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2022 MILITARY & AEROSPACE EMC GUIDE

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EMC EQUIPMENT MANUFACTURERS

Introduction

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

EMC Equipment Manufacturers		Type of Product/Service																
Manufacturer	Contact Information - URL	Amplifiers	Antennas	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	Software	Spectrum Analyzers/EMI Receivers	TEM Cells
A.H. Systems	www.ahsystems.com	X	X			X						X						
Aaronia AG	www.aaronia.com	X	X									X					X	
Advanced Test Equipment Corp. (ATEC)	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	
AR RF/Microwave Instrumentation	www.arworld.us	X	X		X			X		X	X	X	X		X	X	X	
Coilcraft	www.coilcraft.com			X														
DLS Electronic Systems, Inc.	www.dlsemc.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
EMC Partner	www.emc-partner.com				X				X									
Empower RF Systems	www.empowerrf.com	X											X					
Exodus Advanced Communications	www.exoduscomm.com	X	X					X										
Gauss Instruments	www.gauss-instruments.com/en/																X	
Haefley-Hippotronics	www.haefely-hipotronics.com				X				X									
Instrument Rental Labs	www.testequip.com	X			X				X	X		X	X	X	X		X	

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Instruments For Industry (IFI)	www.ifi.com	X			X								X					
ITG Electronics	www.itg-electronics.com						X											
Keysight Technologies	www.keysight.com/us/									X	X	X			X	X	X	
Kikusui America, Inc.	www.kikusuiamerica.com/solution/	X																
Microlease	www.microlease.com/us/home	X			X				X	X		X	X	X	X		X	
Milmega	www.milmega.co.uk	X			X								X					
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X		X					X		X	X		X		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										
RECOM Power GmbH	www.recom-power.com							X										
Rigol Technologies	www.rigolna.com	X				X					X	X			X	X	X	
Rohde & Schwarz	www.rohde-schwarz.com/us/	X	X		X	X				X	X	X	X		X	X	X	
Siglent Technologies	www.siglentamerica.com										X	X			X	X	X	
Signal Hound	www.signalhound.com										X	X			X	X	X	
TekBox Technologies	www.tekbox.net	X								X	X	X				X		X
Tektronix	www.tek.com										X	X				X	X	
Teseq	www.teseq.com/en/index.php	X			X	X			X			X	X					X
Test Equity	www.testequity.com/leasing/	X			X				X	X		X	X	X	X		X	
Thermo Keytek	www.thermofisher.com/us/				X				X									
Thurlby Thandar (AIM-TTi)	www.aimtti.us											X			X		X	
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X							X		X	X				X	
TPI	www.rf-consultant.com											X			X			
Transient Specialists	www.transientspecialists.com				X								X					X
TRSRenTelCo	https://www.trsrentelco.com/	X	X		X					X		X	X	X	X		X	
Vectawave Technology	www.vectawave.com	X																
Windfreak Technologies	www.windfreaktech.com											X			X			

WHAT IS MIL-STD-461?

Quell Corporation

For over 20 years, Quell Corporation has been committed to providing top-quality EMI/RFI filters for a wide variety of connectors. Quell's customizable EESeal® filter connector inserts have become a quick, cost-effective way to mitigate EMI in thousands of mil/aero applications around the globe.

WHAT IS MIL-STD-461?

MIL-STD-461 has been the DoD standard for Electromagnetic Compatibility (EMC) qualification testing for many years, and has become the basis for many industrial and commercial applications. The standard has evolved since the initial issue was released more than 50 years ago, with many changes to the specific requirements and tests. Technology advances and issues with compatibility have spurred updates to the standard. The main goal, however, has been to provide a reasonable assurance that equipment's unintentional emission limits are managed, and that the devices are not vulnerable to interference from natural and machine-made electronic signals and noise.

MIL-STD-464 provides the system level requirements. This system document points to MIL-STD-461 as the standard for qualifying individual subsystems and equipment. The system requirements may impose tailored MIL-STD-461 requirements for the subsystem qualification to support a specific application. This indicates that MIL-STD-461 requirements support generic usage for equipment that serve most cases, and tailoring applies to unique cases. Even as a generic type of standard, many variances to support wide-spread applications are included.

The evolvement of MIL-STD-461 includes some significant milestones that the product developers have faced and how changes have affected their approach to designing control measures. Although MIL-STD-461 is a test standard, the requirements drive many design parameters to obtain compatibility.

Documentation has always been a key element of EMC test and evaluation programs. Three specific documents are identified in MIL-STD-461G under the umbrella of Data Item Descriptions (DIDs) as applicable to the EMC qualification.

Configuration Management is a key to standardization, as described in MIL-STD-461 for various applications. However, tailoring may be preferred where the test configuration conforms to the actual installation if the device is used for a specific purpose. Documentation of the test configuration should support being able to re-create the initial test.

The standard includes 19 test and evaluation methods that document the various test parameters, plus general requirements to document many of the test parameters.

These methods are:

- 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

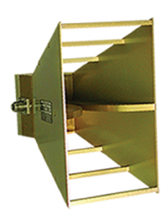
Does your antenna supplier do *all* this?

	Your Supplier	A.H. Systems
Design / build their own?		✓
99% in stock now?		✓
Next day, on-time delivery?		✓
Over a hundred items to choose from?		✓
Portable antenna kits?		✓
Equipment still working after 40 years?		✓
Over 80 years of experience?		✓
Personal technical support?		✓
Personal Customer Service?		✓
Global support network?		✓

A.H. Systems does ***all*** of this, ***all*** of the time because we are the EMI test Antenna Specialists. We do not build "Boxes". We do not build "Systems". We do design and build the highest quality, most accurate EMI test antennas (20 Hz - 40 GHz).

It may be more convenient to buy everything from one supplier, but remember "Your test system is only as good as the antenna you put in front of it!"

Log Periodics
80 MHz - 7 GHz
13 Models



DRG Horns
170 MHz - 40 GHz
6 Models

All in one small package
20 Hz - 40 GHz

Biconicals
20 MHz - 18 GHz
7 Models

The Antenna Specialists

Innovation Quality Performance

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A.H. Systems

MIL-STD-461 AND RTCA-DO-160 PREPARATION FOR TEST

Quell Corporation

For over 20 years, Quell Corporation has been committed to providing top-quality EMI/RFI filters for a wide variety of connectors. Quell's customizable EESeal® filter connector inserts have become a quick, cost-effective way to mitigate EMI in thousands of mil/aero applications around the globe.

READY FOR TEST?

When Alexander Graham Bell said "Before anything else, preparation is the key to success," he was of course not referring to Electromagnetic Compatibility (EMC) testing – but it certainly applies. The cost of EMC testing is significant, but it is far outweighed by the costs in redesigns and product delays caused by inadequate planning.

In the MIL/AERO environment, EMC compliance requirements are established by MIL-STD-461 for military applications and RTCA-DO-160 for commercial aviation. The qualification test process for both standards involve significant preparation to ensure test execution proceeds efficiently. This article poses numerous questions regarding test preparation, then provides their answers along with helpful guidance to keep tests running smoothly.

Although the focus of this article is MIL-STD-461 and RTCA-DO-160, the preparation discussion can be applied to virtually any test program.

The following "checklist" identifies several preparation topics and gives details regarding why that topic needs to be part of your "Ready for Test" review. Many test representatives, witnesses and laboratory personnel can readily add other elements from experiences that show a lack of preparation. Hopefully, this article will help supplement your preparation list.

HAVE YOU SELECTED A TEST LABORATORY?

Selecting the test laboratory should be accomplished early in the preparation for qualification testing. In-house, independent or government laboratories require coordination to effectively conduct the test program. The test facility layout has a large influence on how the test is configured; challenges from physical constraints and test and measurement equipment to locations for the testing should weigh heavily in our preparation.

Prior to requesting test support, a basic test procedure should be assembled which provides the test requirements and a description of the Equipment Under Test (EUT). Without having this basic information, the test laboratories will have a lot of questions to determine their capability to accomplish the required tests.

Information provided when requesting a laboratory pricing proposal should include a minimum of the following:

- The physical properties (size, weight, and information on mounting hardware).
- Power parameters (voltage, current, power frequency).
- A listing of the applicable test methods.
- A listing of the support Equipment that will accompany the EUT (this should include the space and power requirement for this equipment).
- A list of the different modes of operation involved in the testing. This could be just one of various modes which are exercised at the same time or within a sequence. Duty cycle restrictions associated with the EUT need to be identified. If the test article requires a long time to complete an operation or if the duty cycle presents continuous operation, the test laboratory needs to be aware to schedule the test program properly.
- If radio transmitters or receivers are present in the test article, the details about each wireless module is needed.

The approval status for operating the transmitters at the test location should be included.

- Any restricted access or special handling (e.g., ITAR, Government classification, etc.) requirements need to be provided.

Your request for proposal should also include questions to understand the expectations as well as what is provided and what is required. Avoiding assumptions will help the test program progress with minimal delays. At a minimum, it is beneficial to request that the laboratory provide information on:

- The capability to accomplish the required test methods and levels for this type of device.
- Where the testing is going to be accomplished. (This may be apparent, but often tests are accomplished with sub-contracted laboratories that could impact your support or witnessing.)
- Accreditation body; confirm that the specified standard(s) and test methods are included in your accreditation.
- Personnel experience, certifications and credentials associated with accomplishing or overseeing the testing.
- Is a representative from the manufacturer required to be present to operate and monitor the EUT during test?
- In addition to the pricing, the expected duration of the testing.

A reply to your proposal request should be timely – a delayed reply may be indicative of how responsive the laboratory will be in accomplishing the testing and dealing with issues that may arise (such as scheduling adjustments).

IS A TEST PROCEDURE ESTABLISHED?

Test procedures are the key to successful testing, providing detailed instructions for accomplishing the complete test program. Scheduling testing by just stating MIL-STD-461 along with listing the applicable test methods (or RTCA-DO-160 applies) omits the details for selecting the appropriate frequencies, test levels and configuration for the testing. In the absence of this information, the laboratory will be asking a lot of questions to ensure that they have the capability to perform the tests. Often, additional

questions which were not previously addressed (such as what emission limit applies) will surface at the onset of testing. A good test procedure provides the answers. In almost every case, the absence of a test procedure is more costly than the cost of preparing a procedure.

MIL-STD-461 identifies a Data Item Description (DID) DI-EMCS-80201C that provides an outline and describes the content to be provided in the EMI Test Procedure (EMITP). RTCA-DO-160 serves as a procedure document. It supports preparation of a separate document incorporating the required procedures which describes combining the various tests and the product specification. Although the DID provides instructions on preparing the procedure, many details necessary to the test program are not listed.

ARE ALL REQUIRED TEST METHODS CONSIDERED?

This seems like an obvious detail, but if overlooked, recovery can be painful. During development, the requirements can be amended to accommodate additional applications for multi-service, various aircraft or simply to support open sales. If discovered during the test report approval phase, a redo can be expensive and delay the approval process. This is especially difficult if the redo results in identifying non-compliance issues.

HAVE YOU DEFINED THE RESPONSIBILITIES?

Most laboratories have general guidance that requires the customer to provide the Equipment Under Test (EUT) and all support items to establish and monitor operation of the EUT. The laboratory will normally provide the test instrumentation to capture and measure emissions and to generate and apply interference signals. However, a general guide may not be detailed enough to avoid getting the test underway.

Power for the EUT may be assumed, however special power needs should be coordinated with the laboratory. For example, has the availability of DC, 50 Hz or 400 Hz power with the necessary ampacity been confirmed? If special power considerations apply, has the responsibility to make the connections and filter (if necessary) been defined?

Wireless devices are incorporated into many EUTs, and with that, the need to operate the transmitters with support equipment and to protect the measurement equipment from overloads is needed. If the transmitter is not approved, has a Special Temporary Authorization been granted or controls established with the laboratory to prevent unauthorized transmissions and the risk of FCC fines?

The incorporation of wireless devices often brings the need for tunable equipment testing where each tuning band is subject to many of the individual test methods. The test procedure should address this need and identify how many different tests apply. A simple radio operating with VHF-AM, UHF-AM and UHF-FM capability will require testing with EUT operating at three frequencies per tuning band for three or more of the test methods. Make sure that the laboratory is fully aware of this need and that the time for testing has been allotted.

Is the equipment available to prevent measurement system overloads (such as notch filters that attenuate the required transmission frequency without attenuating the unintentional emissions from the EUT)? Even if these filters are part of the measuring system, the laboratory may not have items with the ratings appropriate for your device readily available.

WHAT IS GOING INTO THE TEST?

The test procedure introduction should contain a description of the EUT, however details of the build level may not have been available. When the EUT is prepared for test, an expanded description should be prepared with the details of the actual test item. Each of the sub-assemblies are listed with revision identification to document how the actual test item is constructed. This configuration management tool supports the ongoing compliance need to identify changes during the item life cycle. Take pictures (inside and out) to supplement the description and provide the information for inclusion in the test report.

ARE THE PROPER BONDING AND GROUNDING PROVISIONS IN PLACE?

Both MIL-STD-461G and RTCA-DO-160G provide guidance on the bonding and grounding provisions for the test configuration. Contrary to commonly used practices, the resistance from the EUT surface to the facility ground plane is not less than 2.5 milliohms. Both standards specify that only provisions included in the design or installation instructions be used to connect the EUT to the chassis.

The less than 2.5 milliohm resistance requirement is associated with bonding of the ground plane to the shielded enclosure, the bonding of the Line Impedance Stabilization Networks (LISN) to the ground plane and the junction resistance of individual faying surfaces.

Normally the measurements of the grounding provisions for the EUT are accomplished without cables being attached to obtain the worst-case values. When cables are incorporated, the associated grounded connections and cable shields are placed in parallel with the grounding provisions resulting in a lower resistance.

Incidental ground connections should be avoided when establishing the grounding. For example, a rack mounted equipment may be placed in a rack arrangement for testing with a designated ground wire connection between the equipment chassis and the rack. In addition, the mounting may make a contact between the equipment mounting tabs and the rack. This additional contact lowers the resistance.

If the real installation uses a rack with a non-conductive mounting surface, then the lower resistance is not supported for the “as installed” configuration. If the installation uses a conductive surface rack mount, then the measurement with the contact would be correct.

Additionally, the materials selected for the grounding may influence the resistance. A ground strap making an electrical connection around a shock mount may use a metal that tolerates vibration and corrosive effects but has a higher resistance than the test configuration strap. The standard calls for matching the installation material. RTCA-DO-160 specifies the use of a 30 cm wire of the representative type if the length is not defined in the installation. The representative type is normally the same size wire as the power lead.

When the installation parameters are unknown, using the MIL-STD-464C guidance can help us arrive at a target value for the DC resistance of the bonding:

- 10-milliohms from equipment enclosure to the system structure
- 15-milliohms from cable shields to the equipment enclosure
- 2.5-milliohms across individual faying interfaces within the equipment

This guidance would place a requirement of 25-milliohms between a cable shield and the system structure. This could be significant for rack mounted enclosures if the rack provisions are not carefully considered. The bonding also has an impact on the performance of filter connectors, filter inserts or transient suppressors that rely on connection to the equipment ground point or chassis. The bonding resistance is placed in series with the reactive component of the filter component that decreases the effectiveness of the filter.

For safety purposes, if hazardous voltages are present, MIL-HDBK-2036 reminds us to achieve 100-milliohms or less to avoid shock hazards presented by fault conditions.

As part of your preparation, you will need the proper ground provisions and adequate knowledge of the installation requirements to duplicate the installation in the test configuration.

DO YOU HAVE THE INTERFACE CABLES?

Cables and the arrangement of those cables tend to be the primary cause of test variances even with the details for the test configuration documented thoroughly in the standards. Many years ago, a lot of effort was expended trying to make the cables disappear as part of the test configuration. They served as radiating/re-

ceiving antennae, and their positioning contributed to the parasitic effects such as distributed capacitance and mutual inductance which allowed cable crosstalk. Test configurations would place cables inside shielded boxes which abutted the EUT interface to demonstrate (through test) that the EUT complied with the requirements and passed the responsibility of field EMC issues to the installation team for resolution.

A few years back, the standards addressed these concerns by requiring that the cables which were suitable for the installation be used during test. This included guidance on the cable layout to arrive at a standardized test program. It soon became apparent that EMC control measures related to cable management which resulted in the test configuration driving changes into the installation that were unrealistic. Now the standards require that installation practices be incorporated into the test configuration with limitations driven by the test facility constraints.

Generally, cables are arranged based on guidance provided in the standard with the cable length as used in the installation with length restrictions for long cables. The cable arrangement places the cable 10 cm from the ground plane front (front is the side facing the measurement system antenna) on top of a 5 cm non-conductive spacer above the ground plane. A length of cable (at least 1-meter for RTCA-DO-160 and at least 2-meters for MIL-STD-461) is aligned along the ground plane front (10 cm behind the front edge) with excess cable placed in a zig-zag pattern at the rear of the ground plane.

Do not arrange the excess cable on a spool – this is like fabricating an inductor and it degrades the test configuration. The cable end is terminated into the appropriate load or stimulus equipment that may be located on the ground plane or routed outside the shielded enclosure to the support equipment. At the shielded enclosure boundary, connections penetrating the enclosure will most likely need some isolation to limit the support equipment and the outside environment exposure to the test conditions.

For RTCA-DO-160, the cable length used for test is 3.3-meters unless a specified length is called out for installation. If cable length exceeds 15-meters, then up to 15-meters is the maximum required length for the test configuration. MIl-STD-461 calls for the length as used in the installation with at least 10-meters for long cables.

It should be noted that the standard provides generic guidance on the test configuration that may be applied for a variety of installations. For equipment that has limited applications or are always installed the same way, a test configuration that mimics the actual installation should be considered.

DO YOU HAVE THE PROPER POWER CABLES?

Power cables for the test configuration merit a separate discussion because the test configuration power arrangement is a bit more complex than the outward appearance. RTCA-DO-160 prescribes a 1-meter power cable length to the LISN following the same layout guidance. MIL-STD-461 specifies a maximum 2.5-meter power cable length to the LISN. Based on the wording, it appears that a 1-meter cable would meet both standards, but that theory falls apart when MIL-STD-461 specifies placing 2-meters of the power cable along the front of the ground plane.

Where power leads are part of an overall cable bundle, RTCA-DO-160 calls for separating the power leads from the bundle where the bundle the test area. MIL-STD-461 indicates separation of power leads at the EUT connector and routing them outside the overall bundle. Mil-STD-461 discusses an exception to remove power leads from the bundle if power is derived from a source the includes filtering to the mains. For example, if the EUT receives USB power, the USB source would normally provide a level of filtering between the mains power and the USB interface to the equipment. In cases like this, separation of the power leads from the bundle would not be applicable. A test that calls for testing of power leads would default to bundles testing only.

Where power leads are not specified to be part of a bundle, the leads are separated from the interface bundle and treated as a separate interface for testing even if the power shares the same interface connector.

Additionally, if the power return wire uses a local ground in the installation, then connecting the return to the ground plane without a LISN is specified. If unknown, then a LISN in each lead would be appropriate.

The cable discussion points out the cables are an integral part of the preparation. Be sure that the cables meet the layout needs and that cables are included to make connection inside and outside the enclosure. Make sure that the cable lengths will also reach the enclosure interface panels with connections for isolation as described in the test procedure.

ARE APPLICABLE ELECTRICAL AND MECHANICAL LOADS AVAILABLE?

Providing terminations for the various electrical interfaces is usually included in the support equipment identification and configuration of the test item. Having passive load circuits or loop-back wiring in place of an active piece of equipment is generally preferred for the test configuration. Dummy loads attached to antenna ports instead of including the associated antenna are used throughout the test community.

Often, the requirement to include appropriate mechanical loads as required by the standard is forgotten or inappropriate loads are substituted. It is not correct for a pump designed to move fluids to be operated pumping air during the testing; the load does not conform to the installation effects. It is feasible to incorporate substitute loads that will produce the appropriate loading, however the means to attain the mechanical loads must be considered and included in the preparation.

DO YOU HAVE THE SUPPORT EQUIPMENT AND ISOLATION?

Support equipment are normally the numerous items that make the EUT operate and the monitoring equipment to assess the performance of the EUT during test. We should also include software in the aggregate of support equipment, especially if the software is tailored to provide continuous or multiple modes of operation. The support equipment can produce emissions or demonstrate susceptibility during test that appears to be a EUT non-compliance and it may be difficult to determine that the issue is directly attributed to the support devices.

Emission testing provides methods to accomplish a test configuration ambient evaluation that is required to be below the applicable limit with all support equipment operating and the EUT off. Simulated loads are used to substitute for the EUT during the ambient testing. Normally, the support equipment with active circuits are not designed to meet the stringent emission requirements. Therefore, additional control measures may be required. This also applies to the support equipment immunity where susceptibility testing causes support equipment interference.

An additional concern is the coupling of the environment into and out of the shielded enclosure. Conductors penetrating the enclosure boundary tend to carry ambient signals such as radio, TV and general communications and these signals radiate from the conductor. This causes the test chamber to show high level emissions preventing detection of EUT emissions and high-level ambient conditions. The same conduction path allows susceptibility test signals to be radiated into the environment, violating FCC regulations.

The planning process should have addressed support equipment risks with a detailed plan to provide isolation or control. During the preparation process, the control measures that have been defined need confirmation of availably for use during test.

WHAT ARE THE NECESSARY PRECAUTIONS?

Most of the time we rely on the test laboratory to observe test precautions regarding accessory equipment, excess equipment (clutter), overloads, RF hazards, shock hazards, spectrum restrictions and other concerns that could affect the measurements or violate regulatory rules should be documented in the procedure.

Spectrum restrictions need to be addressed if radio transmitters are present. In the absence of clear approvals to operate the transmitters, the laboratory will need to assume that the transmitter operation is restricted.

Are special precautions applicable to your EUT or the test configuration? The laboratory needs to be made aware of risk areas that may not be obvious. For example, the equipment may use materials with a low flash point (fuels, inks, lubricants, etc.) and methods to mitigate electrostatic charges must be incorporated to prevent ignition risks.

HAS THE PASS/FAIL CRITERIA BEEN ESTABLISHED?

This may appear obvious because the applicable test limits are specified so pass/fail is simply a measurement and comparison to the limit process. Frequently, indicators of susceptibility are not identified or adequately defined. The susceptibility monitoring needs to be objective and measurable, so the acceptability of the results is easily determined. Monitoring for illumination of an alarm light with a requirement that the light remains off seems to be an easy indicator to use.

However, if an alarm condition existed and the indicator circuit was susceptible the inability to detect the alarm condition would be an unacceptable condition. Would the operational software to exercise the equipment need to generate an alarm and the criteria for acceptance changed to require that an alarm be detected at specific intervals?

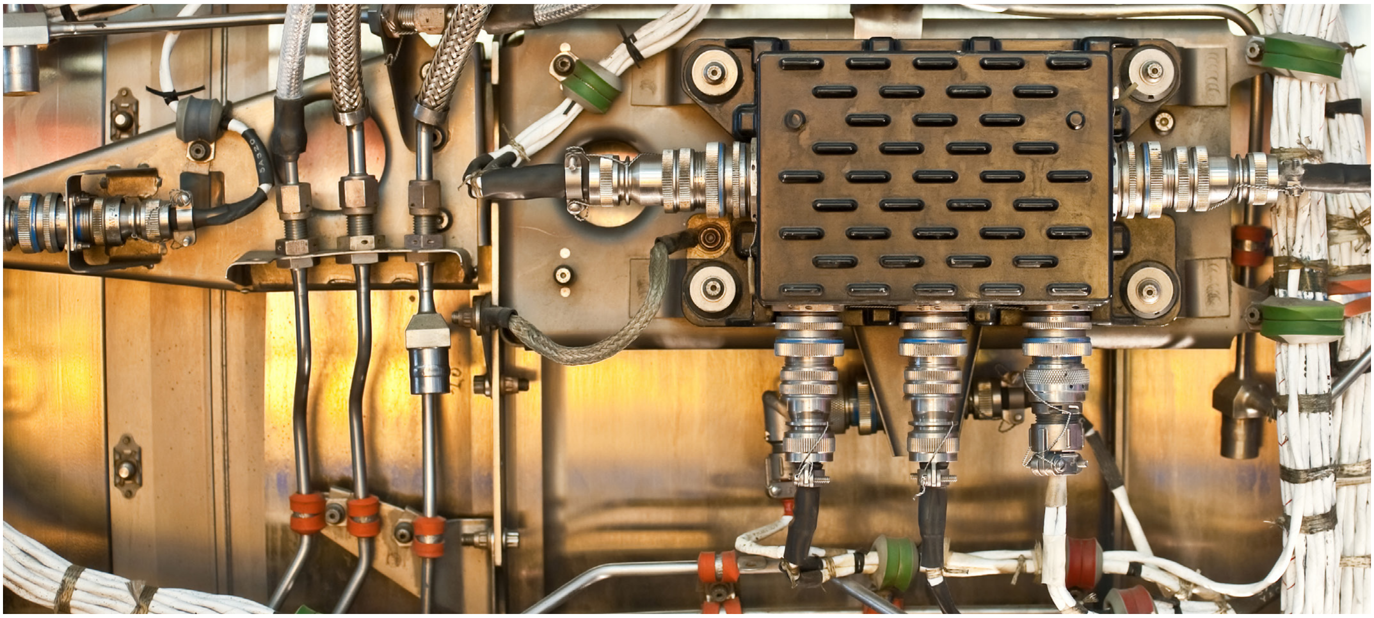
Another subtle example may be that a temperature-controlled fan is activated when a certain temperature is reached. So, normally the fan would be off at room ambient conditions. If the temperature measurement system is susceptible the actual temperature could cause the fan to run continuously or never start. One condition could be acceptable and the other unacceptable, but in either case the EUT is susceptible to failing to operate at the required performance. In this example, we need to make sure that the risks are known, and monitoring is established.

Preparation needs to provide the means to assess compliance and that the necessary hardware and software to support operation and monitoring is present and functioning.

IS THERE AN ESCAPE PLAN?

It's unfortunate but not uncommon that unexpected events occur during testing; they are not always an indication of a test failure.

For example, maybe an over-limit emission is detected, but can no longer be detected during the investigation. A retest is performed, and the emission returns, then disappears once again while observing the signal. While in-



vestigating the EUT operation to determine what circuits operate intermittently, the emission returns, so the EUT is powered off. The signal amplitude decreases but does not disappear.

After a long investigation, it is discovered that an ambient signal is present related to another test in the laboratory which provides a carrier for an EUT emission, so the measurements show the modulated carrier elevates the emission level.

Another scenario: during susceptibility testing the EUT stops operating and repairs find a circuit failure. The failure analysis does not reveal the relationship of the failure to the test being accomplished. What steps are needed to continue the testing? Just repair and repeat? Repair and repeat 3-times? Repeat other tests to see if the failure was attributable to cumulative effects?

Because irregularities and unforeseen issues can always crop up, we need to have a documented approach to proceeding with the evaluation project. Consider potential events, such as:

- What happens if a failure occurs related to the testing?
- What happens if a failure occurs but cannot be duplicated?
- What happens if support equipment induces a failure?
- What happens if the EUT fails because of an operator error?
- What happens of the EUT goes Tango Uniform (toes up)?

The above and other issues may occur, so it's important to have a recovery plan. Identify the person that will make decisions or approve any paths applicable to the project. Not having a plan will normally cause delays with each occurrence.

CREATE A SOLUTIONS KIT

Although you believe that the design team has produced a product that will comply with the requirements, risk elements may be present in the design. These risks are expected to accept trade-offs associated with constraints and the cost escalation from an over-design. Of course, the unexpected issue may be identified during test.

As part of the test preparation, assemble a kit of parts that could be implemented to mitigate an issue or at least help identify the source of the problem. Common passive components (resistors, capacitors, inductors), ferrites, filters, shielding materials, fingerstock, copper tape and the like that are readily available can be a vital asset. Components that can be installed quickly without the delays of having a buyer seek a source, place orders and have drop shipped to the laboratory can avoid major delays in solving problems.

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

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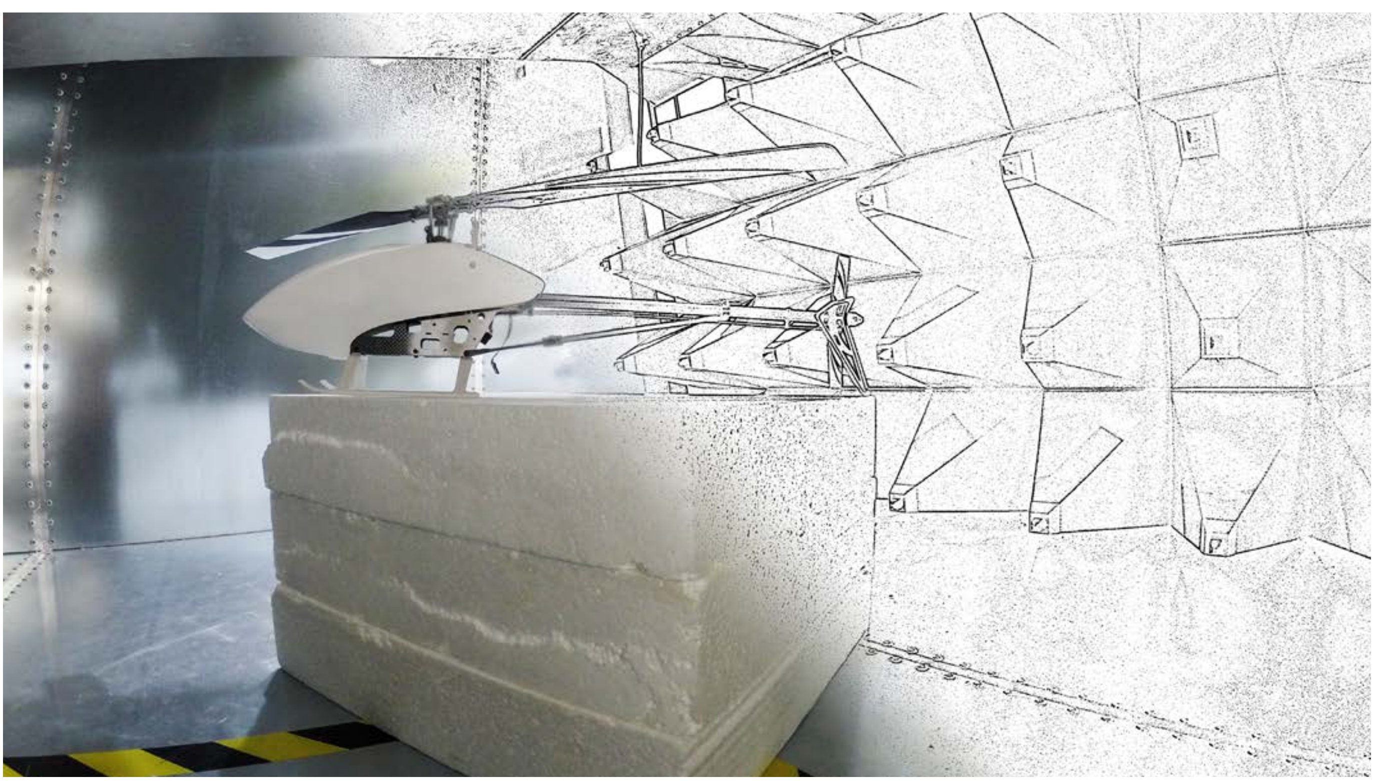
Introduction

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.

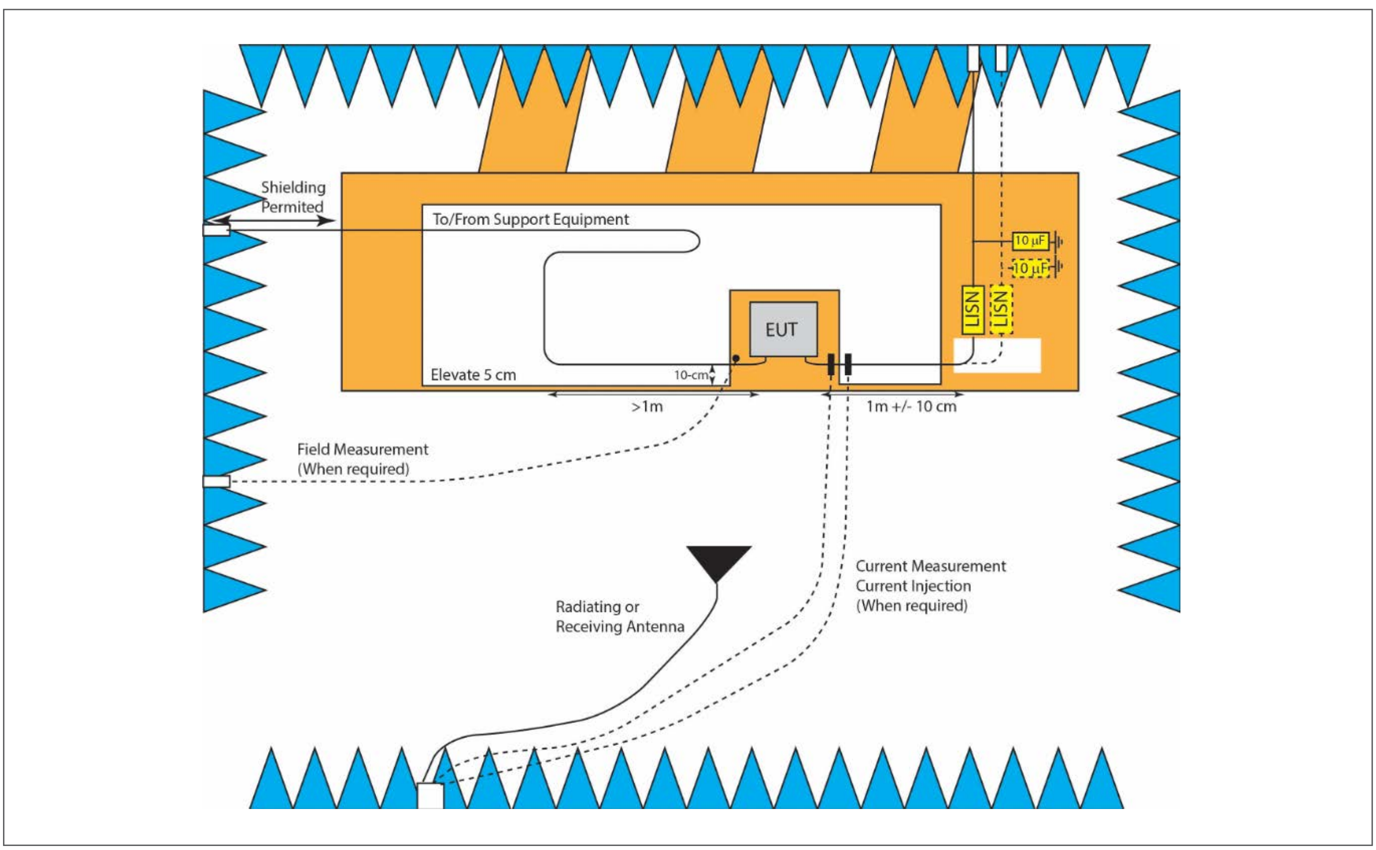


Figure 1: General Test Configuration

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 ($\lambda/2$) 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.

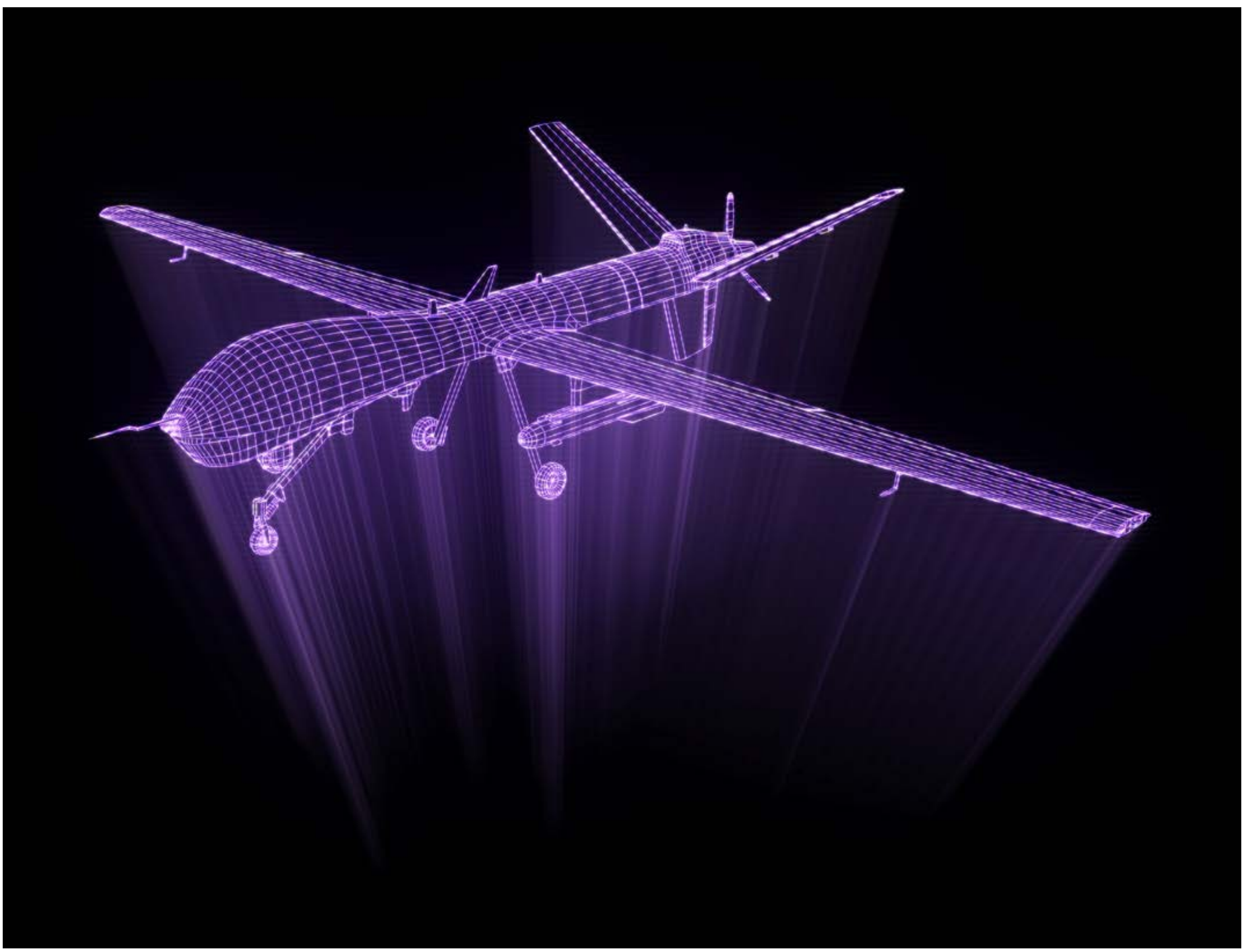
Current Probe Arrangement

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.



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.

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 the following table, 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	

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 emissions 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 usable for commercial testing, others may not. If testing to MIL-STD-461G, ensure that the equipment is proper for the tests being performed. A detailed understanding of the requirements in MIL-STD-461G is required to ensure that the proper equipment is being used and the laboratory is following the appropriate processes.

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www.afcea.org/site/

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https://www.asce.org/education-and-events

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https://aviationweek.com/

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www.defenseconference.com/

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

ICMST Events:
http://www.icmst.org/

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

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

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RF/Microwave Aerospace and Defense Applications

RF and Microwave Community

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

Tony Keys
EMC Analytical Services

Ken Javor
EMC Compliance

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

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

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

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

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

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

Table of New Equipment Required for Latest Updates to MIL-STD-461G			
Requirement	Equipment Type	Vendor(s)	Websites
General	Time Domain EMI Receivers*	Amplifier Research 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/products/test-measurement/emc-field-strength-test-solutions/emc-field-strength-test-solutions_105344.html
CS101	Frequency Domain Ripple Monitoring Transducer* High-voltage Differential Probe, 100 MHz, 1k V(RMS) Digital Oscilloscopes (200 MHz - 4 GHZ, 5/10 GSa/s)	Pearson Electronics Rohde & Schwarz Rohde & Schwarz	http://www.pearsonelectronics.com/news/179 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 (with Option RTO-K17)
CS114	Current Probe Calibration Fixture	ETS/Lindgren Fischer Custom Communications Pearson Electronics Solar Electronics	http://www.ets-lindgren.com/EMC (fixture not listed on web site but should be part of current probe/injection clamp line-up) http://www.fischercc.com/ViewProductGroup.aspx?productgroupid=141 http://www.pearsonelectronics.com/news/180 (fixture holds both injection clamp and current probe) http://www.solar-emc.com/RFI-EMI.html (scroll to bottom of page)
CS117	Indirect Lightning Test Systems	HV Technologies Thermo Scientific Solar Electronics	http://www.hvtechnologies.com/TestsTrack/Lightning/tabid/408/Default http://www.thermoscientific.com/en/product/ecat-lightning-test-system-lts.html http://www.solar-emc.com/2654-2.html
CS118	ESD Gun	EMC Partner EM Test Haefely Kikusui LISUN Group Noiseken Thermo Scientific TESEQ	https://www.emc-partner.com/products/immunity/esd/esd-generator http://www.emtest.com/products/productGroups/ESD_generators.php http://www.haefely-hipotronics.com/product/product-category/electrostatic-discharge-test-systems-esd/ http://www.kikusui.co.jp/en/product/detail.php?IdFamily=0020 http://www.lisungroup.com/product-id-318.html http://www.noiseken.com/modules/products/index.php?cat_id=1 http://www.thermoscientific.com/en/product/minizap-15-esd-simulator.html 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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The following references are not intended to be all inclusive, but rather a representation of available sources of additional information and point of contacts.

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