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2019 MILITARY & AEROSPACE EMC GUIDE

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INTRODUCTION

Kenneth Wyatt
Sr. Technical Editor
Interference technology
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There some exciting technologies occur ring within the military and aerospace sectors. Advances in millimeter wave communications and control, and especially autonomous vehicles, more advanced UAVs, drones, and robotics, are playing a greater role in military strategy. For example, drones now make up half the U.S. Air Force fleet and the next generation are already under development.

NASA is celebrating its 60th year anniversary and working on a second Mars rover to be launched shortly. They are also involved in additional flights to the moon as a primary jump-off spot to support a manned Mars mission.

In general, the aerospace sector is moving ahead with many exciting projects, including James Webb Space Telescope with improved technology over the current Hubble Telescope. Several companies are starting to develop prototype autonomous aircraft.

Commercial space launch platforms from Virgin Galactic, SpaceX, Scaled Composites, and the many "mini" launch companies, such as Sierra Nevada, Star Chaser, Venturer Aerospace, XCOR, Blue Origin, and others, are bringing more affordable alternatives to NASA and Arianne programs, as well as existing programs in Russia, China, Japan, and many other countries.

This new downloadable guide helps bring product designers and EMC engineers up to date on current DoD procurement policies and procedures. It also includes articles on MIL-STD-461 key tests and we've started a new series on DO-160 for aerospace applications, electronic equipment grounding, and selecting the right filter for military and defense applications. Finally, we wrap up with some useful reference data on military and aerospace standards, a chart of EMC-related equipment suppliers, links to longer articles, and other valuable references.

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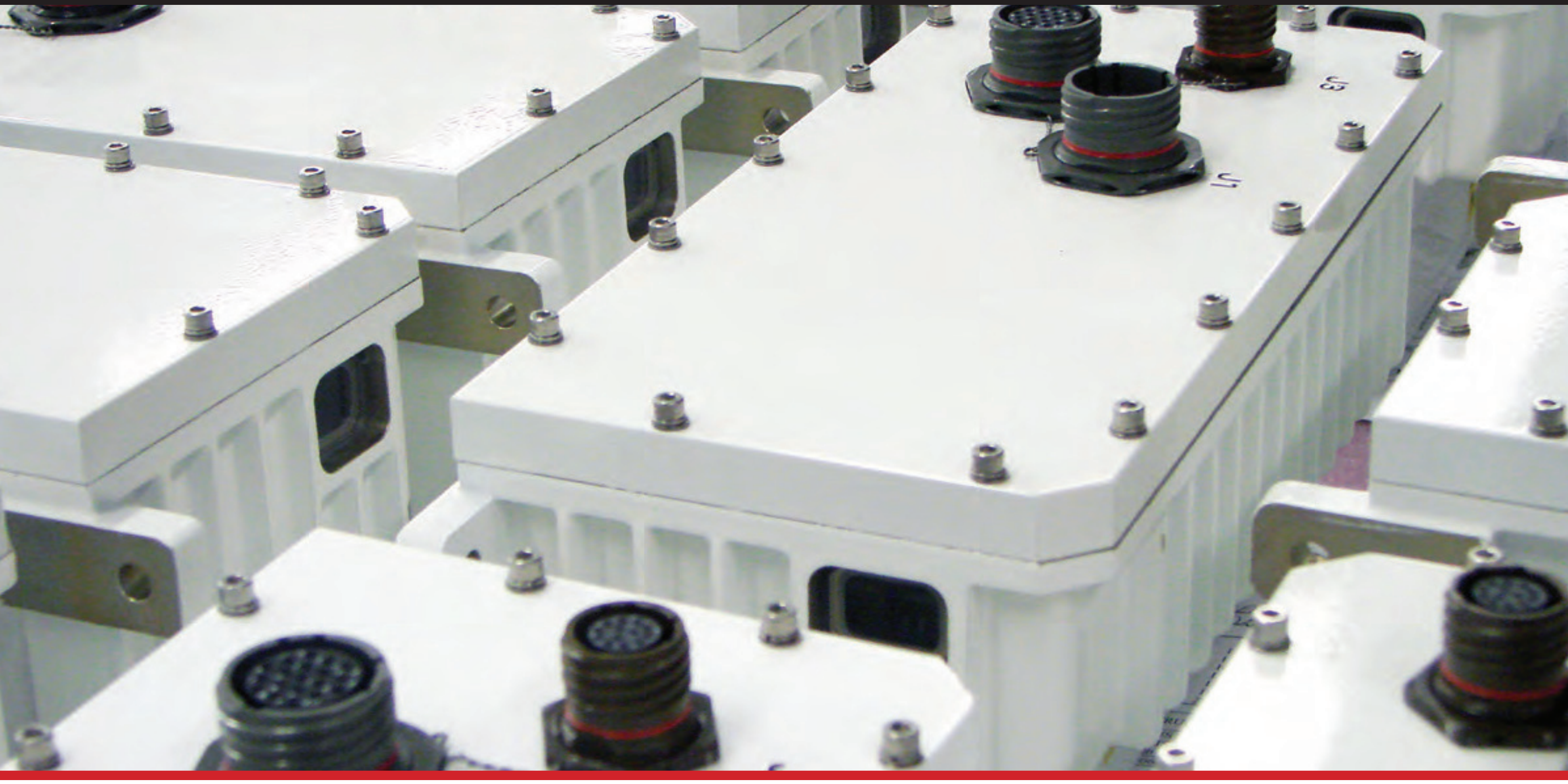

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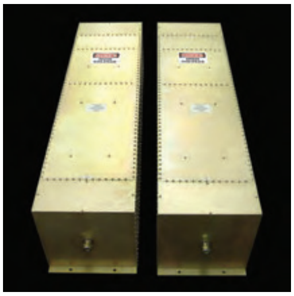

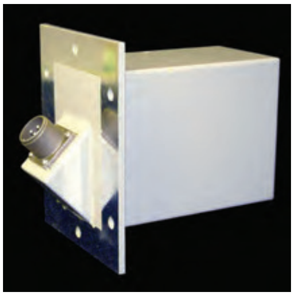

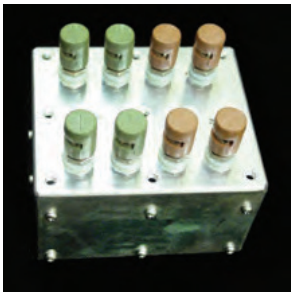

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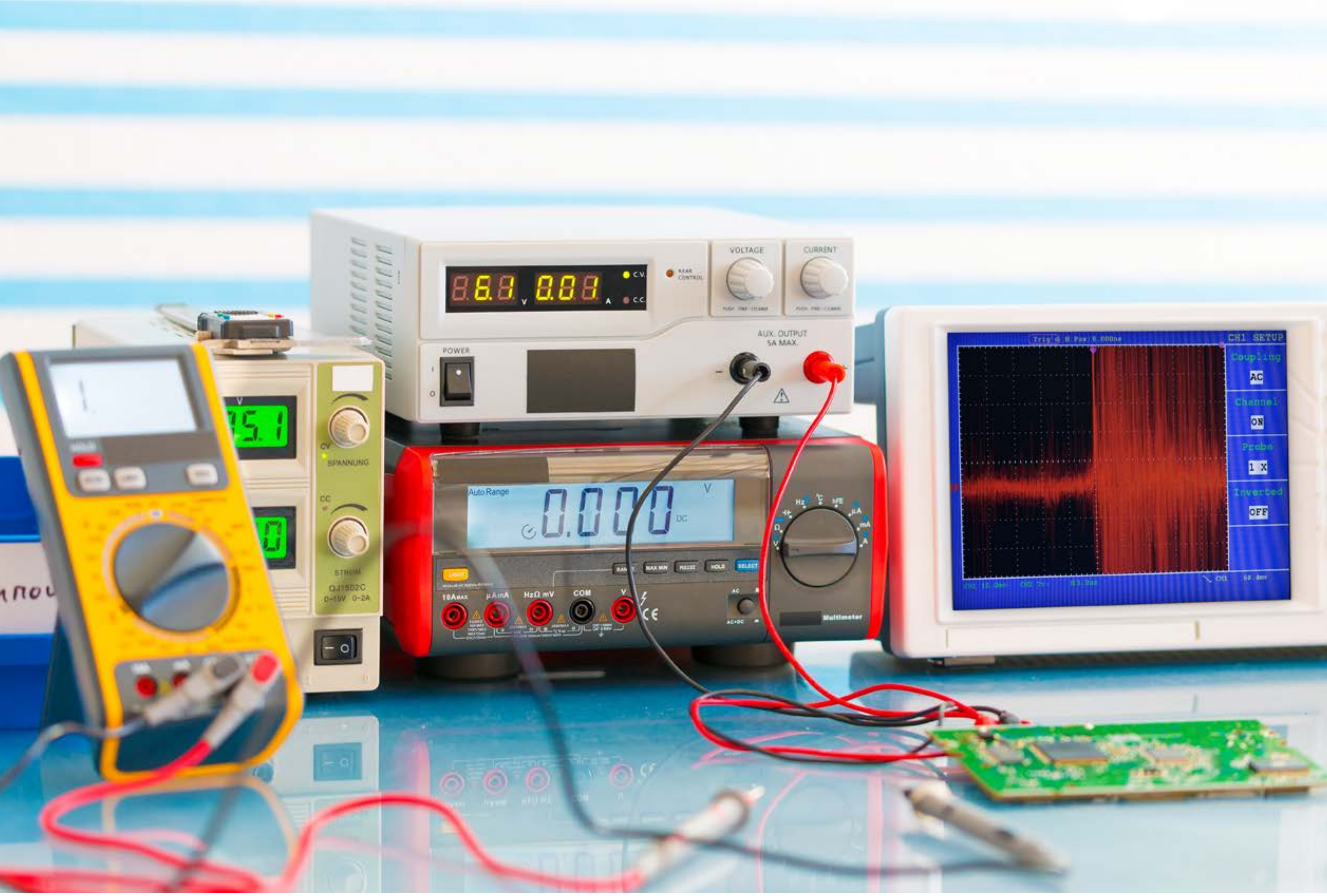
EMC EQUIPMENT MANUFACTURERS

Introduction

The following chart is a quick reference guide of test equipment and includes everything you'll need from the bare minimum required for key evaluation testing, probing, and troubleshooting, to setting up a full in-house precompliance or full compliance test lab for military and aerospace testing. The list includes amplifiers, antennas, current probes, ESD simulators, LISNs, near field probes, RF signal generators, spectrum analyzers, EMI receivers, and TEM cells. Equipment rental companies are also listed. The products listed can help you evaluate radiated and conducted emissions, radiated and conducted immunity and a host of other immunity tests, such as the new ESD test for MIL-STD-461G.



EMC Equipment Manufacturers		Type of Product/Service															
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Conducted Immunity	Current Probes	EMC Filters	EMC Testing	ESD Simulators	LISNs	Near Field Probes	Pre-Compliance Test	Radiated Immunity	Rental Companies	RF Signal Generators	Software	Spectrum Analyzers/EMI Receivers	TEM Cells
A.H. Systems	www.ahsystems.com	X	X		X						X						
Aaronia AG	www.aaronia.com	X	X								X					X	
Advanced Test Equipment Rentals	www.atecorp.com	X	X	X	X			X	X	X	X	X	X	X		X	X
ALTAIR	www.altair.com														X		
Amplifier Research (AR)	www.amplifiers.com	X	X	X					X		X	X		X		X	
Anritsu	www.anritsu.com										X			X		X	
Electro Rent	www.electrorent.com	X		X				X	X		X	X	X	X		X	
EM Test	www.emtest.com/home.php			X							X						X
EMC Partner	www.emc-partner.com			X				X									
Empower RF Systems	www.empowerrf.com	X										X					
Fischer Custom Communications	www.fischercc.com				X				X	X	X						
Gauss Instruments	www.gauss-instruments.com/en/															X	
Haefley-Hippotronics	www.haefely-hipotronics.com			X				X									
HV Technologies, Inc.	www.hvtechnologies.com	X		X								X		X		X	
Instrument Rental Labs	www.testequip.com	X		X				X	X		X	X	X	X		X	
Instruments For Industry (IFI)	www.ifi.com	X		X								X					
ITG Electronics	www.itg-electronics.com					X											
Keysight Technologies	www.keysight.com/main/home.jspx?cc=US&lc=eng								X	X	X			X	X	X	
Microlease	www.microlease.com/us/home	X		X				X	X		X	X	X	X		X	
Milmega	www.milmega.co.uk	X		X								X					
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X	X					X		X	X				X	
Noiseken	www.noiseken.com			X				X			X						
Ophir RF	www.ophirrf.com	X		X													
Pearson Electronics	www.pearsonelectronics.com				X												
PPM Test	www.ppmtest.com		X								X	X			X	X	
R&B Laboratory	www.rblaboratory.com						X										
Rigol Technologies	www.rigolna.com				X					X	X			X	X	X	
Rohde & Schwarz	www.rohde-schwarz.com/us/home_48230.html	X	X	X	X				X	X	X	X		X	X	X	
Siglent Technologies	www.siglentamerica.com									X	X			X	X	X	
Signal Hound	www.signalhound.com									X	X			X	X	X	
TekBox Technologies	www.tekbox.net	X							X	X	X				X		X
Tektronix	www.tek.com									X	X				X	X	
Teseq	www.teseq.com/en/index.php	X		X	X			X			X	X					X
Test Equity	www.testequity.com/leasing/	X		X				X	X		X	X	X	X		X	
Thermo Keytek	www.thermofisher.com/us/en/home.html			X				X									
Thurlby Thandar (AIM-TTi)	www.aimtti.us										X			X		X	
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X						X		X	X				X	
TPI	www.rf-consultant.com										X			X			
Transient Specialists	www.transientspecialists.com			X								X					X
TRSRenTelCo	www.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X	X					X		X	X	X	X		X	
Vectawave Technology	www.vectawave.com	X															
Windfreak Technologies	www.windfreaktech.com										X			X			

OVERVIEW OF THE DO-160 STANDARD

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patrick@aerospacepal.com

Introduction

In aerospace, there is one standard that always seems to be popping up, DO-160. Aircraft suppliers are often complying with aviation authorities' regulations by testing their product to DO-160.

DO-160 is a standard that was published by the industry group Radio Technical Commission for Aeronautics known as RTCA. RTCA is not a government regulation, however the FAA, EASA and others will often cited RTCA/DO-160 as a means of compliance for certification. In fact, it is the de facto standard in aerospace environmental testing.

DO-160 includes both environmental plus EMC, but in this article, we'll provide an overview of just the EMC-related sections. In later blogs, we'll go through each section, describing the tests in more detail, along with specific challenges for each.

So what is in RTCA/DO-160?

OVERVIEW OF THE DO-160 STANDARD

DO-160 ENVIRONMENTAL TESTING

The first thing to note is that DO-160 is test procedure. It is not a requirement. It is not a handbook. Sure, it gives some guidance of what testing is applicable but at its core is the need for companies to standardize testing categories, methods, and procedures. With this standardization, aerospace suppliers can produce products that more easily get certified on multiple aircraft.

For example, if Bombardier, Embraer and Boeing all have different testing needs then a supplier needs to understand all three testing requirements. In addition, the testing facilities that test to these standards will also have to read and comply with all the different procedures.

With the advent and adoption of RTCA/DO-160, airlines, suppliers, testing facilities and airlines all benefit from the standardization of testing.

- Airlines are not required to maintain test standards, methods, and procedures
- Suppliers can produce products that comply with multiple aircraft platforms
- Test Facilities become more efficient and familiar with one set of testing
- Airlines recognize test pedigrees from a common standard

So, what does DO-160 look like?

RTCA/DO-160 TOC

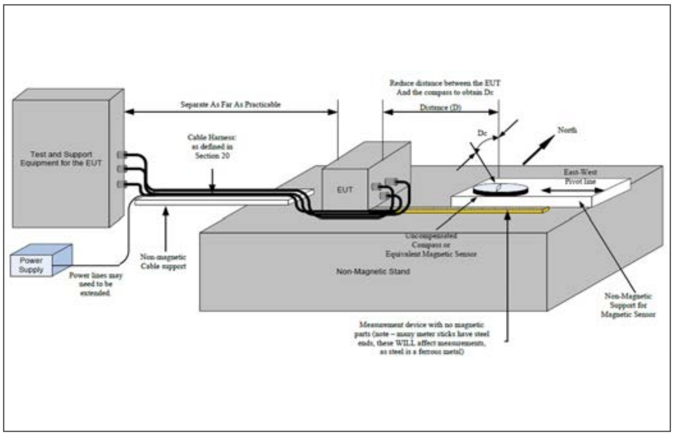
- Sect 1 – Purpose and Applicability
- Sect 2 – Definitions of Terms
- Sect 3 – Conditions of Tests
- Sect 4 – Temperature and Altitude
- Sect 5 – Temperature Variation
- Sect 6 – Humidity
- Sect 7 – Operational Shocks and Crash Safety
- Sect 8 – Vibration
- Sect 9 – Explosion Proofness
- Sect 10 – Waterproofness
- Sect 11 – Fluids Susceptibility
- Sect 12 – Sand and Dust
- Sect 13 – Fungus Resistance
- Sect 14 – Salt Spray
- Sect 15 – Magnetic Effect
- Sect 16 – Power Input
- Sect 17 – Voltage Spike
- Sect 18 – Audio Frequency Conducted Susceptibility (Power Inputs)
- Sect 19 – Induced Signal Susceptibility
- Sect 20.0 – Radio Frequency Susceptibility (Radiated and Conducted)
- Sect 21.0 – Emission of Radio Frequency Energy
- Sect 22.0 – Lightning Induced Transient Susceptibility
- Sect 23.0 – Lightning Direct Effects
- Sect 24.0 – Icing
- Sect 25.0 – Electrostatic Discharge
- Sect 26.0 – Fire, Flammability
- Appendix A – Environmental Test Identification
- Appendix B – Membership
- Appendix C – Change Coordinators

After that quick preview, let's take a look at each EMC related section.

RTCA/DO-160 EMC SECTIONS

Section 15.0 – Magnetic Effect

Technically Magnetic Effect is part of EMC, just barely. This test measures your equipment's effect on critical flight sensor like a compass. The goal is to determine where your product can be located, relative to these aircraft sensors. There is rarely an issue with the test results from Magnetic Effect.

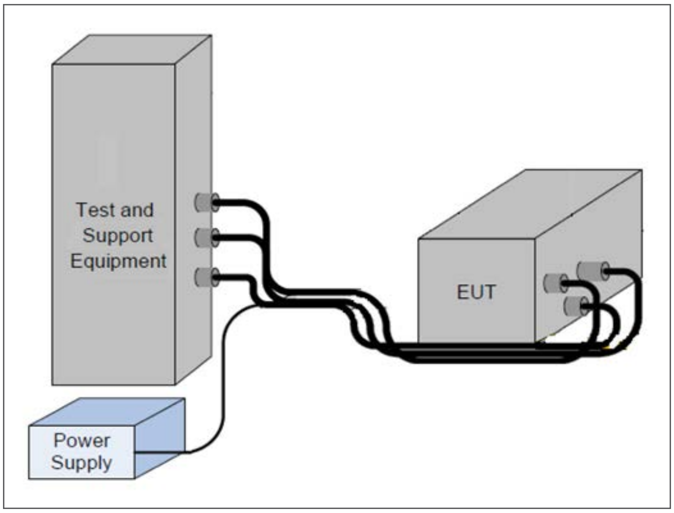


DO-160 Figure 15-1 Test Installation and Procedure

Section 16.0 – Power Input

Power input is the longest section of the standard stretching almost 70 pages. The tests are run depending on your products power source (i.e. 28VDC, 115VAC, 270VDC.) The tests in the section range from normal, abnormal and emergency operating voltages to voltage surges. It also can measure to AC harmonics, current inrush and power factor. This section encompasses all things about your power input lines.

Categories for AC equipment are sorted by the expected frequency range. For example, category A(CF) – is for power sources that stay at the center frequency, 400Hz. A(NF) is for Narrow Frequency (360 to 650 Hz) and A(WF) is for Wide Frequency (360 to 800 Hz.)

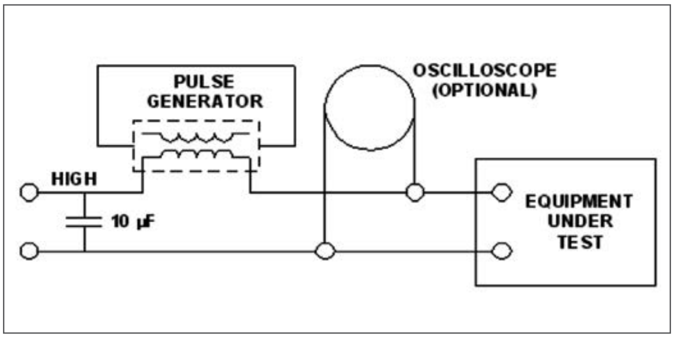


DO-160 Figure 16-1 Generic Test Setup Example

DC categories are “A” for sources with DC supplied from transformer-rectifier units, “B” for sources with significant battery capacitance, “D” 270VDC equipment and “Z” sources without constant battery capacitance.

Section 17.0 – Voltage Spike
Voltage Spike determines whether your product can tolerate the voltage spikes arriving at the unit’s power leads (AC or DC). The main adverse effects to be anticipated are permanent damage, component failure, insulation breakdown, susceptibility degradation, or changes in equipment performance.

Voltage Spike is separated in two categories, category “A” applying a 600V spike or category “B” applying a 200V spike or twice the line voltage (whichever is less).

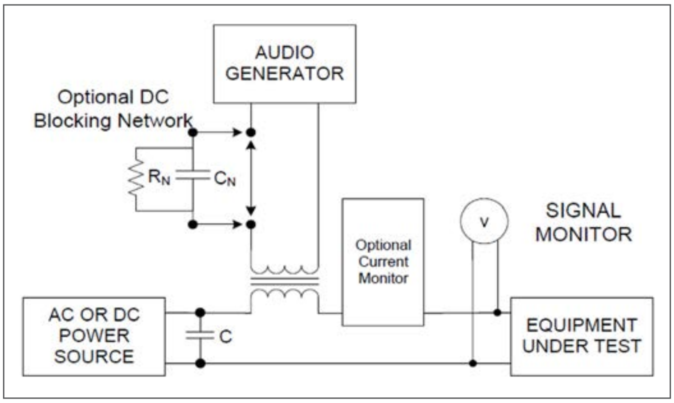


DO-160 Figure 17-2 Voltage Spike Test Setup, DC or single-phase AC

Section 18.0 – Audio Frequency Conducted Susceptibility (Power Inputs)
Audio Frequency determines whether your unit will tolerate frequency components normally seen during operation of the aircraft. These frequency components are typically harmonics of the power source fundamental frequency.

The categories for Audio Frequency mirror that or power input. They include R(CF), R(NF) or R(WF) for AC power sources and R, B, or Z for DC sources. Cat K(CF), K(NF) or K(WF) may also be required for AC systems with higher distortion levels.

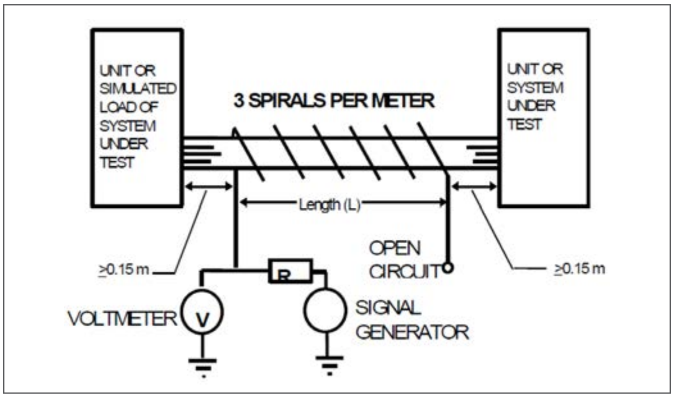
The test applies distortion to the primary power through an audio transformer.



DO-160 Figure 18-1 Test Setup for Audio Frequency Conducted Susceptibility Test (For AC and DC Power Lines, Differential Mode)

Section 19.0 – Induced Signal Susceptibility
Inducted signal susceptibility includes five tests that determine the effect of interfering signals related to the power frequency harmonics, audio frequency signals, and electrical transients created by other systems. The test simulates noise generated on other interconnecting bundles that are routed in close proximity to your unit’s wire harness on the aircraft.

The categories include B, A, Z and C which include increasing levels of susceptibility. The most severe test of 5 tests involves a switching relay chattering noise on to closely wrapped wires



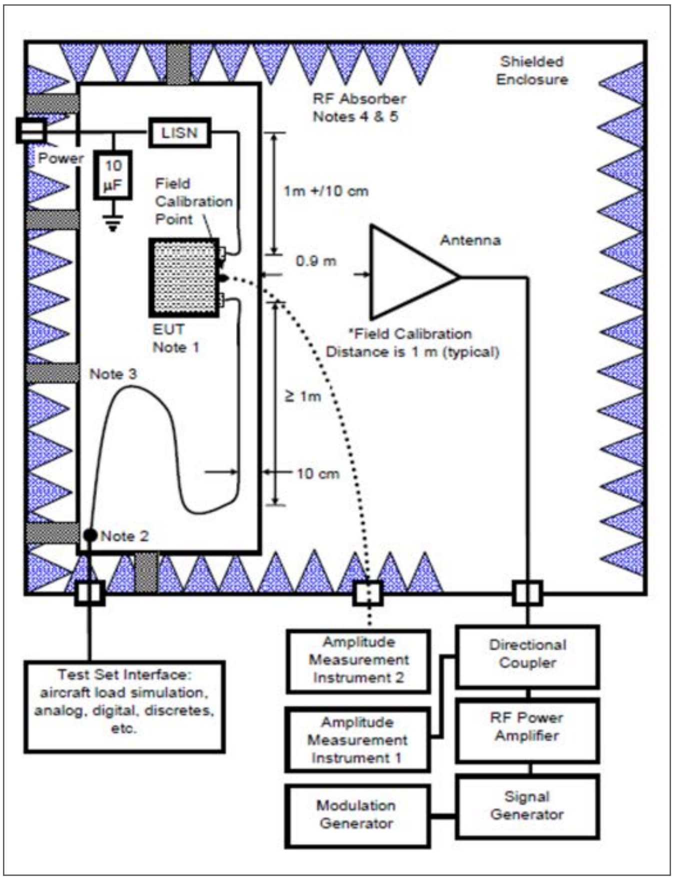
DO-160 Figure 19-4 Audio Frequency Electric Field Susceptibility Test Setup

Section 20.0 – Radio Frequency Susceptibility (Radiated and Conducted)
Radio Frequency Susceptibility’s purpose is to determine whether your product will operate within when the unit and its cable are exposed to a RF field. RF susceptibility is actually two tests; Radiated and Conducted Susceptibility, often referred to as RS and CS respectively. RF noises is applied to the EUT in continuous wave, square

wave and pulsed modulation modes.

Both tests ensure the products uninterrupted operation when it is installed in the aircraft. The section's categories includes a designator for the CS level first and the RS level second (i.e. "YG".)

Radiated Susceptibility uses an anechoic chamber and an antenna to blast the product with RF whereas Conducted Susceptibility uses an injection clamp in induce the noise onto the EUT's I/O cable.

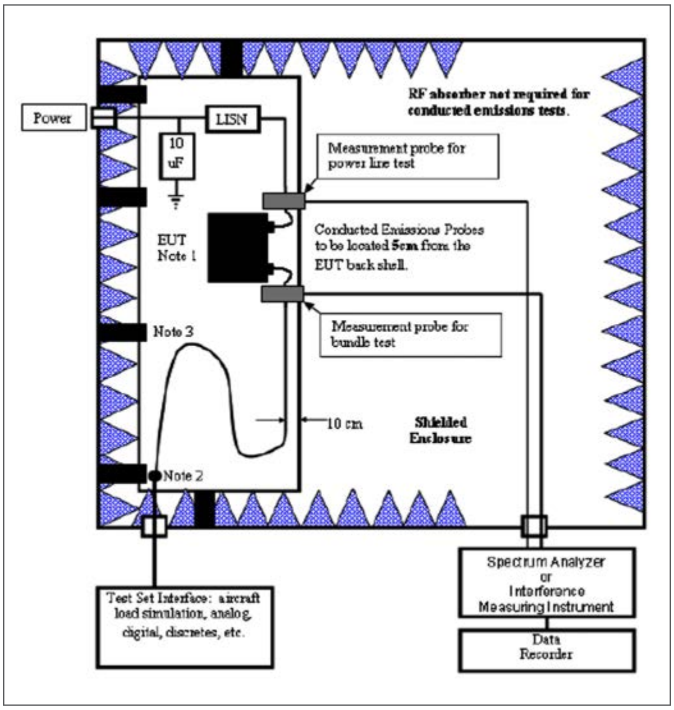


DO-160 Figure 20-2 Radiated Susceptibility Test Setup

Section 21.0 – Emission of Radio Frequency Energy
Radiated and Conducted Emissions is your typical emissions testing for aerospace products. Just like section 20.0, this section is broken into two tests; radiated and conducted. The purpose of Emission of Radio Frequency Energy is to put an upper limit on the amount of RF energy your equipment can emit on the airplane. This will ensure proper integration and operation of the aircraft.

The categories include varying levels of acceptable emissions based on the location of the equipment. Consideration is also given by the aircraft manufacturer to the nature of the product being designed.

A typical setup for the conducted emissions portion is shown below.

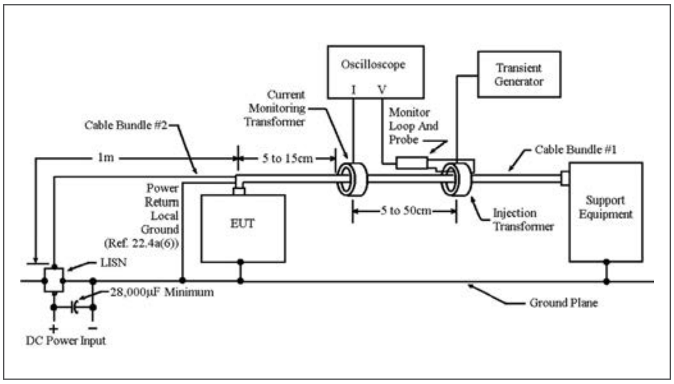


DO-160 Figure 21-6 Typical Setup for Conducted RF Interference Test

Section 22.0 – Lightning Induced Transient Susceptibility
Lightning Induced Transient Susceptibility is intended to simulate lightning events striking the airplane and coupling onto your product's interconnecting cables.

This section, sometimes referred to as indirect lightning, is severe in nature, often driving hundreds or thousands of amps into a single pin of your unit's connector.

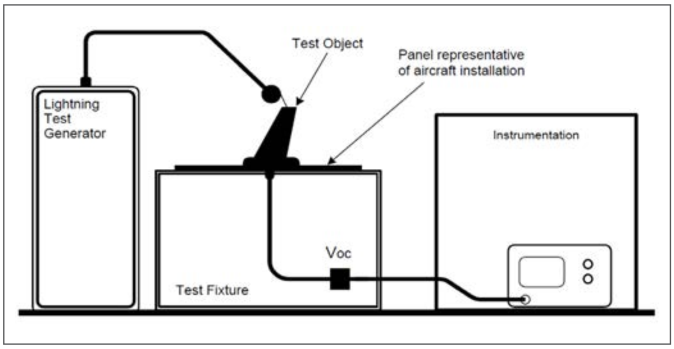
The section is broken into 3 separate parts; pin injection, induced cable bundle strikes and multiple burst testing. Pin injection looks for hard failures in your product after the strike where as cable bundle and multiple burst often requires your unit to operate while the event is occurring. Each test includes different waveforms that have durations as long as 500µs. Levels 1 – 5 increase in severity, topping out at 3200 volts and 5000 amps. This section is often the hardest to pass.



DO-160 Figure 22-17 Typical Cable Induction Test Setup

Section 23.0 – Lightning Direct Effects

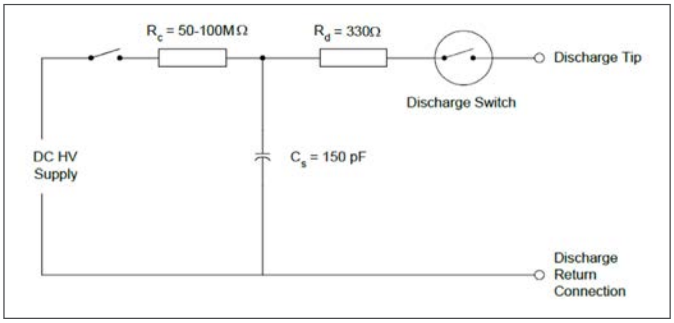
Direct Effects, contrary to indirect lightning, tests products that may be directly struck by lightning. This is limited to products that will be mounted on the exterior aircraft. The section includes a high voltage strike test and a high current test. The equipment is often not expected to survive but must not cause any unsafe condition to the aircraft.



DO-160 Figure 23-10 – Typical Installation for Measurements of Injected Transients

Section 25.0 – Electrostatic Discharge

Electrostatic Discharge or ESD is a test to ensure your products reliance to static charges. This section test relates to airborne equipment which may be involved in static electricity discharges from human contact. It is applicable for all products that are accessible during normal operation or maintenance of the aircraft. Though no applicable to connector pins, aircraft manufacturers often require it.



DO-160 Figure 25-2 Simplified Diagram of the ESD Generator

SUMMARY

The EMC sections of DO-160 thoroughly tests your products ability to survive and operate in normal and abnormal conditions seen on an aircraft. Passing this 500-page standard is not easy. Understanding the test and how it is applied to your design is critical.

I have written extensively at www.aerospacepal.com including a DO-160 video to help users understand. Please also continue to read my blog on Interference Technology Magazine as I dive deeper into the sections listed above.

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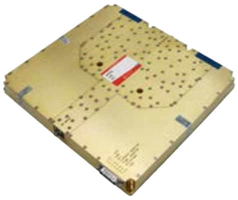

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SUMMARY OF MILITARY AND AEROSPACE EMC TESTS

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Introduction

Military and aerospace EMC tests cover a wide range of products. While the standards, including limits and test methods may differ, all EMC test standards have a few things in common. The most basic are the limits for emissions and the types and levels of susceptibility testing.

Emissions tests (and their associated limits) are put in place for military and aerospace equipment primarily to protect other systems from interference. These other systems may or may not include radio equipment. Examples abound showing the effect of inadequate EMC design. The Interference Technology 2016 Military EMC Guide (Reference 1) provides 3 such examples on page 11.

SUMMARY OF MILITARY AND AEROSPACE EMC TESTS

While many military and aerospace EMC issues may be addressed by operational changes, testing is still required to find weaknesses.

Military and aerospace EMC testing is performed at the system and subsystem levels. MIL-STD-464C provides requirements at the system or platform level. The latest version, MIL-STD-461G, provides requirements at the equipment or subsystem level. *Reference 1* provides details on both of the standards, but this article will highlight some key tests, particularly as they relate to MIL-STD-461G.

Ratio	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
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

Table 1: MIL-STD-461G Emission and Susceptibility Requirements

MIL-STD-461G divides test requirements into 4 basic types. Conducted Emissions (CE), Conducted Susceptibility (CS), Radiated Emissions (RE) and Radiated Susceptibility (RS). There are a number of tests in each category and *Table I*, taken from MIL-STD-461G Table IV, shows these test methods.

A brief description of each these tests will be provided below. These are summarized from a more detailed introduction to MIL-STD-461G, which is found in the *References 1, 2*, and *3*. Keep in mind that a complete copy of MIL-STD-461G is 280 pages, so any information here is brief and the standard must be read and understood. A copy of MIL-STD-461G may be obtained free. See *Reference 4*.

CE101 Conducted Emissions, Audio Frequency Currents, Power Leads. CE101 is applicable from 30 Hz to 10 kHz for leads that obtain power from sources that are not part of the EUT. There is no requirement on output leads from power sources. Emission levels are determined by measuring the current present on each power lead. There is different intent behind this test based on the usage of equipment and the military service involved. The specific limits are based on application, input voltage, frequency, power and current.

CE102 Conducted Emissions, Radio Frequency Potentials, Power Leads. CE102 is applicable from 10 kHz to 10 MHz for leads that obtain power from sources that are not part of the EUT. There is no requirement on output leads from power sources. The 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. The emission levels are determined by measuring voltage present at the output port of the LISN. Unlike CE101, CE102 limits are based on voltage. The basic limit is relaxed for increasing source voltages, but independent of current. Failure to meet the CE102 limits can often be traced to switching regulators and their harmonics.

CE106 Conducted Emissions, Antenna Port. CE106 is applicable from as low as 10 kHz to as high as 40 GHz (depending on the operating frequency) for antenna terminals of transmitters, receivers, and amplifiers and is designed to protect receivers on and off the platform from being degraded by antenna radiation from the EUT. CE106 is not applicable for permanently mounted antennas.

CS101 Conducted Susceptibility, Power Leads. CS101 is applicable from 30 Hz to 150 kHz for equipment and subsystem AC and DC power input leads. For DC powered equipment, CS101 is required over the entire 30 Hz to 150 kHz range. For AC powered equipment, CS101 is only required from the second harmonic of the equipment power frequency (120 Hz for 60 Hz equipment) to

150 kHz. In general, CS101 is not required for AC powered equipment when the current draw is greater than 30 amps per phase. The exception is when the equipment operates at 150 kHz or less and has an operating sensitivity of 1 µV or better. The intent is to ensure that performance is not degraded from ripple voltages on power source waveforms.

CS103, CS104 and CS105 Conducted Susceptibility, Antenna Port, Intermodulation, Rejection of Undesired Signals and Cross-Modulation. This series of receiver front-end tests include test methods for Intermodulation (CS103), Rejection of Undesired Signals (CS104) and Cross Modulation (CS105). They were designed for traditional tunable super-heterodyne type radio receivers. Due to the wide diversity of radio frequency 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.

CS109 Conducted Susceptibility, Structure Current. CS109 is a highly specialized test applicable from 60 Hz to 100 kHz for very sensitive Navy shipboard equipment (1 µV or better) such as tuned receivers operating over the frequency range of the test. Handheld equipment is exempt from CS109. The intent is to ensure that equipment does not respond to magnetic fields caused by currents flowing in platform structure. The limit is derived from operational problems due to current conducted on equipment cabinets and laboratory measurements of response characteristics of selected receivers.

CS114 Conducted Susceptibility, Bulk Cable Injection. CS114 is applicable from 10 kHz to 200 MHz for all electrical cables interfacing with the EUT enclosures.

CS115 Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation. CS115 is applicable to all electrical cables interfacing with EUT enclosures. The primary 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.

CS116 Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads. CS116 is applicable to electrical cables interfacing with each EUT enclosure and also on each power lead. The concept is to simulate electrical current and voltage waveforms occurring in platforms from excitation of natural resonances with a control damped sine waveform.

CS117 Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads. CS117 is one of two new test methods added to MIL-STD-461G. CS117 is applicable to safety-critical equipment interfacing cables and also on each power lead. Applicability for surface ship equipment is limited to equipment located above deck or which includes interconnecting cables, which are routed above deck. The concept is to address the equipment-level indirect effects of lightning as outlined in MIL-STD-464 and it is not intended to address direct effects or nearby lightning strikes.

CS118 Conducted Susceptibility, Personnel Borne Electrostatic Discharge. CS118 is applicable to electrical, electronic, and electromechanical subsystems and equipment that have a man-machine interface. It should be noted that CS118 is not applicable to ordnance items. The concept is to simulate ESD caused by human contact and test points are chosen based on most likely human contact locations. Multiple test locations are based on points and surfaces which are easily accessible to operators during normal operations. Typical test points would be keyboard areas, switches, knobs, indicators, and connector shells as well as on each surface of the EUT.

RE101 Radiated Emissions, Magnetic Field. RE101 is applicable from 30 Hz to 100 kHz and is used to identify radiated emissions from equipment and subsystem enclosures, including electrical cable interfaces. RE101 is a specialized requirement, intended to control magnetic fields for applications where equipment is present in the installation, which is potentially sensitive to magnetic induction at lower frequencies.

RE102 Radiated Emissions, Electric Field. RE102 is applicable from 10 kHz to 18 GHz and is used to identify radiated emissions from the EUT and associated cables. It is intended to protect sensitive receivers from interference coupled through the antennas associated with the receiver.

RE103 Radiated Emissions, Antenna Spurious and Harmonic Outputs. RE103 may be used as an alternative for CE106 when testing transmitters with their intended antennas. CE106 should be used whenever possible. However, for systems using active antenna or when the antenna is not removable or the transmit power is too high, RE103 should be invoked. RE103 is applicable and essentially identical to CE106 for transmitters in the transmit mode in terms of frequency ranges and amplitude limits. The frequency range of test is based on the EUT operating frequency.

RS101 Radiated Susceptibility, Magnetic Field RS101 is a specialized test applicable from 30 Hz to 100 kHz for Army and Navy ground equipment having a minesweeping or mine detection capability, for Navy ships and submarines, 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 equipment installed on ASW capable aircraft, and external equipment on aircraft that are capable of being launched by electromagnetic launch systems. The requirement is not applicable for electromagnetic coupling via antennas. RS101 is intended to ensure that performance of equipment susceptible to low frequency magnetic fields is not degraded.

RS103 Radiated Susceptibility, Electric Field. RS103 is applicable from 2 MHz to 18 GHz in general, but the upper frequency can be as high as 40 GHz if specified by the procuring agency. It is applicable to both the EUT enclosures and EUT associated cabling. The primary 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. The limits are platform dependent and are based on levels expected to be encountered during the service life of the equipment. It should be noted that RS103 may not necessarily be the worst case environment to which the equipment may be exposed.

RS105 Radiated Susceptibility, Transient Electromagnetic Field. RS105 is intended to demonstrate the ability of the EUT to withstand the fast rise time, free-field transient environment of EMP. RS105 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 and the electrical interface cabling should be protected in shielded conduit.

Not all tests are required for each type of device or intended use environment. MIL-STD-461G provides a matrix in Table V showing how these tests are used based on the intended use of the device.

Equipment and Subsystems Installed In, On, or Launched From the Following Platforms or Installations	Type of Product/Service																		
	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		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	

Legend:
A: Applicable (in green)
L: Limited as specified in the individual sections of this standard. (in yellow)
S: Procuring activity must specify in procurement documentation. (in red)

Table 2: MIL-STD-461G Requirement matrix

Again, the reader is referred to *References 1* through *3* for more details, or to MIL-STD-461G for the details of the standard (*Reference 4*). This guide also provides a list of standards that apply to various military equipment.

A popular and common aerospace EMC requirement required by the FAA for commercial aircraft is RTCA/DO-160, Environmental Conditions and Test Procedures for Airborne Equipment. The latest version is RTCA/DO-160 G, published on December 8, 2010, with Change 1 published on December 16, 2015. DO-160 covers far more than just EMC issues, but the EMC subjects covered include input power conducted emissions and susceptibility, transients, drop-outs and hold-up; voltage spikes to determine whether equipment can withstand the effects of voltage spikes arriving at the equipment on its power leads, either AC or DC; audio frequency conducted susceptibility to determine whether the equipment will accept frequency components of a magnitude normally expected when the equipment is installed in the A/C; induced signal susceptibility to determine whether the equipment interconnect circuit configuration will accept a level of induced voltages caused by the installation environment; RF emissions and susceptibility; lightning susceptibility; and electrostatic discharge susceptibility.

This document can be purchased from RTCA on their website (*Reference 5*). A manufacturer producing products subject to the requirements in RTCA/DO-160 should obtain a copy and ensure they have a complete understanding of the content of the document and that any laboratory testing to it is properly accredited.

Examples of differences in test equipment between commercial and military standards.

There are differences in test equipment used compared with commercial EMC tests. Some examples are provided below.

Where 50 μH LISNs are universally required for commercial EMC tests, there are specific cases for CE01 and CE02 tests where a 5 μH LISN is called out. Limits for CE101 tests are provided in dBμA. LISNs are only used for line impedance stabilization. The measurements are taken with current probes. Limits for CE102, on the other hand, are given in dBμV and measurements are taken in much the same way as for commercial standards with the receiver connected to the RF output port of one of the LISNs and the other RF output port(s) terminated in 50 Ohms. It should be noted that MIL-STD-461G calls out a 20 dB pad on the output of the LISN to protect the receiver from transients. This is not a requirement in the commercial standards, but is worth considering when setting up a laboratory for commercial testing, as well.

Military EMC standards, such as MIL-STD-461G will require the use of different antennas for radiated emis sions testing. Commercial equipment standards, such as CISPR 32 and ANSI C63.4, require the use of linearly polarized antennas and do not contain requirements for magnetic field testing.

MIL-STD-461G, RE101, requires the use of a 13.3 cm loop sensor, not required in the commercial standards. A receiver capable of tuning from 30 Hz to 100 kHz is needed.

MIL-STD-461G, RE102, requires testing of radiated emissions to as low as 10 kHz. From 10 kHz to 30 MHz a 104 cm (41 inch) rod antenna is used. This frequency range is not covered in CISPR 32 or the FCC Rules for radiated emissions. Thus, the antenna and receiver requirements are different. From 30 MHz to 200 MHz a biconical antenna is used, also commonly used in commercial testing. From 200 MHz to 1 GHz a double ridge horn antenna is called out in 461G. This is different than the tuned dipole or log periodic dipole array antennas used for commercial testing.

The test procedures are also different for radiated emissions testing, requiring different laboratory set-ups and test facility types. No turntable is needed for MIL-STD-461G, nor is an antenna mast capable of moving the antenna over a range of heights.

MIL-STD-461G, RS103, can require significantly higher field intensities for radiated susceptibility testing. Where CISPR 35 requires 3 V/m from 80 MHz to 1 GHz and at a few discrete frequencies up to 5 GHz (with the option of testing a few discrete frequencies at up to 30 V/m), MIL-STD-461G requires testing from 20 V/m to as high as 200 V/m over the range of 2 MHz to 40 GHz for certain equipment. Additional test equipment (signal generators, amplifiers, antennas, etc.) is required over that needed for commercial testing.

Each test in MIL-STD-461G requires its own unique test equipment. Some may be useable for commercial testing, others may not. If testing to MIL-STD-461G, ensure that the equipment is proper for the tests being performed. A detailed understanding of the requirements in MIL-STD-461G is required to ensure that the proper equipment is being used and the laboratory is following the appropriate processes.

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3. Ken Javor, Why Is There AIR (in MIL-STD-461G)?, Interference Technology, April 2016
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REVIEW OF MIL-STD 461 CS118 – ELECTROSTATIC DISCHARGE

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Introduction

MIL-STD-461G, released in December 2015, added a test for Personnel Borne Electrostatic Discharge (ESD). Prior to this release, this type of test for electronic systems and sub-systems was managed at the system level under MIL-STD-464C released in 2010. Both of these standards contain similar requirements. MIL-STD-461G provides the details on testing and MIL-STD-464C established the compliance requirements without detail on how to verify compliance.

Prior to 2010, several ESD programs were in use by DoD to provide control measures and in some cases test methods to verify tolerance to ESD events were included. A couple of more common standards have been used and are still active:

- *MIL-STD-1686 provided a ESD control program for non-ordnance electronic devices with reference to HBM (Human Body Model), MM (Machine Model and CDM (Charged Device Model). The various models are divided in classes based on sensitivity and marked to provide guidance on control measure implementation. ANSI and IEC standards for HBM evaluation are referenced but newer versions are used than cited in the current MIL-STD-1686C.*
- *MIL-STD-331D is the current standard for ordnance ESD control and includes a different model than personnel borne ESD. The difference is associated with control measures required for ordnance handling. The standard refers to JOTP 062 for ordnance ESD testing and requirements.*

REVIEW OF MIL-STD 461 CS118 – ELECTROSTATIC DISCHARGE

Background

From our high school years, physics training taught us about the atomic structure with electrons orbiting the nucleus and the net charge being related to the number of electrons relative to the number of protons. Materials with an unbound electron can release the electron to another atom with a small amount of energy. Contacting two materials can support the electron migration and separation of the materials may leave electrons trapped in another atom creating a net static charge between the two materials.

Depending on the forces present the static charge can reach very high voltage levels. If the voltage levels reach the point that the separating insulation allows the electron charge to recombine, a spark occurs bringing the two materials to a neutral charge. The static charge is created by many forces such as:

1. Tribocharging where two bodies in contact are separated without allowing the electrons to return to their atoms. We encounter this from various sources such as walking across a carpet with each step supplementing our body charge. See *Figure 1* for a conceptual sketch. The charge will dissipate through the air or we contact an object that provides the conduction path with a transient discharge. Note that moisture molecules in the air provide for dissipating the charge through the air more easily, so in a humid environment the charge accumulation is typically reduced.
2. Electrostatic induction where an object is placed near a charged object and the field of the charged object causes electron redistribution. This charged object is present with an open circuit provides a voltage without current flowing.
3. Particles bombarding an object causing surface charging. Electrons are dislodged and moved in the direction of the particle movement creating the charge differential. This charge is often associated with moving objects or wind driven water referred to as precipitation static.

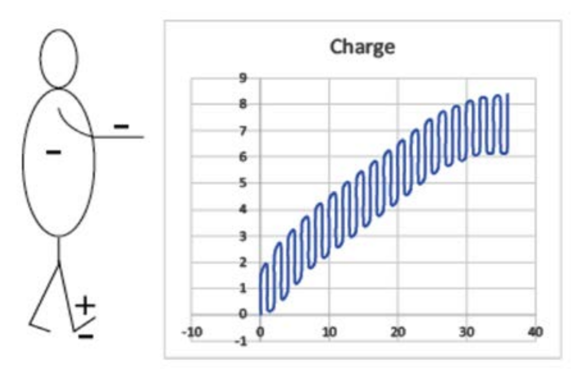


Figure 1: ESD Charge Accumulation Concept

We realize that ESD events occur when a breakdown potential of the insulation is reached. Keep in mind that air is an insulator as well as non-conducting materials. The breakdown potential of air is approximately 80V/mil of distance. The breakdown potential for most insulating material is approximately 200V/mil of thickness. So, based on these approximations, a 100 mil air gap or a 40 mil thick insulator should prevent a discharge with an 8kV charge. Damage to an insulator if subjected to a discharge can produce small "pin-holes" and the insulator becomes an air gap with significantly less insulating properties.

CS118 Calibration Verification

As with most tests in MIL-STD-461G, CS118 begins with the calibration verification or signal integrity check. *Figure 2* provides a general configuration for the calibration verification with two different checks to be accomplished. The ESD generator tip voltage is checked with an electrostatic voltmeter. The ESD generator is set for 2kV and the tip is placed at the measurement distance specified for the particular electrostatic voltmeter being used. Most electrostatic voltmeters have a guide or light convergence method to aid in placing the sensor at the correct distance. The voltmeter displays the measured voltage. The tip voltage tolerance is 10%. The tip voltage is repeated for each potential test voltage (4kV, 8kV, 15kV). If the tip voltage is not within tolerance correct the issue and redo the calibration verification.

The discharge current waveform is the second part of the calibration verification. *Figure 2* includes a configuration drawing for the discharge current check with the target schematic. The ESD generator is charged to the 8kV in the contact mode for the discharge current waveform check.

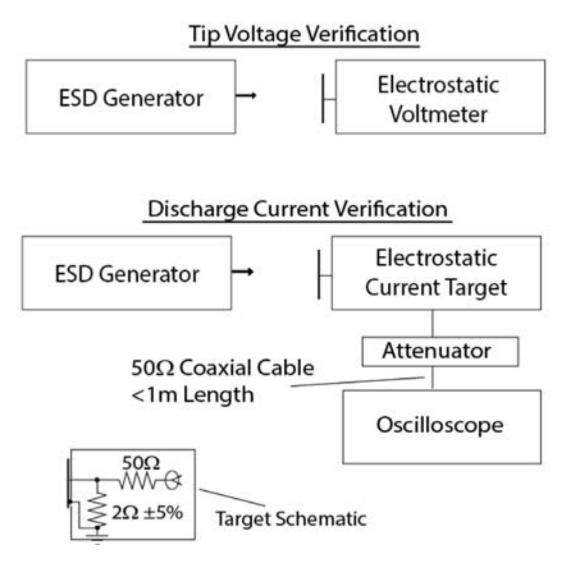


Figure 2: CS118 Calibration Verification Configurations

Set the oscilloscope to capture the waveform and place the ESD generator contact tip against the target plate.

Trigger the discharge and review the captured waveform for compliance with the standard. The waveform shape is shown in *Figure 3* and detailed parameters are provided in *Table 1*. Note that the target design is the same as used for IEC 61000-4-2 testing standard.

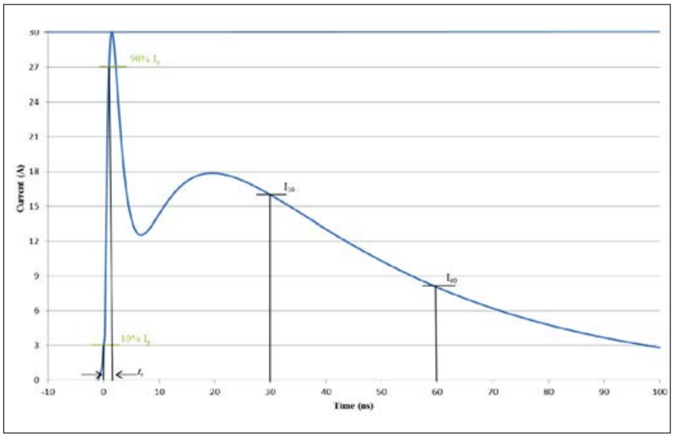
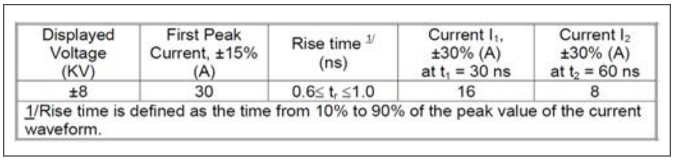


Figure 3: Discharge Current Waveform



Displayed Voltage (KV)	First Peak Current, ±15% (A)	Rise time 1/ (ns)	Current I_1, ±30% (A) at t_1 = 30 ns	Current I_2 ±30% (A) at t_2 = 60 ns
±8	30	$0.6 \le t_r \le 1.0$	16	8

1/Rise time is defined as the time from 10% to 90% of the peak value of the current waveform.

Table 1: Discharge Current Waveform Parameters

CS118 Test

The test configuration for ESD testing uses the standard configuration without tailoring. This differs from the customized ESD configuration called out in the similar IEC standard, so if you are familiar with IEC testing, pay attention to this difference.

Connect the ESD generator ground strap to the EUT's chassis ground point. Only contact discharge at 8kV is required for conductive surfaces. Set the ESD generator to the test voltage and set for contact discharge. Apply 5-positive and 5-negative discharges while monitoring the EUT performance for indications of susceptibility.

Air discharge testing is applicable to test points where a contact discharge cannot be applied. Set the test voltage at 2kV for air discharge tests and apply 5-positive and 5-negative discharges to the test point. Note that discharges may not occur for each test point, but a residual charge could be present. Use a discharge conductor routed through a 1 MΩ resistor to ground to remove the charge between discharge applications. After testing each point at the 2kV level repeat testing at each of the higher test levels (4kV, 8kV, 15kV) to determine compliance.

The air discharge is accomplished by moving the ESD generator air tip toward the test point at a rate up to 0.3 meters/sec until discharge or contact to the test point occurs. During test maintain a perpendicular orientation between the tip and the test point.

Test points should include locations likely to be contacted by the operator during normal use. The standard states that "test points to be considered shall include the following locations as applicable: any conductive or non-conductive points in the control or keyboard area and any other point of human contact such as switches, knobs, buttons, indicators LEDs, seams slots, grilles, connector shells and other accessible areas. As a minimum, each face shall be included." Recall that air serving as the insulator has a lower breakdown voltage that insulating material so be sure to include ventilation openings as test points.

Earlier in configuring the test, the ESD generator ground strap was to be connected to the EUT chassis. Nothing is mentioned about this connection for equipment with an ungrounded chassis such as portable or battery powered units. In these cases, the EUT generator ground strap would be connected to the test location ground reference plane. Also note that residual charge removal between discharges is very important to prevent over-testing from charge accumulation.

Summary

ESD events are common and often are not noticed where the event occurs with low voltage levels but still can produce defects in sensitive circuits. A good control program is necessary to minimize issues stemming from ESD. Factories where circuit exposure is normal incorporate many controls and continually verify that the control measures are followed.

Prevention of charge accumulation is a control measure that may be built into the product or installation. Maintaining conductivity between items provides the path for electrons to recombine and neutralize the charge. Providing a means to discharge with the unit allowing the personnel borne charge to be dissipated to a point not subject to damage.

Product testing allows us to have confidence that our devices have a reasonable ability to tolerate ESD and continue to perform as intended. This test addition to MIL-STD-461G provides a logical location for this evaluation and it provides the detailed test instructions to verify compliance.

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IS THE ELECTRIC EQUIPMENT GROUNDING THE BASIC PROTECTION MEANS AGAINST HEMP?

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Abstract

The article discusses the differences between the electromagnetic pulses at lightning (LEMP) and at high altitude nuclear explosion (NEMP or HEMP). The article also shows that these differences do not allow to transfer LEMP experience on to NEMP. The author questions the effectiveness of grounding of electronic equipment as the main protection principle against NEMP, even though this method of protection is stipulated by all the regulatory documents and standards.

Keywords: *grounding, electronic equipment, electromagnetic interferences, EMP, NEMP, LEMP, filters*

IS THE ELECTRIC EQUIPMENT GROUNDING THE BASIC PROTECTION MEANS AGAINST HEMP?

Introduction

Electromagnetic pulse (EMP) occurring when lightning (LEMP) hits grounded facilities (either a tree, tower, building or a lightning rod) is a natural phenomenon that has been known for as long as mankind exists. During the last century, this phenomenon was well studied and this allowed to adopt some methods and techniques, which are widely used as protection from EMP.

As for electromagnetic pulse of high altitude nuclear explosion (NEMP), which occurs near the ground surface upon nuclear weapon detonation at high altitudes (30 – 400 km), the situation is different. The first trials to study NEMP were held in USA in the summer of 1962. During these trials, powerful electro-magnetic pulses were registered, which could vastly affect electronic equipment, communication and power supply lines, radio- and radar stations. They even knocked out street lighting in Hawaii, which is located about 1,500 km from the center of explosion.

In the fall of 1962, the Soviet Union also conducted three high altitude nuclear explosions, (each with a capacity of 300 kt) under the project called “Project-K” above the military fire range Sary-Shagan (Karaganda region, Kazakhstan) in order to study NEMP phenomenon.

During these trials, an impulse current of up to 3400 A was registered in aerial telephone line cables, which resulted in the emergence of a pulse voltage with an amplitude of up to 28 kV; actuation of all the arresters installed in the equipment and blowing of all the fuses accompanied by shutdown of communication system; damage of radio communication systems located 600 km away from the center of explosion; outage of a radio location unit located 1000 km away; damage of transformers and power generators at power plants; insulator punctures of overhead transmission lines.

Serious damage of equipment was also reported at Baikonur Cosmodrome. It should be noted that this refers to equipment manufactured in the 1960s, i.e. the one using electromechanical elements and vacuum tubes, which is much more resistant to EMP than modern digital and micro-processor based equipment.

The destructive impact of both types of EMP on the objects is alike and is stipulated by two factors: very high amplitude of voltage pulse applied to the object and high pulse current flowing through this object, as well as other secondary EMP outcomes related to these two factors, which are dangerous and damaging for electronic and electrical equipment.

This similarity of destructive impact resulted in the fact that the lightning protection methods and techniques, which have been properly researched and tested, started to be applied to NEMP. An example would be the fundamental principle of protection against the lightning: compulsory grounding of objects through the minimum possible resistance and the use of gas discharge tubes and filters that divert the pulse’s energy to the ground.

Is it really true? Are the specifications of LEMP and NEMP so similar to allow identical methods and techniques of protection?

Main Differences Between LEMP and NEMP

In fact, LEMP is a local electric breakdown of gas space (air) between two electrodes featuring high potential difference between them: a cloud and the earth (or an object located on the earth and featuring the earth’s potential), *Fig. 1*.

However, NEMP is a distributed electric field, which covers a large area and affects the objects located hundreds and thousands of kilometers away from the explosion epicenter due to spatial relocation of charged particles, e.g. electrons and ions that appeared as a result of complex physical processes, which occur upon the nuclear explosion in the atmosphere, *Fig. 1*.

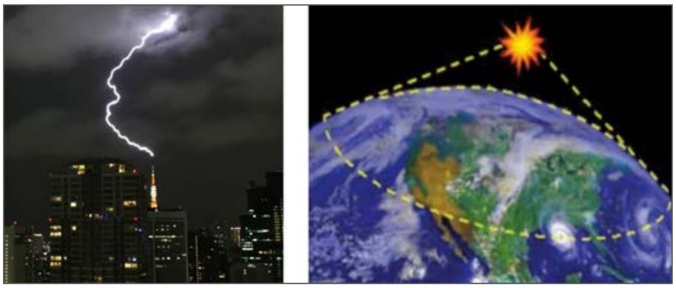

Fig. 1. The area of lightning and high altitude nuclear explosion impact.

Moreover, the structure of this field is not uniform and can be conditionally split into three component parts: E1, E2 and E3. E1 is a very short pulse of electric field shaped as 2/25 ns with the field gradient of 50 kV/m near the ground surface. E2 is a weaker electric field’s pulse with duration from several to dozens milliseconds. E3 is a very long low voltage pulse of electric field, which has to do with various processes in ionospheric medium. This can last up to several minutes and stipulates occurrence of significant quasi-DC currents in long-distance conductive media, such as rails, pipes, cables and wires. E1 is the most powerful, destructive and complex pulse (from the standpoint of protection) with vertical and horizontal polarized parts. Thus, when saying NEMP in this article, it will mean E1 as its main component.

Compared to LEMP, NEMP is less powerful (*Fig. 2*) and significantly shorter (*Fig. 3*), but as it covers a large area and affects thousands of facilities simultaneously; it is more dangerous than LEMP.

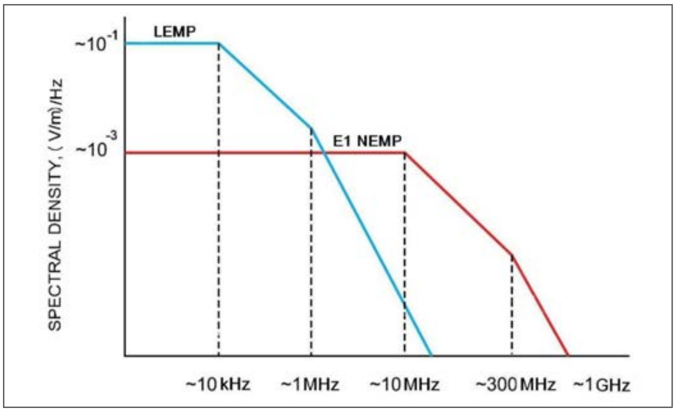

Fig. 2. Spectral density of LEMP and NEMP energy.

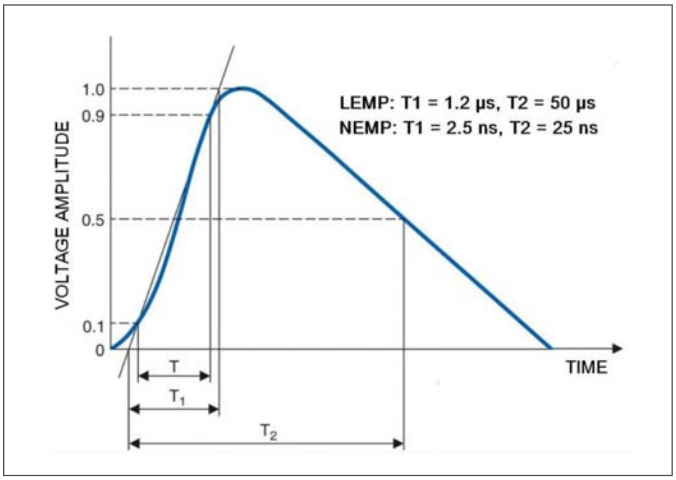

Fig. 3. Differences in time parameters of LEMP and NEMP

As stated above, both LEMP and NEMP can relocate over a distance and reach the ground surface in different ways. In case of LEMP's relocation through the ionized channel represented by a single or even branched cord, the situation is more or less clear. However, in case of NEMP the situation is much more complicated. First, the shape of NEMP's electric field near the ground surface is developed subject to the Earth's magnetic field; it is rather uneven. Second, the electromagnetic wave reaches the ground surface at a specific angle and thus, the electric field near the ground surface possesses both vertical and horizontal components. Third, part of electromagnetic energy, falling onto the ground surface at an angle, will be reflected and can consolidate with the energy falling onto the ground.

These differences between LEMP and NEMP make it possible to assume that they are different in their effect on the objects located on the ground surface.

Indeed, if we take a 10-meter metal rod, push one of its ends into the soil (vertically) and attach to it a current sensor, when lightning hits the open end of the rod, the sensor will register high amplitude current flowing through the rod as its grounded end has got zero (conditionally) potential, while the upper end takes up high (relative to ground) potential of the lightning.

When we have the bottom end of the rod well insulated from the ground surface and install it vertically, then there will be no current in the rod, even if we assume that lightning hits it, as there is no potential difference between the rod's ends (different capacitance values of the rod's ends relative the ground can be neglected due to their low level).

If NEMP impacts the same insulated rod, there will be high potential difference between its ends (theoretically, dozens of kilovolts) and the current sensor will register the relatively high amplitude current pulse flowing through it. Moreover, high potential difference occurs between the rod's ends, even if it is located horizontally relative to the ground surface.

What happens if we ground one of the ends of this horizontal rod? It is a much more complex case because NEMP penetrates in the soil and induces gradients directly in the soil. This effect takes into consideration the model of a power transmission line with grounded neutral to study the NEMP affect. In such a model, the voltage on the open second end of the line to the ground will depend on the transmission line height above ground, its length and soil conductivity [1]. But this model is not our case with insulated ends of the rod, and in our case the grounding of one of its ends does not affect the voltage gradient between the ends.

The same effect will occur at a single electronic device installed in a cabinet in a control room with fully electrical insulated (without considering capacity to ground) control cables connected to its inputs. The electric field affecting these cables has nothing to do with the ground and its potential. In other words, such cables with potential difference induced on its ends by NEMP acts as a EMP source insulated from the ground for electronic devices. It works as a charged accumulator battery in an insulated body.

What happens, when only one pole of the accumulator battery is grounded? Just nothing! Neither with the accumulator battery, nor with the insulated load, that receives power from this accumulator.

So, why would something happen if we ground the NEMP affected small local object as a control cabinet with electronic devices inside? This question is very important and highly relevant as it directly affects efficiency of equipment intended to ensure protection against NEMP. According to [2]: "The early-time E1 HEMP waveform also couples efficiently to short lines (1-10 meter) connected to equipment (power, signal lines, etc.) and can induce large voltages and currents that can be conducted to the inside of the equipment". In this sentence there is no relation to ground.

Unfortunately, it is a very difficult to study this phenomenon in an open area test site simulator (OATS) suitable for simultaneous testing the group of electrical control cabinets with cable connection between them, because most such simulators contain a Marx generator and two electrodes: one grounded mesh and another one – an insulated mesh placed above the grounded mesh at a height 5 – 20 m, *Fig. 4* (so-called "single port open waveguide simulators"

Fig. 4. Single port open area guided-wave simulators, produce a vertical electric field.

A simulated electrical pulse field is applied directly between these two electrodes, between the upper electrode and the ground. In such a simulator, well grounding the equipment under test (that is a low impedance connection the shields and metal shells of equipment to the down electrode) will always play the role of effective protection means as at lightning testing.

The grounding of down electrode is due to necessity simulating influence of ground reflection on the field in the test volume. However, in contrast, in small radiated test facilities equipment under test (EUT) shall be placed on dielectric stand above the ground plane within the test volume, according to IEC 61000-4-20 standard [7]. In our opinion, to study aforementioned phenomenon in a large OATS also can be use dielectric plate between EUT and down electrode without EUT grounding.

Grounding of Electric Equipment as the Main Protection Means Against NEM

Various standards, (both civil and military) as well as different guidelines and recommendations, justify the necessity of compulsory grounding of all types of electronic and electrical equipment as the main protection means against NEMP. But why, if the grounding system does not act as an opposite electrode with an opposite charge for NEMP (unlike a lightning strike)?

According to [3] "In general, the reason for grounding are varied, and it would be presumptuous to attempt to specify grounding procedures without first establishing the reasons for grounding and the goals that the grounding system should achieve. These reasons and goals are usually based on system functional, safety and RF interference considerations as a consideration in the ground-system design, at least one more goal has been added (EMP hardness), but the reason for grounding may remain unchanged. The basic reason for providing a "ground" in electronic equipment is to establish a firm reference potential against which signal and supply voltage are measured (or established)".

Such considerations are a reason for standard recommendation about standard grounding methods in all documents related to NEMP, despite the grounding is not a clear and proven protection means against NEMP. But the functional and safety considerations and reference potential necessity for electronic equipment have also another direct grounding solution [4 - 6]. At the same time, it is obvious that the branched and spatially distributed grounding system acts as a huge antenna for NEMP, absorbing energy from a large area and delivering it directly to sensitive electronic equipment via the grounding circuits. Of course, the energy level will be partially lowered by the conductive soil. However, the part that finds its way into the system will be enough to result in a dangerous potential rise directly in electronic circuits of highly sensitive microprocessor-based equipment (such as digital protection relays - DPR):

> - *"Many elements of a facility can act as efficient collectors and provide propagation paths for EMP energy. EMP can couple to structures such as power and telephone lines, antenna towers, buried conduits, and the facility grounding system* [8]*;*
>
> - *"Based upon coupling calculations it is appears that levels up to 10 kV may be coupled to horizontal buried lines in a substation yard (although 20 kV is possible under some scenarios)"* [2]*;*
>
> - *"A "ground" is commonly thought of as a part of a circuit that has relatively low impedance to the local earth surface. A particular ground arrangement that satisfies this definition may, however, not be optimum and may be worse than no ground for EMP protection"* [9]*.*
>
> - *"For HEMP protection, however, the grounding system is considered a potential path for transient penetration into the system and a means of distributing transients throughout the interior* [10]*.*

There are two contradictory ideas about grounding appears in many engineering books and documents, for example:

> *“The primary effect of the HEMP is, therefore, the production of large voltages or currents in large structures and conductors such power lines, buried cables, and antennas, as well as in facility grounding systems” (page 935)…. And in the same page: “The goal of all grounding and bounding techniques is to redirect the HEMP-induced currents to the earth”* [11].
>
> *“Grounding does not directly provide protection against EMP…” (page 5-3) and*
>
> *“The grounding required for EMP protection... (page 5-5)”* [8].

What conclusion may appear from such ideas?

In fact, many individual printed circuit boards of this equipment have got their own “ground”, i.e. a system of conductor strips with a so called “zero” or “reference” potential; all the other potentials necessary for equipment operation will emerge relative to the former. As a rule, this internal ground is connected to a metal body, which, in turn, is connected to an external grounding system. The potential of the grounding system is known to increase under the common lightning strike. At the same time, it is considered that if all the electronic devices will share the potential of a grounding system, i.e. there will be no difference of potentials between the circuits of “zero potential” of various devices, this increase of common potential and its difference from zero, that takes place in all the devices simultaneously, cannot cause malfunctioning of these devices.

The whole theory of grounding is based on this assumption prescribing to maintain minimum resistance of grounding system’s elements, using equipotential planes, etc., in other words, the measures aimed at prevention of a difference of potentials between “zero potential” circuits, distanced from each other and hence grounded at different locations, but at the same time they stay in electric and informational contact. Furthermore, the issue of what happens in a single electronic device during the rise of its “zero potential” circuit is not addressed. The fact is that any electronic circuit contains a lot of non-linear elements and those that possess capacitance and inductance and connected to “zero potential” circuit. As a consequence, voltage and current will not rise simultaneously at different points of the circuit during the potential rise in it.

You can visualize it as a plate supporting weights of different mass that are attached to this plate by means of springs of various rigidity. If we start raising this plate gradually (i.e. during the gradual increase of potential energy), the potential energy of all the elements resting on this plate will increase simultaneously. However, if we raise the plate abruptly, the elements will not change their position and potential energy simultaneously. Additionally, if they were mechanically united, perhaps this would even result in breakages of those connections. Thus, availability of equipotential plane and maintaining zero difference between the circuits of “zero potential” of different devices does not guarantee the absence of malfunctioning of highly sensitive electronic equipment.

In real life, when using electronic equipment located at spatial facilities, it is very difficult and sometimes even impossible to maintain zero difference of potentials between the circuits of “zero potential, especially when the grounding system is working as an antenna, *Fig. 5*.

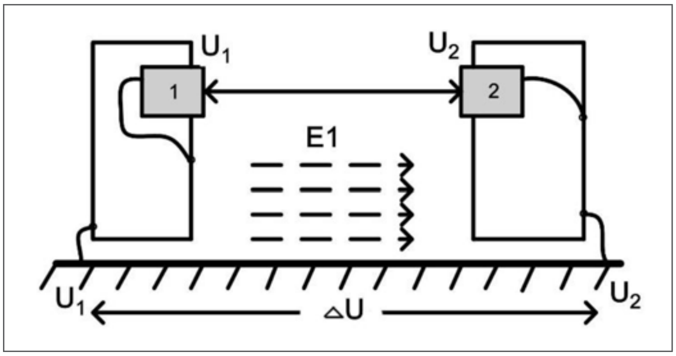

Fig. 5. The impact of high voltage on the inputs of electronic equipment remotely located from each other in grounded bodies upon the impact of E1 component of NEMP onto the grounding system.

This situation is true for large energy producers and industrial enterprises, such as power plants and substations, oil refineries, etc.

Protection Devices Against NEMP

Usually, devices designed for protecting equipment from NEMP overvoltage, are connected between the circuits to be protected and the grounding system (common mode protection), *Fig. 6*.

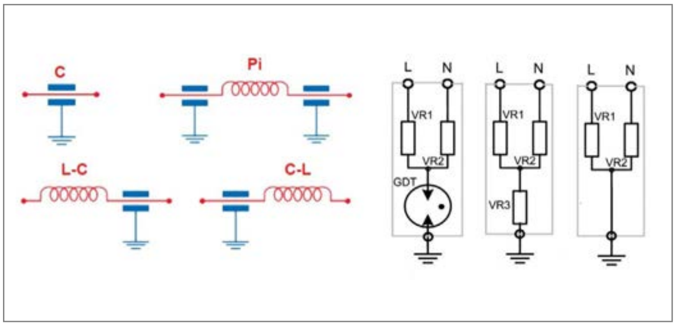

Fig. 6. Simplified design of various LC-filters against NEMP and devices protecting from pulse overvoltage with parallel elements that divert impulse energy from the input to the ground. VR – varistors, GDT – gas discharge tube.

Special filters intended for NEMP protection include non-linear elements that divert impulse energy from the filter inputs to the ground, *Fig. 7*.

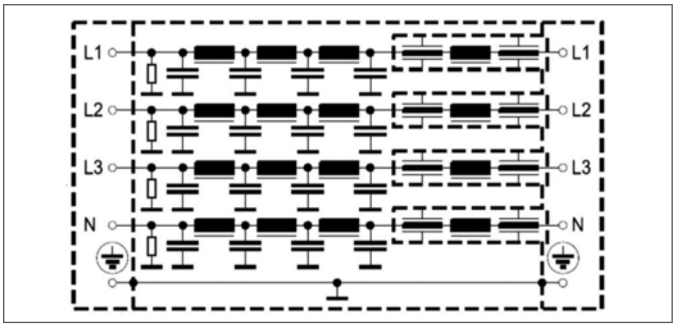

Fig. 7. Real design of 3-phase NEMP filter that contains non-linear resistors connected between each input of the filter and the ground (in addition to capacitors that divert energy to the ground).

Another problem is the difference in parameters of such filters for a pulse applied between the input and the ground compared to the pulse, applied between individual inputs, *Fig. 7*. At the same time, main protection is designed between each input and the ground. Many filters have been designed with only one input terminal, one output terminal and the grounded body (*Fig. 8*). Thus, they are intended to protect sensitive inputs of equipment solely from pulses featuring higher amplitude relative to the ground and divert energy from the input to the ground.

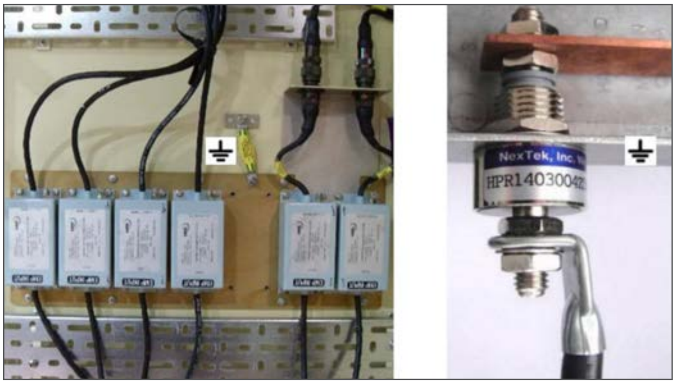

Fig. 8. Filters protecting from NEMP pulse applied to equipment input terminals relative to the ground.

However, when the grounding system does not represent the area of reverse potential or zero potential for NEMP, where will the pulse energy be diverted? And when a similar pulse occurs on the grounding electrode simultaneously with high voltage pulse occurring on the input of a filter or a device protecting from overvoltage, how will this filter weaken NEMP?

These questions are still waiting to be answered. Thus, the specialists invite active discussions concerning this problem because “grounding may not be a solution; rather it could be part of the problem” [11].

Conclusions

Use of grounding of electronic and electric equipment as the main NEMP protection is not only questionable, but also may be dangerous, as instead of NEMP weakening, it can enhance its destructive impact on equipment. However, since this grounding is stipulated in all the regulatory documents, this problem needs to be further discussed with the relevant specialists.

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REVIEW OF MIL-STD 461 RE101– RADIATED EMISSIONS, MAGNETIC FIELD AND RE102 RADIATED EMISSIONS, ELECTRIC FIELD

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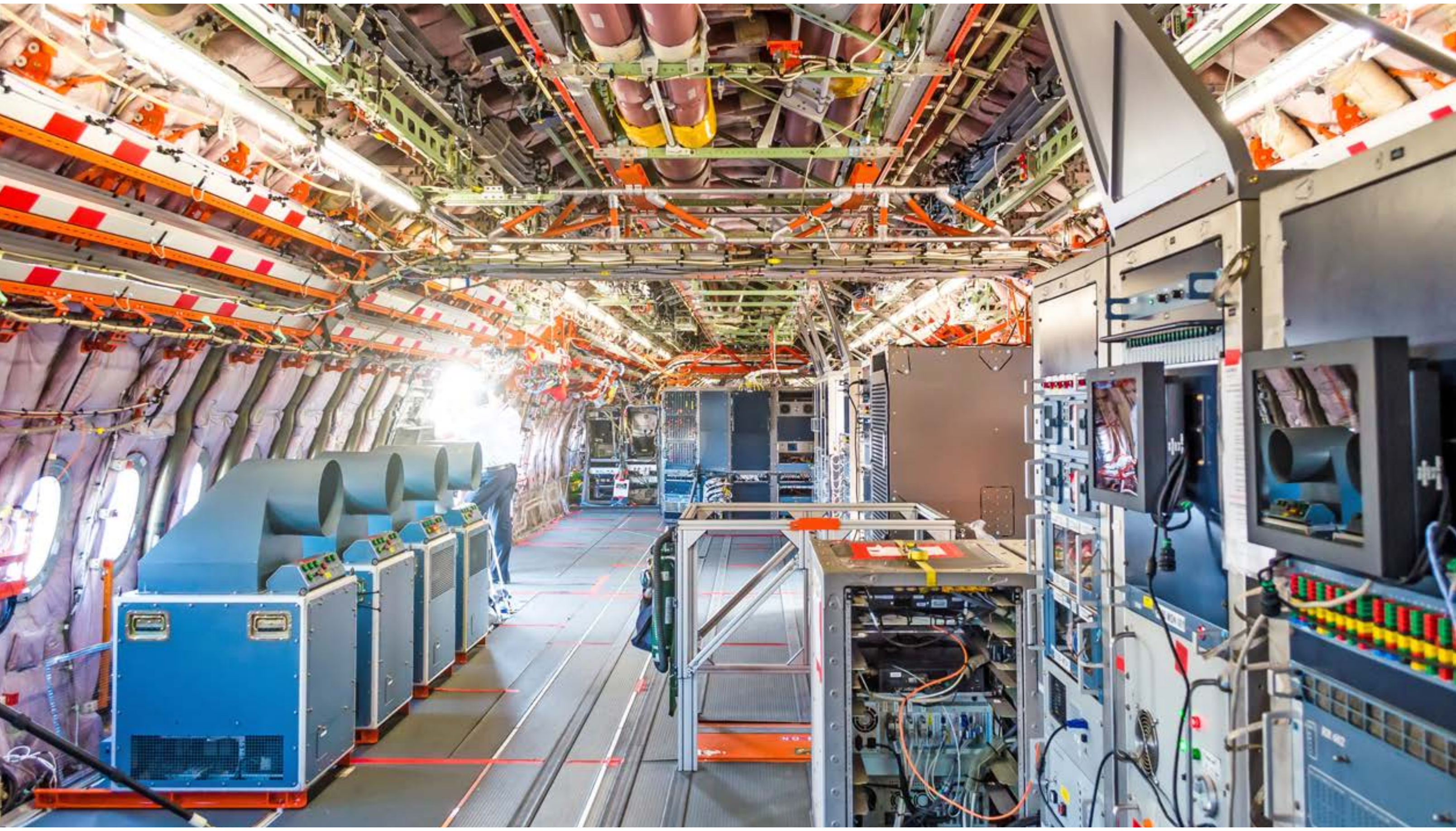
Introduction

This article discusses RE101 and RE102, including the updates contained in MIL-STD-461 revision "G", the current version. These tests quantify undesired signals being radiated into the air from a device and the associated cables. If unchecked, these signals couple onto other equipment cables or may enter into the other equipment chassis and onto internal conductors. The received field has the potential to induce current in other equipment conductors and may cause harmful interference from either field.

Both of these test methods have been a part of the MIL-STD-461 test program from the onset using RE04 (Magnetic Field) and RE02 (Electric Field) numbering. Release of MIL-STD-461C changed the RE04 number to RE01 for the magnetic field radiation test method but MIL-STD-462 continued to refer to RE04 even with issued notices updating the standard.



REVIEW OF MIL-STD 461 RE101– RADIATED EMISSIONS, MAGNETIC FIELD AND RE102 RADIATED EMISSIONS, ELECTRIC FIELD

Introduction

RE01 (RE04) covered the frequency range of 30 Hz to 50 kHz with the magnetic loop antenna located 1-meter from the Equipment Under Test (EUT). The limit was in dBpT (dB referenced to 1 picotesla) terms indicating a flux density measurement. RE02 covered the frequency range of 14 kHz to 10 GHz for narrowband (NB) emissions and limited the upper frequency to 1 GHz for broadband (BB) emissions with the antenna located 1-meter from the EUT. The limit was in dBmV/m for NB emissions and dBmV/m/MHz for BB emissions.

As noted above, RE02 called for tests to determine if the emissions were classified as narrowband (NB) or broadband (BB). The limits would allow broadband emissions to be higher in amplitude since this kind of noise tended to have a more benign impact to human senses. Compare the sound of wind blowing through trees creating many sound frequencies (BB) to a siren with a single frequency (NB). The wind would permit audio speech and the siren would provide a greater interference to speech reception. In the early days, interference to radio communications was a dominate problem so the separation of NB and BB had a significant impact on product qualification.

While we are on the BB subject a review on making the decision seems timely. MIL-STD-462 provided two tests to support the decision.

Test One:

1. Tune the receiver to the peak signal frequency.
2. Adjust the frequency ±2 IBW (IBWNote 1 is impulsive bandwidth part of the receiver calibration).
3. If the amplitude changed by <3 dB the signal was classified as BB.

   Note 1: *IBW is a measure of how the receiver reacts to an impulse signal. An impulse generator (IG) signal with the impulse peak calibrated for a 1 MHz bandwidth is applied to the receiver. If the receiver bandwidth is set for 10 kHz, the impulse should measure 40 dB lower than the IG amplitude setting. Assume that the IG output is set for 80 dBmV/MHz and the receiver measurement is 42 dBmV for a 38 dB impulse restriction indicating an IBW of 12.6 kHz. Calibration of the IBW is only necessary if measuring BB signals and converting to the /MHz units.*

Test Two:

1. Measure the pulse repetition frequency of the emission
2. If the pulse repetition frequency was less than or equal to the IBW of the receiver the emission was classified as BB.

If either of these two tests resulted in a BB classification, the emission was BB and was compared to the limit to determine acceptance. Let's not forget that the limit measurement units for BB is dBmA/MHz, so the measurement had to be normalized to the /MHz units by applying a -20logBW in MHz conversion factor. For example if your measurement was using a 10 kHz bandwidth (BW), then -20log(0.01) would provide a 40 dB conversion to conform the measurement to dBmA/MHz units. *Note 1* above provides more detail on the conversion.

Back in the day when these measurements were common, a spectrum analyzer with custom proprietary software to make the NB/BB determination was used and the measurements were plotted on the applicable chart. Today, this process is manual and can be somewhat time consuming, so when this is applicable to your test program, allow sufficient time for the manual interaction needed.

For a quick assessment, tune receiver to the emission frequency and change the receiver BW by a factor of ten. If the measurement did not change the emission is NB, if the measurement changed by 10 dB the emission is random noise and if the measurement changed by 20 dB the emission is BB. Note that this technique doesn't follow the standard, so for official measurements use the standard approach.

In 1993 the release of MIL-STD-461D and MIL-STD-462D, changed the testing to RE101 for the 30 Hz to 100 kHz frequency range measured with a 13.3 cm loop sensor located 7 cm and 50 cm from the EUT. The two distances were specified to determine if the magnetic field attenuation would allow the item to be accepted for use if the 7 cm test showed non-compliance and the application did not jeopardize other equipment in the vicinity. RE102, the electric field test method, changed the frequency range to 10 kHz to 18 GHz (actually 1 GHz or 10-times the highest intentionally generated frequency up to 18 GHz) and called out particular antennae for various frequency ranges. This revision also deleted the NB / BB determination requirement and prescribed specific BWs for selected test frequency ranges. This version required that cables were exposed during test, so cable radiation could be measured during the radiated portion of the test program.

MIL-STD-461D specified that an anechoic test chamber be used for RE102 testing to reduce the effect of reverberation causing very large measurement errors. The anechoic room required that the RF absorber minimum absorption be 6 dB (80 MHz – 250 MHz) and 10 dB (above 250 MHz).

MIL-STD-461E removed the 50 cm testing distance calling for compliance at the 7 cm test distance. This took away having measurements at another distance making the decision to grant a waiver more difficult. I want to expand on this a bit because reducing magnetic field emissions can be challenging. Let's consider a laptop computer where the current associated with a bright screen produces an over limit at 7 cm. Moving the receiving loop to a distance of 15 cm reduces the field below the limit with the 15 cm distance from the front or rear of the display. If the laptop is used on a desk, it is unlikely that a susceptible device will be located within the 15 cm distance especially the front where the operator will be located during operation. If by some remote chance, the rear causes an issue, placing a ferrous metal sheet between the laptop and the susceptible device should redirect the flux lines and resolve the problem.

MIL-STD-461F added a distance measurement to the RE101 test method. If the device was non-compliant at the 7 cm distance, the procedure calls for increasing the distance to meet the limit and provide that distance information in the test report for assessment by the procuring agency. RE102 implemented a significant change in positioning and configuring the rod antenna for measurements below 30 MHz. The standard of connecting the base counterpoise to the ground plane was deleted. The rod antenna base also connected the cable connector to the base instead of using an isolated coaxial connector. A ferrite was installed on the cable to the receiver. The changes brought about a lot of concern from the EMC community, but several studies demonstrated that the MIL-STD-461F configuration obtained more consistent results from one facility to another.

MIL-STD-461G brought forth a few minor changes to the RE101 test method. RE102 also had minor changes but one that is significant. The test frequency range 10 kHz to 18 GHz, eliminating the option to end the test at 1 GHz or 10-times the highest intentionally generated frequency up to 18 GHz. This can be a significant impact in test time for large devices where the antenna beam-width demands multiple antenna positions in the 1-18 GHz frequency range, especially when using a tuning receiver (time is low when using a FFT receiver because you can measure 100 MHz or more at the same dwell time instead of ½ bandwidth per dwell time interval).

Our discussion on the detailed requirements is based on MIL-STD-461G, the current standard.

RE101 Radiated Emissions, Magnetic Field

Let's delve into RE101 first with the signal integrity verification where we check the measurement system by creating a known signal frequency and amplitude. We then measure the signal to ensure we obtain the correct values using the measurement system we have selected for test. Adding to the check, the target amplitude should be 6 dB below the applicable limit to demonstrate measurement system sensitivity to detect emissions at that level.

Assemble the signal source for measurement as shown in *Figure 1* part A using the coaxial cable selected for EUT testing. Set the signal generator frequency to 50 kHz and amplitude to the limit minus 6 dB minus the loop conversion factor. The loop is not present for this signal check, but the measurement system will include the factor as part of the data reduction. Operate the measurement receiver to capture the 50 kHz signal and verify that the measurement is 6 dB below the limit (±3 dB).

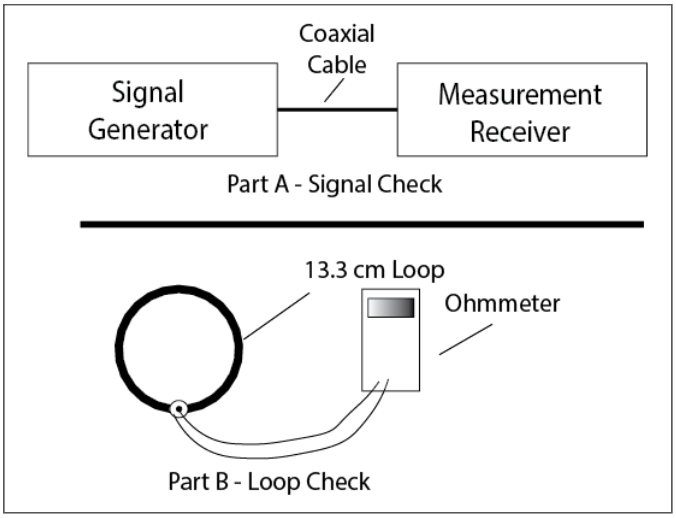


Figure 1: RE101 Signal Integrity Check Configuration

Now we can configure the test item as shown in *Figure 2* for testing after successful completion of the signal integrity check. The loop antenna is placed 7 cm from the EUT with the loop parallel to the EUT and perpendicular to the ground plane. Move the loop antenna into position after the EUT is operating and stabilized to avoid capture of inrush current effects. Set the receiver to capture a segment of the test frequency range, normally the range for one of the bandwidth settings. Set the receiver to max hold to capture worst case emissions. While observing the receiver display, move the loop antenna over the EUT face maintaining the 7 cm spacing.

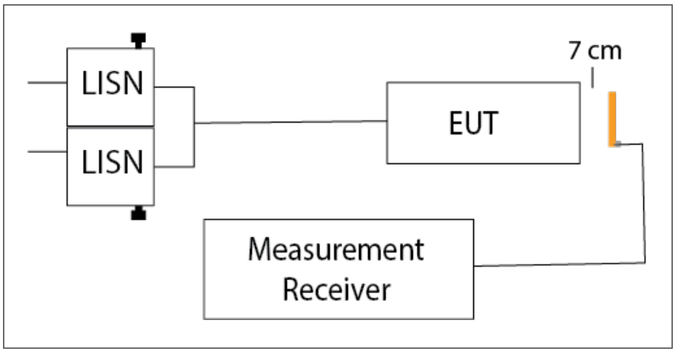


Figure 2: RE101 Test Configuration

At the location where the worst-case emissions were detected, orient the loop to perpendicular to the EUT and perpendicular to the ground plane to verify maximum emissions. The third orientation, perpendicular to the EUT and parallel to the ground plane will be used to complete that segment of the test. Repeat the testing for each frequency range segment and each face of the EUT. The standard discusses measuring worst-case emission and a number of frequency points, but this method described above captures all frequency points instead of a select few.

It is common on large test items to discover that different antenna locations show different emissions as indicated in *Figure 3*. In a case like this each point would need to be captured separately. If the results show over-limit emission, measure the distance from the EUT where the limit is met to support review by the procuring agency as we discussed earlier.

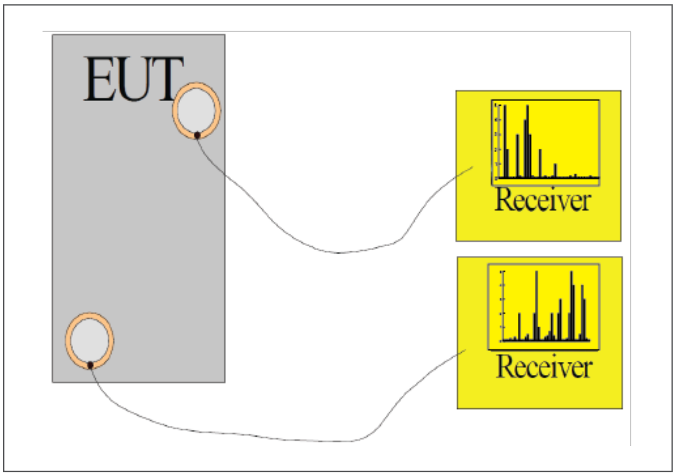


Figure 3: RE101 Results Example

RE102 Radiated Emissions, Electric Field

We begin the RE102 procedure with the system integrity verification. Recall that revision "G" permitted removing several passive test equipment items from periodic calibration including passive antennas.

Assemble the signal source for measurement as shown in *Figure 4* using the coaxial cable selected for EUT testing. Include attenuators, filter or pre-amplifiers as required for testing. The rod antenna amplifier section is connected to the coaxial cable by a calibrator providing termination and capacitive coupling to the antenna input replacing the rod portion of the antenna. Refer to MIL-STD-461G for more detail on the rod calibrator configuration. Other antennae are not included in the signal integrity check. Set the signal generator frequency to 10 kHz (2 MHz if test range is not below 2 MHz).and amplitude to the limit minus 6 dB minus the antenna conversion factor. The antenna is not present for this signal check, but the measurement system will include the factor as part of the data reduction. Operate the measurement receiver to capture the signal and verify that the measurement is 6 dB below the limit (±3 dB). Repeat the checks for the specified check frequencies. Repeat the check for each measurement path configuration change such as addition or removal of a filter or other element of the path.

Note that during the check the passive antennae were not present. A physical inspection of each antenna should be accomplished and repaired if found damaged. After a repair the antenna should be calibrated. Using a stub radiator *Note 2*, radiate a signal in the reception band for each antenna to confirm that the antenna is receiving the radiated signal. Note that accurate measurement of the stub radiation is not required but if the stub radiator and receiving antenna are consistently placed, measurements should be very close from one test to another.

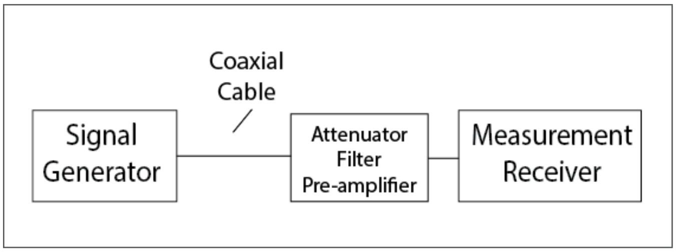


Figure 4: RE102 Signal Integrity Check Configuration

Note 2: Stub radiator is typically a coaxial cable with the outer braid removed on one end that will act like a monopole antenna providing a radiated signal to check the measurement system antenna for function.

Once all measurement path and antennae have been checked you are ready to establish the test configuration as shown in *Figure 5*. The antenna replaced the signal generator used in the integrity check.

The antenna is positioned 1-meter from the test boundary. The test boundary is the area that encompasses the EUT, cables and LISNs – not the ground plane. If the cables are 10 cm from the ground plane front edge, then the antenna is 0.9-meter from the ground plane. The rod and biconical antennae are normally located near the center of the test boundary. The doubled ridge horn antenna is positioned so that the EUT plus 35 cm of cable is within the antenna beam-width for the 200 MHz to 1 GHz range. The double ridge horn for the 1 GHz to 18 GHz antenna is positioned to place the EUT plus 7 cm of cable in the antenna beam-width. For large test articles, multiple antenna positions may be necessary to examine the EUT. Horizontal and vertical antenna polarizations present different beam-widths so one polarization may require more positions that the other polarization.

The standard indicates that testing should be accomplished on the EUT face with maximum emissions. Prior to test, a probing process may be used to look at all faces to determine worst-case orientations. Frequently, the cable interface side is worst at lower frequencies and an operator display face or open panels are worse at higher frequencies. Testing of more than one face may be necessary.

Establish operation of the EUT and operate the measurement receiver system to collect and record emission measurements. Normally a separate chart is provided for each antenna, each antenna polarization and each antenna position.

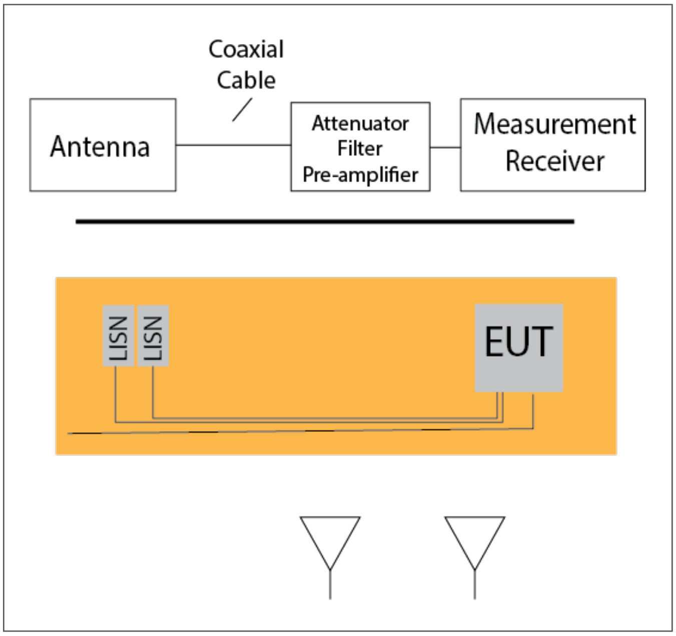


Figure 5: RE102 Test Configuration

Summary

The RE testing is not difficult, but there are many items that can cause flawed data. Consider the results and ask yourself "does this data make sense" and if you doubt the validity, examine for mistakes or simply redo things in question. At an antenna change point, the emissions should not suddenly disappear. A bandwidth change should see a noise floor change and a broadband signal would change by 20 dB for a decade of bandwidth change.

The signal integrity checks should not be taken lightly – lots of things are checked in this process from the hardware operation to selecting the correct file for applying correction and conversion factors. Measurement system cables are part of the integrity checks so don't ignore their influence.

As with any emission testing, make sure that the EUT cycle time is considered. If the EUT takes longer than the minimum dwell time of the measurement receiver, the dwell time will need to be set for the EUT cycle time.

SELECTING THE PROPER EMI FILTER CIRCUIT FOR MILITARY AND DEFENSE APPLICATIONS

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Introduction

Insertion loss, the term used to express a filter's ability to reduce or attenuate unwanted signals, has traditionally been measured in a 50 ohm source and 50 ohm load impedance condition, as standardized in MIL-STD-220.

In this matched 50 ohm impedance condition, various types of filter circuit configurations, single capacitor, "L's", "PI's", and "T's", will exhibit the same response for that given circuit regardless of the relationship between the input, output, and RF signal source.

MIL-STD-220 insertion loss tests are well defined, universal, and are excellent for monitoring filter manufacturing consistencies. However, the results can be misleading when it comes to selecting the proper filter circuit that must function in a complex impedance setting.

SELECTING THE PROPER EMI FILTER CIRCUIT FOR MILITARY AND DEFENSE APPLICATIONS

Introduction

Passive inductive and capacitive filters are impedance sensitive devices by nature and therefore source and load conditions must be taken into consideration when selecting a filter circuit.

This is particularly true, and becomes more pronounced, when you consider that most EMI line filters are not matched filter networks. That is to say the ideal design value of the individual components that make up the network have been modified, or intentionally mismatched, in order to accommodate operating line voltages, operating line currents, and reasonable packaging schemes.

In most cases the ideal inductor for a given response has been greatly reduced in value to accommodate the operating current and reduce the DCR; therefore the capacitors have to be increased in value to achieve the required insertion loss.

This intentional mismatch, which is widely practiced throughout the industry, only affects the very low frequencies by introducing ripple in the pass-band and has little, if any, negative effect in the reject band.

Circuit Configuration

EMI line filers are passive devices and their effect are bidirectional. They are all low-pass brute force networks, passing DC and power line frequencies with very low losses while attenuating the unwanted signals at higher frequencies.

They do not differentiate between EMI generated inside or outside the subsystem or system. They are equally effective in reducing EMI emissions as well as protecting a device from unwanted EMI entering via the power lines.

Each additional element improves the slope of the insertion loss curve. That is, the reject-band will be reached must faster with each section, or element, added. Increasing or decreasing the individual elements values does not change the slope of the curve but does affect the cutoff frequency.

More importantly, when the source and load impedance of the circuit changes, the slope of the insertion loss curve also changes. A “PI” circuit type filter, for example, is best suited when the source and load impedances are of similar values and relatively high. As these impedances become lower, the insertion loss for the “PI” filter also becomes lower. The reverse is true for “T” circuits.

If the circuit impedances varies with frequency, as most circuits do, then it is advantageous to use multiple element filters such as a “PI” or “T” circuit. In the case of a “PI” circuit that exhibits maximum or load impedance is reduced the filter still has two active elements. For all practical purposes it becomes an “L” circuit. Additionally, the amount of filtering achievable is limited by the inductance (ESL) and resistance (ESR) in the capacitor and the parasitic capacitance in the inductors. The results are that the insertion loss curves “levels off” at approximately 80 to 90 dB.

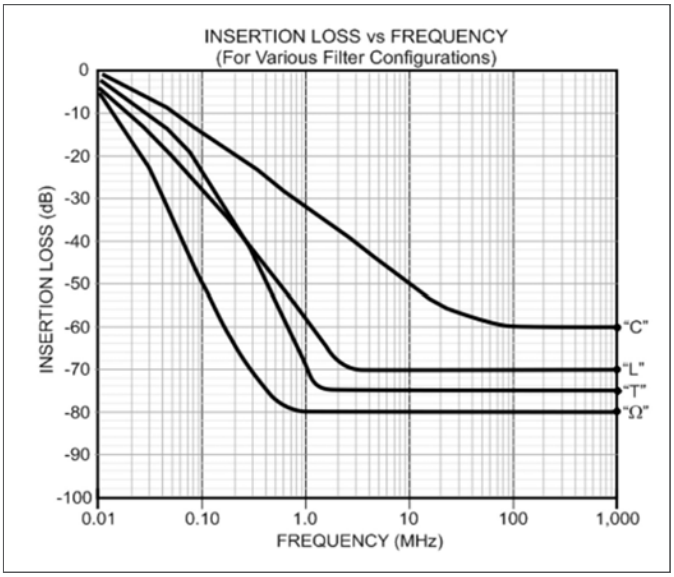

Figure 1. Insertion Loss vs Frequency Curves

The following is a brief description of the most popular types of EMI Filter circuits and their application. It should be pointed out that these are only general guidelines due to the fact that most impedance conditions and EMI profiles are dynamic, complex, and change with frequency.

- Feedthrough Capacitor – A single element shunt feedthrough capacitor has attenuation characteristics that increases at a rate of 20 dB per decade (10 dB at 10 kHz, 30 dB at 100 kHz). A feedthrough capacitor filter is usually the best choice for filtering lines that exhibit very high source and load impedances.

- L-Circuit Filter – A two element network consisting of a series inductive component connected to a shunt feedthrough capacitor. This type of filter network has attenuation characteristics that increases at a rate of 40 dB per decade (20 dB at 100 kHz, 60 dB at 1MHz). An “L” circuit filter is best suited for filtering lines when the source and load impedances exhibit large differences. For most applications this type of network provides the greatest performance when the inductor is facing the lower of the two impedances.

- PI-Circuit Filter – This is a three element filter consisting of two shunt feedthrough capacitors with a series inductive component connected between them. This three element filter has attenuation characteristics

- that increases at a rate of 60 dB per decade (20 dB at 15 kHz, 80 dB at 150 kHz). A “PI” circuit filter is usually the best choice when high levels of attenuation are required and when the source and load impedances are of similar values and relatively high.

- T-Circuit Filter – This also is a three element filter consisting of two inductive components with a single shunt feedthrough capacitors connected between them. Like the “PI” circuit filter, this device has attenuation characteristics that also increase at a rate of 60 dB per decade (20 dB at 15 kHz, 80 dB at 150 kHz). A “T” circuit filter is the best choice when high levels of attenuation are required and when the source and load impedances are of similar values and relatively low.

- Double Circuits – Double “L’s,” double “PI’s”, and double “T’s” consisting of four and five elements are best suited when extremely high levels of attenuation are required. Double “L’s” have a theoretical attenuation of 80 dB per decade, while double “PI’s” and double “T’s” have a theoretical attenuation of 100 dB per decade. The source and load impedance conditions that apply to the single circuit devices apply to the double circuit filters.

The following table summarizes the various source and load impedance settings and the proper filter circuit for that condition.

Mismatching

As previously stated, most EMI line filters are intentionally mismatched for ease in manufacturing. A typical example of this industry wide practice is a cylindrical style filter.

The military specifications for this particular filer are:

Operating Voltage: 70 VDC

Operating Current: 5 ADC

Circuit Configuration: “PI”

DC Resistance: .015 ohms maximum

Case Diameter: .410 inches maximum

Full Load Insertion Loss per MIL-STD-220 (50 ohms):

150 kHz	300 kHz	1 MHz	10 MHz	100 MHz
16 dB	38 dB	75 dB	80 dB	80 dB

Based on a source and load impedance of 50 ohms, MIL-STD-220, a properly designed Butterworth filter (a filter network that has a maximum flat pass-band with average cutoff frequency to reject-band ratio), would produce the following element values in order to satisfy the minimum insertion loss requirements:

C1 = .0769 µfd

L2 = 385 µHy

C3 = .0769 µfd

The theoretical MIL-STD-220 insertion for a “PI” filter of these values is as indicated below:

150 kHz	300 kHz	1 MHz	10 MHz	100 MHz
33 dB	51 dB	83 dB	>100 dB	>100 dB

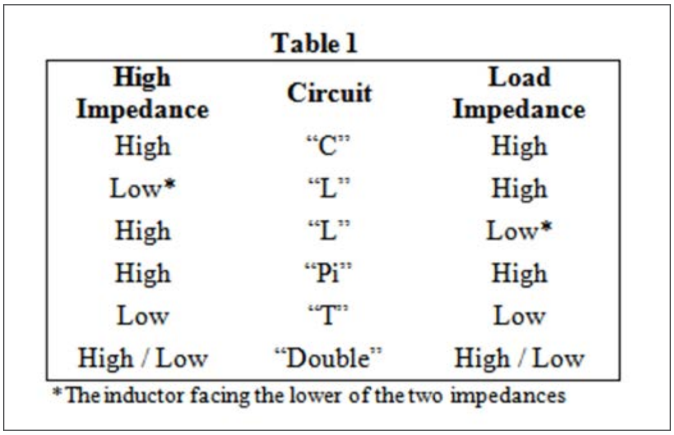

Table 1

High Impedance	Circuit	Load Impedance
High	“C”	High
Low*	“L”	High
High	“L”	Low*
High	“Pi”	High
Low	“T”	Low
High / Low	“Double”	High / Low

*The inductor facing the lower of the two impedances

The capacitance values for C1 and C3, .0769 µfd, are acceptable for a 70 VDC rated filter and are easily manufactured. However, L2 must be 385 µHy in order to satisfy the insertion loss requirements.

In order to achieve 385 µHy at 5 ADC, allow for core saturation (the change in incremental permeability of the core material with DC bias), and comply with the .015 DC resistance requirement, the diameter of the inductor would be in excess of 2.0 inches. This inductor would obviously not fit a case with an outside diameter of .410 inches.

By simply reducing the inductor to a realistic value and increasing the value of C1 and C3, we can achieve the required insertion loss in the reject-band with a design that can easily be manufactured. The typical values for this application would be:

C1 = .70 µfd

L2 = 5 µHy

C3 = .7 µfd

The theoretical MIL-STD-220 insertion for this modified filter is:

150 kHz	300 kHz	1 MHz	10 MHz	100 MHz
25 dB	50 dB	83 dB	>100 dB	>100 dB

As previously stated, this practice of intentionally mismatching the element values will introduce a substantial amount of ripple, as much as 10 to 20 dB, in the passband. However, at frequencies below 1 KHz, the response is normally flat to within ± 1 dB.

Figure 2 depicts the MIL-STD-220 insertion loss characteristics for the ideal filter network and the modified design as compared to the specification requirements.

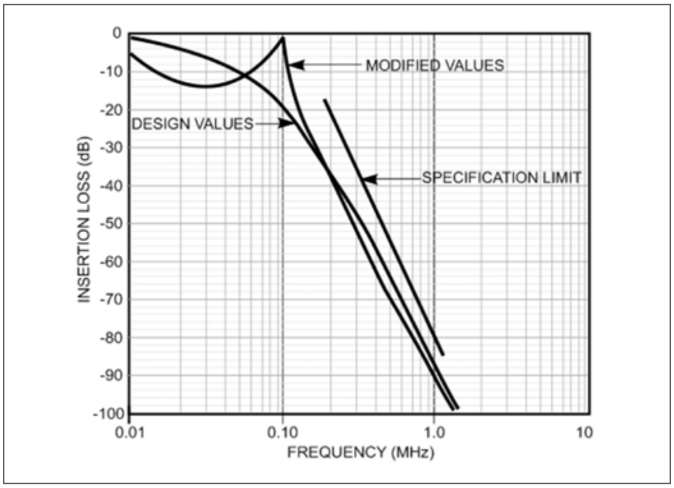

Figure 2. MIL-STD-220 insertion loss characteristics for ideal filter network and modified design compared to specification requirements.

MIL-STD-220 Insertion Loss Verses MIL-STD-461 EMI Testing

The majority of EMI filters are employed in order to cause system compliance to one of various military or commercial EMI/EMC specifications.

The most widely references military EMI/EMC specification is Military Specification MIL-STD-461 (462,463). This document specifies the allowable amount of conducted and radiated emissions that a subsystem or system can generate.

Conducted emissions is interference that is present, or ‘conducted’ on primary power lines (AC or DC) and/or signal lines as detected by a current probe or other means. Radiated emissions is interference, both ‘E” and “H” fields, that is being transmitted or radiated from the total system as detected by a receiving antenna.

In addition, MIL-STD-461 also delineates a series of tests that subject the device under test to various types of conducted and radiated interference to determine the survivability of the device when exposed to a harsh EMI environment. This series of tests is referred to as conducted and radiated susceptibility.

Conducted emission requirements and test methods are referred to as “CE”. The numbers that follow refer to the applicable frequency range and whether it pertains to input power lines or signal lines. (i.e., CE03 establishes test methods and maximum allowable interference that can be present on AC and DC power lines over the frequency range of 15 kHz to 50 MHz.) Similarly, “CS” stands for Conducted Susceptibility, “RE” for Radiated Emission, and “RS” for Radiated Susceptibility.

As previously stated, EMI filters being bidirectional devices not only help to reduce the amount of conducted emissions generated within, but also protect the system from unwanted interference entering via the power lines and signal lines.

To some degree EMI filers also help to reduce the radiated interference. This is due to the fact that the power lines and signal lines can act as ‘transmitting antennas’ if too much EMI is present. However, the majority of radiated problems are system configuration related (i.e., improper grounding, shielding, lack of EMI gaskets, the choice of materials in the case of “H” fields, etc.).

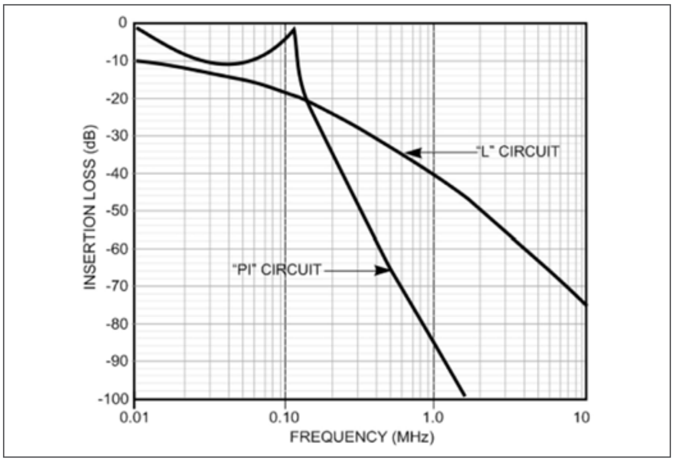

Figure 3. comparison of theoretical MIL-STD-220 50 ohm insertion loss of a “PI” filter and a “L” filter

The EMI profiles, and impedance, of any device is very complex and will change drastically over a given frequency range. It’s this phenomenon that makes selecting an EMI filter based solely on 50 ohm insertion loss data difficult.

Figure 3 compares the theoretical MIL-STD-220 50 ohm insertion loss of a “PI” filter and a “L” filter comprised of the following components.

“PI” Circuit:

C1 = .70 µfd

L2 = 5 µHy

C3 = .70 µfd

“L” Circuit:

C1 = .70 µfd

L2 = 5 µHy

Looking at this comparison, and if size was not an issue, one would have a tendency to choose the “PI” circuit over the “L” circuit based on performance. At 1 MHz the “PI” circuit provides 80+ dB of insertion loss where the “L” circuit only provides 40+ dB.

However, MIL-STD-461 conducted emission tests are not performance under 50 ohm source and load conditions.

Figure 4 illustrates a typical MIL-STD-461 conducted emissions test configuration.

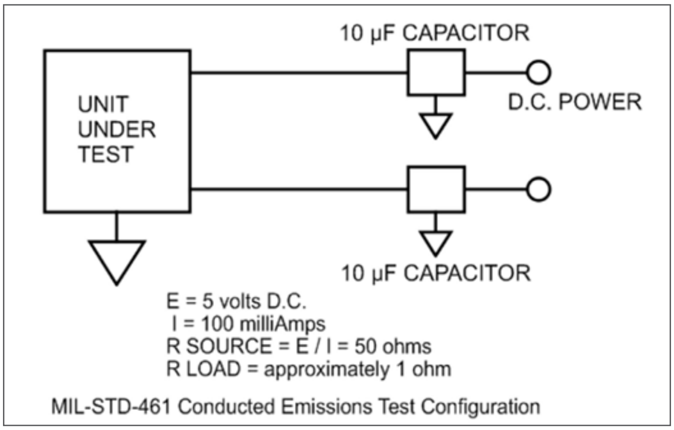

Figure 4. MIL-STD-461 Conducted Emissions Test Configuration

Not knowing the EMI source impedance (the device under test), we will assume ohms law. In this case 50 ohms. We don’t know what the load impedance is, however, due to the 10 µfd line stabilization capacitors (required by MIL-STD-461 as part of the test configuration), we can assume it is low compared to the source impedance. In this case, we will theorize 1 ohm.

In this more realistic setting, 50 ohm source and 1 ohm load, the “L” circuit performs almost as well as the “PI” circuit as illustrated in *Figure 5*. By slightly increasing the values of C1 and L2 in the “L” circuit, a response identical to the “PI” circuit can be achieved.

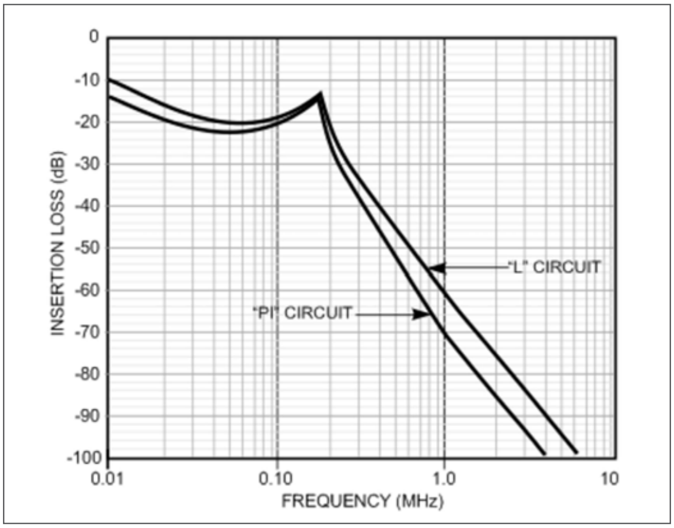

Figure 5. Performance of “L” and “PI” circuits for 50 ohm source and 1 ohm load

In the previous example we were only concerned with EMI emanating from the test sample. If we were also concerned about protecting against unwanted interference entering the device then a “T” circuit would be the filter of choice. In essence, by using a “T” circuit we have two “L” circuits with the inductor facing the lower impedance.

If the “T” circuit consisted of L1 facing the unit under test and, L3 facing the load with C2 in the middle, then for conduced emissions the “L” circuit is comprised of C2 and L3. For conducted susceptibility, if we assume the unit under test to be the lower of the two impedances, the “L” circuit is comprised of C2 and L1. In both instances the secondary inductor will provide some additional filtering. However, its contribution is relatively small compared to the other two components.

There are an infinite number of source and load impedance combinations for signal line applications where the 10 µfd line stabilization capacitors are not required as part of the test configuration. For these situations the theoretical insertion loss can be calculated by varying RS and RL in the equations.

Although the circuits that we have been discussing only address common mode (interference which is present as a common potential between ground and all power lines) EMI, the same philosophies apply when selecting differential mode (interference which is present as a potential between individual power lines) EMI filtering elements commonly found in multicircuit filter assemblies, or “Black Box”.

Conclusion

Selecting the proper EMI filter circuit is not a difficult task provided, that as a minimum, the following parameters are taken into consideration:

- The EMI source impedance
- The EMI load impedance
- The EMI propagation mode (common mode, differential mode or both)
- Conducted emission requirements
- Conducted susceptibility requirements

Other considerations that are not readily apparent are the effects caused by mismatching; performance at full load; and the inability to achieve the theoretical insertion loss due to the inductance (ESL) and resistance (ESR) in the capacitor, and the parasitic capacitance in the inductors.

For more information about EMI Filters and Filter Connectors, please contact:

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Vice President Sales and Marketing
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Office: 310-644-0251 ext. 110
Email: mmacbrair@wems.com

INTRODUCTION TO DoD POLICY, GUIDANCE, & THE ACQUISITION PROCESS

Tony Keys
EMC Analytical Services

Brian Farmer
EMC Management Concepts

Introduction

This article provides an introduction to DoD policy, guidance and the acquisition process. E3 is defined as the impact of the Electromagnetic Environment (EME) upon the operational capability of military forces, equipment, systems, and platforms. E3 encompasses all electromagnetic disciplines, including Electromagnetic Interference and Electromagnetic Compatibility (EMI/EMC); Electromagnetic Vulnerability (EMV); Electromagnetic Pulse (EMP); natural phenomena such as lightning, electrostatic discharge (ESD) and precipitation static; and Hazards of Electromagnetic Radiation to Personnel (HERP), Ordnance (HERO), and Fuel (HERF). In addition, Spectrum Supportability must be addressed in conjunction with E3 for Spectrum Dependent (S-D) systems.

INTRODUCTION TO DoD POLICY, GUIDANCE, & THE AQUISITION PROCESS

Early consideration of E3 and Spectrum Supportability (SS) in electronic and S-D systems is a fundamental criterion that must be satisfied before communications-electronics (CE) equipment and related weapons systems are developed and fielded. Development or acquisition of systems that meet operational requirements, but are not electromagnetically compatible or fail to obtain spectrum supportability, creates a potential for severe mutual interference between themselves and other spectrum users, squanders resources, and delays fielding warfighting capabilities to field units.

Equipment, subsystems and systems employed for military purposes are exposed to extreme EMEs. Providing the warfighter with systems that will operate within these extreme EMEs requires specific requirements, design and test considerations. This new mini guide from Interference Technology will review E3 related policies and requirements specific to military equipment, subsystems and systems, from a top down perspective, including overviews of MIL-STD-464C and MIL-STD-461G, a listing of relevant military E3 related documents and points of contact.

Real World Operational Impacts/Examples

There are many examples of EMC and spectrum supportability problems in military systems which have caused serious, and even catastrophic, operational and programmatic problems. Some examples include:

Between 1981 and 1987, several UH-60 Blackhawk helicopters nose-dived and crashed, killing 22 servicemen. The crashes were attributed to insufficient flight control immunity to high intensity radiated fields when flying past radio broadcast towers. This interference produced uncommanded control surface movements causing fatal dives.

The US Air Force has had to address a potential frequency-interference issue with their B-2 bombers. Analysis indicates a high probability of the Raytheon AN/APQ-181 radar system on the B-2As interfering with commercial satellite communications after 2007.

The B-2's radar would most likely disrupt their transmissions and could damage commercial communications satellites, for which the USAF likely would be liable, according to industry sources. The total estimated cost is expected to exceed $1.3B.

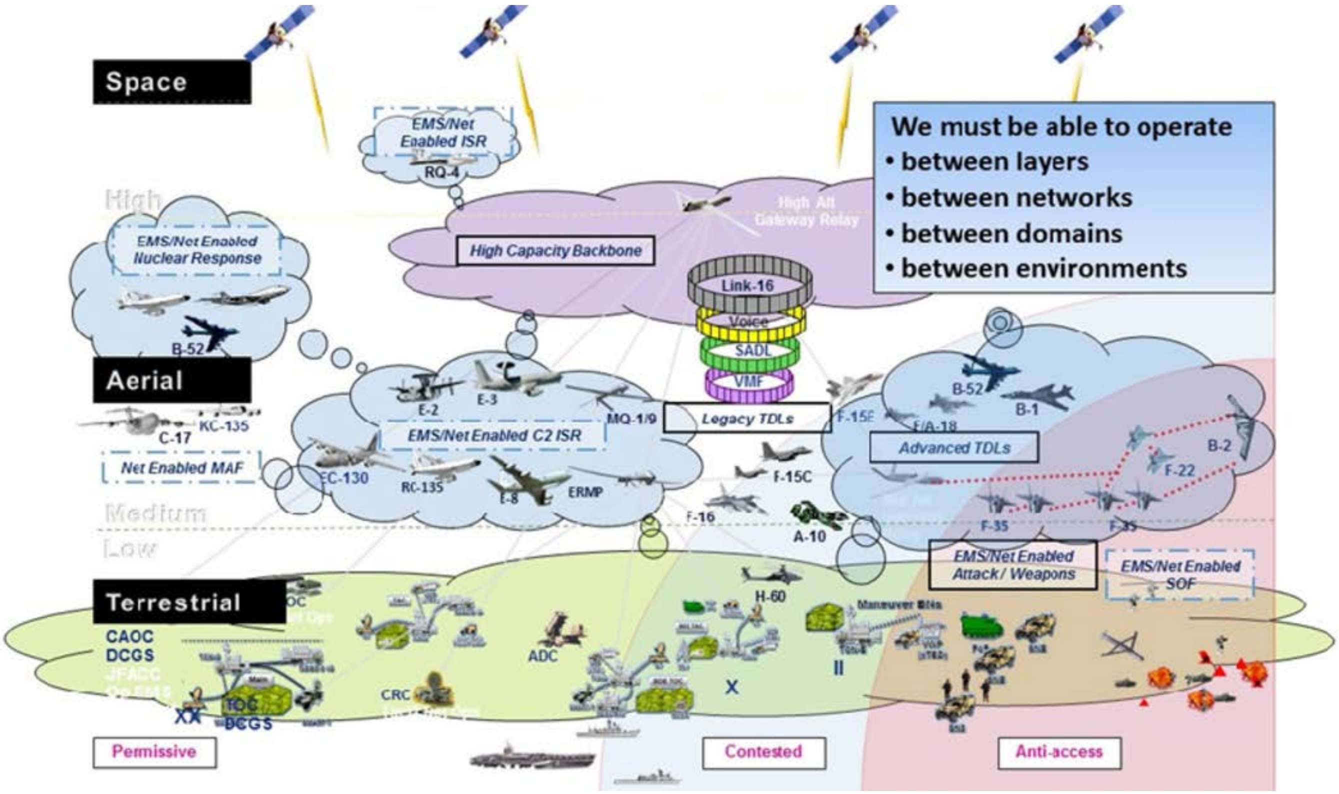


FIGURE 1: Spectrum Dominance Illustration

> An AV-8B Harrier was lost and the pilot killed as a result of the indirect effects of a lightning strike. The lightning strike caused large internal electrical currents inside the wing. A coupler inside the wing fuel tank system was not designed to withstand such a current flowing across it and sparked, causing a fuel explosion.

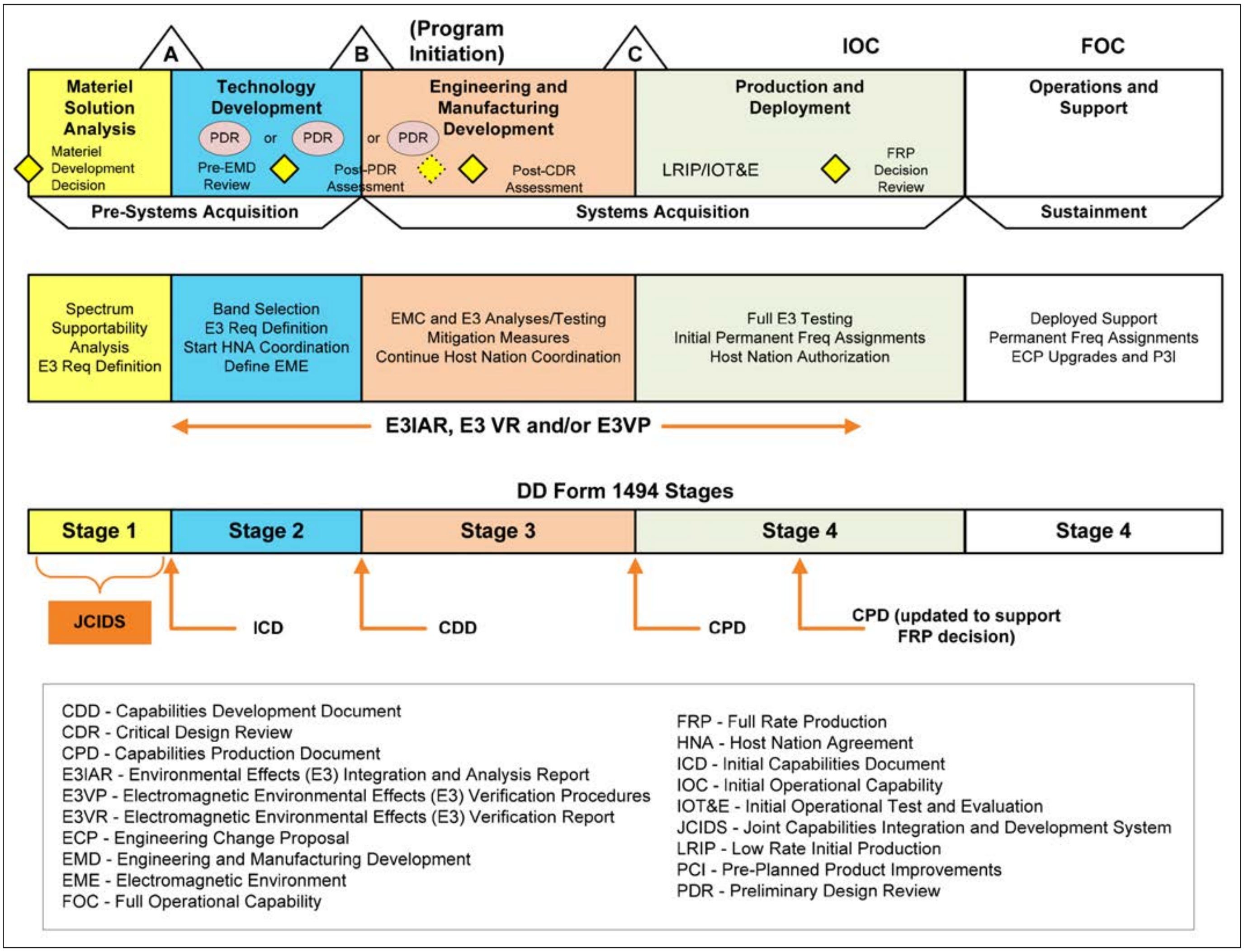
While there have been these and other catastrophic examples, the vast majority are simply performance degradation problems that put our fighting forces at risk, delay fielding of important capabilities or stretch budgets beyond their limits.

DoD Policy and Perspective

The need for control of the electromagnetic spectrum and the EME is understood at the highest levels of DoD management and military operational directors, who must ensure that U.S. Forces have the ability to operate effectively in all domains: space, sea, land, air, information; and can conduct operations with a combination of forces tailored to different situations. Military success relies on Information Superiority: Obtaining, processing, distributing, and protecting accurate information while exploiting or denying the adversary's ability from doing the same. Much of the information superiority depends on access to the RF spectrum. The priority placed on force mobility, range, and speed dictates that much of the information technology be wireless. Again, the critical medium is the EM spectrum with EMI free operations.

Spectrum dominance is a cornerstone of the DoD's warfighting strategy. To maintain this spectrum dominance, the spectrum and system EMC within the spectrum must be carefully controlled.

While EMI (including interference caused by spectrum management problems) can cause catastrophic problems, the majority of interference problems render systems less than fully effective, which reduces operational readiness and increases costs. These may be hard to see, and more difficult to quantify in terms of return on investment; however, taking care of E3 and Spectrum Certification requirements early on in a program provides significant future cost savings. *Figure 1* illustrates the concept of spectrum dominance.



CDD - Capabilities Development Document
CDR - Critical Design Review
CPD - Capabilities Production Document
E3IAR - Environmental Effects (E3) Integration and Analysis Report
E3VP - Electromagnetic Environmental Effects (E3) Verification Procedures
E3VR - Electromagnetic Environmental Effects (E3) Verification Report
ECP - Engineering Change Proposal
EMD - Engineering and Manufacturing Development
EME - Electromagnetic Environment
FOC - Full Operational Capability
FRP - Full Rate Production
HNA - Host Nation Agreement
ICD - Initial Capabilities Document
IOC - Initial Operational Capability
IOT&E - Initial Operational Test and Evaluation
JCIDS - Joint Capabilities Integration and Development System
LRIP - Low Rate Initial Production
PCI - Pre-Planned Product Improvements
PDR - Preliminary Design Review

FIGURE 2: E3 and SS Processes

Acquisition Process

The military procurement system is driven by high level policies that flow down to processes and procedures covering anything that is considered a technical requirement. E3 and SS are no different.

There are high level policies that require programs to consider E3 and SS in system design, procurement and fielding as well as policies requiring that military systems follow the rules of frequency use. The two most significant top level directives that require spectrum management and E3 control in the acquisition cycle are:

DoD Instruction 3222.03 DoD Electromagnetic Environmental Effects (E3) Program, 24 Aug 2014

This Instruction drives the requirement that "All electrical and electronic systems, subsystems, and equipment, including ordnance containing electrically initiated devices, shall be mutually compatible in their intended EME without causing or suffering unacceptable mission degradation due to E3." It identifies many high level DoD organizations and outlines their responsibilities for E3 control within systems acquisition and operational communities.

DoD Instruction 4650.01, Policy and Procedures for Management and Use of the Electromagnetic Spectrum, 09 Jan 2009

This instruction outlines the requirements for DoD spectrum use to ensure that systems can operate without interference. Some requirements include:

Obtaining a written determination that there is reasonable assurance of Spectrum Supportability for DoD organizations developing or acquiring spectrum-dependent equipment.

Applicability of Spectrum Supportability determination requirements for "off-the-shelf" or other non-developmental systems (including commercial items).

The requirement to produce a Spectrum Supportability Risk Assessment (SSRA) to identify and assess an acquisition's potential to affect the required performance of the newly acquired system or other existing systems within the operational EME. SSRAs identify SS and E3 risks and the steps that need to be taken to mitigate the risks.

The fundamental E3 and SS related processes and tasks over the military system procurement cycle are shown in *Figure 2*.

About the Authors

Tony Keys is the President and Principal Consultant for EMC Analytical Services. Mr. Keys has over 20 years of experience in Electromagnetic Environmental Effects (E3) engineering. His experience covers a wide range of E3 specialty areas from a multitude of organizational aspects including E3 support contracting, DoD E3 service, and DoD system development. He can be reached at tony.keys@emcanalyticalservices.com.

The author would like to thank Brian Farmer for his significant contribution to the article.

Brian Farmer has a long career providing E3 and Spectrum Supportability systems engineering and program management services to the DoD, including the Naval Air Systems Command (NAVAIR), the Joint Spectrum Center (JSC) and the Naval Surface Warfare Center Dahlgren Division. After working for several companies in the E3 engineering business, Brian formed EMC Management Concepts in 2002.

In addition to being CEO of EMC Management Concepts, Brian still provides direct E3 program management support to several Navy offices and the JSC. He leads contract efforts to develop and deliver E3 and Spectrum Supportability training to the acquisition community.He can be reached at *bdfarmer@emcmanagement.com*

REFERENCES

(ARTICLE LINKS, DIRECTORIES, CONFERENCES, & LINKEDIN GROUPS)

LINKS TO LONGER ARTICLES

"MIL-STD-461G – The Compleat Review"
https://interferencetechnology.com/mil-std-461g-compleat-review/

"Selecting the Proper EMI Filter Circuit For Military and Defense Applications"
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"Why is there AIR (In MIL-STD-461G)?"
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"DO-160 cable bundle testing for indirect lightning"
https://interferencetechnology.com/do-160-critical-sections-cable-bundle-for-indirect-lightning/

TEST HOUSE DIRECTORY

Test House Directory – 2016 Test and Design Guide
http://learn.interferencetechnology.com/2016-emc-test-and-design-guide/

2018 CONFERENCE DIRECTORIES

AFCEA Events:
www.afcea.org/site/

ASCE Events:
www.asce.org/aerospace-engineering/aerospace-conferences-and-events/

ASD Events:
www.asdevents.com/shopcontent asp?type =aerospace_defence

Aviation Week Event Calendar:
www.events.aviationweek.com/current/Public/Enter.aspx

Defense Conferences:
www.defenseconference.com/

Global Edge (MSU):
www.globaledge.msu.edu/industries/aerospace-and-defense/events/

ICMST Events (PDF):
www.drdo.gov.in/drdo/egate/FICMST_Vol_12_No_03_January_2017.pdf

IEEE AESS Events:
www.ieee-aess.org/conferences/home

Jane's Events:
www.janes.com/events

LINKEDIN GROUPS

Aerospace and Defense Subcontractor and Suppliers

Aerospace and Security and Defence Technology and Business (Defence spelled correctly)

Defense and Aerospace

EMP Defense Council

High Intensity RF (HIRF) Professionals

Radio, Microwave, Satellite, and Optical Communications

RF/Microwave Aerospace and Defense Applications

RF and Microwave Community

TABLE OF NEW EQUIPMENT ALLOWED/REQUIRED IN MIL-STD-461G

Tony Keys
EMC Analytical Services

Ken Javor
EMC Compliance

The following table was compiled by Ken Javor, of EMC Compliance. The updated changes to MIL-STD-461G require some new equipment. One of these changes allows the use of time domain EMI receivers, which will help speed up the testing, due to their fast FFT-based signal acquisition. Following is a list of some specific changes and equipment requirements:

CS101 *(Conducted Susceptibility, Power Leads) - There is now a requirement to measure induced AC power line ripple. This requires a new "*power ripple detector", which is a specially designed isolation transformer that matches the power line to 50 ohms.

CS114 *(Conducted Susceptibility, Bulk Cable Injection) - This injection probe test now requires the use of a current probe calibration fixture to validate the test level during* pre-calibration.

CS117 *(Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads) - This* is a new test added to MIL-STD-461G and requires a lightning transient simulator.

CS118 *(Conducted Susceptibility, Personnel Borne Electrostatic Discharge) - This* is a new test added to MIL-STD-461G and requires a standard electrostatic discharge simulator.

RS103 *(Radiated Susceptibility, Electric Field) - This test requires an E-field antenna that can go down to 2 MHz.*

Table of New Equipment Required for Latest Updates to MIL-STD-461G

Requirement	Equipment Type	Vendor(s)	Websites
General	Time Domain EMI receivers*	Amplifier Research	http://www.arworld.us/html/dsp-receiver-multistar.asp
		Gauss Instruments	http://www.gauss-instruments.com/en/products/tdemi
		Keysight	http://www.keysight.com/en/pdx-x201870-pn-N9038A/mxe-emi-receiver-3-hz-to-44-ghz?cc=UG&lc=eng
		Rohde & Schwarz	https://www.rohde-schwarz.com/us/products/test-measurement/emc-field-strength-test-solutions/emc-field-strength-test-solutions_105344.html
CS101	Frequency domain ripple monitoring transducer* High-voltage differential probe, 100 MHz, 1k V(RMS) Digital Oscilloscopes (200 MHz - 4 GHZ, 5/10 GSa/s)	Pearson Electronics	http://www.pearsonelectronics.com/news/179
		Rohde & Schwarz	https://www.rohde-schwarz.com/us/product/rtzd01-productstartpage_63493-34629.html
		Rohde & Schwarz	https://www.rohde-schwarz.com/us/product/rto-productstartpage_63493-10790.html or https://www.rohde-schwarz.com/vn/product/rte-productstartpage_63493-54848.html (with Option RTO-K17)
CS114	Current probe calibration fixture	ETS/Lindgren	http://www.ets-lindgren.com/EMC (fixture not listed on web site but should be part of current probe/injection clamp line-up)
		Fischer Custom Communications	http://www.fischercc.com/ViewProductGroup.aspx?productgroupid=141
		Pearson Electronics	http://www.pearsonelectronics.com/news/180 (fixture holds both injection clamp and current probe)
		Solar Electronics	http://www.solar-emc.com/RFI-EMI.html (scroll to bottom of page)
CS117	Indirect lightning test systems	HV Technologies	http://www.hvtechnologies.com/TestsTrack/Lightning/tabid/408/Default
		Thermo Scientific	http://www.thermoscientific.com/en/product/ecat-lightning-test-system-lts.html
		Solar Electronics	http://www.solar-emc.com/2654-2.html
CS118	ESD gun	EMC Partner	https://www.emc-partner.com/products/immunity/esd/esd-generator
		EM Test	http://www.emtest.com/products/productGroups/ESD_generators.php
		Haefely	http://www.haefely-hipotronics.com/product/product-category/electrostatic-discharge-test-systems-esd/
		Kikusui	http://www.kikusui.co.jp/en/product/detail.php?IdFamily=0020
		LISUN Group	http://www.lisungroup.com/product-id-318.html
		Noiseken	http://www.noiseken.com/modules/products/index.php?cat_id=1
		Thermo Scientific	http://www.thermoscientific.com/en/product/minizap-15-esd-simulator.html
		TESEQ	http://www.teseq.com/product-categories/esd-simulators.php
RS103	1 – 18 GHz electric field probe (most test facilities already have one)	Amplifier Research	http://www.arworld.us/html/field-analyzers-field-monitoring.asp
		ETS/Lindgren	http://www.ets-lindgren.com/EMCProbes
		NARDA	http://www.narda-sts.us/products_highfreq_bband.php

* Specified as acceptable for use, but not required.

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