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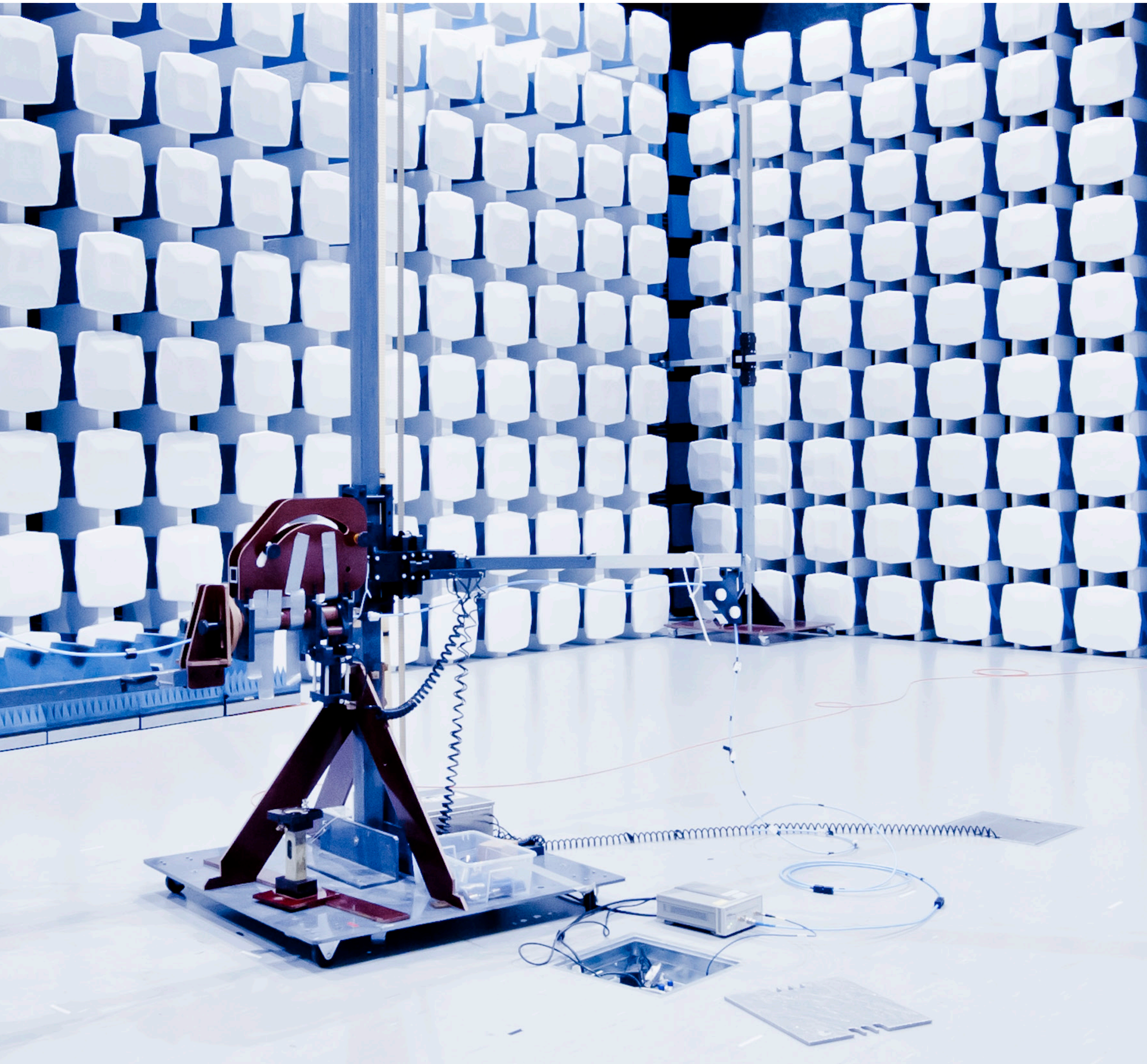
2019 EMC TESTING GUIDE



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INTRODUCTION

Jennifer Arroyo
Editorial Director, *Interference Technology*

Hello, and welcome to the 2019 edition of the EMC Testing Guide from *Interference Technology*. We hope you enjoy the informative articles and helpful resources and references we have featured in this guide.

Testing in an integral part of the engineering and manufacturing process. Electromagnetic compatibility (EMC) testing, in particular, is important as electromagnetic interference (EMI) is often overlooked during the design phase of an electronic device. This oversight will often come back to haunt engineers at the testing phase with delays and added costs.

The articles included in this year's guide speak to EMC testing and planning. "*How to Build Your Own EMI Troubleshooting and Pre-Compliance Kit*," by Dylan Stinson, explains the steps required to build an EMI pre-compliance kit and the benefits to testing in house versus with a third party.

Next up we have "*Protecting RF and Receiver Input Circuits Against the RTCA DO-160 Pin Injection Lightning Test*," by David Weston, which centers on the DO-160 pin injection test that is conducted between the pin and chassis.

We round out our articles with "*Developing an In-House EMC Troubleshooting & Pre-Compliance Test Lab*," by Ken Wyatt, delivers an overview on what is required for an in-house pre-compliance test lab.

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

Cheers,

Jennifer Arroyo
Editorial Director, Interference Technology
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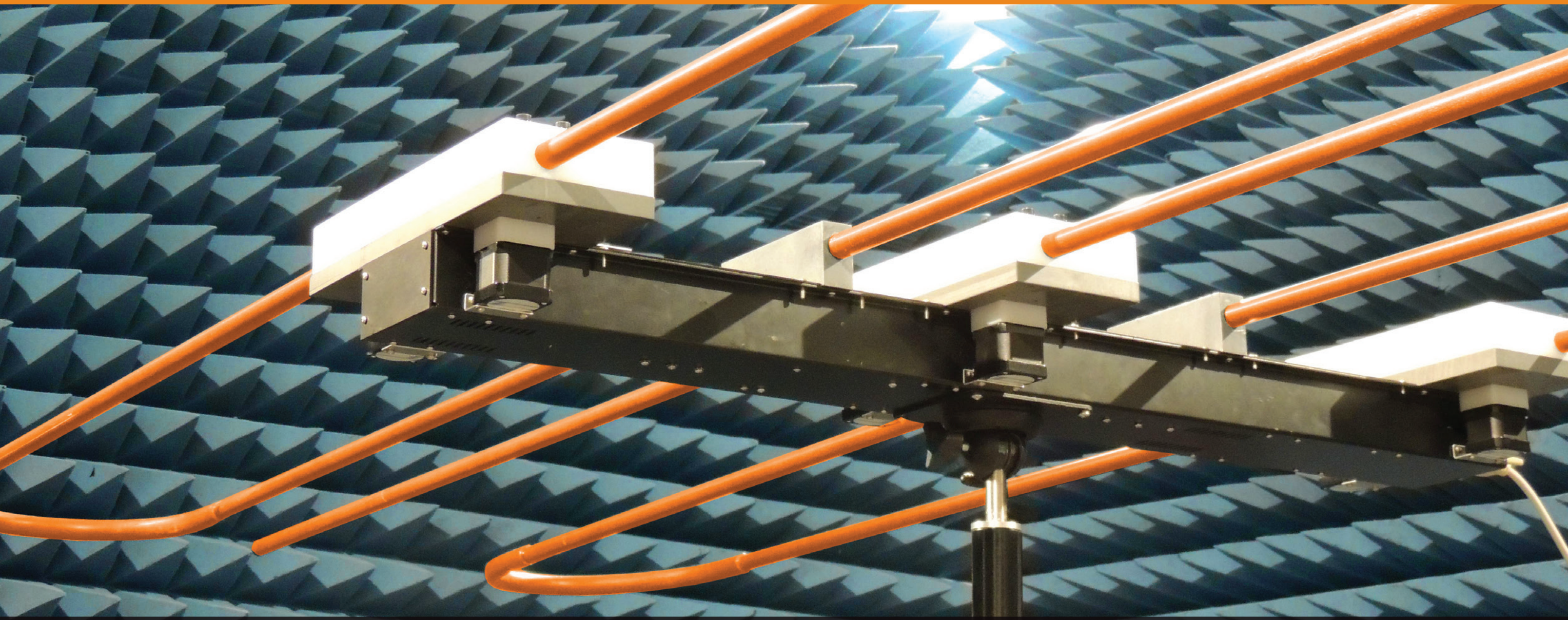
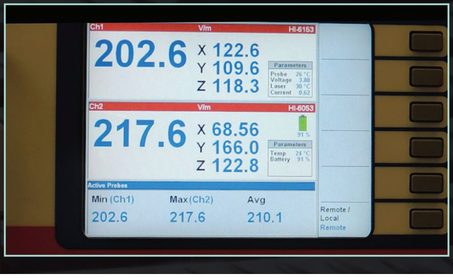
200V/m THE WAY IT WAS MEANT TO BE

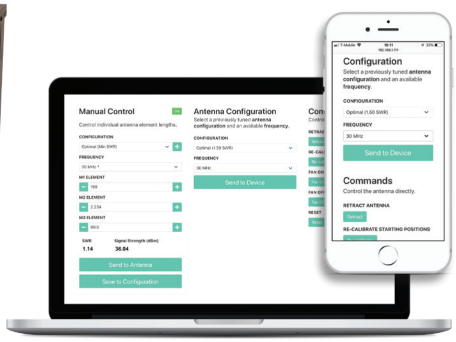


The SteppIR SY3-EMC Auto-tuned Yagi system is the solution to MIL-STD-461G and RS-103 for radiated susceptibility testing within the 30-200 MHz frequency range – making it the only system in the world that can legitimately claim to reach or exceed the required 200 V/m @1 Meter, at the fundamental frequency.



- 200 V/m achieved with average input power of 975 watts*
- 1.5:1 average SWR throughout the frequency range
- Hi-Q antenna design greatly reduces harmonics, with typical reduction of 25 dB – ensures the field probe is measuring the field from the fundamental frequency – not from the harmonics
- Fully auto-tuned system using patent pending software algorithm creates optimized, resonant antennas at every single test frequency

* Power requirements will vary depending on the test chamber configuration. Chamber for this test was fully anechoic.



The user interface is available for PC / Mac and iphone /android devices. We also have a developer site available for interfacing the OptimizIR-EMC system with popular industry software.

steppIR EMC

AVAILABLE FOR PURCHASE - INQUIRE AT:
steppir.com/e-series

EMC EQUIPMENT MANUFACTURERS SUPPLIER MATRIX

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 Supplier Matrix		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	www.ahsystems.com	X	X		X						X			
Aaronia AG	www.aaronia.com	X	X			X					X			
Advanced Test Equipment Rentals	www.atecorp.com/category/emc-compliance-esd-rfi-emi.aspx	X	X			X	X	X	X	X	X		X	X
AR RF/Microwave Instrumentation	www.arworld.us	X	X			X		X	X	X	X			X
Anritsu	www.anritsu.com					X					X			X
Electro Rent	www.electrorent.com		X			X	X	X	X	X	X		X	X
EM Test	www.emtest.com/home.php									X	X	X		
EMC Partner	www.emc-partner.com						X			X				
Empower RF Systems	www.empowerrf.com		X						X					
Gauss Instruments	www.gauss-instruments.com/en/					X								
Haefley-Hippotronics	www.haefely-hipotronics.com						X			X				
BHD Test and Measurement	www.bhdtm.com		X			X	X	X	X	X	X		X	X

EMC Equipment Manufacturers Supplier Matrix		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
Instruments For Industry (IFI)	www.ifi.com		X						X	X				
Kent Electronics	www.wa5vjb.com	X												
Keysight Technologies	www.keysight.com/main/home.jspx?cc=US&lc=eng			X		X		X			X			X
Microlease	www.microlease.com/us/home		X			X	X	X	X	X	X		X	X
Milmega	www.milmega.co.uk		X						X	X				
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X			X		X	X	X	X			
Noiseken	www.noiseken.com						X			X	X			
Ophir RF	www.ophirrf.com		X							X				
Pearson Electronics	www.pearsonelectronics.com				X									
Rigol Technologies	www.rigolna.com			X	X	X					X			X
Rohde & Schwarz	www.rohde-schwarz.com/us/home_48230.html	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	www.siglentamerica.com			X		X					X			X
Signal Hound	www.signalhound.com			X		X					X			X
Solar Electronics	www.solar-emc.com	X			X		X	X		X				
TekBox Technologies	www.tekbox.com		X	X				X			X	X		
Tektronix	www.tek.com			X		X					X			
Teseq	www.teseq.com/en/index.php		X		X		X		X	X	X	X		
Test Equity	www.testequity.com/leasing/		X			X	X	X	X	X	X		X	X
Thermo Keytek	www.thermofisher.com/us/en/home.html						X			X				
Thurlby Thandar (AIM-TTi)	www.aimtti.us					X					X			X
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X			X		X	X		X			
TPI	www.rf-consultant.com													X
Transient Specialists	www.transientspecialists.com								X	X		X		
TRSRenTelCo	www.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X			X		X	X	X	X		X	X
Vectawave Technology	www.vectawave.com		X											
Windfreak Technologies	www.windfreaktech.com													X

HOW TO BUILD YOUR OWN EMI TROUBLESHOOTING AND PRE-COMPLIANCE KIT

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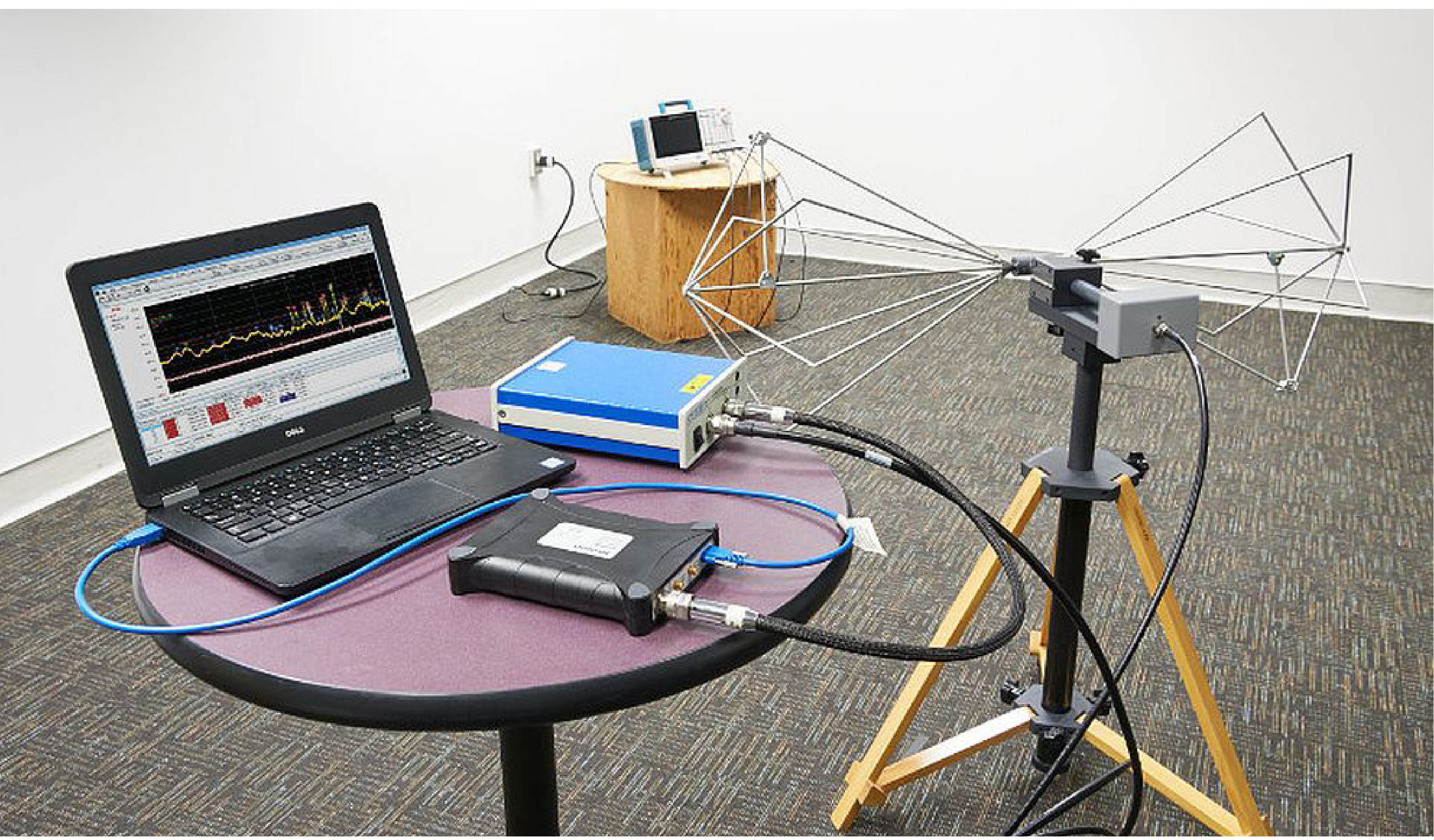

HOW TO BUILD YOUR OWN EMI TROUBLE-SHOOTING AND PRE-COMPLIANCE KIT

Electromagnetic compatibility (EMC) and the related electromagnetic interference (EMI) are some of the obstacles that must be overcome before nearly any electronics product can be brought to market—whether it's an Industrial Internet of Things (IIoT) device, a consumer electronics product, or military and aerospace equipment. Products must not interfere with one another (radiated or conducted emissions), and they must be designed to be immune to external energy sources. Countries around the world impose EMC standards, which place limits on the level of emissions allowed, requiring full compliance testing of products at certified EMC test houses.

Failing EMI/EMC compliance testing can be among the design engineer's worst nightmare. Costs and time delays add up quickly, whether it's additional compliance and external lab testing costs, debug engineering time, or in some cases, unexpected board spins. To avoid these scenarios, a growing number of design teams—even those working on limited budgets—are developing their own in-house labs for conducting EMI troubleshooting and pre-compliance testing. As shown in *Figure 1*, such capabilities enable them to characterize and mitigate problems before heading to the third-party test house for emissions testing.

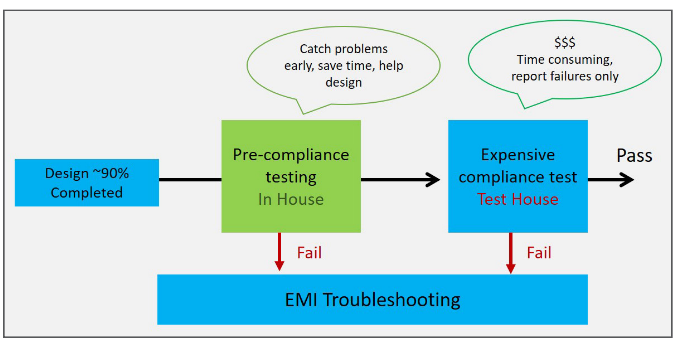

Figure 1: A suggested product workflow and testing process to keep a lid on EMC compliance test costs and avoid unexpected delays.

But is putting together an EMI lab really worth the time and effort involved? To answer that question, we'll first take a look at the costs involved with EMC compliance testing when in-house testing is not available and then look at how the latest real-time spectrum analyzers and RF-capable oscilloscopes coupled with dedicated software are making this job fast and easy, even for non-EMC experts.

Typical Costs

When calculating EMC/EMI compliance test costs, a number of factors come into play. These can include the type of product, the number of countries, the number of trips to an external test house, design and debug time, the number of boards involved, and certification test cost.

Table 1 provides an example of typical costs associated with FCC and CE compliance. The costs are not inclusive and additional expenses may exist, but this is a good start to illustrate some of the costs involved.

EMC Cost Estimate (EMC + RF Only)	Cost Estimate
Certification cost	
– Unintentional Radiator (FCC + CE)	$5,000 – $10,000
– Intentional Radiator (FCC + CE)	$10,000 – $20,000
External Testing Lab	$1,000 - $10,000 per day
Engineering Resources (debug, design, layout, test)	$80 - $200 per hour per person
Board Spin if necessary (Cost/Board + Set-up Cost)	$1,000 - $15,000
Total (not including Engineering Resources)	$17,000 - $55,000

Table 1: An estimate of EMC/EMI compliance testing costs for FCC and CE compliance.

As if those numbers aren't daunting enough, let's take a look at a couple of real-world scenarios:

Scenario #1: The design team has been taking products to a test house for years and uses the services of an external anechoic chamber provider to prepare for compliance. For the last two products they developed, they estimated taking 40 trips per year at a cost of $700 per half day, for a total of $28,000. In addition, they estimated the cost for full compliance testing, which involves more than just emission testing, was approximately $30,000.

Scenario #2: This team faced a major challenge as it spent a year trying to figure out where the "noise" in their product was coming from. To test the product, they went to a lab with an anechoic chamber for pre-scans at a cost of $1,250 per hour for a technician, equipment, and chamber. They went to the lab once a quarter with up to 12 boards. On some occasions, they would spend a full day. In reviewing their EMC/EMI pre-compliance expenses, they discovered they had incurred lab expenses of approximately $30,000 for the year, not to mention product delays and lost staff time. This number also doesn't include actual certification costs.

The bad news is that these are far from isolated incidents. As product complexities increase and form factors shrink, designers need to find cost-effective ways to identify issues well in advance during product development cycles—not just before heading to production.

EMI Troubleshooting Versus Pre-Compliance Testing

There's a difference between general troubleshooting or debugging EMI issues and pre-compliance testing, which is important to understand when planning your own in-house EMI test kit. General troubleshooting is usually performed with a set of near-field probes or RF current probe, and a spectrum analyzer or an RF-capable oscilloscope. The goal is to identify sources of harmonic energy and determine fixes that reduce the harmonic amplitudes. Here, we're mainly looking for relative changes. While full compliance testing procedures are designed to produce absolute, calibrated measurements, troubleshooting can be performed using relative measurements.

Pre-compliance testing, on the other hand, attempts to duplicate the way the full compliance tests are run to the best ability possible and to compare with actual emission test limits (*Figure 2*). This requires a calibrated EMI antenna, knowledge of the gains or losses in the measurement system, and emission limit tables based on the standards of interest.

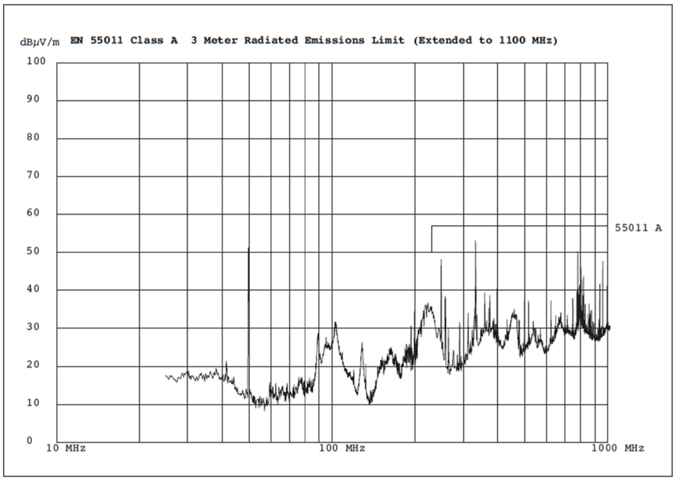

Figure 2: Example of an EMC scan from a compliance lab showing a spur exceeding the limit at about 50 MHz.

For best results, the radiated and conducted emissions test is usually performed inside a semi-anechoic chamber or GTEM cell in order to eliminate outside received signals (ambient signals), such as broadcast radio, television, two-way radio, or cell phones. However, this can add considerable expense and is not always needed with modern test equipment and software tools. As a result, in-house emissions pre-compliance tests can often be set up outside a shielded chamber and techniques can be used to distinguish ambient signals from those emanating from the product under test.

For example, some spectrum analyzers with *EMC pre-compliance software* (https://www.tek.com/landing-page/emcvu-software-and-accessories) support making an ambient measurement of the environment while the product is turned off to give a baseline of what RF noise is present. This can then be subtracted from the actual measurement using a math trace so the user can distinguish between failures coming from the device under test and the surrounding environment.

Setting Up Your Lab

So, what's involved in developing a basic EMI troubleshooting and pre-compliance test lab? It's not nearly as expensive as you might think. As noted above, pre-compliance EMC testing and troubleshooting does not necessarily require a semi-anechoic or EMC chamber, and the equipment is less expensive than full compliance test equipment.

Figure 3 shows the equipment required for radiated emissions pre-compliance testing, including a calibrated antenna, preamp, and spectrum analyzer with EMC software. For conducted emissions testing, all you'll likely need are a spectrum analyzer and a line impedance stabilization network (LISN), and optional power filter or preamp. However, by far, the most common EMC failure encountered by designers during a full EMC compliance test is due to radiated emissions.

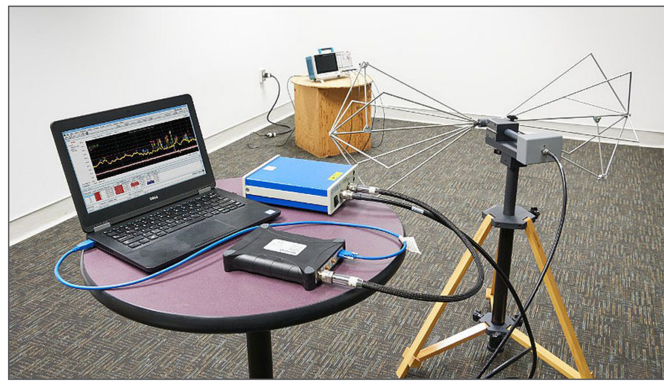

Figure 3: Typical radiated emissions pre-compliance test setup in a large room. The spacing between the EMI antenna and equipment under test is 3 m.

Here's a run-down on the equipment you'll need to get started performing your own radiated and conducted emissions testing:

Spectrum Analyzer or RF-Capable Oscilloscope

An affordable USB-based real-time spectrum analyzer is the preferred option for this application because unlike a traditional swept-tuned spectrum analyzer, it can capture and *display intermittent or infrequent signals* (https://interferencetechnology.com/emi-troubleshooting-with-real-time-spectrum-analyzers/) with high precision and high probability of intercept. The real-time spectrum/signal analyzer can make measurements, using narrow resolution bandwidths (RBW), orders of magnitude faster than traditional swept-tuned analyzers, saving users time when scanning and searching for low-level RF spurs. To verify the performance of a wireless module or radio, it can also perform signal analysis such as EVM measurements and constellation diagrams to verify the quality and performance of many common wireless signal standards.

But for teams with limited budgets or who prefer to focus their testing on EMI troubleshooting, it may make more sense to consider a multi-purpose RF-capable oscilloscope that has a separate RF input coupled with an internal spectrum analyzer. The latest mixed-signal oscilloscopes also offer multi-domain capabilities beyond traditional oscilloscope FFTs, allowing independent time and frequency domain control over multiple channels. The ability to correlate signals in both domains significantly improves troubleshooting.

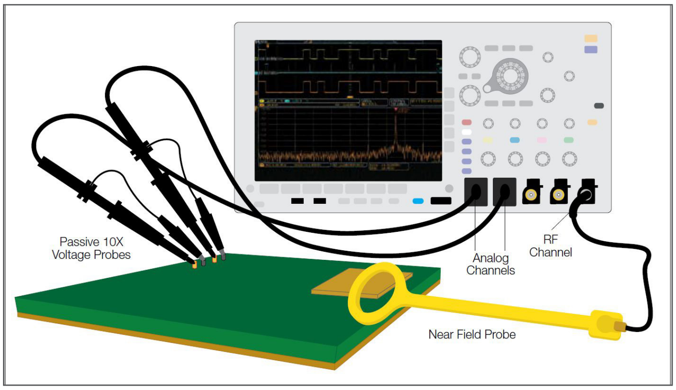

Figure 4: Test setup combines analog oscilloscope channels and a spectrum analyzer channel with near field probe on a mixed domain oscilloscope (MDO).

While an oscilloscope is very useful for determining rise times and ringing and may have built-in frequency-domain capabilities, a real-time spectrum analyzer is still the desired instrument for EMI troubleshooting and pre-compliance measurements. For pre-compliance scanning, depending on the standard, CISPR detectors for peak, avg, and quasi-peak (QP) may be needed. So, make sure your spectrum analyzer supports CISPR detectors, when necessary and to always refer to your standard(s) of interest to determine exactly what's needed.

The frequency range required will depend on the standards and regions you will be testing for. The lowest frequency range is typically determined by the lowest frequency clock included in your design. The maximum frequency measurement range is a factor of the highest frequency generated or used in the device, or on which the device operates or tunes. *Table 2* shows how the FCC defines it for unintentional radiators:

Highest frequency generated or used in the device, or the device operates or tunes	Upper frequency of measurement range
Below 1.705 MHz	30 MHz
1.705 -108 MHz	1,000 MHz
108 - 500 MHz	2,000 MHz
500 – 1,000 MHz	5,000 MHz
Above 1,000 MHz	5th harmonic of the highest frequency or 40 GHz, whichever is greater

Table 2. Instrument frequency range for EMI pre-compliance testing

There are many caveats with frequency ranges depending on the type of product. For understanding this more for your exact frequency measurement range, be sure to look at FCC Part 15.33 or the specific standards you're testing for. Important things to look for when deciding on a spectrum analyzer or oscilloscope-based solution for EMC pre-compliance testing include the following:

- Low noise floor
- Wide frequency range (to cover your measurement range)
- Peak, avg, and quasi-peak detectors (similar to actual EMI receivers)
- Adjustable RBW that can go as low as 1 Hz
- Programmable interface
- Reliable and within cal
- EMC software allowing you to:
    - Account for the gains/losses of accessories
    - Compare traces
    - Distinguish ambient signals
    - Apply limit lines
    - Report notes, images, and results

Antenna, Probes

For troubleshooting, you'll want a set of near-field probes and current probe. For pre-compliance radiated emissions scanning you'll want an EMI antenna. The antenna you need will depend on the frequency range of your required measurement. Occasionally, you will need multiple antennas because gain profiles vary with frequency. You may not be able to see your measurement if the gain of the antenna isn't high enough and the measured signal is hidden by the noise floor. To boost the gain, you can use an external preamplifier or RF amplifier between the antenna and spectrum analyzer.

Here are the four most common types of antennas used for EMC compliance testing and their typical frequency ranges:

- Loop: 10 kHz–30 MHz
- Biconical: 25 MHz–300 MHz
- Log periodic: 300 MHz–1 GHz
- Horn: 1 GHz–26 GHz

Line Impedance Stabilization Network

For conducted emissions measurements, instead of antennas you use a LISN. A LISN is essentially a low-pass filter that is placed between an AC or DC power source and the DUT to create a known impedance (often 50 ohms) and to provide an RF noise measurement port. It also serves to isolate the unwanted RF signals from the power source.

Preamplifier

A preamplifier can help by boosting low-level signals above the noise floor and improving the sensitivity of your measurement system. Make sure it operates over your frequency range of interest and has sufficient gain. Some preamplifiers have the added benefit of having a rechargeable battery, allowing you to make measurements when a power source is not available.

Antenna Tripod

You'll need a non-radiating tripod, preferably capable of raising, lowering, and rotating. Your particular standard may require a different kind of tripod. There's a benefit to having a solidly constructed tripod made specifically for EMC testing if you can afford it, but you may be able to get away with constructing your own tripod out of wood and PBC piping.

Coaxial Cables

You'll need two RF cables. One for connecting between the antenna and preamplifier and one for connecting between the preamplifier and spectrum analyzer or oscilloscope. They don't need to be very expensive. As long as they operate over the frequency range you need, match the impedance of your antenna, and are stable while being bent you should be good. Cable lengths typically vary between 1 m, 5 m, or 10 m.

Turntable

You're going to need to position your device or equipment under test in various angles depending on the EMC standard. Turntables designed for EMC testing can be purchased to allow easy and precise rotation. For those on a budget, a cardboard box positioned at the correct height and distance is a cost-effective alternative.

Test Environment

Unlike full EMC/EMI compliance testing, pre-compliance testing does not necessarily require compliant test equipment or anechoic chamber. Today you can make relatively accurate results in your own office environment, conference room, or basement. While an actual chamber is ideal, you can usually get along fine without it and save 10s or even 100s of thousands of dollars. However, when in very noisy environments, low cost pre-compliance RF enclosures or TEM cells can be used as well.

When selecting a test site, it is best to pick a location that will minimize external signal sources. Rural areas, conference rooms or basements are good because they minimize signals that might mask the DUT emission levels you are trying to measure. Other considerations for improving accuracy involve having a good ground plane and reducing the number of reflective objects around the test area. You can also implement measurement techniques which involve making a baseline ambient noise measurement, as mentioned earlier.

Conclusion

An in-house pre-compliance EMC/EMI test solution can help you pass full compliance testing, saving you considerable time, frustration, and expense, particularly when you test early in the design cycle when problems can be identified and mitigated relatively easily. Developing in-house EMC pre-compliance and troubleshooting capability can be done cost effectively, especially in comparison to the cost of multiple-trips to the test house. And, unlike full compliance testing, pre-compliance testing does not necessarily require expensive compliant test equipment or an anechoic chamber.

References

1. EMC Test Lab Guide – https://emcfastpass.com/emc-testing-beginners-guide/emc-test-lab-guide/
2. The Financial Case for an EMI/EMC Pre-Compliance Test Solution – https://www.tek.com/blog/financial-case-emi-emc-pre-compliance-test-solution
3. Electronic Code of Federal Regulations, e-CFR data is current as of September 25, 2019, Title 47, Chapter I, Subchapter A, Part 15, Subpart A, §15.33 – https://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title47/47cfr15_main_02.tpl
4. Low-cost EMI Pre-compliance Testing using a Spectrum Analyzer – https://www.tek.com/document/application-note/low-cost-emi-pre-compliance-testing-using-spectrum-analyzer
5. Conducted and Radiated Emissions Testing Application Note – https://info.tek.com/www-conducted-radiated-emissions-testing-app-note.html?_ga=2.7789618.1818033532.1565629341-217846865.1564189683
6. EMI Pre-Compliance Testing and Troubleshooting with Tektronix EMCVu – https://www.tek.com/document/application-note/emi-pre-compliance-testing-and-troubleshooting-tektronix-emcvu
7. EMI Troubleshooting with Real-Time Spectrum analyzers – https://interferencetechnology.com/emi-troubleshooting-with-real-time-spectrum-analyzers/
8. Practical EMI Troubleshooting – https://www.tek.com/document/application-note/emi-pre-compliance-testing-and-troubleshooting-tektronix-emcvu
9. Assembling a Low Cost EMI Troubleshooting Kit – Part 1 (Radiated Emissions) https://interferencetechnology.com/assembling-low-cost-emi-troubleshooting-kit-part-1-radiated-emissions/

PROTECTING RF AND RECEIVER INPUT CIRCUITS AGAINST THE RTCA DO-160 PIN INJECTION LIGHTNING TEST

David A. Weston
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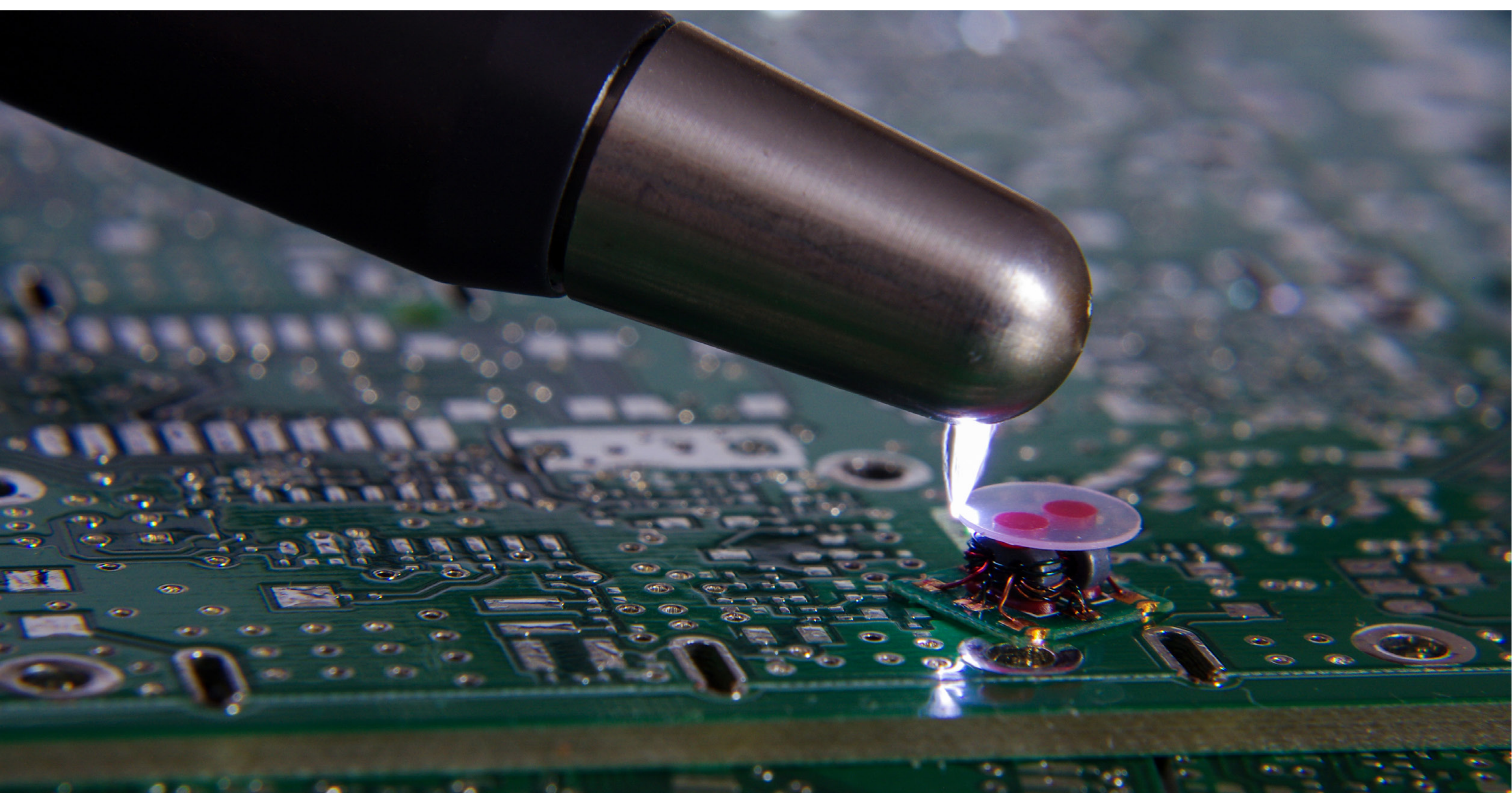
Abstract
A circuit is described as something that effectively protects RF and receiver circuits from three types of transient injection, described in DO-160, directly into the input pin of the RF connector.

The goal was to achieve a circuit that would not affect the performance of the RF circuit over an input frequency range of 20 MHz to above 1 GHz. The circuit was tested both for RF performance and with the three types of transient specified by DO-160 injected into the input circuit.

Index terms
- *DO-160 pin injection test*
- *RF and receiver input protection*
- *20 MHz to above 1 GHz operating frequency range*
- *Low VSWR*
- *Low attenuation*



PROTECTING RF AND RECEIVER INPUT CIRCUITS AGAINST THE RTCA DO-160 PIN INJECTION LIGHTNING TEST

Introduction

When a significant series impedance can be inserted in the RF circuit, followed by diodes to the supply rail and power return, this can provide adequate protection. However, the goal is that the circuit has only 0.27 dB total loss, which includes attenuation and mismatch loss, and so precludes the addition of any series impedance.

Low capacitance transient voltage suppressor (TVS), which includes a low capacitance series diode in series with the TVS, are available but even the low capacitance results in an unacceptable VSWR loss above about 100 MHz. These and other devices for protection are described in *Reference 1*.

The DO-160 pin injection is conducted between the pin and chassis.

If the RF ground is isolated from chassis with a sufficiently high impedance over the frequency range typical of the pin injection waveforms, then both the input circuit and the RF ground will rise above the chassis in voltage to the test level. If this technique is used, it is thus important that any circuits, such as the input of isolated switching power supplies, are able to withstand the voltage. In most RF circuits, the RF ground is chassis ground, and that is the assumption used in the design of the protection circuit, so isolation is not feasible.

The DO-160 pin injection waveforms are transient current waveforms 1, 3, 4, and 5A or 5B with waveform 5A more common than type 5B. These wavefoms are shown in *Figures 1, 2,* and *3*. The test levels are specified from 1-5 with 3 the most common maximum level and this was used in the development of the protection circuit. The peak open circuit voltage and peak short circuit voltage at level 3 are shown in *Table 1*.

Table 1		
Waveform 3	Waveform 1 and 4	Waveform 5A
600V/24A +10%-0%	300V/60A +10%-0%	300V/300A +10%-0%

Table 1: Level 3 peak open circuit voltage and peak short circuit current.

DO-160 also specifies a cable bundle test that is used to evaluate the functional upset tolerance of equipment when transients are applied to interconnecting cables. As the majority of RF circuit interface cables are shielded and use shielded connectors, the level of shielding effectiveness thereby achieved means that it is highly unlikely that the input circuit will be damaged by the transients, although an upset may occur, depending on the RF signal level. An input impedance of 50 W is used in the development of the protection circuit as this is the most common input impedance.

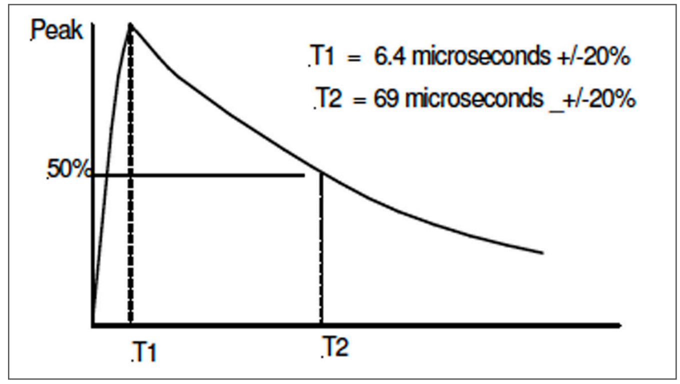


Figure 1: Waveform 1 and 4.

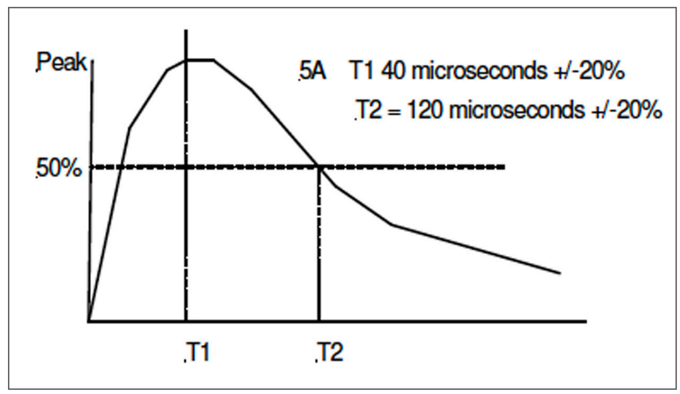


Figure 2: Waveform 5A

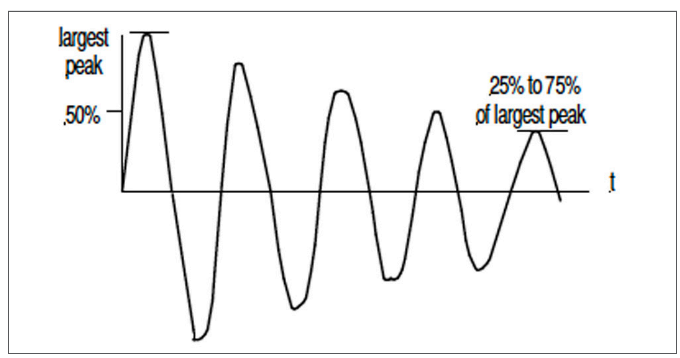


Figure 3: Waveform 3.

Protection Circuit

Adding an inductor in parallel with the 50-ohm input impedance can represent a low impedance to waveform 1 and 5A, but a high impedance from 20 MHz and above to the RF signal. Above some frequency, the inductor will modify the VSWR of the input. An arbitrary maximum VSWR of 1.1 was used in selecting the inductors.

The inductors chosen were designed for power as they are most likely to withstand the high transient current. They are rated for dc current and no information was available on the transient current carrying capability. Instead the inductors, which were found ideal, based on their RF performance, were tested with 50 positive and 50 negative transients and the dc resistance and inductance were measured before and after exposure. All of the inductors tested were unchanged after this testing.

The inductors tested had values of 220 nH, 470 nH, 1 µH, 1.5 µH, 2 µH, 4.7 µH,10 µH and 23 µH. The 1.5-µH part number 744314150 measured 48 Ω or higher from 20 MHz to 337 MHz. The 1.5µ-H part number DR73-1R5-R1 measured 48 Ω or higher from 20 MHz to 380 MHz.

The 744314150 inductor is manufactured by Würth and the DR73-1R5-R by Eaton Electronics Division.

These two inductors passed the transient injection test, and it was decided to proceed testing with the 1.5-µH DR73-1R5-R1 inductor. The dimensions of this inductor are 7.5 x 7.5 mm with a height of 3 mm. The impedance of the DR73-1R5 in parallel with 50 Ω is shown in *Table 3.*

To increase the frequency range further a 11 turn air coil was wound with a diameter of 6.5 mm and a length 9 mm and with an inductance of 0.495 µH. This was added in series with the 1.5-µH DR73-1R5-R1 inductor, as shown in *Figure 5.* The impedance when in parallel with a 50-Ω resistor was 48.5 W at 500 MHz and 49.2 Ω at 1 GHz thus the useful frequency range of the combination was 20 MHz to 1 GHz.

The 220 nH and 470 nH fixed power inductors did not perform any where near as well as the air wound coil.

The voltage developed across the 50-W load and 1.5-µH inductor with the 6.9 µS/69 µS 300 V/60A waveform 1 / 4 was 61 V. The voltage developed across the 50-W load and 1.5-µH inductor with the 40 µS/120 µS, 300 V/300A waveform #5A applied was 35 V with a 9 µS pulse width at 50% amplitude.

These levels are still too high. Also the damped sine wave, waveform 3, is usually tested at 1 MHz and 10 MHz and the impedance of the 1.5 µH inductor is too high at these frequencies.

However due to the short duration of the resultant transients the electrical energy is much lower than in the applied test transients. Also the half cycles in the 1 MHz and 10 MHz damped sine wave have a short duration.

The use of a limiter to further reduce the transient across the inductor was examined. The 1N5711 and BAT81S small signal schottky diodes in parallel with the 1.5-µH inductor were tested and both failed with the 40 µS/120 µS pulse applied.

Mini-Circuits manufacture small limiters. An application engineer at Mini-Circuits suggested the RLM-43-5W+, which can handle 37 dBm (5 W), but could not predict the performance with the transients generated across the 1.5-µH inductor. The frequency range of the RLM-43-5W+ is 20 MHz to 4,000 MHz. The loss and VSWR are shown in *Table 2*.

Table 2		
Frequency (MHz)	Loss	VSWR
20	0.15	1.36
50	0.05	1.13
90	0.04	1.06
200	0.04	1.03
500	0.05	1.02
1000	0.09	1.02

Table 2: RF performance of RLM-43-5W+ Frequency.

Table 3	
Frequency (MHz)	Z
20	48
66	50
103.6	50
141	50
174	50
199	51
258	49
315	50
368	50
380	48

Table 3: DR73-1R5-R1 in parallel with 50 Ω.

The Mini-Circuits engineer's recommendation was to test it and that is what was done. The final protection circuit is shown in *Figure 4.* A photo of the 1.5 µH in series with the 0.495 µH inductor is shown in *Figure 5*.

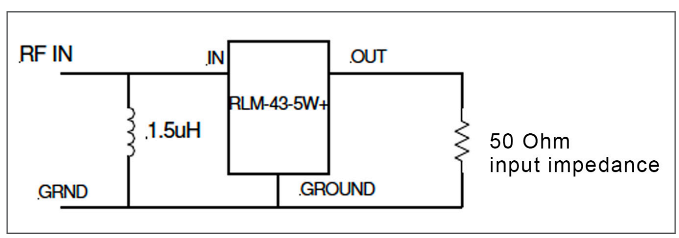


Figure 4: Final protection circuit.

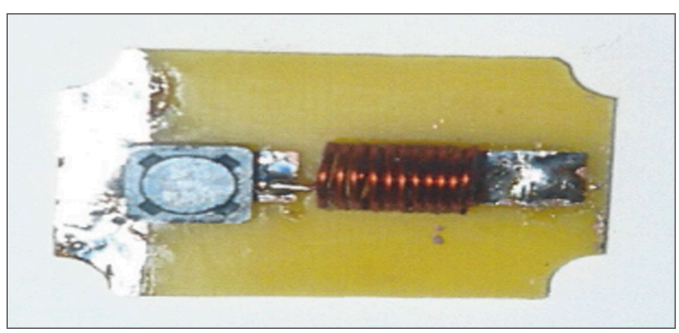


Figure 5: Photo of 1.5-µH and 0.495-µH inductors.

To prove that the 1.5-µ inductor is necessary the RLM-43-5W was tested without the 1.5-µH inductor, but as expected, failed open circuit.

Test Results With Final Circuit

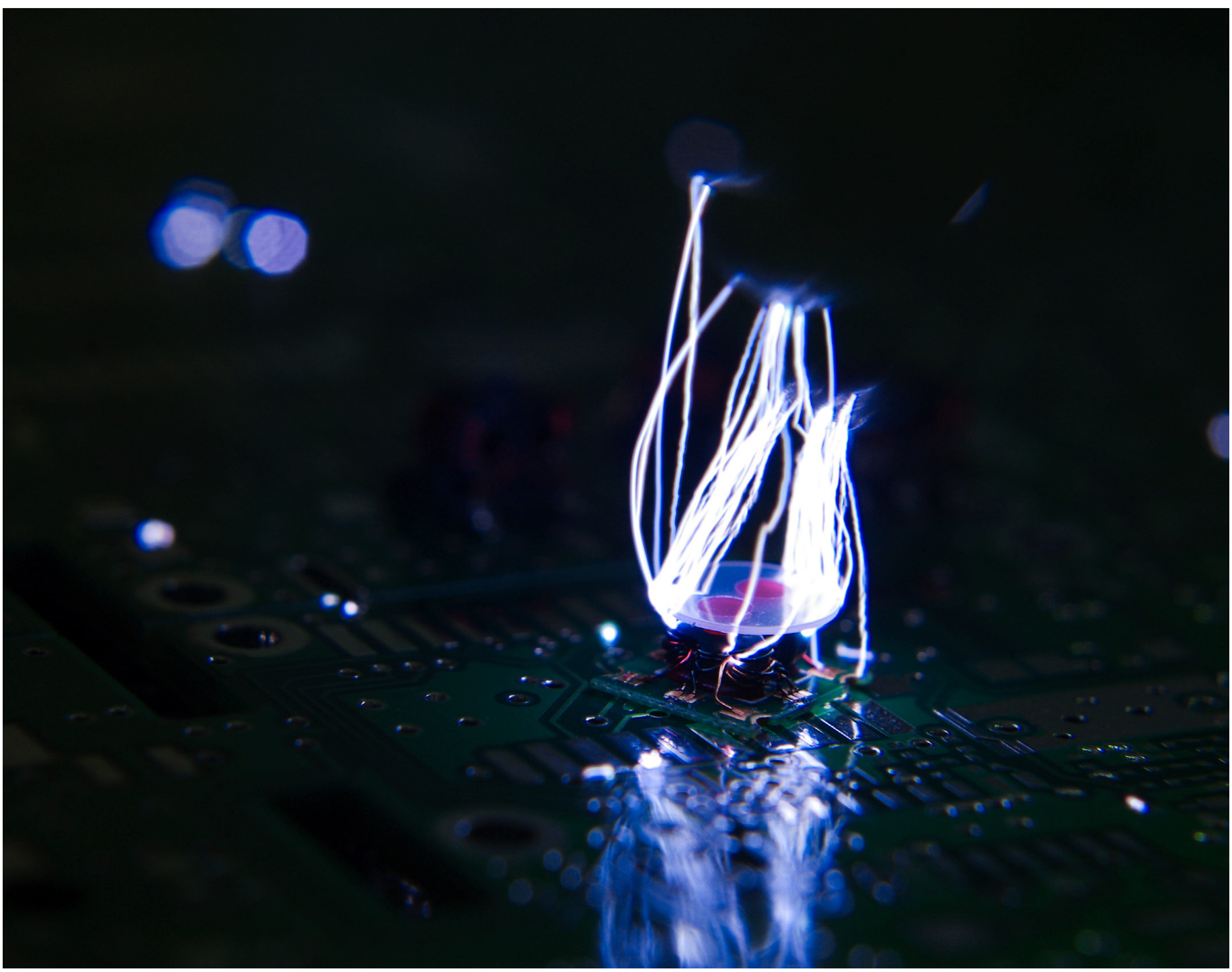
The circuit was tested with 50 positive and 50 negative transients for each of the four tests and the resultant induced transient remained the same throughout. *Table 4* shows the amplitude of the induced transients for each test.

Table 4	
Waveform	Peak voltage
1	4.72
5 A	13 V
3 (1MHz)	13.8
3 (10MHz)	16

Table 4: Induced response with the final protection circuit Waveform Peak voltage.

References

1. Electromagnetic Compatibility: Methods, Analysis, Circuits and Measurements, third edition, D. A. Weston, CRC Press, Taylor and Francis Group, 2016.



DEVELOPING AN IN-HOUSE EMC TROUBLESHOOTING AND PRE-COMPLIANCE TEST LAB

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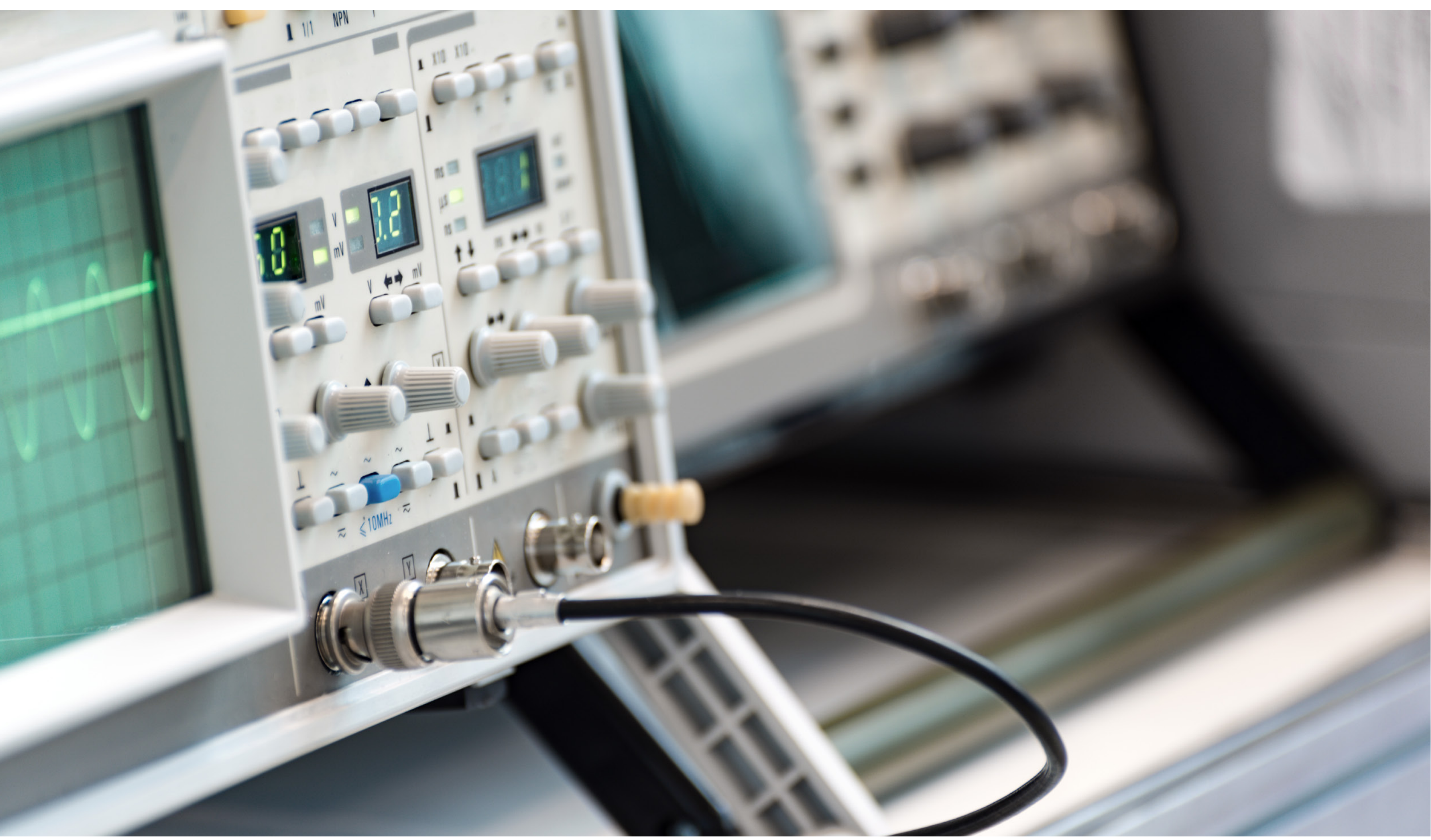
While investing in your own full in-house EMC test laboratory may seem difficult to justify, most companies should be able to afford to implement some level of pre-compliance testing capability. Outside compliance test labs can cost upwards of $2,000 per day. The advantage of being able to perform some of the key tests in-house is that you can quickly determine whether your product is anywhere close to passing. Identifying "red flags" or problem areas early allows more cost-effective implementation of fixes. Waiting until the end of a product development cycle to determine EMC compliance is always very risky and usually expensive in time and money.

As a consultant, I frequently run into clients that have worked for weeks or months to beat down a radiated emissions problem by repeatedly cycling between their R&D lab and third-party compliance test lab. This is very frustrating for both the designers and their management. By performing some very quick and simple tests, you can identify failures, narrow down the root cause, and try various fixes well before taking the product in for full compliance testing.



DEVELOPING AN IN-HOUSE EMC TROUBLESHOOTING AND PRE-COMPLIANCE TEST LAB

Developing Your Own EMI Test Lab

So, what's involved in developing a basic EMC pre-compliance test lab? It's not nearly as expensive as you might think. For example, there are only four common test failures I run into regularly: radiated emissions (RE) is always the number one issue, followed by radiated immunity (RI), electrostatic discharge (ESD), and conducted emissions (CE). With few exceptions and assuming a good power line and I/O port filtering, many of the line- or I/O port-related immunity tests are lower risk and usually pass OK. However, some low-end Asian power supplies do have inadequate or non-existent line filtering, and so I've added the CE test, which is relatively easy to perform.

Briefly, radiated emissions measures the radiated E-fields emanating from the product, equipment, or system under test. There are worldwide limits on how much these emissions can be, depending on the environment the equipment I designed to work in.

Radiated immunity is a measure of how much external E-fields the product or system can tolerate from external sources like broadcast, cellular phones or two-way radios, etc. Electrostatic discharge is a test to see how immune the product or system is to external static discharges, usually from operators touching keypads or touch screens.

Conducted emissions is a measure of the broadband and narrow band noise conducting out the line cord from switch-mode power supplies.

EMI Troubleshooting versus Pre-Compliance Testing

There's a difference between general troubleshooting and pre-compliance testing. General troubleshooting is usually performed with a set of probes and a spectrum analyzer. The goal is to identify sources of harmonic energy and determine fixes that reduce the harmonic amplitudes. Here, we're mainly looking for relative changes.

Pre-compliance testing, on the other hand, attempts to duplicate the way the compliance tests are run to the best ability possible and to compare with actual test limits.

Here is a list of basic equipment required for these four tests:

1. **Radiated Emissions** — While an oscilloscope is very useful for determining rise times and ringing, a spectrum analyzer is really the desired instrument for most EMI troubleshooting and measurement. In addition, you'll want a set of near-field probes, a current probe, a calibrated (or uncalibrated — see *Note 1*) EMI antenna, and possibly a 20 dB gain broadband preamplifier to boost the signal from the probes.
2. **Radiated Immunity** — You'll need an RF generator that can tune the required frequency band and possibly an RF amplifier to boost the signal level.
3. **Electrostatic Discharge** — You'll need an ESD simulator.
4. **Conducted Emissions** — Conducted emissions testing is performed according to CISPR 11 or 22 and requires a LISN between the source of AC line (or DC) voltage and the product under test. A spectrum analyzer is connected to the 50-ohm port and the conducted RF noise voltage is displayed on the analyzer. Different model LISNs are made for either AC or DC supply voltage.

All the above equipment may be purchased on the used market. There is also a new category of "affordable" equipment, as well as lab-quality level equipment, depending on your budget. Generally, most pre-compliance testing does not require very expensive equipment, but you also need to factor in some niceties, such as real-time spectrum analysis for signals that may only appear infrequently or signals, such as wireless communications, that may not display clearly on low-cost swept analyzers. More on this is described in our 2016 *Real-Time Spectrum Analyzer Guide* (*Reference 1*). In addition, there may be important reasons to stick with higher-end lab-quality equipment with their higher performance.

Radiated Emissions

Because radiated emissions is usually the most frequent test failure, most of your investment should be focused on this test. Even so, there is a wide range of test investment choices. For example, a basic troubleshooting test setup I use frequently, is merely an uncalibrated receiving antenna positioned at one end of a workbench, connected to a small bench top spectrum analyzer. The product under test is positioned at the other end of the work bench (*Figure 1*). Cables are attached to the EUT and various troubleshooting techniques are used to help pinpoint product design issues.

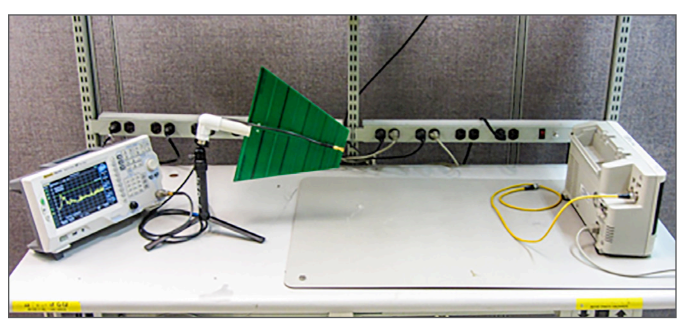


Figure 1: A typical troubleshooting test setup for radiated emissions.

Pre-compliance testing, requires a calibrated EMI antenna positioned either 1 m or (better) 3 m away from the product under test. This way, you'll be able to compare the emissions with actual test limits. The test may be set up in any area large enough and far away from other equipment that could interfere with the testing. Sometimes a parking lot is used. I've more often used a large conference room (*Figure 2*). The one big issue in testing outside a shielded semi-anechoic chamber is you must deal with ambient signals — that is transmissions from broadcast radio/TV, cellular transmissions, and two-way radio.

Figure 2: An example of a 3 m pre-compliance test set up in a large conference room. Note the DIY turntable for helping maximize emissions.

Radiated Immunity

Radiated immunity testing may also be performed using simple troubleshooting techniques or in a shielded semi-anechoic chamber. Most of what I call "pre-compliance" testing is really just using an RF generator and near field probes, or a small Family Radio Service (FRS) license-free walkie-talkie. If the product under test can pass these simple tests, then it's also likely it will pass the formal tests at test levels of 3 V/m or 10 V/m (for commercial/industrial products). Military RI testing will more likely require much higher test levels that fall outside the scope of these simple bench top level tests.

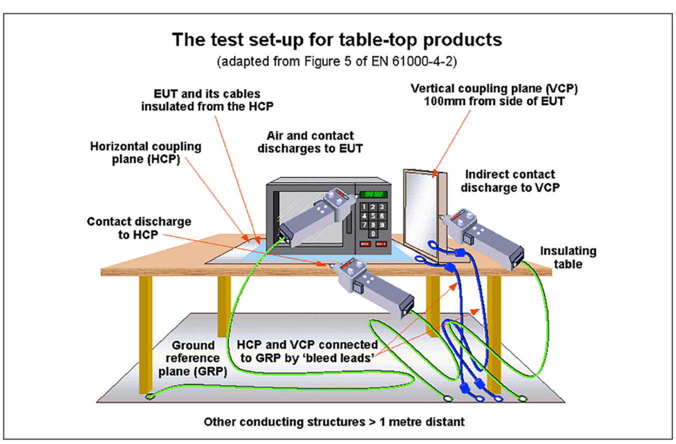


Figure 3: The ESD test setup according to IEC 6100-4-2. Image, courtesy Keith Armstrong.

Electrostatic Discharge

Electrostatic discharge pre-compliance testing can be performed on a work bench, but it's much better to duplicate the test table and ground planes as specified in the IEC 61000-4-2 test standard. This requires certain table dimensions with a conductive table surface and ground plane of certain size underneath. (*Figure 3*).

Conducted Emissions

Conducted emissions testing is performed according to CISPR 11 or 22 and requires a LISN between the source of AC line (or DC) voltage and the product under test. A spectrum analyzer is connected to the 50-ohm port and the conducted RF noise voltage is displayed on the analyzer. Different model LISNs are made for either AC or DC supply voltage.

Summary

Investing in the equipment required to test and troubleshoot the most likely things that cause test failures is usually well worth the expense. Repeatedly moving back and forth between the R&D lab and compliance test lab can consume weeks of time and lead to project cost overruns.

Note on the Use of External Antennas

Note that there are two distinct goals when using external EMI antennas:

1. Relative troubleshooting, where you know areas of failing frequencies and need to reduce their amplitudes. A calibrated antenna is not required, as only relative changes are important. The antenna also does not necessarily need to be tuned to the frequency of the harmonics. Almost any "hunk of metal" connected to the spectrum analyzer should work. The important thing is that harmonic content from the EUT should be easily visible.
2. Pre-compliance testing, where you wish to duplicate the test setup as used by the compliance test lab. That is, setting up a calibrated antenna 3 m or 10 m away from the product or system under test and determining in advance whether you're passing or failing.

References

1. Real-Time Spectrum Analyzer Guide - https://interferencetechnology.com/wp-content/uploads/2016/10/2016-IT-Real-Time-Spectrum-Analyzer-Guide.pdf
2. List of recommended equipment - http://www.emc-seminars.com/EMI_Troubleshooting_Equipment_List-Wyatt.pdf

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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
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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 24	Information technology equipment - Immunity characteristics - Limits and methods of measurement *Will be withdrawn July 2020
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

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MILITARY RELATED DOCUMENTS & 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. Cancelled.

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, 4 April 2013.

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. Cancelled.

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

MIL-STD-331D Fuze and Fuze Components, Environmental and Performance Tests for, 31 May, 2017.

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), 15 Nov, 1991.

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

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, ORGANIZATIONS, LINKEDIN GROUPS)

RECOMMENDED BOOKS, MAGAZINES, & JOURNALS

2019 Directory & Design Guide
Since 1971, this publication has set the standard for all things related to EMI/EMC.
https://learn.interferencetechnology.com/2019-directory-and-design-guide/

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 commercial EMC test failures.

Archambeault
PCB Design for Real-World EMI Control
Kluwer Academic Publishers, 2002.

Bogatin
Signal & Power Integrity - Simplified
Prentice-Hall, 2018 (3rd Edition).
Great coverage of signal and power integrity from a fields viewpoint.

Hall, Hall, and McCall
High-Speed Digital System Design - A Handbook of Interconnect Theory and Design Practices
Wiley, 2000.

Joffe and Lock
Grounds For Grounding
Wiley, 2010.
This huge book includes way more topics on product design than the title suggests. Covers all aspects of grounding and shielding for products, systems, and facilities.

Johnson and Graham
High-Speed Digital Design - A Handbook of Black Magic
Prentice-Hall, 1993.
Practical coverage of high speed digital signals and measurement.

Johnson and Graham
High-Speed Signal Propagation - Advanced Black Magic
Prentice-Hall, 2003.
Practical coverage of high speed digital signals and measurement.

Kimmel and Gerke
Electromagnetic Compatibility in Medical Equipment
IEEE Press, 1995.
Good general product design information.

Mardiguian
EMI Troubleshooting Techniques
McGraw-Hill, 2000.
Good coverage of EMI troubleshooting.

Mardiguian
Controlling Radiated Emissions by Design
Springer, 2016.
Good content on product design for compliance.

Montrose
EMC Made Simple
Montrose Compliance Services, 2014.
The content includes several important areas of EMC theory and product design, troubleshooting, and measurement.

Morrison
Digital Circuit Boards - Mach 1 GHz
Wiley, 2012.
Important concepts of designing high frequency circuit boards from a fields viewpoint.

Morrison
Grounding And Shielding - Circuits and Interference
Wiley, 2016 (6th Edition).
The classic text on grounding and shielding with up to date content on how RF energy flows through circuit boards.

Morrison
Fast Circuit Boards
Wiley, 2018.
Morrison explains how signals propagate via transmission lines and why it's so important to include reference planes for every signal layer.

Ott
Electromagnetic Compatibility Engineering
Wiley, 2009.
The "bible" on EMC measurement, theory, and product design.

USEFUL EMC TESTING REFERENCES (CONTINUED)
(DIRECTORY, BOOKS, ORGANIZATIONS, LINKEDIN GROUPS)

RECOMMENDED BOOKS (CONTINUED)

Paul
Introduction to Electromagnetic Compatibility
Wiley, 2006 (2nd Edition).
The one source to go to for an upper-level course on EMC theory.

Sandler
Power Integrity - Measuring, Optimizing, and Troubleshooting Power Related Parameters in Electronics Systems
McGraw-Hill, 2014.
The latest information on measurement and design of power distribution networks and how the network affects stability and EMC.

Smith and Bogatin
Principles of Power Integrity for PDN Design - Simplified
Prentice-Hall, 2017.
Getting the power distribution network (PDN) design right is the key to reducing EMI.

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
EMC Desk Reference
Interference Technology, 2017.
A handy guide with technical articles and pertinent EMC reference information.

Wyatt & Jost
Electromagnetic Compatibility (EMC) Pocket Guide
SciTech Publishing, 2013.
A handy pocket-sized reference guide to EMC.

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

EMC & DESIGN CONFERENCES 2019-2020

The following is a partial listing of major EMC and electronics design conferences planned for 2019 to 2020 in order of date. If your conference is not listed, please contact: info@interferencetechnology.com

Applied Power Electronics (APEC)
March 15 to 19, 2020
New Orleans, Louisiana, USA
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
- Manufacturers and suppliers of components and assemblies used in power electronics
- Manufacturing, quality and test engineers involved with power electronics equipment
- Marketing, sales and anyone involved in the business of power electronics
- Compliance engineers testing and qualifying power electronics equipment or equipment that uses power electronics

International Exhibition and Conference on Electromagnetic Compatibility EMC (EMV 2020)
March 17 to 19, 2020
Cologne, Germany
https://emv.mesago.com/events/en.html

Europe's most significant exhibition and conference, the EMV, will take place in Cologne and provide a comprehensive overview of the latest trends and developments within electromagnetic compatibility.

Automotive Test Expo | 2020 Europe
June 16 to 18, 2020
Halls 8 + 10, Messe Stuttgart, Germany

https://www.testing-expo.com/europe/en/
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 for the automotive industry.

Automotive Test Expo (includes EMC)
June 16 to 18, 2020
Stuttgart, Germany
www.testing-expo.com/europe/en/

The event is the world's largest vehicle and component testing and validation technology and services exhibition, featuring more than 480 exhibitors and attracting over 9,000 attendees.

The 2020 Symposium on EMC+SIPI
July 27 to 31, 2020
Reno, Nevada, USA
https://www.emc2020.emcss.org/

The 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.

International Symposium and Exhibition on Electromagnetic Compatibility (EMC Europe 2020)
September 7 to 11, 2020
Rome, Italy
www.emceurope2020.org

The Symposium will cover the entire scope of EMC including traditional areas and EMC aspects of emerging technologies as 5G, autonomous drive systems, industry 4.0, IoT, wireless power transfer, nanotechnologies, health, etc

European Microwave Week 2020
September 13 to 18, 2020
Utrecht, Netherlands
www.eumweek.com

The European Microwave Association (EuMA) is an international non-profit association with a scientific, educational and technical purpose. The aim of the Association is to develop in an interdisciplinary way, education, training and research activities.

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