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TABLE OF CONTENTS

INTRODUCTION

Your product has EMC requirements. They may be included in the design specifications for the product. They may be included in the regulations your product must meet in order to be sold in its intended marketplace. Or, a customer may have included them in his purchase order. Whatever the reason, your product will have EMC requirements placed on it.

Now that you have some requirements, how do you demonstrate that your product meets them? Typically, you test the product. OK, what does this mean? What sorts of tests might this entail?

We'll go into more detail in subsequent articles in this series, but tests can be divided into two broad categories. Emissions and immunity (called susceptibility in the military and aerospace world). Emissions tests are run to determine how much RF energy the product emits. Limits in the commercial world are typically designed to provide a reasonable (not absolute) level of protection to radio and television receivers that may be nearby or a higher level of protection from interference to nearby equipment in the military or aerospace world. Immunity tests are run to determine that the product will operate as intended while subjected to various sources of electromagnetic energy in its intended operating environment. Whether these specified test levels are adequate or not is a subject open to debate, and not one for this series of articles.

EMC standards are always changing. A classic emissions standard for Information Technology Equipment (ITE), a fancy term for computers and their peripheral devices was CISPR 22. CISPR is an acronym for the French words for the International Special Committee on Radio Interference and is a special committee of the International Electrotechnical Commission. CISPR Publication 22 was first published in 1985 and the sixth and final edition was published in September 2008. CISPR 22 was replaced (along with CISPR 13, the emissions standard for broadcast receivers) by CISPR 32 in 2012. CISPR 13 and 22 were withdrawn by the IEC in early March of 2017. CISPR 32 provides emissions requirements for broadcast receivers, ITE and multimedia equipment. While first published in 2012, the 2nd Edition of CISPR 32 followed in 2015 and CISPR Subcommittee I Working Group 2 is beginning work on an amendment to the 2nd Edition of CISPR 32. This purpose of this description isn't to provide details, but to show that standards continually are updated, revised and replaced.

The immunity side of standards are also continually being updated. CISPR 35 was finally published in August 2016 after 15 years of work in CISPR SC I WG4. And WG4 has begun work on creating Amendment 1 to this standard. CISPR 35 replaced CISPR 20 (immunity for broadcast receivers) and CISPR 24 (immunity for ITE) and now provides immunity requirements for broadcast receivers, ITE and multimedia equipment. CISPR 20 and CISPR 24 will be withdrawn by the IEC in 2020.

These are just a sampling of standards that are continually under revision. A significant challenge for a manufacturer is keeping up with the regulations in the countries in which a product is to be sold and knowing what version(s) of a standard may be required for the product in question.

So, what is in store in the future? Standards will continue to evolve and be replaced. Standards will continue to be required of products in various product areas. EMC will not be going away, it will only become more important. And we're only talking about the standards that regulations require a product meet. What about EMC requirements that may need to be developed in-house so that a product can live with itself? Just think about the challenges that a smart phone manufacturer must deal with. A product that may have several different radios in it (cell phone, Bluetooth, WiFi, GPS, FM broadcast, etc.) and digital circuits that must operate with the transmitters functioning and that must not cause unacceptable interference to the on-board receivers. This second area is left to the developers of the products. This is not a regulatory requirement (yet), but if your product can't live with itself it likely isn't going to be very successful.

The following articles provide an introduction to EMC testing. We provide a summary of commercial EMC tests and a summary of military/aerospace tests. There is an article on how to prepare your product and yourself for EMC testing. We provide an article on troubleshooting in the EMC lab (after all, the product that meets all EMC requirements the first time can be rare). We have one of the first articles on EMC Risk Analysis. We also provide a number of useful lists and charts showing equipment manufacturers, standards (commercial, military, automotive, wireless) and a number of other items of interest.

Take some time, look through this guide and see if it answers some of your questions about EMC testing.

A past president of the IEEE EMC Society, Ghery S. Pettit has worked in the areas of TEMPEST and EMC for the past 40 years, working at the Naval Electronic Systems Engineering Center, Vallejo, Martin Marietta Denver Aerospace, Tandem Computers, Intel Corporation and now as an independent consultant. He is presently the Vice Chair of CISPR SC I and will take the Chair's position on November 1, 2016. He has been active in CISPR standardization work since 1998, initially as a member of the USNC IEC / CISPR G TAG and now as a member of the USNC IEC / CISPR I TAG, USNC IEC / SC77B TAG, CISPR SC I WG2 and WG4, in addition to the leadership position noted above. Mr. Pettit is also a member of ASC® C63 SC 1.

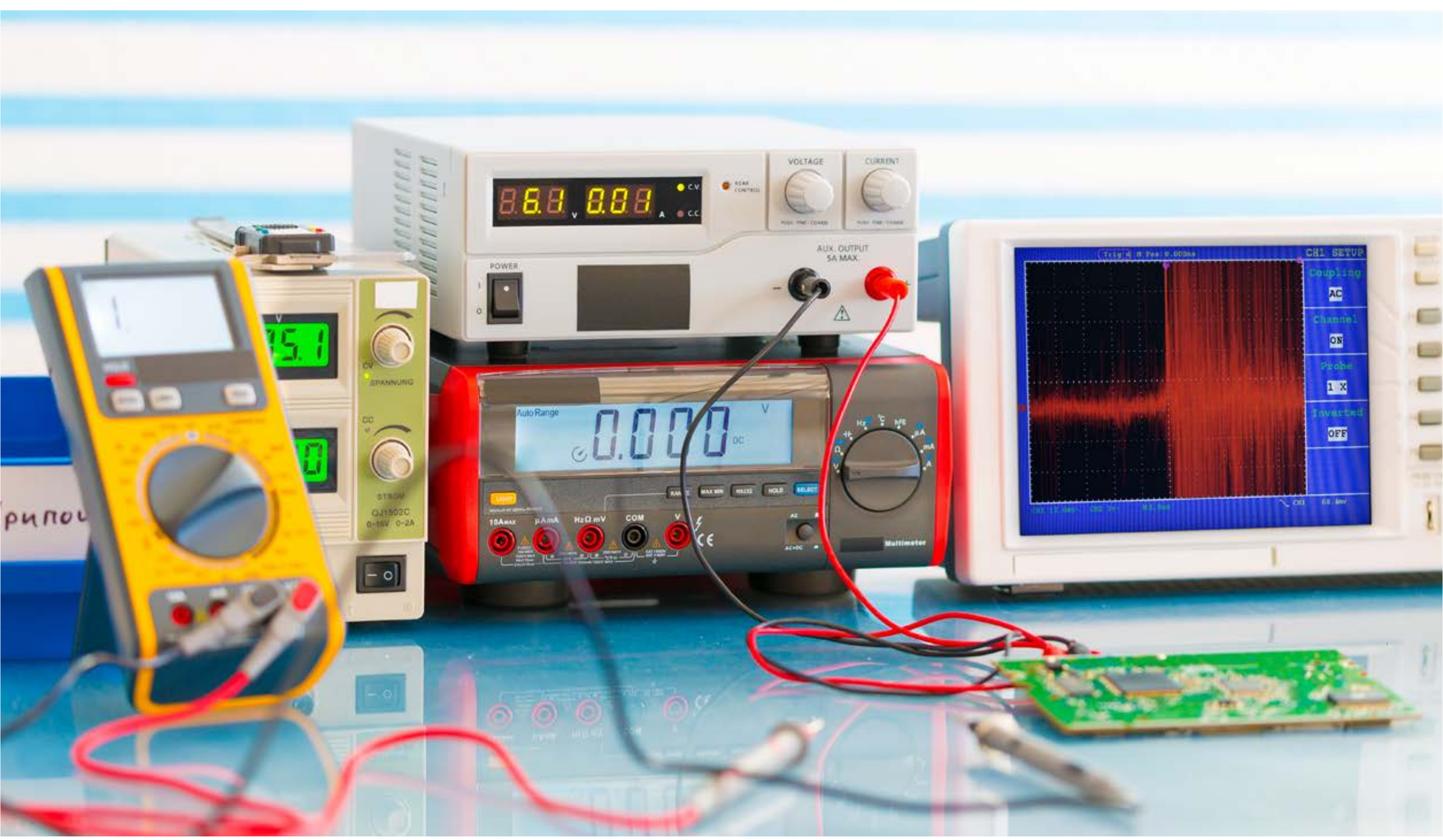
Ghery has written 8 papers and articles for publication and contributed a chapter for the 2nd Edition of the ARRL's Radio Frequency Interference Handbook. He is a member of the dB Society and serves as a Technical Advisor for the ARRL in the area of EMC. He holds an Amateur Extra class ham license (N6TPT) and is an instrument rated private pilot.

Mr. Pettit may be reached at: Ghery@PettitEMCConsulting.com or at (360) 790-9672.

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. 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 ESD and EFT.



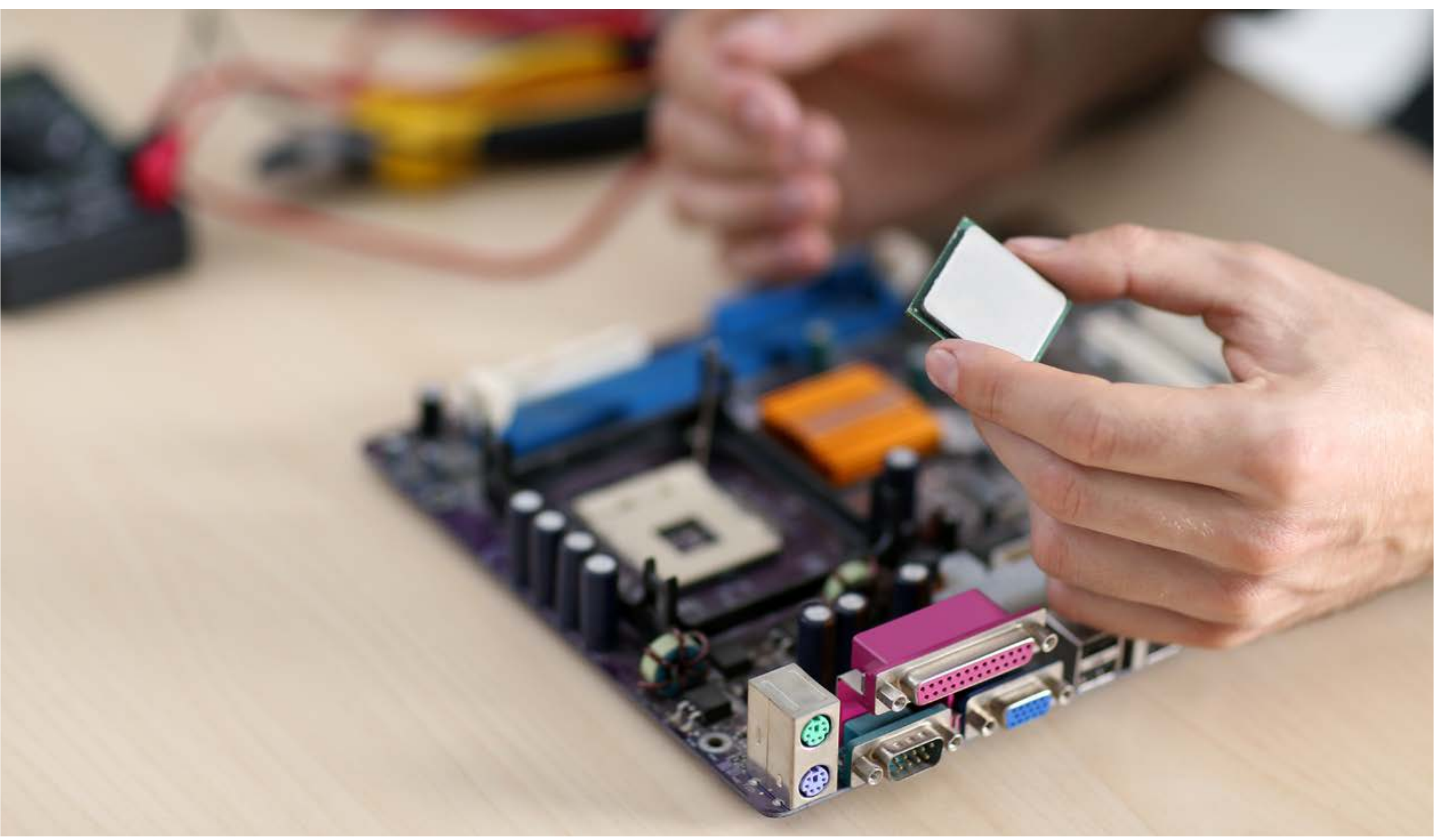
EMC Equipment Manufacturers		Type of Product/Service												
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Near Field Probes	Current Probes	Spectrum Analyzers/EMI Receivers	ESD Simulators	LISNs	Radiated Immunity	Conducted Immunity	Pre-Compliance Test	TEM Cells	Rental Companies	RF Signal Generators
A.H. Systems	http://www.ahsystems.com	X	X		X						X			
Aaronia AG	http://www.aaronia.com	X	X			X					X			
Advanced Test Equipment Rentals	http://www.atecorp.com/category/emc-compliance-esd-rfi-emi.aspx	X	X			X	X	X	X	X	X		X	X
Amplifier Research (AR)	https://www.amplifiers.com	X	X			X		X	X	X	X			X
Anritsu	http://www.anritsu.com					X					X			X
Electro Rent	http://www.electrorent.com		X			X	X	X	X	X	X		X	X
EM Test	http://www.emtest.com/home.php									X	X	X		
EMC Partner	https://www.emc-partner.com						X			X				
Empower RF Systems	http://www.empowerrf.com		X						X					
Emscan	http://www.emscan.com										X			
Gauss Instruments	https://www.gauss-instruments.com/en/					X								
Haefley-Hippotronics	http://www.haefely-hipotronics.com						X			X				
Instrument Rental Labs	http://www.testequip.com		X			X	X	X	X	X	X		X	X
Instruments For Industry (IFI)	http://www.ifi.com		X						X	X				
Kent Electronics	http://www.wa5vjb.com	X												
Keysight Technologies	http://www.keysight.com/main/home.jspx?cc=US&lc=eng			X		X		X			X			X
Microlease	https://www.microlease.com/us/home		X			X	X	X	X	X	X		X	X
Milmega	http://www.milmega.co.uk		X						X	X				
Narda/PMM	http://www.narda-sts.it/narda/default_en.asp	X	X			X		X	X	X	X			
Noiseken	http://www.noiseken.com						X			X	X			
Ophir RF	http://ophirrf.com		X							X				
Pearson Electronics	http://www.pearsonelectronics.com				X									
Rigol Technologies	https://www.rigolna.com			X	X	X					X			X
Rohde & Schwarz	https://www.rohde-schwarz.com/us/home_48230.html	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	http://siglentamerica.com			X		X					X			X
Signal Hound	https://signalhound.com			X		X					X			X
TekBox Technologies	https://www.tekbox.net		X	X				X			X	X		
Tektronix	http://www.tek.com			X		X					X			
Teseq	http://www.teseq.com/en/index.php		X		X		X		X	X	X	X		
Test Equity	https://www.testequity.com/leasing/		X			X	X	X	X	X	X		X	X
Thermo Keytek	https://www.thermofisher.com/us/en/home.html						X			X				
Thurlby Thandar (AIM-TTi)	http://www.aimtti.us					X					X			X
Toyotech (Toyo)	https://toyotechus.com/emc-electromagnetic-compatibility/	X	X			X		X	X		X			
TPI	http://www.rf-consultant.com													X
Transient Specialists	http://www.transientspecialists.com								X	X		X		
TRSRenTelCo	https://www.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X			X		X	X	X	X		X	X
Vectawave Technology	http://vectawave.com		X											
Windfreak Technologies	https://windfreaktech.com													X

SUMMARY OF COMMERCIAL EMC TESTS

Ghery Pettit
Pettit EMC Consulting
Ghery@PettitEMCConsulting.com

Introduction

Commercial EMC tests cover a wide range of products. These include the obvious ones like computers and their peripherals, but also cover household appliances, electric tools and a wide variety of other 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 immunity testing.



SUMMARY OF COMMERCIAL EMC TESTS

Emissions tests (and their associated limits) are put in place for commercial equipment primarily to protect radio and television broadcasting services. Other radio communications services are also protected. While a very few commercial emissions standards existed prior to the introduction of the personal computer to the marketplace, the proliferation of these devices spurred the development of standards and regulations around the world due to the large number of interference complaints directly traceable to these new devices. Early personal computing devices were designed and built with no regard to controlling radio frequency emissions and, as a result, they generated large amounts of RF emissions. Indeed, it could be argued that the early personal computing devices were broadband radio transmitters masquerading as computers. Mainframe computers had similar weaknesses, but as they typically weren't installed in residential areas the impact was smaller.

Emissions testing typically comprises of two parts. Conducted emissions on power and telecommunications ports and radiated emissions. The breakpoint between the two (conducted and radiated) in commercial standards is 30 MHz. This frequency was chosen as at the typical test distances involved (3 meters and 10 meters today) frequencies above 30 MHz tend to provide plane wave (far field) emissions, allowing for fairly repeatable measurements from laboratory to laboratory. Below 30 MHz this may not be the case. Thus, conducted emissions are measured. Limits for powerline conducted emissions were set based on the source and victim devices being connected to the same circuit. Limits for conducted emissions on telecommunication ports are set assuming a certain conversion of the differential mode (desired) signals on the cable being converted to common mode (due to characteristics of the cable) which then radiates.

Conducted Emissions

Conducted emissions on the incoming power lines are measured (typically) using a Line Impedance Stabilization Network (LISN) or Artificial Mains Network (AMN). These are two different names for the same box. The LISN or AMN is placed between the Equipment Under Test (EUT) and the incoming power line (mains) to provide a defined power line impedance and a coupling point to the receiver (*Figure 1*). The LISN or AMN is placed on the horizontal ground plane, or directly beneath it with the EUT connected directly to the EUT port. The block diagram below shows this test setup.

The EUT is placed either on the horizontal ground plane on the floor (with an insulating spacer) or on an 80 cm high non-conducting table, depending on the intended installation of the EUT (table top or ground mounted). The frequency range of interest is scanned with the appropriate detectors and bandwidth and the results are noted. Measurement are made on each conductor of the incoming line separately. Most commercial EMC standards have measurements made over the frequency range of 150 kHz to 30 MHz.

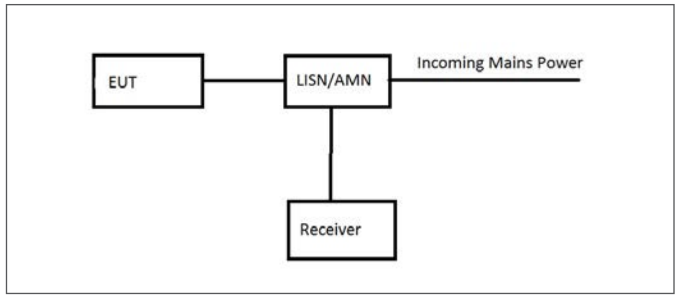


Figure 1 – Generalized test setup for conducted emissions using a line impedance stabilization network (LISN).

Radiated Emissions

Radiated emissions may be measured in either an Open Area Test Site (OATS) or an RF Semi-Anechoic Chamber (SAC). The OATS is the "gold standard" test facility. It consists of a large open area free of objects which might reflect RF energy. It typically is equipped with a reflecting ground plane. The size of the clear area is defined in various standards as an elliptical area whose major axis is twice the measurement distance and whose minor axis is the square root of 3 times the measurement distance. Experience has shown over the decades that these dimensions are too small. Doubling them has been tried and even that has been shown to have its weaknesses, especially when the OATS is surrounded by a chain link fence for security. The picture below shows a 30 meter OATS built in 1989 for Tandem Computers Incorporated near Hollister, California. The clear area is at least twice the required dimensions for a 30 meter site and takes a considerable amount of land. This site is no longer in operation, but it illustrates the point. The building on the ground plane was constructed of RF transparent material and covered the turntable. All utilities were run underground, including the air conditioning ducts with the air conditioning units being installed outside the clear area. The site was never utilized at a measurement distance of 30 meters, so it was a superb 10 meter site.

Figure 2 – A typical open area test site (OATS).

A significant weakness of the OATS facility is that in addition to measuring the emissions from the EUT it is a great facility to measure all the local RF ambient signals from broadcast and communications services, as well. If these signals are strong enough they will totally mask the emissions from the EUT that you were trying to measure. As a result, for best operation an OATS must be located in a very remote area. And this is no guarantee that the ambient level will remain low. Apple Computer had a great OATS near Pescadero, California that had a very low ambient when it was built in the 1980s. Apple ultimately stopped using the facility when the local ambient signals grew to the point where operation was no longer possible and moved totally to 10 meter SACs near their development facilities.

Regardless of whether measurement are taken at an OATS or in a SAC, the block diagram of the test set-up remains the same. Emissions from the EUT are measured using an antenna for the appropriate frequency range, a pre-amplifier (if necessary) and a measuring receiver. Measurements are taken with the antenna in both the vertical and horizontal polarities. See the block diagram in *Figure 3*.

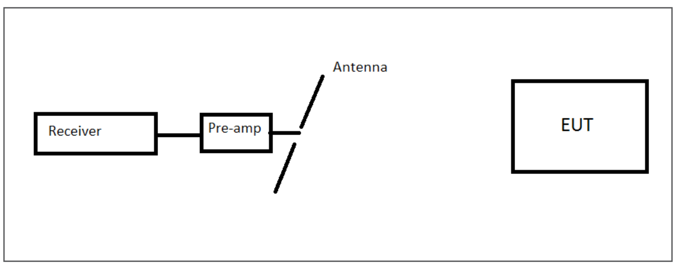


Figure 3 – General test setup for radiated emissions testing.

The need for height scans is shown by the diagram in *Figure 4*. The objective is to adjust the antenna height until the direct and reflected signals are maximized. An example of an antenna mast for this purpose is shown in the photograph above of the Tandem 30 meter OATS (*Figure 2*).

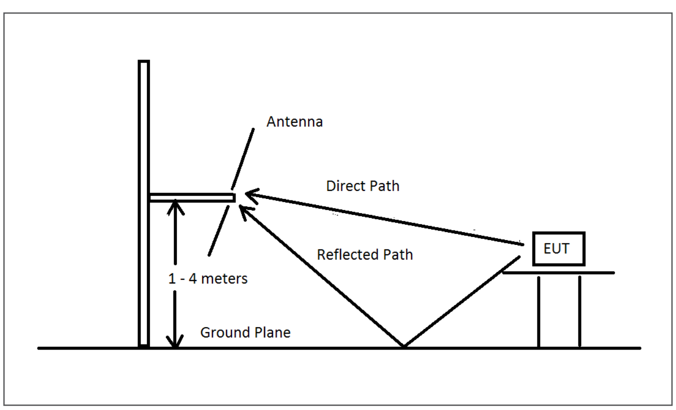


Figure 4 – Diagram showing the direct and reflected waves. The antenna height is adjusted to maximize the measurement.

Emissions tests are required in many countries around the world. Immunity testing of commercial products is required in a smaller number of countries, but these are some major countries, so a manufacturer must be aware of them.

Commercial Immunity Tests

Commercial immunity testing typically covers the following types of tests:

1. Electrostatic Discharge (ESD)

There are two types of ESD tests – contact discharge and air discharge. In the contact discharge test the tip of the ESD simulator is placed on the test point of the EUT and the discharge is initiated. The discharge occurs inside the simulator and these tests are fairly repeatable. In the air discharge test the simulator is charged to the specified voltage and brought into contact with the EUT. The discharge, if it occurs, happens before contact is made jumping the air gap between the tip of the simulator and the EUT. How large this gap is depends of the atmospheric pressure, temperature, angle of approach, and relative humidity. It can also depend on how fast the operator approaches the EUT with the ESD gun Air discharge testing is not as repeatable, but it simulates a different ESD event. Both types of tests are typically required. For computer equipment CISPR 24 requires a contact discharge test at 4 kV and air discharge tests up to 8 kV. Tests are typically performed using the equipment and procedures called out in IEC 61000-4-2. The EUT is allowed to react to the test, but it must self-recover after the test. A classic example is a computer playing music over a speaker. You hear a POP! in the speaker when the ESD event occurs, but the music keeps playing afterwards. This is considered a pass. If the music stopped and required operator intervention to re-start, that would be considered a failure.

2. Radiated electric field immunity

This tests the immunity of the EUT to nearby radio transmitters. The frequency range of 80 MHz to 1 GHz is typically tested, although newer standards have tests required as high as 6 GHz. This test is performed in a fully anechoic chamber or a SAC with removable absorbers placed on the floor. Signal levels are used that would annoy the neighbors and cause the local regulators to issue fines, so a shielded environment is a necessity. The current requirements in IEC 61000-4-3 (a commonly used basic standard) call for the E-field to be uniform to within certain requirements before the EUT is brought into the test volume. Four sides of the EUT are typically evaluated. The EUT typically must continue to operate through the test as though nothing was happening to it or must self-recover with no loss of data to be considered a pass.

3. Electrical Fast Transients

This test introduces a series of rapid pulses into the EUT through the power and any signal lines that could exceed 3 meters in length. Like ESD testing, the EUT must operate after the test without operator intervention, but may react to the test as it occurs, so long as the system self-recovers with no loss of data. IEC 61000-4-4 calls out the test equipment and procedures for this test.

4. Electric Surge
This test simulates what happens on the power input to the EUT when there is a nearby lightning strike. High energy surges are applied to the EUT line input. IEC 61000-4-5 details the test equipment and procedures for performing surge testing.

5. Conducted RF
In commercial standards the breakpoint between conducted RF and radiated RF immunity testing is typically 80 MHz. Generating uniform fields much below 80 MHz is difficult. As a result, below that frequency RF energy is typically injected onto cables connected to the EUT. An example of a block diagram for such a test is shown in *Figure 5*. The 6 dB attenuator is placed as close to the Coupling Decoupling Network (CDN) as possible. While this isn't clearly shown in IEC 61000-4-6, the reason for placing it as close to the CDN as possible is that it provides a matching impedance to the transmission line, maximizing power transfer to the CDN, whose input impedance is not precisely known. Otherwise, you may be throwing away half the power you paid to generate.

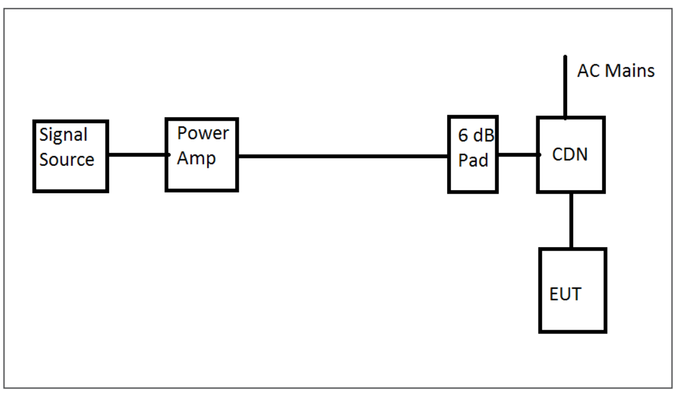


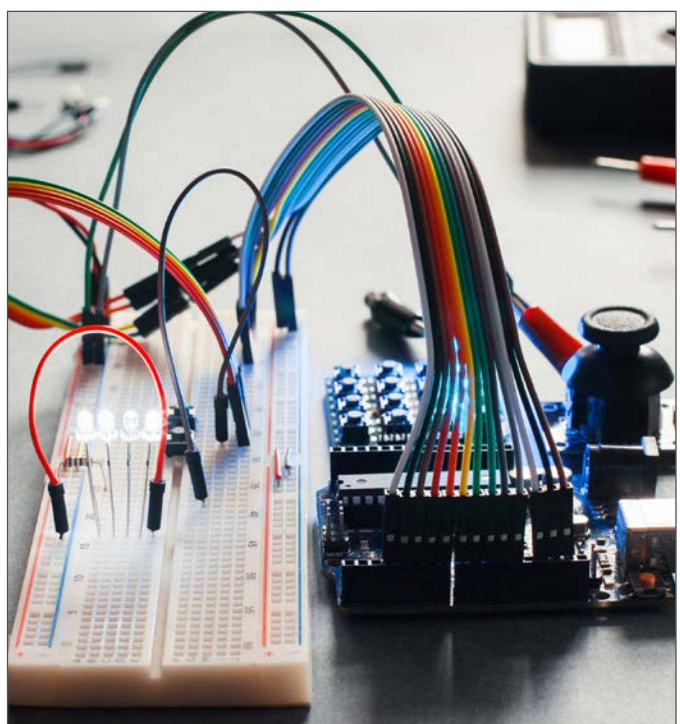
Figure 5 – Typical test setup for the conducted immunity test.

The typical frequency range for conducted RF immunity testing of commercial equipment is 150 kHz to 80 MHz.

6. Power Frequency Magnetic Fields
This test is run for products which might reasonably be expected to have immunity problems with power frequency magnetic fields. Such products, as called out in CISPR 24 for example, might include Cathode Ray Tube (CRT) displays, magnetic field sensors and Hall devices. The EUT is placed in the middle of a large coil of wire through which a power frequency current flows. The current level to generate the specified field level (for example, 1 Amp/meter in CISPR 24) is run through the coil and the EUT is checked for proper operation. All three axes are tested. Most products do not require this test, but it is included in the product family standards. IEC 62000-4-8 details how to perform this test.

7. Dips and dropouts
This test is designed to simulate real world examples of momentary input power voltage fluctuations. In the case of CISPR 24 (and CISPR 35) there are three tests that are performed, typically by a computerized power source. The first is a >95% voltage reduction for one half cycle of the incoming power. The voltage change occurs at the zero crossover point on the power waveform. This simply means that one half cycle of the incoming power to the EUT is chopped off. The EUT is allowed to react, but must self-recover without operator intervention. The second test is a 30% reduction (70% residual voltage) for one half second (25 cycles at 50 Hz or 30 cycles at 60 Hz) - a short brown-out. Again, the EUT may react, but must self-recover. The third commonly used test is a >95% reduction in input voltage for 5 seconds. It's like the power cord was pulled out of the wall socket for 5 seconds and then plugged back in. Obviously, unless the EUT has a built in battery or UPS, it will crash. As long as function can be restored by the operator in accordance with the instructions and no data protected by battery back-up is lost or damaged, the EUT passes this test. IEC 61000-4-11 provides the details on how these tests are to be run.

The test levels utilized in commercial immunity tests are designed to provide a reasonable level of certainty that the product will operate in its intended environment. They do not represent the worst case that a product might experience in the field, but they have been shown over the years to be adequate. Indeed, most products exhibit higher levels of immunity that required when tested to their breaking point and the design features used to meet the emissions requirements typically are adequate for providing this level of immunity.



SUMMARY OF MILITARY AND AEROSPACE EMC TESTS

Ghery Pettit
Pettit EMC Consulting
Ghery@PettitEMCConsulting.com

Introduction

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

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

SUMMARY OF MILITARY AND AEROSPACE EMC TESTS

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

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

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

Table 1: MIL-STD-461G Emission and susceptibility requirements

MIL-STD-461G divides test requirements into 4 basic types. Conducted Emissions (CE), Conducted Susceptibility (CS), Radiated Emissions (RE) and Radiated Susceptibility (RS). There are a number of tests in each category and 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	

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

Table 2: MIL-STD-461G Requirement matrix

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

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

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

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

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

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

Military EMC standards, such as MIL-STD-461G will require the use of different antennas for radiated 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 useable for commercial testing, others may not. If testing to MIL-STD-461G, ensure that the equipment is proper for the tests being performed. A detailed understanding of the requirements in MIL-STD-461G is required to ensure that the proper equipment is being used and the laboratory is following the appropriate processes.

References

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

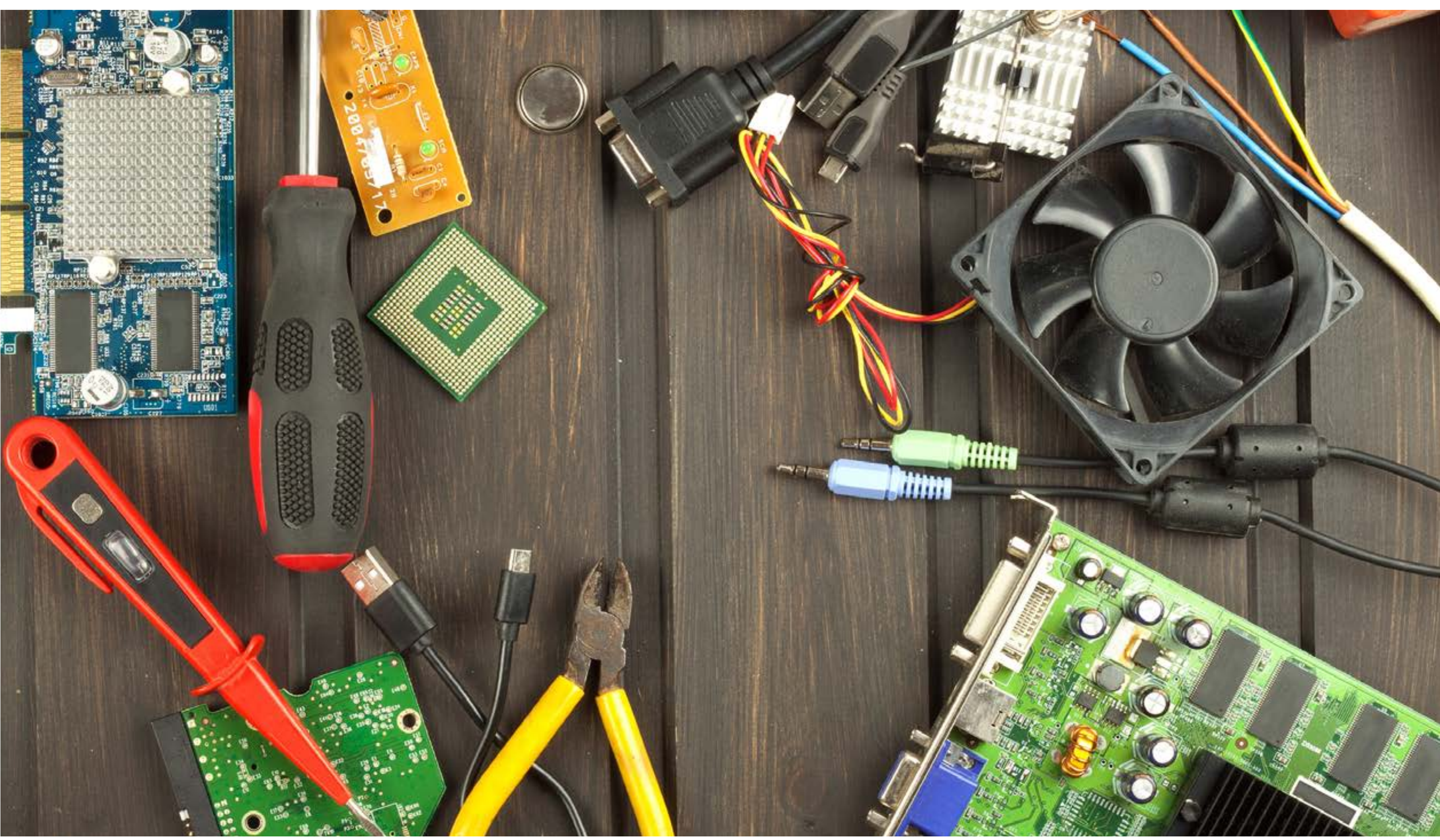
HOW TO PREPARE YOUR PRODUCT AND YOURSELF FOR EMC TESTING

Ghery Pettit
Pettit EMC Consulting
Ghery@PettitEMCConsulting.com

Introduction

Your product has EMC requirements. You have to test it to demonstrate compliance with those requirements. How do you prepare for the test? How do you prepare your product for the test?

These are two different areas that need preparation before you go to the lab. Let's look at them, one at a time.



HOW TO PREPARE YOUR PRODUCT AND YOURSELF FOR EMC TESTING

How do you prepare for the test?
First, you need to understand what you need to gather before going to the lab. A step before that is that you must select a lab to perform the tests. Then, you need to know what information the lab will need prior to the tests in order to allow them to properly test your product and write a test report. Some labs may require a written test plan before performing the tests, and the contents of the test plan will aid them by gathering information needed for the test reports.

How do you select a lab? First, you need to know what will be required of the laboratory in order for its results to be acceptable in the countries in which you wish to sell your product. Not all labs are acceptable everywhere in the world. The requirements for a lab to be accepted in various parts of the world is beyond the scope of this article, but you should ensure that the lab's results and reports will be acceptable. Some parts of the world have no restrictions on what lab you may use, others may require that the lab be accredited for testing in their country. When in doubt, ask to see proof.

Secondly, mere possession of accreditation is not, in and of itself, evidence that the lab truly does quality work. You should become educated on the requirements around the world and perform your own inspections of the candidate laboratories. Some labs will welcome your visit, others might not. You will have to decide what level of comfort is adequate for your company. If you don't have the expertise in-house you might consider hiring a consultant to evaluate the laboratory or laboratories you are considering.

Once you have settled on a laboratory to perform the tests, find out from the lab what information they need you to provide. Later we'll talk about the information that a laboratory must include in the test report, and you will see that much of it comes from you. Know what information is needed and have it available when you go to the lab. Part of you laboratory selection process should include asking about lead time requirements. Are they so busy that they can't fit in the number of days you will need for the tests until 6 months from now? And you need to ship in 1 month? That is important information. Few things upset management more than being told that they can't start shipping product (and receiving money) until a few months after they had planned. Your fault or not, you will be blamed, so make sure you understand your company's schedule requirements and what the laboratory can deliver. Also, talk to the lab and

have a good idea how long the tests will take and then when they can deliver a test report for your review. Talk to your marketing people to see when they plan on announcing this product and start shipping it. You don't want to be the bottleneck that stops the process. Have these discussions early (both with the lab and with your own people) and keep the information up to date. Ensure that you keep your management informed of the status and any delays that you see coming.

How do you prepare the product for the test?
First, design the product with EMC in mind. Provide guidance to the development team early and often on design features that they should include to increase their chances of passing the first time. Review the designs to make sure that obvious mistakes are not included in the product design. Perform preliminary development tests when possible to catch mistakes and failures early, when they can more easily be fixed.

Once the product is designed and debugged, make sure that all necessary hardware and software is available for the test. The hardware that you will need to provide to the laboratory may be more than just the box you are testing. What about peripheral devices? Are they common items that the laboratory might already have in their possession? Or are they special items that only you might have? You might also ensure that all subassemblies are installed correctly and that all chassis and enclosure fasteners are tight. What about the cables connecting the various parts of the system? Are specially designed cables necessary?

A classic example to consider is if your product includes an HDMI interface. If your product depends on properly shielded cables, with the shields properly terminated, cables that simply meet the HDMI cable specification may not be adequate. The HDMI specification does not address the termination of the outer shield of the cable and many HDMI compliant cables do not have this outer shield terminated or terminated properly. They meet the HDMI specification, but are not typically adequate from an EMC perspective. Does your product need the shield terminated? Make sure the cables used for the test (and sold with your product) have the shields terminated correctly.

If any software is required in order for your product to be exercised as required by the EMC standard to which it is being tested make sure you pack that software with the product, or pre-install it and test it to make sure it works. Remember that the clock is running when you arrive at the lab and you don't want to be paying their hourly rate to troubleshoot you product to make it work, or waste time running back to your company to get software you forgot.

Also, it's wise to bring the following items: product documentation, installation manual, user manual, extra tools – especially specialized ones required to remove covers or cables, etc., backup copies of software, a backup laptop, backup hardware in case of product failure (especially important for potentially destructive tests like ESD), extra cables, troubleshooting items like ferrite chokes, copper tape, and aluminum foil.

What information might you need to provide to the lab? The laboratory is going to write a test report (or reports) for you at the completion of the tests (assuming the product passed, writing a full report for a product that fails is a waste of time and your money). ISO/IEC Guide 17025:2005 provides a list of items that must be included in the test report and regulatory agencies add their own requirements. Let's look at the items that ISO/IEC 17025 requires:

Articles 5.10.2 and 5.10.3 of ISO/IEC 17025 list a number of required items to be included. These are;

- 5.10.2a – The report is labeled with a title, such as "Test Report"
- 5.10.2b – The name and address of the laboratory used for the measurement
- 5.10.2c – Unique identifier of the report on each page and a clear identification of the end of the report
- 5.10.2d – Name and address of the client
- 5.10.2e – Test methods clearly identified
- 5.10.2f –
    - Description of the condition of the EUT
    - Clear and unambiguous identification of the EUT on the cover or first page of the report. All applicable model numbers and manufacturer's trade names are to be listed here
- 5.10.2g – Date(s) of the test shall be identified
- 5.10.2h – reference to the sampling plan and procedures used by the lab (not typically needed in an EMC test report)
- 5.10.2i – test results with units of measurement
- 5.10.2j – name(s), function(s) and signature(s) of person(s) authorizing the test report
- 5.10.2k – a statement to the effect that the results relate only to the items tested
- 5.10.2 Note 1 – hard copies of test reports should include the page number and total number of pages
- 5.10.2 Note 2 – a statement that the test report shall not be reproduced except in full, without written approval of the lab.
- 5.10.3.1a – deviations from, additions to, or exclusions from the test methods, and information on specific test conditions, such as environmental conditions
    - Temperature, humidity, barometric pressure
    - Operating voltage and frequency
- 5.10.3.1b – a statement of compliance/non-compliance with requirements and/or specifications
- 5.10.3.1c – a statement on the estimated uncertainty of measurement
- 5.10.3.1d – where appropriate and needed, opinions and interpretations
- 5.10.3.1e – additional information which may be required by specific methods, customers or groups of customers

In the United States, the Federal Communications Commission (FCC) has some additional requirements. These will vary depending on the type of approval process used for the product.

Devices authorized under Verification

- 47 CFR 2.955(a)(3)
- (i) Indicate the actual date all testing was performed (see also 17025 5.10.2g)
- (ii) State the name of the test laboratory, company, or individual performing the verification testing. (see also 17025 5.10.2b)
- (iii) Contain a description of how the device was actually tested, identifying the measurement procedure and test equipment that was used (see also 17025 5.10.2e)
- (iv) Contain a description of the equipment under test (EUT) and support equipment connected to, or installed within, the EUT (see also 17025 5.10.2f)
- (v) Identify the EUT and support equipment by trade name and model number and, if appropriate, by FCC Identifier and serial number
- (vi) Indicate the types and lengths of connecting cables used and how they were arranged or moved during testing
- (vii) Contain at least two drawings or photographs showing the test set-up for the highest line conducted emission and showing the test set-up for the highest radiated emission. These drawings or photographs must show enough detail to confirm other information contained in the test report. Any photographs used must be focused originals without glare or dark spots and must clearly show the test configuration used
- (viii) List all modifications, if any, made to the EUT by the testing company or individual to achieve compliance with the regulations in this chapter
- (ix) Include all of the data required to show compliance with the appropriate regulations in this chapter (see also 17025 5.10.2i)
- (x) Contain, on the test report, the signature of the individual responsible for testing the product along with the name and signature of an official of the responsible party, as designated in §2.909

Devices authorized under Certification

- 47 CFR 2.1033(b)
    - (1) The full name and mailing address of the manufacturer of the device and the applicant for certification (see also 17025 5.10.2d)
    - (2) FCC identifier
    - (3) A copy of the installation and operating instructions to be furnished the user. A draft copy of the instructions may be submitted if the actual document is not available. The actual document shall be furnished to the FCC when it becomes available
    - (4) A brief description of the circuit functions of the device along with a statement describing how the device operates. This statement should contain a

description of the ground system and antenna, if any, used with the device

- (5) A block diagram showing the frequency of all oscillators in the device. The signal path and frequency shall be indicated at each block. The tuning range(s) and intermediate frequency(ies) shall be indicated at each block. A schematic diagram is also required for intentional radiators
- (6) A report of measurements showing compliance with the pertinent FCC technical requirements. This report shall identify the test procedure used (e.g., specify the FCC test procedure, or industry test procedure that was used), the date the measurements were made, the location where the measurements were made, and the device that was tested (model and serial number, if available). The report shall include sample calculations showing how the measurement results were converted for comparison with the technical requirements
- (7) A sufficient number of photographs to clearly show the exterior appearance, the construction, the component placement on the chassis, and the chassis assembly. The exterior views shall show the overall appearance, the antenna used with the device (if any), the controls available to the user, and the required identification label in sufficient detail so that the name and FCC identifier can be read. In lieu of a photograph of the label, a sample label (or facsimile thereof) may be submitted together with a sketch showing where this label will be placed on the equipment. Photographs shall be of size A4 (21 cm x 29.7 cm) or 8 x 10 inches (20.3 cm x 25.4 cm). Smaller photographs may be submitted provided they are sharp and clear, show the necessary detail, and are mounted on A4 (21 cm x 29.7 cm) or 8.5 x 11 inch (21.6 cm x 27.9 cm) paper. A sample label or facsimile together with the sketch showing the placement of this label shall be on the same size paper
- (8) If the equipment for which certification is being sought must be tested with peripheral or accessory devices connected or installed, a brief description of those peripherals or accessories. The peripheral or accessory devices shall be unmodified, commercially available equipment

Devices authorized under Declaration of Conformity

- 47 CFR 2.1075(a)(3)

  - (i) The actual date or dates testing was performed
  - (ii) The name of the test laboratory, company, or individual performing the testing. The Commission may request additional information regarding the test site, the test equipment or the qualifications of the company or individual performing the tests
  - (iii) A description of how the device was actually tested, identifying the measurement procedure and test equipment that was used
  - (iv) A description of the equipment under test (EUT) and support equipment connected to, or installed within, the EUT
  - (v) The identification of the EUT and support equipment by trade name and model number and, if appropriate, by FCC Identifier and serial number
  - (vi) The types and lengths of connecting cables used and how they were arranged or moved during testing
  - (vii) At least two photographs showing the test set-up for the highest line conducted emission and showing the test set-up for the highest radiated emission. These photographs must be focused originals which show enough detail to confirm other information contained in the test report
  - (viii) A description of any modifications made to the EUT by the testing company or individual to achieve compliance with the regulations
  - (ix) All of the data required to show compliance with the appropriate regulations
  - (x) The signature of the individual responsible for testing the product along with the name and signature of an official of the responsible party, as designated in §2.909
  - (xi) A copy of the compliance information, as described in §2.1077, required to be provided with the equipment

In Taiwan, the Bureau of Standards, Metrology and Inspection (BSMI) has a few of their own requirements for report content.

- If testing with different numbers of cables connected to multiple samples of a given I/O port type is performed, data for each number of cables used shall be provided to show that the addition of the final cable did not increase emissions by more than 2 dB.
- A statement that the final test results represent the worst case, along with a listing of the configuration variations that were investigated to determine the worst case.
- Clear photographs of the test setup providing sufficient detail to duplicate the test results. Each test setup must be documented.

  - 6 exterior pictures of a system EUT for class A equipment
  - 6 exterior and 6 interior pictures of a system EUT for class B equipment.
  - Pictures required for the power supply and internal boards. Board photos required of both sides with sufficient detail to identify EMC critical parts.
  - Minimum photo size is 4 by 6 inches

- List of removable EMI suppression components in the product.
- List of key EMI generation components (clock generators and distribution parts)

- Block diagram of the EUT showing the clock distribution
- BSMI cover sheet containing the following information:

    - Product Name. This shall be the same name as provided on shipping and final sales packaging
    - Applicant (Intel for our products)
    - Description of nameplate mains characteristics
    - Logo or Brand
    - Model Number or Type. Detailed model number(s)
    - Test Result. Passed. State class A or class B
    - Original Signature. Electronic signatures are acceptable if the report and all supporting documentation is submitted on a CD-ROM

The following items may be specific to one regulator, but should be provided in the report:

- List of accreditations, approvals, listings, etc held by the laboratory. Include identification numbers if applicable.
- If multiple model numbers are covered by the report, provide a description and evidence of differences reviewed by the laboratory.
- Name and signature of the person taking the data. Needed for each set of data in the report.
- List all test equipment used during the tests.

    - Test equipment type
    - Manufacturer
    - Model number
    - Serial number
    - Calibration date and calibration due date

- Details of applicable regulatory compliance labels showing label details and location on the product.
- List of all components of the EUT system. Include internal components such as power supplies, motherboards, hard disk drives, floppy disk drives, CD-ROM drives and add-in cards.

    - Equipment type
    - Manufacturer
    - Model number
    - Serial number

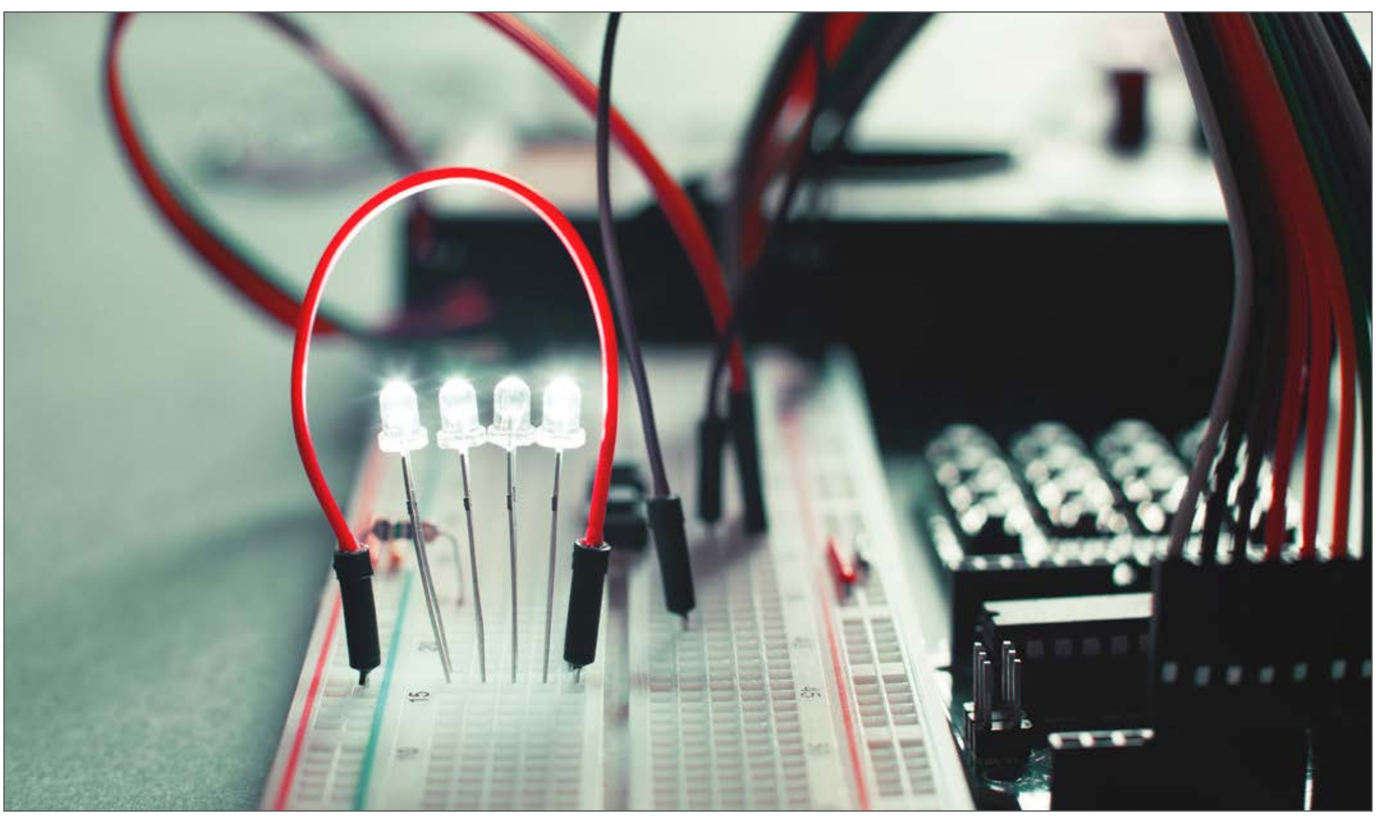
- List of all cables

    - Length
    - Type (shielded, unshielded, coax, etc)
    - Devices interconnected with the cable

- EUT exercise/stimulation software used
- Any required user warning statements.

As you can see, preparation for testing a product to EMC requirements is an intensive process. You will need to go through this list of information and make sure that any of it that must be provided to the laboratory is identified and provided in a format that is useful to the laboratory.

Talk to them in advance and make sure that you have everything they need, in a format that they can use. The time (and money) that you save is your own (or your employers).



WHAT IS AN EMC RISK ANALYSIS?

Steve Hayes, Technical Editor
Aerospace PQT, Element Materials Technology
Steve.Hayes@element.com

Introduction

The European EMC Directive (2014/30/EU) was updated in 2014, replacing the old directive (2008/108/EC) and became mandatory from April 2016 for any new product entering the EU from that date onwards. The change of directive was aimed at aligning the wording and terminology to ensure it was consistent with other CE Marking directives and implement standard text and modules laid out in the New Legislation Framework (NLF).

WHAT IS AN EMC RISK ANALYSIS?

Most digital-based products create a host of on-board The principal objectives of the NLF were to:

1. Provide legislation governing products which should be clear and more consistent across sectors.
2. Clarify the obligations of all economic operators in the supply chain.
3. Make provisions such that products are more traceable.
4. Ensure that bodies which carry out conformity assessments should have certain attributes (e.g. independence and capability) and certain operational obligations.
5. Ensure that each Member State shall have robust, but proportionate, market surveillance and enforcement mechanisms in place based on a set of common requirements at the EU level.

As part of the changes that the implement the above objectives, 'risk' was introduced into all the NLF affected directives, including the EMC Directive.

Risk however has multiple meanings within the directive ranging from risks associated with the product (which is the responsibility of the manufacturer); products that present a risk which is the responsibility of the market enforcement agencies and actions required by actors in the supply chain where risks have been identified.

What does 'Risk' mean in the context of EMC?
The EMC Directive requires that manufacturers '…shall include an adequate analysis and assessment of the risk(s)…' but since the EMC directive is all about functionality and does not have any assessment of safety (including electromagnetic safety, which are covered by other CE Marking directives such as Low Voltage, Machinery Safety, Medical devices directive etc.), what type of risks are being assessed?

In order to answer this, it is firstly important to understand what a risk analysis and risk assessment are.

Risk analysis is the process of identifying all of the potential EM hazards associated with both the product and the environment in which it is going to be used. For each of the risks that have been identified, their impact has to be assessed (risk evaluation). The combination of the risk analysis and evaluation is called the risk assessment.

If, as a result of this process, the residual risk is high, additional action is required to reduce the risk to a more acceptable level. This latter stage and taking into account information from other sources (articles in publications like Interference Technology for example) and feedback from customers, focus groups, etc., forms the risk management as illustrated in *Diagram 1*.

Many of the hazards identified in a risk assessment will be covered by the application of an applicable 'harmonised standard'. However it should be noted that not all hazards and hence risk will be covered in this process.

A harmonised standard provides a 'presumption of conformity' to the directive for areas that the standard covers but cannot be used to simply justify that the product will meet the requirements of the directive by simple application of the harmonised standard without further analysis.

By way of an illustrative example, a battery powered test equipment used for the logging of temperatures in a

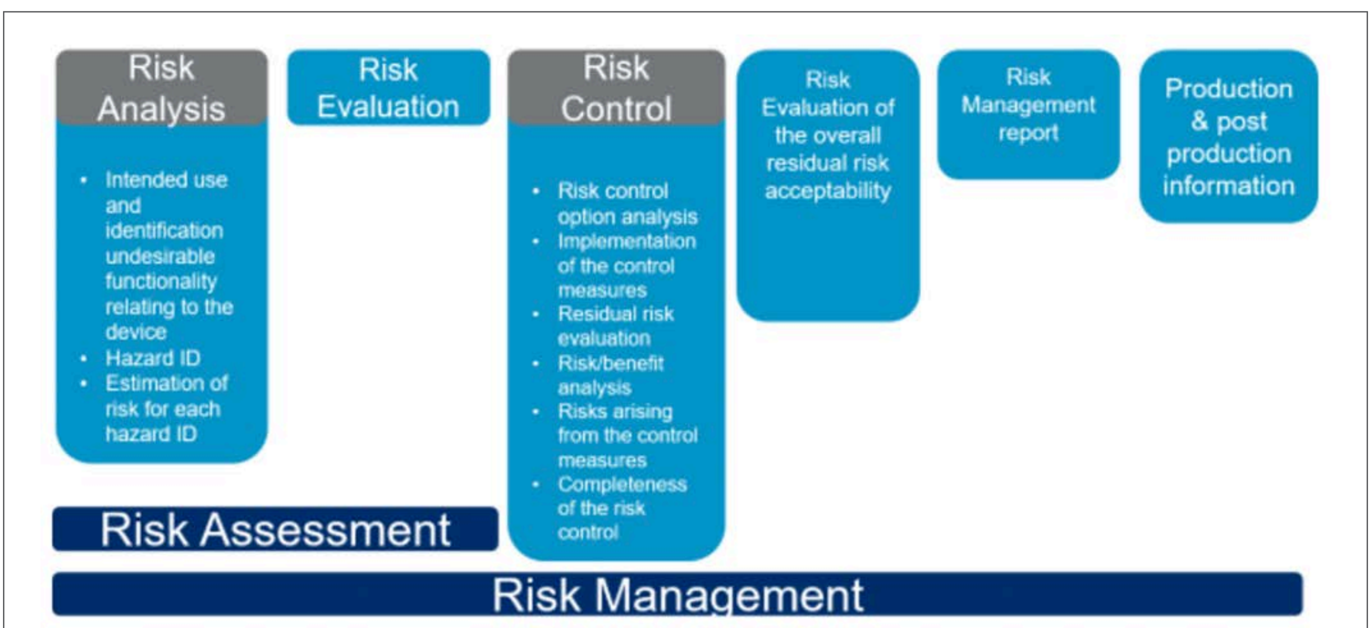


Diagram 1 – Risk Assessment v Risk Management heating furnace in an industrial process may be assessed against the product specific standard, EN/IEC 61326-1 - Electrical equipment for measurement, control and laboratory use — EMC requirements — Part 1: General requirements.

This standard contains tests to assess the functionality of the product in the presence of radiated RF fields from intentional transmitters and ISM devices in the frequency range above 80MHz (EN/IEC 61000-4-3). It also defines test requirements for the assessment of RF transmitters and ISM devices below 80MHz (down to 150kHz) and uses the standard EN/IEC 61000-4-6 for this.

The problem is that EN/IEC 61000-4-6 is performed as a conducted assessment since the wavelengths below 80MHz are very long and conduction predominates over radiation.

Does that mean that a manufacturer can simply ignore the test and all frequencies below 80MHz? In short, no. The risk identification would (should) identify that fact that 27MHz is a well-used ISM frequency for the treatment of material and is used as the fundamental frequency for many RF heating applications. It will be known that there will be a significant EM field generated and yet there is no assessment if only the tests contained in the standard are performed. The manufacturer would identify this hazard and mitigate the risk by performing additional tests to supplement those defined in the harmonised standard, thus ensuring that the residual risk is low.
The above is just one example of where the application of a harmonised standard alone is not suitable for demonstrating compliance with the EMC Directive – there will be many more, based on the type and use of the product.

Here is another example, a tablet PC can be used in an environment other than the classic ‘domestic, commercial and light industrial’. Given that a manufacturer needs to think about both the use and also foreseen misuse (part of the risk analysis), it is certainly expected that this type of product will be used on a train, a vehicle or much closer proximity to a cellular device than the product specific standard (CISPR 35/EN55035) anticipates. The close proximity of higher power transmitters to products results in the product being exposed to higher levels of EM radiation than the standard covers. All these situations are foreseen and should be covered in the risk assessment.

Most conducted emissions standards start from 150kHz however there is an increasing amount of electrical noise generated below this frequency. Electric vehicle chargers, inverters for PV installations and the like all use switching technologies in the low kHz region and produce potentially significant EM emissions. Very few EMC standards require testing below 150kHz due to the unknown compatibility levels (this is an standards body related issue) but there is significant noise being generated and a lack of immunity tests in the standards to mitigate the risks.

It is important for EM hazards to be considered as part of the overall risk assessment of the product. The safety related community is very familiar with safety related risk assessments and is normally based around a wide selection of people with differing focus. EM knowledge unfortunately is not normally well represented meaning that EMC safety risks are often overlooked.

Before any EMC testing is performed, it should be considered in parallel with the EM safety aspects. EMC testing for functionality would require the product to be operating in its normal mode(s) whereas EM Safety testing would require a different set of parameters to be assessed (such as a product with an electronic power switch, switching ‘on’ when is should be ‘off’) which would require the standby mode to be assessed as well.

Conclusions
Manufacturers need to ensure that an EM risk analysis and assessment is performed as part of complying with the EMC Directive. The risk assessment needs to be documented and include the justification that leads to the overall residual risk.

Only the tests contained in harmonised standards provide a presumption of conformity for the parameters that they cover and a manufacturer should supplement these with their overall risk management to ensure that other hazards are identified and assessed accordingly.

Risk assessments are not something that can be subcontracted out from a manufacturer since the overall risk always has to lie with them. Understanding EM hazards and how to mitigate these risks however is something that can be outsourced and irrespective of who does it, should be considered as part of the overall risk assessment during the product realisation phase of bringing a product to market.

TROUBLESHOOTING RADIATED EMISSIONS AT THE EMC TEST LAB

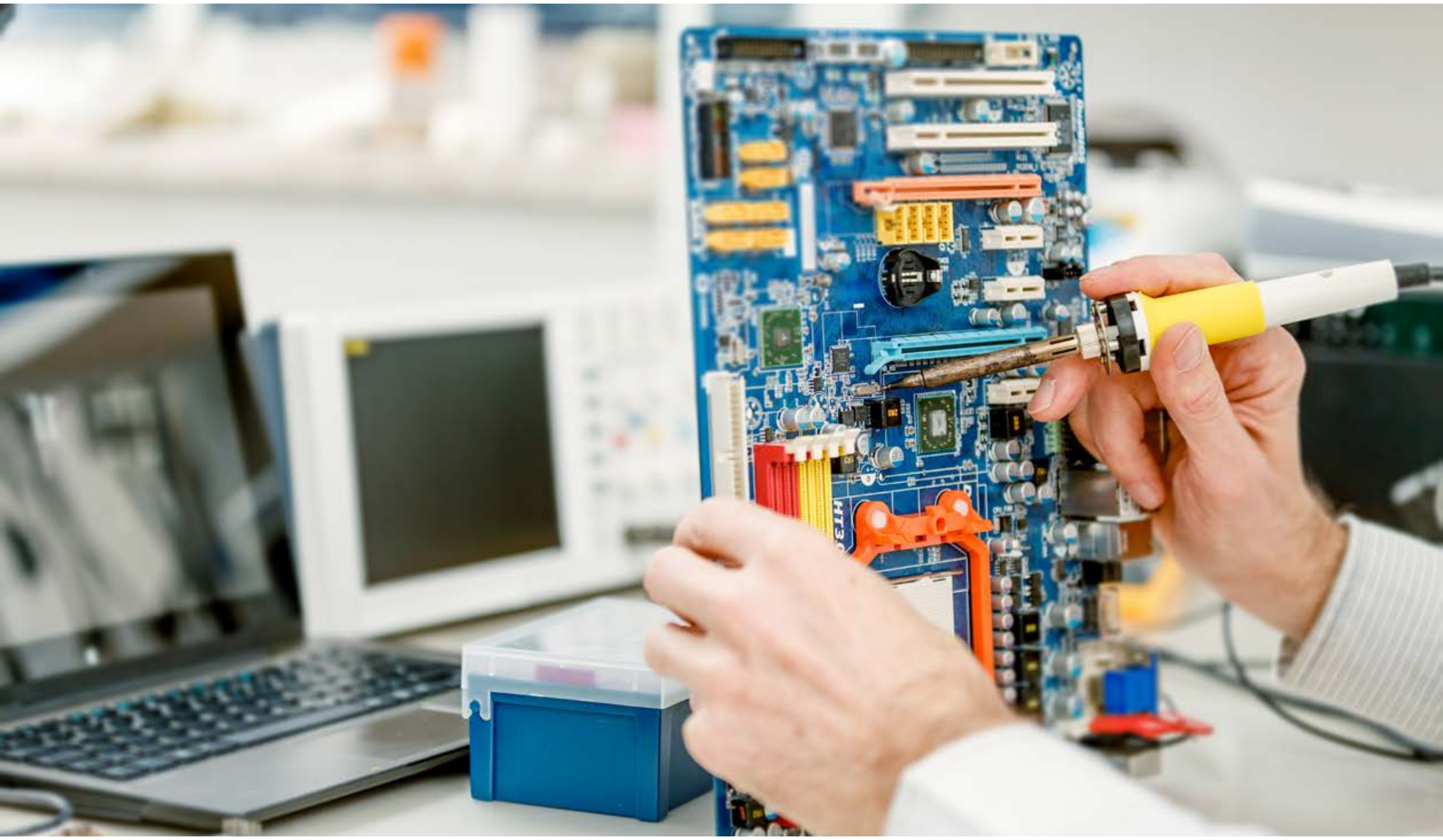
Kenneth Wyatt
Wyatt Technical Services LLC
ken@emc-seminars.com

Note: *This is an excerpt from the book, EMI Troubleshooting Cookbook for Product Designers, by Patrick André and Kenneth Wyatt. See Reference 1.*

Introduction

Radiated emissions are by far your highest risk when performing compliance testing at the test facility. With all the high-speed digital circuitry inside electronic products today, it becomes all too easy for harmonics of the clock frequencies and other fast-edged devices to be the source of radiating EM fields. Typically, failure modes will be cable radiation or leakage from enclosure seams or apertures.

Here is a handy checklist you can use, either as a pre-test check prior to compliance testing, or as a check following a test failure. Because the "clock is ticking" at the test lab, the checklists and recommendations are brief and to the point, so you avoid wasting too much time.



TROUBLESHOOTING RADIATED EMISSIONS AT THE EMC TEST LAB

Radiated Emissions Check List

- Frequencies below 200 MHz, likely the cables are the source of radiation. The wires are better antennas at lower frequencies, where the wavelengths are longer.
- Frequencies above 200 MHz may come from the chassis. The higher the frequency, the more likely it is the chassis of the unit, or a circuit board when there is no chassis or an open frame unit.
- Assure that all shielded cables have a low impedance bond at both ends. Assure the shields are terminated with direct contact to the chassis or connector. Avoid using a pigtail unless absolutely necessary.
- If using a pigtail to bond a shielded cable, assure it is as short as possible.
- Assure chassis metal pieces are making excellent contact with each other (10 milliohms or less) – no paint or other coatings, grease or dirt, corrosion or oxidation, which could create an impedance.
- Verify that each line leaving the equipment is filtered, and that the filter is located next to the point of penetration out of the equipment.
- If performing commercial testing (FCC, CE, etc.) and vertically polarized emissions exist below 80 MHz, try lifting the power cord away from contacting the ground plane. This will reduce the coupling path from product to antenna via the ground plane. Conversely, try increasing contact with the ground plane and see if emissions increase.
- If there is support equipment connected to the unit, assure it is not the source of the noise. Turn off the support equipment if you can. If not, turn off your equipment and leave the support equipment on. If the signals remain, your source may not be the equipment under test, but the support equipment.

Typical Failure Modes

Most products fail the radiated emissions test due to radiating cables or leaky chassis enclosures. Here are some things to check quickly.

Cable Radiation – I/O or power cables generally radiate high-frequency harmonics due to poor bonding of the shield to chassis or enclosure, lack of adequate filtering or are simply “poked through” the shielded enclosure. Generally, if you have failures below 200 MHz, that indicates cable radiation. The reason lower frequency emissions tend to come from the cables is the need for physical length to make a good antenna (the bigger, the more efficiently they can transmit emissions). The cables tend to be the longest part of the equipment, and thus the source of most low frequency emissions.

Metal Chassis - Higher frequency (typically greater than 200 MHz) emissions are more common from the metal chassis of the equipment. At these higher frequencies, the I/O cables tend to become inductive and therefore are higher impedance than the chassis is for flowing RF currents, and so, tend to radiate. One exception to this is when the equipment being tested is physically large. A seven-foot high metal cabinet, which is resting on the ground plane, may have a quarter wave resonance around 30-40 MHz.

Seams - One common source is the seams of the chassis enclosure. Circuit boards inside the unit can generate currents on the inside surface of the chassis. These HF currents leak out of seams or gaps, and then will flow around the outside of the chassis or enclosure of the equipment. Thus, the entire enclosure becomes a transmitting antenna. An exception is when most of the current can be returned to the source very close to the point where it is coupled onto the chassis. This is why it is good to use bypass capacitance on a circuit board, or circuit board reference return planes which are well bonded with the chassis.

However, when HF currents flow inside the enclosure of the equipment, and they come to a seam, they must be able to flow across that joint very easily. Impedances of a few milliohms will create a voltage across the seam (a strong E-field) that can radiate. Note that a horizontal seam will have a voltage gradient or vector from top to bottom, creating a vertically polarized E-field and a vertical seam will produce a dominant horizontal polarized E-field. A good troubleshooting technique is to note the polarity of the E-field (assuming an E-field antenna is used) and determine if this could be generated by a poorly bonded seam.

If the product includes an LCD display, leakage can occur around the edges of the display. In many cases, LCD displays are not well bonded to the enclosure and the entire display can act as a transmitting antenna. Other areas of leakage can include the spaces between plug-in daughter cards (as is used in the typical PC chassis) or ventilation ports.

Troubleshooting Emissions at the Test Lab

Often you will need to troubleshoot the emissions at the test laboratory. There are several things you must be aware of and be able to do.

- You must be able to see the display of the spectrum analyzer. This may be a projected image inside the chamber, or an analyzer, which is brought into the chamber. If the only option is a monitor which is placed at the door of the shield room, and the door must be left open to see it, be sure the emission you are observing is not an ambient signal from FM broadcast, cell phones or digital TV. You may need to turn your equipment off to assure this is true.
- When you observe the emissions, realize you are loading the room just by being in the chamber. The

emissions will not be the same level as before. Also, the azimuth of the unit under test may not be at a maximized position (for commercial testing). However, this may change by slight movements of the cables and unit, so be aware of this fact when you feel an improvement has been made – it might have only shifted in angle or position.

- Do not stand between the antenna and the equipment. The human body makes a wonderful radio frequency absorber.

When approaching a radiated emissions problem, and once the setup is as shown, make sure you are in control of the area. Tell people where to stand and make sure they don't move. Their movement and position will affect your investigation.

Start by grabbing cables with your hands (if it is safe to do so). If the cables are the main radiators, you may be able to identify a cable quickly by grabbing and releasing the cable. While you do this, minimize your movement, since your movement will also tune and detune the room and area. You may need to take a wood or plastic stick to lift cables without coming in contact with them and to minimize your influence on the cables. A hockey stick may be used for this purpose, which allows you to stand some distance from the unit, minimizing your effect on the radiated field. Thus, any changes you see will be from the cable movement.

Many times, I/O cables may be connected to the product under test, but are disconnected at the far end. Try disconnecting these cables one at a time, leaving them off until all cables not used during the testing have been disconnected. This may also help identify which cable, or cables, are radiating.

If the cables do not seem to be the problem, try placing your hands on the case or chassis of the equipment, again only if it is safe to do so. Press and squeeze the box if possible to assure metal pieces are touching, or to open their contacts. In this case, you may see the emissions make a sudden jump up or down, indicating a make or break of contact somewhere. While you are there, look for coatings or overspray that might be between metal interfaces.

Assure the support equipment is not at fault. Turn it off, if you can, without turning off significant portions of your equipment under test. If that can't be done, attempt to reverse that, and turn off the equipment under test, while leaving the support equipment on. Does the problem remain? If so, the support equipment may be the issue. This is also true if the support equipment is outside the chamber. The cables passing from outside to inside can contain a significant amount of RF energy, which can rebroadcast inside the chamber. Assure these cables are well filtered, shielded, or somehow treated to avoid this issue. Sometimes, loading these long support cables with a series of several ferrite chokes can effectively "remove" them from affecting the actual system or product under test. If you cannot power down either the equipment under test or the support equipment, try changing loads, states of operation, data rates, or other functions and watch for changes on the emissions.

It may be helpful to have a non-conductive plastic or wooden crochet hook. Use it to pull individual wires out of a cable bundle. If safe to do so, you can touch these wires with your fingers to determine if they are sensitive, changing the emission levels as you pinch and let go of the wire.

One of the best ways to identify radiating cables is to measure the common-mode currents traveling on the wires or cable shield. By clamping a current probe with spectrum analyzer around them close to the unit you can measure the RF current in the wires, which is strongly correlated to radiated emissions. In fact, for electrically short cables (less than a quarter wavelength), it's possible to predict the e-field in V/m, which may be compared with the regulatory limits. This will be described shortly.

Consider purchasing a pair of long aluminum knitting needles. Wrap one of them most of the length with insulation tape (e.g. black electrical tape). You can use this to probe the connectors, connector pins, circuit boards, cases and chassis parts, by touching them with the conductive end of the knitting needle (be cautious about shorting connector pins, etc.). Watch for increases or decreases in emissions while you do so. Both of these can identify a sensitive area, which should be investigated more carefully. Instead of knitting needles, you can use a disconnected multimeter probe, or a connector pin with a wire soldered onto it. In fact, these may be easier to use, since the wire can be oriented in the same direction as the antenna polarity while connected to the sensitive area.

Emergency remedies for small to medium sized equipment include wrapping the whole unit in aluminum foil. Since large areas need to be covered, it is best to not use copper or aluminum tape. Also, aluminum foil does not suffer from the build up of impedances the way conductive tape does. That is to say, when using metallic tapes with conductive adhesives, remember that the adhesive is not very conductive, as much as we would like it to be. As you layer tape on tape, the resulting build-up of impedances can greatly reduce the effectiveness of the shield. Using aluminum foil without any coatings will improve this bond by orders of magnitude.

To use, aluminum foil in this manner, fold the seams of the foil over several times, as in the seam of your pants. Bond the foil to any connectors and cable shield possible. To assure bonds, use wire ties or "zip ties" around the connectors. If this continues to radiate, try placing the foiled unit on the conductive ground plane (yes, the floor, if that is serving as the ground plane). If it continues to radiate, then likely the cables are still an issue.

If this cures the problem, then the chassis is likely at fault. Slowly peel back the aluminum foil over areas you feel are less likely to be an issue, such as over solid panels without displays or connectors. Reveal connectors and displays last. Each time you peel back some foil, check to see if the emissions are returning or if they remain low. Often this is best performed while watching a monitor of the emissions while you perform the work.

Summary

Testing your product for EMC compliance at third-party test labs can be a harrowing experience. Radiated emissions is usually the riskiest test and I hope these suggestions might be of benefit in your future testing. For additional suggestions for the remaining EMC compliance tests, I'd refer you to Reference 1. Finally, for best success, I'd also refer you to the article in this guide, How to Prepare Your Product and Yourself for EMC Testing.

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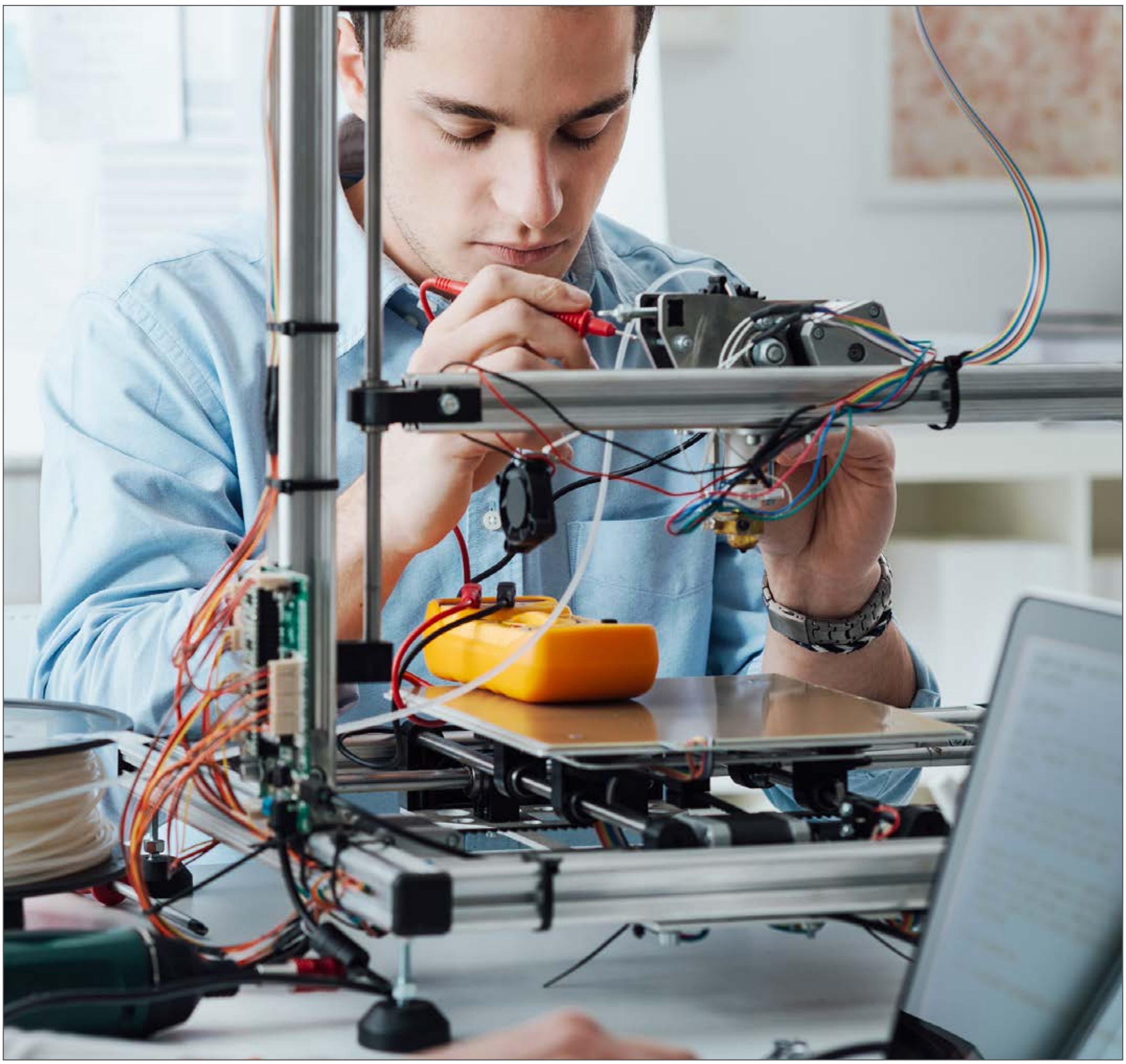
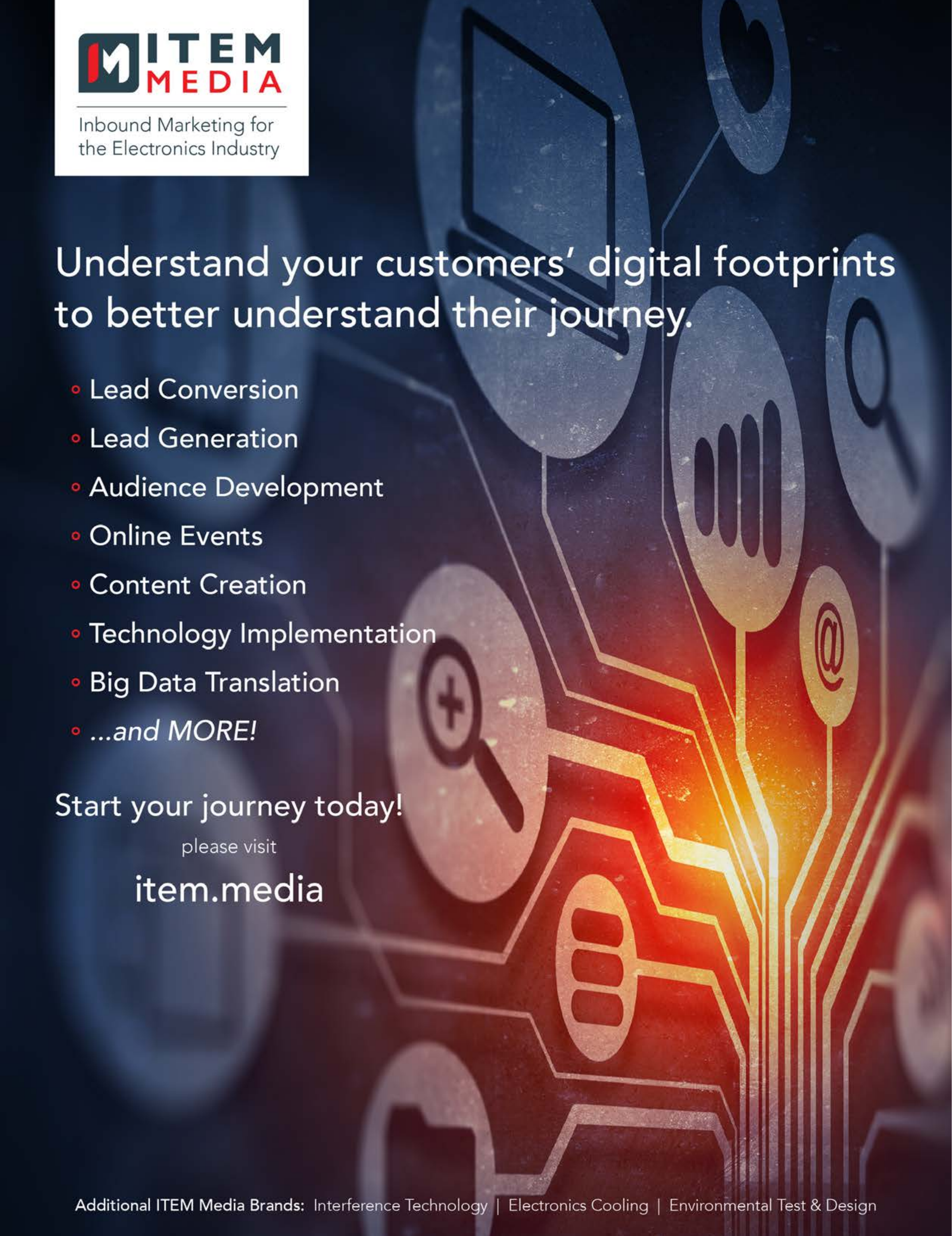
1. André and Wyatt, EMI Troubleshooting Cookbook for Product Designers, SciTech Publishing, 2014.
2. 2017 EMC Precompliance Test Guide, Interference Technology.

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COMMON COMMERCIAL EMC STANDARDS

Commercial Electromagnetic Compatibility (EMC) Standards

ANSI	
Document Number	Title
C63.4	Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz

IEC	
Document Number	Title
IEC 60050-161	International Electrotechnical Vocabulary. Chapter 161: Electromagnetic compatibility
IEC 60060-1	High-voltage test techniques. Part 1: General definitions and test requirements
IEC 60060-2	High-voltage test techniques - Part 2: Measuring systems
IEC 60060-3	High-voltage test techniques - Part 3: Definitions and requirements for on-site testing
IEC 60118-13	Electroacoustics - Hearing aids - Part 13: Electromagnetic compatibility (EMC)
IEC 60255-26	Measuring relays and protection equipment - Part 26: Electromagnetic compatibility requirements
IEC 60364-4-44	Low-voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbance
IEC 60469	Transitions, pulses and related waveforms - Terms, definitions and algorithms
IEC 60533	Electrical and electronic installations in ships - Electromagnetic compatibility (EMC) - Ships with a metallic hull
IEC 60601-1-2	Medical electrical equipment - Part 1-2: General requirements for basic safety and essential performance - Collateral Standard: Electromagnetic disturbances - Requirements and tests
IEC 60601-2-2	Medical electrical equipment - Part 2-2: Particular requirements for the basic safety and essential performance of high frequency surgical equipment and high frequency surgical accessories
IEC 60601-4-2	Medical electrical equipment - Part 4-2: Guidance and interpretation - Electromagnetic immunity: performance of medical electrical equipment and medical electrical systems
IEC 60728-2	Cabled distribution systems for television and sound signals - Part 2: Electromagnetic compatibility for equipment
IEC 60728-12	Cabled distribution systems for television and sound signals - Part 12: Electromagnetic compatibility of systems

IEC (continued)	
Document Number	Title
IEC/TS 60816	Guide on methods of measurement of short duration transients on low-voltage power and signal lines
IEC 60870-2-1	Telecontrol equipment and systems - Part 2: Operating conditions - Section 1: Power supply and electromagnetic compatibility
IEC 60940	Guidance information on the application of capacitors, resistors, inductors and complete filter units for electromagnetic interference suppression
IEC 60974-10	Arc welding equipment - Part 10: Electromagnetic compatibility (EMC) requirements
IEC/TR 61000-1-1	Electromagnetic compatibility (EMC) - Part 1: General - Section 1: Application and interpretation of fundamental definitions and terms
IEC/TS 61000-1-2	Electromagnetic compatibility (EMC) - Part 1-2: General - Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena
IEC/TR 61000-1-3	Electromagnetic compatibility (EMC) - Part 1-3: General - The effects of high-altitude EMP (HEMP) on civil equipment and systems
IEC/TR 61000-1-4	Electromagnetic compatibility (EMC) - Part 1-4: General - Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz
IEC/TR 61000-1-5	Electromagnetic compatibility (EMC) - Part 1-5: General - High power electromagnetic (HPEM) effects on civil systems
IEC/TR 61000-1-6	Electromagnetic compatibility (EMC) - Part 1-6: General - Guide to the assessment of measurement uncertainty
IEC/TR 61000-1-7	Electromagnetic compatibility (EMC) - Part 1-7: General - Power factor in single-phase systems under non-sinusoidal conditions
IEC/TR 61000-2-1	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signaling in public power supply systems
IEC 61000-2-2	Electromagnetic compatibility (EMC) - Part 2-2: Environment - Compatibility levels for low-frequency conducted disturbances and signaling in public low-voltage power supply systems
IEC/TR 61000-2-3	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 3: Description of the environment - Radiated and non-network-frequency-related conducted phenomena

IEC (continued)	
Document Number	Title
IEC 61000-2-4	Electromagnetic compatibility (EMC) - Part 2-4: Environment - Compatibility levels in industrial plants for low-frequency conducted disturbances
IEC/TS 61000-2-5	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 5: Classification of electromagnetic environments. Basic EMC publication
IEC/TR 61000-2-6	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances
IEC/TR 61000-2-7	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 7: Low frequency magnetic fields in various environments
IEC/TR 61000-2-8	Electromagnetic compatibility (EMC) - Part 2-8: Environment - Voltage dips and short interruptions on public electric power supply systems with statistical measurement results
IEC 61000-2-9	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 9: Description of HEMP environment - Radiated disturbance. Basic EMC publication
IEC 61000-2-10	Electromagnetic compatibility (EMC) - Part 2-10: Environment - Description of HEMP environment - Conducted disturbance
IEC 61000-2-11	Electromagnetic compatibility (EMC) - Part 2-11: Environment - Classification of HEMP environments
IEC 61000-2-12	Electromagnetic compatibility (EMC) - Part 2-12: Environment - Compatibility levels for low-frequency conducted disturbances and signaling in public medium-voltage power supply systems
IEC 61000-2-13	Electromagnetic compatibility (EMC) - Part 2-13: Environment - High-power electromagnetic (HPEM) environments - Radiated and conducted
IEC/TR 61000-2-14	Electromagnetic compatibility (EMC) - Part 2-14: Environment - Overvoltages on public electricity distribution networks
IEC 61000-3-2	Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
IEC 61000-3-3	Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection
IEC/TS 61000-3-4	Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A
IEC/TS 61000-3-5	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 5: Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 16 A
IEC/TR 61000-3-6	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 6: Assessment of emission limits for distorting loads in MV and HV power systems - Basic EMC publication
IEC/TR 61000-3-7	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 7: Assessment of emission limits for fluctuating loads in MV and HV power systems - Basic EMC publication
IEC 61000-3-8	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 8: Signaling on low-voltage electrical installations - Emission levels, frequency bands and electromagnetic disturbance levels
IEC 61000-3-11	Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current <= 75 A and subject to conditional connection

IEC (continued)	
Document Number	Title
IEC 61000-3-12	Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and <=75 A per phase
IEC/TR 61000-3-13	Electromagnetic compatibility (EMC) - Part 3-13: Limits - Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems
IEC/TR 61000-3-14	Electromagnetic compatibility (EMC) - Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems
IEC/TR 61000-3-15	Electromagnetic compatibility (EMC) - Part 3-15: Limits - Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network
IEC TR 61000-4-1	Electromagnetic compatibility (EMC) - Part 4-1: Testing and measurement techniques - Overview of IEC 61000-4 series
IEC 61000-4-2	Electromagnetic compatibility (EMC)- Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test
IEC 61000-4-3	Electromagnetic compatibility (EMC) - Part 4-3 : Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
IEC 61000-4-4	Electromagnetic compatibility (EMC) - Part 4-4 : Testing and measurement techniques – Electrical fast transient/burst immunity test
IEC 61000-4-5	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test
IEC 61000-4-6	Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
IEC 61000-4-7	Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto
IEC 61000-4-8	Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test
IEC 61000-4-9	Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Impulse magnetic field immunity test
IEC 61000-4-10	Electromagnetic compatibility (EMC) - Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field immunity test
IEC 61000-4-11	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests
IEC 61000-4-12	Electromagnetic compatibility (EMC) - Part 4-12: Testing and measurement techniques - Ring wave immunity test
IEC 61000-4-13	Electromagnetic compatibility (EMC) - Part 4-13: Testing and measurement techniques - Harmonics and interharmonics including mains signaling at a.c. power port, low frequency immunity tests
IEC 61000-4-14	Electromagnetic compatibility (EMC) - Part 4-14: Testing and measurement techniques - Voltage fluctuation immunity test
IEC 61000-4-15	Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 15: Flickermeter - Functional and design specifications
IEC 61000-4-16	Electromagnetic compatibility (EMC) - Part 4-16: Testing and measurement techniques - Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz

IEC (continued)	
Document Number	Title
IEC 61000-4-17	Electromagnetic compatibility (EMC) - Part 4-17: Testing and measurement techniques - Ripple on d.c. input power port immunity test
IEC 61000-4-18	Electromagnetic compatibility (EMC) - Part 4-18: Testing and measurement techniques - Damped oscillatory wave immunity test
IEC 61000-4-19	Electromagnetic compatibility (EMC) - Part 4-19: Testing and measurement techniques - Test for immunity to conducted, differential mode disturbances and signalling in the frequency range 2 kHz to 150 kHz at a.c. power ports
IEC 61000-4-20	Electromagnetic compatibility (EMC) - Part 4-20: Testing and measurement techniques - Emission and immunity testing in transverse electromagnetic (TEM) waveguides
IEC 61000-4-21	Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation chamber test methods
IEC 61000-4-22	Electromagnetic compatibility (EMC) - Part 4-22: Testing and measurement techniques - Radiated emissions and immunity measurements in fully anechoic rooms (FARs)
IEC 61000-4-23	Electromagnetic compatibility (EMC) - Part 4-23: Testing and measurement techniques - Test methods for protective devices for HEMP and other radiated disturbances
IEC 61000-4-24	Electromagnetic compatibility (EMC) - Part 4-24: Testing and measurement techniques - Test methods for protective devices for HEMP conducted disturbance
IEC 61000-4-25	Electromagnetic compatibility (EMC) - Part 4-25: Testing and measurement techniques - HEMP immunity test methods for equipment and systems
IEC 61000-4-27	Electromagnetic compatibility (EMC) - Part 4-27: Testing and measurement techniques - Unbalance, immunity test
IEC 61000-4-28	Electromagnetic compatibility (EMC) - Part 4-28: Testing and measurement techniques - Variation of power frequency, immunity test
IEC 61000-4-29	Electromagnetic compatibility (EMC) - Part 4-29: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests
IEC 61000-4-30	Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods
IEC 61000-4-31	Electromagnetic compatibility (EMC) - Part 4-31: Testing and measurement techniques - AC mains ports broadband conducted disturbance immunity test
IEC/TR 61000-4-32	Electromagnetic compatibility (EMC) - Part 4-32: Testing and measurement techniques - High-altitude electromagnetic pulse (HEMP) simulator compendium
IEC 61000-4-33	Electromagnetic compatibility (EMC) - Part 4-33: Testing and measurement techniques - Measurement methods for high-power transient parameters
IEC 61000-4-34	Electromagnetic compatibility (EMC) - Part 4-34: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current more than 16 A per phase
IEC TR 61000-4-35	Electromagnetic compatibility (EMC) - Part 4-35: Testing and measurement techniques - HPEM simulator compendium
IEC 61000-4-36	Electromagnetic compatibility (EMC) - Part 4-36: Testing and measurement techniques - IEMI immunity test methods for equipment and systems
IEC TR 61000-4-37	Electromagnetic compatibility (EMC) - Calibration and verification protocol for harmonic emission compliance test systems
IEC TR 61000-4-38	Electromagnetic compatibility (EMC) - Part 4-38: Testing and measurement techniques - Test, verification and calibration protocol for voltage fluctuation and flicker compliance test systems

IEC (continued)	
Document Number	Title
IEC/TR 61000-5-1	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 1: General considerations - Basic EMC publication
IEC/TR 61000-5-2	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 2: Earthing and cabling
IEC/TR 61000-5-3	Electromagnetic compatibility (EMC) - Part 5-3: Installation and mitigation guidelines - HEMP protection concepts
IEC/TS 61000-5-4	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 4: Immunity to HEMP - Specifications for protective devices against HEMP radiated disturbance. Basic EMC Publication
IEC 61000-5-5	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 5: Specification of protective devices for HEMP conducted disturbance. Basic EMC Publication
IEC/TR 61000-5-6	Electromagnetic compatibility (EMC) - Part 5-6: Installation and mitigation guidelines - Mitigation of external EM influences
IEC 61000-5-7	Electromagnetic compatibility (EMC) - Part 5-7: Installation and mitigation guidelines - Degrees of protection provided by enclosures against electromagnetic disturbances (EM code)
IEC 61000-5-8	Electromagnetic compatibility (EMC) - Part 5-8: Installation and mitigation guidelines - HEMP protection methods for the distributed infrastructure
IEC 61000-5-9	Electromagnetic compatibility (EMC) - Part 5-9: Installation and mitigation guidelines - System-level susceptibility assessments for HEMP and HPEM
IEC 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments
IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments
IEC 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
IEC 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments
IEC 61000-6-5	Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for power station and substation environments
IEC 61000-6-6	Electromagnetic compatibility (EMC) - Part 6-6: Generic standards - HEMP immunity for indoor equipment
IEC 61000-6-7	Electromagnetic compatibility (EMC) - Part 6-7: Generic standards - Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations
IEC 61326-1	Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements
IEC 61326-2-1	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-1: Particular requirements - Test configurations, operational conditions and performance criteria for sensitive test and measurement equipment for EMC unprotected applications
IEC 61326-2-2	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-2: Particular requirements - Test configurations, operational conditions and performance criteria for portable test, measuring and monitoring equipment used in low-voltage distribution systems

IEC (continued)	
Document Number	Title
IEC 61326-2-3	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-3: Particular requirements - Test configuration, operational conditions and performance criteria for transducers with integrated or remote signal conditioning
IEC 61326-2-4	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-4: Particular requirements - Test configurations, operational conditions and performance criteria for insulation monitoring devices according to IEC 61557-8 and for equipment for insulation fault location according to IEC 61557-9
IEC 61326-2-5	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-5: Particular requirements - Test configurations, operational conditions and performance criteria for field devices with field bus interfaces according to IEC 61784-1
IEC 61326-2-6	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-6: Particular requirements - In vitro diagnostic (IVD) medical equipment
IEC 61326-3-1	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-1: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - General industrial applications
IEC 61326-3-2	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-2: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - Industrial applications with specified electromagnetic environment
IEC 61340-3-1	Electrostatics - Part 3-1: Methods for simulation of electrostatic effects - Human body model (HBM) electrostatic discharge test waveforms
IEC 61543	Residual current-operated protective devices (RCDs) for household and similar use - Electromagnetic compatibility
IEC 61800-3	Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods
IEC 61967-1	Integrated circuits - Measurement of electromagnetic emissions, 150 kHz to 1 GHz - Part 1: General conditions and definitions
IEC 62040-2	Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility EMC) requirements
IEC 62041	Power transformers, power supply units, reactors and similar products - EMC requirements
IEC 62153-4-0	Metallic communication cable test methods - Part 4-0: Electromagnetic compatibility (EMC) - Relationship between surface transfer impedance and screening attenuation, recommended limits
IEC 62153-4-1	Metallic communication cable test methods - Part 4-1: Electromagnetic compatibility (EMC) - Introduction to electromagnetic screening measurements
IEC 62153-4-2	Metallic communication cable test methods - Part 4-2: Electromagnetic compatibility (EMC) - Screening and coupling attenuation - Injection clamp method
IEC 62153-4-3	Metallic communication cable test methods - Part 4-3: Electromagnetic compatibility (EMC) - Surface transfer impedance - Triaxial method
IEC 62153-4-4	Metallic communication cable test methods - Part 4-4: Electromagnetic compatibility (EMC) - Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method
IEC 62153-4-5	Metallic communication cables test methods - Part 4-5: Electromagnetic compatibility (EMC) - Coupling or screening attenuation - Absorbing clamp method

IEC (continued)	
Document Number	Title
IEC 62153-4-6	Metallic communication cable test methods - Part 4-6: Electromagnetic compatibility (EMC) - Surface transfer impedance - Line injection method
IEC 62153-4-7	Metallic communication cable test methods - Part 4-7: Electromagnetic compatibility (EMC) - Test method for measuring of transfer impedance ZT and screening attenuation aS or coupling attenuation aC of connectors and assemblies up to and above 3 GHz - Triaxial tube in tube method
IEC 62153-4-8	Metallic communication cable test methods - Part 4-8: Electromagnetic compatibility (EMC) - Capacitive coupling admittance
IEC 62153-4-9	Metallic communication cable test methods - Part 4-9: Electromagnetic compatibility (EMC) - Coupling attenuation of screened balanced cables, triaxial method
IEC 62153-4-10	Metallic communication cable test methods - Part 4-10: Electromagnetic compatibility (EMC) - Transfer impedance and screening attenuation of feed-throughs and electromagnetic gaskets - Double coaxial test method
IEC 62153-4-11	Metallic communication cable test methods - Part 4-11: Electromagnetic compatibility (EMC) - Coupling attenuation or screening attenuation of patch cords, coaxial cable assemblies, pre-connectorized cables - Absorbing clamp method
IEC 62153-4-12	Metallic communication cable test methods - Part 4-12: Electromagnetic compatibility (EMC) - Coupling attenuation or screening attenuation of connecting hardware - Absorbing clamp method
IEC 62153-4-13	Metallic communication cable test methods - Part 4-13: Electromagnetic compatibility (EMC) - Coupling attenuation of links and channels (laboratory conditions) - Absorbing clamp method
IEC 62153-4-14	Metallic communication cable test methods - Part 4-14: Electromagnetic compatibility (EMC) - Coupling attenuation of cable assemblies (Field conditions) absorbing clamp method
IEC 62153-4-15	Metallic communication cable test methods - Part 4-15: Electromagnetic compatibility (EMC) - Test method for measuring transfer impedance and screening attenuation - or coupling attenuation with triaxial cell
IEC 62236-1	Railway applications - Electromagnetic compatibility - Part 1: General
IEC 62236-2	Railway applications - Electromagnetic compatibility - Part 2: Emission of the whole railway system to the outside world
IEC 62236-3-1	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle
IEC 62236-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus
IEC 62236-4	Railway applications - Electromagnetic compatibility - Part 4: Emission and immunity of the signalling and telecommunications apparatus
IEC 62236-5	Railway applications - Electromagnetic compatibility - Part 5: Emission and immunity of fixed power supply installations and apparatus
IEC 62305-1	Protection against lightning - Part 1: General principles
IEC 62305-2	Protection against lightning - Part 2: Risk management
IEC 62305-3	Protection against lightning - Part 3: Physical damage to structures and life hazard

IEC (continued)	
Document Number	Title
IEC 62305-4	Protection against lightning - Part 4: Electrical and electronic systems within structures
IEC 62310-2	Static transfer systems (STS) - Part 2: Electromagnetic compatibility (EMC) requirements
IEC/TR 62482	Electrical installations in ships - Electromagnetic compatibility - Optimising of cable installations on ships - Testing method of routing distance

CISPR	
Document Number	Title
CISPR 11	Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement
CISPR 12	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers
CISPR 13	Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement
CISPR 14-1	Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission
CISPR 14-2	Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 2: Immunity – Product family standard
CISPR 15	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
CISPR 16-1-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-1: Radio disturbance and immunity measuring apparatus - Measuring apparatus
CISPR 16-1-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-2: Radio disturbance and immunity measuring apparatus - Coupling devices for conducted disturbance measurements
CISPR 16-1-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-3: Radio disturbance and immunity measuring apparatus - Ancillary equipment - Disturbance power
CISPR 16-1-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-4: Radio disturbance and immunity measuring apparatus - Antennas and test sites for radiated disturbance measurements
CISPR 16-1-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-5: Radio disturbance and immunity measuring apparatus - Antenna calibration sites and reference test sites for 5 MHz to 18 GHz
CISPR 16-1-6	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-6: Radio disturbance and immunity measuring apparatus - EMC antenna calibration
CISPR 16-2-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-1: Methods of measurement of disturbances and immunity - Conducted disturbance measurements
CISPR 16-2-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-2: Methods of measurement of disturbances and immunity - Measurement of disturbance power
CISPR 16-2-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-3: Methods of measurement of disturbances and immunity - Radiated disturbance measurements

CISPR (continued)	
Document Number	Title
CISPR 16-2-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-4: Methods of measurement of disturbances and immunity - Immunity measurements
CISPR TR 16-2-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-5: In situ measurements for disturbing emissions produced by physically large equipment
CISPR TR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports
CISPR TR 16-4-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-1: Uncertainties, statistics and limit modelling - Uncertainties in standardized EMC tests
CISPR 16-4-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modelling - Measurement instrumentation uncertainty
CISPR TR 16-4-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-3: Uncertainties, statistics and limit modelling - Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR TR 16-4-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-4: Uncertainties, statistics and limit modelling - Statistics of complaints and a model for the calculation of limits for the protection of radio services
CISPR TR 16-4-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-5: Uncertainties, statistics and limit modelling - Conditions for the use of alternative test methods
CISPR 17	Methods of measurement of the suppression characteristics of passive EMC filtering devices
CISPR TR 18-1	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena
CISPR TR 18-2	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits
CISPR TR 18-3	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 3: Code of practice for minimizing the generation of radio noise
CISPR 20	Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement
CISPR 22	Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement
CISPR 24	Information technology equipment - Immunity characteristics - Limits and methods of measurement
CISPR 25	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers
CISPR 32	Electromagnetic compatibility of multimedia equipment – Emission requirements
CISPR 35	Electromagnetic compatibility of multimedia equipment - Immunity requirements

MILITARY RELATED DOCUMENTS AND STANDARDS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MIL-STD-1542B Electromagnetic Compatibility and Grounding Requirements for Space System Facilities, 15 Nov 1991. MIL-STD-1605 Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009.

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

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

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

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

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

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

AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY (EMC) STANDARDS

The following list of automotive EMC standards was developed by Dr. Todd Hubing, Professor Emeritus of Clemson University Vehicular Electronics Lab (http://www.cvel.clemson.edu/auto/auto_emc_standards.html). A few of these standards have been made public and are linked below, but many others are considered company confidential and are only available to approved automotive vendors or test equipment manufacturers.

While several standards are linked on this list, an internet search may help locate additional documents that have been made public. Permission to republish has been approved.

CISPR (Automotive Emissions Requirements)	
Document Number	Title
CISPR 12	Vehicles, boats, and internal combustion engine driven devices – Radio disturbance characteristics – Limits and methods of measurement for the protection of receivers except those installed in the vehicle/boat/device itself or in adjacent vehicles/boats/ devices
CISPR 25	Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices – Limits and methods of measurement

ISO (Automotive Immunity Requirements)	
Document Number	Title
ISO 7637-1	Road vehicles – Electrical disturbances from conduction and coupling – Part 1: Definitions and general considerations
ISO 7637-2	Road vehicles – Electrical disturbances from conduction and coupling – Part 2: Electrical transient conduction along supply lines only
ISO 7637-3	Road vehicles – Electrical disturbance by conduction and coupling – Part 3: Vehicles with nominal 12 V or 24 V supply voltage – Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines
ISO/TR 10305-1	Road vehicles – Calibration of electromagnetic field strength measuring devices – Part 1: Devices for measurement of electromagnetic fields at frequencies > 0 Hz
ISO/TR 10305-2	Road vehicles – Calibration of electromagnetic field strength measuring devices – Part 2: IEEE standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz
ISO 10605	Road vehicles – Test methods for electrical disturbances from electrostatic discharge
ISO/TS 14907-1	Road transport and traffic telematics – Electronic fee collection – Test procedures for user and fixed equipment – Part 1: Description of test procedures
ISO/TS 14907-2	Road transport and traffic telematics – Electronic fee collection – Test procedures for user and fixed equipment – Part 2: Conformance test for the onboard unit application interface
ISO/TS 21609	Road vehicles – (EMC) guidelines for installation of aftermarket radio frequency transmitting equipment
ISO 11451-1	Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 1: General principles and terminology

ISO (Automotive Immunity Requirements) continued	
Document Number	Title
ISO 11451-2	Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 2: Off-vehicle radiation sources
ISO 11451-3	Road vehicles – Electrical disturbances by narrowband radiated electromagnetic energy – Vehicle test methods – Part 3: On-board transmitter simulation
ISO 11451-4	Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Bulk current injection (BCI)
ISO 11452-1	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 1: General principles and terminology
ISO 11452-2	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 2: Absorber-lined shielded enclosure
ISO 11452-3	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 3: Transverse electromagnetic mode (TEM) cell
ISO 11452-4	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Bulk current injection (BCI)
ISO 11452-5	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 5: Stripline
ISO 11452-7	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 7: Direct radio frequency (RF) power injection
ISO 11452-8	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 8: Immunity to magnetic fields
ISO 11452-10	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 10: Immunity to conducted disturbances in the extended audio frequency range
ISO 11452-11	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 11: Reverberation chamber
ISO 13766	Earth-moving machinery – Electromagnetic compatibility

SAE (Automotive Emissions and Immunity)	
Document Number	Title
J1113/1	Electromagnetic Compatibility Measurement Procedures and Limits for Components of Vehicles, Boats (Up to 15 M), and Machines (Except Aircraft) (50 Hz to 18 Ghz)
J1113/2	Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft)–Conducted Immunity, 15 Hz to 250 kHz–All Leads
J1113/3	Conducted Immunity, 250 kHz to 400 MHz, Direct Injection of Radio Frequency (RF) Power (Cancelled August 2010)
J1113/4	Immunity to Radiated Electromagnetic Fields-Bulk Current Injection (BCI) Method
J1113/11	Immunity to Conducted Transients on Power Leads
J1113/12	Electrical Interference by Conduction and Coupling – Capacitive and Inductive Coupling via Lines Other than Supply Lines
J1113/13	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 13: Immunity to Electrostatic Discharge
J1113/21	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 21: Immunity to Electromagnetic Fields, 30 MHz to 18 GHz, Absorber-Lined Chamber
J1113/24	Immunity to Radiated Electromagnetic Fields; 10 kHz to 200 MHz–Crawford TEM Cell and 10 kHz to 5 GHz–Wideband TEM Cell (Cancelled August 2010)
J1113/26	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Immunity to AC Power Line Electric Fields
J1113/27	Electromagnetic Compatibility Measurements Procedure for Vehicle Components – Part 27: Immunity to Radiated Electromagnetic Fields – Mode Stir Reverberation Method
J1113/28	Electromagnetic Compatibility Measurements Procedure for Vehicle Components–Part 28–Immunity to Radiated Electromagnetic Fields–Reverberation Method (Mode Tuning)
J1113/42	Electromagnetic Compatibility–Component Test Procedure–Part 42–Conducted Transient Emissions (Cancelled Dec 2010, Superseded by ISO 7637-2)
J1752/1	Electromagnetic Compatibility Measurement Procedures for Integrated Circuits-Integrated Circuit EMC Measurement Procedures-General and Definition
J1752/2	Measurement of Radiated Emissions from Integrated Circuits – Surface Scan Method (Loop Probe Method) 10 MHz to 3 GHz
J1752/3	Measurement of Radiated Emissions from Integrated Circuits – TEM/Wideband TEM (GTEM) Cell Method; TEM Cell (150 kHz to 1 GHz), Wideband TEM Cell (150 kHz to 8 GHz)
J551/5	Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz To 30 MHz
J551/11	Vehicle Electromagnetic Immunity–Off-Vehicle Source (Cancelled March 2010)

SAE (Automotive Emissions and Immunity) continued	
Document Number	Title
J551/12	Vehicle Electromagnetic Immunity–On-Board Transmitter Simulation (Cancelled August 2009)
J551/13	Vehicle Electromagnetic Immunity–Bulk Current Injection (Cancelled August 2009)
J551/15	Vehicle Electromagnetic Immunity–Electrostatic Discharge (ESD)
J551/16	Electromagnetic Immunity – Off-Vehicle Source (Reverberation Chamber Method) – Part 16 – Immunity to Radiated Electromagnetic Fields
J551/17	Vehicle Electromagnetic Immunity – Power Line Magnetic Fields
J1812	Function Performance Status Classification for EMC Immunity Testing
J2628	Characterization–Conducted Immunity
J2556	Radiated Emissions (RE) Narrowband Data Analysis–Power Spectral Density (PSD)

GM	
Document Number	Title
GMW3091	General Specification for Vehicles, Electromagnetic Compatibility (EMC)-Engl; Revision H; Supersedes GMI 12559 R and GMI 12559 V
GMW3097	General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility-Engl; Revision H; Supersedes GMW12559, GMW3100, GMW12002R AND GMW12002V
GMW3103	General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility Global EMC Component/Subsystem Validation Acceptance Process-Engl; Revision F; Contains Color; Replaces GMW12003, GMW12004 and GMW3106

Ford	
Document Number	Title
EMC-CS-2009.1	Component EMC Specification EMC-CS-2009.1
FORD F-2	Electrical and Electronics System Engineering
FORD WSF-M22P5-A1	Printed Circuit Boards, PTF, Double Sided, Flexible

DaimlerChrysler	
Document Number	Title
DC-10614	EMC Performance Requirements – Components
DC-10615	Electrical System Performance Requirements for Electrical and Electronic Components
DC-11224	EMC Performance Requirements – Components
DC-11225	EMC Supplemental Information and Alternative Component Requirements
DC-11223	EMC Performance Requirements – Vehicle

Other Automotive Manufacturers	
Audi TL 82466	Electrostatic Discharge
BMW 600 13.0	Electric- / Electronic components in cars
BMW GS 95002	Electromagnetic Compatibility (EMC) Requirements and Tests
BMW GS 95003-2	Electric- / Electronic assemblies in motor vehicles
Chrysler PF 9326	Electrical electronic modules and motors
FIAT 9.90110	Electric and electronic devices for motor vehicles
Freightliner 49-00085	EMC Requirements
Honda 3838Z-S5AA-L000	Noise Simulation Test
Honda 3982Z-SDA-0030	Battery Simulation Test
Hyundai/Kia ES 39110-00	EMC Requirements
Hyundai/Kia ES-95400-10	Battery Simulation Tests
Hyundai/Kia ES 96100-01	EMC Requirements
IVECO 16-2103	EMC Requirements
Lotus 17.39.01	Lotus Engineering Standard: Electromagnetic Compatibility
Mack Trucks 606GS15	EMC Requirements
MAN 3285	EMC Requirements
Mazda MES PW 67600	Automobile parts standard (electronic devices)
Mercedes A 211 000 42 99	Instruction specification of test method for E/E-components
Mercedes AV EMV	Electric aggregate and electronics in cars
Mercedes MBN 10284-2	EMC requirements and tests of E/E-systems (component test procedures)
Mercedes MBN 22100-2	Electric / electronic elements, devices in trucks
Mitsubishi ES-X82010	General specification of environment tests on automotive electronic equipment
Nissan 28401 NDS02	EMC requirements (instruction concerning vehicle and electrical ...)
Nissan 28400 NDS03	Low frequency surge resistance of electronic parts
Nissan 28400 NDS04	Burst and Impulse Waveforms
Nissan 28400 NDS07	Immunity against low frequency surge (induction surge) of electronic parts
Peugeot B217110	Load Dump Pulses
Porsche AV EMC EN	EMC Requirements
PSA B21 7090	EMC Requirements (electric and electronics equipment)
PSA B21 7110	EMC requirements (electric and electronics equipment)
Renault 36.00.400	Physical environment of electrical and electronic equipments
Renault 36.00.808	EMC requirements (cars and electrical / electronic components)
Scania TB1400	EMC Requirements
Scania TB1700	Load Dump Test

Other Automotive Manufacturers	
Smart DE10005B	EMC requirements (electric aggregate and electronics in cars)
Toyota TSC7001G	Engineering standard (electric noise of electronic devices)
Toyota TSC7001G-5.1	Power Supply Voltage Characteristic Test
Toyota TSC7001G-5.2	Field Decay Test
Toyota TSC7001G-5.3	Floating Ground Test
Toyota TSC7001G-5.4	Induction Noise Resistance
Toyota TSC7001G-5.5.3	Load Dump Test-1
Toyota TSC7001G-5.5.4	Load Dump Test-2
Toyota TSC7001G-5.5.5	Load Dump Test-3
Toyota TSC7001G-5.6	Over Voltage Test
Toyota TSC7001G-5.7.3	Ignition Pulse (Battery Waveforms) Test-1
Toyota TSC7001G-5.7.4	Ignition Pulse (Battery Waveforms) Test-2
Toyota TSC7001G-5.8	Reverse Voltage
Toyota TSC7006G-4.4.2	Wide Band-Width Antenna Nearby Test (0.4 to 2 GHz)
Toyota TSC7006G-4.4.3	Radio Equipment Antenna nearby Test (28 MHz ...)
Toyota TSC7006G-4.4.4	Mobile Phone Antenna Nearby Test (835 MHz ...)
Toyota TSC7018G	Static Electricity Test
Toyota TSC7025G-5	TEM Cell Test (1 to 400 MHz)
Toyota TSC7025G-6	Free Field Immunity Test (20 MHz to 1 GHz AM, 0.8 to 2 GHz PM)
Toyota TSC7025G-7	Strip Line Test (20 - 400 MHz)
Toyota TSC7026G-3.4	Narrow Band Emissions
Toyota TSC7203G	Voltage Drop / Micro Drops
Toyota TSC7508G-3.3.1	Conductive Noise in FM and TV Bands
Toyota TSC7508G-3.3.2	Conductive noise in LW, AM and SW Bands
Toyota TSC7508G-3.3.3	Radiated Noise in FM and TV Bands
Toyota TSC7508G-3.3.4	Radiated Noise in AM, SW, and LW Bands
Toyota TSC7203G	Engineering standard (ABS-TRC computers)
Toyota TXC7315G	Electrostatic Discharge (Gap Method)
Visteon ES-XU3F-1316-AA	Electronic Component - Subsystem Electromagnetic Compatibility (EMC) Requirements and Test Procedures
Volvo EMC Requirements	EMC requirements for 12V and 24V systems
Volkswagen VW TL 801 01	Electric and electronic components in cars
Volkswagen VW TL 820 66	Conducted Interference
Volkswagen VW TL 821 66	EMC requirements of electronic components - bulk current injection (BCI)
Volkswagen VW TL 823 66	Coupled Interference on Sensor Cables
Volkswagen VW TL 824 66	Immunity Against Electrostatic Discharge
Volkswagen VW TL 965	Short-Distance Interference Suppression

USEFUL EMC TESTING REFERENCES
(DIRECTORY, BOOKS, JOURNALS, FORMULAS & TABLES)

RECOMMENDED BOOKS, MAGAZINES, & JOURNALS

2016 EMC Directory & Design Guide
(includes a worldwide listing of commercial test labs)
http://learn.interferencetechnology.com/2016-emc-directory-design-guide/

EMC STANDARDS ORGANIZATION

ANSI
http://www.ansi.org

ANSI Accredited C63
http://c63.org/index.htm

IEEE Standards Association
http://standards.ieee.org

SAE
http://www.sae.org

SAE EMC Standards Committee
http://www.sae.org/standards/

IEC
http://iec.ch

CISPR
http://www.iec.ch/emc/iec_emc/iec_emc_players_cispr.htm

ETSI
http://www.etsi.org

LINKEDIN GROUPS

EMC Experts

EMC Testing and Compliance

Electromagnetic Compatibility Forum

ESD Experts

EMC Troubleshooters

RECOMMENDED BOOKS

- André and Wyatt, EMI Troubleshooting Cookbook for Product Designers, SciTech Publishing, 2014. Includes chapters on product design and EMC theory & measurement. A major part of the content includes how to troubleshoot and mitigate all common EMC test failures.
- Goedbloed, Electromagnetic Compatibility, Prentice-Hall, 1990.
- Kimmel and Gerke, Electromagnetic Compatibility in Medical Equipment, IEEE Press, 1995. Good general product design information.
- Mardiguian, Controlling Radiated Emissions by Design, Springer, 2016.
- Ott, Electromagnetic Compatibility Engineering, Wiley, 2009. The “bible” on EMC measurement, theory, and product design.
- Paul, Introduction to Electromagnetic Compatibility, Wiley, 2006 (2nd Edition). The one source to go to for an upper-level course on EMC theory.
- Mardiguian, EMI Troubleshooting Techniques, McGraw-Hill, 2000. Good coverage of EMI troubleshooting.
- Williams, EMC For Product Designers, Newnes, 2017. Completely updated text on product design for EMC compliance.
- Weston, Electromagnetic Compatibility - Methods, Analysis, Circuits, and Measurement, CRC Press, 2017 (3rd Edition). A comprehensive text, primarily focused on military EMC.
- Wyatt & Jost, Electromagnetic Compatibility (EMC) Pocket Guide, SciTech Publishing, 2013. A handy pocket-sized reference guide to EMC.

EMC AND DESIGN CONFERENCES 2017

The following is a partial listing of major EMC and electronics design conferences planned for 2017 in order of date. If your conference is not listed, please contact:
info@interferencetechnology.com

Applied Power Electronics (APEC)
March 26-30, 2017
Tampa, Florida
http://www.apec-conf.org

APEC focuses on the practical and applied aspects of the power electronics business. This is not just a designer's conference; APEC has something of interest for anyone involved in power electronics:

- Equipment OEMs that use power supplies and dc-dc converters in their equipment
- Designers of power supplies, dc-dc converters, motor drives, uninterruptable power supplies, inverters and any other power electronic circuits, equipment and systems
- Compliance engineers testing and qualifying power electronics equipment or equipment that uses power electronics

International Exhibition with Workshops on Electromagnetic Compatibility EMC (EMV 2017)
March 28-30, 2017
Stuttgart, Germany
https://www.mesago.de/en/EMV/home.htm?ovs_tnid=0

EMV is Europe's leading event on electromagnetic compatibility. Meet the industry's leading companies for EMC-equipment, components and EMC-services. The event offers a wide range of EMC-specific topics. The perfect platform to get the latest information on newest trends and developments!

The 2017 Symposium on EMC+SIPI
August 7-11, 2017
National Harbor, Maryland
http://www.emc2017.emcss.org

The 2017 Symposium on EMC+SIPI is the leading event to provide education of EMC and Signal and Power Integrity techniques to specialty engineers. The Symposium features five full days of innovative sessions, interactive workshops, tutorials, experiments, demonstrations, and social networking events.

Automotive Test Expo
October 24-26, 2017
Novi, MI
http://www.testing-expo.com/usa/

This conference includes the very latest technologies and services that are designed to ensure that the highest standards are met in terms of product quality, reliability, durability and safety.

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Aaronia
Gewerbegebiet Aaronia AG,
54597 Strickscheid

page: 2 & 5
t: +49 (0) 6556-93033
e: mail@aaronia.de
w: www.aaronia.de
www.aaronia.com

AMETEK Compliance Test Solutions
52 Mayfield Avenue
Edison, New Jersey 08837

page: 8
t: (732) 417-0501
e: usasales.cts@ametek.com
w: www.ametek-cts.com

A.H. Systems, Inc.
9710 Cozycroft Ave,
Chatsworth, CA 91311

page: 25
t: (818) 998-0223
e: sales@ahsystems.com
w: www.ahsystems.com

ATEC
10401 Roselle Street
San Diego, CA 92121

page: 19
t: (800) 404-2832
e: sales@atecorp.com
w: www.atecorp.com

AR RF/Microwave Instrumentation
160 School House Rd.
Souderton PA 18964-9990

page: 13
t: (215) 723-8181
e: info@arworld.us
w: www.arworld.us

EDI Con Boston 2017
Septebmer 11-13
Hynes Convention Center

page: 47
t: (781) 619-1930
e: aconnell@mwjournal.com
w: www.ediconusa.com

ITEM Media
1000 Germantown Pike
Plymouth Meeting, PA 19462

page: 34
t: (484) 688-0300
e: info@item.media
w: item.media

MiCOM Labs
575 Boulder Court
Pleasanton, CA 94566

t: (925) 462-0304
e: sales@micomlabs.com
w: www.micomlabs.com

Rhode & Schwarz
Muehldorfstrasse 15
81671 Munich, Germany

page: 29
t: Germany: +49 (0) 89 4129 12345
United States: (410) 910-7800
e: email address
w: www.rohde-schwarz.com
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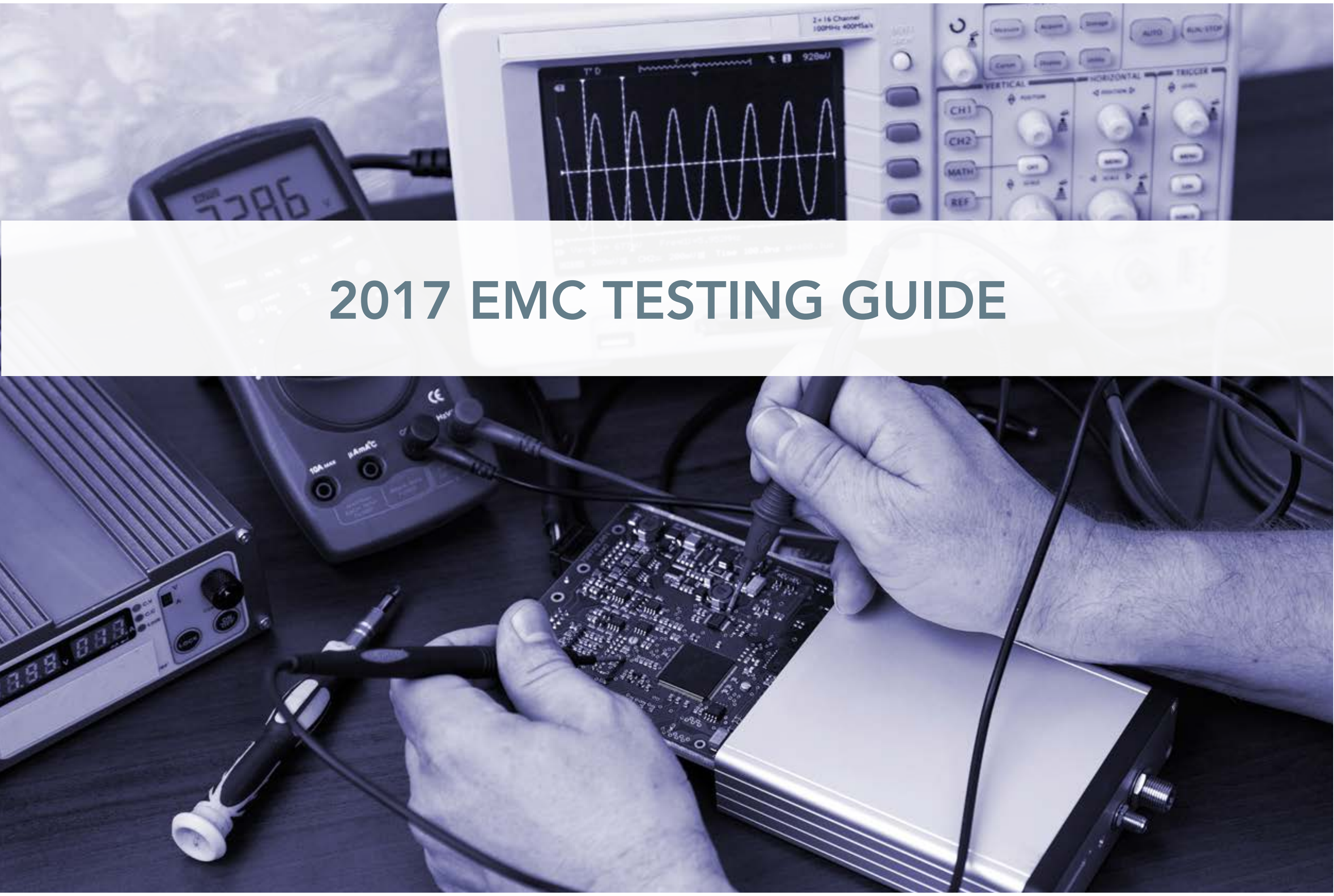

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