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2017 MILITARY & AEROSPACE EMC GUIDE

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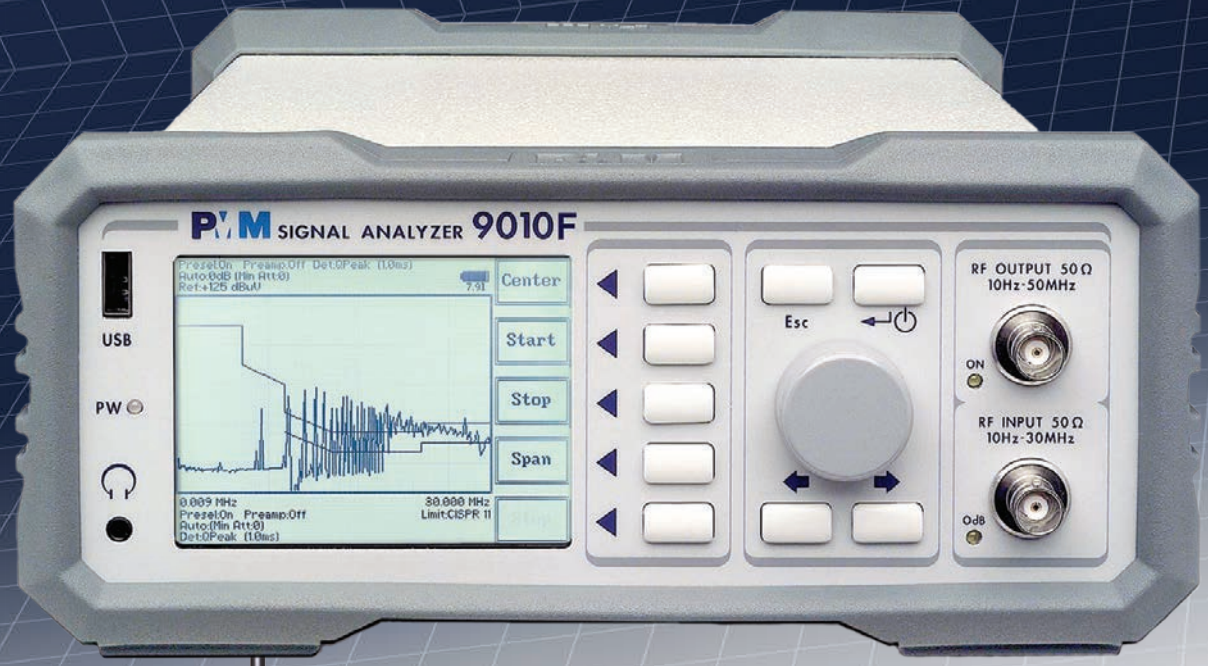

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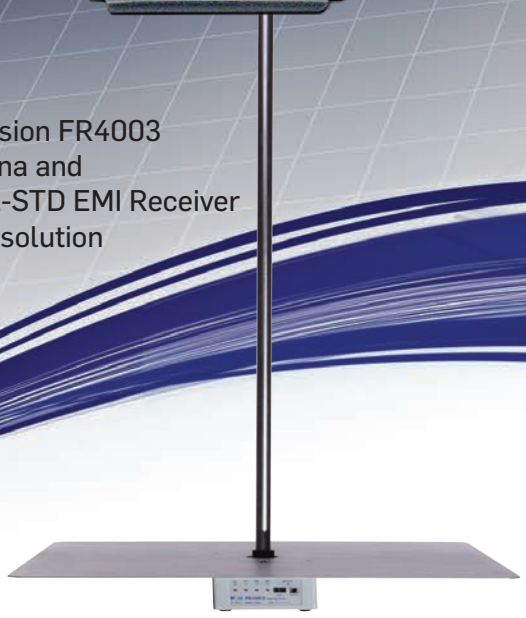

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INTRODUCTION

Kenneth Wyatt
Wyatt Technical Services
ken@emc-seminars.com

There are some exciting technologies occurring within the military and aerospace sectors, and with an increase in world tensions comes the possibility of increased military budgets. Advances in millimeter wave communications and control, and even autonomous vehicles 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.

In addition, the aerospace sector is moving ahead with many exciting projects, including the soon to launch, James Webb Space Telescope with improved technology over the current Hubble Telescope. 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 and Blue Origin, are bringing more affordable alternatives to NASA and Arianne programs, as well as existing programs in Russia, China, Japan, and many other countries. Refer to a more complete listing here.

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 and aerospace tests and standards, an introduction to the newly released MIL-STD-461G, background on the new CS-117 cable induction test, EMI simulation for launchers and satellites, 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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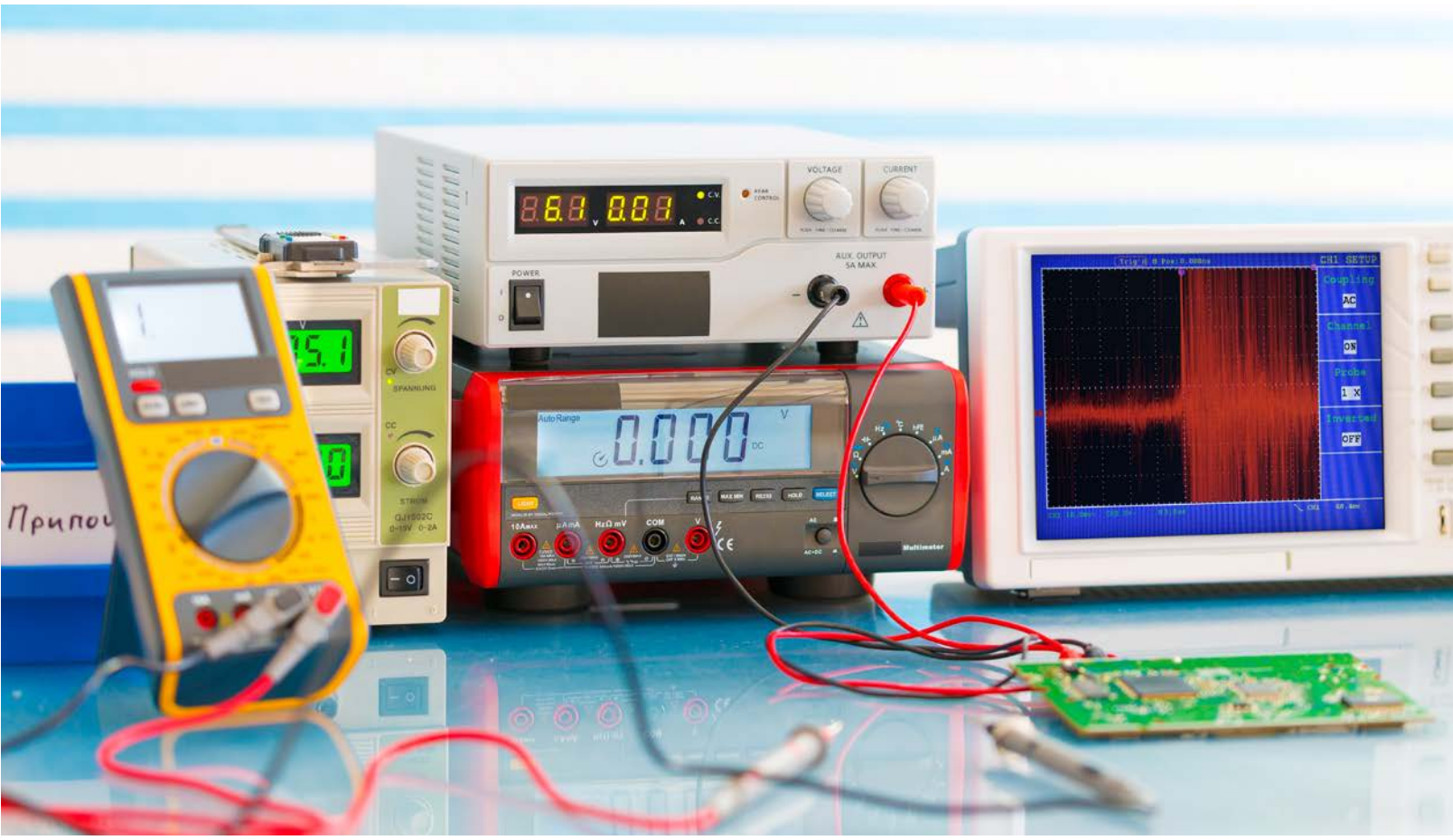
EMC EQUIPMENT MANUFACTURERS

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

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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.

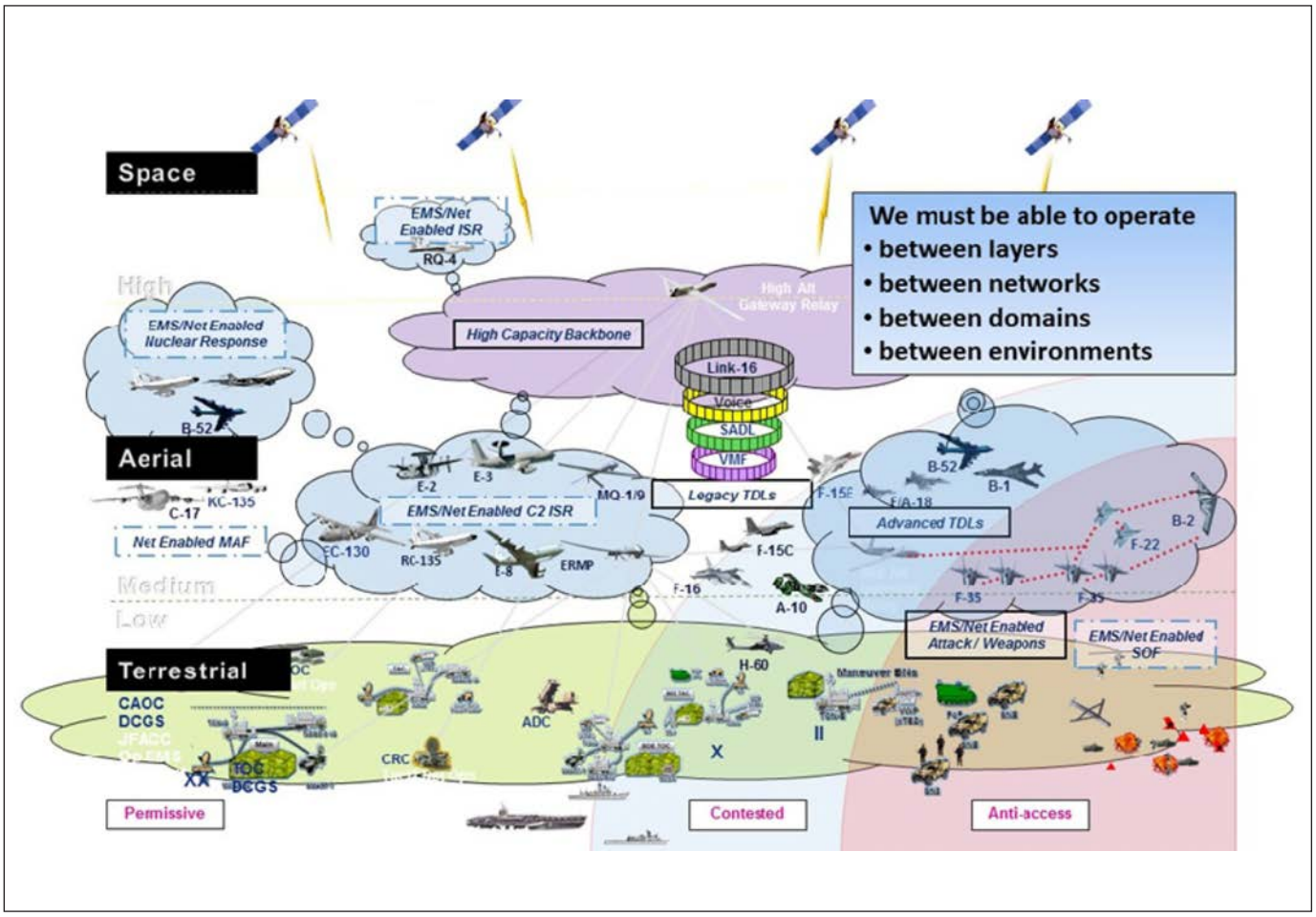

FIGURE 1: Spectrum Dominance Illustration

An AV-8B Harrierwas 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.

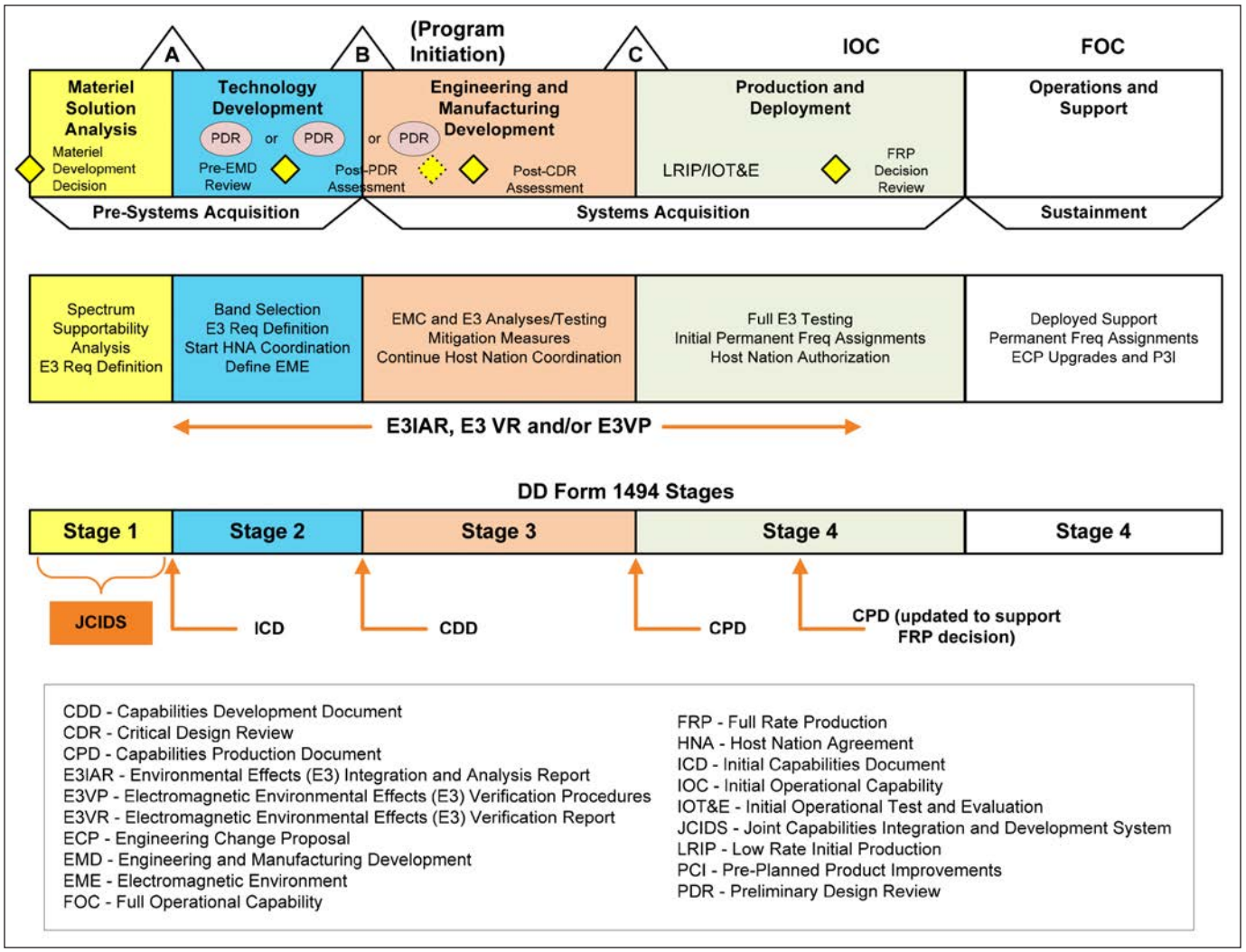

FIGURE 2: E3 and SS Processes

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:

DODI 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


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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.

References

1. 2016 Military EMC Guide, Interference Technology
2. Ken Javor, MIL-STD-461G: The “Compleat” Review, Interference Technology, April 2016
3. Ken Javor, Why Is There AIR (in MIL-STD-461G)?, Interference Technology, April 2016
4. MIL-STD-461G, December 2015, Defense Acquisition System
5. RTCA/DO-160G, RTCA, December 2010.

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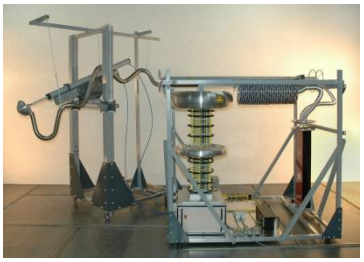

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INTRODUCTION TO MIL-STD-461G

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Introduction

Where MIL-STD-464C serves as a system/platform level set of requirements, MIL-STD-461G serves as an equipment/ subsystem level set of requirements. Similar to MIL-STD-464C, MIL-STD-461G was developed as an "Interface Standard" to allow usage without a waiver. The overall structure of the two documents is also the same in that both have a contractual main body and a very informative non-contractual rationale and lessons-learned appendix. However, unlike MIL-STD-464C, MIL-STD-461G provides pass/fail criteria, limits, test levels and detailed procedures. The purpose of MIL-STD-461G is to control EMI characteristics of equipment/ subsystems procured by the DoD to increase the likelihood of compatibility in its EME. It is not applicable for platforms/systems or modules/parts. Applicable items include enclosures no larger than an equipment rack, electrical interconnections that are discrete wiring harnesses between enclosures and electrical power derived from prime power sources. Requirements depend on equipment/ subsystem type and use and may be tailored. It is important to note that passing MIL-STD-461G testing does not ensure platform level EMC and failing MIL-STD-464G testing does not necessarily mean a platform EMI problem.

INTRODUCTION TO MIL-STD-461G

As background, MIL-STD-461 is officially prepared by the US Air Force, but it is the product of a Tri-Service Working Group (TSWG) made up, not surprisingly, of representatives from the Army and Navy as well. In addition to Service members there are industry representatives.

Since 1993, MIL-STD-461 has been on a five-year review cycle, to ensure that it remains current and useful. This does not mean a new revision has to be released every five years; just that a review must be performed on that cycle. It would be entirely acceptable to simply reaffirm the old version with no changes. To date, that hasn't happened.

MIL-STD-461D and MIL-STD-462D released in 1993 remain the major "revolution" in military EMI standards, with evolutionary changes following. MIL-STD-461E combined MIL-STD-461 and MIL-STD-462 into a single standard, obsoleting MIL-STD-462 in 1999. MIL-STD-461F was released on 10 December 2007 and provided a number of changes from MIL-STD-461E, but the changes were minor in nature when compared to the changes between revisions D and E. MIL-STD-461G, released 11 December 2015, makes the most structural changes since that time, adding two new requirements (lightning indirect effects, CS117, and personnel electrostatic discharge, CS118) while eliminating the CS106 requirement that was added the last time around in MIL-STD-461F.

This guide will focus on MIL-STD-461G, but given the recent revision change and the fact that most programs are contractually under MIL-STD-461F, major differences between the two revisions will be highlighted as required. MIL-STD-461G imposes requirements in only four major areas for equipment and subsystems: Conducted Emissions (CE), Conducted Susceptibility (CS), Radiated Emissions (RE) and Radiated Susceptibility (RS) and are identified by a 1XX, to differentiate them from the earlier MIL-STD-461A/B/C requirements that were numbered XX. The complete listing of test methods is shown in *Table 1*. CS106 in blue text was required in MIL-STD-461F, but was eliminated from MIL-STD-461G. CS117 and CS118 in red text were added to MIL-STD-461G. The following is not intended to serve as an all-inclusive tutorial on MIL-STD-461G, but rather an overview to illustrate how MIL-STD-461G is employed as a tool by the DoD to support the warfighter. The applicability of each test method is dependent on Service Branch and specific platform installation.

Table 2 illustrates the applicability of each test method.

Requirement	Description
CE101	Conducted Emissions, Audio Frequency Currents, Power Leads
CE102	Conducted Emissions, Radio Frequency Potentials, Power Leads
CE106	Conducted Emissions, Antenna Port
CS101	Conducted Susceptibility, Power Leads
CS103	Conducted Susceptibility, Antenna Port, Intermodulation
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation
CS106	Conducted Susceptibility, Transients, Power Leads
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

Note: CS117 and CS118 were added for MIL-STD-461G (indicated in red).
Note: CS106 was a requirement in MIL-STD-461F, but has been removed from MIL-STD-461G (in blue).
TABLE 1. MIL-STD-461G Test Methods

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

A = Applicable (in green).
L = Limited as specified in the individual sections of MIL-STD-461G (in yellow).
S = Procuring activity must specify in procurement documentation (in red).

TABLE 2. MIL-STD-461G Requirements Matrix

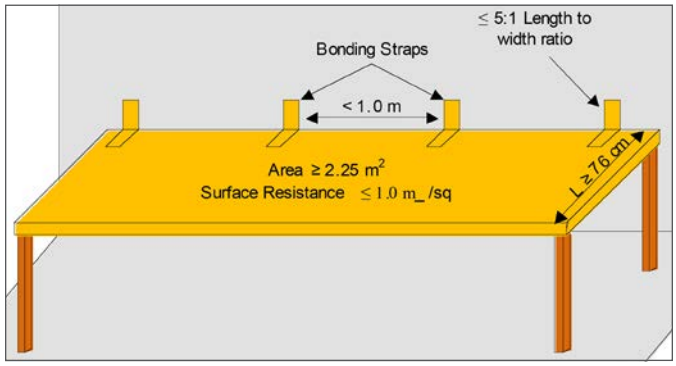

FIGURE 1: Test Ground Plane Configuration

MIL-STD-461G provides a set of general interface and verification requirements. The general interface requirements include motherhood style guidance on joint procurements, self-compatibility, non-developmental items (NDI), Government Furnished Equipment (GFE), switching transients and interchangeable modular equipment. They also include specific requirements on minimizing the use of line-to-ground filters for EMI control in Navy systems. The general verification requirements include detailed information for verification testing on topics including; measurement tolerances, shielded enclosures, ambient electromagnetic level, ground planes, power source impedance, general test precautions, EUT test configurations and operations, and the use and calibration of measurement equipment.

Measurement tolerances are specified for distance (±5%), frequency (±2%), amplitude of the measurement receiver (±2 dB), time waveforms (±5%), resistors (±5%), capacitors (±20%) and the overall amplitude of the complete measurement system (±3 dB). Shielded enclosures are normally required for MIL-STD-461G testing with RF absorber material placed above, behind, and on both

sides of the EUT as well as behind the transmitting or receiving antenna. The RF absorber material is required to have a minimum absorption of 6 dB from 80 MHz to 250 MHz and 10 dB above 250 MHz. Controlling the ambient environment during testing is critical.

The ambient electromagnetic level measured with the EUT de-energized and all auxiliary equipment turned on must be at least 6 dB below the allowable specified limits when the tests are performed in a shielded enclosure. Ambient conducted levels on power leads should be measured with the leads disconnected from the EUT and connected to a resistive load, which draws the same rated current as the EUT. Testing must be performed with ground planes that simulate the actual installation if it is known. In cases where the specific installation is not known, or there will be various installations employed, then a metallic ground plane is used. For cases where the EUT does not employ a ground plane when installed, testing is performed on a non-conductive table. In some cases, conductive composite ground planes are used in the installed configuration. In these cases, the surface resistivity of the typical installation is used. *Figure 1* summarizes the ground plane requirements delineated in MIL-STD-461G.

The impedance of power sources providing primary input power to the EUT is controlled by specific (50 µH) Line Impedance Stabilization Networks (LISNs) for all measurement procedures. There are specific cases for CE101 and CE102, where the use of a 5 µH LISNs may be acceptable, but for the vast majority of applications, the 50 µH LISN is used. The specified LISN parameters are shown in *Figure 2*.

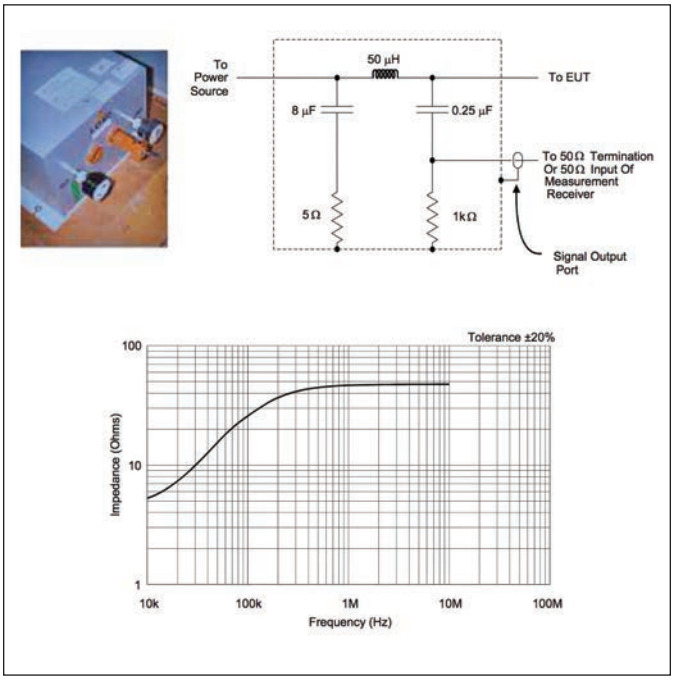

FIGURE 2: MIL-STD-461G 50 µH LISN

While it was always understood that LISNs must have an excellent RF bond to the ground plane for proper operation, it was not specifically stated until the MIL-STD-461G release.

One of the prime factors in MIL-STD-461G radiated (and conducted for that matter) test results is the arrangement and treatment of the electrical interfaces. Electrical cable assemblies are required to simulate actual installation and usage. The cable design and construction must be production representative (preferably actual production cables!). The cables used for testing must be fabricated identical to actual cables in terms of shielding and shield termination technique, wire size, twisting, etc. Shielded cables or shielded leads are only allowed if they have been specified in installation requirements. Input (primary) power leads, returns, and wire grounds shall not be shielded. Cables shall be checked against installation requirements to verify proper construction.

Individual leads are to be grouped into cables in the same manner as in the installation configuration with the lengths identical to the actual platform installation. In cases of cables longer than 10 meters, at least 10 meters must be included. The first 2 meters of cable length (except for cables less than 2 meters in the actual installation) must be run parallel to the front boundary of the setup. The remaining lengths are routed to the back of the setup and placed in a zigzagged arrangement, minimizing cable overlap or crossing. Individual cables are required to be separated by 2 cm measured from each other, but this can be become very difficult to achieve for systems employing a significant number of cables. The cable closest to the front boundary must be placed 10 cm from the front edge of the ground plane MIL-STD-461G now stipulates that the entire length of the cable, not just the two meters exposed to the antenna, be supported 5 cm above the ground plane using “non-conductive material such as wood or foam.” MIL-STD-4G1G addresses cable routing for floor standing units and requires that cables are routed from the top of the EUT then routed down to the bench ground plane with 2 meters run parallel to the front edge of the boundary. If the cables are routed from the bottom, then the cables must be routed up to the bench ground plane and then 2 meters run parallel to the front edge of the boundary.

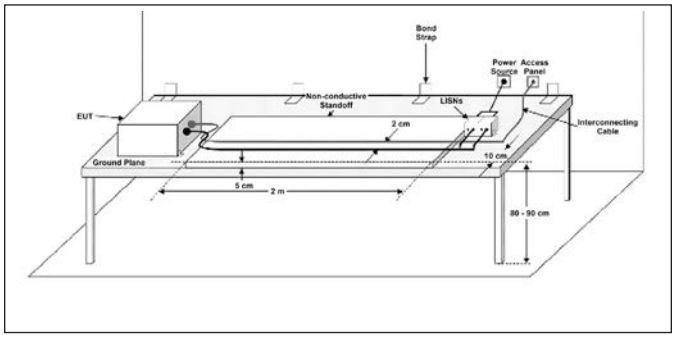

FIGURE 3: Ground Plane Mounted EUT Cable Routing

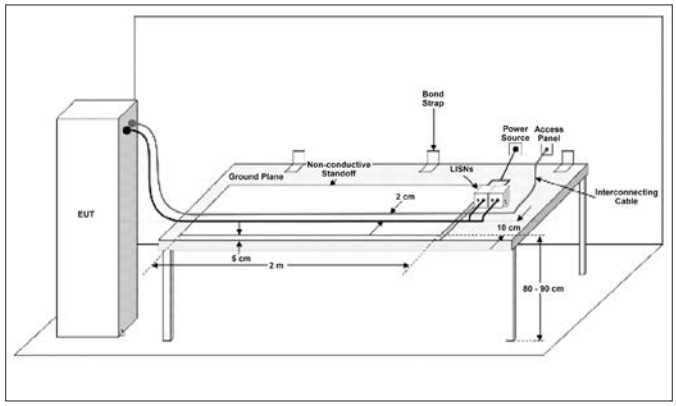

FIGURE 4: Floor Mounted EUT Cable Routing

Power leads are treated in a similar manner with regards to routing, but after the 2 meter exposed length, the power lead to LISN connection length must be as short as possible with a total length not to exceed 2.5 meters, except in cases of large EUTs. Cable routing requirements can be seen in *Figures 3* and *4*.

The operation of the EUT during testing should represent the mode producing the maximum emissions expected during emissions testing and mode which is most susceptible during susceptibility testing. This is very easy to state and attempt to require, but the reality is that engineering judgment is often needed to balance cost and technical aspects. In most cases, this will require a joint effort between systems engineers and EMI engineers to resolve, depending on the complexity and number of modes of operation.

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

TABLE 3: Emissions Bandwidth and Measurement Times

For emission measurements, a peak detector is required and measurement parameters are shown in *Table 3* with the changes for MIL-STD-461G highlighted in red. The use of FFT or time domain receivers, a new technology since the last release of the standard, is specifically addressed and *Table 3* below shows parameters for the use of such machines.

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

TABLE 4: Susceptibility Scanning

FFT receivers differ from traditional EMI receivers. Traditional EMI receivers tune to a particular frequency, dwell for a time, then step to the next frequency. FFT receivers look at very large bands and use FFT algorithms to display signals as they would appear if measured traditionally. FFT receivers are much faster than traditional receivers. FFT operation must be in accordance with ANSI C63.2 and *Table II* parameters must be directly addressable, not as FFT quantities such as window type and percentage overlap. The appendix of MIL-STD-461G provides an excellent overview of the use of FFT receivers.

Specific guidance is provided for susceptibility testing on measurement scan rates, sweep times, dwell time and step size based on frequency range and is shown in *Table 3* or *4*.

The modulation of the CS114 and RS103 test stimulus is pulse modulated (on/off ratio of 40 dB minimum) at a 1 kHz rate with a 50% duty cycle. The dwell time of the susceptibility signal is often challenging. MIL-STD-461G requires a dwell time of 3 seconds or EUT response time, whichever is greater. However, when multiple modes of operation are required to be evaluated and the EUT response times are long, this requirement can be a larger cost and schedule driver due to the inherent length of RS103 and CS114 testing in general. This is another area where systems engineering and EMI engineering should work together for the best solution.

MIL-STD-461G includes 19 specific requirements and attendant test methods. *Figure 9* provides a generic military system with the applicability for each requirement. An overview of each requirement/method follows. It should be noted that each and every test method contains very specific details and nuances and the appendix of MIL-

STD-461G provides clarification on the requirements and applicability and detailed information on the test approach and procedures which are outside the scope of this mini guide.

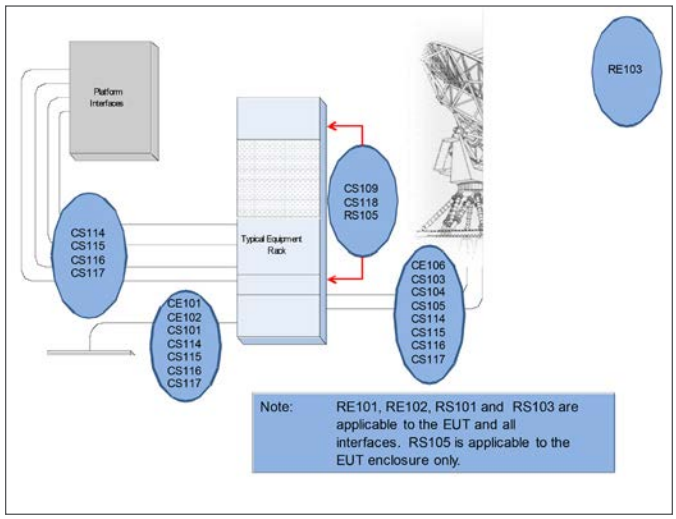

FIGURE 9: Test Method Applicability

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.

For surface ships and submarines, the intent is to control the effects of conducted emissions peculiar to the shipboard power distribution system. For Army aircraft, the concern is to ensure that the EUT does not corrupt the power quality on platform power buses.

For Navy aircraft, CE101 is only applicable for installations using anti-submarine warfare (ASW) equipment, which operate between 30 Hz and 10 kHz. The specific limits are based on application, input voltage, frequency, power and current. One of the more common problem areas is rectifier noise at power line harmonic frequencies.

Changes made for MIL-STD-461G include clarification of the applicability to Navy aircraft in the following text: For equipment intended to be installed on Navy aircraft, this requirement is applicable only if the platform contains Anti-Submarine Warfare (ASW) equipment, which operate between 30 Hz and 10 kHz, such as Acoustic (Sonobouy) Receivers or Magnetic Anomaly Detectors (MAD).

Test changes include specific measurement system check frequencies at 1.1 kHz, 3 kHz and 9.9 kHz instead of 1.0 kHz, 3 kHz and 10.0 kHz and a change to *Figure CE101-1* which now specifies limits for both surface ship and submarine DC applications.

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.

The major change to CE102 in MIL-STD-461G is verifying the LISN impedance at frequencies where it isn't 50 Ω, by recording how hard the signal generator must be driven at 10 and 100 kHz during the measurement system integrity test.

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. The upper test frequency requirement has been modified from MIL-STD-461F such that systems with the frequencies < 1 GHz, the upper frequency limit will be 20 times the highest frequency or 18 GHz whichever is greater. For systems with frequencies ≥ 1 GHz, the upper frequency limit will be 10 times the highest frequency or 40 GHz whichever is less. There is also a Navy shipboard specific frequency exclusion for transmitters with peak transmitter power greater than 1 kW. The standard 5% frequency exclusion will be increased by an additional 0.1% of the fundamental frequency for each dB above 1 kW of peak power.

The limits for receivers and transmitters and amplifiers in standby mode are 34 dBμV. For transmitters and amplifiers in transmit mode, harmonics, except the second and third, and all other spurious emissions shall be at least 80 dB down from the level at the fundamental. The second and third harmonics shall be suppressed to a level of -20 dBm or 80 dB below the fundamental, whichever requires less suppression. For Navy shipboard applications, the second and third harmonics will be suppressed to a level of -20 dBm and all other harmonics and spurious emissions shall be suppressed to -40 dBm, except if the duty cycle of the emissions are less than 0.2%, then the limit may be relaxed to 0 dBm.

CE106 limits for transmit mode operation may disagree with the system performance specification. Unfortunately, in many procurements, the transmitter performance specifications are developed independent of the CE106 requirements and suppression to meet requirements can result in significant design penalties if not identified early enough in the program.

Changes made to Mil-STD-461G include specific guidance given for Navy shipboard applications with peak transmitter power greater than 1 kW and the previously mentioned frequency exclusion. The upper test frequency is modified. For systems with intentional frequencies < 1 GHz, the upper test frequency is 20 times the highest intentional frequency or 18 GHz whichever is greater and for systems with intentional frequencies ≥ 1 GHz, the upper test frequency is 10 times the highest intentional frequency or 40 GHz whichever is less. The Navy shipboard applications limits are modified such that the 2nd and 3rd harmonics will be suppressed to a level of -20 dBm and all other harmonics and spurious emissions shall be suppressed to -40 dBm, except if the duty cycle of the emissions are less than 0.2%, then the limit may be relaxed to 0 dBm.

CS101 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. Two test voltage levels are defined. One for equipment operating at input voltages greater 28 Volts and one for equipment operating at 28 Volts and below. The requirement is also met when the power source is adjusted to dissipate the power level shown on *Figure CS101-2* of MIL-STD-461G in a 0.5 Ω load and the EUT is not susceptible.

Changes in MIL-STD-461G for CS101 include reducing applicability from a maximum load current of 100 Amps per phase to ≤ 30 Amps per phase, unless the system has an operating frequency 150 kHz or less and an operating sensitivity of 1 μV or better (such as 0.5 μV). Another change is allowing the use of Power Line Ripple Detectors (PRDs) to measure ripple induced on an AC power line in the frequency domain, which is very difficult to monitor in the time domain. The PRD functions as an interface between the power line and the 50 Ω input of a spectrum analyzer or EMI receiver, allowing the measurement to be made in the frequency domain so that the ripple component can be seen entirely separately from the power line frequency.

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. These tests are particularly difficult to perform on modern channelized digital receiving systems and require a coordinated effort between systems engineering and EMI engineering. The reality of these tests is that they are most often used and perhaps best performed as characterization tests and not true qualification tests. There is very little guidance provided in MIL-STD-461G except for the original super-heterodyne type radio. The intent of CS103 is to control the response of antenna connected receiving subsystems to in-band intermodulation products of two signals outside of the intentional passband of the subsystem. CS103 is most applicable to fixed frequency, tunable, super-heterodyne receivers.

The intent of CS104 is to control response of antenna connected receiving subsystems to signals outside the intentional passband of the subsystem. CS104 is most applicable to fixed frequency, tunable, super-heterodyne receivers. CS104 has been used to characterize performance related to the EME tables defined in MIL-STD-464 for systems where the antenna characteristics were well-defined and direct injection was feasible.

The intent of CS105 is to control the response of antenna connected receiving subsystems to modulation being transferred from an out-of-band signal to an in-band signal. CS105 should be considered only for receivers, transceivers, amplifiers, and the like, which extract information from the amplitude modulation of a carrier.

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 re-

sponse 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. There is also a common mode test applicable from 4 kHz to 1 MHz for shipboard and submarine installations with a test level of 77 dBµA for complete power cables. Multiple test levels are imposed based on application. The concept is to simulate currents developed on platform cabling from electromagnetic fields generated by antenna transmissions both on and off the platform. CS114 is not applicable for coaxial cables to antenna ports of antenna-connected receivers except for surface ships and submarines. Similar to CS101, protection against over-testing is accomplished by limiting both injected current and potential. Under MIL-STD-461D and G, the requirement is also met if the EUT is not susceptible at forward power levels sensed by the directional coupler that are below those determined during calibration provided that the actual current induced in the cable under test is Curve 5 = 115 dBµA, Curve 4 = 103 dBµA, Curve 3 = 95 dBµA, Curve 2 = 89 dBµA and Curve 1 = 83 dBµA across the frequency range. Due to impedance variations in the cable under test, the current injected may exceed the calibrated levels.

MIL-STD-461G introduces the requirement to insert a current probe and its fixture during the forward power pre-calibration in order to verify that the current probe's transfer impedance is properly taken into account by the measurement software, and that the current probe is functioning properly.

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. CS115 replaces "chattering relay" type requirements (RS06 in MIL-STD-461C). The excitation waveform from the generator is a trapezoidal pulse and a single pulse type is required for all applications. The pulse has a 2 ns rise time which is consistent with waveforms created by inductive devices interrupted by switching actions and the 30 ns pulse width standardizes each pulse energy and separates the rise and fall portions of the pulse so that each act independently. The 5 ampere amplitude covers most induced levels observed during aircraft testing. The 30 Hz pulse rate ensures that a sufficient number of pulses are applied to increase confidence that the EUT will satisfactorily operate.

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. Switching transients within the platform can also result in similar waveforms. At a minimum, testing is performed at 0.01 MHz (0.1 Amp peak), 0.1 MHz (1 Amp peak), 1 MHz (10 Amp peak), 10 MHz (10 Amp peak), 30 MHz (10 Amp peak), and 100 MHz (3 Amp peak).

Additionally, if there are other frequencies known to be critical to the equipment installation, such as platform resonances, testing should also be performed at those frequencies. The pulse repetition rate is not greater than one pulse per second and no less than one pulse every two seconds and is applied for a period of five minutes.

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. CS117 was borrowed from RTCA/DO-160 section 22, but many aspects of section 22 were left out of CS117. Two important simplifications are no pin testing, and just two levels, internal and external, mapping from RTCA/DO-160 section 22 levels 3 and 4, respectively. CS117 contains six waveforms borrowed from section 22. CS117 contains no separate table for a single stroke application. Instead, the single stroke levels of section 22 *Table 22-3* have been incorporated into the multiple stroke *Table VII* of CS117. *Table 22-3* levels 3 and 4 become the first stroke of the multiple stroke requirements in CS117 *Table VII*. Level 3 maps to internal, and level 4 maps to external. Subsequent strokes in CS117 *Table VII* are from section 22 *Table 22-4*, except that for Waveforms 4/5A, there was some mixing and matching from levels under Waveform 4/1 in section 22 *Table 22-4*.

Multiple bursts in the same CS117 *Table VII* are exactly the same as section 22 *Table 22-5* levels 3 & 4, again mapping to internal and external installations, respectively.

CS118 Conducted Susceptibility, Personnel Borne Electrostatic Discharge
CS118 is the other new test method added to MIL-STD-461G. 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 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. The limit and method is borrowed from RTCA/DO-160 Section 25 and IEC 61000-4-2. CS118 requires the EUT to be electrically bonded in accordance with the product installation requirements. Limits are 8 kV for contact, 15 kV for air discharge. Contact discharge is the preferred method unless the test item has nonconductive surfaces requiring an air discharge approach. Air discharges are performed not only at the 15 kV limit, as per RTCA/DO-160 section 25, but also at 2, 4, and 8 kV.

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. For Navy aircraft, this requirement is only applicable for ASW capability operating between 30 Hz and 10 kHz.

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. Applicable for equipment intended for Navy ships and submarines, Navy ASW, or Army aircraft. RE101 and RS101 are complimentary, imposed to control magnetic EMI to sensitive low frequency (LF) equipment.

The Navy is concerned with the potential effects to LF, VLF, ELF and acoustic and communication systems and sensors with nano-volt sensitivities. The Army is concerned with potential effects to engine, flight, and weapon turret control systems and sensors with millivolt sensitivities. Limits are based on specific service applications with different limits for Navy and Army equipment. Common RE101 failures include equipment containing CRT yokes, transformers and switching power supplies.

Changes to MIL-STD-41G for RE101 include clarification for Navy aircraft applicability, specifically “Aircraft with ASW equipment which operates between 30 Hz and 10 kHz such as: Acoustic (Sonobouy) Receivers or Magnetic Anomaly Detectors (MAD).” Another subtle change is the specification that the loop winding resistance should be between 5 Ω and 10 Ω.

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. Many tuned receivers have sensitivities on the order of 1 uV and are connected to intentional apertures (the antenna) that are constructed for efficient reception of energy in the operating range of the receiver. RE102 identifies specific antennas are specified for use in measurements. Antenna placement is defined including separation from the EUT and elevation from the floor. The number of antenna positions is determined based on size of the EUT and interfacing cables as well as beamwidth of the measurement antennas. Antenna placement is now based on EUT area and not just width. The RE102 limits vary with installation location, service branch and platform.

Changes to MIL-STD-41G for RE102 include setting the upper test frequency to 18 GHz for all applications versus 1 GHz or 10 times the highest intentionally generated frequency in previous versions. Another change is specifying the measurement system check frequencies as 10.5 kHz, 2.1 MHz, 12 MHz and 29.5 MHz for the active rod antenna instead of low mid and high frequencies, 197 MHz for the biconical antenna, 990 MHz for the large horn and 17.5 GHz for the small horn. However, the largest change in RE102 is a small change in wording regarding antenna positioning.

Previous versions required that the number of antenna positions used above 200 MHz be based on the width of the EUT and the first 35 cm of interfacing cables from 200 MHz to 1 GHz and the first 7 cm of interfacing cables from 1 GHz to 18 GHz as related to the 3 dB beamwidth of the measurement antenna. MIL-STD-461G changes the word “width” to “area” thus bringing the height of an EUT into the equation and thus potentially adding more positions. This was a much-needed change in order to more accurately test large vertical test objects such as shipboard racks. There are also minor changes to the 41” rod antenna set-up.

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 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.

The test procedure is laborious and will require a large open area to meet antenna separation distances in many cases. The minimum acceptable antenna separations are calculated based on antenna size and operating frequency of the EUT and measurements in azimuth and elevation are required.

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. Two different limits are cited based on service branch.

The Navy RS101 limit was established by measurement of magnetic field radiation from power distribution components (transformers and cables), and the magnetic field environment of Navy platforms. The Army RS101 limit is based on 5 mV (independent of frequency) being induced in a 12.7 cm (5 inch) diameter loop.

An alternative test approach using Helmholtz coils is provided. Helmholtz coils generate a relatively uniform magnetic field that is more representative of the environment experienced on some platforms, particularly submarines. For this reason, the AC Helmholtz coil test option is preferred for submarine applications.

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.

For aircraft and ships, different limits are specified depending on whether the equipment receives protection from platform structure. Alternative method and procedures are provided for use in a mode-tuned reverberation chamber from 200 MHz to 40 GHz.

Changes to MIL-STD-41G for RS103 include requiring testing below 30 MHz for Army and Navy applications, but optional for all others. Additionally, receivers with permanently attached antennas, are allowed reduced performance over the intended receiver band of operation, but must meet its performance requirements after in-band exposure to the radiated field.

The major change for RS103 is identical to that of RE102 explained above – illumination of test set-up area, not just width.

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.

The EMP field is simulated in the laboratory using bounded wave TEM radiators such as TEM cells and parallel plate transmission lines. Since the polarization of the incident EMP field in the installation is not known, the EUT must be tested in all orthogonal axes. Potential equipment responses due to cable coupling are controlled under CS116. Full RS105 testing capability is rare.

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ENGINEERING YOUR SUCCESS.

THE NEW CS117: ASSESSMENT OF PIN INJECTION & CABLE INDUCTION TEST METHODS

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Introduction
The new MIL-STD-461G standard, released in December 2015, includes requirements for lightning induced transients. Besides other fundamental differences to DO-160G Section 22, the decision to renounce the Pin Injection method and Single Stroke tests requires an analysis. The standard committee established that these requirements are harmonized and covered by the test levels applied via the Cable Induction method. This article will compare the mentioned test levels, and will provide a rationale for assessing the equivalence of the Pin Injection method and the Cable Induction method.

THE NEW CS117: ASSESSMENT OF PIN INJECTION & CABLE INDUCTION TEST METHODS

Introduction

The new requirement CS117 from MIL-STD-461G refers to lightning induced transients, a set of tests that have been applied previously to commercial aircraft through DO-160G Section 22 standard. However, requirements for military aircraft and surface ships are slightly different from the ones in Section 22. Both standards specify 6 pulse waveforms to be applied during test.

The waveforms appear as part of 3 event types in Section 22: Single Stroke (SS), Multiple Stroke (MS) and Multiple Burst (MB). Requirements in CS117 refer only to MS and MB, excluding thus SS. Section 22 specifies three application methods for disturbances: Pin Injection (PIN), Cable Induction (CI) and Ground Injection (GI), whereas CS117 requires application of pulses with CI method.

The rationale for previously mentioned modifications in comparison to Section 22 is consistent with the prescriptive approach utilized in MIL standards generally, aiming at a reduced and simplified decision-making process.

Aircraft zoning, a procedure necessary for establishing applicable waveform sets and test levels, is relatively complex and time consuming. Furthermore, a standardized test setup is considered of major importance.

In the next section, an extensive comparison of test levels from the two standards will be performed.

Test levels compared: Section 22 vs CS117

Test levels are defined specifically for each waveform in both standards. In Section 22 there are five test levels for a waveform, whereas in CS117 only two test levels. Additionally, CS117 defines special (reduced) test levels for low count wire bundles or power leads. However, reduced test levels from CS117 do not have equivalents in Section 22 and will not be included in the comparison.

Finally, when comparing PIN test levels from Section 22 to CI test levels from CS117, an important difference in generator definition is to be mentioned: a PIN generator has a fixed virtual impedance, provided by the ratio of open circuit voltage and short circuit current, whereas in the case of CI testing, a voltage or current waveform is applied with no fixed impedance and a current or voltage limit is set in order to prevent overstressing equipment. In order to maintain a coherent approach, only test levels will be compared: WF1 as current waveform, WF2 as voltage waveform, WF3 as voltage waveform, WF4 as voltage waveform, WF5A as current waveform and WF6 as current waveform. Current or voltage limits established for Cable Bundle (CB) tests are not taken into consideration for this analysis.

Section 22 PIN vs CS117 CI

In DO-160G Section 22, three waveforms are applied using the PIN method: WF3 (1 MHz), WF4 and WF5A. The PIN test levels are compared for each waveform with corresponding level (first stroke) of same waveform specified for CI in CS117.

Table I. Section 22 PIN vs CS117 CI (WF3 1 MHz)

WF3 1 MHz	
DO160G S22	MIL-STD-461G CS117
PIN	CI (First Stroke)
L1 100 V	-
L2 250 V	-
L3 600 V	Internal 600 V
L4 1500 V	External 1500 V
L5 3200 V	-

Both test levels (first stroke) specified in CS117 for WF3 1 MHz (see *Table I*), CB tests with CI method, have amplitudes equal to level 3 and level 4 PIN from Section 22. Since the 10 MHz waveform is not defined in Section 22 for PIN tests, no comparison has been considered in this section. The highest single stroke peak requirement for WF3 can be found in Section 22.

A similar comparison for WF4 is to be found in *Table II*. The test levels from CS117 are equivalent to level 3 and level 4 from Section 22. The highest single stroke peak requirement for WF4 can be found in Section 22.

Table II. Section 22 PIN vs CS117 CI (WF4)

WF4	
DO160G S22	MIL-STD-461G CS117
PIN	CI (First Stroke)
L1 50 V	-
L2 125 V	-
L3 300 V	Internal 300 V
L4 750 V	External 750 V
L5 1600 V	-

Table III introduces the comparison between peak level requirements concerning WF5A in Section 22 (PIN method) and CS117 (CI method). Unlike PIN test levels for WF3 and WF4, highest single stroke peak requirement in the case of WF5A is specified in CS117. Since the waveform has a relatively long rise time, and cable inductance has less influence in propagation of disturbance from coupler to EUT input connector, it can be asserted that CS117 requirement for CI might cover all PIN requirements for WF5A from Section 22.

Table III. Section 22 PIN vs CS117 CI (WF5A)	
WF5A	
DO160G S22	MIL-STD-461G CS117
PIN	CI (First Stroke)
L1 50 A	-
L2 125 A	-
L3 300 A	-
L4 750 A	Internal 1000 A
L5 1600 A	External 2000 A

As a partial conclusion, PIN level 5 amplitudes from Section 22 are higher than the highest first stroke amplitude from CS117 in the case of WF3 and WF4, and lower in the case of WF5A. In the case of CI method, the effective test level at connector will be estimated for all 3 waveforms in section 3 of this article. This estimation is required in order to compare more precisely the test levels, as long as PIN disturbance is applied at connector and CI method from CS117 applies the disturbance on the cable bundle, i.e. at a certain distance from connector.

Following tables compare the test levels required in Section 22 for CB tests (both CI and GI) to the test levels required in CS117. In the case of MS events, only the amplitude of first stroke is considered.

Table IV. Section 22 CI and GI (SS, MS, MB) vs CS117 CI				
WF1 – current waveform				
DO160G S22				MIL-STD-461G CS117
CI				CI (FS)
	SS	MS(FS)	MB	MS
L1[A]	100	50	-	-
L2[A]	250	125	-	-
L3[A]	600	300	-	Internal 600
L4[A]	1500	750	-	External 1500
L5[A]	3200	1600	-	-

Table V. Section 22 CB/CI vs CS117 CI (WF2)				
WF2 – voltage waveform				
DO160G S22				MIL-STD-461G CS117
CI				CI (FS)
	SS	MS(FS)	MB	MS
L1[V]	50	50	-	-
L2[V]	125	125	-	-
L3[V]	300	300	-	Internal 300
L4[V]	750	750	-	External 750
L5[V]	1600	1600	-	-

Table VI. Section 22 CB/CI vs CS117 CI (WF3)				
WF3, 1 and 10 MHz – voltage waveform				
DO160G S22				MIL-STD-461G CS117
CI				CI (FS)
	SS	MS(FS)	MB	MS
L1[V]	100	100	60	-
L2[V]	250	250	150	-
L3[V]	600	600	360	Internal 600 (MB 360V)
L4[V]	1500	1500	900	Ext. 1500 (MB 900V)
L5[V]	3200	3200	1920	-

Tables VII and VIII refer to waveforms 4 and 5A, for which DO-160G Section 22 specifies GI as preferred injection method.

However, it is allowed to use the CI method if more suitable in some cases and some products standards demand the exclusive use of CI method for injection of waveform 5A.

Table VII. Section 22 CB/GI vs CS117 CI (WF4)				
WF4 – voltage waveform				
DO160G S22				MIL-STD-461G CS117
GI preferred				CI (FS)
	SS	MS(FS)	MB	MS
L1[V]	50	25	-	-
L2[V]	125	62.5	-	-
L3[V]	300	150	-	Internal 300
L4[V]	750	375	-	External 750
L5[V]	1600	800	-	-

Table VIII. Section 22 CB/GI vs CS117 CI (WF5A)				
WF5A – current waveform				
DO160G S22				MIL-STD-461G CS117
GI preferred				CI (FS)
	SS	MS(FS)	MB	MS
L1[A]	150	60	-	-
L2[A]	400	160	-	-
L3[A]	1000	400	-	Internal 1000
L4[A]	2000	800	-	External 2000
L5[A]	5000	2000	-	-

Table IX. Section 22 CB/CI vs CS117 CI (WF6)				
WF6 – current waveform				
DO160G S22				MIL-STD-461G CS117
CI				CI (FS)
	SS	MS(FS)	MB	MS
L1[A]	-	-	5	-
L2[A]	-	-	12.5	-
L3[A]	-	-	30	Internal 30
L4[A]	-	-	75	External 75
L5[A]	-	-	160	-

The analysis of Tables IV to IX indicates that:

- For all waveforms, the amplitude of SS test level 3 from Section 22 corresponds to the amplitude of first stroke in the MS requirement for aircraft internal equipment and equipment below ships' deck (from CS117).
- For all waveforms, the amplitude of SS test level 4 from Section 22 corresponds to the amplitude of first stroke in the MS requirement for aircraft external equipment and equipment above ships' deck (from CS117).
- In the case of waveforms 2 and 3 specified in Section 22, the amplitude of SS events is equal to the one of first stroke from the MS events. Since CS117 specifies MS events as test requirements, it can be considered for these waveforms that test levels are equivalent in the two standards (at common test levels).
- In the case of waveforms 1, 4 and 5A specified in Section 22, the amplitude of SS events is higher than first stroke from MS events. Equivalence in the two standards at designated test levels cannot be established directly.
- As for MB requirements, the test levels and limits from CS117 are directly equivalent to the ones from Section 22 (levels 3 and 4 respectively).

Analysis of Test Requirements and Test Levels

This section will approach two topics, i.e. relevant differences between PIN, CI and GI injection methods, and a case analysis respectively. The case study will compare the situation in which waveforms 3, 4, 5A are applied with PIN and CI methods.

Pin Injection vs Cable Induction

Injection methods, or test types, specified in DO-160G Section 22 are basically divided in two categories: pin injection and cable bundle (tests).

In the case of pin injection tests:

- EUT must be "energized", pulses are applied on either powered or unpowered pins.
- Positive and negative pulses are applied between designated pins and case.
- The generator has a fixed impedance, i.e. 25 Ω for WF3, 10 Ω for WF4 and 1 Ω for WF5A.
- After calibrating the generator in OC and SC conditions at a certain level setting, pulses are applied without any adjustment during the test.
- Monitoring voltage and current while pulses are applied identifies whether changes in the waveform or dielectric breakdowns occurred.

Voltage calibration is carried out at the end of test tips, as shown in *Figure 1*, in order to make sure that during the test no additional impedance is added between calibrated point and EUT interface.

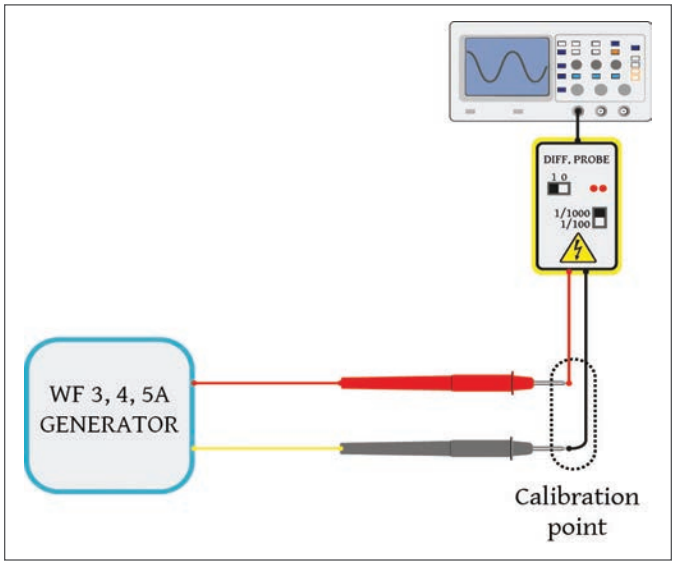

Figure 1. PIN voltage calibration.

With the same cables and tips connected to the generator, current calibration is performed using a short-circuit with the shortest shunt possible, as in *Figure 2*. Generator settings must remain unaltered from those required for the voltage calibration. Measurement of short-circuit current allows the calculation of generator's virtual impedance.

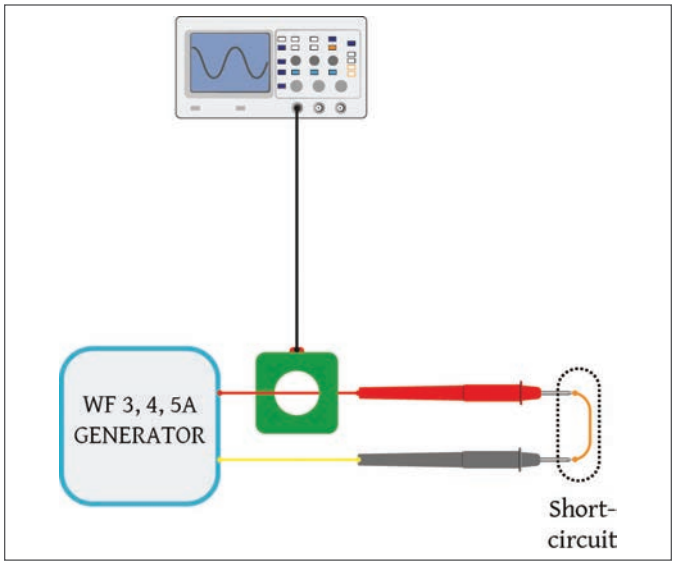

Figure 2. PIN current calibration.

When performing a test, the calibration point must be directly connected to EUT pins. The test is carried out in common mode only, as described in *Figure 3*.

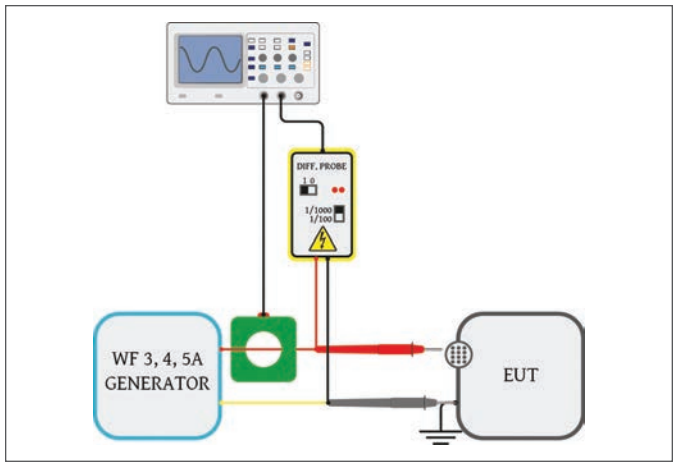

Figure 3. Simplified PIN test setup.

In the case of powered pins, additional protection elements are required to prevent EUT power damaging the generator. Likewise, protection elements would be required to decouple the power supply from test pulses. These elements are not included in diagrams, since their relevance for the comparison is relatively low.

An important aspect is the fact that a ground plane is not necessary for this injection method when compared to CI and GI methods.

In the case of cable bundle (CI and GI methods) tests:

- EUT must be fully functional and running during the test, with all sub-systems connected, powered and communicating.
- - Positive and negative pulses are either induced in cable bundles with couplers, or injected between the grounding point and case of the EUT.
- The generators are not necessarily supposed to have a fixed output impedance, current and voltage waveforms are monitored during the test.
- During the test, a specified test level must be reached and the injected waveform must be achieved at that test level. The generator setting can be increased in order to achieve established test level.
- Current must be monitored while increasing the generator setting when applying a voltage waveform for example. In order to avoid overstressing the EUT, a current limit is specified and in case this limit is reached before the voltage test level is achieved, test must be stopped and the voltage waveform test must be replaced with a current waveform test. The same principle is utilized when applying current waveforms.
- CI method is recommended for waveforms 1, 2, 3 and 6 while GI is the “preferred” method for waveforms 4 and 5A. An analysis will be performed in order to establish their equivalence for different configurations.

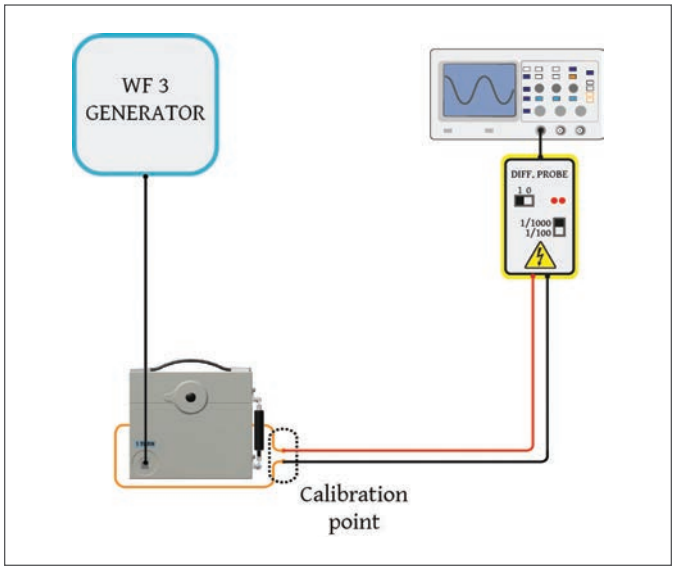

Figure 4. Simplified CI voltage calibration setup example.

Simplified calibration setups for CI method are presented in *Figure 4* and *Figure 5*, the example being taken for waveform 3. Calibration is performed at output of the coupler, it is thus considered that the entry point of a lightning strike could be situated somewhere on the cable bundle. This can be indeed the case in reality.

Although Section 22 specifies a ground plane for the actual test setup, this is not regarded in calibration setups. The influence of ground plane during calibration would be more visible at waveforms with fast rise time, as the presence of a ground plane may impact the high frequency impedance of injection and calibration loops. However, the same simplified calibration setups are present in CS117.

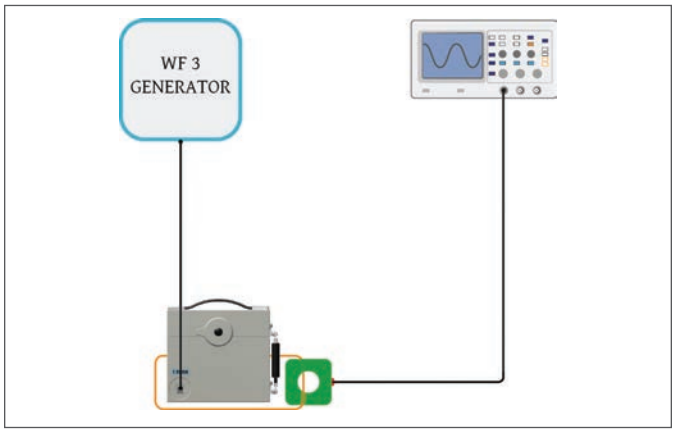

Figure 5. Simplified CI current calibration setup example.

In *Figure 6*, an example of test setup with CI method is presented. Section 22 requires voltage and current monitoring while applying the pulses. Furthermore, the insulation between ground plane and cable bundles should be minimum 5 cm unless otherwise specified. EUT, as well as auxiliary equipment or LISN, should be placed on the insulation support.

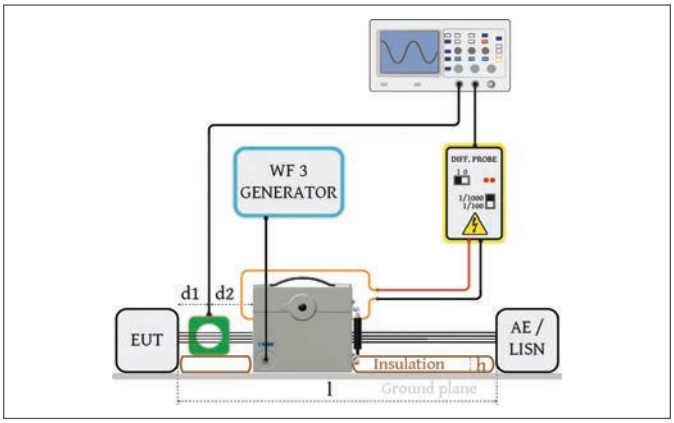

Figure 6. Simplified CI test setup example.

In comparison to a PIN test, where the calibrated point is applied to EUT interface directly, the CI test applies test signals to the interface through the cable bundle.

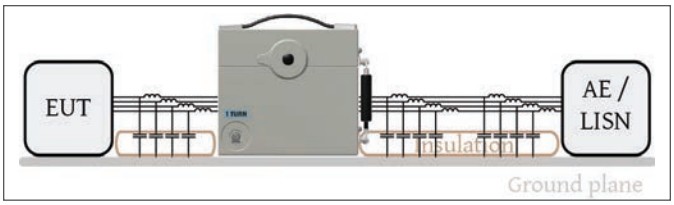

Figure 7. Simplified transmission line model for a cable bundle.

The distance between EUT and current monitoring probe (d1) should be in the range 5 – 15 cm, while distance between monitoring probe and injection transformer (d2) should be in the range 5 – 50 cm. Another important parameter in this context is cable bundle's length, Section 22 recommends a length not shorter than 3.3 m and not longer than 15 m. In order to better assess the difference between injection directly at interface and via the cable bundle, the transmission line model will be considered for cables in the bundle (*Figure 7*).

In order to simplify the demonstration of effects, only common mode capacitance and each conductor's serial inductance are considered (distributed parameters). Mutual inductance and differential mode capacitance are not considered.

A measurement of inductance and capacitance for the case wire on ground plane has been performed, in order to establish which effect is predominant. Results are presented in *Table X*. It is expected that cable bundle's inductance will be the predominant effect, but capacitive effect will also play a role in reducing voltage at EUT and AE ends of cable bundle.

Table X. Inductance and capacitance of 1 Wire over ground.

Length	Section	Height	C(approx.)	L(approx.)
3.3 m	1.5 mm2	5 cm	40 pF	2 µH
15 m	1.5 mm2	5 cm	120 pF	14 µH

Furthermore, capacitance to ground and series inductance of wires in a bundle are increasing with length of the cable between EUT and auxiliary equipment. As the voltage signal travels towards EUT or AE, voltage amplitude is expected to decrease. However, voltage amplitude at EUT side (situated closer to the coupler) is expected to be higher than the one at AE side (bundle's length to the coupler is higher).

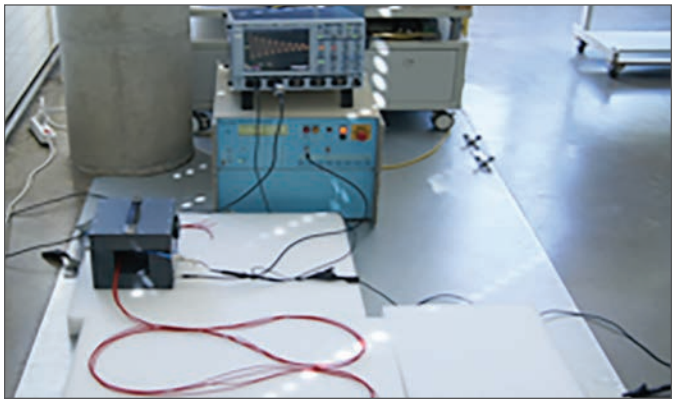

Figure 8. Test setup with 15 m cable bundle.

Following cases will be considered:

Table XI. Experimental setup cases.

	d1	d2	l	h	ZT
Case 1	5 cm	5 cm	3.3 m	5 cm	OC
Case 2	5 cm	5 cm	3.3 m	5 cm	SC
Case 3	15 cm	50 cm	15 m	5 cm	OC
Case 4	15 cm	50 cm	15 m	5 cm	SC

Measurements have been performed as follows:

- Calibration in open circuit and short circuit has been performed at test level 600 V.
- Waveform 3 1 MHz was applied at test level 1 from CS117, i.e. 600V.
- Generator has been calibrated in open circuit and short circuit conditions. Same generator setting has been maintained during the entire test.
- Insulation between cable bundle and ground plane was 5 cm, with µr ≈ 2.
- Tests and measurements have been carried out for two bundles. First bundle consisted of 4 wires, with Ø 1.8 mm, length 3.3 m, while the second had 15 m length. The lengths chosen reflect dimensions suggested by Section 22 as minimal and maximal.
- In cases 1 and 3 (*Figure 8*), the cable bundle's ends were open circuit (corresponding to high impedance to ground), whereas in cases 2 and 4, a short circuit to ground has been set (corresponding to low impedance to ground).

The results of measurements are presented in *Table XII*, as peak values.

Table XII. Results of measurements for cases 1 to 4.			
	$V_{EUT\ END}$	I_{EUT}	$V_{AE\ END}$
Case 1	519 V	n/a	213 V
Case 2	n/a	30 A	n/a
Case 3	~ 505 V	n/a	~ 107 V
Case 4	n/a	12.4 A	n/a

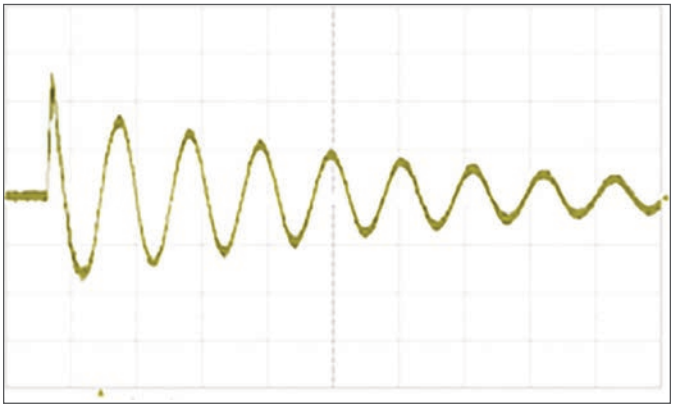

Figure 9. WF3 voltage measured in Case 1 at EUT side.

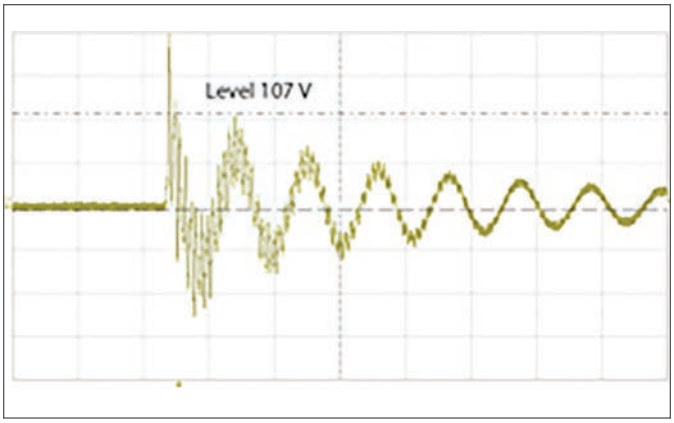

Figure 10. WF3 voltage measured in Case 3 at AE side.

A set of partial conclusions can be drawn:

- In the case of high input impedance EUTs, voltage applied to EUT terminals depends on length and mainly inductance of cable bundle.
- In the case of low input impedance EUTs, current in the cable bundle decreases with the increasing length of the bundle.
- In cases 2 and 4, the inductance of cable bundle prevents all the current delivered by the generator to flow, so voltage measured at output of the coupler may remain high. An interpretation of this phenomenon is not performed here, since it would require more detailed data.
- Current at both sides of the coupler has been measured in cases 1 and 3. Due to capacitive coupling to ground, currents up to 10 A were measured in cases 3, at the coupler output towards auxiliary equipment. The value represents more than 10 % of short circuit current measured during calibration, indicating that capacitive effect to ground is significant in the case of long cable bundles.
- Current measured at EUT end and AE/LISN end had similar waveforms and amplitudes. Thus, it is acceptable to include IEUT only in *Table XII*.
- In cases 1 and 2, both voltage (*Figure 9*) and current waveforms are similar to calibrated waveforms. However, in cases 3 (*Figure 10*) and 4, a significant superposed oscillation can be noticed, confirming that long cable bundles can form resonating circuits. The procedures from DO-357 (Section 22 User Guide) have been utilized in assessing peak values in all cases. Resonance phenomenon is common and requires no additional argumentation for the case of cable bundles.

Conclusions

This article introduced two comparisons, i.e. between Section 22 PIN test levels and CS117 CI test levels, and between Section 22 CI test levels and CS117 CI test levels.

Generally, CS117 test levels represent level 3 and level 4 from Section 22 requirements for PIN or CI single stroke.

The CI requirements for waveforms 2 and 3 are similar for SS and first stroke of MS events at levels 3 and 4.

In the case of cable induction tests, lowest difference between injected (current) amplitude and the one present at EUT connector is achieved when distance between EUT and measurement probe is minimal (5 cm), and distance between injection probe and measurement probe is minimal (5 cm).

CS117 is focusing especially on current waveforms. This is demonstrated by specification of MS requirements and the fact that reduced test levels are always given as current (also for waveform 3 that is generally considered a voltage waveform).

The claim that PIN requirements are covered in CS117 by CI tests is mostly verifiable. However, measurements have demonstrated that voltage applied to EUT terminals in worst case (coupler 65 cm away from EUT input), is reduced with approx. 16 % (600 V applied at coupler, 505 V measured at EUT input). The phenomenon is normal, and reproduces the reality of a lightning strike coupled into the cable bundle.

However, if a certain test level must be validated at EUT input with CI method, generator setting must be increased to compensate cable bundle's impedance. The necessary increase in voltage and/or current depends on bundle's impedance. Increasing the test level may result in an over test if the limit level is exceeded.

For other waveforms, test levels and cable bundles, the necessary reserve of energy in the test generator may vary.

Author and Affiliation

Adrian Maţoi, currently engaged in market development and strategic sales at EMC PARTNER AG in Laufen Switzerland, holds a PhD in EMC. He has gained extensive experience working with test equipment manufacturers in the European EMC market and spent time gaining practical experience in an EMC test laboratory. Publications to his name, on specific EMC topics ranging from evaluation of disturbances in automotive communication systems to research on EMF distribution in the environment, are complemented in the past few years by a series of technical webinars, seminars and trainings on indirect lightning test.

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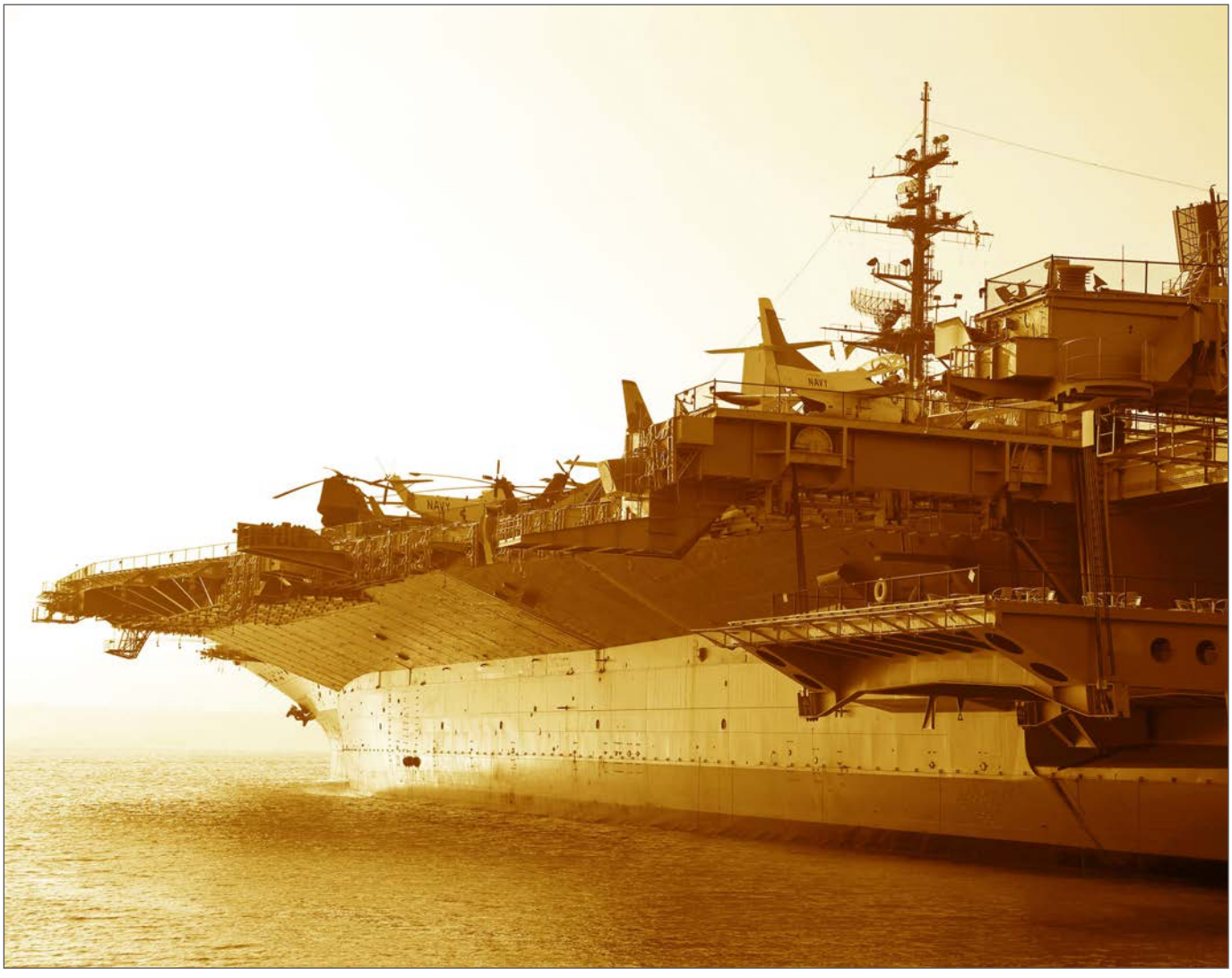
EMC PARTNER AG is a worldwide leading supplier of impulse test generators with over 22 years experience in the field. Key domains are indirect lightning tests on aircraft components, CE mark / ANSI or UL tests, insulation tests, different impulse tests on electric/electronic components and related.

References

1. RTCA Inc., “RTCA/DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment – Section 22: Lightning Induced Transient Susceptibility”, Washington DC, 2010

2. Department of Defense Interface Standard, “MIL-STD-461G: REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT”, USA, 2015

3. RTCA Inc., “RTCA/DO-357 User guide: Supplement to DO-160G”, Washington DC, 2014



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EMC AND EMI SIMULATION FOR LAUNCHERS AND SATELLITES

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Introduction

EMC and EMI analysis plays an important role in ensuring the correct functioning of electronic systems and guaranteeing reliability throughout their lifetimes. This task is all the more difficult and crucial when the system is complex or exists in a challenging EM environment. This is the case for any electronics intended to be sent into space, which have many operating constraints and need exceptional durability. Testing a prototype in the environment of space is prohibitively expensive, and once the system is launched it can't be repaired. The success of a spacecraft mission, both in its launch phase and when installed in its orbit, requires careful study of electromagnetic compatibility. This article explores how EM simulation can help engineers in the space industry master environmental electromagnetic effects and susceptibility in these complex systems.

EMC AND EMI SIMULATION FOR LAUNCHERS AND SATELLITES

Introduction

Today's satellites and launchers contain many densely-packed and complex high-power systems. A single satellite will have many communication systems, sensors and high-end technologies. Making such a complicated platform EMC compliant can be extremely difficult. Confidence in the performance of the system before launch is essential.

There are now many players in the space market, including both government agencies and commercial companies. New competitors are very aggressive in proposing innovative solutions at the cheapest price. Because of the very competitive situation in the satellite and launcher markets, over-testing and over-engineering is no longer a viable solution and shortening the design stage is mandatory. This is where simulation can play a role.

At the design stage, EMC simulation can anticipate risks by predicting the electromagnetic behavior of the equipment and propose solutions even before the first prototype. Simulation does not replace testing but helps to predict potential failures, and allows the investigation of technical issues and novel concepts.

In the next sections, four EMC simulation workflows will be demonstrated. These cover both environmental electromagnetic effects (E3) and emissions within the satellite.

Lightning attachment analysis

As a tall metal object, a launcher is especially prone to lightning strikes. For this reason, launch pads are surrounded by several grounded metal towers linked by cables. These act as lightning rods and reduce the likelihood of the rocket being struck.

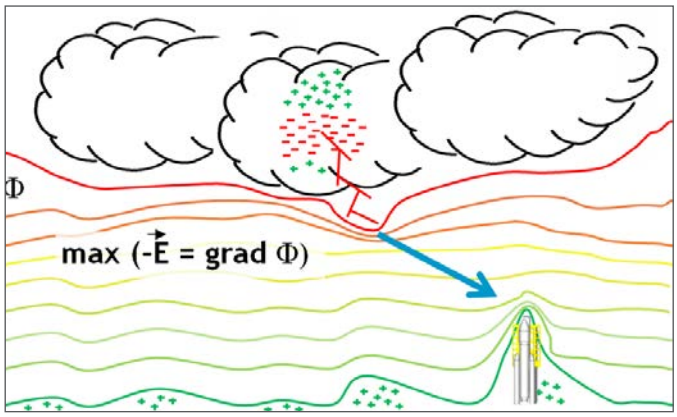

Figure 1: Electrostatic potential during a thunderstorm around a launch pad.

Lightning attachment analysis allows engineers to calculate the effectiveness of a lightning protection system. The odds of lightning striking a given point are related to the electric field around it during a thunderstorm. The build-up of charge means that a strong electrostatic potential develops between the earth and the clouds. The gradient of this potential is the electric field strength, and this is highest around sharp metal objects (*Figure 1*). The lightning leader is therefore most likely to strike here.

This can be modeled and analyzed using electrostatic simulation. A model of the system of interest is imported into the simulation environment and the potential is defined. From this, the gradient of the potential and the electric field around the structure can be quickly calculated with a static simulation. *Figure 2* shows a lightning attachment simulation performed with the CST STUDIO SUITE® Electrostatic Solver. The lightning protection system reduced the electric field strength at the tip of the rocket fairing by 44%, significantly reducing the likelihood of lightning striking the launcher.

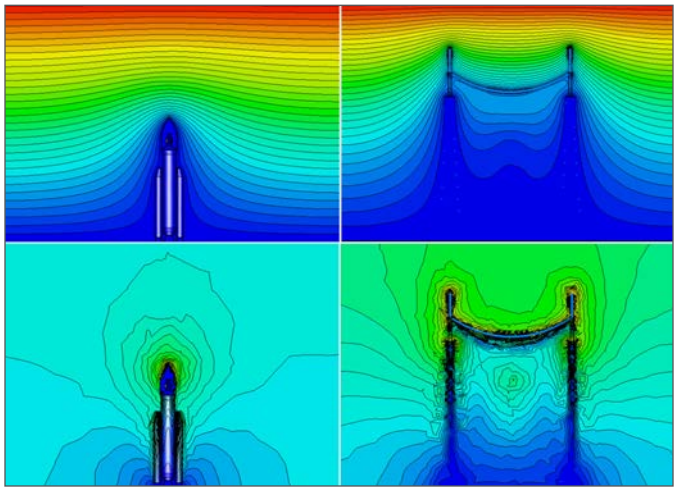

Figure 2: Potential (top) and E-field (bottom) around a launcher without (left) and with (right) lightning protection.

Lightning strike simulation

An electrostatic simulation is a good starting point for a full lightning simulation. Lightning is a transient current pulse typically modeled with a double-exponential waveform, and is effectively broadband (the frequency spectrum of lightning runs from DC up to around 10MHz). This means that it is best simulated in the time domain.

The lightning attachment simulation results suggest the best place to attach the lightning channel, which is then modeled as a wire that defines the contact position. The lightning stroke is modeled as a double exponential, per MIL-STD-464.[1] Currents can propagate through very fine structures, such as the rods that comprise the pylons, seams and vents in the structure, and cables within the launcher. These can be challenging to simulate with traditional simulation methods, since they are very small compared to the overall size of the structure that is simulated, and therefore require a very fine mesh and a short time-step.

Compact models, available in the Transmission-Line Matrix (TLM) Solver, are a more efficient way to simulate

these fine structures. The compact model replaces the detailed model in the simulation, and can offer a significant speed-up while maintaining the same accuracy. A lightning strike simulation using the TLM Solver in CST STUDIO SUITE is shown in *Figure 3* and *Figure 4*. This simulation made use of octree meshing and the PERFECT BOUNDARY APPROXIMATION (PBA)®, with cable harness and compact models. This approach also allows the incorporation of circuit elements into the model - for example transient voltage suppressors.

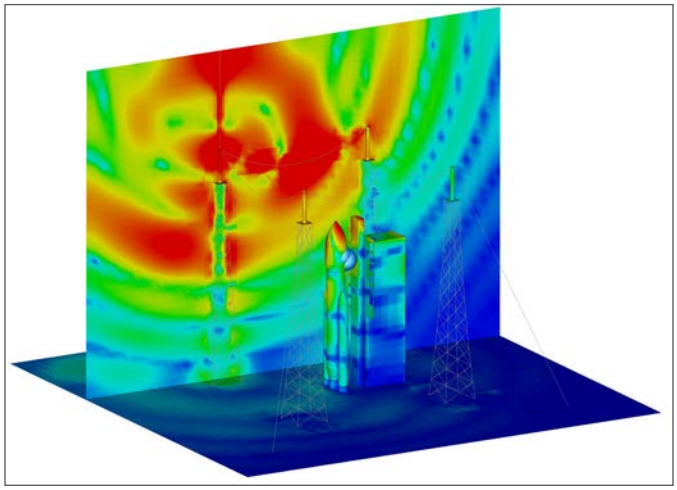

Figure 3: Electric field during a lightning strike.

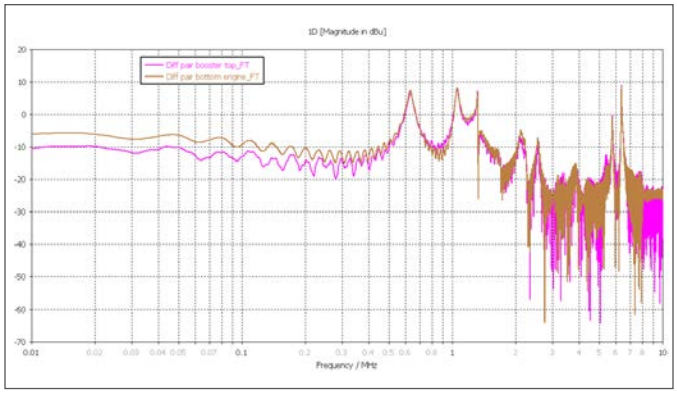

Figure 4: Spectrum (in dBuV) on cables within the launcher.

Radiated susceptibility

Once in orbit, there are other sources of interference. In this example, the excitation is a plane wave which mimics an incoming communication – for example, a telemetry signal. The same technique detailed in this section can be applied to other effects such as solar flare and electromagnetic pulse.

The immunity of a satellite across the entire frequency spectrum can be calculated in a single run by performing a time domain simulation. In this case a Gaussian pulse was used for a plane wave excitation with a circular polarization in order to excite equally all the frequencies up to 1 GHz.

Again, seams, vents and cables are crucial to the immunity of the satellite, and need to be modeled with cable harness and compact models. Probes are placed within the structure at relevant points to measure currents, voltages and field strength.

Once the simulation has been run, the spectrum of the interference can be investigated in order to find which frequencies correspond to high voltages. Problematic frequencies can then be analyzed by visualizing the fields in 3D to reveal the coupling paths and identify where shielding is most needed (*Figure 5*).

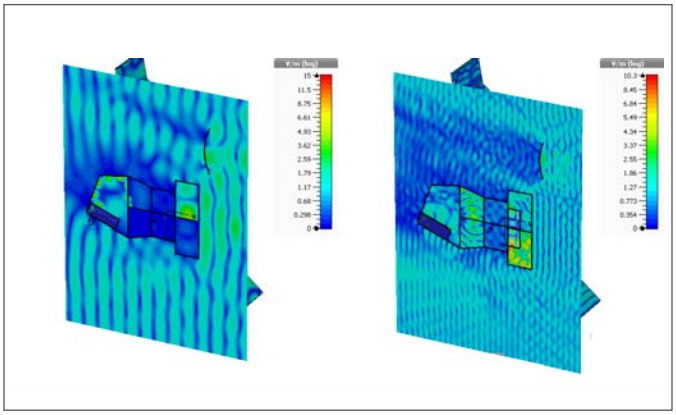

Figure 5: E-field plot of a satellite (cutaway) at 247 MHz (left) and 635 MHz (right), showing coupling paths between cavities.

Oversize Cavity Theory

Frequencies used on a space-based communication system can reach into the tens of gigahertz. At these frequencies, the satellite may be hundreds or thousands of wavelengths in each dimension. This can be challenging to simulate with full wave simulation. Oversize cavity theory (OCT) offers a different approach which is well suited to satellites and launchers where leakage from one cavity to another is a major coupling path for interference.

OCT was developed by Lehmann in 1993 and is a statistical theory of electromagnetic field distribution in over-moded, large and complex cavities.[2]

It is based on the principle that the field in the cavity is statistically homogeneous and isotropic with a known statistical distribution: for the electric field, this known distribution is a chi2 distribution with 6 degrees of freedom. This theory is based on a power balance. For each single cavity, the total input must be equal to the total output. The inputs are the incident power and the power coming from other cavities, and the outputs are the dissipated power and the power coupling to other cavities. OCT can then calculate quantities such as field strength, power density and Q-factor.

Satellite systems can be modeled as a set of cavities, with sources, losses and connections, as shown in *Figure 6*, and the results of an OCT analysis with CST STUDIO SUITE is shown in *Figure 7*. With OCT analysis, complex structures such as these can be analyzed in a matter of

seconds. OCT is a useful alternative to full wave in these scenarios, as it is very fast even on a basic computer, and is perfect for quick EM field assessments on satellite or launcher. However, it is only suitable for large, complex and over-moded cavities and cannot fully calculate 3D structures such as cables or complex vents; it is best seen as a complement to 3D simulation.

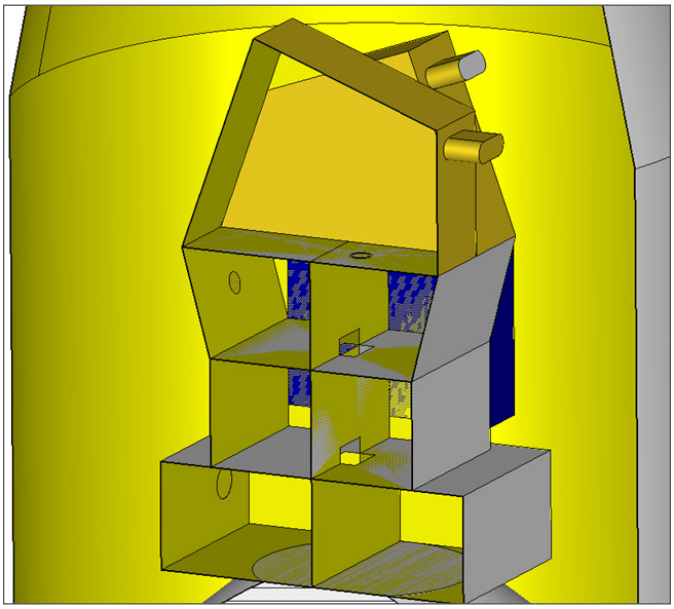

Figure 6: Chassis of a satellite inside a payload fairing, showing the cavity structure within.

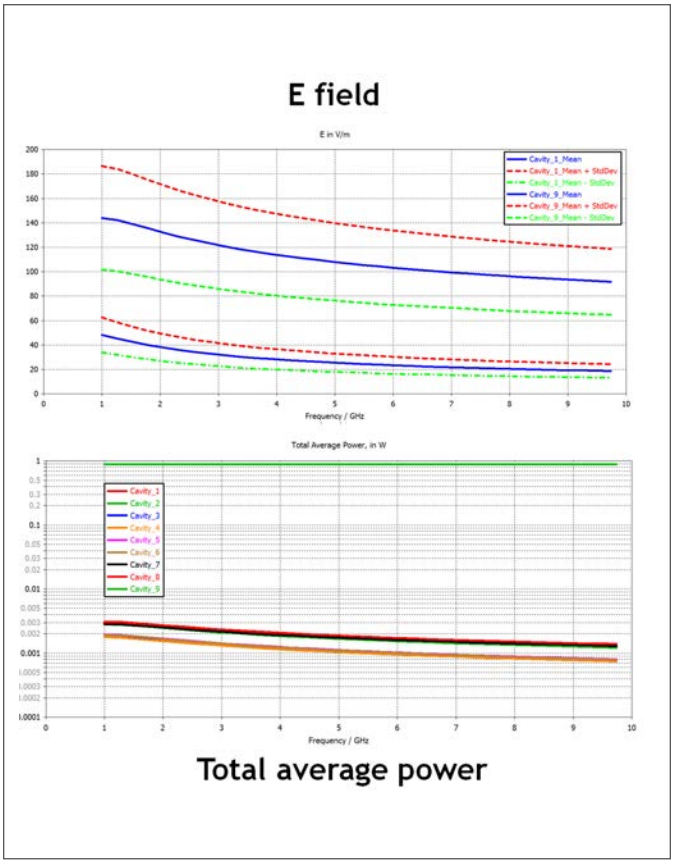

Figure 7: OCT field and power results for the model in Figure 6.

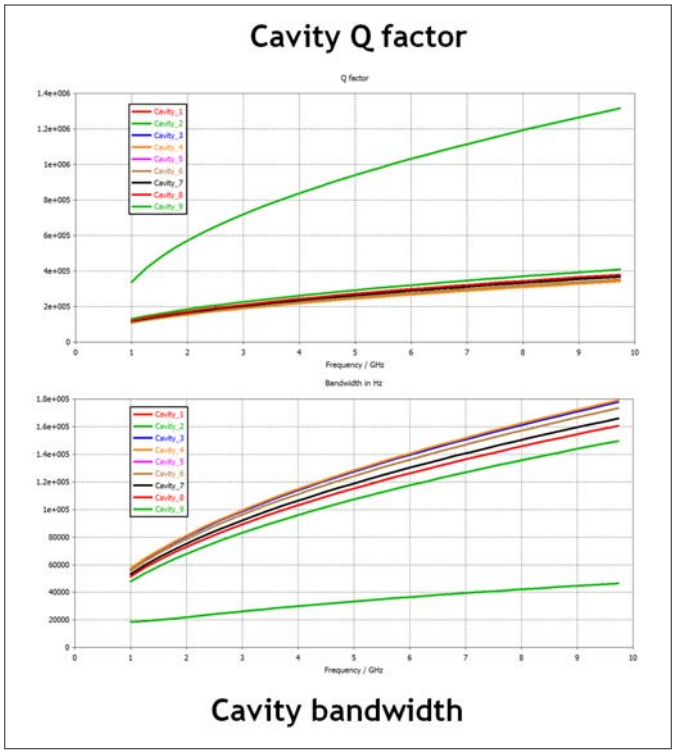

Figure 8: OCT cavity results for the model in Figure 6.

Conclusion

This article has demonstrated several EMC simulation workflows for aerospace applications. 3D EM simulation can be used to analyze environmental electromagnetic effects, susceptibility and coupling and can be used to develop countermeasures against EMC issues that arise. 3D technologies can be complemented by cable and circuit co-simulation and by additional analysis tools like OCT. Analysis can be performed at both the system and sub-system level, and simulation is useful at design, pre-testing and investigation stage.

References

1. "Electromagnetic Environmental Effects – Requirements for Systems", MIL-STD-464, United States Department of Defense.
2. T.H. Lehman, "A statistical theory of electromagnetic fields in omplex cavities". Interaction Notes, note 494, May 1993.

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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.

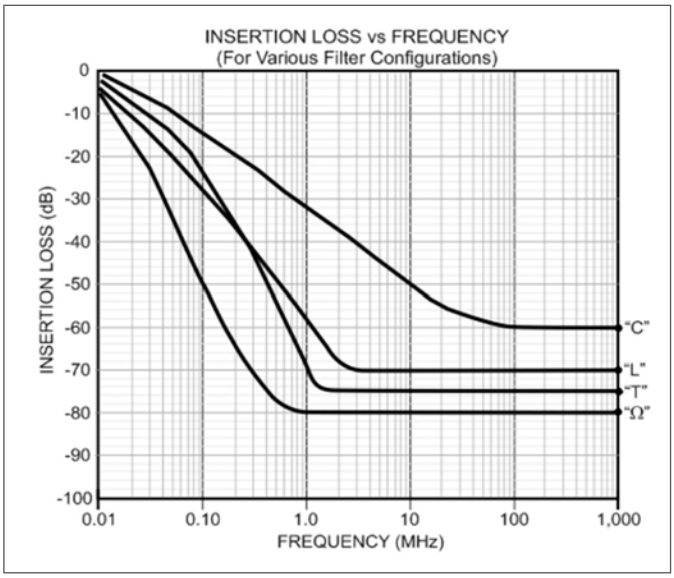

Figure 1. Insertion Loss vs Frequency Curves

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 pass-band. 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.

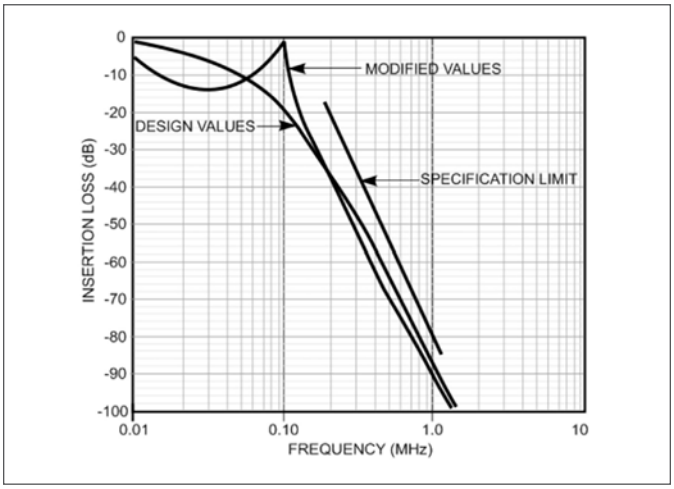

Figure 2. MIL-STD-220 insertion loss characteristics for ideal filter network and modified design compared to specification requirements.

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.).

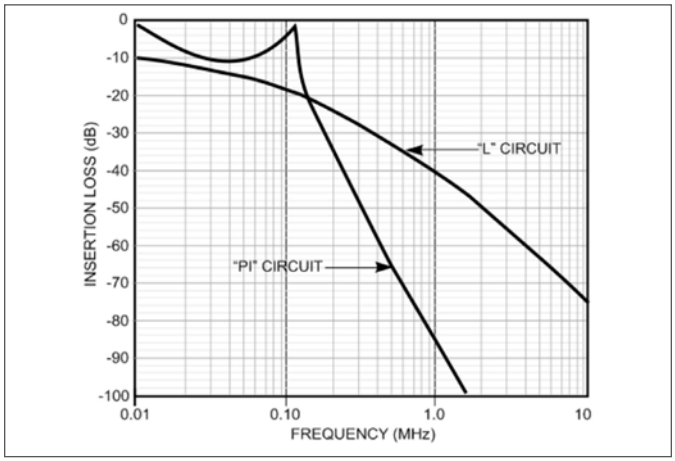

Figure 3. comparison of theoretical MIL-STD-220 50 ohm insertion loss of a "PI" filter and a "L" filter

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.

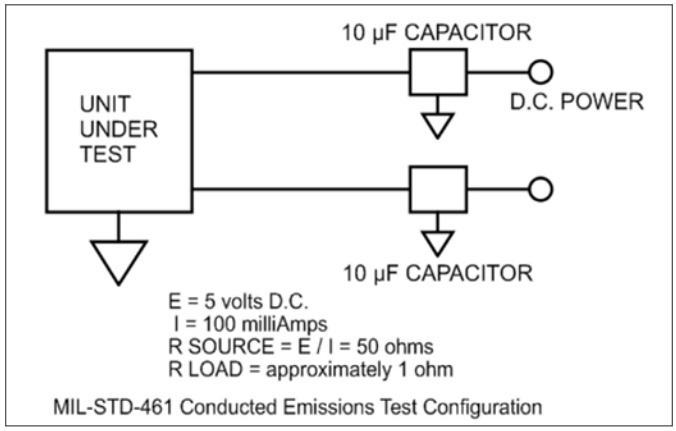

Figure 4. MIL-STD-461 Conducted Emissions Test Configuration

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.

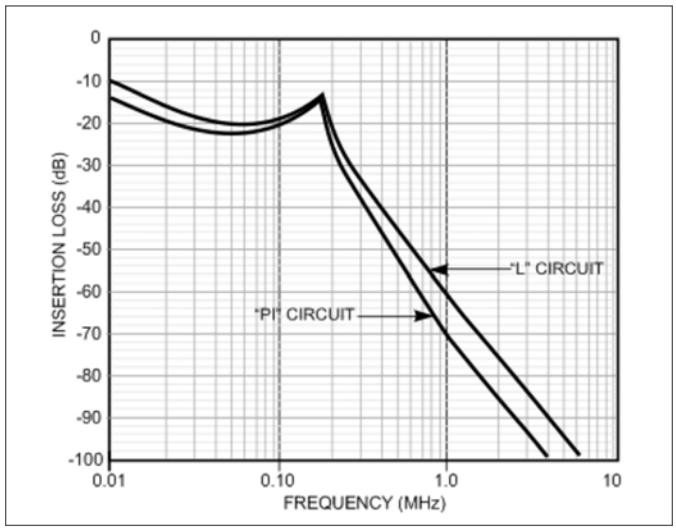

Figure 5. Performance of "L" and "PI" circuits for 50 ohm source and 1 ohm load

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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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 "p*ower 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 duri*ng pre-calibration.

CS117 *(Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads) - Thi*s 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*	Pearson Electronics	http://www.pearsonelectronics.com/news/179
	High-voltage differential probe, 100 MHz, 1k V(RMS)	Rohde & Schwarz	https://www.rohde-schwarz.com/us/product/rtzd01-productstartpage_63493-34629.html
	Digital Oscilloscopes (200 MHz - 4 GHZ, 5/10 GSa/s)	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.

MILITARY RELATED DOCUMENTS AND STANDARDS

The following references are not intended to be all inclusive, but rather a representation of available sources of additional information and point of contacts.

MIL-HDBK-235-1C Military Operational Electromagnetic Environment Profiles Part 1C General Guidance, 1 Oct 2010.

MIL-HDBK-237D Electromagnetic Environmental Effects and Spectrum Certification Guidance for the Acquisition Process, 20 May 2005.

MIL-HDBK-240A Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide, 10 Mar 2011.

MIL-HDBK-263B Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices), 31 Jul 1994.

MIL-HDBK-274A Electrical Grounding for Aircraft Safety, 14 Nov 2011.

MIL-HDBK-335 Management and Design Guidance Electromagnetic Radiation Hardness for Air Launched Ordnance Systems, Notice 4, 08 Jul 2008.

MIL-HDBK-419A Grounding, Bonding, and Shielding for Electronic Equipment and Facilities, 29 Dec 1987.

MIL-HDBK-454B General Guidelines for Electronic Equipment, 15 Apr 2007.

MIL-HDBK-1004-6 Lightning Protection, 30 May 1988.

MIL-HDBK-1195, Radio Frequency Shielded Enclosures, 30 Sep 1988.

MIL-HDBK-1512 Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods, 30 Sep 1997.

MIL-HDBK-1857 Grounding, Bonding and Shielding Design Practices, 27 Mar 1998.

MIL-STD-188-124B Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communications-Electronics Facilities and Equipment, 18 Dec 2000.

MIL-STD-188-125-1 High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C41 Facilities Performing Critical, Time-Urgent Missions Part 1 Fixed Facilities, 17 Jul 1998.

MIL-STD-220C Test Method Standard Method of Insertion Loss Measurement, 14 May 2009.

MIL-STD-331C Fuze and Fuze Components, Environmental and Performance Tests for, 22 Jun 2009.

MIL-STD-449D Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973.

MIL-STD-461F Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 10 Dec 2007.

MIL-STD-461G Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 11 Dec 2015.

MIL-STD-464C Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010.

MIL-STD-704E Aircraft Electric Power Characteristics, 12 Mar 2004.

MIL-STD-1310H Standard Practice for Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility Electromagnetic Pulse (EMP) Mitigation and Safety, 17 Sep 2009.

MIL-STD-1377 Effectiveness of Cable, Connector, and Weapon Enclosure Shielding and Filters in Precluding Hazards of EM Radiation to Ordnance; Measurement of, 20 Aug 1971.

MIL-STD-1399 Section 300B Interface Standard for Shipboard Systems, Electric Power, Alternating Current, 24 Apr 2008.

MIL-STD-1541A Electromagnetic Compatibility Requirements for Space Systems, 30 Dec 1987.

MIL-STD-1542B Electromagnetic Compatibility and Grounding Requirements for Space System Facilities,

15 Nov 1991. MIL-STD-1605 Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009.

MIL-STD-1686C Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices). 25 Oct 1995.

ADS-37A-PRF Electromagnetic Environmental Effects (E3) Performance and Verification Requirements, 28 May 1996.

DOD-STD-1399 Section 070 Part 1 D.C. Magnetic Field Environment, Notice 1, 30 Nov 1989.

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

DoDD 4650.01 Policy and Procedures for Management and Use of the Electromagnetic Spectrum, 09 Jan 2009.

DoDI 6055.11 Protecting Personnel from Electromagnetic Fields, 19 Aug 2009.

AEROSPACE STANDARDS

AIAA Standards
http://www.aiaa.org/default.aspx

S-121-2009, Electromagnetic Compatibility Requirements for Space Equipment and Systems

RTCA Standards
https://www.rtca.org/

DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment

DO-160G Change 1, Environmental Conditions and Test Procedures for Airborne Equipment

DO-233, Portable Electronic Devices Carried on Board Aircraft

DO-235B, Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band

DO-292, Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band

DO-294C, Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft

DO-307, Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

DO-307A, Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

DO-357, User Guide: Supplement to DO-160G

DO-363, Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft

DO-364, Minimum Aviation System Performance Standards (MASPS) for Aeronautical Information/Meteorological Data Link Services

DO-363, Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft

DO-307A, Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

SAE Standards
http://www.sae.org/

ARP 5583 – Guide to Certification of Aircraft in a High Intensity Radiation (HIRF) Environment http://standards.sae.org/arp5583/

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

LINKS TO LONGER ARTICLES

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

"Why is there AIR (In MIL-STD-461G)?"
https://interferencetechnology.com/air-mil-std-461g/

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https://globaledge.msu.edu/industries/aerospace-and-defense/events/

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

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

Jane's Events:
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