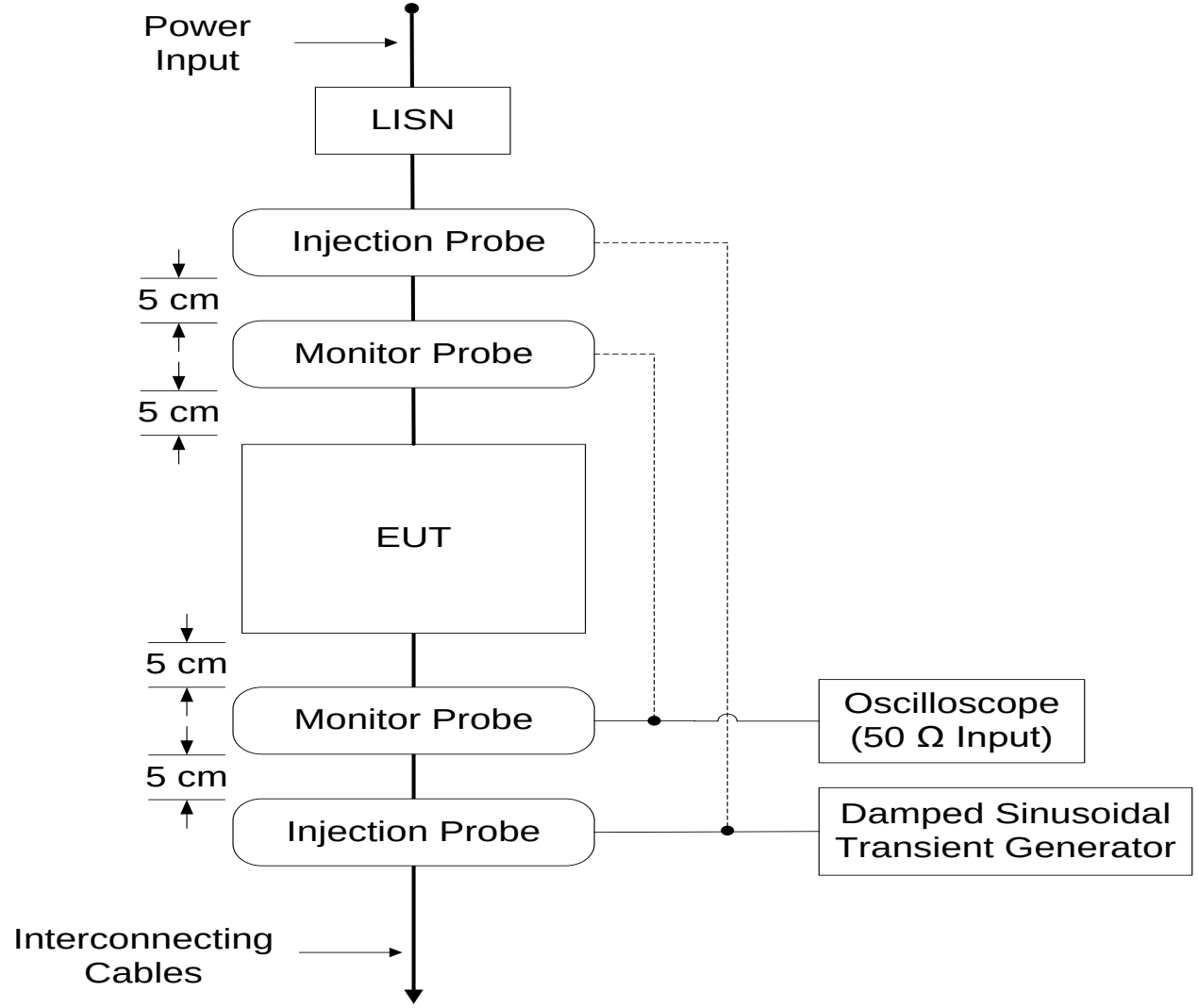
Cal plot and test plot will vary due to impedance changes!

Detailed Requirements

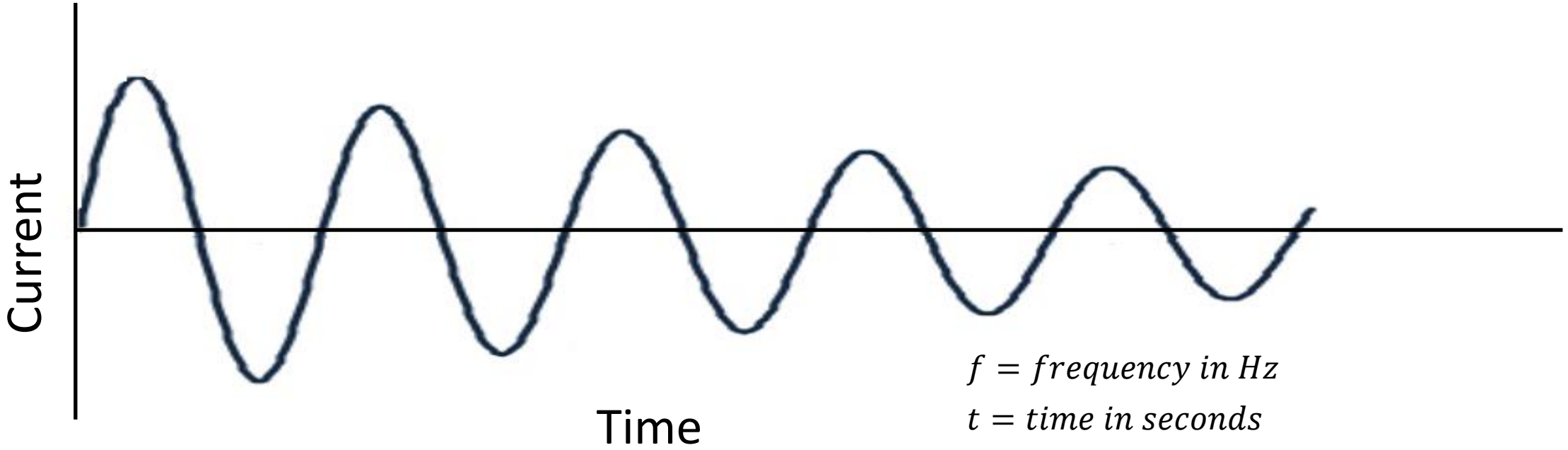
- **Conducted Susceptibility,** Damped Sinusoidal Transients, Cables and Power Leads **- CS116**

CS116

- Applicable to electrical cables interfacing with each EUT enclosure and on each power lead.
- Concept is to simulate electrical current and voltage waveforms occurring in platforms from excitation of natural resonances.
- Intent is to control waveform as a damped sine.
- Wide frequency coverage accounts for a wide range of conditions.
- Switching transients within the platform can also result in similar waveforms.



CS116 Calibration Pulse



$f = frequency\ in\ Hz$

$t = time\ in\ seconds$

$Q = Damping\ Factor = 15\ \pm 5$

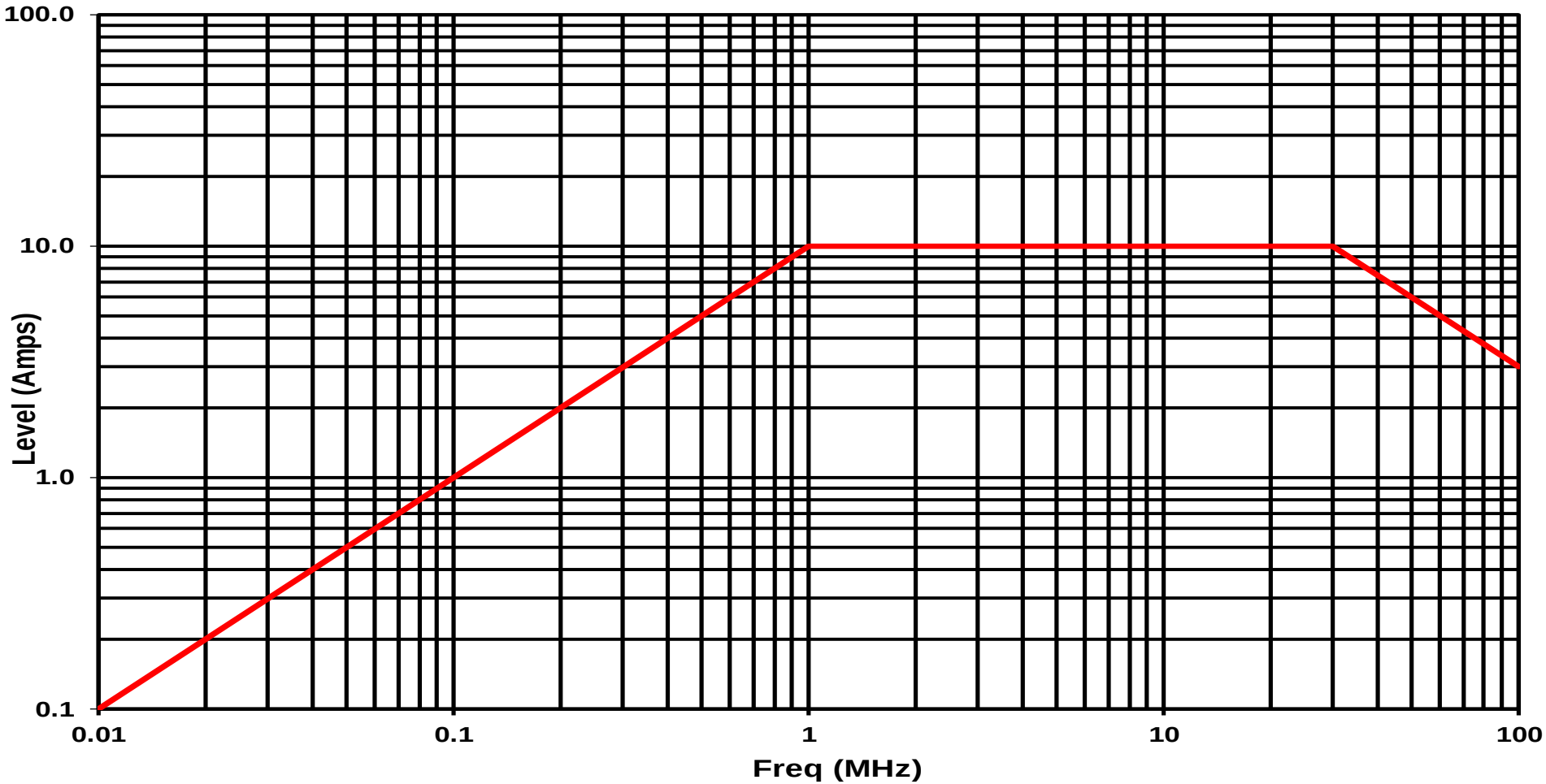
$$Q = \frac{\pi(N-1)}{ln\left(\frac{I_p}{I_N}\right)}$$

$N = Cycle\ Number\ (i.e. 2, 3, 4, 5$

$I_P = Peak\ Current\ at\ 1st\ Cycle$

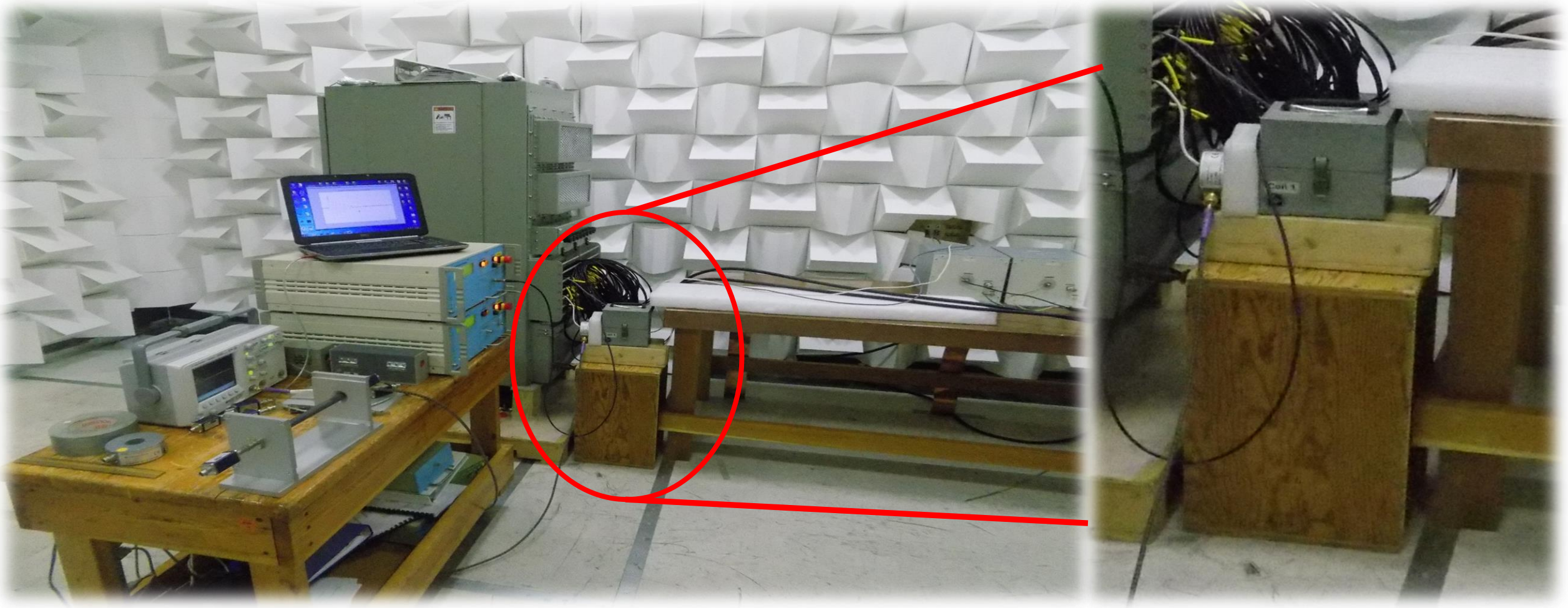
$I_N = Peak\ Current\ at\ Cycle\ N$

CS116 Test Levels

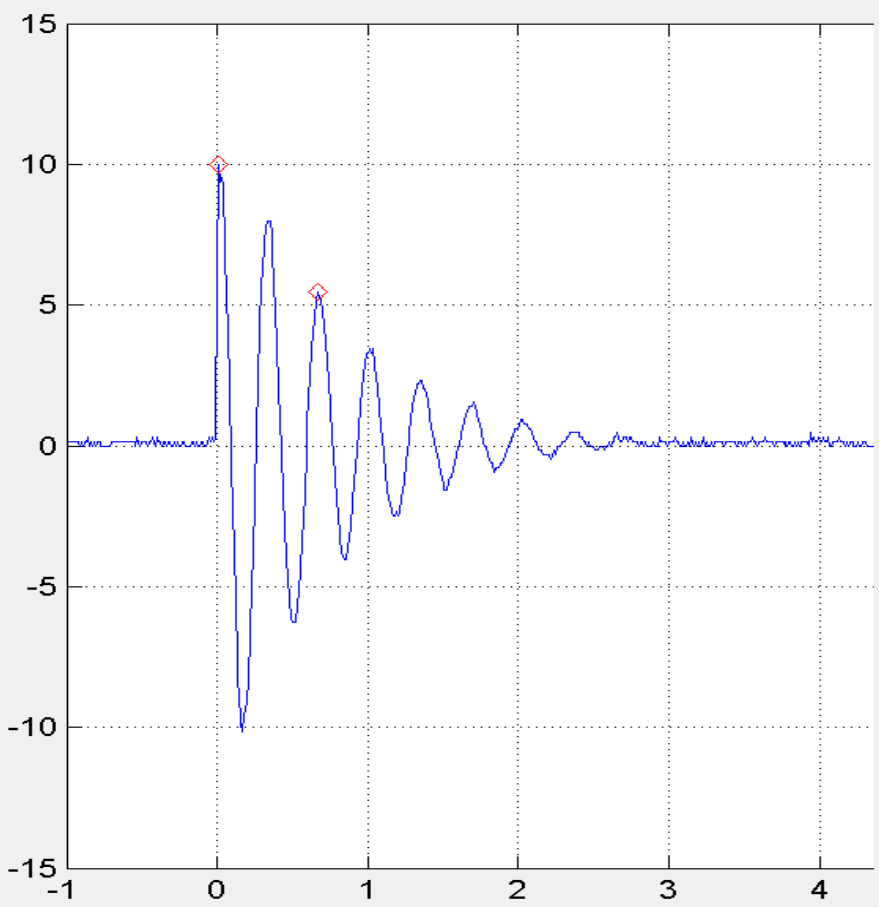


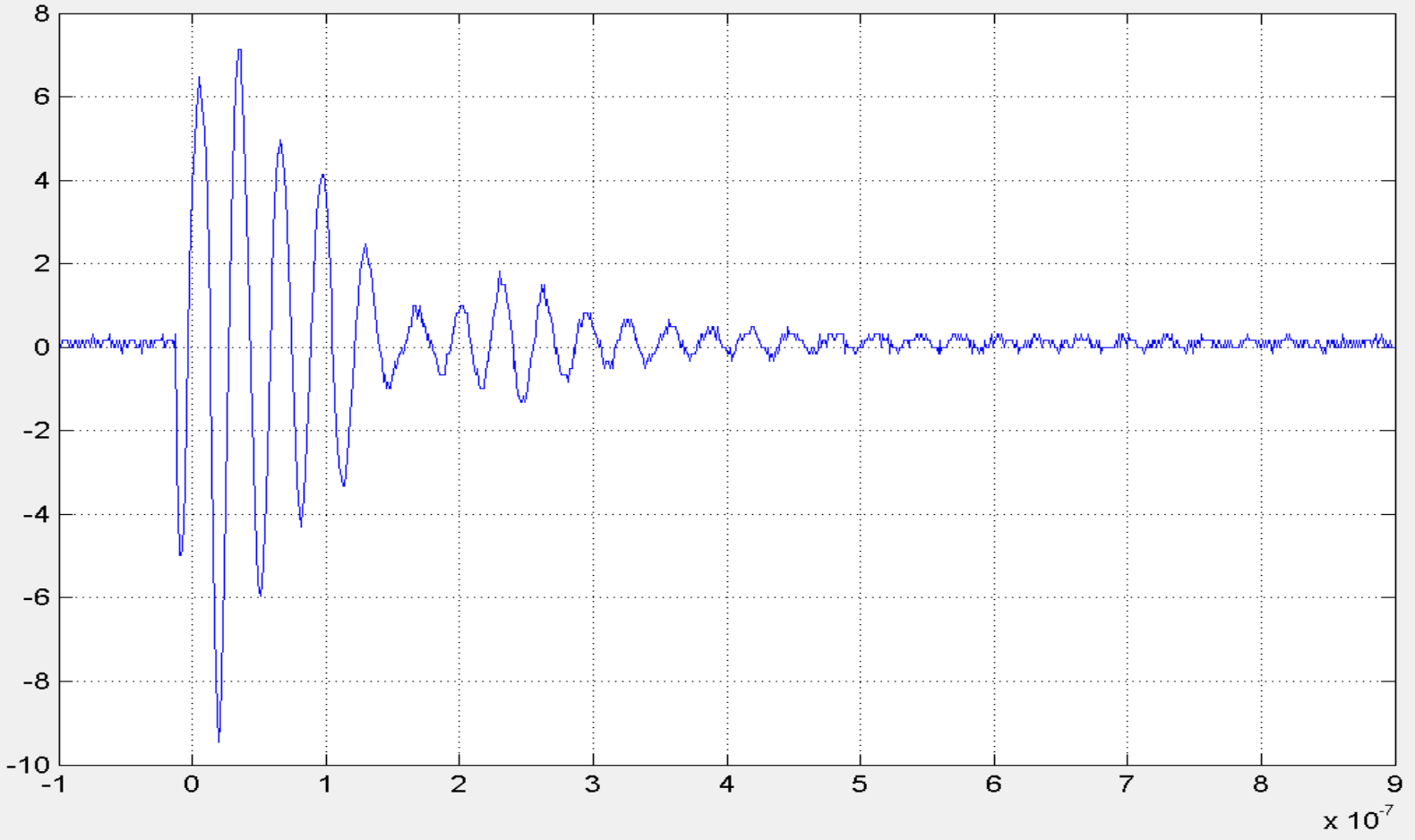
Damped Frequency	I_P Amps
10 kHz	0.1
100 kHz	1
1 MHz	10
10 MHz	10
30 MHz	10
100 MHz	3

CS116 Test Example



CS116 Test Pulse Example





Cal plot and test plot will vary due to impedance changes!

Detailed Requirements

- **Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads - CS117**

CS117

- Applicable to safety-critical equipment interfacing cables and on each power lead. Limited applicability to surface ship equipment located above deck or which includes interconnecting cables which are routed above deck.
- Concept is to address the equipment-level indirect effects of lightning as outlined in MIL-STD-464.
- Not intended to address direct effects or nearby lightning strikes.
- Includes Multiple Stroke and Multiple Burst tests.

CS117 Multiple Stroke

Applicability	Test Description	Internal Equipment Levels **	External Equipment Levels **
All Equipment Installations	Waveform 2 (WF2)/ Waveform 1 (WF1)	First Stroke V_L = 300 V (WF2) I_T = 600 A (WF1) I_T = 60 A* Subsequent Strokes V_L = 150 V (WF2) I_T = 150 A (WF1) I_T = 30 A*	First Stroke V_L = 750 V (WF2) I_T = 1500 A (WF1) I_T = 150 A* Subsequent Strokes V_L = 375 V (WF2) I_T = 375 A (WF1) I_T = 75 A*
All Equipment Installations	Waveform 3 (WF3) – 1 MHz and 10 MHz	First Stroke V_T = 600 V (WF3) I_L = 120 A (WF3) I_L = 24 A* Subsequent Strokes V_T = 300 V (WF3) I_L = 60 A (WF3) I_L = 12 A*	First Stroke V_T = 1500 V (WF3) I_L = 300 A (WF3) I_L = 60 A* Subsequent Strokes V_T = 750 V (WF3) I_L = 150 A (WF3) I_L = 30 A*
Equipment installations routed in areas with composite skin/structure.	Waveform 4 (WF4)/ Waveform 5A (WF5A)	First Stroke V_L = 300 V (WF4) I_T = 1000 A (WF5A) I_T = 300 A* Subsequent Strokes V_L = 75 V (WF4) I_T = 200 A (WF5A) I_T = 150 A*	First Stroke V_L = 750 V (WF4) I_T = 2000 A (WF5A) I_T = 750 A* Subsequent Strokes V_L = 187.5 V (WF4) I_T = 400 A (WF5A) I_T = 375 A*

*These current levels are intended for individual power leads or low count wire bundles. When multiple leads are tested together, this current shall be increased to the full bundle level or to the number of leads multiplied by the appropriate individual current test or limit level, whichever is less.

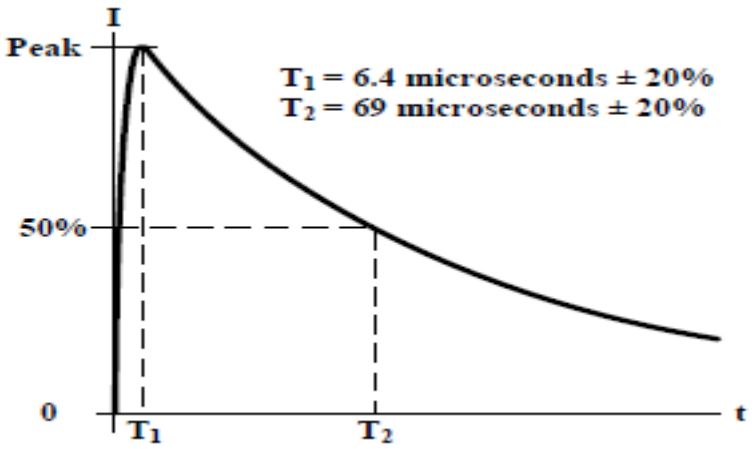
**Amplitude Tolerance is +20%,-0% for all waveforms, except the tolerance is relaxed to +50%,-0% for the Subsequent Strokes. V_T represents the test voltage level in volts and I_T represents the test current level in amperes. V_L (volts) and I_L (amperes) represent limits intended to prevent over-stressing the EUT beyond the requirements.

CS117 Multiple Burst

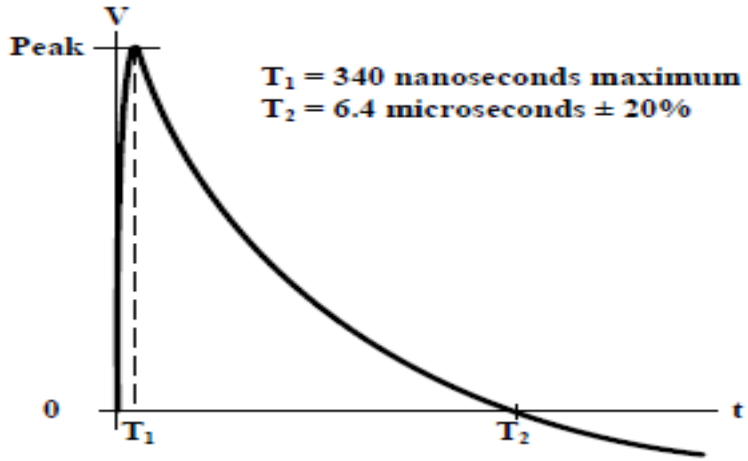
Applicability	Test Description	Internal Equipment Levels **	External Equipment Levels **
All Equipment Installations	Waveform 3 (WF3) – 1 MHz and 10 MHz	V_T = 360 V (WF3) I_L = 6 A (WF3)	V_T = 900 V (WF3) I_L = 15 A (WF3)
Equipment installations that utilize short, low impedance cable bundle installations.	Waveform 6 (WF6)	V_L = 600 V (WF6) I_T = 30 A (WF6)	V_L = 1500 V (WF6) I_T = 75 A (WF6)

**Amplitude Tolerance is +20%,-0% for all waveforms, except the tolerance is relaxed to +50%,-0% for the Subsequent Strokes. V_T represents the test voltage level in volts and I_T represents the test current level in amperes. V_L (volts) and I_L (amperes) represent limits intended to prevent over-stressing the EUT beyond the requirements.

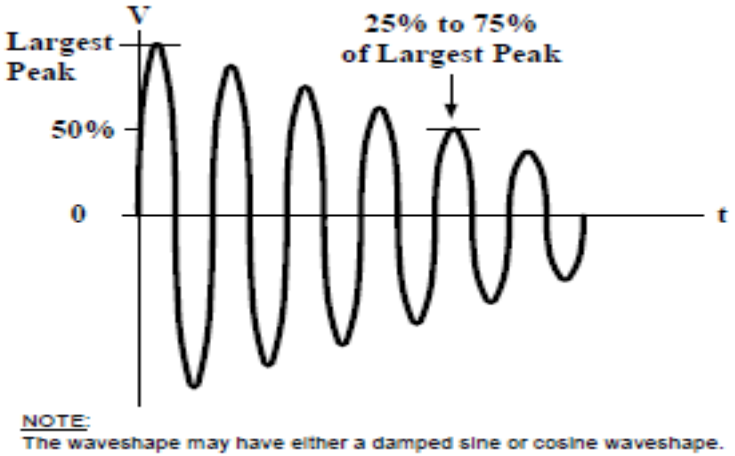
CS117 Waveforms



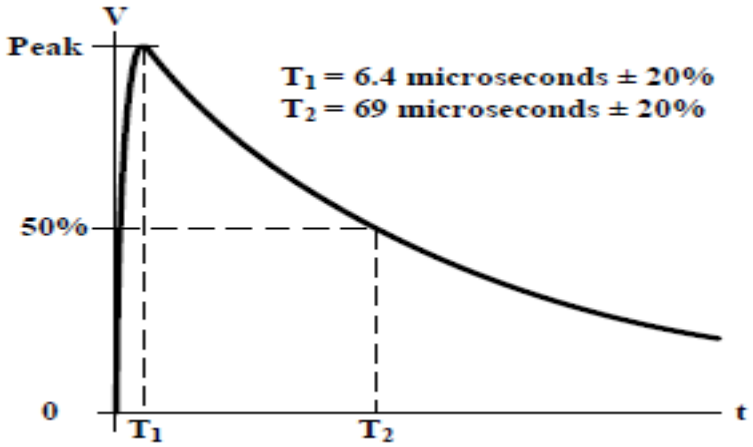
Current WF 1



Voltage WF 2

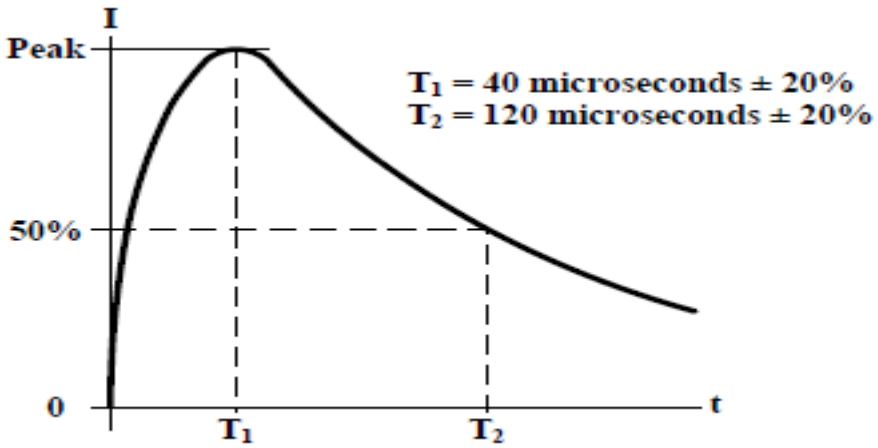


Voltage WF 3

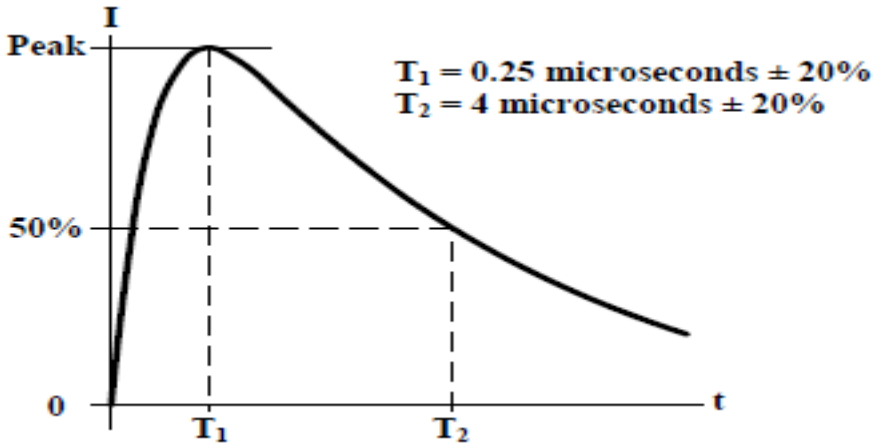


Voltage WF 4

CS117 Waveforms (cont)

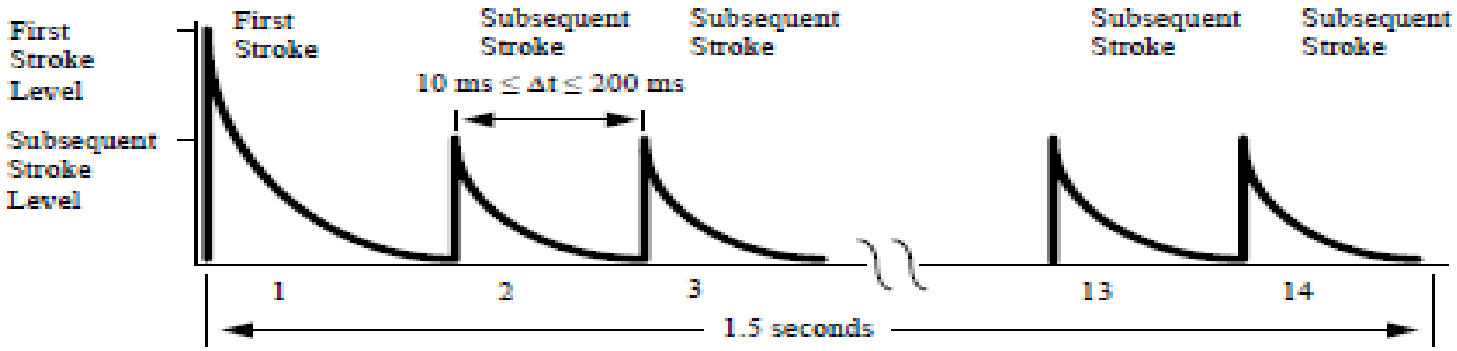


Current WF 5A



Current WF 6

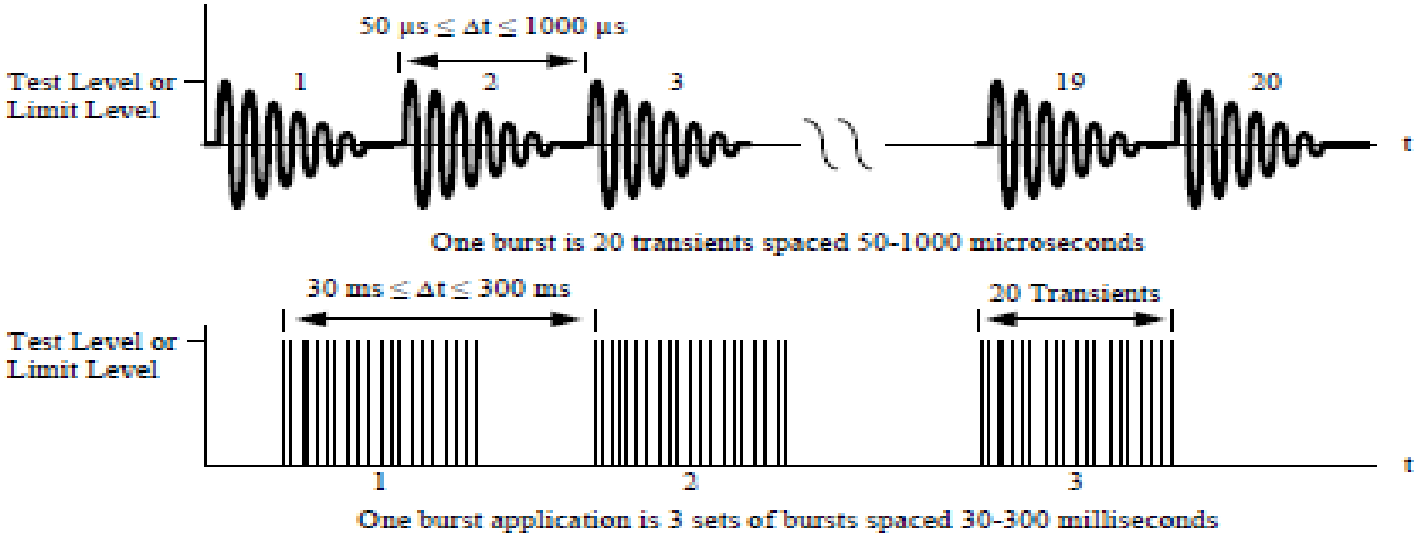
CS117 Waveforms (cont)



One first transient followed by thirteen subsequent transients distributed over a period of up to 1.5 seconds.

Multiple Stroke Application

Multiple Burst Application



One burst is 20 transients spaced 50-1000 microseconds

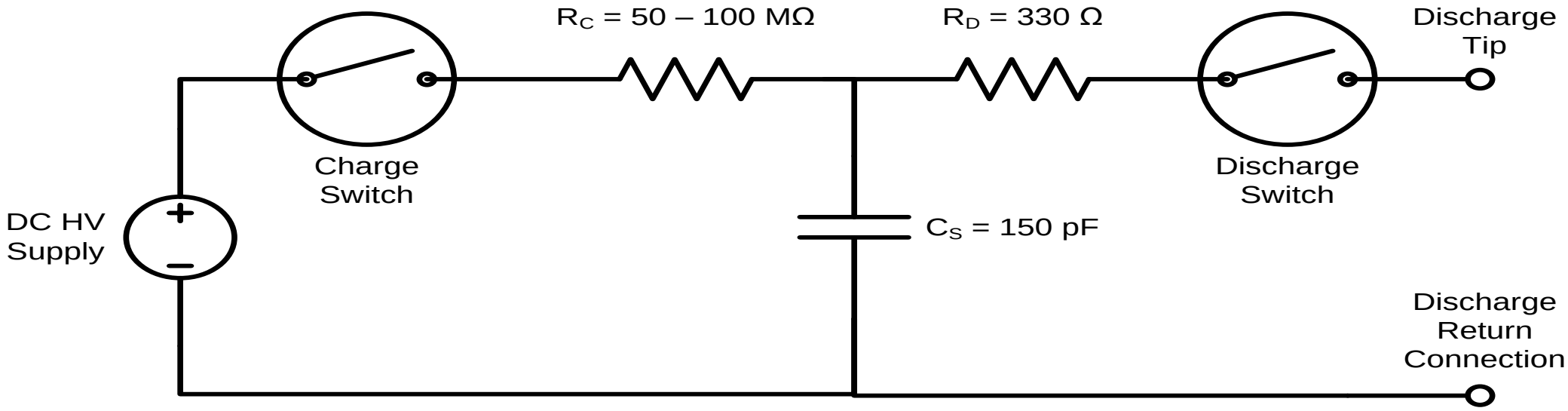
One burst application is 3 sets of bursts spaced 30-300 milliseconds

Detailed Requirements

- **Conducted Susceptibility, Personnel Borne Electrostatic Discharge - CS118**

CS118

- Applicable to electrical, electronic, and electromechanical subsystems and equipment that have a man-machine interface.
- Not applicable to ordnance items.
- Concept is to simulate ESD caused by human contact. Test points chosen based on most likely human contact locations.
- Based on IEC 61000-4-2. However, CS118 requires the EUT to be electrically bonded in accordance with the product installation requirements.



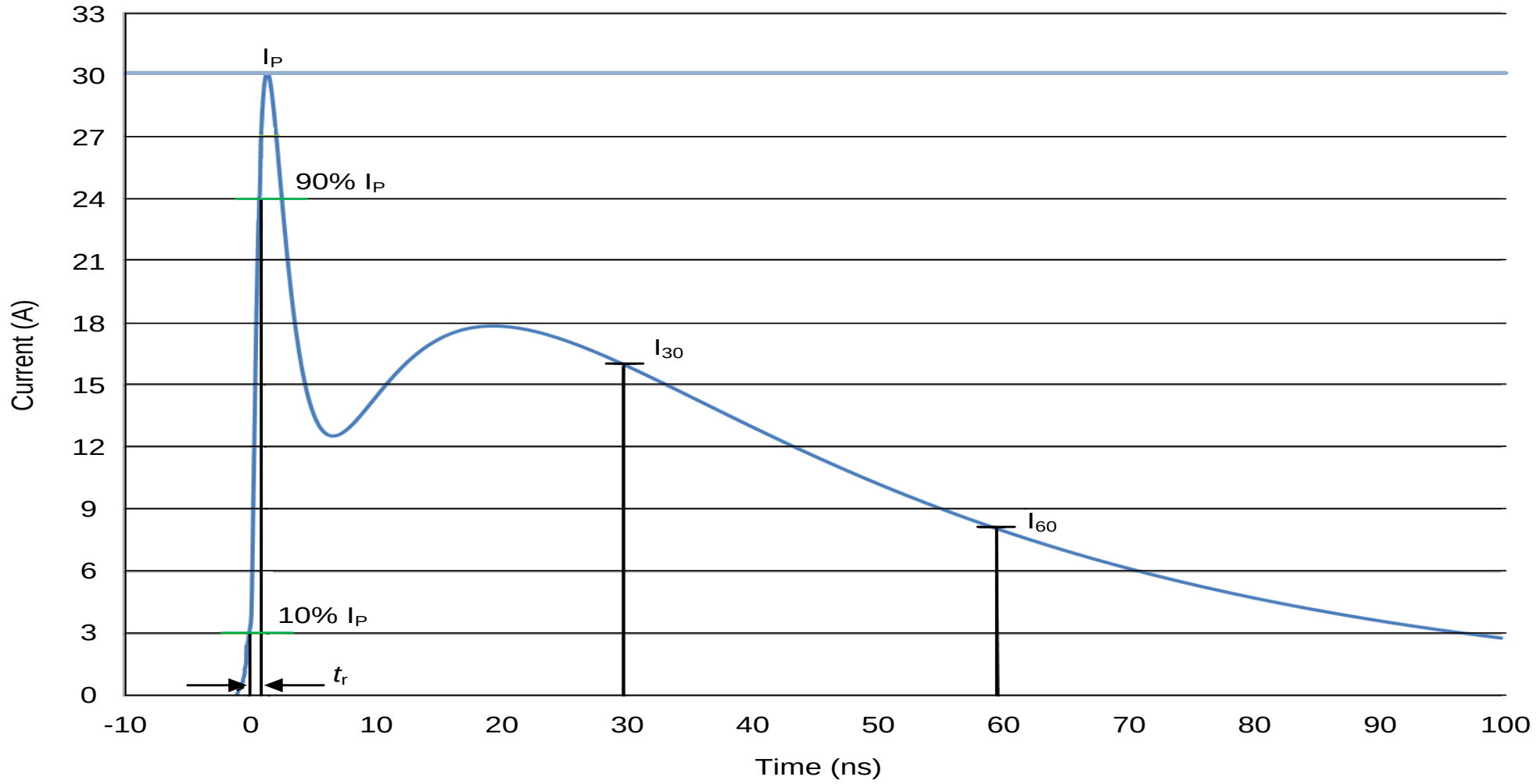
CS118 Test Levels and Values

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

Display Voltage (kV)	First Peak Current, ± 15% (A)	Rise Time (ns)	Current I_1, ± 30% (A) at t_1 = 30 ns	Current I_2, ± 30% (A) at t_2 = 60 ns
± 8	30	$0.6 \leq t_r \leq 1.0$	16	8
Rise time is defined as the time from 10% to 90% of the peak value of the current waveform.				

Typical test consists of 5 positive discharges and 5 negative discharges per test point.

CS118 Ideal Waveform



Waveform Based on ESD Test Level 3 at 8 kV Contact Discharge.

CS118 Test Points

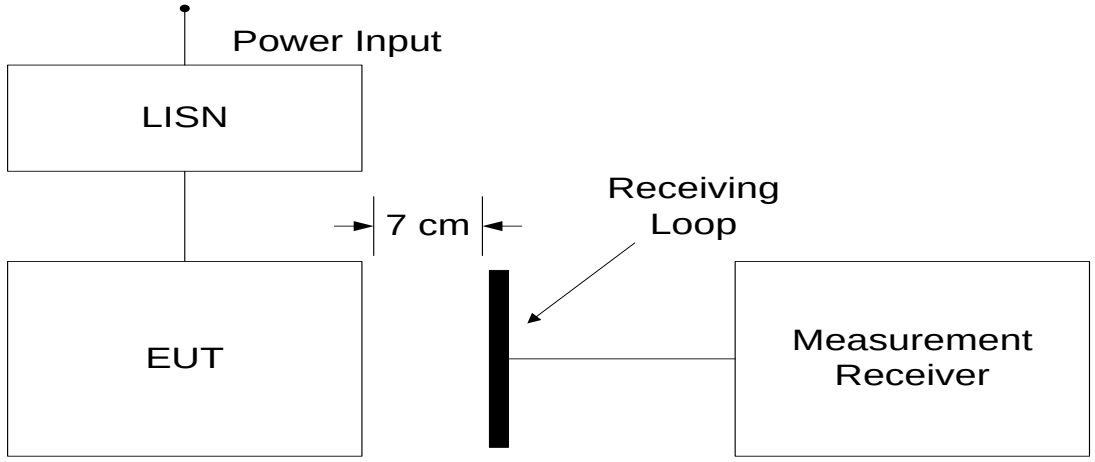
- **Multiple test locations based on points and surfaces which are easily accessible to operators during normal operations.**
- **Keyboard areas, switches, knobs, indicators, and connector shells.**
- **Test point locations on each surface of the EUT.**

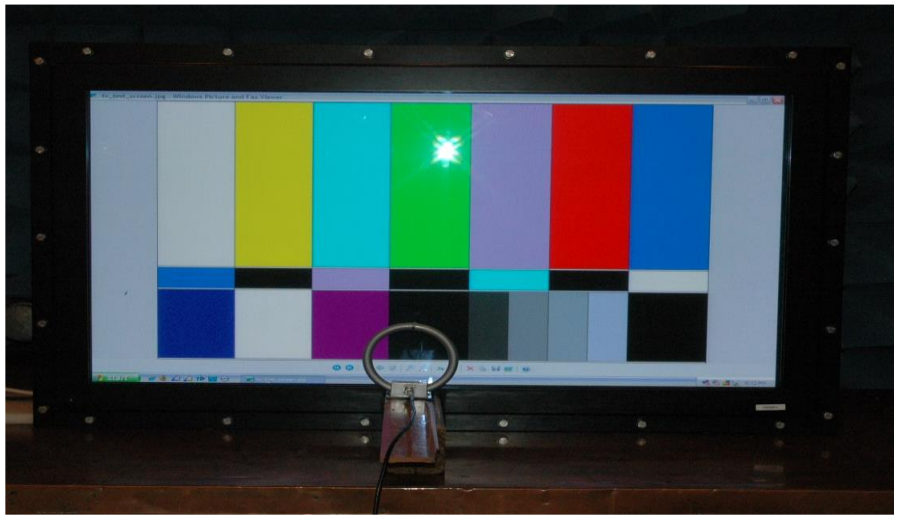
Detailed Requirements

- **Radiated Emissions, Magnetic Field - RE101**

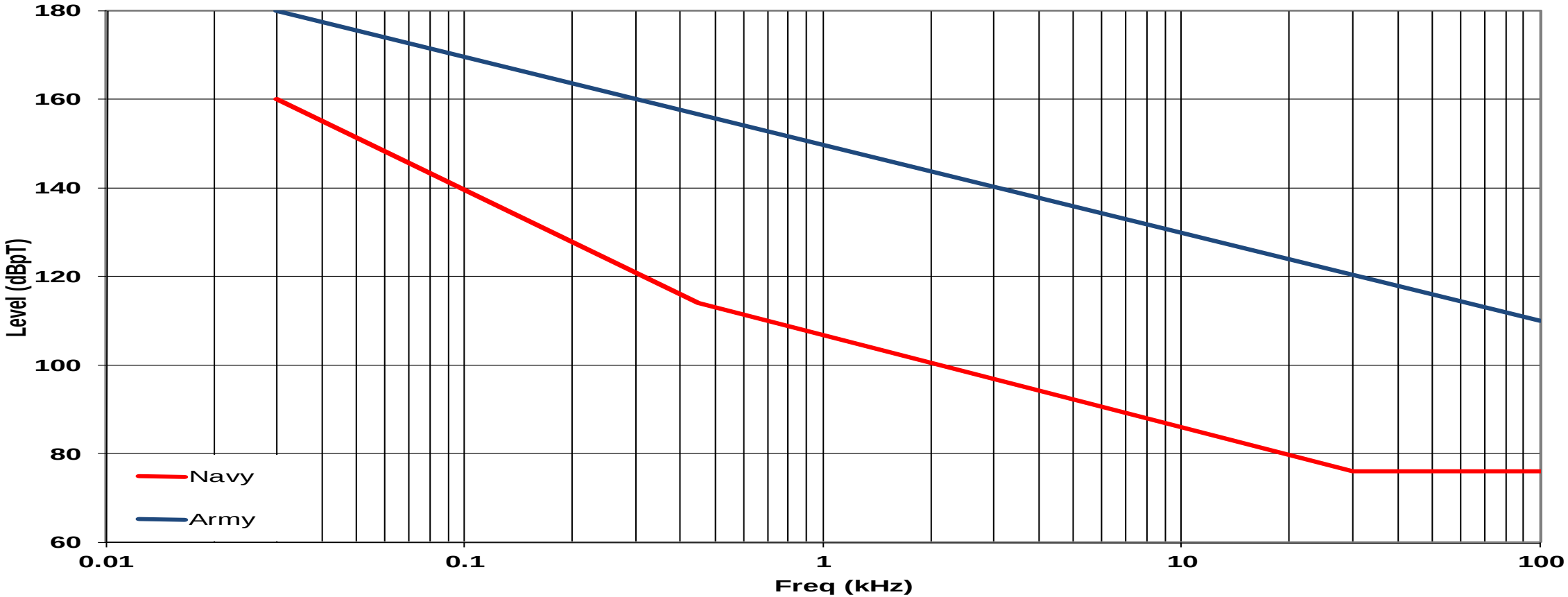
RE101

- Applicable for radiated emissions from equipment and subsystem enclosures, including electrical cable interfaces from 30 Hz to 100 kHz. For Navy aircraft, this requirement is only applicable for ASW capability operating between 30 Hz and 10 kHz.
- Specialized, intended to control magnetic fields for applications where equipment is present in the installation which is potentially sensitive to magnetic induction at lower frequencies.
- A 13.3 cm loop is specified for the test.
- Loop sensor winding resistance specified between 5 and 10 ohms.



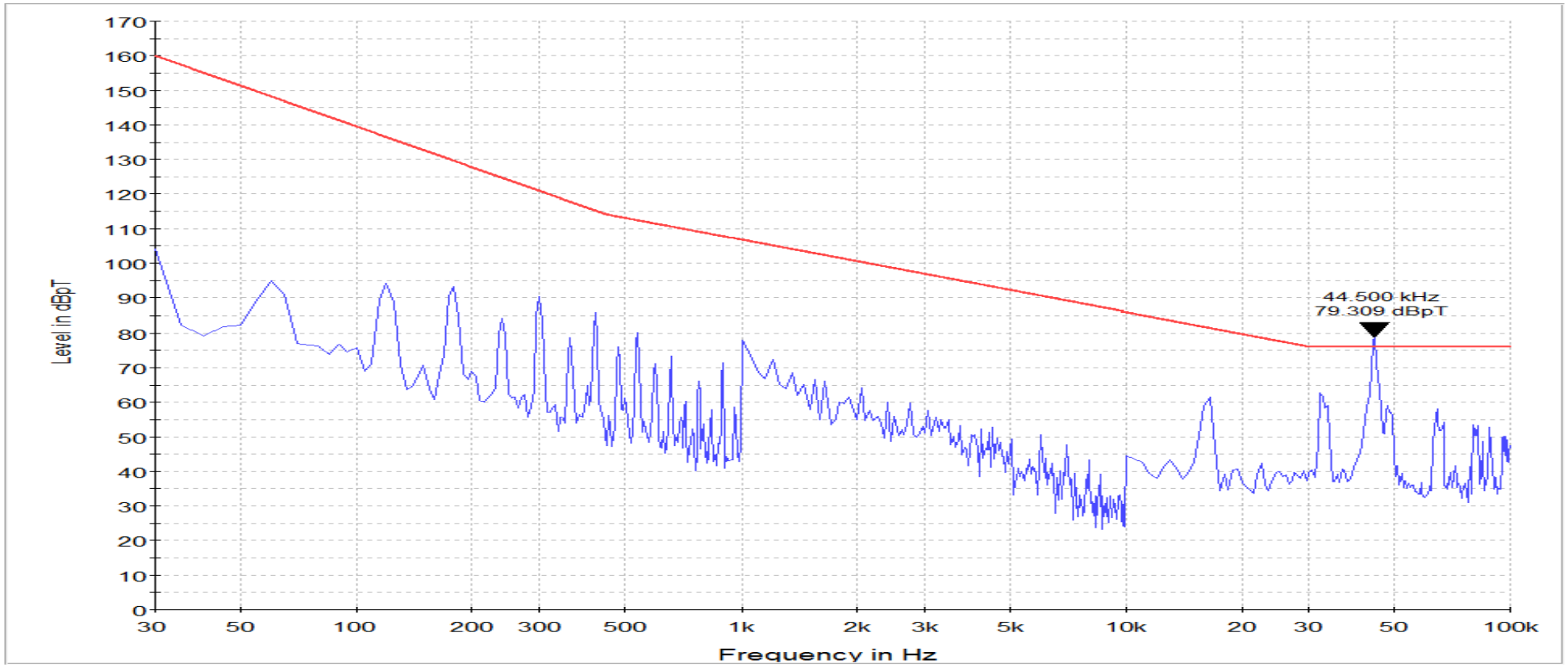


RE101 Limits



Limits based on service application

RE101 Sample Data



Common problem areas include equipment containing CRT yokes, transformers and switching power supplies

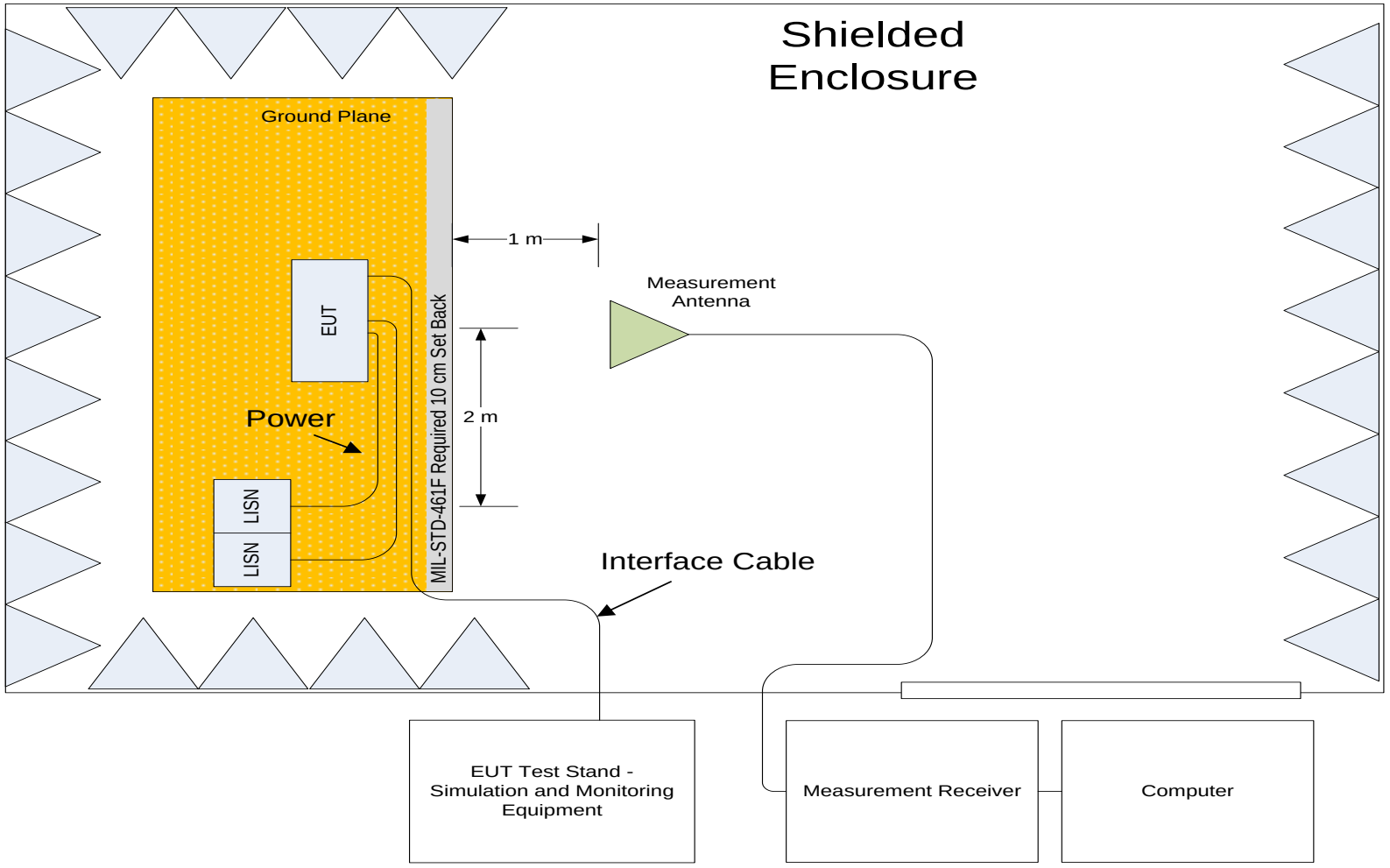
Detailed Requirements

- **Radiated Emissions, Electric Field - RE102**

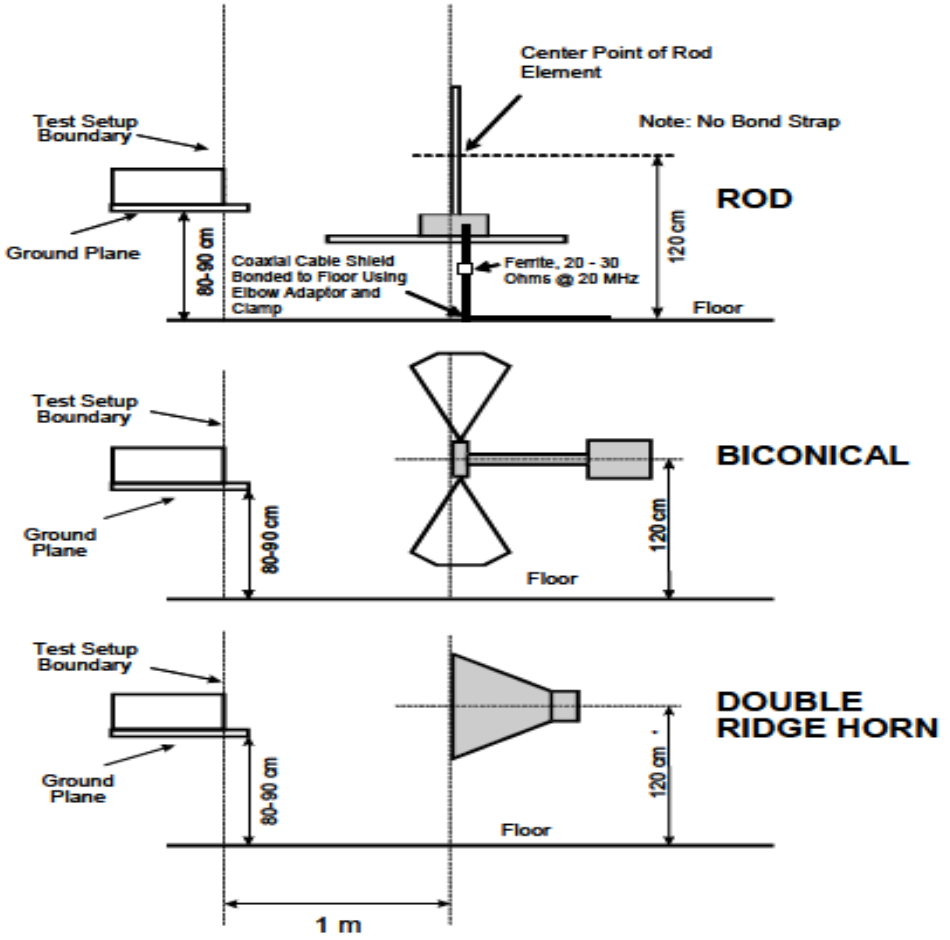
RE102

- Applicable to electric field emissions from the EUT and associated cables from 10 kHz to 18 GHz (application specific).
- Intent is to protect sensitive receivers from interference coupled through the antennas associated with the receiver.
- Many tuned receivers have sensitivities on the order of 1 uV and are connected to intentional apertures (the antenna) that are constructed for efficient reception of energy in the operating range of the receiver.
- Specific antennas are specified for use in measurements.
- Antenna placement is defined including separation from the EUT and elevation from the floor.
- Number of antenna positions determined based on size of the EUT and interfacing cables as well as beamwidth of the measurement antennas.
- Antenna placement is now based on EUT area and not just width.
- Specific guidance provided for calibration of the measurement system including the rod antenna specified for use from 10 kHz to 30 MHz.

RE102 Basic Setup

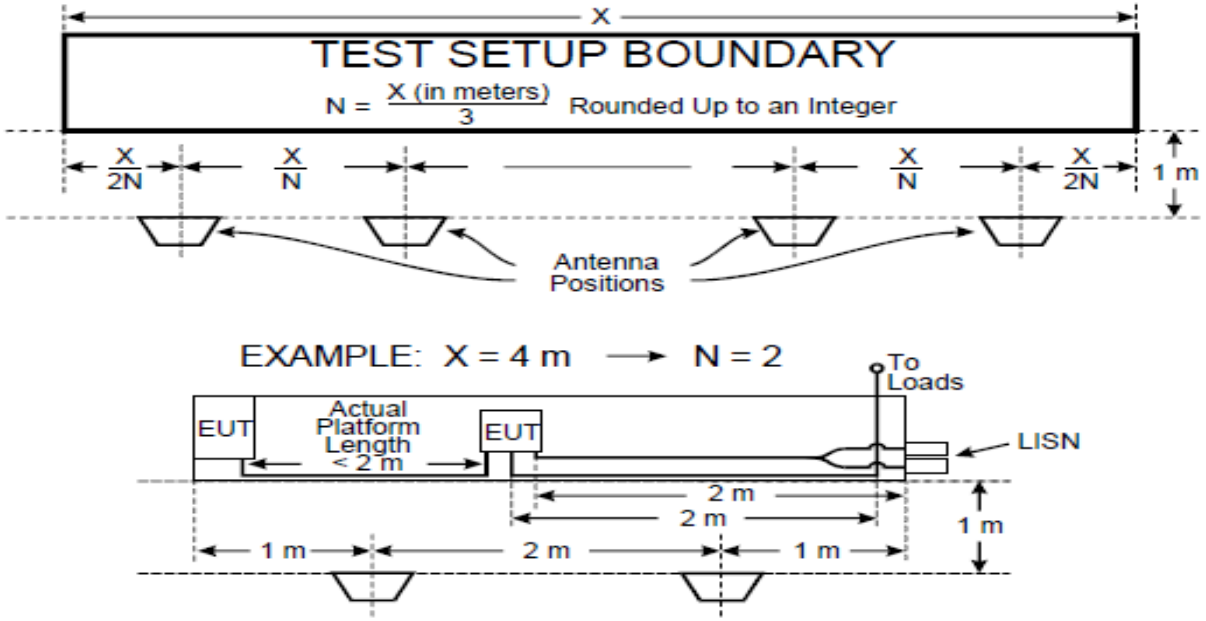


RE102 Antenna Positioning



- All antennas placed 1 meter from the test setup boundary and 120 cm above the ground plane floor.
- No part of any antenna can be closer than 1 meter from the walls and 0.5 meter from the ceiling of the shielded enclosure.
- 104 cm rod antenna specified from 10 kHz to 30 MHz with impedance matching network. A square counterpoise measuring at least 60 cm on a side is specified.
- 137 cm tip to tip biconical antenna specified from 30 MHz to 200 MHz.
- Double ridge horn with a 69.0 by 94.5 cm opening specified from 200 MHz to 1 GHz.
- Double ridge horn with a 24.2 by 13.6 cm opening specified from 1 GHz to 18 GHz.

RE102 Multiple Positions



Narrow antenna beamwidths at higher frequencies (12 GHz - 18 GHz) can lead to a large number of positions.

Antenna beamwidths for horizontal and vertical polarities will vary and hence different number of positions for different polarities.

Below 200 MHz

- **Boundary < 3 meters:**
- **1 position centered on the test setup boundary.**
- **Boundary > 3 meters:**
- **Number of positions determined by dividing the edge-to-edge boundary distance (in meters) by 3 and rounding up to an integer.**

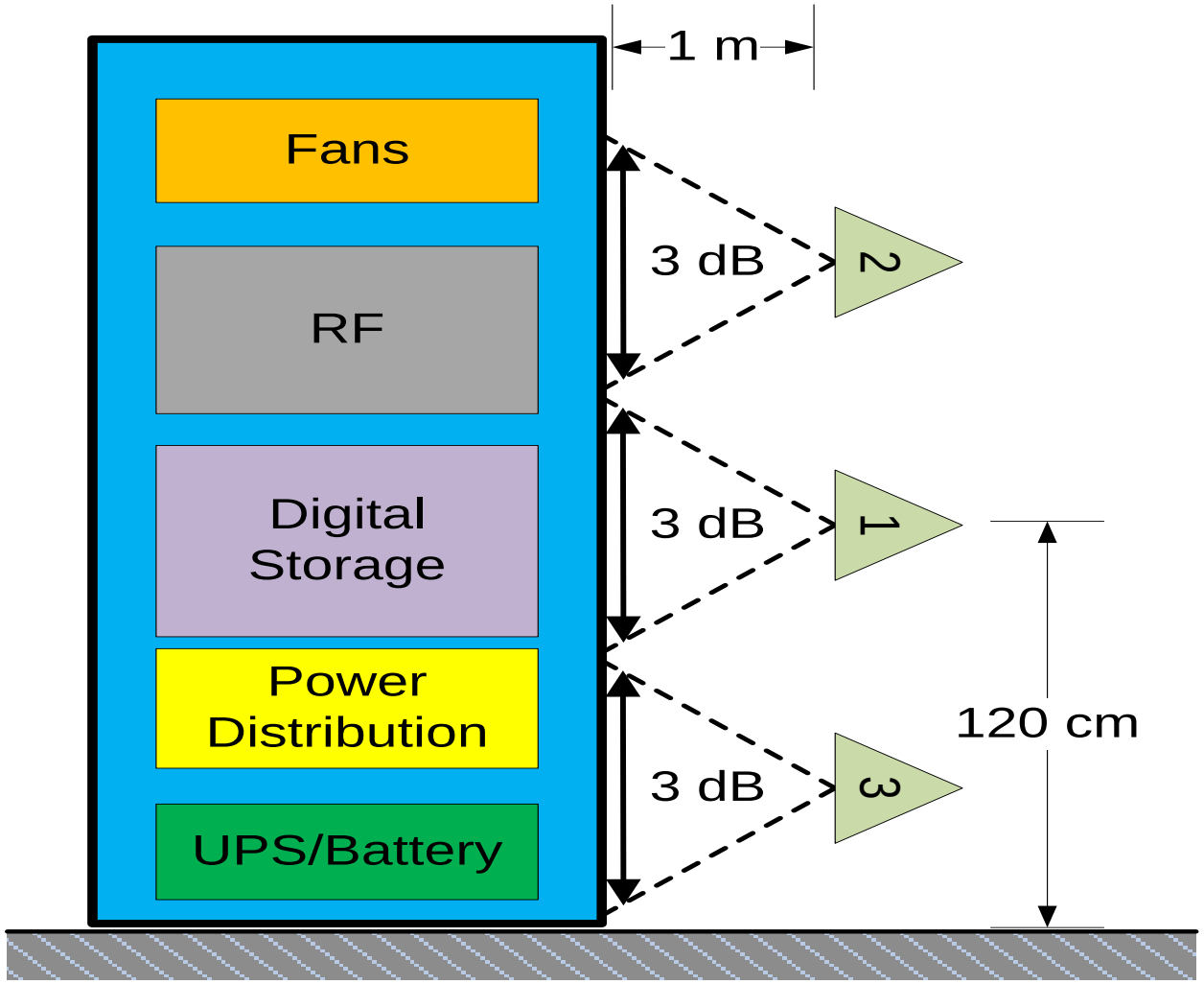
200 MHz to 1 GHz

- **Number of positions determined such that the area of each EUT enclosure and the first 35 cm of interfacing cables and leads are within the 3 dB beamwidth of the antenna.**

1 GHz to 18 GHz

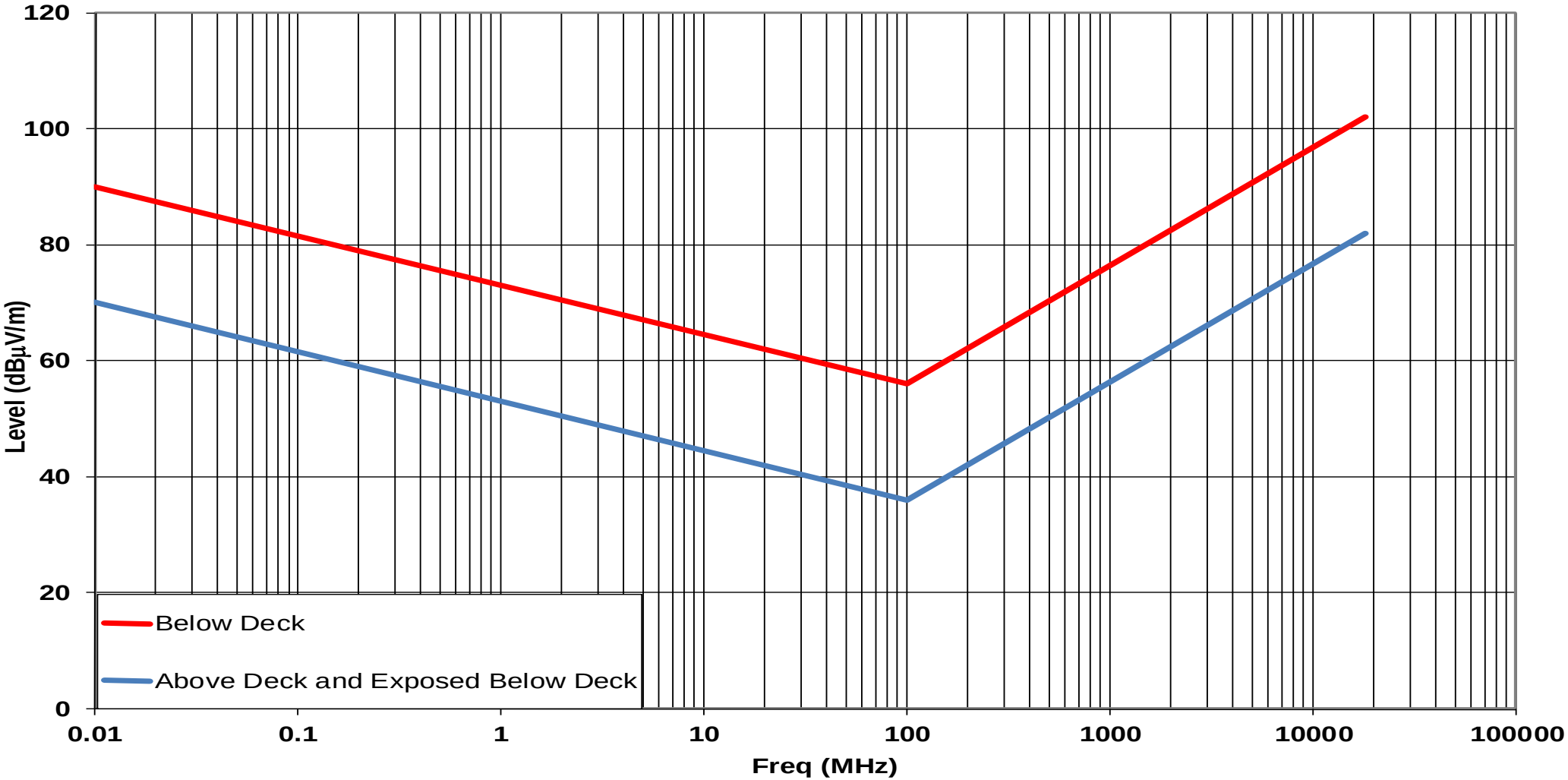
- **Number of positions determined such that the area of each EUT enclosure and the first 7 cm of interfacing cables and leads are within the 3 dB beamwidth of the antenna.**

RE102 Increased Positions



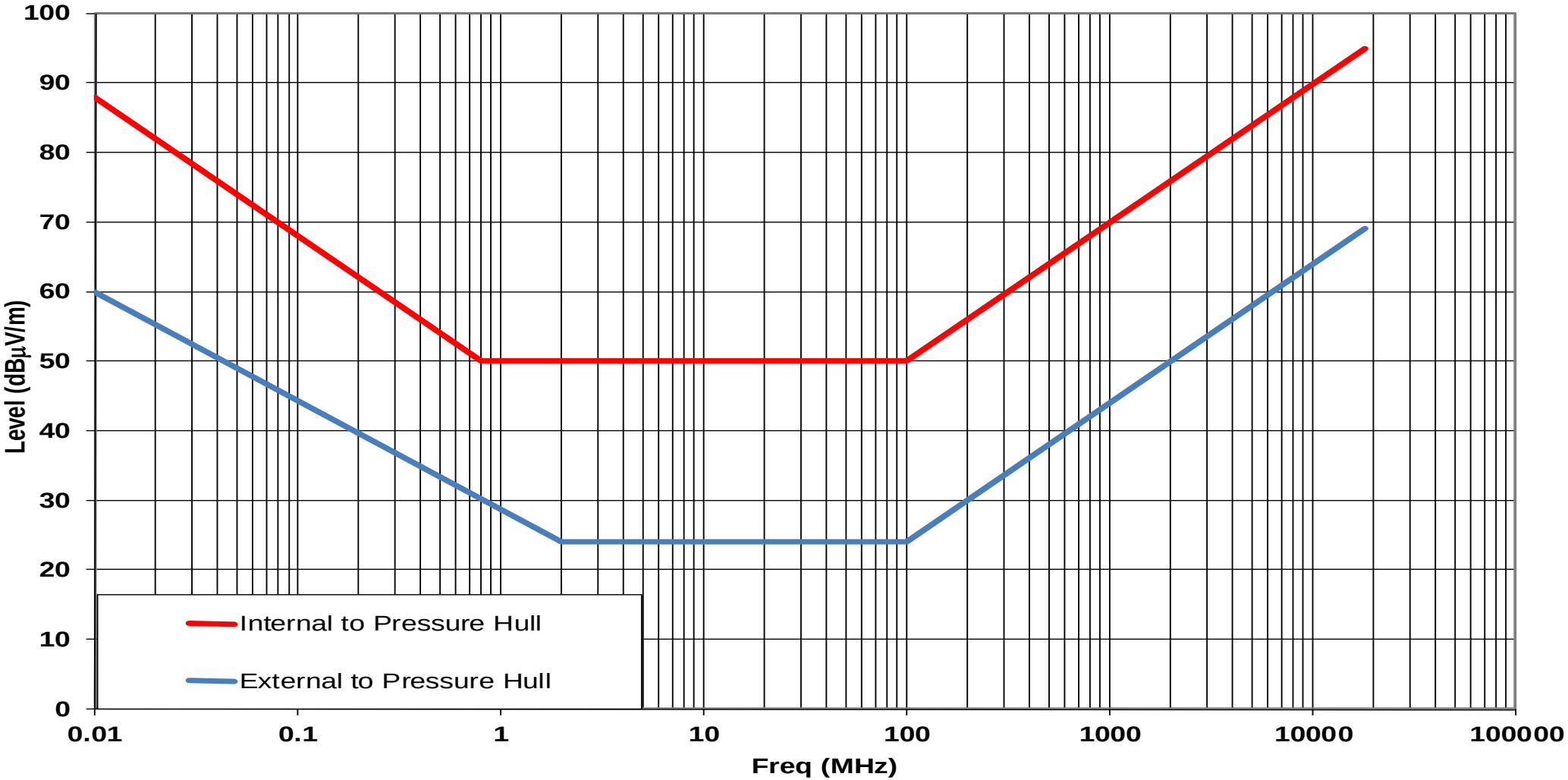
- Previous versions did not address tall equipment chassis such as ship base 6-foot racks.
- The 3 dB beamwidth requirement is now levied against the total area and not just the width.
- Increased number of antenna positions in the vertical plane.
- Increased test time and cost.
- Better test!

RE102 Limits



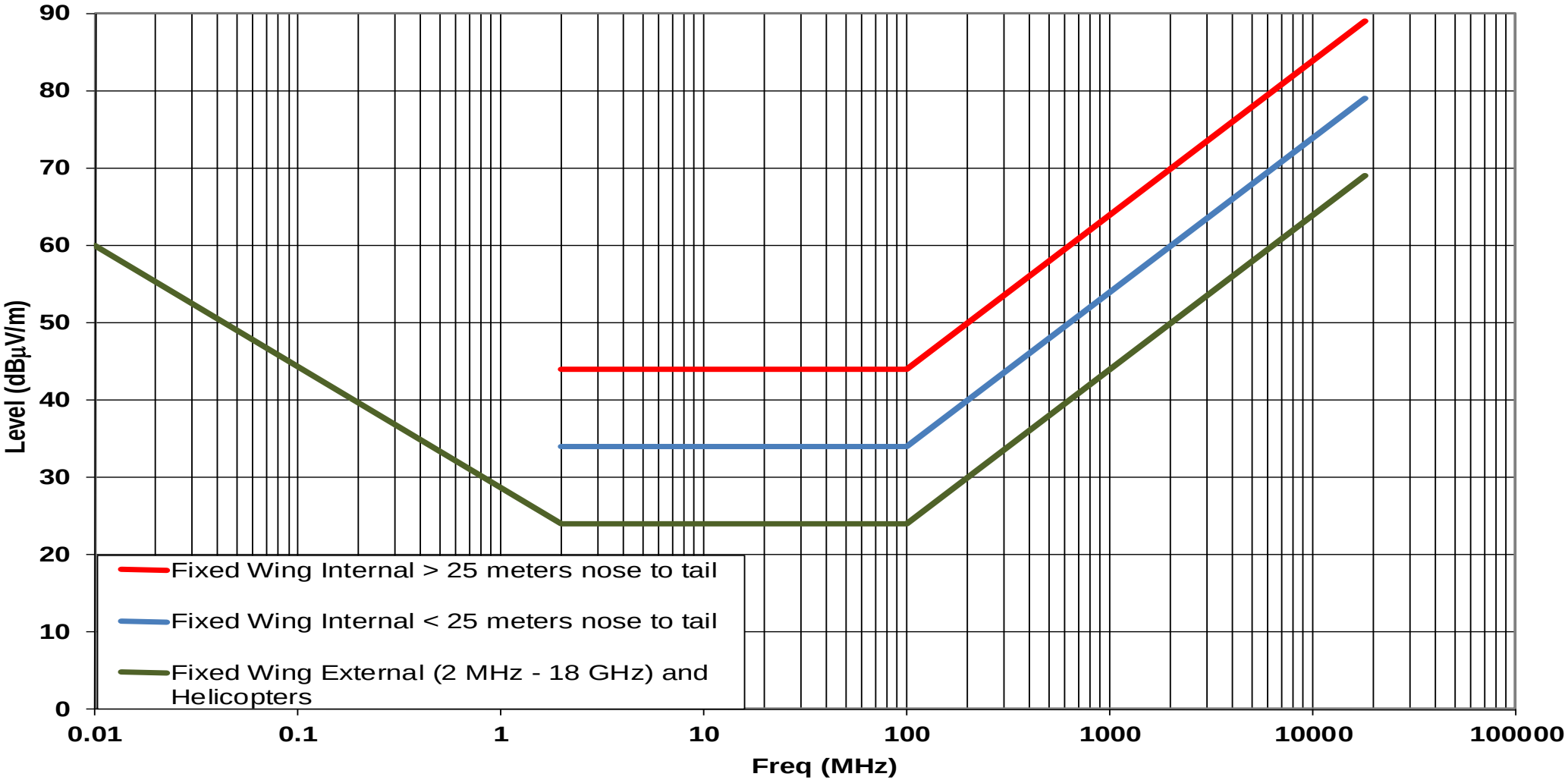
Surface Ship Applications

RE102 Limits (cont.)



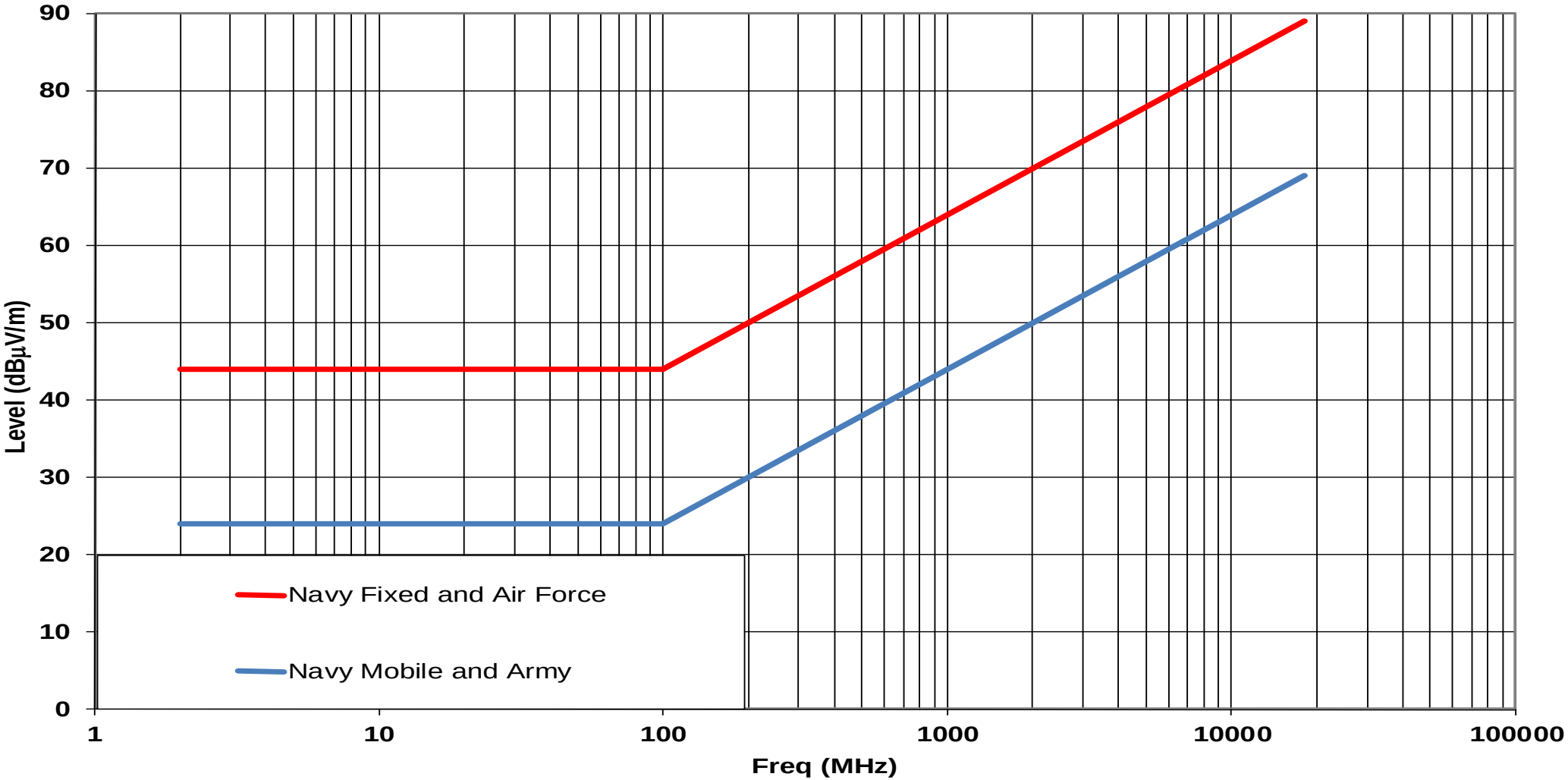
Submarine Applications

RE102 Limits (cont.)



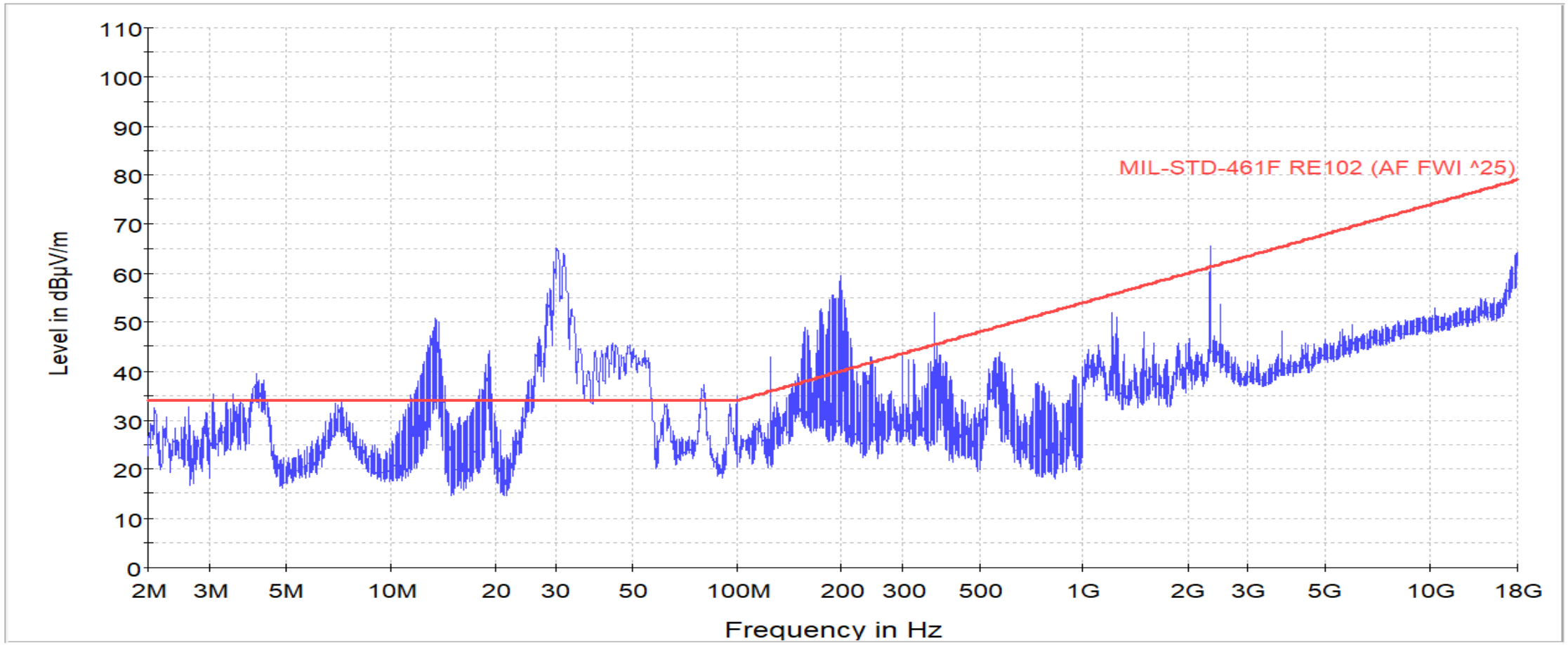
Aircraft and Space System Applications

RE102 Limits (cont.)



Ground Applications

RE102 Sample Data

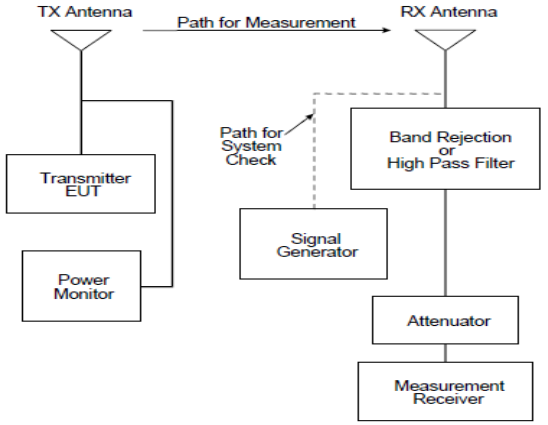


Detailed Requirements

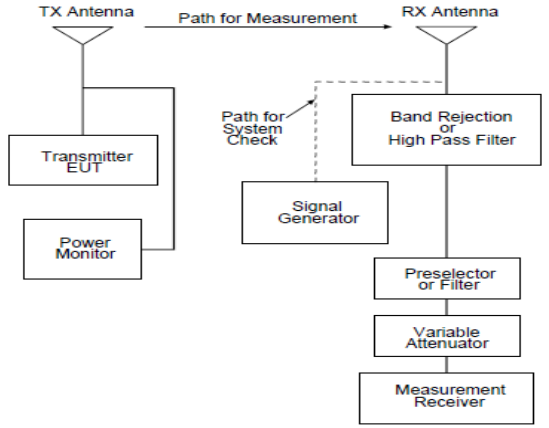
- **Radiated Emissions, Antenna Spurious and Harmonic Outputs - RE103**

RE103

- Essentially identical with CE106 for transmitters in the transmit mode.
- No requirements for receivers or transmitters in the standby mode.
- Frequency range of test is based on the EUT operating frequency.
- The test procedure is laborious and will require a large open area to meet antenna separation distances.
- Minimum acceptable antenna separations are calculated based on antenna size and operating frequency of the EUT.
- Measurements in azimuth and elevation are required.
- Preamps may be required to enhance sensitivity.
- Coordinate with local frequency allocation authorities.



10 kHz to 1 GHz



1 GHz 40 GHz

RE103 (cont.)

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 to a level of -20 dBm or 80 dB below the fundamental, whichever requires less suppression. For Navy shipboard applications, the second and third harmonics will be suppressed to a level of -20 dBm and all other harmonics and spurious emissions shall be suppressed to -40 dBm, except if the duty cycle of the emissions are less than 0.2%, then the limit may be relaxed to 0 dBm.**

Far Field Issues

For f ≤ 1.24 GHz, the greater distance of the following relationships shall be used

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

$$R = 3\lambda$$

For f > 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 ≥ d use $R = (D+d)2/\lambda$

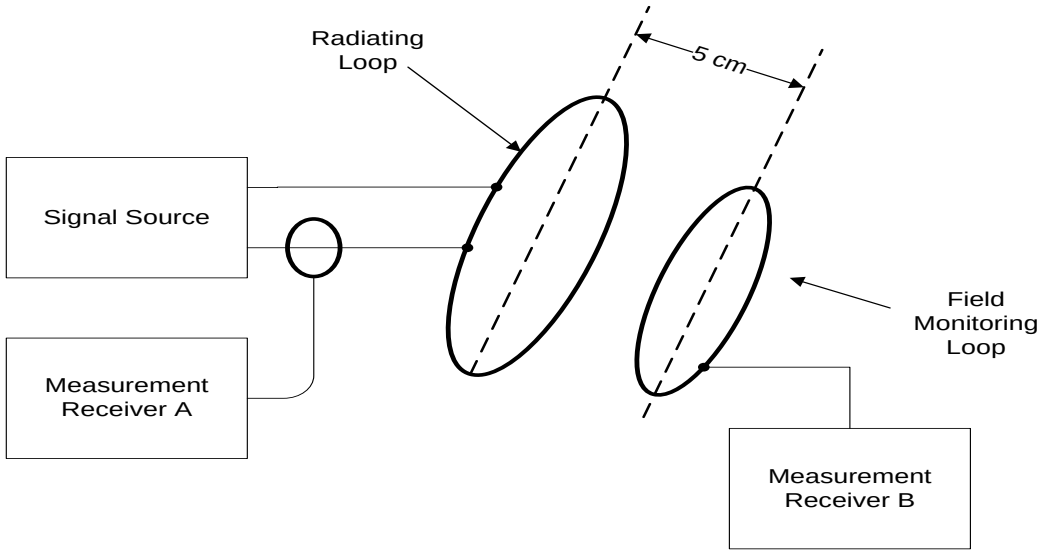
R = distance between transmitter antenna and receiver antenna
D = maximum physical dimension of transmitter antenna
d = maximum physical dimension of receiver antenna
λ = wavelength of frequency of the transmitter

Detailed Requirements

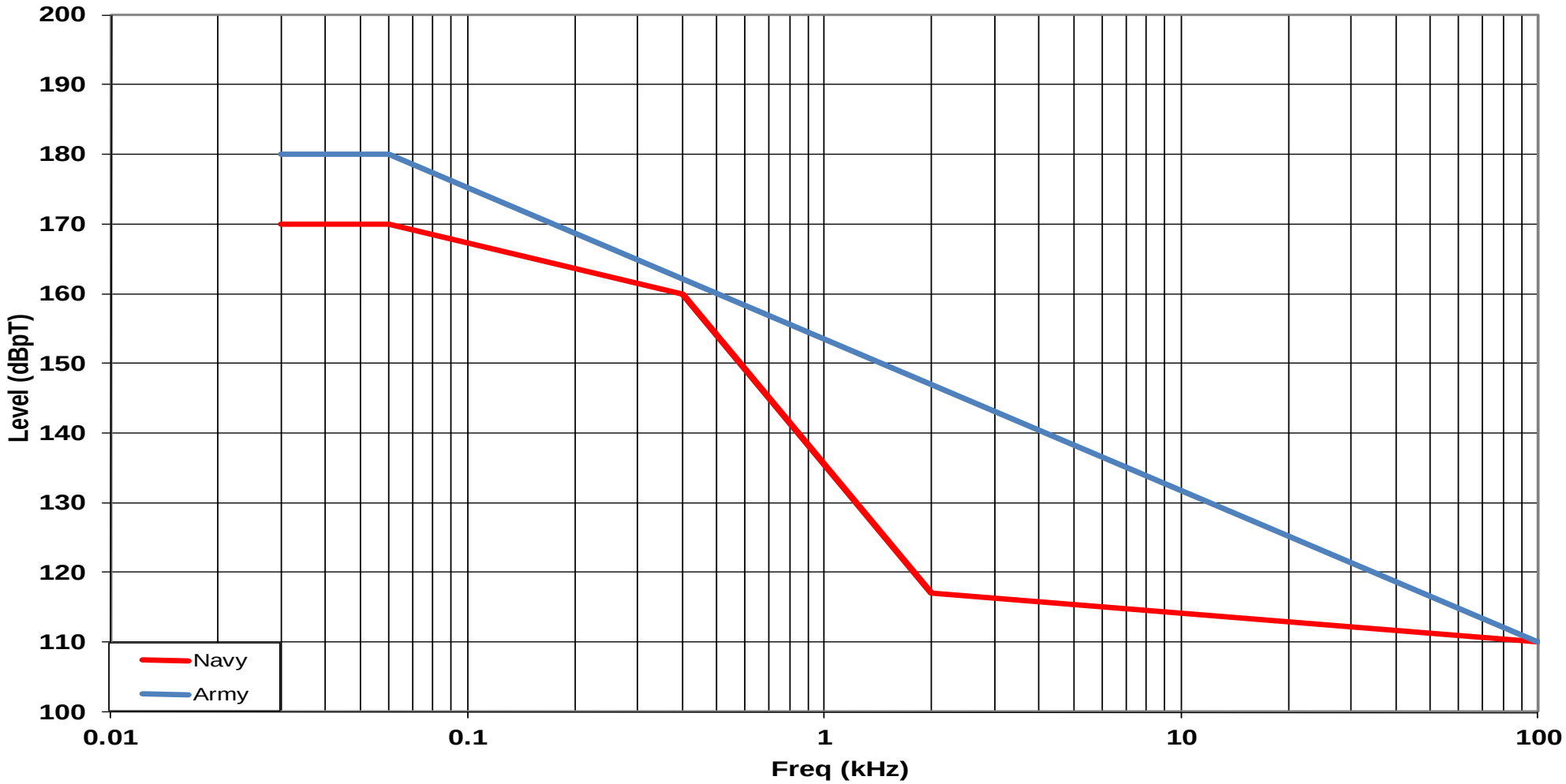
- **Radiated Susceptibility, Magnetic Field - RS101**

RS101

- Specialized test intended to ensure that performance of equipment susceptible to low frequency magnetic fields is not degraded.
- Applicable from 30 Hz to 100 kHz
- Due to its smaller size, the 4 cm loop sensor provides an accurate measure of the field near the axis of the radiating loop.
- Helmholtz coils generate a relatively uniform magnetic field that is more representative of the environment experienced on some platforms, particularly submarines. For this reason, the AC Helmholtz coil test option is preferred for submarine applications.



RS101 Limits



Limits based on service application

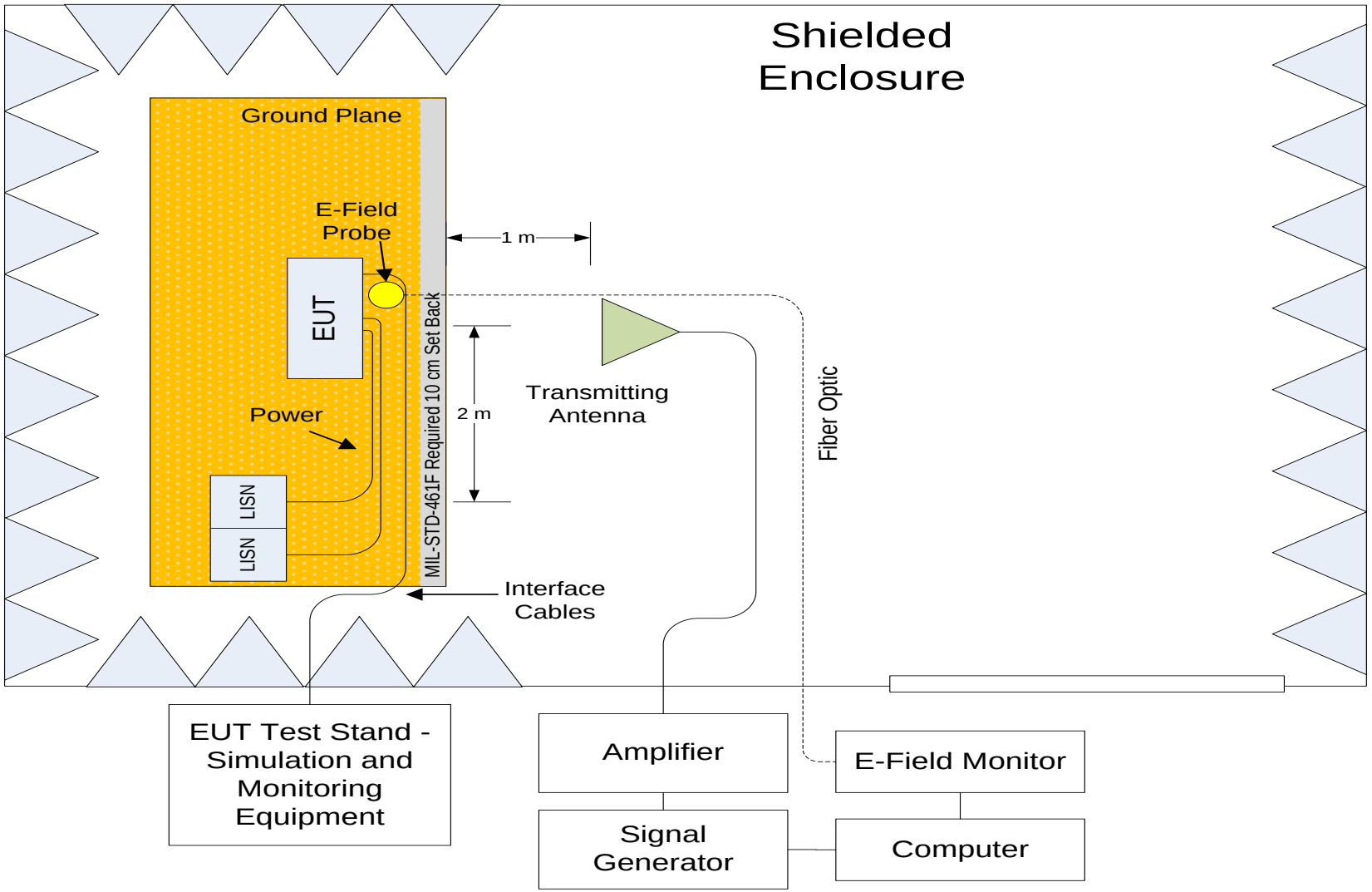
Detailed Requirements

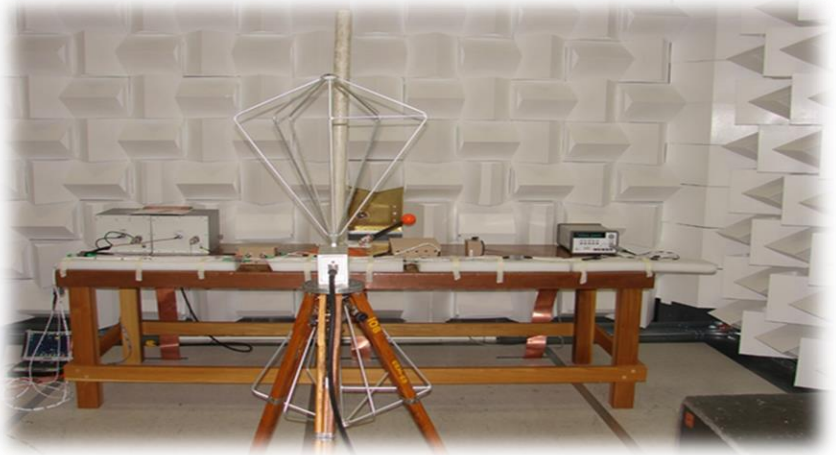
- **Radiated Susceptibility, Electric Field - RS103**

RS103

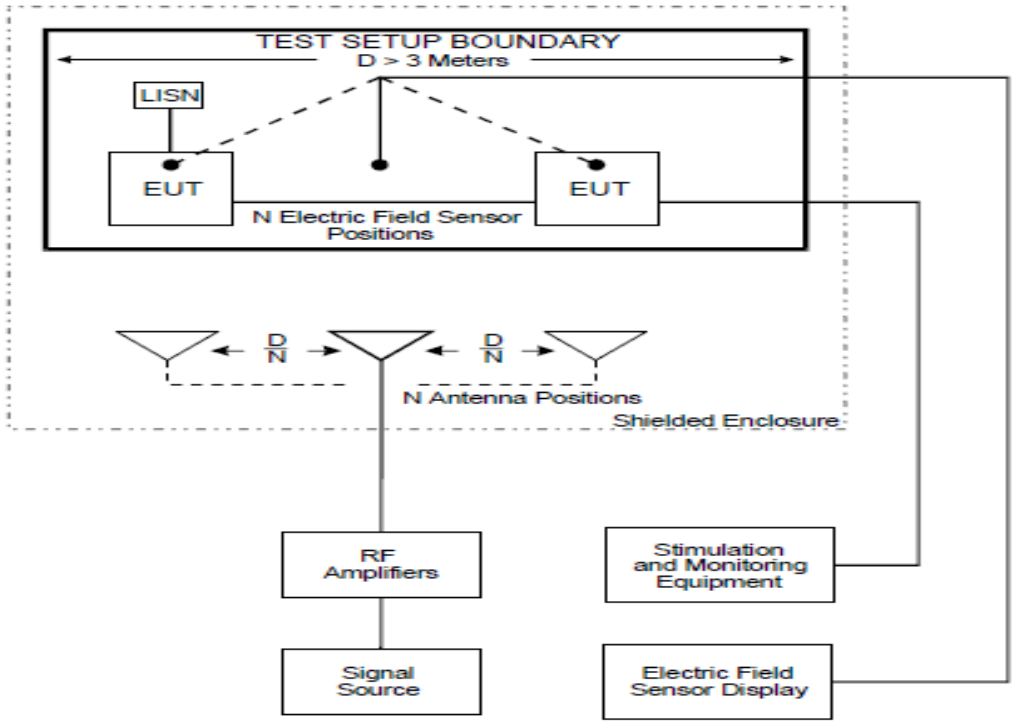
- Applicable to both the EUT enclosures and EUT associated cabling.
- Concern is to ensure that equipment will operate without degradation in the presence of electromagnetic fields generated by antenna transmissions both onboard and external to the platform.
- Limits for different platforms are based on levels expected to be encountered during the service life of the equipment.
- Not necessarily worst-case environment to which the equipment may be exposed.
- For aircraft and ships, different limits are specified depending on whether the equipment receives protection from platform structure.
- Alternative method and procedures provided for use in a mode-tuned reverberation chamber from 200 MHz to 40 GHz.

RS103 Basic Setup





RS103 Multiple Positions



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Antenna beam widths for horizontal and vertical polarities will vary and hence different number of positions for different polarities.

Below 200 MHz

Boundary < 3 meters:

1 position centered on the test setup boundary.

Boundary > 3 meters:

Number of positions determined by dividing the edge-to-edge boundary distance (in meters) by 3 and rounding up to an integer.

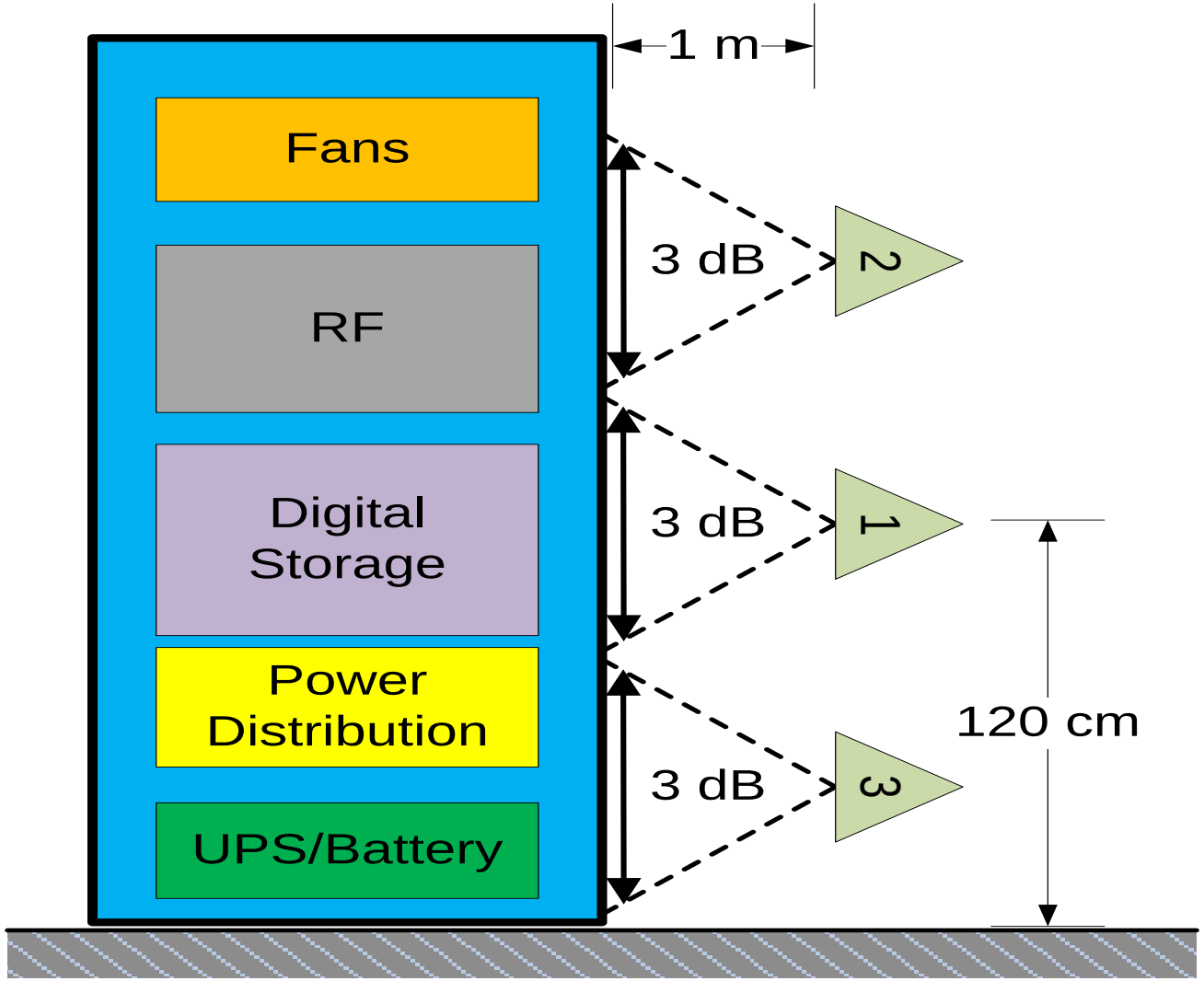
200 MHz to 1 GHz

Number of positions determined such that the **area** of each EUT enclosure and the first 35 cm of interfacing cables and leads are within the 3 dB beamwidth of the antenna.

1 GHz and Above

Number of positions determined such that the **area** of each EUT enclosure and the first 7 cm of interfacing cables and leads are within the 3 dB beamwidth of the antenna.

RS103 Increased Positions



- Previous versions did not address tall equipment chassis such as ship base 6-foot racks.
- The 3 dB beamwidth requirement is now levied against the total area and not just the width.
- Increased number of antenna positions in the vertical plane.
- Increased test time and cost.
- Better test!

RS103 Limits

	Limit Level (Volts/meter)								
Frequency Range	**Platform**	**Aircraft (External Or Safety Critical)**	**Aircraft Internal**	**All Ships (Above Deck & Exposed Below Deck) And Submarines (External) ***	**Ships (Metallic) (Below Decks)**	**Ships (Non-Metallic) (Below Decks) ****	**Submarine (Internal)**	**Ground**	Space
2 MHz to 30 MHz	Army	200	200	200	10	50	5	50	20
	Navy	200	200	200	10	50	5	10	20
	Air Force	200	20	-	-	-	-	10	20
30 MHz to 1 GHz	Army	200	200	200	10	10	10	50	20
	Navy	200	200	200	10	10	10	10	20
	Air Force	200	20	-	-	-	-	10	20
1 GHz to 18 GHz	Army	200	200	200	10	10	10	50	20
	Navy	200	200	200	10	10	10	50	20
	Air Force	200	60	-	-	-	-	50	20
18 GHz To 40 GHz	Army	200	200	200	10	10	10	50	20
	Navy	200	60	200	10	10	10	50	20
	Air Force	200	60	-	-	-	-	50	20

* For equipment located external to the pressure hull of a submarine but within the superstructure, use Ships (Metallic) (Below Decks)

** For equipment located in the hanger deck of Aircraft Carriers

RS103 – Reverberation Chamber

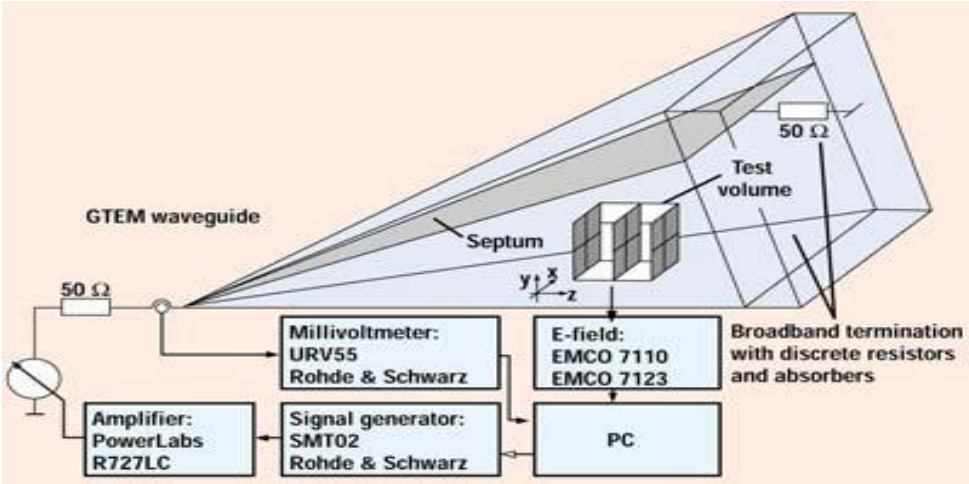
- **MIL-STD-461G provides an alternative RS103 test method using reverberation chambers (mode-tuned) from 200 MHz to 40 GHz.**
- **The lower frequency limit is dependent on chamber size.**
- **Advantages include producing relatively higher fields than other techniques for a particular power input, EUT orientation less critical.**
- **Chamber performance depends on its dimensions, Q of the chamber, number of available propagation modes, and frequency range of use.**
- **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 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 suitability**

Detailed Requirements

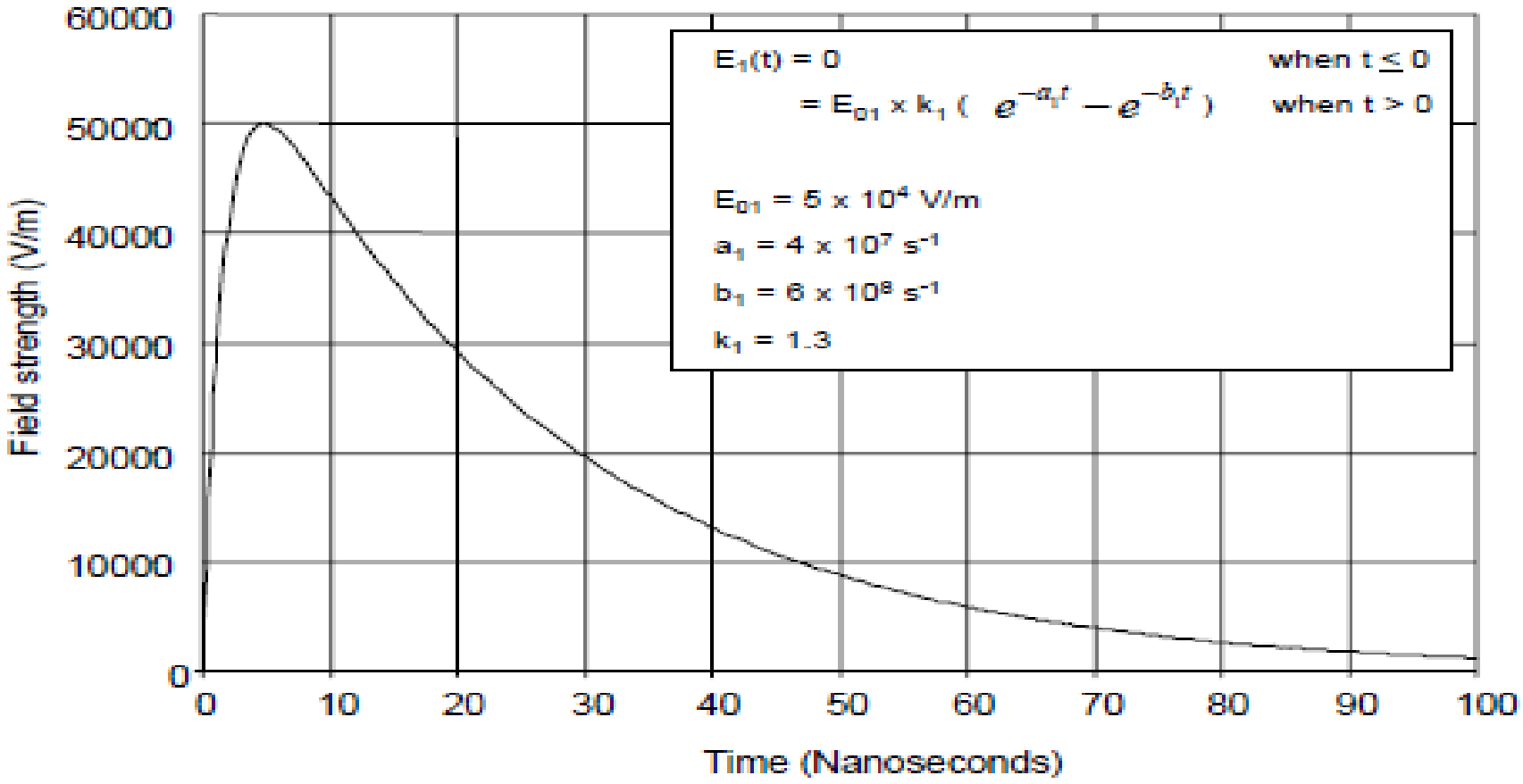
- **Radiated Susceptibility, Transient Electromagnetic Field - RS105**

RS105

- Intended for EUTs to withstand the fast rise time, free-field transient environment of EMP.
- Applies for equipment enclosures which are directly exposed to the incident field outside of the platform structure or for equipment inside poorly shielded or unshielded platforms.
- The electrical interface cabling should be protected in shielded conduit.
- The EMP field is simulated in the laboratory using bounded wave TEM radiators such as TEM cells and parallel plate transmission lines.
- Since the polarization of the incident EMP field in the installation is not known, the EUT must be tested in all orthogonal axes.



RS105 Limits



Free-field EMP transient waveform

Wrap Up

- Additional Training
- Questions
- Backup Slides

Additional Training Available At:

https://www.dau.edu/cop/e3/Pages/Topics/E3%20-%20SS%20Awareness%20Training%20and%20E3%20-%20Spectrum%20Conferences.aspx

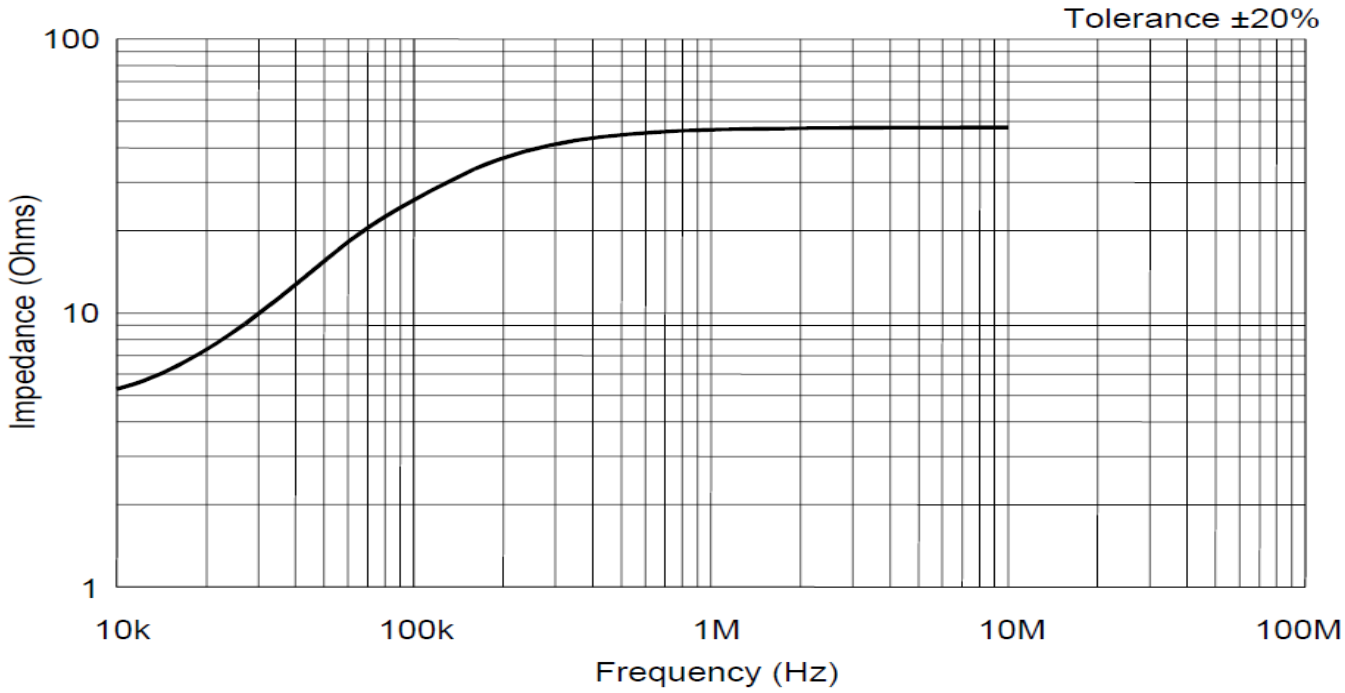
Questions

CE101 Changes in MIL-STD-461G

- For equipment intended to be installed on Navy aircraft, this requirement is applicable only if the platform contains Anti-Submarine Warfare (ASW) equipment, which operate between 30 Hz and 10 kHz, such as Acoustic (Sonobuoy) Receivers or Magnetic Anomaly Detectors (MAD).
- Measurement system check frequencies specified 1.1 kHz, 3 kHz and 9.9 kHz instead of 1.0 kHz, 3 kHz and 10.0 kHz.
- Figure CE101-1 is now specified for both surface ship and submarine DC applications.

CE102 Changes in MIL-STD-461G

- **Measurement system check frequencies specified 10.5 kHz, 100 kHz, 1.95 MHz and 9.8 MHz instead of 10.0 kHz, 100 kHz, 2 MHz and 10 MHz.**
- **Measurement system check procedure is clarified for lower frequencies and requires verification of the LISN impedance voltage to 50 ohm voltage ratio.**
- **LISN impedance is less than 50 Ohms at 10 kHz and 100 kHz. Therefore, the signal source output amplitude must be increased above the actual level resulting across the LISN.**



CE106 Changes in MIL-STD-461G

- **MIL-STD-461F statement - "RE102 is applicable for emissions from antennas in receive and standby modes for equipment designed with antennas permanently mounted to the EUT." Has been deleted.**
- **For Navy shipboard transmitters, the exclusion zone surrounding the transmit frequency (previously 5%) is increased for transmitters operating above 1 kW.**
- **Upper test frequency range has been changed:**
  - 20 times the highest frequency or 18 GHz whichever is greater for systems with the frequencies generated or received less than 1 GHz.
  - 10 times the highest frequency or 40 GHz whichever is less for systems with frequencies generated or received greater than or equal to 1 GHz.
- **The limit for Navy shipboard transmitters has changed:**
  - **2nd and 3rd harmonics will be suppressed to a level of -20 dBm and all other harmonics and spurious emissions shall be suppressed to -40 dBm, except if the duty cycle of the emissions are less than 0.2%, then the limit may be relaxed to 0 dBm.**

CS101 Changes in MIL-STD-461G

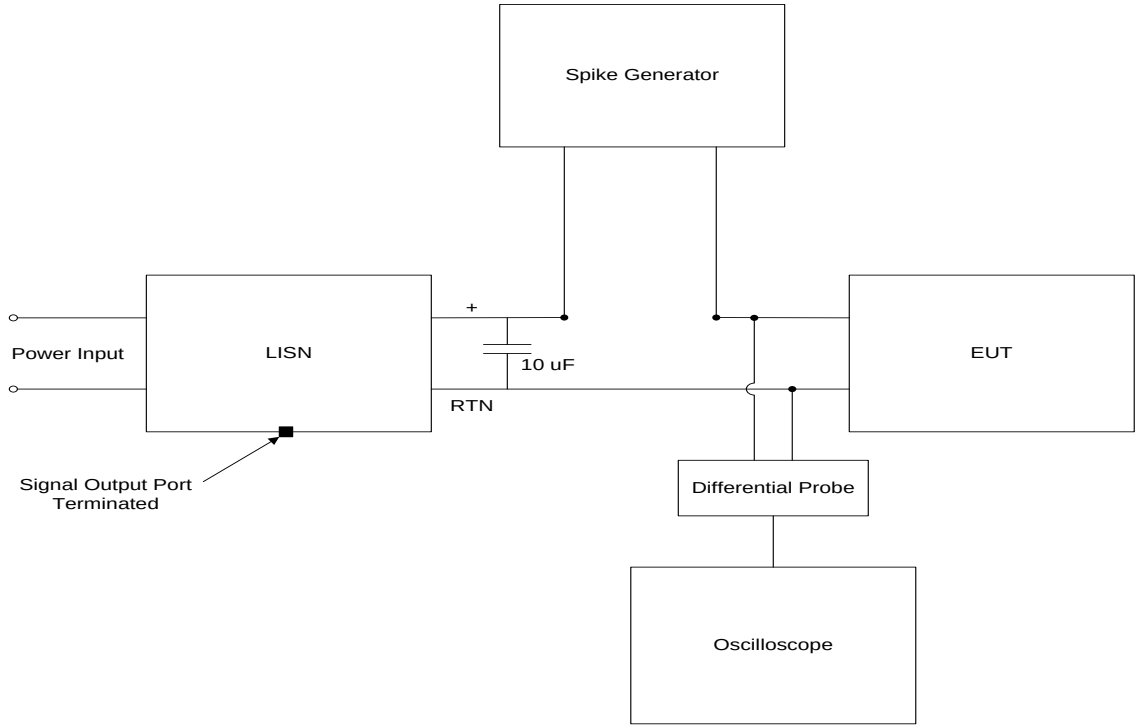
- **Changes to the applicability.**
  - Current limitation reduced from ≤ 100 Amps per phase to ≤ 30 Amps per phase.

Unless…

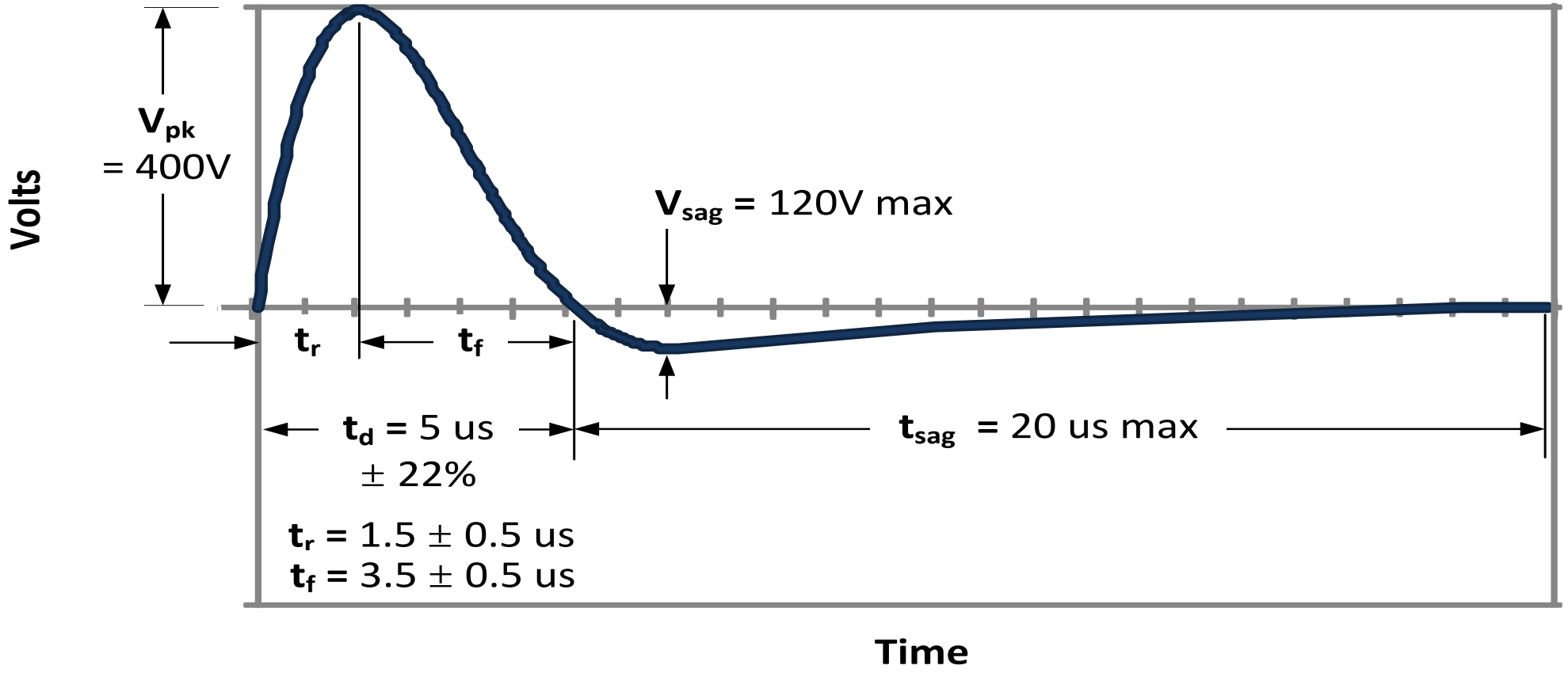
  - The system has an operating frequency 150 kHz or less and an operating sensitivity of 1 µV or better (such as 0.5 µV).
- **Clarification provided for Wye and Delta power test setups.**
- **Power Line Ripple Detector (PRD) use is now allowed.**
  - The PRD contains an isolation transformer and allows a frequency domain measurement.

CS106 Removed For 461G

- Applicable to power input leads on surface ships and submarines that obtain power from the platform's primary power source that are not part of the EUT.
- Primary concern is to ensure that performance is not degraded from voltage transients from shipboard power systems.
- On submarines and surface ships, these transients can be caused by switching of inductive loads, circuit breaker (or relay) bounce, and load feedback onto the power distribution system.
- CS115 already meets the intent behind CS106.



CS106 Removed For 461G (cont.)

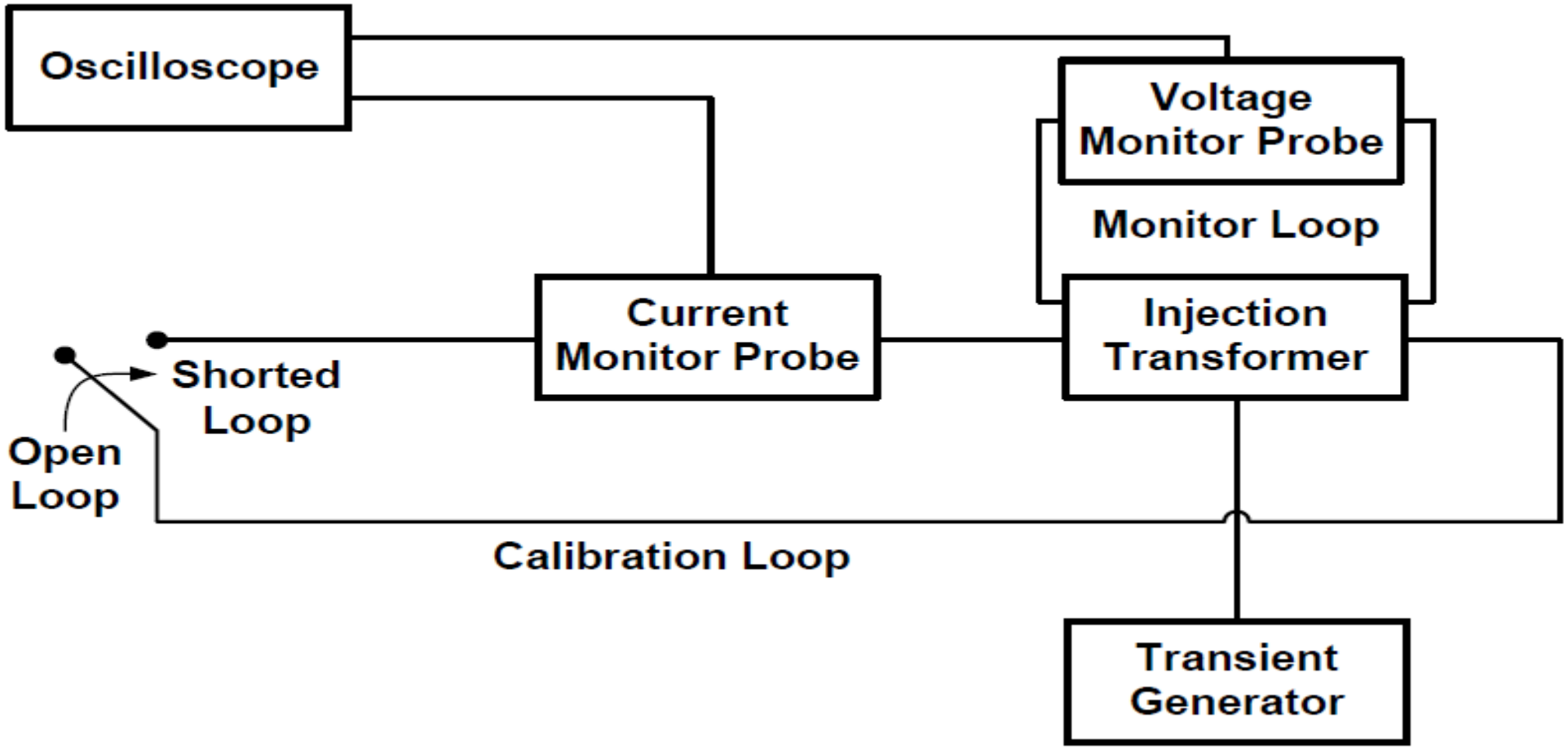


Limits based on a representation of the typical transients observed on Navy platforms.

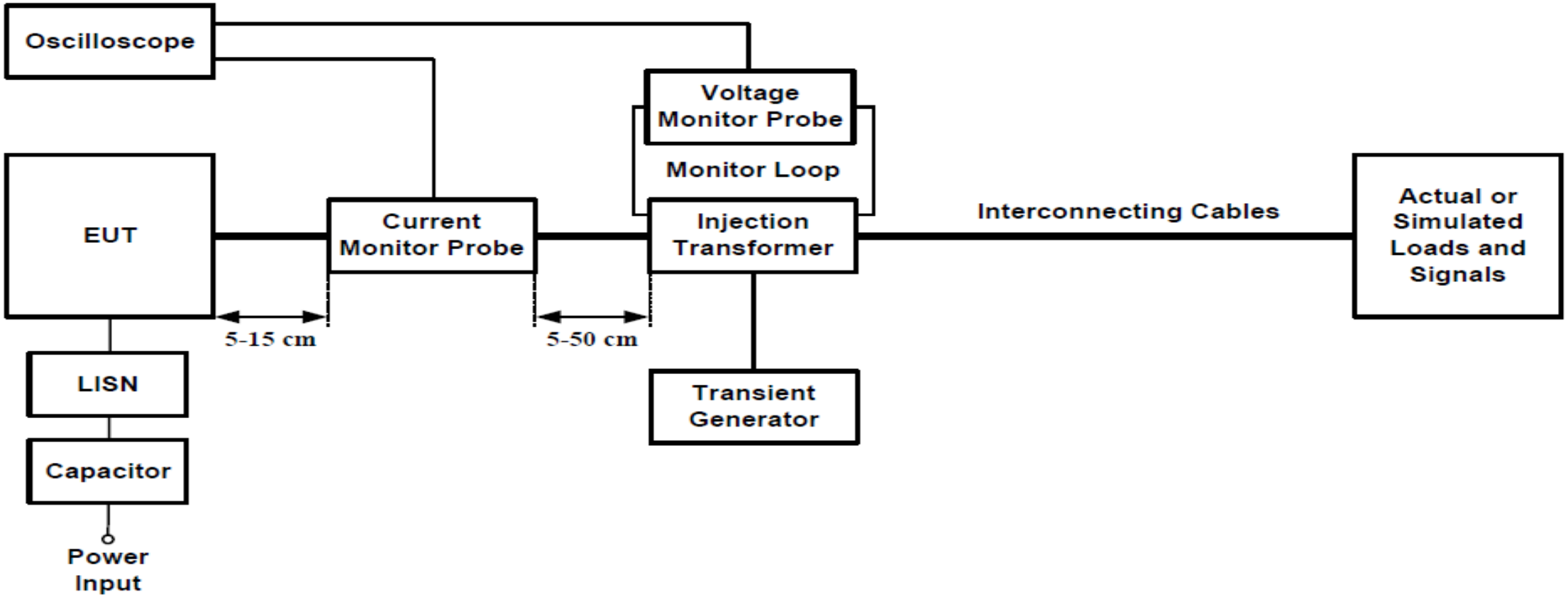
CS114 Changes in MIL-STD-461G

- Calibration with the monitor probe in place within the calibration fixture to compensate for the monitor probe loading effects encountered during EUT testing.
- Verification check required to ensure that the forward power follows the calibration and that the developed current is within a 3 dB tolerance of the current test limit.
- Actual current induced in the cable under test is now limited to: Curve 5 - 115 dBµA, Curve 4 - 103 dBµA, Curve 3 - 95 dBµA, Curve 2 - 89 dBµA and Curve 1 - 83 dBµA across the frequency range. Instead of 6 dB above the curve as in 461F.

CS117 Calibration Setup

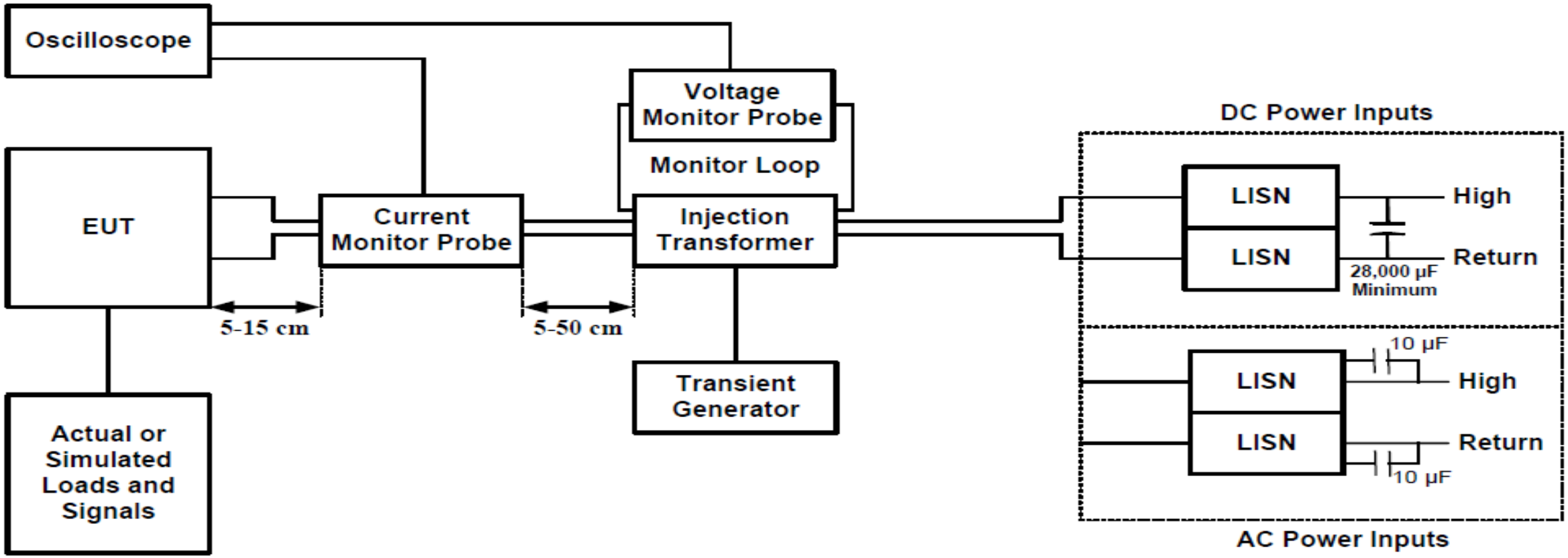


CS117 Test Setup



Interconnecting Cable Bundles

CS117 Test Setup (cont.)

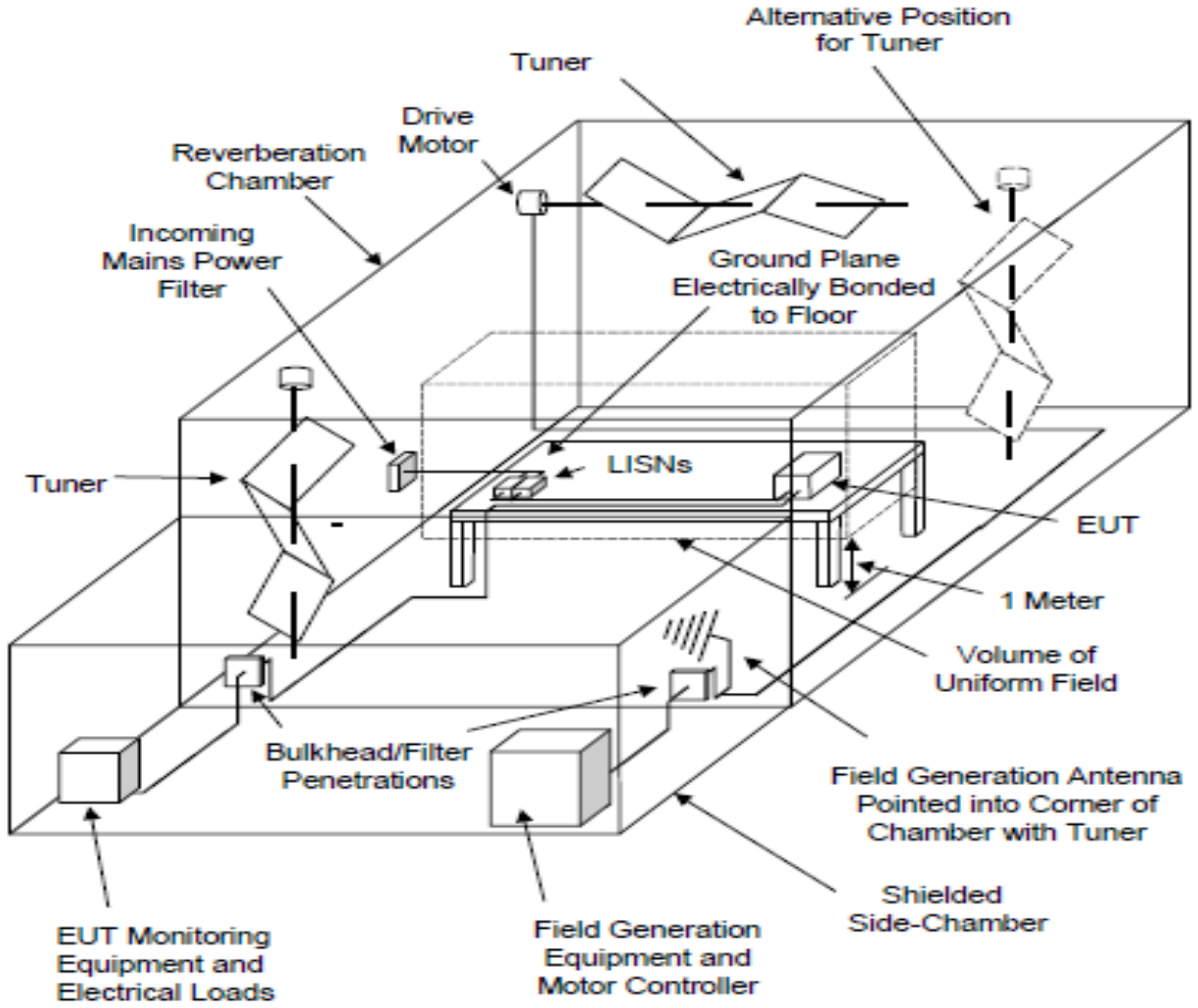


Complete Power Cable Bundles

RE101 Changes in MIL-STD-461G

- **For Navy aircraft, this requirement is only applicable for ASW capability operating between 30 Hz and 10 kHz.**
  - Clarified from 461F
- **Loop sensor winding resistance now specified to be between 5 and 10 ohms**
  - 461F stated “approximately 10 ohms”

RS103 – Reverberation Chamber (cont.)



RS103 – Reverberation Chamber (cont.)

- The lower frequency limit is dependent on chamber size.
- Must have a minimum of 100 possible modes (N) at a given frequency.

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

a, *b*, and *d* are chamber dimensions

f is the operating frequency in Hertz

c is the speed of light

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

RE102 Changes in MIL-STD-461G

- **Upper test frequency now 18 GHz for all applications versus 1 GHz or 10 times the highest intentionally generated frequency.**
- **New antenna position requirements for free standing equipment.**
- **Section 5.18.1 RE102 applicability under MIL-STD-461G: "… this requirement does not apply at the transmitter fundamental frequency and the necessary occupied bandwidth of the signal."**
- **Measurement system check frequencies specified:**
  - 10.5 kHz, 2.1 MHz, 12 MHz and 29.5 MHz for the active rod antenna instead of low mid and high frequencies.
  - 197 MHz for the biconical antenna.
  - 990 MHz for the large horn and 17.5 GHz for the small horn.
- **Rod antenna output capacity is changed from 10 pF nominal to manufacturer's recommendation and the detuning bead specs moved from the appendix to main body.**

RE103 Changes in MIL-STD-461G

- **Specific guidance given for Navy shipboard applications with peak transmitter power greater than 1 kW.**
  - Frequency exclusion is increased by 0.1% for each 1 dB above 1 kW.
- **Upper test frequency now based on intentional frequencies instead of 40 GHz or 20 times the highest intentional frequency.**
  - Intentional frequencies < 1 GHz – upper test frequency is 20 times the highest intentional frequency or 18 GHz whichever is greater.
  - Intentional frequencies ≥ 1 GHz – upper test frequency is 10 times the highest intentional frequency or 40 GHz whichever is less.
- **Navy shipboard applications limit is modified.**
  - 2^{nd} and 3^{rd} harmonics will be suppressed to a level of -20 dBm and all other harmonics and spurious emissions shall be suppressed to -40 dBm, except if the duty cycle of the emissions are less than 0.2%, then the limit may be relaxed to 0 dBm.

RS101 Changes in MIL-STD-461G

- **Navy Ship ands Submarine applicability clarified.**
  - "For Navy ships and submarines, this requirement is applicable only to equipment and subsystems that have an operating frequency of 100 kHz or less and an operating sensitivity of 1 µV or better (such as 0.5 µV). For Navy aircraft, this requirement is applicable only to equipment installed on ASW capable aircraft, and external equipment on aircraft that are capable of being launched by electromagnetic launch systems."

RS103 Changes in MIL-STD-461G

- **New antenna position requirements for free standing equipment.**
- **Use of receive antennas for field calibration above 1 GHz has been eliminated and the use of E-Field sensors for real time field leveling over the entire frequency range is now required.**
- **Testing below 30 MHz required for Army and Navy, optional for all others.**
- **Receivers with permanently attached antennas, reduced performance over the intended receiver band of operation is allowed.**
  - The receiver shall meet its performance requirements after in-band exposure to the radiated field.

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