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2020 MILITARY & AEROSPACE EMC GUIDE

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EDITORIAL

Jennifer Arroyo
Editorial Director, *Interference Technology*

Welcome to the 2020 edition of the Military & Aerospace EMC Guide from *Interference Technology*. We hope you enjoy the informative articles and helpful resources and references we have featured in this guide.

Electromagnetic compatibility (EMC) is a consideration for most electronic devices, but it becomes even more important in the military and aerospace sectors. Products and components in these markets must hold up to harsh environmental conditions and pass stringent standards set by government organizations.

The articles in the guide keep this in mind as they deliver valuable information to the EMC engineering community. In "MIL-STD-461G and RTCA/DO-160 Test Configuration Management," Steve Ferguson explains various test configuration parameters for these standards and offers some supplementary guidance on best practices.

Patrick Andre provides real-life examples on how to identify causes of electromagnetic interference (EMI) during testing in his article, "Things Not on the Schematic—How the Unseen Keeps Us Busy."

We round out our feature articles with "Circuit Level Design and Test for the MIL-STD-461 200 V/m RS103 and the DO-160 Radiated Susceptibility Test at 200 V/m," by David Weston, who provides a thorough look at designing circuits with Mil/Aero standards in mind.

Finally, I wanted to note the new downloadable EMC guides we've produced this year. If you visit our homepage, you'll see the list of guides. Some of the more popular ones include Automotive, Testing, EMC Fundamentals, and IoT, Wireless, 5G.

Cheers,

Jennifer Arroyo
Editorial Director, Interference Technology
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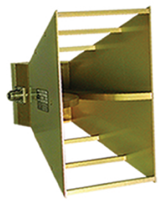

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MILITARY & AEROSPACE EMC EQUIPMENT MANUFACTURERS

Introduction

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

EMC Equipment Manufacturers		Type of Product/Service																	
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Chokes	Conducted Immunity	Current Probes	EMC Filters	EMC Testing	ESD Simulators	LISNs	Near Field Probes	Pre-Compliance Test	Radiated Immunity	Rental Companies	RF Signal Generators	Shielding	Software	Spectrum Analyzers/EMI Receivers	TEM Cells
A.H. Systems	www.ahsystems.com	X	X			X						X							
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Advanced Test Equipment Rentals	www.atecorp.com	X	X		X	X			X	X	X	X	X	X	X			X	X
ALTAIR	www.altair.com																X		
Anritsu	www.anritsu.com		X									X			X			X	
API Technologies	www.apitech.com						X												
AR RF/Microwave Instrumentation	www.arworld.us	X	X		X					X		X	X		X		X	X	
Captor Corporation	www.captorcorp.com						X												
Coilcraft Inc.	www.coilcraft.com			X															
Electro Rent	www.electrorent.com	X			X				X	X		X	X	X	X			X	
EM Test	www.emtest.com/home.php				X							X							X
Empower RF Systems	www.empowerrf.com	X											X						
Exodus Advanced Communications	www.exoduscomm.com	X	X					X											
Fischer Custom Communications	www.fischercc.com					X				X	X	X							
Gauss Instruments	www.gauss-instruments.com/en/																	X	
HV Technologies, Inc.	www.hvtechnologies.com	X	X		X								X		X			X	
Instruments For Industry (IFI)	www.ifi.com	X			X								X						
ITG Electronics	www.itg-electronics.com						X												
Keysight Technologies	www.keysight.com/main/home.jspx?cc=US&lc=eng									X	X	X			X		X	X	
Milmega	www.milmega.co.uk	X			X								X						
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X		X					X		X	X					X	
Noiseken	www.noiseken.com				X				X			X							
Ophir RF	www.ophirrf.com	X			X														
Pearson Electronics	www.pearsonelectronics.com					X													
PPM Test	www.ppmtest.com		X									X	X				X	X	
R&B Laboratory	www.rblaboratory.com							X											
Rigol Technologies	www.rigolna.com	X				X					X	X			X		X	X	
Rohde & Schwarz	www.rohde-schwarz.com/us/home_48230.html	X	X		X	X				X	X	X	X		X		X	X	
Siglent Technologies	www.siglentamerica.com										X	X			X		X	X	
Signal Hound	www.signalhound.com					X					X	X			X		X	X	
Solar Electronics	www.solar-emc.com	X	X			X		X	X		X						X		
Spira Manufacturing	www.spira-emi.com															X			
TekBox Technologies	www.tekbox.com	X								X	X	X					X		X
Tektronix	www.tek.com										X	X					X	X	
Teseq	www.teseq.com/en/index.php	X			X	X			X			X	X						X
Test Equity	www.testequity.com	X			X				X	X		X	X	X	X			X	
Thurlby Thandar (AIM-TTi)	www.aimtti.us											X			X			X	
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X							X		X	X					X	
Transient Specialists	www.transientspecialists.com				X								X						X
TRSRenTelCo	www.trsrentelco.com/categories/spectrum-analyzers/emc-test-equipment	X	X		X					X		X	X	X	X			X	
Vectawave Technology	www.vectawave.com	X																	
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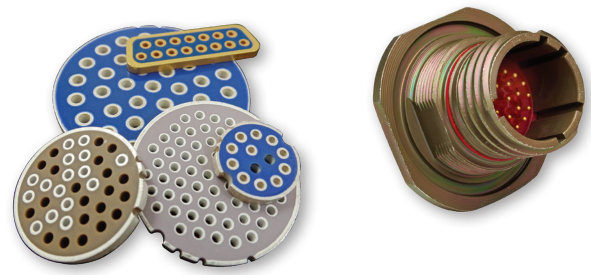

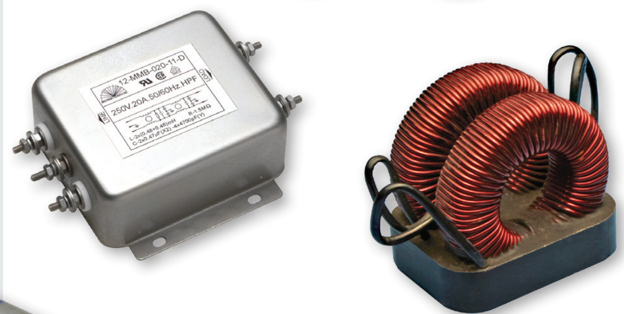

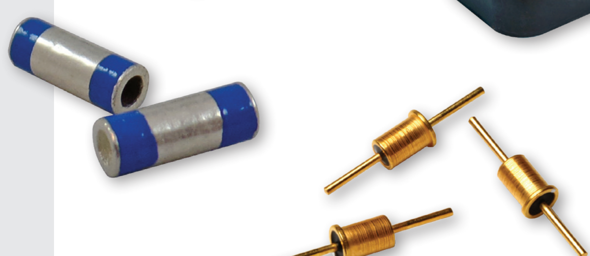

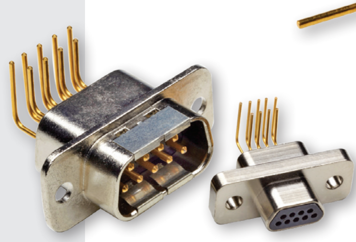

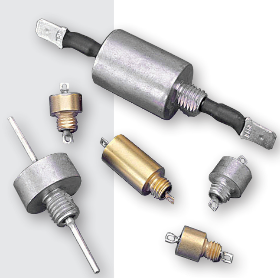

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MIL-STD-461G AND RTCA/DO-160 TEST CONFIGURATION MANAGEMENT

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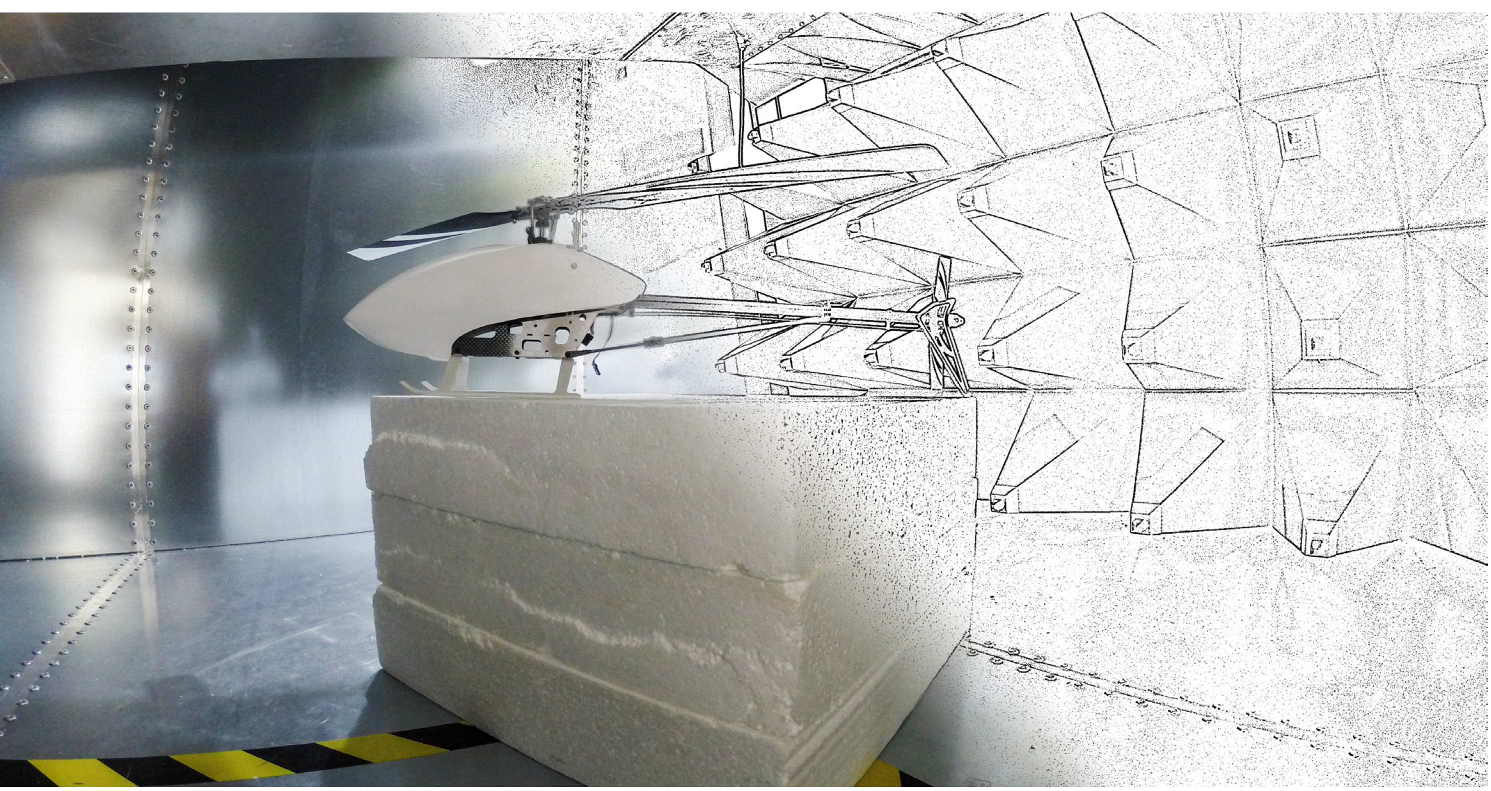
Introduction

MIL-STD-461G and RTCA/DO-160 (DO-160) provide in-depth discussions regarding the test configuration with generalized diagrams to support the discussion. The primary purpose for the discussions is to provide guidance and standardize testing at various laboratories hoping to obtain like results at any test facility. Variations in the test configuration are listed for some of the individual test methods if directed to accommodate the usage of the test and measurement equipment and transducers.

We recognize that the test configuration in either standard is a generic arrangement meant to simulate various installation requirements. Many of the specific configuration parameters make efforts to relate the arrangement to an assumed installation, but if we were able to exactly duplicate the installation, more realistic results would be obtained. This desired duplication of the installation is only realizable for testing a few items with single applications. If this is reasonable, I believe that the duplication is worthwhile and should be proposed in the test procedure instead of using a generic arrangement. But, this is seldom reasonable.

A discussion of various test configuration parameters follows with some explanatory information to supplement the guidance provided. Note that the DO-160 user guide RTCA/DO-357 contains additional information supplementing the DO-160 standard and it should be used in conjunction with DO-160 for supporting information.



MIL-STD-461G AND RTCA/DO-160 TEST CONFIGURATION MANAGEMENT

General Configurations

The two standards being reviewed here have a few differences, so a couple of general diagrams are provided here to establish a discussion basis. The discussion is based on using the anechoic shielded enclosure method for testing, but if other methods are used the basic principles would still apply. These will be used throughout this review. *Figure 1* shows a general test configuration diagram including some optional items that are included or removed depending the test being accomplished and specifics about the deployed installation. Although the diagram is closely associated with DO-160, the MIL-STD-461 only has a few variations that will be discussed as we review the configuration layout details.

The details are normally documented in a test procedure so the test personnel and approval authority can readily see how things are arranged and how the various items are implemented. Having knowledge of the test configuration helps in the overall preparation for testing, by providing a guide that identifies the detailed parameters of the layout.

The general test configuration shown in *Figure 1* includes layout considerations for a variety of tests, and one must realize that maintaining the exact layout for each test is not feasible. Some test methods call for changes in the arrangement, therefore being able to restore the general configuration established as the standard configuration for the specific test program is necessary. The "standard" configuration for a particular test will see some difference to accommodate the test article size and cable routing demands. In addition, the physical layout of the test facility regarding interface panel positions and doors will influence the layout and cable routes. Positioning changes of the cable arrangement can change the test results by 20 dB or more, making documenting the layout critical for testing and the ability to repeat the testing.

In the the diagram below, some details are provided to describe the configuration and how the various elements differ between DO-160 and MIL-STD-461 (note that revision "G" is used as the configuration basis for both standards).

Ground straps are attached between the ground plane and the shielded enclosure using copper sheets with a length to width ratio of 5:1 or less to minimize the inductive reactance effects. Several ground straps are typically used to provide a parallel path to further reduce the resistance and inductance. The DC bonding resistance between the ground plane and enclosure wall is required to be less than 2.5 milliohms.

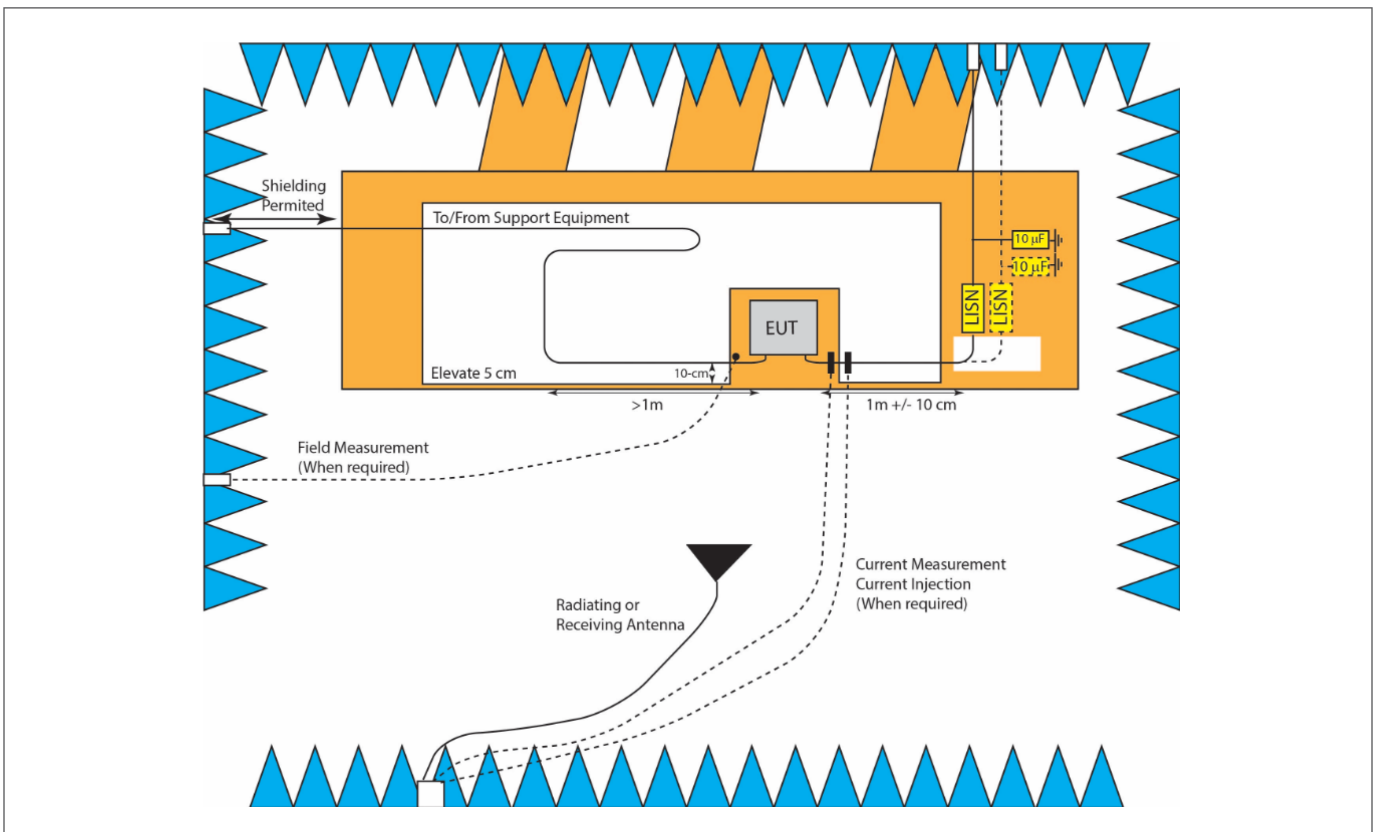


Figure 1: General Test Configuration

EUT Positioning

Figure 1 indicates that the EUT tends to be centered in the test boundary, but both standards support positioning at either side of the ground plane allowing cables to be routed in the same direction.

The diagram indicates that the EUT interface side faces the antenna in DO-160 and is shown parallel to the ground plane front in MIL-STD-461. These diagram orientations may be a bit misleading because the test orientation should be selected to produce the maximum emissions or most susceptible face. Experience indicates that the cable face tends to be the worst case for lower-frequency signals (<~200 MHz) and equipment aperture face tends to be worse at higher frequencies (>~200 MHz). Often, this leads us into testing multiple faces unless probing clearly identifies a worst-case orientation.

The white areas in *Figure 1* indicate a 5 cm spacing to elevate the cables. This elevation could possibly (although rarely) include the EUT. Normally the EUT is placed directly on the ground plane unless the installation does not provide for this kind of ground connection.

EUT Grounding and Bonding

Both standards call for conforming to the installation for the grounding and bonding of the EUT, specifying the use of the same materials and size grounds that is called out in the installation. This includes using an equipment mount that matches the installation. This could present some difficulty for some installation types. When a vehicle or aircraft mount is specified, the mount is normally part of the EUT configuration, and this includes the associated straps, mounting base, and ground straps. The installation of rack-mounted equipment could indicate isolation of the chassis from the ground plane if the rack-mounting flanges are insulated. The connection of the EUT chassis to the ground plane should not include these incidental connections unless the installation specifies the physical contacts.

Included in the grounding instructions, the chassis ground terminal is to be connected as installed using the materials as defined in the installation drawings. DO-160 adds a 30 cm representative type of wire, if the installation fails to define the ground terminal connection. A representative wire is usually a wire of the same size as used or the power lead.

The bonding and grounding method used is to be documented in the test report. MIL-STD-461 requires that measurement of the bonding resistance be included in the report, and it is a good practice to include the measurements for DO-160 tests, although, it is not specifically required. This bonding measurement should be accomplished prior to installing cables to obtain the highest bonding resistance representative of the installation.

The maximum resistance of the EUT bonding is not specified in the standards, it needs to conform to the installation. However, safety regulations may impose a maximum resistance if hazardous voltage levels are present, for example MIL-HDBK-2036 calls out less than 100 milliohms for safety considerations in the final installation. MIL-STD-464C also notes some specific maximums for selected ground connections and points to less than 2.5 milliohms for individual faying surfaces.

Most test configurations use a copper ground plane meeting the size and conductivity requirements. If the installation uses a different plane or no ground plane, then the test configuration should match the installation by using a composite material or no ground plane for items that may be hand-held.

Line Impedance Stabilization Network (LISN) Arrangement

Power for the test article is normally brought into the enclosure via a filtering arrangement to reduce ambient signals that could affect the test. The LISN is used to standardize the power line impedance, compensating for a wide variety of installation impedances.

Notice in the diagram that two LISNs are shown with one in a dotted line indicating that only one may be required. The second LISN is not used if the EUT installation uses a local ground for the power return. For that configuration, the power return lead is connected to the ground plane along with the input power return being connected to the ground plane. This single LISN configuration is appropriate for both DO-160 and MIL-STD-461 testing.

The LISN chassis is bonded to the ground plane with a resistance of less than 2.5 milliohms, indicating that the surfaces of the ground plane and LISN base be free of contaminates to assure the low resistance requirement.

MIL-STD-461 calls out the use of a 50 μH LISN but supports the use of 5 μH LISNs for certain applications. If a 5 μH LISN is used, adjustments to the test and limits are necessary for power line conducted tests. DO-160 calls for using a 5 μH LISN and places 10 μF capacitors on the line side of the LISN.

Arrangement of Signal/Control Leads and Cables

Figure 1 shows a general layout of cables but often the actual configuration requires some creative placement to manage multiple cables and provide for the connection to the support equipment. Standardization and the ability to fit within the test chamber dictate several elements associated with the arrangement.

Both standards call for elevating the cables 5 cm above the ground plane with the front cable located 10 cm behind the front edge of the ground plane. The location of the EUT and the cable arrangement on the ground plane forms the test boundary. DO-160 calls for at least 1 meter of cable be aligned at the test boundary front and MIL-STD-461 specifies at least 2 meters at this edge. After meeting the front edge length requirement, excess cable is routed toward the rear of the ground plane arranged in a zig-zag pattern until the required cable length is satisfied.

The cable length maximum is 10 meters for MIL-STD-461 and 15 meters for DO-160 for installations calling for long cable runs. Actual cable lengths should be used if known, and DO-160 uses 3.3 meter length as standard if installation parameters are unknown. This implies that if the actual cable length is shorter than the specified front edge layout, then a shorter cable is used in the test configuration.

Cables are to be of the type used in the installation. Shielded cables, twisted pairs or triplets, types of shields, wire diameters, insulation type, and other parameters bring parasitic elements into the configuration and aid in simulating the installation environment. Using the correct cables and following the layout guidance supports the desired standardization. Note that the test configuration should not drive the installation—the installation should drive the configuration. If testing reveals that certain installations practices need to be modified, those changes must be accepted prior to accepting the test results.

Cables that exit the area above the ground plane are not typically considered to be within the test boundary. The cable length beyond the ground plane normally routed to external support equipment, may be shielded as stated in DO-160. MIL-STD-461 does not acknowledge that this portion of the cable is present, so the test procedure should account for this layout and should incorporate shielding as indicated in DO-160.

Do not forget that the cables should be properly terminated into loads or support equipment representative of the system equipment associated with the test item. Also, remember that mechanical loads need to be included in the termination requirements.

Arrangement of Power Leads and Cables

Power cable arrangements are much like the signal/control cable arrangements, but a few specific requirements merit this separate discussion.

DO-160 is very specific regarding a 1 meter power cable length with a ±10% tolerance and MIL-STD-461 calls for less than 2.5 meters. This prevents being able to do a DO-160 test and a MIL-STD-461 test with the same power cable because of the front edge requirement for 2 meters of power cable. If needing to do testing for both standards, seek approval to implement a common power cable arrangement.

MIL-STD-461 is very specific that shielded power cables are not to be used and DO-160 basically uses the same concept. Where power connections share a common interface with other signal connections, the power leads are separated from the other wires at the EUT interface. When power leads are normally included in a shielded cable, MIL-STD-461 calls for separating the power leads at the EUT connector. However, when the power leads are installed in a shielded cable connected to another equipment instead of the mains connection, keeping the shielded cable intact is permitted if the other equipment provided isolation or filtering between the mains and the EUT.

Using a local ground for the power neutral or return calls for direct connection to the ground plane as discussed in the LISN arrangement above.

Antenna Cable Arrangement

Antenna cables are often ignored in the MIL-STD-461 test configuration. DO-160 calls for terminating the antenna cable with a dummy load matching the cable characteristic impedance and MIL-STD-461 calls for terminating the antenna port. The word choice leads some people to believe that the antenna cable is not present in the configuration and they simply place a terminator on the EUT antenna connector. This action virtually eliminates radiated emissions from the antenna cable from being detected and fails to assess susceptibility associated with cable coupling into a sensitive circuit. The CS114 test method helps alleviate the ambiguity by calling for antenna cable testing for surface ship and submarine applications.

The antenna cable representative of the installation should be present in the MIL-STD-461 test configuration, with a terminator at the end of the cable.

Measurement System Antenna Arrangement

During radiated emission testing, the measurement system antenna is positioned 1 meter from the test boundary (0.9 meter from the ground plane). The antenna center is 120 cm above the enclosure floor for MIL-STD-461 testing and 30 cm above the ground plane level for DO-160 testing. MIL-STD-461 provides additional guidance on using multiple antenna positions and the EUT and cable coverage within the antenna beamwidth. DO-160 provides for multiple antenna positions where the entire EUT plus a half-wavelength (λ/2) of cabling. This multiple positioning is discussed in the radiated susceptibility section of the standard and would also apply to the radiated emissions section.

Radiated susceptibility and radiating antenna positions may be greater than 1 meter if the required field strength can be generated. This increased distance provides greater coverage area, so fewer antenna positions are required to fully illuminate the EUT.

Field Probe Arrangement

Figure 1 shows the field probe adjacent to the EUT at the test boundary. Positioning of the probe should avoid the probe being in a shadow of the EUT and to avoid reflections from the EUT. The elevation above the ground plane should be at least 30 cm to avoid ground plane reflections reaching the measurement head. Many layout drawings show the probe directly in front of the EUT, which works for pre-calibrating the field without the EUT being present. This position should be avoided when active field leveling is used during test. The important issue is to make sure that the illuminating field is at the proper level to avoid over- or under-testing.

DO-160 supports a field pre-calibration method where the field probe is located where the front of the EUT will be placed. The field is measured without the EUT, and the required power is recorded. The recorded power is used during test once the EUT is in test to apply the test field strength.

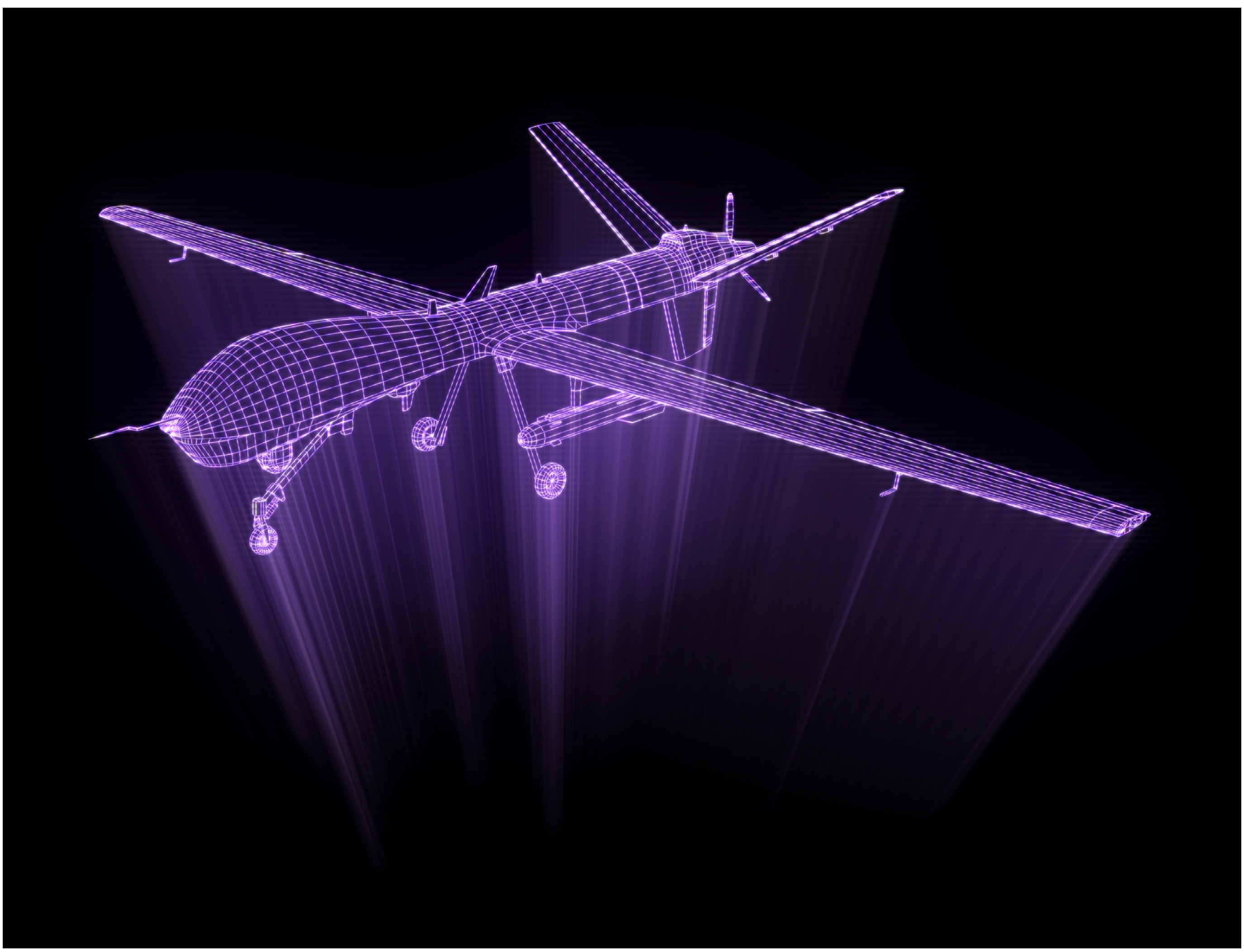
Current Probe Arrangement

Current probes are used during conducted emission and conducted susceptibility testing. The measurement probe is placed around the cable under test, 5 cm from the EUT (EUT connector not 5 cm from the cable backshell). Injection probes are located 5 cm from the monitor probe. MIL-STD-461 conducted emission testing places the monitor probe 5 cm from the LISN connection instead of near the EUT. Although the drawing shows current probe cables being routed to measurement equipment outside the enclosure, it is common to locate the measurement equipment in the enclosure to minimize cable lengths and prevent injected signals radiating from the cable into the environment.

Summary

Some specific test methods call for changes to the general configuration discussed above, so make sure to make the changes for those tests—the details are noted in the standards for those tests and should also be included in the test procedure. Do not forget to restore the general configuration minimizing the variations in how the layout is arranged—changes in cable positions can significantly impact the test repeatability.

Hopefully, you will find this information useful and I welcome questions. If you have a topic associated with EMC that you would like to have reviewed, let me know and I will try to place it in the queue for future articles.



THINGS NOT ON THE SCHEMATIC—HOW THE UNSEEN KEEPS US BUSY

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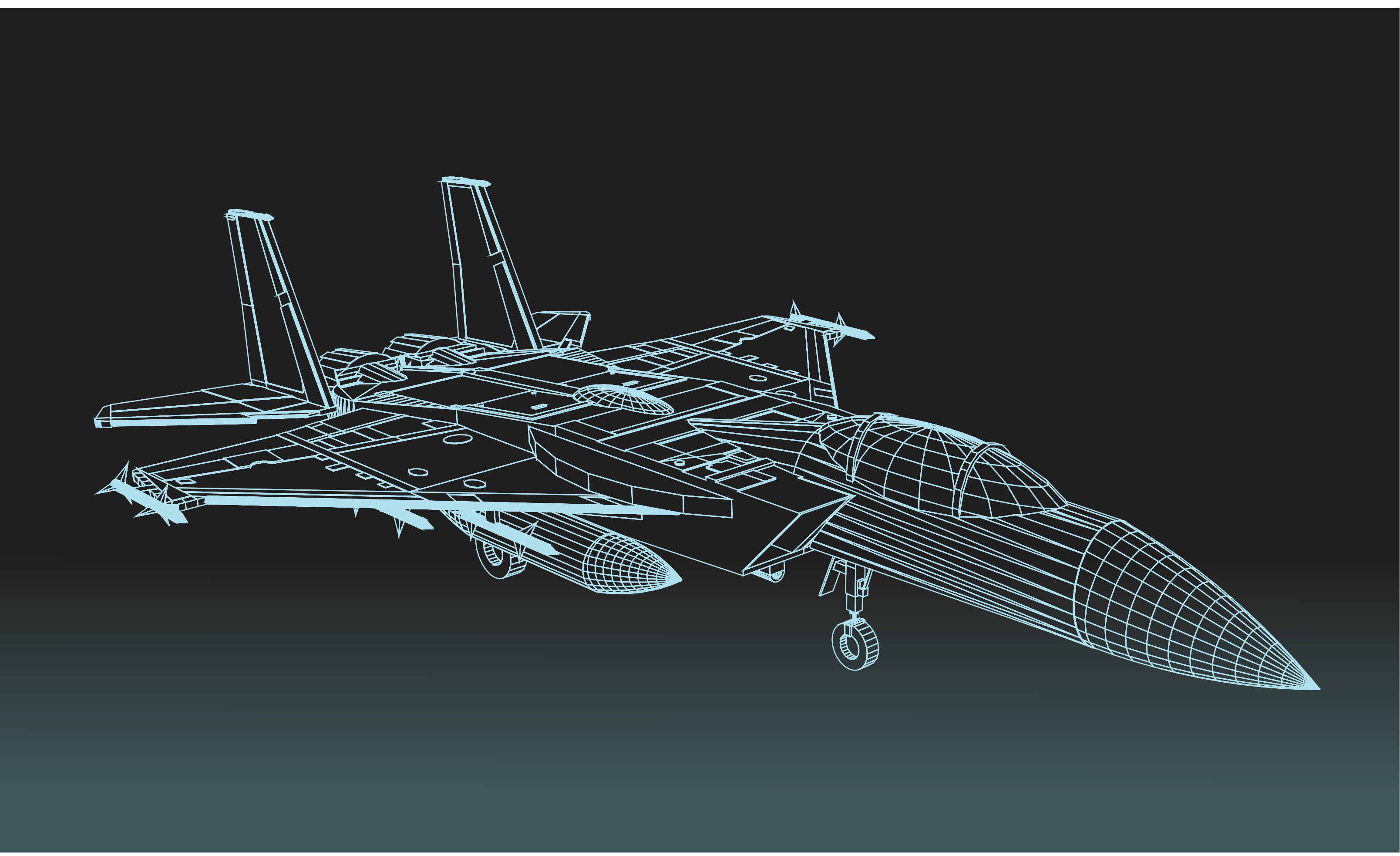

THINGS NOT ON THE SCHEMATIC—HOW THE UNSEEN KEEPS US BUSY

The engineer I was working with and I stood amazed at the results. A capacitor that was moved less than 1 inch away from a connector and turned sideways degraded the emission results several dB and increased it above the limit. How could that be? They were identical on the schematic.

I heard once that the field of EMC is the design of circuits and equipment which considers things that do not appear on a schematic. These are the issues of electric field and magnetic field coupling into adjacent circuits, wires, and components, and issues of unknown or uncontrolled current paths. To control these issues, it requires being aware of these fields, how they are generated, and the mechanism by which they couple, as well as how currents are generated and how they return to the source of the energy that created those currents.

When EMI problems occur, they are often due to unknown or unforeseen issues of components. Take the following, for example. In *Figure 1*, if we were going to be concerned with cross coupled issues, we may want to reroute that cable we see over the circuit board. Or, maybe, we would have concerns about the large inductor in the upper right corner, or the small one in the lower right under the cable. These may have uncontrolled magnetic fields, which could couple energy into nearby traces. It turns out, neither of these were a problem.

Look at where the arrow is pointing on the left side of the photo. This is a DC-DC converter, which contains an internal transformer. The fields from this device ended up coupling into the input power trace running under the near side of the device indicated in this picture. Due to a misplaced filter, the input power conducted emissions increased by 20 dB and more, due to the proximity of this converter and internal transformer. Rerouting the trace improved the results radically (see *Figure 2*).

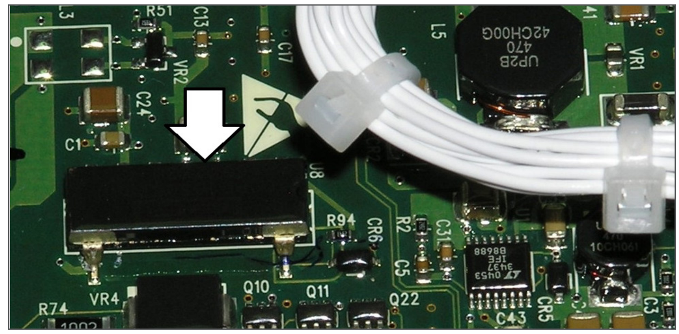

Figure 1: Where are the fields from?

The cause of this issue was due to magnetic field coupling. Magnetic fields from the device's internal transformer coupled into an adjacent trace, which induced a current in that trace. It was a surprise to us. From the outside, it does not look like something that will cause any issues with conducted emissions. And the specification for this component shows performance with a wide margin with respect to conducted emissions limits.

If you use this device, just make sure you do not have anything important next to it.

These magnetic coupling issues are usually found in lower impedance circuits, where currents can flow with greater ease. But what happens in high impedance circuits? These are more susceptible to capacitive coupling. One way to demonstrate that is using a standard MIL-STD-461 or DO-160 setup.

I took an inexpensive spectrum analyzer with a tracking generator. A tracking generator is an internal signal source that creates a signal at a set amplitude and the same frequency the analyzer is measuring. I ran the tracking generator signal into an unterminated 5-foot wire (150 cm), and the return signal was routed to a ground plane. A current probe was placed on the drive end of the wire. A simplified setup drawing is shown in *Figure 3*.

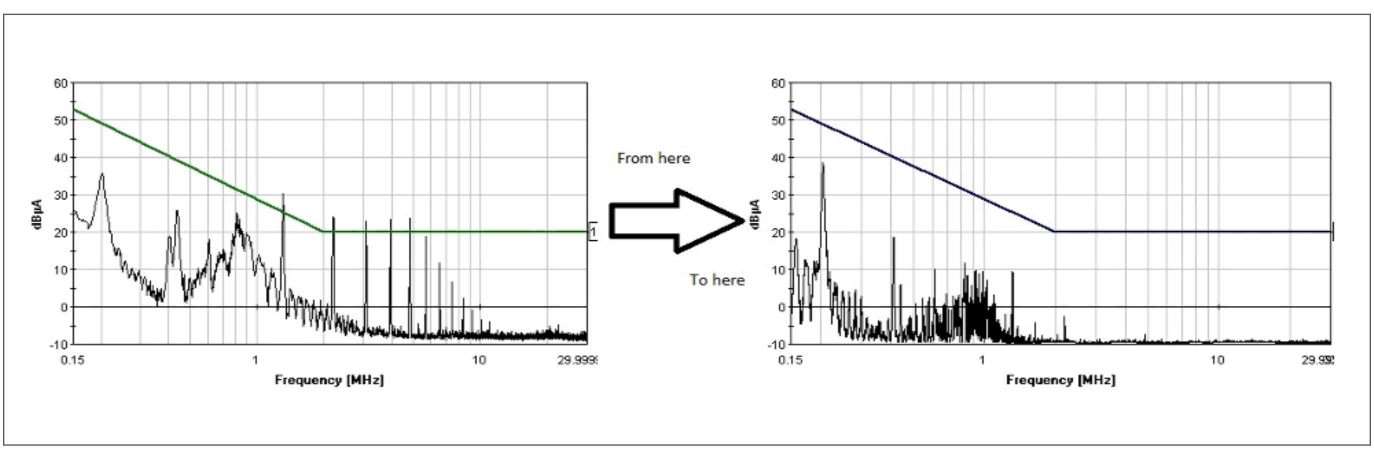

Figure 2: Rerouted trace and the resulting emissions

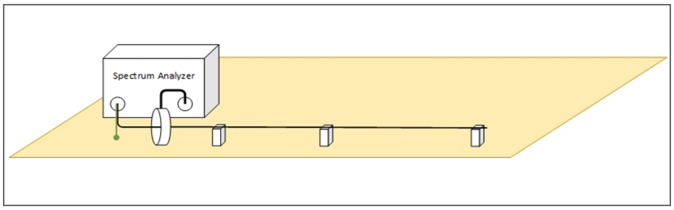

Figure 3: An experiment on capacitive coupling

The figure shows the wire on 5 cm standoffs, as is commonly used for our tests. However, I then routed the wire directly on the ground plane, and also routed the wire off the ground plane so that it was in space (held up with a plastic stand to avoid other parasitic coupling). The wire was swept with a signal from 100 kHz to 100 MHz. Only the wire was moved during the three scans, and no other changes were made to the setup, and the current probe was as close to the output port as physically possible. The results are shown in *Figure 4*.

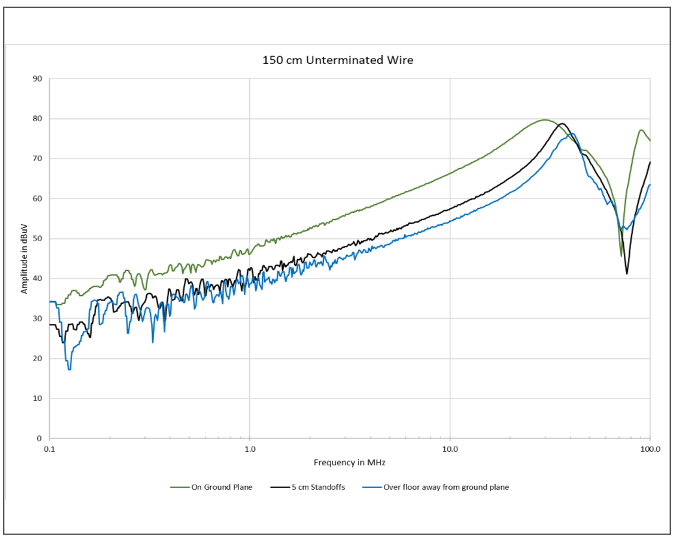

Figure 4: Wire over a ground plane

Upon closer examination I found the following. At 10 MHz the induced current in the wire on the ground plane was 9 dB higher than the same wire on 5 cm standoffs, and 12 dB higher than the wire routed away from the ground plane. Above 30 MHz, this system starts to break down, likely due to the cross coupled energy at the source, the line impedances (inductance), and so forth. However, up to 30 MHz, the results were repeatable.

So, what does this tell us? First, there is some coupling of energy from wires on 5 cm standoffs over a ground plane. That should not surprise most experienced military and aerospace test engineers. This is also how the wires are routed in most military and aerospace applications—wires over a metal structure. Also, note that unterminated wires closely coupled to conductive surfaces can capacitively couple their own return path. Remember this is an unterminated wire, so I did not allow a connection to the ground plane to close the current loop. The loop is closed by displacement currents, a time varying electric field due to the voltage difference between the wire and the ground plane (which was the return). Now, how do we use this to our advantage or to avoid problems?

If I have a cable inside my equipment that I want to avoid radiating on to a sensitive circuit, I can route that wire away. If I can route it near a conductive surface, such as a chassis, the conductor can couple that energy away, and preferably back to the source in a controlled manner. Conversely, if that cable is sensitive to energy being picked up from high-energy or noisy circuits or systems, routing the cable along the conductive surface will help minimize the energy induced onto it. This comes from the concept that parallel electric fields at the surface of a perfect conductor go to zero.

So, the solution may be to route wires near chassis, or maybe not. And, care may be needed to assure traces do not couple electric field into them from unwanted sources. However, using traces over ground planes are often highly beneficial and improve signal integrity when designed properly.

In a recent article, I discussed an issue with chassis bonds. A common method of determining the quality of a shield was to consider the material conductivity, the thickness and the screw spacing. The conductivity along with the thickness will provide the maximum capability of the material to shield. If it is not conductive enough, or thick enough, you may never get the desired results.

But what about screw spacing. I have often seen drawings that show contact points as shown in *Figure 5*. One concept is that contact occurs for the first third of the spacing between fasteners, and again for the last third, but the middle third is open.

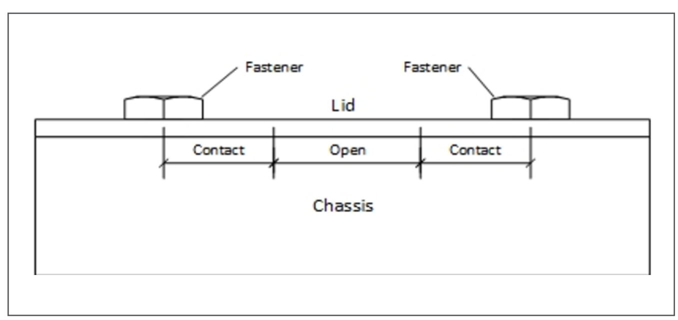

Figure 5: Chassis bonds

Some of these “rules of thumb” do not consider the stiffness of the materials, the spacing of the fasteners, nor the coatings. For example, if I have a steel box with a sheet metal lid that is 50 cm wide and only put fasteners in the corners, the likelihood of gaps in the middle of the seam is rather significant. There is not enough rigidness in the lid to maintain a bond in the middle. In this case, fasteners may need to be 5 to 10 cm apart to assure a bond. But what if I have a thick-walled chassis that has a thick lid? The spacings between fasteners may be a bit wider and still maintain the bond. And yet the whole thing can go to waste if there is a coating on the chassis.

If one only looks at the potential opening, or window created between fasteners, as the driving factor in shielding effectiveness, you may miss a critical aspect of shielding. Take my sheet metal box with 50 cm spacing. If the window is the full 50 cm, and that relates to the half wavelength of the leakage, then we would think that below 300 MHz, this shield should start to work well. If we reduce the spacing to 5 cm, the shield should be 20 dB better across the frequency range. Yet often that is not the case. For the situation I discussed in my past article, the unit had a thick-walled chassis made of aluminum, with fasteners about 5 cm apart. The emissions we found from 1-10 MHz failed the MIL-STD-461 limit where the shielding effectiveness should have been well over 100 dB. The emissions did not change much when the lid was off. If you were wondering, no, the emissions were not from the cables. However, once we cleaned off all the oil and grease built up on the chassis and lid from the handling and construction of the unit, the emissions dropped 20 dB and we passed the test.

In this case, we were working on a power supply with significant currents flowing internally and several magnetic cores inside. The resulting fields from the current flow and the magnetics would induce currents in the aluminum chassis under and around the circuit board, as well as in the lid near the magnetics. Once these currents started to flow, they need to complete a loop. When the induced currents reached the seam, they met an impedance that prevented the flow of the current directly. This created a voltage between the lid and the chassis. Voltages between two pieces of metal with an impedance between them act like an antenna and tend to transmit energy. This may have been viewed as a transfer impedance problem, or the creation of displacement currents. The impedance between these metal parts could have been one molecule thick, too thin to transmit radio frequencies sideways through it. However, if currents cannot flow across the gap, even that small, then the resulting voltages on the two sides of this barrier will still transmit energy.

This same issue arose recently on a display I was working on. The case it was mounted in was nearly 1 inch thick, and yet we developed significant emissions from the display that were not found earlier. We discovered one corner bolt used to seal the chassis had stripped out. The corner was not bonded well and was leaking. Clamping the corner dropped the emissions a great deal.

Try as we might to capture all the relevant issues concerning EMC on a schematic, we often find we missed several things. They do not provide DC to DC converters with magnetic field maps. And, inductors are best modeled with capacitance across them, and capacitors with inductors in series. Wires and traces include a bit of everything. Diodes are making wonderful noise generators over 30 MHz now.

As EMC engineers, we need to be proficient in several disciplines, in many fields of engineering, to fully support the engineers we work with. Schematics will only tell you part of the story. Many parasitic elements are not documented. Mechanical and manufacturing techniques play a role in passing EMC requirements. I guess we, as EMC engineers, will just keep busy.

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CIRCUIT LEVEL DESIGN AND TEST FOR THE MIL-STD-461 200 V/M RS103 AND THE DO-160 RADIATED SUSCEPTIBILITY TEST AT 200 V/M

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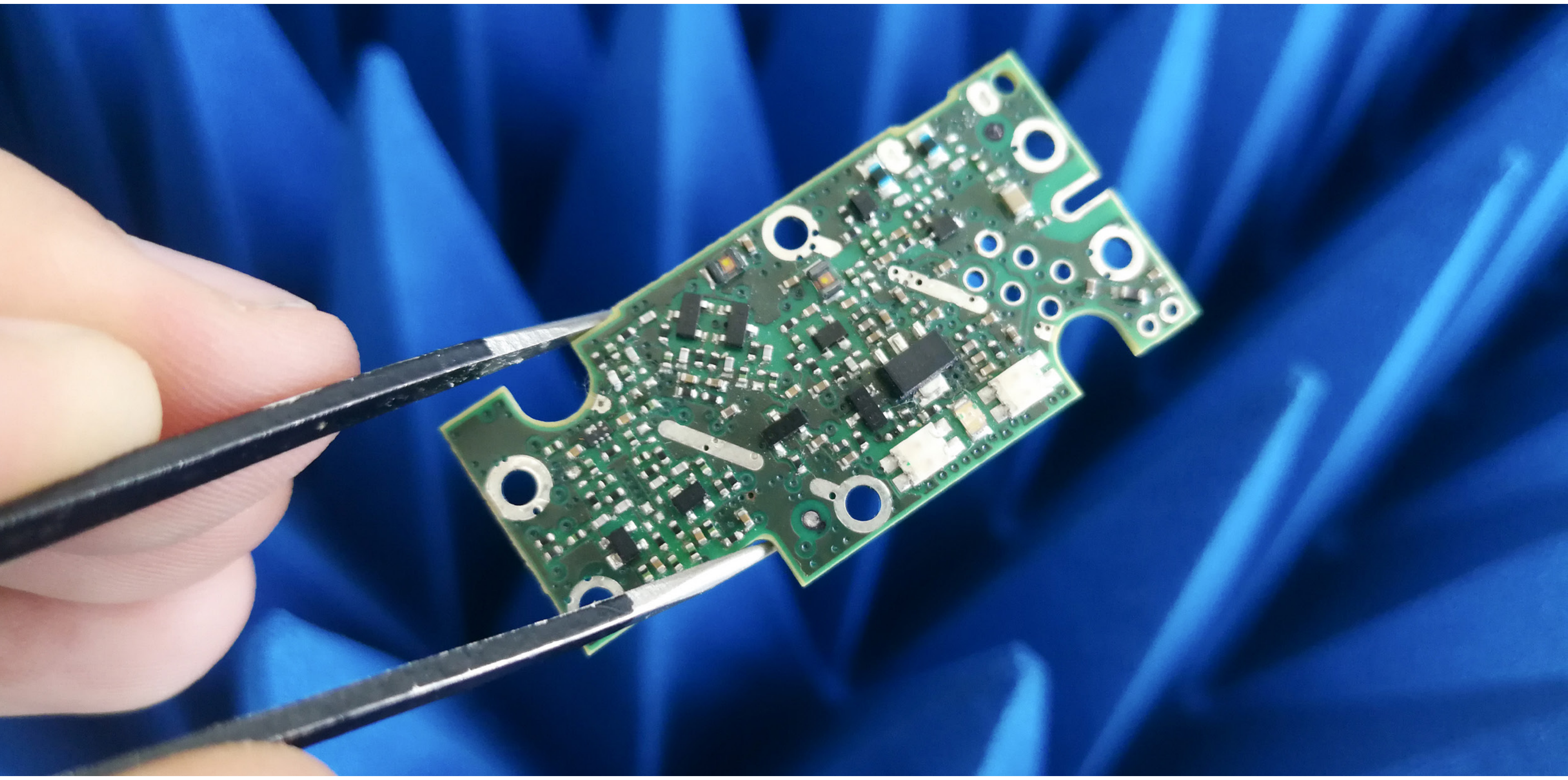
Introduction

For Army, Navy, and Air Force military equipment and DO-160 commercial aircraft avionics, radiated susceptibility test levels as high as 200 V/m may be specified. As always, it is better to design immunity to the test levels into equipment than to wait until equipment is completed and then perform tests.

This article assumes the worst-case qualification test levels of 200 V/m. If the radiated susceptibility test levels are lower than all of the predicted circuit test levels can be reduced accordingly.

This article shows levels induced into the circuits when 200 V/m is incident on the equipment's shielded or unshielded cables. With this information, circuits can be designed to be immune to the levels. The high-level tests require high-power amplifiers and antennas capable of coping with the power. Although common in test labs, these are not so common in manufacturers' test facilities. The circuit-level tests described here require only signal generators or low power amplifiers with a spectrum analyzer or oscilloscope.

Military equipment and avionic equipment are typically enclosed in well-shielded enclosures and the coupling from an incident E field is predominantly to cables at 1 GHz and at lower frequencies. For this reason, this report concentrates on cable coupling.



CIRCUIT LEVEL DESIGN AND TEST FOR THE MIL-STD-461 200 V/M RS103 AND THE DO-160 RADIATED SUSCEPTIBILITY TEST AT 200 V/M

Analyzing the Circuit Test Levels

The methods of moments (MOM) formulation was used to model the RS103 and the DO-160 test set up. A ground plane 4 m x 2 m constructed of numerous patches with the patch maximum dimension limited to 0.3 λ. Either a single conductor or two conductors 3 m long in were constructed at a height of 5 cm above the ground plane. The single conductor was located 10 cm from the front of the ground plane. The second conductor was placed a few mm apart from the first. The single conductor was terminated in an S/C representing the connection of a shielded cable to the ground plane. One conductor of the twin conductor cable was terminated in either a short circuit, a 50 Ohm, or 1,000 Ohm load and the second to the ground plane.

With the asymmetrical connection of the cable/s (connected to the ground plane at one end only) the MOM calculation has been proven to be correct (*Reference 1*). However, with the symmetrical connection, the MOM fails. This is not a problem as the load current and maximum cable currents are the same as the asymmetrical connection only the resonant frequencies change.

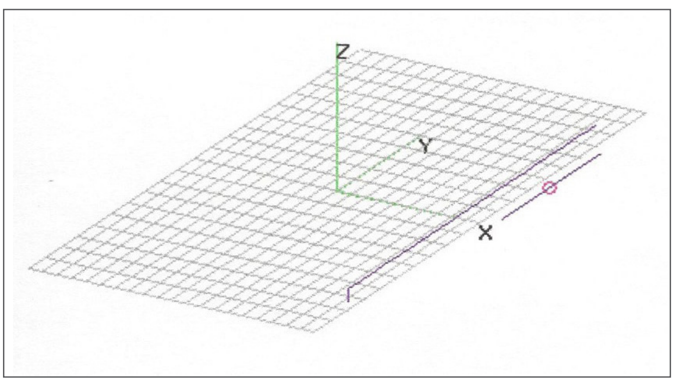


Figure 1: MOM RS103 test set up low frequency

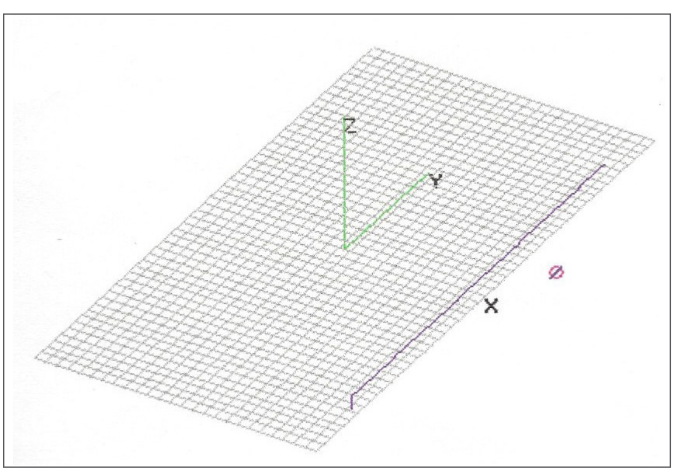


Figure 2: MOM RS103 test set up at 975 MHz

For example, for the asymmetrical connection these frequencies are 25 MHz, 75 MHz, 125 MHz, 225 MHz, 275 MHz, 325 MHz, 375 MHz, 425 MHz, and 975 MHz, and for the symmetrical connection 50 MHz, 150 MHz, 250 MHz, 350 MHz, 450 MHz, 550 MHz, 650 MHz, 750 MHz, 850 MHz, and 1950 MHz. The MOM program used was 4NEC2D by Arie Voors. *Figure 1* shows the model for a single conductor at low frequency and *Figure 2* at 975 MHz.

The 4NEC2D program was used to predict the E field at the center of the conductor, 5 cm above the ground plane and the current through the termination to the ground plane. Also the current down the conductor and in the termination of the conductor to the ground plane. Based on the ratio of the 200 V/m and the MOM predicted E field, the cable and termination currents have been corrected for 200 V/m. *Figure 1a* shows the S/C termination current and *Figure 2a* shows the cable current.

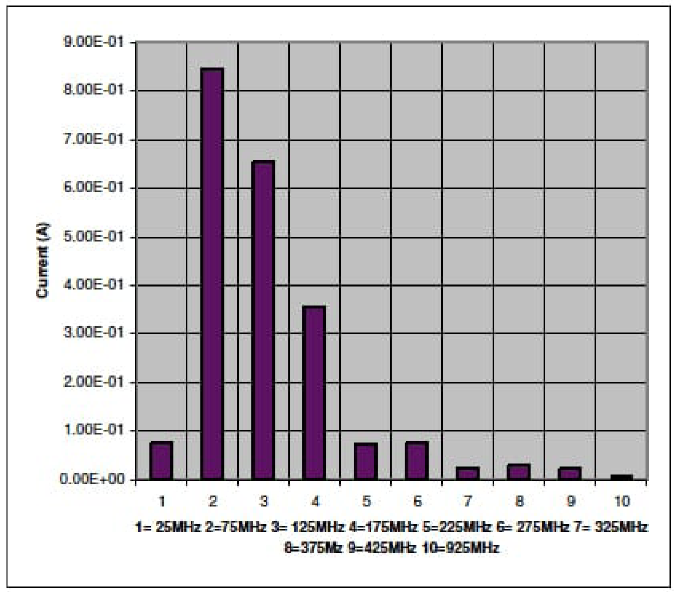


Figure 1a: Current in S/C load

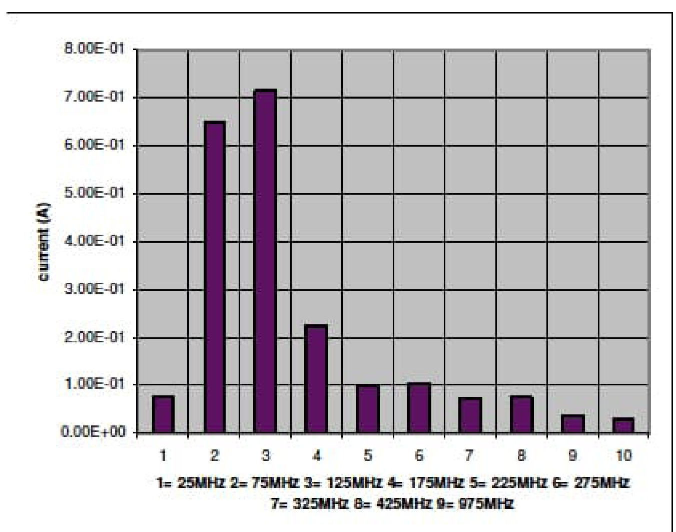


Figure 2a: Current down cable with S/C load

The cable current and voltage induced into a two-conductor line, where one line is terminated to the ground plane and the second line terminated in either 50 Ohm or 1,000 Ohm, was computed. This represents an unshielded signal or control line with 50 Ohm or 1,000 Ohm common mode impedance or the input impedance for signals with the return referenced to chassis. The voltages developed across 50 Ohm for the 200 V/m incident E field is shown in *Figure 3* and for 1,000 Ohm in *Figure 4*.

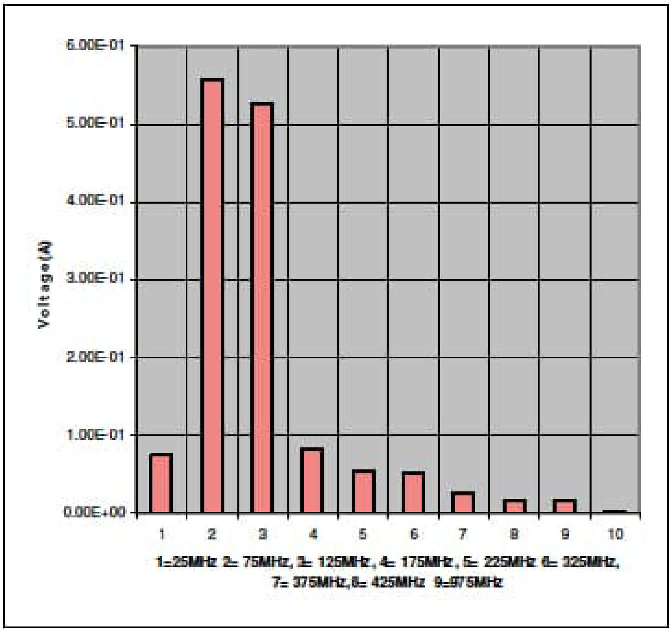


Figure 3: Voltages developed across 50 Ohm load

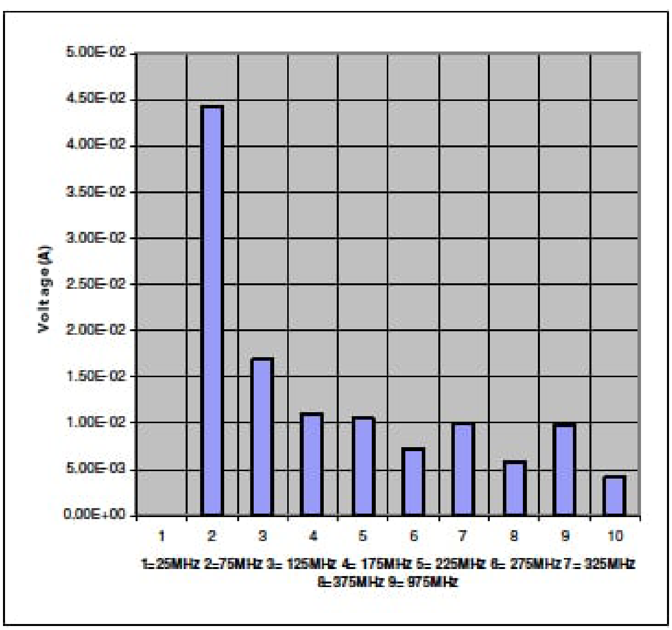


Figure 4: Voltages developed across 1,000 Ohm load

Clearly, for many signal interfaces, a signal line filter will be required. *Reference 1* describes the design and implementation of a large number of such filters.

Table 1 shows also shows the voltages.

Frequency (MHz)	Voltage across 50 Ohm (V)	Voltage across a1000 Ohm (mV)
25	3.75	29
75	27.9	2200
125	26.3	844
175	4.17	553
225	2.7	525
275	2.6	358
325	1.31	497
375	0.87	294
425	0.8	489
975	0.13	208

Table 1: Voltages developed across a 50 Ohm and 1,000 Ohm load

Voltage Developed into a Shielded Cable at 200 V/m

As current flows down a shielded cable, a transferred voltage is developed on the center conductor(s). The voltage is developed across the transfer impedance of the cable. Two common cables used in military and avionic equipment are a single braid with high optical coverage and a double braid with high optical coverage. Assuming the cable shield is terminated at one end to the ground plane, the cable current will be that shown in *Figure 5*.

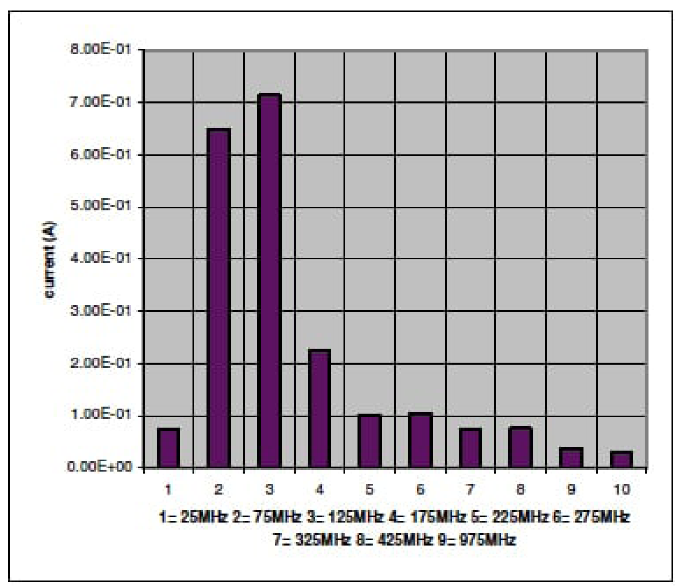


Figure 5: Cable current with a short circuit termination

Reference 1 shows data on single braid and double braid cable from 100 kHz to 20 GHz.

Table 2 shows the current with the transfer impedances of the cables and the transferred voltages.

Frequency MHz)	Shield current (mA)	Transferred voltage single braid (mV)	Transferred voltage double braid (mV)
25	75		0.6
75	650	650	7.16
125	715	786	7.86
175	226	293	2.48
225	100	141	1.21
275	100	146	1.36
325	74	111	0.965
375	76	121	0.985
425	37	63	0.52
925	31	57	.47

Table 2: The values of Vt for single and double braid cables

The values in *Table 2* are based on well-shielded cables, and assume the transfer impedance of the connector and EMI backshell are very low. When these are not the case then the transferred voltages may be much higher.

If the cable shield is terminated in a pigtail, then the shielding effectiveness may be much lower and the transfer impedance higher as shown in *Reference 1*. A secondary effect that may be overlooked is that a voltage will be developed between the ground plane due to the inductance of the pigtail (long wire) shield ground. This voltage will be capacitively coupled between the shield and center conductor/s of the shielded cable, which, if the conductors are referenced to chassis or have an impedance to chassis, may result in EMI.

Voltage Developed at the Input of a Power Line Filter

Very often the requirement for input power lines is that the lines must be unshielded. Often isolating converters are used, in which case the power line and return are isolated from chassis, and this isolation is also commonly a requirement. The current induced and the voltage developed due to the incident field is thus C/M.

A very good practice is to include low-value capacitors between the power line and chassis and the power return and chassis at the location where the power enters the enclosure. A good value for the capacitors is 1,000 pF.

Assuming 0805 surface mount 1,000 V capacitors connected to a double-sided PCB with a single via connecting the power line side to the chassis side of the PCB, the total combined capacitor parasitic inductance and via inductance is approximately 3.0 nH. Based on the short circuit current, the voltage developed across a 1,000 pF capacitor is shown in *Table 3*.

Most power line filters are designed to reduce conducted emissions and are not effective at reducing radiated emissions above a certain frequency. The main purpose for the 1,000 pF capacitors is to reduce the C/M current on the cable, and, thus, the radiated emissions and this has been shown to be effective.

Frequency (MHz)	Voltage across capacitor (V)
25	0.45
45	2.54
105	0.2
205	0.22
425	0.165

Table 3: Voltage across 1,000 pF with the predicted short circuit current

Conclusion

This article provides the predicted voltages developed into cables with an incident 200 V/m E field. An analysis of the effect on the interface circuits can then be made using a tool such as SPICE. Alternatively, a breadboard of the interfaces can be made and common laboratory equipment used to test the immunity of the circuits.

Reference 1

Electromagnetic Compatibility Methods, Analysis, Circuits, and Measurement. David A. Weston. CRC press. 2017

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

LINKS TO LONGER ARTICLES

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

"Selecting the Proper EMI Filter Circuit For Military and Defense Applications"
https://interferencetechnology.com/selecting-proper-emi-filter-circuit-military-defense-applications/

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

"Overview of the DO-160 standard"
https://interferencetechnology.com/overview-of-the-do-160-standard/

"Design for DO-160 pin injection for indirect lightning"
https://interferencetechnology.com/design-for-do-160-pin-injection-for-indirect-lightning/

"DO-160 cable bundle testing for indirect lightning"
https://interferencetechnology.com/do-160-critical-sections-cable-bundle-for-indirect-lightning/

PUBLICATIONS

ITEM 2020 (Interference Technology Engineer's Master)
ITEM is an exhaustive guide full of invaluable EMC directories, standards, formulas, calculators, lists, and "how-to" articles, compiled in easy-to-find formats.
https://learn.interferencetechnology.com/item-2020/

2019 Military & Aerospace EMC Guide
Curated specifically for engineers working in the EMC field—as well as the manufacturers and suppliers of components, test equipment, and services for those engineers.
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CONFERENCE DIRECTORIES

AFCEA Events:
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ASD Events:
https://www.asdevents.com/aerospace-defence

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

Defense Conferences:
www.defenseconference.com/

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

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

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

LINKEDIN GROUPS

- Aerospace and Defense Subcontractor and Suppliers
- Aerospace and Security and Defence Technology and Business (Defence spelled correctly)
- Defense and Aerospace
- EMP Defense Council
- High Intensity RF (HIRF) Professionals
- Radio, Microwave, Satellite, and Optical Communications
- RF/Microwave Aerospace and Defense Applications
- RF and Microwave Community

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

Tony Keys
EMC Analytical Services

Ken Javor
EMC Compliance

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

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

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

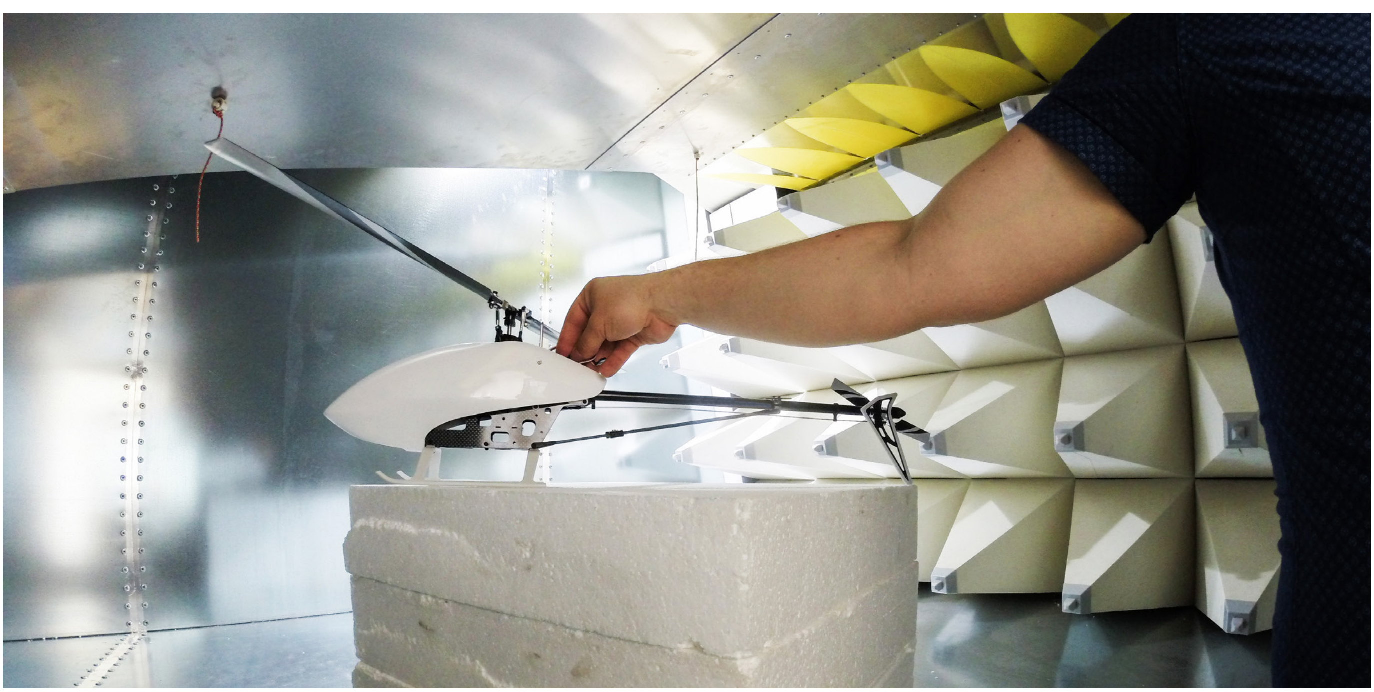

Table of New Equipment Required for Latest Updates to MIL-STD-461G			
Requirement	Equipment Type	Vendor(s)	Websites
General	Time Domain EMI receivers*	Amplifier Research Gauss Instruments Keysight Rohde & Schwarz	http://www.arworld.us/html/dsp-receiver-multistar.asp http://www.gauss-instruments.com/en/products/tdemi http://www.keysight.com/en/pdx-x201870-pn-N9038A/mxe-emi-receiver-3-hz-to-44-ghz?cc=UG&lc=eng https://www.rohde-schwarz.com/us/product/esw-productstartpage_63493-121280.html
CS101	Frequency domain ripple monitoring transducer* High-voltage differential probe, 100 MHz, 1k V(RMS) Digital Oscilloscopes (200 MHz - 4 GHZ, 5/10 GSa/s)	Pearson Electronics Rohde & Schwarz Rohde & Schwarz Rohde & Schwarz	https://www.pearsonelectronics.com/news/225-mil-std-461g-cs101-simplified https://www.rohde-schwarz.com/us/product/rtzd01-productstartpage_63493-34629.html 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
CS114	Current probe calibration fixture	Solar Electronics	http://www.solar-emc.com/RFI-EMI.html (scroll to bottom of page)
CS117	Indirect lightning test systems	Solar Electronics	http://www.solar-emc.com/2654-2.html
CS118	ESD gun	EMC Partner EM Test LISUN Group Noiseken TESEQ	https://www.emc-partner.com/products/immunity/esd/esd-generator http://www.emtest.com/products/productGroups/ESD_generators.php http://www.lisungroup.com/product-id-318.html http://www.noiseken.com/modules/products/index.php?cat_id=1 http://www.teseq.com/product-categories/esd-simulators.php
RS103	1 – 18 GHz electric field probe (most test facilities already have one)	Amplifier Research ETS/Lindgren NARDA	http://www.arworld.us/html/field-analyzers-field-monitoring.asp http://www.ets-lindgren.com/EMCProbes http://www.narda-sts.us/products_highfreq_bband.php

* Specified as acceptable for use, but not required.

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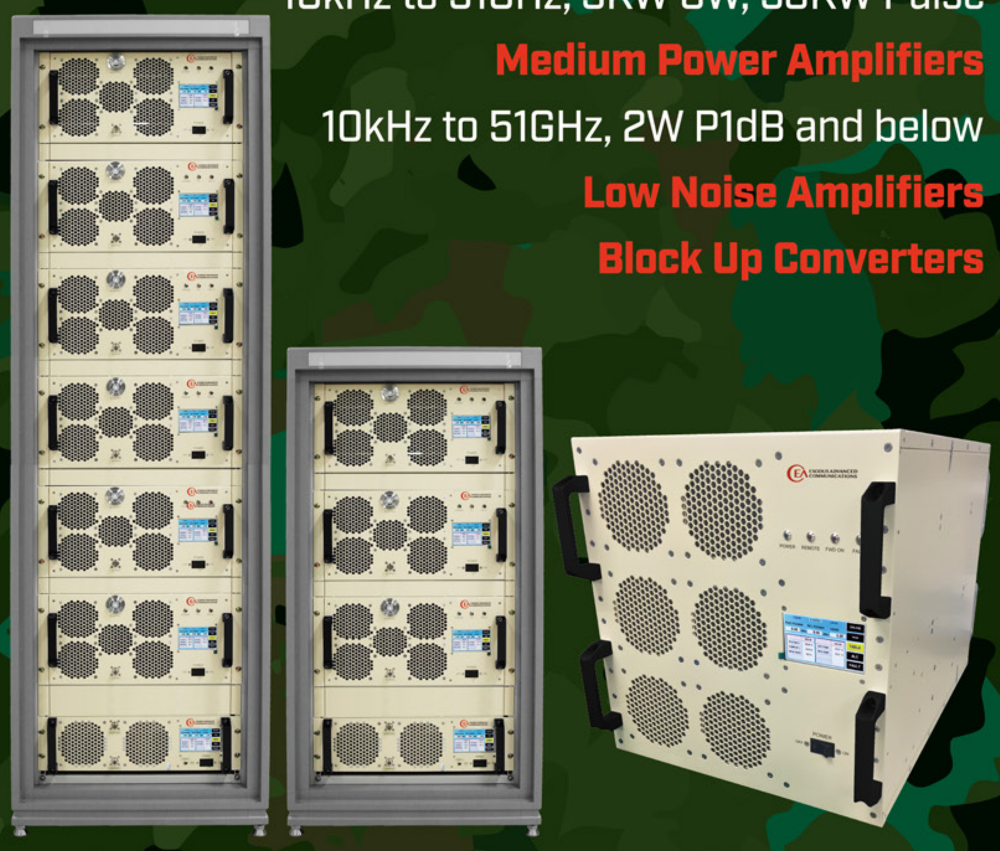

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MILITARY RELATED DOCUMENTS AND STANDARDS

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

Document Number	Title
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.
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S-121-2009	Electromagnetic Compatibility Requirements for Space Equipment and Systems

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Document Number	Title
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-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
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