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2019 DIRECTORY & DESIGN GUIDE

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What Is The Most Important EMC Design Guideline?

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Review of MIL-STD 461 CS117 Lightning Induced Transients, Cables and Power Leads

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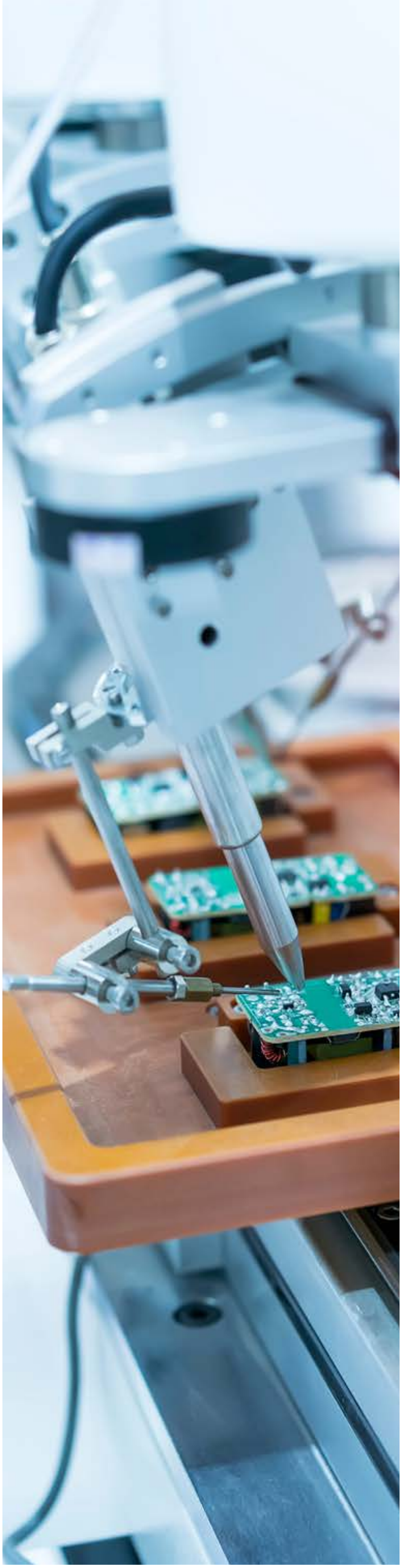

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FROM THE EDITOR:
EMI AND EMC CHALLENGES ABOUND AND GROW

John Blyler
Editor-in-Chief / Interference Technology
john@interferencetechnology.com

This is my first year at the editorial helm of Interference Technology, a publication with a rich 40 plus year history. I don't believe in tampering with success, so my modest goals with I.T. and its publications – like this year's ***Directory and Design Guide*** (DDG) – are simply to continue traditional EMI/EMC technologies while expanding coverage into newer application areas including the Internet-of-Things (IoT), autonomous vehicles, 5G, chip-board packaging and even system-of-systems (SoS). This year's ***EMC Live™*** 2019 event will address the role of EMI/EMC in many of these emerging markets.

This doesn't mean that the traditional markets of electrical/electronic components and modules, avionics, medical, defense and the like will get any less coverage. Instead, I'm hoping that the EMI, EMC and ESD challenges and detailed solutions for these areas will be re-invigorated with a larger perspective.

Examples of the continuing coverage in ***design, military applications*** and ***testing*** are found in this DDG. For example, the **Design Section** contains several articles that deal with EMI challenges at the component level and one article that explains the most important guidelines for EMC design.

Military EMC developers will benefit from the detailed reviews of several key provisions in ***MIL-STD-461***, namely those for intermodulation, cross-modulation and lightning induced transient challenges.

Finally, the **Test Section** provides insights into advanced ESD instrumentation for qualification of shielding bags as well as how to handle EMC laboratory audit items.

Would you like to provide technical content in the above three areas (or others) to help increase the collective knowledge of the design community. If you're interested in contributing technical articles or wish to provide shorter blogs to ***Interference Technology***, check out the "Contribute" link at the bottom of our web site for technical details and feel free to drop me an email with your proposal.

In other news, many of you have downloaded the many free ***Interference Technology*** **Mini Guides**, which focus on several topics within the world of EMC. Plans this year call for updated guides on ***Components & Materials***, ***EMC Fundamentals***, ***Military & Aerospace***, ***EMC Testing***, and ***Automotive EMC.***

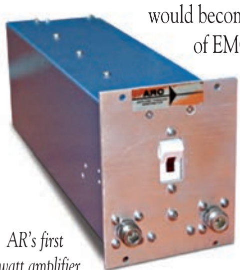
Don't miss our upcoming ***EMC Live™*** 2019 event (May 21 - 23) a worldwide three-day web-based series of seminars and product demos that will be hosted by **Graham Kilshaw**, *CEO of ITEM Media*, and myself. In the last few years, we had over 6000 registrations from over 70 countries attend the event. Registration is now open at: http://emc.live.

Finally, ***Interference Technology*** will again be participating at the **IEEE Symposium** on EMC / SIPI, July 22- 26, 2019. I hope to see you there!

Cheers – John Blyler, EiC

AR RF/Microwave Instrumentation Celebrates 50th Anniversary

50 years ago Don "Shep" Shepherd began designing power amplifiers in the basement of his home, and selling them from the trunk of his car. He and his partner didn't realize it at the time, but they were laying the groundwork for a company that would become a global leader. AR would forever change the world of EMC and RF testing, and positively affect the development of innumerable products in multiple industries.



AR's first 1 watt amplifier.

"My basement was a great place to start," Shep says, "because the only place to go from there was up."

No one envisioned the heights that AR would reach. Within three years, AR was selling amplifiers across the United States and into Europe.

The small company moved to a rented storefront in 1970, then to new headquarters just three years later. As AR grew, it began creating high power RF and microwave amplifiers with capabilities that no one had ever seen before. New innovations changed the industry, and made developing and testing new products much faster, more accurate, and more practical.

First AR storefront property.

Some innovations that catapulted AR to international success include:

- 1976 - Introduction of first 10,000 watt tube amplifier spanning the 10 kHz to 100 MHz frequency range
- 1988 – First 100 watt solid-state, 100 to 1000 MHz linear instantaneous bandwidth amplifier
- 1992 - 500 watt solid-state amplifier that covers 80 to 1,000 MHz
- 2003 - 10,000 watt Class A, 80 kHz to 250 MHz solid-state amplifier
- 2007 - 10-to-20 GHz 5-watt instantaneous bandwidth amplifier

Introduction of first 10,000 watt tube amplifier.

- 2012 - First production 16,000 watt linear solid-state amplifier to 225 MHz
- 2014 - 3,000 watt 1 – 2.5 GHz "S" Series solid-state Class A amplifier
- 2015 – First 50,000 watt Solid-state linear amplifier produced
- 2015 – First production high power linear amplifier capable of covering an instantaneous bandwidth of 0.7 – 6 GHz using microelectronics technology
- 2016 - First production 10,000 watt solid-state amplifier to 1,000 MHz

First 100 watt solid-state, 100-1000 MHz instantaneous bandwidth amplifier built.

Along the way, AR expanded it capabilities to include amplifier modules with the acquisition of Kalmus, now AR Modular RF. It then added Carnel Labs which designed EMI receivers and was eventually called AR Receiver Systems. In 2008 AR Europe was launched to better serve clients throughout the U.K., France, Benelux, and Germany. AR later acquired Sunol Sciences Corporation, now providing positioning equipment and antennas for EMC and Wireless Testing as SunAR RF Motion.

In 2017 and again in 2018 AR was awarded the EMC Product of the Year. Even as it enters its 50th year, AR continues to blaze new trails and set higher standards.

AR Europe is launched with AR United Kingdom, AR France, AR Benelux and now AR GmbH.

Mr. Shepherd sums it up like this: "With the combined resources of all the AR companies, we simply have more options, more solutions and more innovations. Our customers get the benefit of it all when they connect with any AR company."

First 50,000 watt Solid-state linear amplifier.

We can only wonder what's in store for the next 50 years.

For more information, call AR RF/Microwave Instrumentation at 215 723 8181 or visit us at www.arworld.us.

AR acquisition of Kalmus, now AR Modular RF.

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AR acquires Sunol Sciences Corporation, now SunAR RF Motion.

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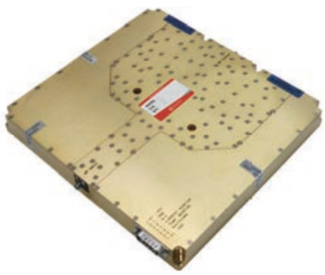

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Ten Tips to Minimize EMI from On-Board DC-DC Converters

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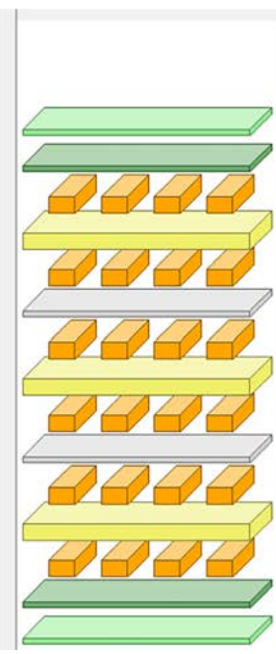
It is fairly common to find multiple on-board DC-DC converters on today's portable, mobile, and IoT devices. If the device uses wireless, GPS, or cellular technologies, the EMI from these converters (which generally use switching frequencies between 1 and 3 MHz) often interferes with the receiver performance of the wireless modules.

The problem really crops up for low-band cellular (700-900 MHz) or GPS (1575.42), and perhaps less so for Wi-Fi (2.4 GHz), as the harmonic emissions from these converters often extend up to 2 GHz, or more. Cellular providers have strict receiver sensitivity requirements and the Total Isotropic Sensitivity (TIS) is one of the tests performed during CTIA compliance. If the receiver is not sensitive enough, the product will not be allowed onto the cellular system (*References 1* and *2*).

This article describes the top ten methods for reducing the emissions from these DC-DC converters. They are listed in no particular order - ALL are important.

1. **Specify low-EMI converters.** Both Texas Instruments (TI) and Analog Devices / Linear Technologies (AD) continue to develop low-EMI devices. AD recently developed their Silent Switcher, which accommodates locating the input and output capacitors particularly close to the IC package. Their newer Silent Switcher 2 low-EMI converters incorporate both the input and output capacitors and their associated loops, within the IC package. Finally, their "µModule" series of converters also incorporate the output inductor, as well. While more expensive, these are all particularly quiet for EMI.

2. **Use a proper PC board stack-up.** Most of my clients get this wrong (*Figure 1*). All signal layers must have an adjacent ground reference plane (GRP) and all power traces (or planes) must also have an adjacent GRP (*Figure 2*). This is because all microstrip, stripline, and power routing should be considered transmission lines in today's fast digital technology. If this rule is not followed, expect noise and signal coupling between circuits (one form of crosstalk), radiated EMI, and board edge radiation directly into the antenna.



Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant
Top Overlay	Overlay				
Top Solder	Solder Mask/Coverlay	Surface Material	0.4	Solder ...	3.5
Top Layer	Signal	Copper	1.4		
Dielectric	Dielectric	Core	7	FR-4	4.2
GND	Signal Gnd	Copper	1.4		
Dielectric 3	Dielectric	Prepreg	15	FR-4	4.2
Signal Layer 1	Signal	Copper	1.4		
Dielectric 5	Dielectric	Core	10	FR-4	4.2
Signal Layer 2	Signal	Copper	1.4		
Dielectric 4	Dielectric	Prepreg	15	FR-4	4.2
Power	Signal Power	Copper	1.4		
Dielectric 1	Dielectric	Core	7	FR-4	4.2
Bottom Layer	Signal	Copper	1.4		
Bottom Solder	Solder Mask/Coverlay	Surface Material	0.4	Solder ...	3.5
Bottom Overlay	Overlay				

Figure 1 - A very common, but poor, EMI stack-up design (6-layer example). Signal layers 4 and 6 are referenced to power, while the GRP and power planes are non-adjacent with two signal layers in between. This will couple power transients on those two signal layers.

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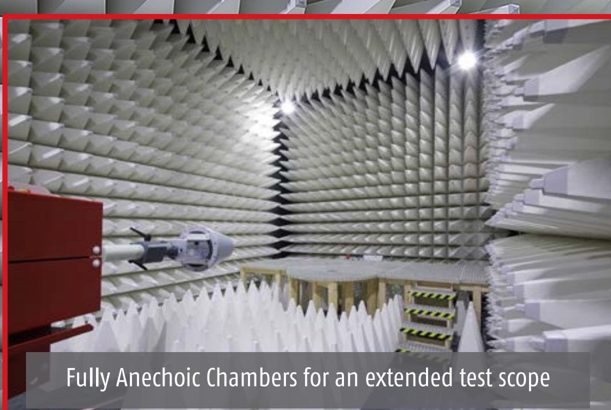

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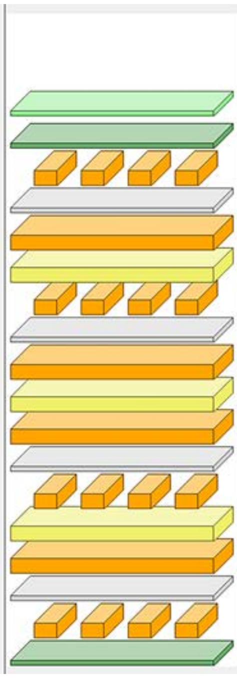

Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant
TOP SILK	Overlay				
TOP MASK	Solder Mask/Cover	Surface Material	0.04	Solder ...	3.5
Top	Signal	Copper	1.417		
Dielectric1	Dielectric	Prepreg	5	FR-4	4.2
Layer02	Internal Plane Gnd	Copper	0.7		
Dielectric 10	Dielectric	Core	10		4.2
Layer03	Signal	Copper	0.7		
Dielectric 5	Dielectric	Prepreg	10		4.2
Layer04	Internal Plane Gnd	Copper	0.7		
Dielectric 3	Dielectric	Core	4		4.2
Layer05	Internal Plane Pwr	Copper	0.7		
Dielectric 2	Dielectric	Prepreg	10		4.2
Layer06	Signal	Copper	0.7		
Dielectric 8	Dielectric	Core	10		4.2
Layer07	Internal Plane Gnd	Copper	0.7		
Dielectric 9	Dielectric	Prepreg	5		4.2
Bottom	Signal	Copper	1.417		
BOT MASK	Solder Mask/Cover	Surface Material	0.04	Solder ...	3.5

Figure 2 - A good EMI stack-up design (8-layer example). All signal layers are referenced to an adjacent GRP, while power is also referenced to an adjacent GRP.

3. **The ground reference plane (or planes) must be solid.** Fast switching signals or converter traces crossing gaps or slots within the ground reference plane (GRP) will couple EMI throughout the board and can couple into sensitive receivers. Note that some of TI's older data sheets (*Note 1*) recommend carving away the GRP (and all other signals) from around the path of the circuit trace from the converter SW node to the input of the output inductor. This is incorrect! This trace MUST be adjacent to a solid GRP. Otherwise, their layout suggestions are OK. Please refer to the video demo explaining why gaps in the GRP are a disaster for EMI (*Reference 3*).

4. **Keep all DC-DC converter circuitry on the top layer and over an adjacent GRP.** One issue that creates noise coupling is running fast switching signals from the top to bottom of the PC board. I had one client locate the converter circuitry on top and the output inductor at the bottom of their board. The resulting 3 MHz switching currents flowing from top to bottom and back created enough interference to block on-board GPS reception. If fast rise-time signals must be routed from top to bottom, this generally requires an adjacent stitching capacitor (connected power to GRP) located next to the via to provide a nearby return path for the signal current back to the source.

5. **Keep all DC-DC converter circuitry extremely close to the converter IC.** DC-DC converters always have an input current loop and an output current loop (*Figure 3*). These loop areas must be minimized! IC manufacturers are starting to recognize EMI is an issue and warn designers about this. The converter manufacturers often (towards the end of the data sheet!) offer a suggested layout. Layout suggestions in the last 2-3 years are usually accurate. If older than that, are often incorrect. Both the input and output capacitors, along with the output inductor, should be located as close to the IC package as possible to minimize these loops.

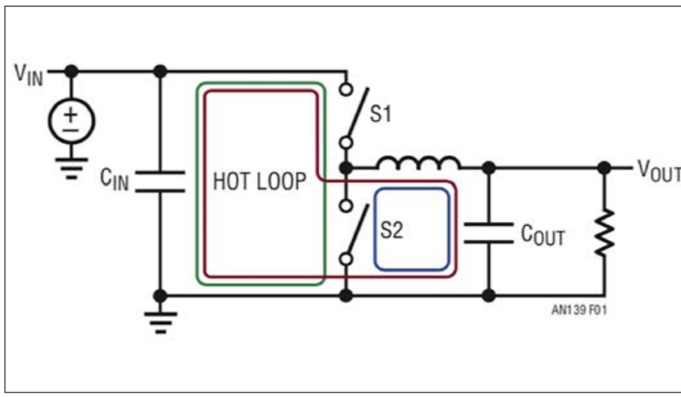

Figure 3 - An illustration showing the two "hot" current loops in typical DC-DC buck converters; one on the primary input and one on the secondary output. Courtesy, Analog Devices / Linear Technology AN-130.

6. **Locate DC-DC converter circuitry close to the power entry of the board.** This will tend to localize the switching currents away from sensitive wireless modules (*Reference 4*). However, there may be cases where the wireless module manufacturer wants a converter located near the module. If this is the case, observe all the other rules and face an increased risk in EMI coupling directly to the antenna!

7. **The output inductor should be a shielded design.** There are two types of inductor; shielded and unshielded. Always use a shielded inductor, because this tends to confine the magnetic H-field better. If you can see the windings, it's an unshielded design (*Figure 4*)!

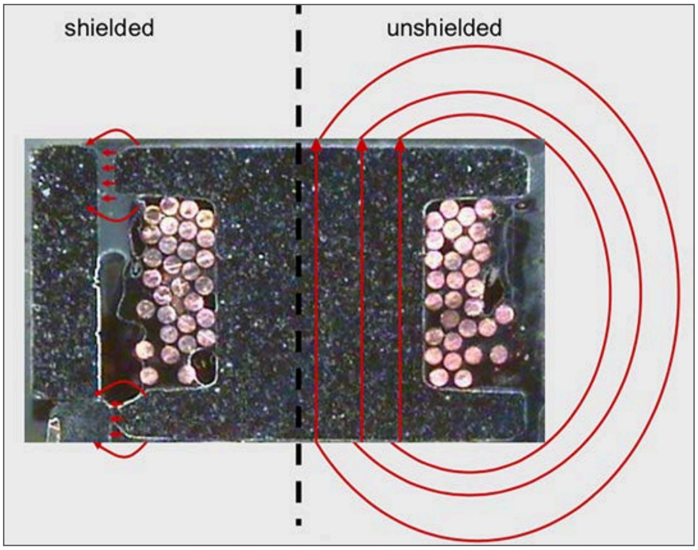

Figure 4 - A cross section of two typical ferrite core inductors. You can see the turns in the unshielded style (right side), but not in the shielded style (left side). The extra ferrite shield confines the magnetic field much better (red arrows). Courtesy, Würth Elektronik eiSos.

8. **Orient the output inductor for lowest EMI.** Inductors have a "start" and an "end" on the winding. The start terminal is sometimes marked on the top of the body with a half-circle or dot (*Figure 5*). Because the start of the winding is buried by the total turns, it is somewhat shielded by those same turns. Orient the start of the winding so it connects to the switched output (often labeled "SW") of the DC-DC converter IC. The end of the winding connects to the output filter, so it's going to be quieter than the start of the winding.

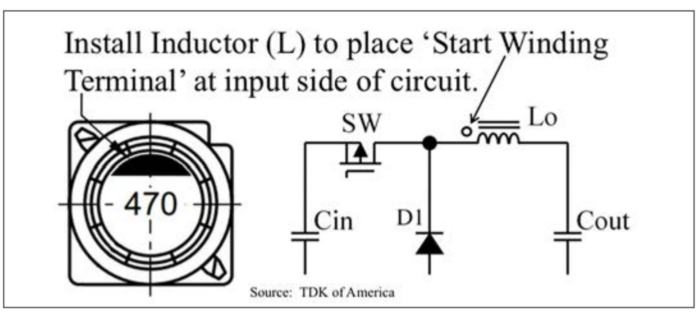

Figure 5 - Some ferrite inductors have a mark of some kind, such as TDK's half-moon, indicating pin 1 (the start of the winding). On Würth Elektronik parts, this is generally a dot. Courtesy Rick Hartley Enterprises and TDK of America.

9. **The DC-DC converters will likely require local shields.** Despite the use of magnetically-shielded inductors, good PC board design, and layout practices, there will still be a strong H-, and especially E-fields, generated around the circuit loops and output inductor. Design your PC boards to accommodate these local shields at the start by adding "fencing solder strips" connected to the GRP. If you don't need them, great.

10. **Locate antennas and coax cables far from converter circuitry.** Antennas and their associated coax cables, if used) should be located as far as possible from DC-DC converters. The input circuit loop of large voltage drop buck converters will have a relatively high dV/dt and the associated electric field can couple directly into the receiver.

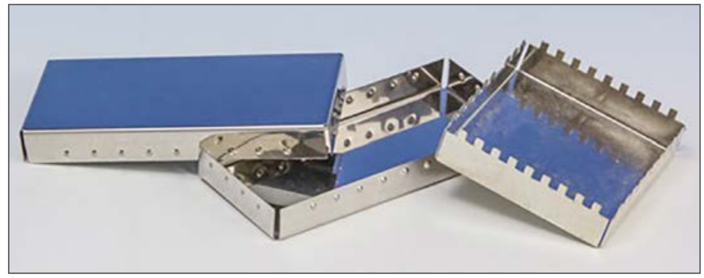

Figure 6 - Examples of local shields that can be soldered to designed-in fencing connecting to the GRP. These should be mounted over the DC-DC converter IC and associated circuitry.

Note 1 - Some of TI's older data sheets (examples below) recommend removing the GRP surrounding the output node (and sometimes the input node, as well) of their DC-DC converter designs or demo boards. This is incorrect, in my opinion, as noted above in *Tip 4*.

- SLVU437A (rev 7/2013) - TPS621X0-505 EVM series
- SLVSAG7E (rev 8/2016) - TPS62130-series
- SLVC394 - Gerbers for the TPS62130-series demo board

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AUTHOR BIO

Kenneth Wyatt is principal consultant of Wyatt Technical Services LLC and spent three years as the senior technical editor for *Interference Technology Magazine* from 2016 through 2018. He has worked in the field of EMC engineering for over 30 years with a specialty is EMI troubleshooting and pre-compliance testing. He is a co-author of the popular *EMC Pocket Guide* and *RFI Radio Frequency Interference Pocket Guide*. He also coauthored the book with Patrick André, *EMI Troubleshooting Cookbook for Product Designers*, with forward by Henry Ott. He is widely published and has authored *The EMC Blog* hosted by EDN.com for three years. Kenneth is a senior member of the IEEE and a longtime member of the EMC Society. To contact Ken or for more information on technical articles, training schedules and links, check out his web site: http://www.emc-seminars.com.

DESIGN

What is the Most Important EMC Design Guideline?

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INTRODUCTION

EMC design guidelines have always been a popular subject in the EMC design community. What is the most important EMC design guideline, i.e. the guideline with the highest impact on the emission and immunity of electronic circuitry? Studying books and literature from renowned EMC experts often tells us that the most important EMC design guideline is[1]:

- **Minimize loop areas associated with high-frequency (HF) signal currents.**

My preferred design guideline is another one. In this article we will show with an experiment demonstration that there is another design parameter that has much more impact on the EMC behavior of an electronic circuit than just the loop area of the signal current. Do you want to know which design parameter this is? Read on.

EXPERIMENT DEMONSTRATION

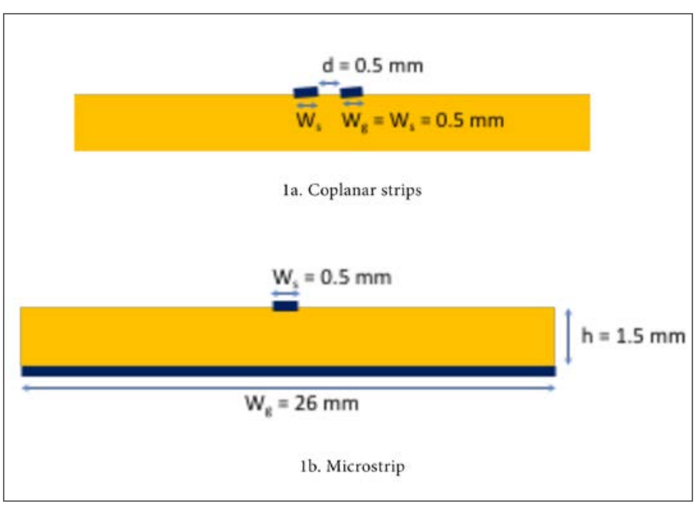

Figure 1. Printed Circuit Board configurations

The experiment demonstration consists of two configurations on a printed circuit board: a coplanar strips line and a microstrip line (*Figure 1*). Both lines have a length l = 100 mm. The coplanar traces have a width $W_{signal} = W_{ground} = 0.5$ mm. The distance between the two traces d = 0.5 mm. The microstrip has a trace width $W_{signal} = 0.5$ mm. The width of the ground plane underneath the trace is $W_{ground} = 26$ mm. The height of the trace above the ground plane is h = 1.5 mm. The copper thickness is 35 µm and the relative dielectric constant of the FR4 board material is $\varepsilon_r = 4.7$.

Figure 2 shows the demo board with the coplanar strips and microstrip lines.

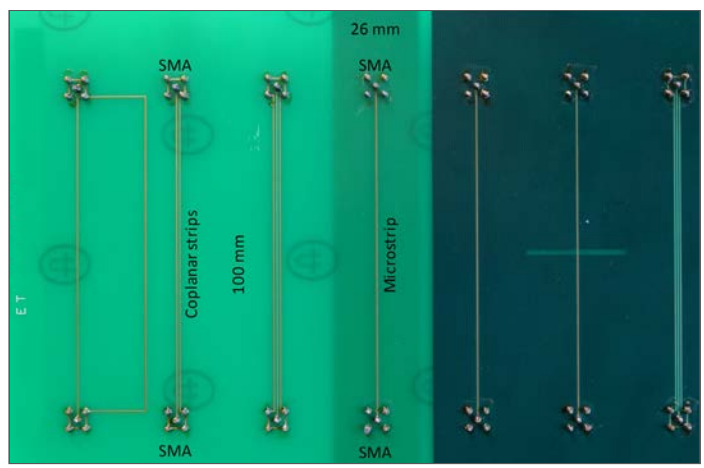

Figure 2. Demo board with coplanar strips and microstrip lines

Figure 3 shows the measurement setup. On the demo board both lines are terminated with an SMA 50 Ω RF load. The input of the line is connected to the tracking generator output of the Rigol DSA815 spectrum analyzer with an RG223 double braided coaxial cable of 1 m length. The tracking generator output level is 100 dBµV (100 mV) over the frequency range 30 MHz to 300 MHz. For the frequencies involved the length l of the board traces is small compared to the wavelength (l << 1 m). In both lines flows a differential mode (DM) current $I_{DM} = 100$ mV/50 Ω = 2 mA. With a current monitoring probe from Fischer Custom Communications (F-61) the common-mode (CM) current on the double braided coax cable is measured. The current probe is connected to the input of the spectrum analyzer. By shifting the current probe along the cable with the spectrum analyzer in the max hold mode the maximum CM current is recorded. The results will be discussed in the next section.

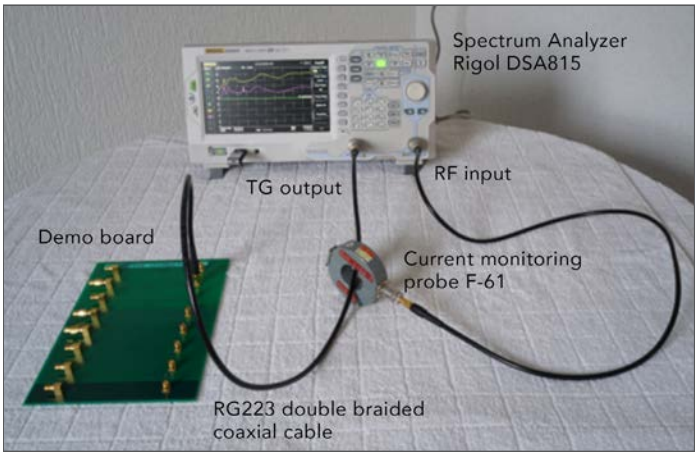

Figure 3. Measurement setup Common-Mode current generated by coplanar strips and microstrip

Now let's have a look to the loop area of the high frequency signal current. For the coplanar strips line, the signal current loop area is approximately (taking the proximity effect into account) l × d = 100 mm × 0.5 mm = 50 mm^2. The microstrip line has a signal current loop area l × h = 100 mm × 1.5 mm = 150 mm^2. In our experiment demonstration the current loop area of the microstrip configuration is 3 times (10 dB) larger than that of the coplanar strips configuration.

At high frequencies (> MHz), signal currents take the path of least impedance, this is generally the path of least inductance, which is generally the path that minimizes the loop area. Currents return as close as possible to the path of the outgoing current. In the case of the microstrip most of the return current flows in the ground plane directly underneath the signal trace.

RESULTS AND DISCUSSION

The measurement results of the maximum CM current for the coplanar strips and microstrip configuration are depicted in *Figure 4*. Over the full frequency range from 30 MHz to 300 MHz the coplanar strips line generates approximately 20 dB higher CM currents than the microstrip line, although its current loop area is 10 dB smaller. The CM current limit line of 10 dBμA (3 μA) shown in *Figure 4* is based on the far field radiation of a resonant half wave dipole antenna and corresponds roughly with a maximum electric field strength of 30 μV/m (30 dBμV/m) at a 10-meter distance from the antenna (legal radiated emission limit). The current probe F-61 has a transfer impedance of 20 Ω in the frequency range 30 MHz to 300 MHz. So, a current of 3 μA will give at the 50 Ω input of the spectrum analyzer a voltage of 3 μA × 20 Ω = 60 μV = 36 dBμV.

What is the physics behind this CM current generation? The DM current I_{DM} in the circuit loop on the board induces a CM voltage V_g across the ground return conductor. This CM ground voltage V_g acts as the antenna voltage for the cable connected to the board and generates antenna currents (CM currents) on the shield of the coax cable. The cable is an efficient antenna in the frequency range 30 MHz to 300 MHz and in the graphs in *Figure 4* the cable resonances are clearly visible. The radiated emission is proportional to the antenna current (CM current).

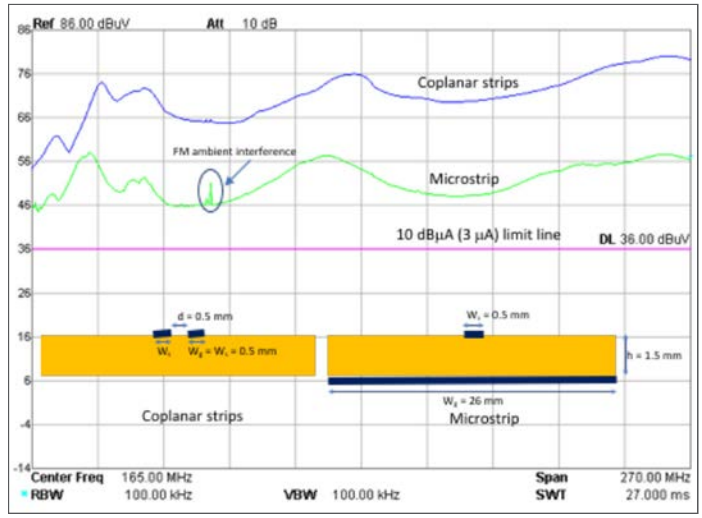

Figure 4. Measurement results common-mode current coplanar strips versus microstrip

The CM ground voltage is determined by the partial inductance of the ground return lead: $V_{CM} = I_{DM} 2\pi f L_g$.

As a first order approximation for the partial inductance of a microstrip ground plane we can use the formula[2]:

$$L_g \approx (\mu_0 h)/(2W_g) \text{ if } W_g >> h \quad \text{permeability } \mu_0 = 4\pi 10^{-7} \text{ (H/m)}.$$

The ground plane inductance L_g (Henry/m) is proportional with the trace height h (m) above the plane and inversely proportional with the ground plane width W_g (m).

For our microstrip configuration (h = 1.5 mm, W_g = 26 mm) the resulting ground plane inductance is:

$$L_{g\ microstrip} = 36 \text{ nH/m}.$$

For our coplanar strips configuration (d = 0.5 mm, W_g = 0.5 mm) the inductance of the ground return trace is approximately:

$L_{g\ coplanar\ trace}$ = 300 nH/m, i.e. an 18 dB higher inductance than that of the microstrip ground plane.

This difference of approximately 18 dB in ground return inductance is reflected in the CM current (radiated emission) plots of the coplanar strips and microstrip in *Figure 4*. The lower the ground return inductance the lower the radiated emission. In[3] the theory of partial inductance to control emissions is explained very clearly.

CONCLUDING REMARKS

From the experiment we learn that although the differential mode current loop area of the microstrip line is much larger (10 dB) than that of the coplanar strips line the radiated emission of the microstrip line is much lower (20 dB) in the frequency range 30

MHz to 300 MHz. The main reason for this behavior is the partial inductance of the ground return lead. The ground plane of the microstrip has a much lower inductance than the ground trace of the coplanar strips, which results in a much lower common-mode ground voltage for the microstrip line and consequently a much lower radiated emission. The design parameter that has the highest impact on the EMC performance of an electronic circuit is not just the signal loop area but the partial inductance of the ground return conductor.

We may conclude that the most important EMC design guideline is:

- **Minimize the inductance of the ground return conductor.**

On a printed circuit board this can be realized by making the ground return conductor shorter, placing the signal trace closer to the ground plane AND by making the ground return plane wider. This is also valid for flex foil cables. The ultimate example of an extremely low ground return inductance (low transfer impedance) is an HF coax cable with a semi-rigid coaxial shield. This solid shield results in hardly any field leakage, assuming perfect connectors.

Do you have a different opinion? Let's start a discussion!
Contact Marcel at: marcel.van.doorn@home.nl

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AUTHOR BIOGRAPHY

Marcel van Doorn was born in Tilburg, The Netherlands, in 1954. He received the Master of Science (M.Sc.) degree in electrical engineering from the University of Technology Eindhoven in 1982.

From 1983 to 1986 he worked at the Dutch Railways in Utrecht. In 1986 he joined Royal Philips Electronics in Eindhoven, where he worked as Technology & Strategy manager in many different areas of the Electro-Magnetic Compatibility (EMC) domain, from testing and standardization, to design and research. He has given many international EMC trainings for the Philips University and to post academic students.

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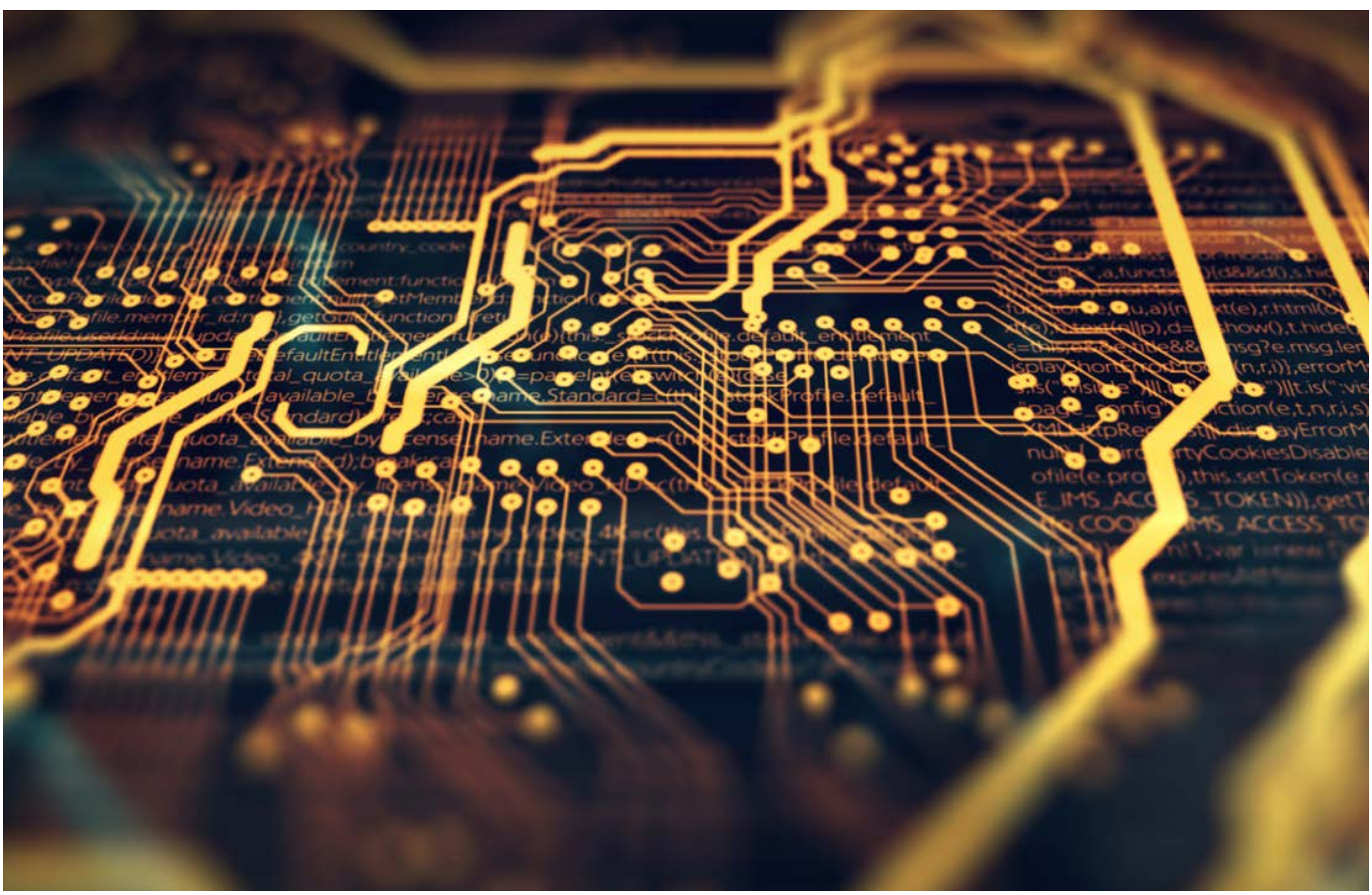


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Be Careful With Low Cost/Quality Common Mode Chokes

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In one of the projects I was involved several weeks ago; a product was failing in conducted emissions on an AC power supply line. Measuring with a LISN (Line Impedance Stabilization Network) the problem was related with common mode emissions.

The designer of the circuit tried to work with a common mode choke to reduce emissions (Y capacitors were not possible for this application).

He was using a low cost (this is important!), common mode choke using toroidal core.

For that component he had several samples for testing and, initially, the choke looked like an effective solution in the trials inside of the company. Let's name the choke used CHKA.

With the promising result in the company, a prototype was especially prepared to go to an external lab (time to cross fingers!). But, in the external lab the product failed again (I think you have experimented similar situation), and a typical question comes to your mind: "How is possible that the solution in the company was failing in the external lab?"

The answer to that question lies, as usual, in discovering what is different between both scenarios.

Analyzing the problem I discovered that the choke used in the prototype for the external lab was a different unit from that soldered in the original prototype. Same part number, same manufacturer, same samples box, but …. a different unit, not EXACTLY the choke used in the company. Let's name the second choke CHKB.

Before explaining the reason for the failure, let's review the basics for a common mode choke.

A common mode choke is a coupled inductor: two inductors are built using the same core. Note the winding strategy (*Fig. 1*) is very important to obtain a common mode choke.

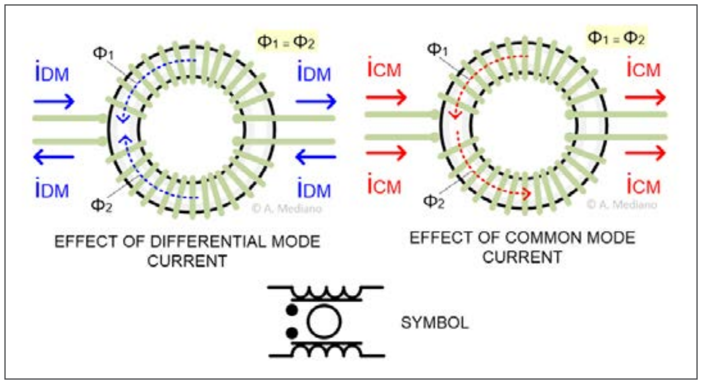


Fig. 1. Ideal common modes choke for differential currents (left), common mode currents (mid), and symbol for schematics (right).

For this ideal choke, magnetic flux in the core because the differential mode currents iDM (*Fig. 1*, left) cancel each other resulting in a zero impedance. But magnetic flux caused by common mode currents iCM (*Fig. 1*, right), is accumulated resulting in a high amount of impedance value. The symbol for this kind of choke (*Fig. 1*, Symbol below) uses two points to specify how the windings must be done to obtain that behavior.

Summarizing, an ideal common mode choke looks like a simple wire for differential mode signals while it looks like an inductor for common mode signals. One of the advantages for this kind of chokes is they will not be saturated by differential mode currents. For those coupled inductors, coupling factor k can be calculated from *Eq. 1*:

$$k = M/\sqrt{(L1 \times L2)} \qquad \text{(Eq. 1)}$$

and common mode and differential mode inductances can be obtained from *Eq. 2:*

$$LDM = 2 \times (L-M) \text{ and } LCM = (L+M)/2 \qquad \text{(Eq. 2)}$$

where M is mutual inductance and L1,L2 are inductances for both inductors.

Considering the inductors are equal, L1 = L and for 100% of perfect coupling k=1, mutual inductance M is from *Eq. 1* equal to inductance L (M=L) and common and differential mode inductances are, from Eq. 2, LDM =0 and LCM = L.

So, it is confirmed that we will find not impedance effect for differential mode signals and some value of impedance for common mode signals.

In a real common mode choke the cancellation is not perfect. As a result, the differential mode impedance is not zero. This effect is called some times, "leakage". This is useful for filtering differential mode signals but the saturation effect must be checked in high current applications.

Let's go back to our example failing in the laboratory. To analyze the situation, I measured the response of both chokes with my Bode 100 network analyzer (a really useful instrument if you are interested in frequencies up to 50MHz).

A simplified measurement of a common mode choke can be done as shown in *Fig. 2*:

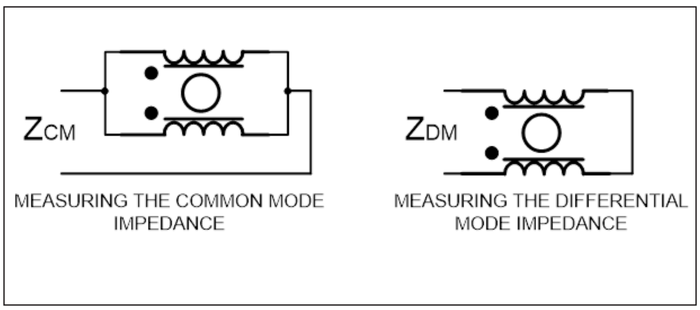


Fig. 2. Simplified measurement of impedances for a common mode choke.

The choke working satisfactorily in our application (CHKA) was measured and results are in *Fig. 3*:

You can see how big is the impedance of the common mode effect compared with the differential mode effect.

For the second choke (CHKB), the one failing in the laboratory, I was able to see a very subtle difference: one of the coils of the choke had ONE TURN missing (*Fig. 4*).

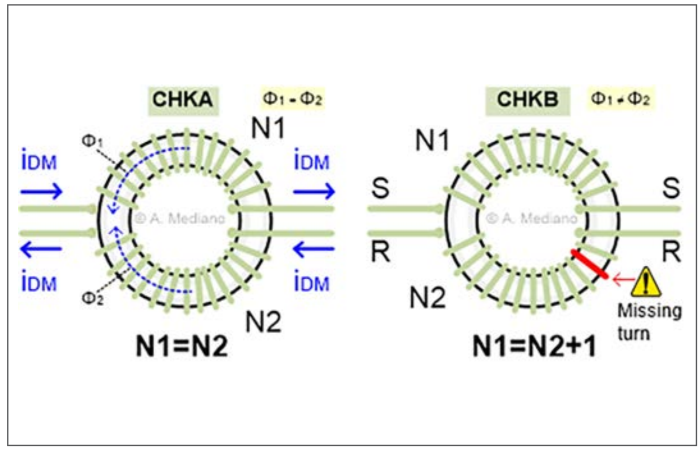


Fig. 4. The chokes used in our example.

CHKA had 14 turns for L1 and L2. CHKB had 14 turns for L1 and 13 turns for L2.

This is a very critical difference. If one of the coils is not exactly as the other, the common mode inductance will be reduced (poor common mode filtering) and the differential inductance will increase (perhaps the core can be saturated with the nominal current in high current applications).

This kind of cores are manually winded so human errors and/or low quality tests can created this difficult to find problems.

The comparison of both chokes is included in *Fig. 5* (page 18):

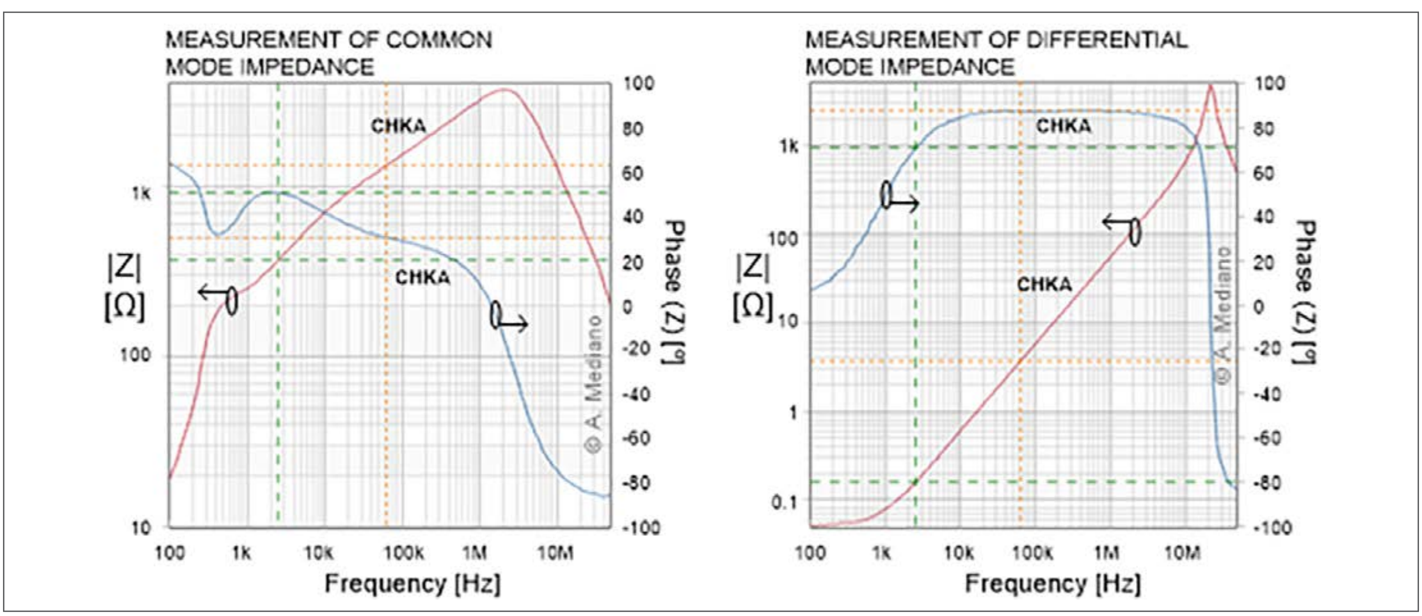


Fig. 3. CHKA simple characterization.

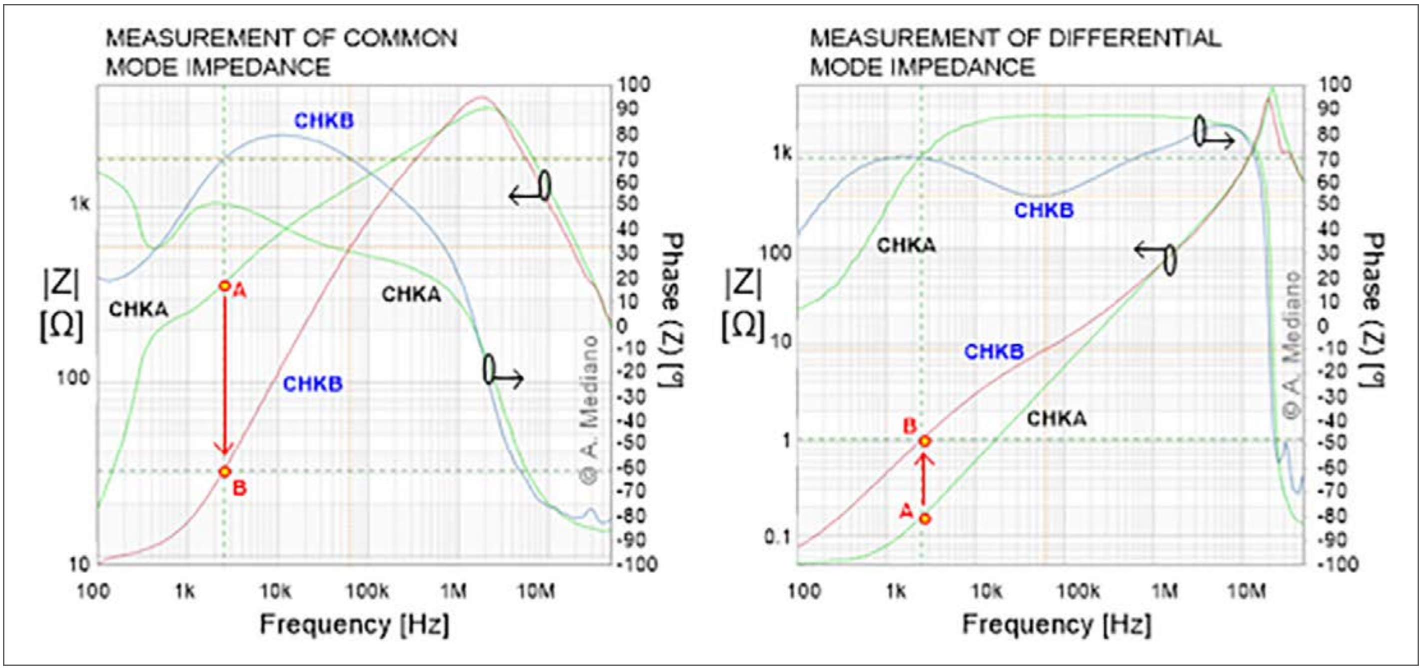


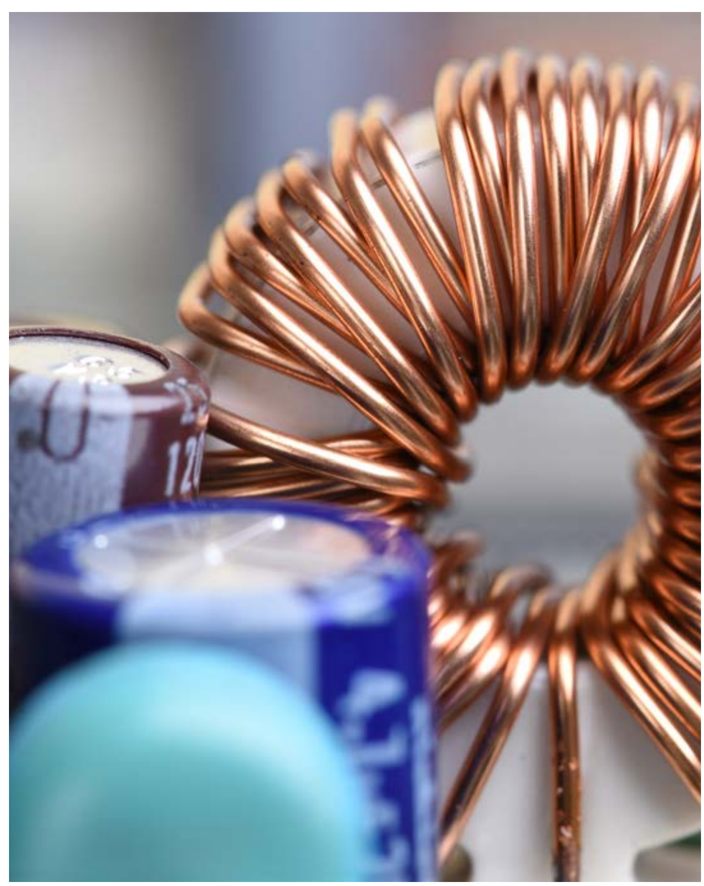
Fig. 5. Comparing chokes CHKA and CHKB.

From the measurements it is clear how important is a perfect symmetry for the two coils in the choke. With only one turn missing in one of the coils the common mode impedance (*Fig. 5*, left) is drastically reduced as for example from point A to point B at same specific frequency. The result will be a lower effectiveness to filter common mode EMI signals.

In the same way, the differential mode inductance increases from A to B (*Fig. 5*, right) with a typical effect of saturation of the core. Let me conclude this post with two important advices: 1) be careful with low cost/low quality components; and, 2) try to have a network analyzer or impedance analyzer in your laboratory to check how the component you are using in your design is. And of course, good luck in your next design!

AUTHOR BIOGRAPHY

Arturo Mediano received his M.Sc. (1990) and his PhD. (1997) in Electrical Engineering from University of Zaragoza (Spain), where he has held a teaching professorship in EMI/EMC/RF/SI from 1992. From 1990, he has been involved in R&D projects in EMI/EMC/SI/RF fields for communications, industry and scientific/medical applications with a solid experience in training, consultancy and troubleshooting for companies in Spain, USA, Switzerland, France, UK, Italy, Belgium, Germany, Canada, The Netherlands, Portugal, and Singapore. He is the founder of The HF-Magic Lab®, a specialized laboratory for design, diagnostic, troubleshooting, and training in the EMI/EMC/SI and RF fields at I3A (University of Zaragoza), and from 2011, he is an instructor for Besser Associates (CA, USA) offering public and on site courses in EMI/EMC/SI/RF subjects through the USA, especially in Silicon Valley/San Francisco Bay Area. He is Senior Member of the IEEE, active member from 1999 (Chair 2013-2016) of the MTT-17 (HF/VHF/UHF) Technical Committee of the Microwave Theory and Techniques Society and member of the Electromagnetic Compatibility Society. Arturo can be reached at a.mediano@ieee.org.



MIL-STD-461 Series - Review of MIL-STD 461 CS103 Intermodulation, CS104 Rejection of Undesired Signals and CS105 Cross-Modulation

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INTRODUCTION

Rapid technology advances in the wireless communications world makes test and evaluation of Radio Frequency (RF) devices a difficult subject. It seems that by the time a new device hits the market, it has been made obsolete by the next generation. I recall hearing from a major electronics manufacturer CEO that 90% of sales happens within 90-days of market release prompting the need for a successor. This applies to commercial products, but similar technology leaps will follow the military equipment demands from the propensity to use commercial-off-the-shelf (COTS) technology for DoD systems.

Many frequency sources are present that operate in close-proximity in our daily life and within military operations including ships, vehicles and aircraft. As the Internet of Things (IOT) expands, the military usage will expand to add more complexity to the spectrum usage and the demand for receiver operations must be included.

The three test methods we are reviewing apply to receivers to assess performance degradation from RF signals arriving at the receiver antenna port. Let's quickly go over the three topics involved to support the test method discussions that follow.

1. *Intermodulation* – Intermodulation results from combining of several signals in a non-linear device. Harmonics of a frequency plus sum and difference frequencies as well as multiples of the frequencies may be created. If the amplitude of undesired frequencies is adequate for reception and the frequency is at the operating receiver frequency, interference can result in degrading the receiver performance. Many non-linear devices may be present in a receiver and non-linear junctions may be created at conductor junctions such as connectors or fractured solder joints. Rusty bolt syndrome has been used to describe certain passive intermodulation causes.

2. *Rejection of Undesired Signals* – Tunable receives selectively accept a desired frequency while preventing other frequencies from being detected. The ability of a receiver to reject other than the tuned frequency is a measure of receiver performance. This can support intermodulation performance rejection by attenuating signals prior to their arrival at a non-linear junction.

3. *Cross-Modulation* – Cross modulation may appear when high-level amplitude modulated signals cause an over-drive condition in a receiver creating non-linear operation resulting in a transfer of the undesired signal modulation to the intentionally received signal. This condition may exist when the strong carrier is within the same band as the desired tuned frequency.

MIL-STD-461G, the current revision, lists these tests with limited applicability with the limitation to RF receiver susceptibility. With the release of MIL-STD-461D and MIL-STD-462D and remaining today the standard defers to the procurement specification for limits and methods with only general testing techniques being provided. This approach is taken because today's technology provides a vast array of wireless communications and the basic techniques from early days of MIL-STD-461 may not reveal risks.

The testing evaluates the receiver, not external causes that produce an input causing susceptibility, so the test configuration needs close attention to prevent false indications. Connector adapters, poorly bonded junctions and contamination can create passive intermodulation; signal source harmonics can provide an in-band signal appearing as a lack of rejection, so pay close attention to the setup minimizing excessive components and connections.

As we review the testing approach, please note that the specific testing defined in the procurement specification will take precedence – this review is to provide an understanding of the goals and will require that a detailed test procedure be developed for a specific device receiver. The test procedure should clearly define what constitutes susceptibility in a quantifiable manner.

To support the discussion, let's establish a few receiver parameters to use for the test method discussions in this review. Our hypothetical Equipment Under Test (EUT) is a UHF radio with selectable AM and FM capability operating in the 225 – 400 MHz frequency range with a 25 kHz channel size. The radio sensitivity is 10 μV. The intermediate frequency (IF) is 10.7 MHz. The rejection requirement is 66 dB within the tuning range and 80 dB outside the tuning range.

CS103 - INTERMODULATION

Figure 1 shows a basic CS103 test configuration where two signals are routed to the EUT receiver input. The dashed line signal generator (SG3) and associated 3-port network are present only if the receiver needs to have an intentional receive signal to function. Depending on the signal generator performance, filtering may be needed between the generator and 3-port networks. The SG1 in our diagram must support modulation used by the EUT to allow the susceptibility to be identified if susceptibility is present.

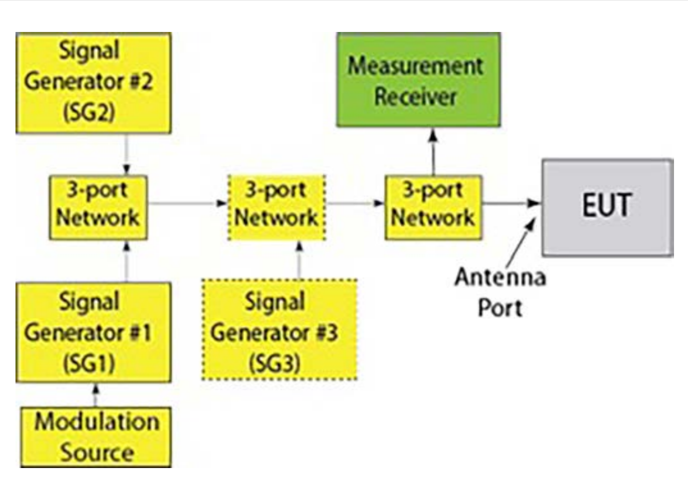

Figure 1: CS103 Test Configuration

The 3-port network is normally a hybrid combiner/splitter and should not be confused with a mixer. The 3-port network configured as a combiner provides 2-input ports and 1-output port where both input signals appear simultaneously. The 3-port network configured as a splitter support 2-output ports with one input port. The splitter configuration is used with SG3 if required and the measurement receiver. Based on the EUT parameters provided, a Mini-Circuits ZAPD-2-252 and a Mini-Circuits ZN-2PD-63S giving good isolation between input ports, reasonably low insertion loss and the necessary frequency range coverage are selected as our 3-port networks. The two 3-port networks have some overlap in the frequency coverage allowing the test frequency range to be supported. The EUT does not require a SG3 so two of each selected 3-port networks are needed. Note that I am not sponsored by or promoting Mini-Circuits – they just happened to pop-up in a search among many suppliers of RF products. When selecting your 3-port network, examine the specification sheet to confirm it will meet your requirements.

The measurement receiver can be an EMI receiver or spectrum analyzer with the ability to measure both input signals simultaneously. It is feasible to use two measurement receivers with a splitter to support measurement of the two input signals independently if more resolution is needed.

Now that we have selected the test equipment let's go through the process.

1. Configure the test setup with the higher frequency 3-port networks installed. If the lower frequency 3-port network is rated to include the upper test frequency, then use the lower frequency networks.

2. Select the first EUT test frequency and tune the EUT to this frequency. Set SG1 to the EUT test frequency with the RF amplitude at a very low level and apply modulation. SG2 RF output remains off.

3. Adjust the SG1 amplitude to produce the EUT standard reference output (SRO) (SRO is the correct operation of the EUT such as the ability to hear an audio modulation or process data from the modulation). The SG1 output is now set to the lowest amplitude that produces the SRO. Record the SG1 output amplitude and the signal amplitude measured by the measurement receiver. Note that the path losses will require that the signal generator amplitude be higher than the EUT specified sensitivity.

4. Turn SG1 RF off. Apply the modulation to SG2 and enable the RF output. Adjust the SG2 frequency to the EUT test frequency and the amplitude to produce the EUT SRO and record the SG2 output amplitude and the signal amplitude measured by the measurement receiver at lowest amplitude that produces the SRO.
    a. If the EUT requires that SG3 be necessary to establish operation of the EUT then set the frequency and amplitude to produce the SRO after turning off the SG2 RF output. Increase the amplitude by 3 dB. This will produce stable operation with a low-level reception being simulated and allow intermodulation to interfere with normal operation if the device is susceptible. This setting will remain throughout the testing.

5. Remove modulation from SG2 and apply modulation to SG1. Turn on the RF output of both signal generators. Adjust the SG1 to the in-band test amplitude (SRO + limit) then increase the frequency until the SRO is lost. If the frequency is out-of-band, increase the SG1 amplitude to the out-of-band limit and increase the frequency until SRO is lost. Record the frequency of SG1 as f1. The difference between f1 and the EUT tuned frequency is Δf.

6. Set SG2 frequency to f1 + Δf and increase the amplitude to the in-band or out-of-band test amplitude (SRO + limit) depending on the frequency. Scan by increasing the SG2 frequency until the upper range test end frequency is reached while monitoring the EUT for indications of susceptibility. Observe that the scan rate or frequency step size of the SG2 frequency sweep conform to the greater of the minimum per MIL-STD-461 or the EUT cycle time to ensure susceptibility indications can be detected.
    a. If susceptibility is detected determine if intermodulation is the cause by reducing the SG1 amplitude to zero. If the susceptibility remains, it is not an intermodulation product and can be ignored for this test.
    b. If susceptibility is a result of intermodulation, decrease the amplitude of both SG1 and SG2 equally until the EUT is

no longer susceptible. Record the frequency and amplitude at the measurement receiver of SG1 and SG2. Determine the intermodulation rejection by subtracting the SG1 amplitude from the SRO + limit amplitude.

7. Configure the setup to the lower frequency range by changing the 3-port network if necessary. If the test configuration hardware changed to test the lower frequency range:
   a. Set SG1 to the EUT test frequency with the RF amplitude at a very low level and apply modulation. SG2 RF output remains off.
   b. Adjust the SG1 amplitude to produce the EUT standard reference output (SRO) (SRO is the correct operation of the EUT. The SG1 output is now set to the lowest amplitude that produces the SRO. Record the SG1 output amplitude and the signal amplitude measured by the measurement receiver.
   c. Turn SG1 RF off. Apply the modulation to SG2 and enable the RF output. Adjust the SG2 frequency to the EUT test frequency and the amplitude to produce the EUT SRO and record the SG2 output amplitude and the signal amplitude measured by the measurement receiver at lowest amplitude that produces the SRO.
   d. If the EUT requires that SG3 be necessary to establish operation of the EUT then set the frequency and amplitude to produce the SRO after turning off the SG2 RF output. Increase the amplitude by 3 dB. This setting will remain throughout the testing.
8. Set SG1 frequency to the EUT operating frequency – Δf and increase the amplitude to the in-band or out-of-band test level depending on the frequency. Verify that SRO is lost. Record the frequency as f2.
   a. If SRO is not lost, decrease the frequency until SRO is lost.
9. Set SG2 frequency to f2-Δf and adjust the amplitude to the in-band or out-of-band test limit depending on the frequency. Scan by decreasing the SG2 frequency until the lower range test end frequency is reached while monitoring the EUT for indications of susceptibility. Observe that the scan rate or frequency step size of the SG2 frequency sweep conform to the greater of the minimum per MIL-STD-461 or the EUT cycle time to ensure susceptibility indications can be detected.
10. Repeat for the next selected test frequency or mode of operation.

Note that measurements at the measurement receiver should be used for setting levels to compensate for variations in the configuration from path losses.

CS104 – REJECTION OF UNDESIRED SIGNALS

The goal is to determine the amount of rejection to signals received outside of the tuned frequency that can produce spurious responses.

Figure 2 shows a basic CS104 test configuration where two signals are routed to the EUT receiver input. SG2 and the associated 3-port network may not be required if the EUT responds to a single signal (e.g., AM or FM receiver). The 3-port networks are similar to those discussed above but the test frequency range may require different models. Depending on the signal generator performance, filtering may be needed between the generator and 3-port networks to reduce effects of harmonic outputs. The SG1 in our diagram must support modulation used by the EUT to allow the susceptibility to be identified if susceptibility is present.

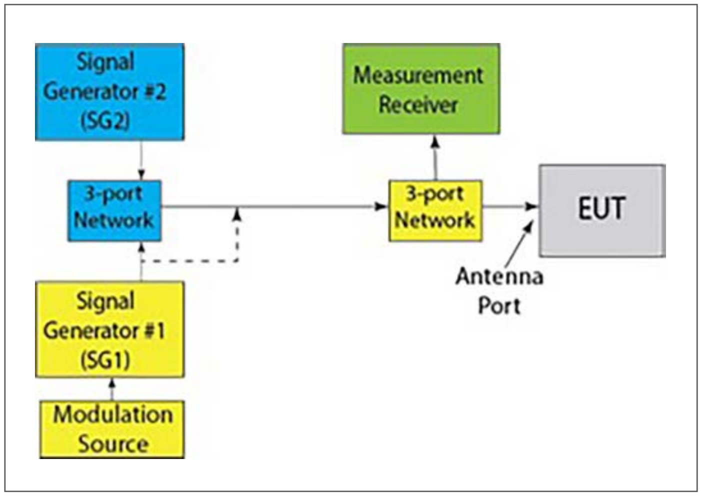

Figure 2: CS104 Test Configuration

In our example EUT a single generator test configuration may be used but I will describe both a single and dual signal generator approach.

The single generator process is:

1. Configure the test setup as shown without SG2 and associated 3-port network using the high frequency 3-port networks.
2. Set SG1 to the EUT tuned frequency, apply modulation and increase the amplitude until SRO is attained. Record SG1 frequency and amplitude.
3. Increase the test level by the in-band limit then increase the frequency until SRO is lost. If the frequency is out-of-band, increase the amplitude to the out-of-band limit and increase the frequency until SRO is lost. Record the frequency and amplitude of the signal.
4. Scan by increasing the SG1 frequency until the upper range test end frequency is reached while monitoring the EUT for spurious responses. Observe that the scan rate or frequency step size of the SG2 frequency sweep conform to the greater of the minimum per MIL-STD-461 or the EUT cycle time to ensure susceptibility indications can be detected.
   a. If susceptibility is detected, lower the SG1 amplitude until SRO is restored and record the amplitude of the signal. Record the frequency and amplitude at the measurement receiver of SG1. Determine the rejection by subtracting the SG1 amplitude from the SRO + limit amplitude.

5. Configure the setup with the low frequency range 3-port networks. If the hardware required change then:
   a. Set SG1 to the EUT tuned frequency, apply modulation and increase the amplitude until SRO is attained. Record SG1 frequency and amplitude.

6. Set the SG1 frequency to the tuned frequency of the EUT and the amplitude to SRO + limit. Decrease the test level by the in-band limit then decrease the frequency until SRO is lost. If the frequency is out-of-band, increase the amplitude to the out-of-band limit and decrease the frequency until SRO is lost. Record the frequency and amplitude of the signal.

7. Scan by decreasing the SG1 frequency until the lower range test end frequency is reached while monitoring the EUT for spurious responses. Observe that the scan rate or frequency step size of the SG2 frequency sweep conform to the greater of the minimum per MIL-STD-461 or the EUT cycle time to ensure susceptibility indications can be detected.

8. Repeat for the next selected test frequency or mode of operation.

The dual signal generator process is:

1. Configure the test setup as shown with SG2 and associated 3-port network using the high frequency 3-port networks.

2. Set SG1 to the EUT tuned frequency, apply modulation and increase the amplitude until SRO is attained. Record SG1 frequency and amplitude.

3. Turn SG1 RF off. Apply the modulation to SG2 and enable the RF output. Adjust the SG2 frequency to the EUT test frequency and the amplitude to produce the EUT SRO and record the SG2 output amplitude and the signal amplitude measured by the measurement receiver at lowest amplitude that produces the SRO.

4. Remove modulation from SG2. Set SG1 to the EUT tuned frequency, apply modulation and increase the amplitude until SRO is attained.

5. Set SG2 to the tuned frequency without modulation and increase the amplitude to the test level (SRO + test limit). Scan by increasing the SG2 frequency until the upper range test end frequency is reached while monitoring the EUT for indications of susceptibility. Observe that the scan rate or frequency step size of the SG2 frequency sweep conform to the greater of the minimum per MIL-STD-461 or the EUT cycle time to ensure susceptibility indications can be detected.
   a. If a spurious response is observed verify that it is not an intermodulation product.
   b. If susceptibility is detected, lower the SG2 amplitude until the spurious response is not present and record the amplitude of the signal. Record the frequency and amplitude at the measurement receiver. Determine the rejection by subtracting the SG2 amplitude from the SRO + limit amplitude.

6. Configure the setup with the low frequency range 3-port networks. If the hardware required change then:
   a. Set SG1 to the EUT tuned frequency, apply modulation and increase the amplitude until SRO is attained. Record SG1 frequency and amplitude.
   b. Turn SG1 RF off. Apply the modulation to SG2 and enable the RF output. Adjust the SG2 frequency to the EUT test frequency and the amplitude to produce the EUT SRO and record the SG2 output amplitude and the signal amplitude measured by the measurement receiver at lowest amplitude that produces the SRO.

7. Set SG2 to the tuned frequency without modulation and increase the amplitude to the test level (SRO + test limit). Scan by decreasing the SG2 frequency until the lower range test end frequency is reached while monitoring the EUT for indications of susceptibility.

8. Repeat for the next selected test frequency or mode of operation.

CS105 – CROSS MODULATION

The goal is to determine the amount of rejection to modulation transfer for signals received outside of the tuned frequency that can produce receiver amplitude responses. This test is applicable to receivers that use amplitude modulation.

Figure 3 shows a basic CS105 test configuration where two signals are routed to the EUT receiver input. The 3-port networks are like those discussed above but the test frequency range may require different models. Depending on the signal generator performance, filtering may be needed between the generator and 3-port network to reduce effects of harmonic outputs. SG1 and SG2 in our diagram must support modulation used by the EUT to allow the susceptibility to be identified if susceptibility is present.

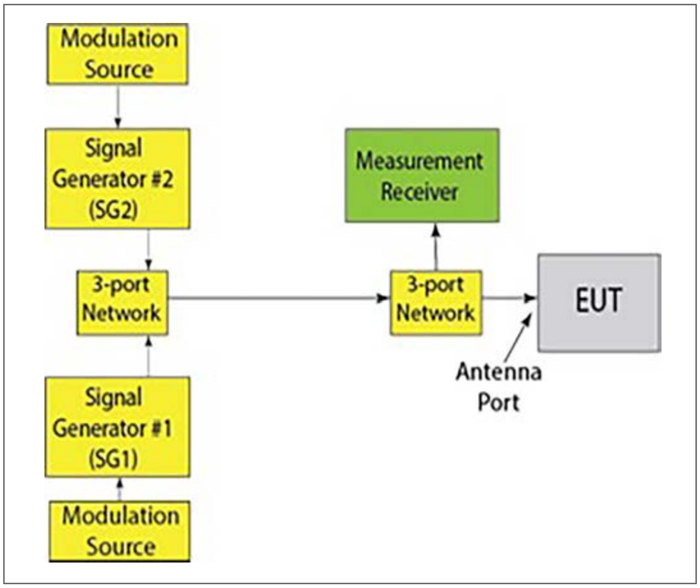

Figure 3: CS105 Test Configuration

The test frequency range is the EUT tuned frequency ±IF, so we will use the low frequency 3-port networks for our example. The process is:

1. Configure the test setup as shown with SG2 and associated 3-port network using the low frequency 3-port networks.
2. Set SG1 to the EUT tuned frequency, apply modulation and increase the amplitude until SRO is attained. Record SG1 frequency and amplitude.
3. Turn SG1 RF off. Apply the modulation to SG2 and enable the RF output. Adjust the SG2 frequency to the EUT test frequency and the amplitude to produce the EUT SRO and record the SG2 output amplitude and the signal amplitude measured by the measurement receiver at lowest amplitude that produces the SRO.
4. Set SG1 to the EUT tuned frequency, apply EUT specified modulation and increase the amplitude to SRO + 10 dB.
5. Set SG2 to the EUT tuned frequency, apply the test specification modulation (AM receiver = 30% AM 400 Hz sine wave; FM receiver – unmodulated; Pulsed receiver = 80% of spectral energy with 3 dB bandwidth of the receiver) and increase the amplitude to the SRO + limit level.
6. Scan SG2 above and below the EUT tuned frequency to the upper and lower end frequencies while monitoring the EUT performance.
    a. If susceptibility is observed, confirm that the cause is cross-modulation by removing the SG1 modulation. If the susceptibility disappears, the cause is cross-modulation.
    b. If susceptibility is observed, lower the SG2 amplitude until the susceptibility is not present and record the amplitude of the signal. Record the frequency and amplitude at the measurement receiver. Determine the rejection by subtracting the SG2 amplitude from the SRO + limit amplitude.
7. Repeat for the next selected test frequency or mode of operation.

SUMMARY

As mentioned earlier, planning for this test is essential and that planning includes defining the hardware necessary to cover the test frequency range.

Don't forget that the test configuration can influence the test, so make sure that you minimize the hardware and associated connectors/adapters. Look for signal generator harmonic outputs that can present a false indication of susceptibility.

Most specifications will have an upper signal generator amplitude limited to 10 dBm. If not specified this should be determined because the receiver will easily be driven into the non-linear operating region when exposed to very high level signals.

The appendix of MIL-STD-461G provides a lot of information regarding the specification and rationale for determining the test levels.

I have an Excel spreadsheet that follows this procedure outline that you can use as an example. I can provide a copy of this spreadsheet at no charge if you request. Send an email to me stevef@complianedirection.com with *CS103_104_105 Example Spreadsheet* in the subject line, provide your contact information, and state that you agree to NOT place the spreadsheet in the public domain.

AUTHOR BIO

Steven G. Ferguson is principal consultant at Compliance Direction, LLC. Steve has over forty years of experience in testing and device evaluation. He has instructed in the area of testing methods for the past twenty years, focusing on electromagnetic compatibility, product safety and environmental test methods. His comprehensive knowledge of MIL-STD-461, MIL-STD-810, MIL-STD 704/1275/1399 and CE Marking requirements for commercial and industrial equipment provides the ability to discuss the many aspects associated with regulatory compliance. With a background operating test laboratories and manufacturing companies designing products, developing test procedures and performing tests, he has the experience to address a wide variety of regulatory compliance topics. He presents various courses on EMI/EMC compliance including EMC for Nuclear Power Facilities, Architectural Shielding and MIL-STD-461 testing presented on-line and at customer facilities.

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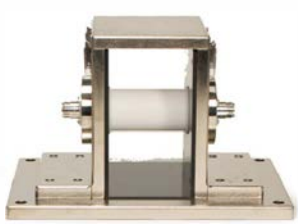

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Review of MIL-STD 461 CS117 Lightning Induced Transients, Cables and Power Leads

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INTRODUCTION

Lightning may produce a spectacular display when viewed, but the associated electromagnetic effects (EME) has the potential (pun intended) to severely damage electrical and electronic circuits. MIL-STD-461G added a new test method to evaluate device tolerance for induced current on equipment cables or insulation breakdown from the effects of indirect lightning. Although new to MIL-STD-461, the induced lightning tests have a background in civil aviation with similar test methods documented in RTCA/DO-160.

Most equipment has been evaluated for effects from indirect lightning events using CS115 and CS116 test methods for several years and these test methods remain present in revision "G" for qualifying equipment. The CS117 test method addition primarily targets aircraft flight or safety critical equipment and some other critical applications calling for this evaluation.

Note that the CS117 test method does ***not*** provide test coverage for MIL-STD-464 lightning direct effects or nearby lightning requirements.

PLANNING FOR TEST

Is testing applicable to my device?

MIL-STD-461G, *Table V* lists CS117 as having Limited (L) applicability or Specified (S) in procurement contract documents. The Limited applicability defers to as specified in individual section of the standard. The individual section (5.15) lists applicability as safety-critical equipment and applies testing to the interconnecting cables including power cables and individual high side power leads. Additionally, non-safety critical equipment that are part of or connected to safety-critical are considered as applicable for this test method. Normally a procurement contract will specify test applicability but consider the design implications if developing a product that potentially fits into the critical category.

What waveforms and test levels apply?

Waveforms associated with CS117 are classified as double exponential or damped sine wave where the waveform generator provides control of the rise and decay times of various waveforms. *Figure 1* provides a generic waveform shape. The double exponential waveform on the left has an amplitude in current (I) terms or in voltage (V) terms. T_1 denote the rise time and T_2 denotes the decay time to 50% of the peak. The rise and decay times vary depending on the waveform selected for test with the detailed waveform parameters provided in the standard. The waveform parameters are verified by applying the transient to a calibration loop configured as a short circuit for current (I) waveforms and configured as an open circuit for voltage (V) waveforms.

The damped sine or cosine waveform on the right amplitude is in voltage terms and has a frequency of 1 MHz or 10 MHz with both frequencies used for testing. The dampening factor is not specified but based on the waveform drawing, the 50% (±25%) decay is reached by the 5th cycle.

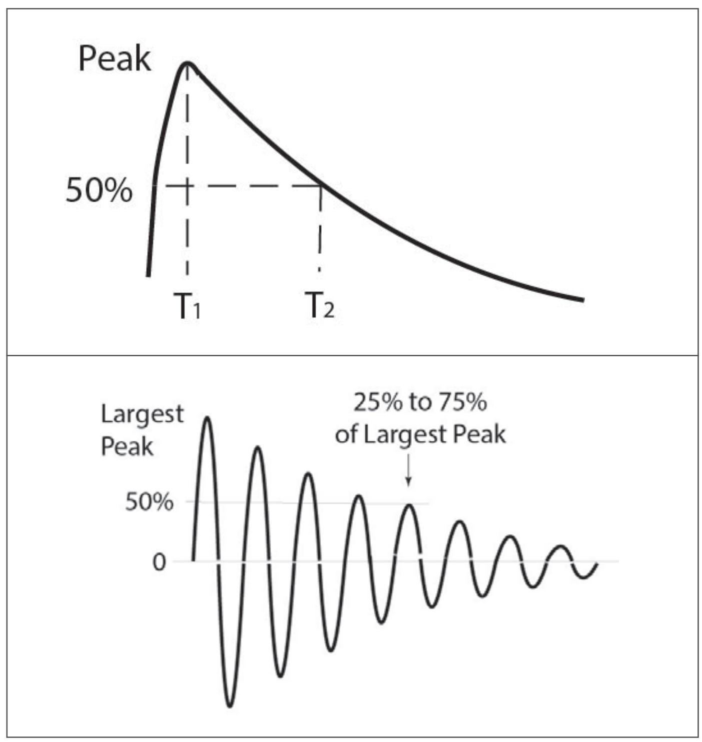


Figure 1: Double Exponential (top) and Damped Sine (bottom) Waveforms

What is a calibration loop?

A low impedance wire loop. Note that impedance is the basis so low self-inductance and low resistance must be considered. High current levels are associated so the wire should be large enough to prevent potential I^2R heating issues. The loop passes through the injection transformer in a single turn with enough length to support injection transformer and monitor probe placement.

What is implied by test level versus limit level?

The test level is the target amplitude for the specific waveform. The waveform calibration verifies that the test level can be produced into the short circuit calibration loop for double-exponential current waveforms or open calibration loop for damped sine voltage waveforms. During test the characteristic cable impedance is not known, so adjusting the amplitude to achieve the test level we may encounter an inability to attain the specified current or voltage. In this case the limit level is used to prevent over-stressing the circuit. We must realize that cable placement can affect the impedance so maintain the test configuration to help with standardization.

Table VII in MIL-STD-461G lists the applicable waveforms and test/limit levels for multiple stroke and multiple burst testing. Single stroke tests are not separately specified but combined into the multiple stroke tests by elevating the first stroke test/limit levels.

The table also sets the test/limit levels for internal and external installation applications. *Table VII* provides the generic test/limit levels, however if platform data is available the test/limit level should be tailored to use platform specific information.

What are low count wire bundles?

Table VII includes a separate test/limit level for individual power leads or low count wire bundles. The lesser of the individual lead test/limit current multiplied by the number of wires or the specified test/limit level is used. Depending on the waveform and test level, a bundle with as many as 10-wires could be considered as a low count cable. For example, in *Table VII* 1st row (see *Figure 2*), the internal first stroke individual I_T is 60 A and bundle I_T is 600 A so a 9-wire bundle would use an I_T of 540 A. If this test level was set, then subsequent strokes would apply 270 A, exceeding the test level prescribed. This issue should be addressed in the test procedure to avoid confusion about the test execution and acceptance of the product.

The standard treats a wire bundle as all wires associated with an interface connector. I somewhat disagree with this standardization when dealing with cable injection testing including the CS117 test method. We need to understand the installation cable layout to determine test levels. Consider that a single interface may have wiring that routes two different directions upon exiting the device – e.g., some wires route to the cockpit control head and other wires route to sensors in the aircraft tail. Coupling exposure is not equal so a common mode current could become differential at the device creating an interference that is not apparent if common mode. A test procedure should address this potential risk and establish appropriate testing.

What about waveform 6 applicability?

MIL-STD-461G, *Table VII* under the multiple burst heading a discussion regarding waveform 6 with some ambiguity. "Equipment installations that utilize short, low impedance cable bundle installations." "Short" and "low" lack definition so the test procedure needs to document applicability with the criteria used to determine applicability. Some would consider less that 1-meter as short and others may consider less than 20-meters as short – this decision needs to be agreed upon prior to testing instead of obtaining a report rejection.

WAVEFORM CALIBRATION

Waveform calibration is an integral part of the CS117 test method as with most test methods in MIL-STD-461G under the signal integrity check mantra. The calibration process confirms the ability for the test level to be attained with the test waveform parameters using the calibration loop configured as shorted loop or open loop as applicable for the test level waveform. Referring to *Figure 2*, you can see that waveform 1 is associated with the test current (not the voltage limit waveform 2) so the shorted loop configuration would be appropriate for the calibration.

Establish the calibration configuration (see *Figure 3*) with a shorted calibration loop for calibration of the current waveform. Adjust the transient generator settings to the I_T level applicable to the cable to be tested and record the settings and waveform. Verify that the waveform parameters comply with the timing parameters established for that waveform.

It is not necessary for the transient generator to produce the associated V_L limit waveform, however if the transient generator can produce the V_L level in the shorted loop configuration the settings and waveforms should be recorded.

Applicability	Test Description	Internal Equipment Levels **	External Equipment Levels **
All equipment installation	Waveform 2 (WF2)/ Waveform 1 (WF1)	First Stroke V_L = 300 V (WF2) I_T = 600 A (WF1) I_T - 60 A* Subsequent Strokes V_L = 150 V (WF2) I_T = 150 A (WF1) I_T = 30 A *	First Stroke V_L = 750 V (WF2) I_T = 1500 A (WF1) I_T - 150 A* Subsequent Strokes V_L = 375 V (WF2) I_T = 375 A (WF1) I_T = 75 A *

Figure 2: MIL-STD-461G, Table VII Extract

Accomplish the calibration process for each applicable waveform recording the settings and waveform parameters. For multiple stroke and multiple burst tests, verify the pulse patterns and timing.

Reverse the transient generator polarity and repeat the calibration process.

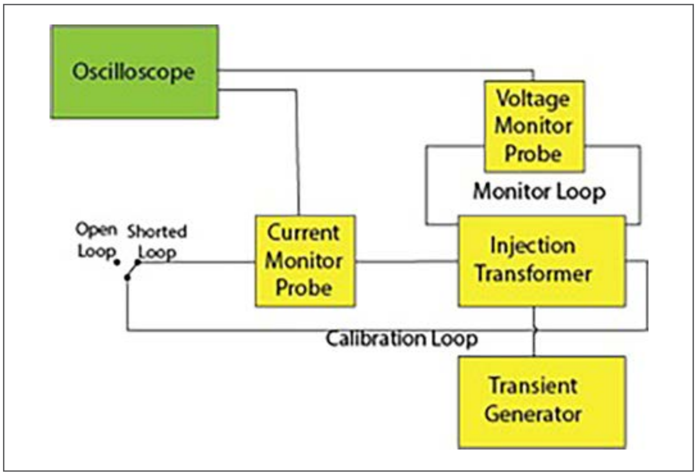


Figure 3: Calibration Configuration

EUT TESTING

Now that the waveform calibration has been successfully completed, the test configuration can be established and testing can proceed. *Figure 4* shows the basic test configuration for signal or control lines. For power line tests, the injection transformer would be installed between the LISNs and the EUT and recall that MIL-STD-461 specifies that the power cable be unshielded and have a length of 2.5-meters for testing.

Once configured, establish EUT operation and allow the EUT to stabilize. Start applying transients with the transient generator adjusted to zero then increase the transient generator amplitude settings or injection transformer configuration until the test level or the limit level is attained. Note that if injection transformer configuration is changed a re-calibration is required. As the amplitude is increased monitor the EUT performance for susceptibility indications.

- If susceptibility is NOT observed the EUT is considered compliant.
- If susceptibility outside the performance requirements is observed the EUT is considered non-compliant.
- If the limit level is attained before the test level is reached an evaluation is used to determine acceptability using the following criteria:
  1. If the transient generator produced a compliant limit level waveform during calibration, the test is acceptable.
  2. If the specified limit level waveform is attained during test and the waveshape meets the parameters, the test is acceptable.
  3. If one of the above criteria is not met, a retest is required using a transient generator that can meet the limit level waveform requirements.

Multiple stroke testing applies at least ten multiple strokes while monitoring EUT performance. The time between multiple stroke applications shall not exceed 5-minutes.

Multiple burst testing applies a multiple burst every 3-seconds for at least 5-minutes while monitoring the EUT for susceptibility indications.

Remember that the testing is repeated with the transient generator polarity reversed.

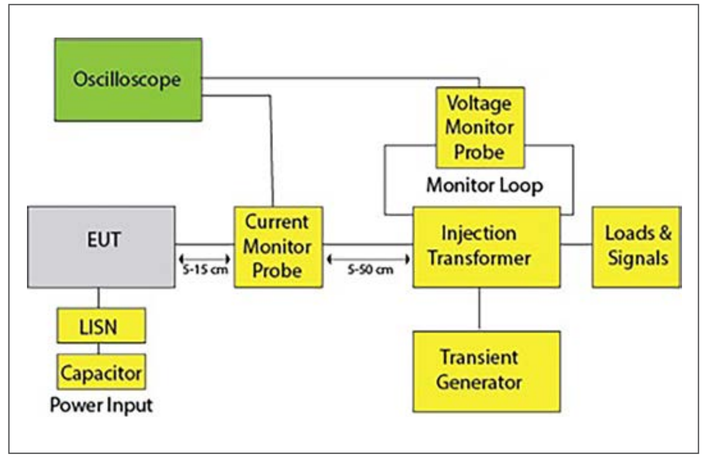


Figure 4: Test Configuration

Note that the standard provides significant guidance on measuring the applied waveforms dealing with RF noise on the waveform. Since the standard is thorough on this topic, I am not going to repeat that information in this article. The guidance is in the MIL-STD-461G appendix.

Remember that cable placement during test may influence the waveform and provide alternate current paths from parasitic reactance – note the physical parameters and conform to the standard layout – good photos of the configuration provides the ability to repeat the test with minimum variance.

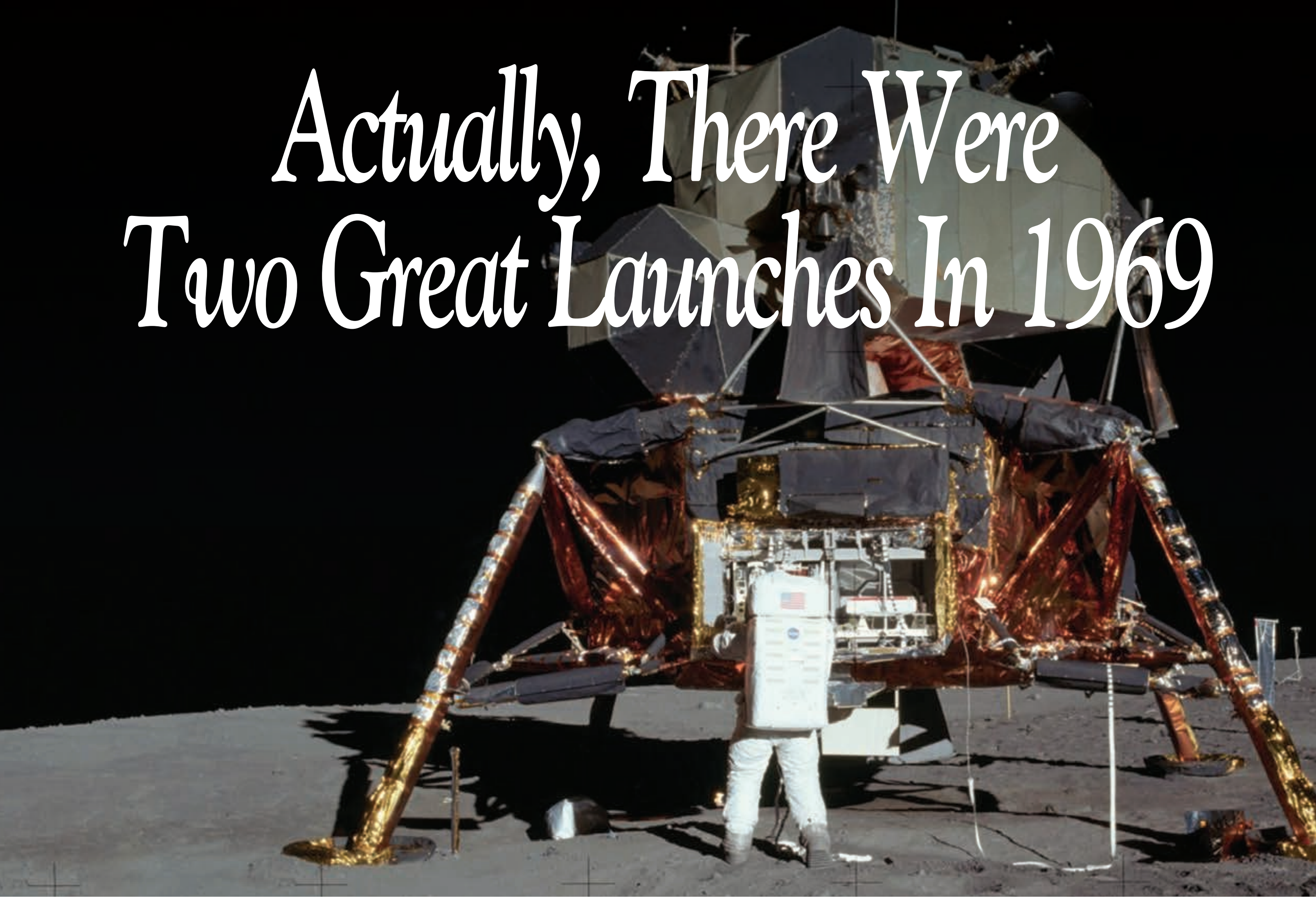
SUMMARY

As we have discussed, planning for this test is essential and that planning includes understanding the installation and platform construction. Understanding the application and test requirements is needed to support inclusion of control measures to prevent susceptibility.

Pay close attention in selecting acceptance criteria for device performance. Failing to allow minor perturbations that do not impair the critical performance can affect the product design and associated costs.

Don't forget that the CS117 testing involves some relatively high current and voltage levels. Maintain a safe test environment to prevent shocking events that can result in injury. Use appropriate personal protective equipment in case the EUT should experience rapid disassembly from high level transients.

The overall test program for CS117 requires many measurement system details so pay attention to the testing,



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Risk Mitigation: Advanced ESD Instrumentation for Qualification Testing of Static Shielding Bags

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Today, Suspect Counterfeit ESD Control and Non-Compliant Packaging is a growing issue throughout the Global Supply Chain. EEE parts (ESD sensitive devices) damage transcends circuit cards, touch screen displays, handheld devices and other microprocessor driven products. Suspect counterfeit static control or non-compliant electrostatic discharge (ESD) shielding bags can be purchased over the internet, in tech savvy catalogs, GSA approved suppliers, recognized brokers, authorized and unauthorized distributors or direct from a manufacturer.

The author is the First to Present on Suspect Counterfeit and Non-Compliant ESD Materials in the Supply Chain at the NASA Quality Leadership Forum 2010, Cape Canaveral, Florida. No longer can a Supplier Technical Data Sheet serve as proof of compliance for a static control shielding bag. The end-user (who is ANSI/ESD S20.20-2014 compliant) is required to have traceable inhouse or 3rd party ANSI/ESD traceable test data for static control products used in and out of the ESD Protected Area (EPA).

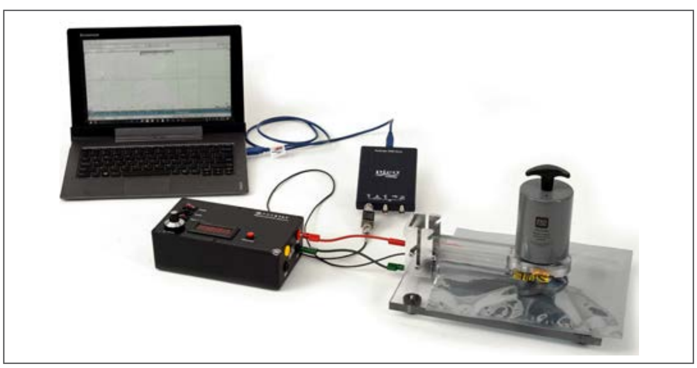

Figure 1

ANSI/ESD S541 is the standard for ESD safe Packaging Materials (ANSI/ESD S20.20 program) that incorporates the following test methods for ESD Qualification: ANSI/ESD S11.4, ANSI/ESD STM11.11, ANSI/ESD STM11.12, ANSI/ESD STM11.13, ANSI/ESD STM11.31 and ESD Adv. 11.2.

ANSI/ESD S11.4 lists qualification requirements for Static Control Bags. Section 6.0 Markings (ESD S11.4) that calls out: "All bags should be marked with information that allows traceability to the packaging manufacturer and to the manufacturer's date / lot code information."

In this article, the commercial designation of Level 3 is used for static shielding bags. Note the Department of Defense (DoD) uses the term "Type III" for static shielding bags.

In this article, several testing methods employed for formal ESD qualification were conducted at 12%±3%RH, $73^0 \pm 5^0$F (23^0C$\pm 3^0$C) for 48 hours minimum as follows:

1. Surface Resistance; inside and outside of bag per ANSI/ESD STM11.11 at <1.0 x 10^{11} Ω
2. Volume Resistance; inside of bag to plate per ANSI/ESD STM11.12 at <1.0 x 10^{11} Ω
3. Electrostatic Decay per Mil-STD-3010C, Method 4046 (±5kV to ±500 volts or lower) at 2.0 seconds max (various RH and Temperature levels were utilized)
4. Charge Retention (Faraday Cup) per ESD Adv.11.2 at <1.0 nC
5. Static Shielding; 12%RH and 50%RH per ANSI/ESD STM11.31 at <20 nJ

An accredited ESD laboratory is a valuable resource to verify static control materials and packaging for qualification testing per ANSI/ESD S541. Several online advertised labs have been known to deviate from the environmental conditioning requirements for ANSI/ESD S541 compliant testing. For example, some will conduct ESD testing at ambient or room conditions even though low RH preconditioning (12%±3%RH) is required. Or, just as bad, one should never pull product out of dry chamber to test at ambient conditions!

This haphazard approach to ESD testing may account for significantly different costs when required testing protocols are circumvented. In an unregulated industry, this practice appears to be the norm for some labs due to the divergent test results for static control materials.

Many static control materials are topically coated with antistats that rely on moisture in the air for performance. Today, it is probable that topically coated antistat packaging material will pass at 50% RH yet fail at 12%RH.

Due to the rise of suspect counterfeit ESD packaging & materials in the supply chain, Google Earth is a valuable tool for the end user to insure that a test lab is not located on an empty lot, home garage, a shack or PO Box. ESD Test Labs because of proprietary technologies must be safeguarded with limited access. Equally important is lab grade, calibrated instrumentation in a controlled environment.

Utilizing advanced instrumentation for ANSI/ESD S541 material qualification testing will better insure static control packaging integrity for the protection of EEE devices. From Aerospace & Defense to the pharmaceutical and medical device sectors, reliability and repeatability of test results will protect the consumer as well as the safety of patients and for soldiers in the field.

Surface Resistance versus Relative Humidity (RH)

At the insulative range, humidity dependent materials become nonconductive and hold static charges for several seconds or more. In practice, however, a lower cut-off is often desired for packaging materials because dry air may be encountered during staging, shipping, material handling and storage. In cold and dry climactic conditions, relative humidity can drop to <4%. Surface resistance testing constitutes a boiler plate ESD test method for the evaluation of static control materials. At 1.0×10^{11} Ω, and above, materials are nonconductive (exhibit insulative properties) and hold static charges for several seconds to days. Surface resistance rises when relative humidity (RH) is lowered. In everyday use, Tribocharging can contribute to damage by Field Induction.

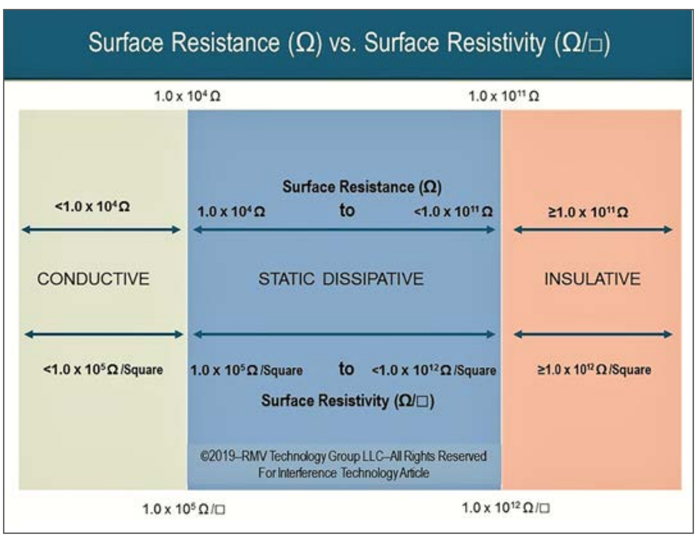

Table 1 - depicts the surface resistance classification in ohms per ANSI/ESD S541 for Packaging & Materials) and ASTM D257 for surface resistivity in ohms per square.

Surface Resistance per ANSI/ESD STM11.11

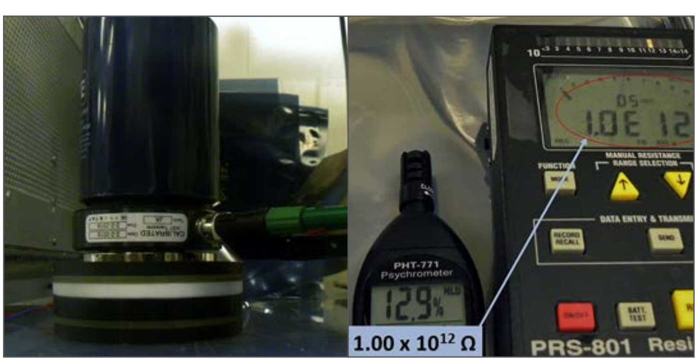

Figure 2 - Left

Figure 2 - Right

A concentric ring fixture is utilized to measure the outside and inside of bags. To insure the electrometer and concentric ring are in calibration, a favorable reference measurement of 1.0×10^{12} Ω is verified for compliance to ANSI/ESD STM11.11 (see *Figure 2*, left and right).

Figure 3

ANSI/ESD STM11.11 is employed to measure the surface resistance of the Level 3 (Type III) vacuum deposited metallized static shielding bag. In *Figure 3*, the surface resistance for the inside of bag measured 1.6×10^{10} Ω under the limit of $<1.0 \times 10^{11}$ Ω.

Figure 4

In *Figure 4*, the outside of bag measured 1.2×10^{10} Ω ($<1.0 \times 10^{11}$ Ω). Test results are listed in *Table 2* of this article. ***Note: Samples must be measured at 12%±3%RH without removal from chamber during any part of the evaluation process for ESD lab integrity and to maintain compliance with the standard.***

ESD Check Bag (Inside)			ESD Check Bag (Outside)		
Inside	Resistance	Constant V	Outside	Resistance	Constant V
1	1.89E+10	100v	1	1.20E+10	100v
2	1.45E+10	100v	2	1.58E+10	100v
3	1.46E+10	100v	3	1.11E+10	100v
4	1.68E+10	100v	4	1.24E+10	100v
5	1.36E+10	100v	5	1.02E+10	100v
6	1.55E+10	100v	6	1.08E+10	100v
Average	1.57E+10	Prostat 801 & PRF911 at 12%RH	Average	1.21E+10	Prostat 801 & PRF911 at 12%RH
Median	1.51E+10		Median	1.16E+10	
Minimum	1.36E+10		Minimum	1.02E+10	
Maximum	1.89E+10		Maximum	1.58E+10	
St. Dev.	1.93E+09		St. Dev.	2.00E+09	

Table 2 - 12%RH at 73.4°F after 48 hours of preconditioning

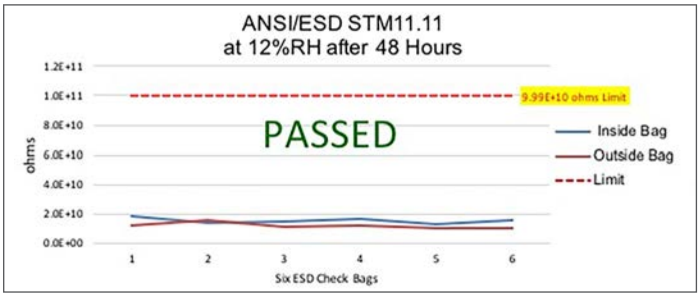

Table 3

Volume Resistance per ANSI/ESD STM11.12

Figure 5

ANSI/ESD STM11.12 defines the standard test procedure, equipment, sample preparation and conditioning required to achieve reproducible volume resistance test results on static dissipative planar materials. This test will determine if charge bleed-off could occur when a static control bag is opened in the ESD Protected Area (EPA). Results were within acceptance levels as illustrated in *Table 4*.

ESD Check Bag (Inside)		
Inside	Resistance	Constant V
1	1.3E+10	100v
2	2.5E+10	100v
3	2.6E+10	100v
4	3.6E+10	100v
5	1.4E+10	100v
6	1.7E+10	100v
Ave	2.2E+10	Prostat 801 & PRF911 at 12%RH
Median	2.1E+10	
Min	1.3E+10	
Max	3.6E+10	
St. Dev.	8.8E+09	

Table 4 - ANSI/ESD STM11.12 at 12.3%RH, 72.3°F for 48 hours

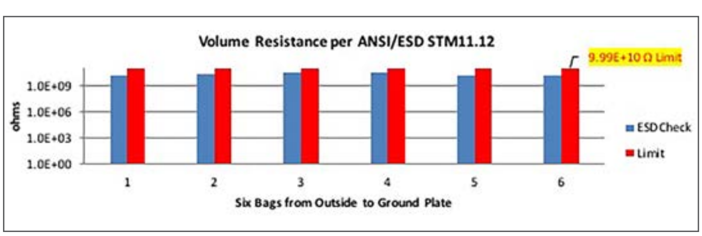

Table 5

In short, the static shielding bags provide favorable volume resistance in compliance with ANSI/ESD STM11.12.

Electrostatic Decay per Mil-STD-3010C, Method 4046 (1 Aug 2013)

The latest revision for Mil-STD-3010C, Method 4046 (1 Aug. 2013) section 5.4.3.4.2 (after 160 ±5 ºF oven conditioning for 12 days) states: Test environment. Immediately after preconditioning, unless otherwise specified in the test plan, all specimens shall be placed in the electrostatic test chamber (maintained at 73±5ºF and 12±3% relative humidity) for a minimum of 24 hours; for this testing sequence, 48 hours of preconditioning after oven and dry conditioning took place.

Figure 6

Figure 7

After preconditioning, the six samples were evaluated for electrostatic decay from ±5kV to ±0 volts. For Type I & III ESD bags, the DoD sets an electrostatic decay time at 2.0 seconds maximum. Using a calibration fixture, said decay test unit was verified at 0.28 and 0.27 seconds respectively and within the level of acceptance. Note: The decay test was modified from ±5kV to ±500 volts for a cutoff at 0 volts to represent a worst-case scenario. The 3" x 5" samples were cut after completion of other electrical tests in the length (blue) and cross (green) direction as illustrated in *Table 6* (see page 25). *Table 7* illustrates passing decay results.

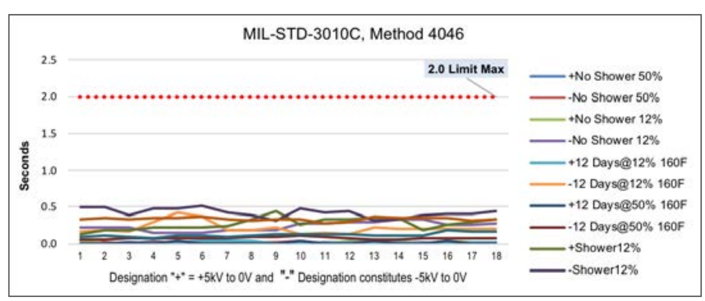

Table 7

It should be noted that electrostatic decay testing is required by many end user organizations. In this case, the results in *Table 5* passed. However, Military Handbook 263B states in Appendix I: "… Decay time measurements, for an induced voltage on a given sample, may not correlate with surface or volume resistivity measurements for materials of complex construction.

Table 6											
No Oven, No Shower, 5kV to 0 v			-5kV to 0 v			No Oven, No Shower, 5kV to 0 v			-5kV to -0 v		
Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample#	Seconds	Applied
1	0.01	5kV	1	0.01	-5kV	1	0.03	5kV	1	0.22	-5kV
1	0.01	5kV	1	0.02	-5kV	1	0.01	5kV	1	0.22	-5kV
1	0.01	5kV	1	0.01	-5kV	1	0.02	5kV	1	0.23	-5kV
2	0.03	5kV	2	0.02	-5kV	2	0.01	5kV	2	0.15	-5kV
2	0.01	5kV	2	0.02	-5kV	2	0.02	5kV	2	0.15	-5kV
2	0.01	5kV	2	0.02	-5kV	2	0.04	5kV	2	0.15	-5kV
3	0.01	5kV	3	0.02	-5kV	3	0.03	5kV	3	0.18	-5kV
3	0.02	5kV	3	0.02	-5kV	3	0.03	5kV	3	0.18	-5kV
3	0.01	5kV	3	0.02	-5kV	3	0.01	5kV	3	0.18	-5kV
1	0.01	5kV	1	0.03	-5kV	1	0.01	5kV	1	0.28	-5kV
1	0.02	5kV	1	0.01	-5kV	1	0.01	5kV	1	0.28	-5kV
1	0.02	5kV	1	0.01	-5kV	1	0.03	5kV	1	0.30	-5kV
2	0.01	5kV	2	0.01	-5kV	2	0.02	5kV	2	0.30	-5kV
2	0.02	5kV	2	0.01	-5kV	2	0.03	5kV	2	0.33	-5kV
2	0.02	5kV	2	0.01	-5kV	2	0.01	5kV	2	0.34	-5kV
3	0.01	5kV	3	0.03	-5kV	3	0.04	5kV	3	0.26	-5kV
3	0.02	5kV	3	0.01	-5kV	3	0.02	5kV	3	0.25	-5kV
3	0.02	5kV	3	0.01	-5kV	3	0.02	5kV	3	0.28	-5kV
Average	0.02		Average	0.02		Average	0.02		Average	0.24	
Median	0.01		Median	0.02		Median	0.02		Median	0.24	
Min	0.01	50%RH	Min	0.01		Min	0.01	12%RH	Min	0.15	
Max	0.03		Max	0.03		Max	0.04		Max	0.34	
St. Dev.	0.01		St. Dev.	0.01		St. Dev.	0.01		St. Dev.	0.06	
160ºF for 12 Days, 5kV to 0 v			-5kV to 0 v			160ºF for 12 Days 5kV to 0 v			-5kV to 0 v		
Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample#	Seconds	Applied
1	0.01	5kV	1	0.17	-5kV	1	0.01	5kV	1	0.06	-5kV
1	0.01	5kV	1	0.19	-5kV	1	0.01	5kV	1	0.05	-5kV
1	0.02	5kV	1	0.17	-5kV	1	0.02	5kV	1	0.07	-5kV
2	0.01	5kV	2	0.30	-5kV	2	0.01	5kV	2	0.07	-5kV
2	0.02	5kV	2	0.42	-5kV	2	0.03	5kV	2	0.07	-5kV
2	0.03	5kV	2	0.36	-5kV	2	0.01	5kV	2	0.08	-5kV
3	0.03	5kV	3	0.19	-5kV	3	0.01	5kV	3	0.08	-5kV
3	0.03	5kV	3	0.19	-5kV	3	0.01	5kV	3	0.09	-5kV
3	0.01	5kV	3	0.22	-5kV	3	0.01	5kV	3	0.09	-5kV
1	0.01	5kV	1	0.13	-5kV	1	0.03	5kV	1	0.11	-5kV
1	0.01	5kV	1	0.14	-5kV	1	0.01	5kV	1	0.09	-5kV
1	0.02	5kV	1	0.13	-5kV	1	0.01	5kV	1	0.08	-5kV
2	0.02	5kV	2	0.23	-5kV	2	0.03	5kV	2	0.05	-5kV
2	0.02	5kV	2	0.21	-5kV	2	0.01	5kV	2	0.06	-5kV
2	0.01	5kV	2	0.20	-5kV	2	0.01	5kV	2	0.07	-5kV
3	0.01	5kV	3	0.21	-5kV	3	0.03	5kV	3	0.07	-5kV
3	0.02	5kV	3	0.20	-5kV	3	0.01	5kV	3	0.08	-5kV
3	0.02	5kV	3	0.21	-5kV	3	0.01	5kV	3	0.08	-5kV

Table 6 - continued onto page 34

Table 6											
Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample#	Seconds	Applied
Average	0.02		Average	0.22		Average	0.02		Average	0.08	
Median	0.02		Median	0.20		Median	0.01		Median	0.08	
Min	0.01	12%RH	Min	0.13		Min	0.01	50%RH	Min	0.05	
Max	0.03		Max	0.42		Max	0.03		Max	0.11	
St. Dev.	0.01		St. Dev.	0.08		St. Dev.	0.01		St. Dev.	0.02	
24 Hour Shower 5kV to 0 v			-5kV to 0 v			24 Hour Shower 5kV to 0 v			-5kV to 0 v		
Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample #	Seconds	Applied	Sample#	Seconds	Applied
1	0.13	5kV	1	0.49	-5kV	1	0.10	5kV	1	0.33	-5kV
1	0.18	5kV	1	0.50	-5kV	1	0.11	5kV	1	0.35	-5kV
1	0.19	5kV	1	0.38	-5kV	1	0.09	5kV	1	0.34	-5kV
2	0.22	5kV	2	0.48	-5kV	2	0.08	5kV	2	0.35	-5kV
2	0.23	5kV	2	0.48	-5kV	2	0.11	5kV	2	0.35	-5kV
2	0.22	5kV	2	0.51	-5kV	2	0.12	5kV	2	0.36	-5kV
3	0.24	5kV	3	0.43	-5kV	3	0.09	5kV	3	0.33	-5kV
3	0.33	5kV	3	0.38	-5kV	3	0.12	5kV	3	0.32	-5kV
3	0.44	5kV	3	0.32	-5kV	3	0.13	5kV	3	0.34	-5kV
1	0.26	5kV	1	0.48	-5kV	1	0.13	5kV	1	0.33	-5kV
1	0.34	5kV	1	0.43	-5kV	1	0.13	5kV	1	0.28	-5kV
1	0.34	5kV	1	0.45	-5kV	1	0.13	5kV	1	0.30	-5kV
2	0.35	5kV	2	0.32	-5kV	2	0.12	5kV	2	0.36	-5kV
2	0.35	5kV	2	0.33	-5kV	2	0.11	5kV	2	0.35	-5kV
2	0.19	5kV	2	0.39	-5kV	2	0.11	5kV	2	0.35	-5kV
3	0.26	5kV	3	0.40	-5kV	3	0.18	5kV	3	0.35	-5kV
3	0.29	5kV	3	0.41	-5kV	3	0.17	5kV	3	0.32	-5kV
3	0.33	5kV	3	0.44	-5kV	3	0.17	5kV	3	0.33	-5kV
Average	0.27		Average	0.42		Average	0.12		Average	0.33	
Median	0.26		Median	0.43		Median	0.12		Median	0.34	
Min	0.13	12%RH	Min	0.32		Min	0.08	50%RH	Min	0.28	
Max	0.44		Max	0.51		Max	0.18		Max	0.36	
St. Dev.	0.08		St. Dev.	0.06		St. Dev.	0.03		St. Dev.	0.02	

Table 6 - continued

Additionally, decay time measurements can become complex from the viewpoint of understanding exactly how materials of complex construction, that is, laminates/ multilayer materials, are performing…”

Figure 8

Charge Retention using a Faraday Cup per ANSI/ESD Adv.11.2 (Modified)

ESD Adv.11.2, Appendix D calls out a Faraday Cup charge retention test required by some end-users in the ESD Materials Qualification Process. Said test requires skill to reproduce findings without human influence. This test was conducted at 12%RH ±3%RH after 48 hours of preconditioning. In *Figure 8* (left), the static shielding bag is positioned on a charge plate. Six static shielding bags were charged to 1000 volts and then removed from the charge plate by the grounded evaluator at 11.8%RH.

Six Level 3 bags were released to free fall into the Faraday Cup. The results are illustrated in *Tables 8* and *9*; the static shielding bags passed the test with a peak charge of <±1.0nC.

Static Shielding Bag		
Bag 1	nJ	Starting V
1	0.091	1000v
2	-0.037	1000v
3	0.074	1000v
4	0.010	1000v
5	-0.010	1000v
6	-0.058	1000v
Average	0.012	
Median	0.000	
Minimum	-0.058	
Maximum	0.091	
St. Dev.	0.060	

Table 8 12%RH after 48 Hours of preconditioning

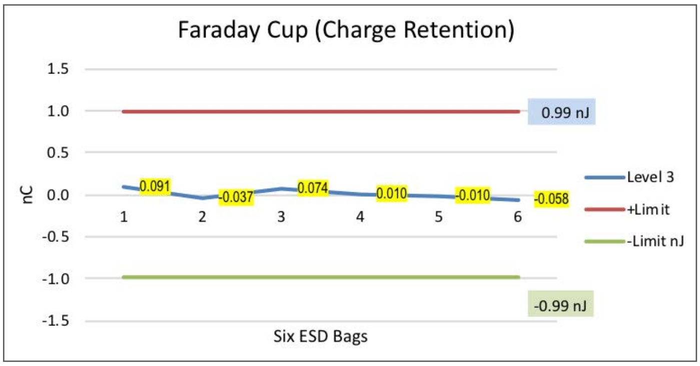

Table 9

Electrostatic Shielding per ANSI/ESD STM11.31

Figure 9

ANSI/ESD S20.20-2014 calls out ANSI/ESD STM11.31 per ANSI/ESD S541. ANSI/ESD S11.4 calls out a limit of <20nJ. Six discharges per bag were conducted. ANSI/ESD STM11.31 provides a test method for determining the shielding capabilities of electrostatic shielding bags. Said method employs a capacitive sensor inside the package. A 1KV discharge to the outer package was conducted; the fixture then measures the current across a resistor connected to the fixture's upper and lower sensing plates. This test has the objective of measuring energy per specified RH levels (at 12% or 50%). See below *Figure 10*.

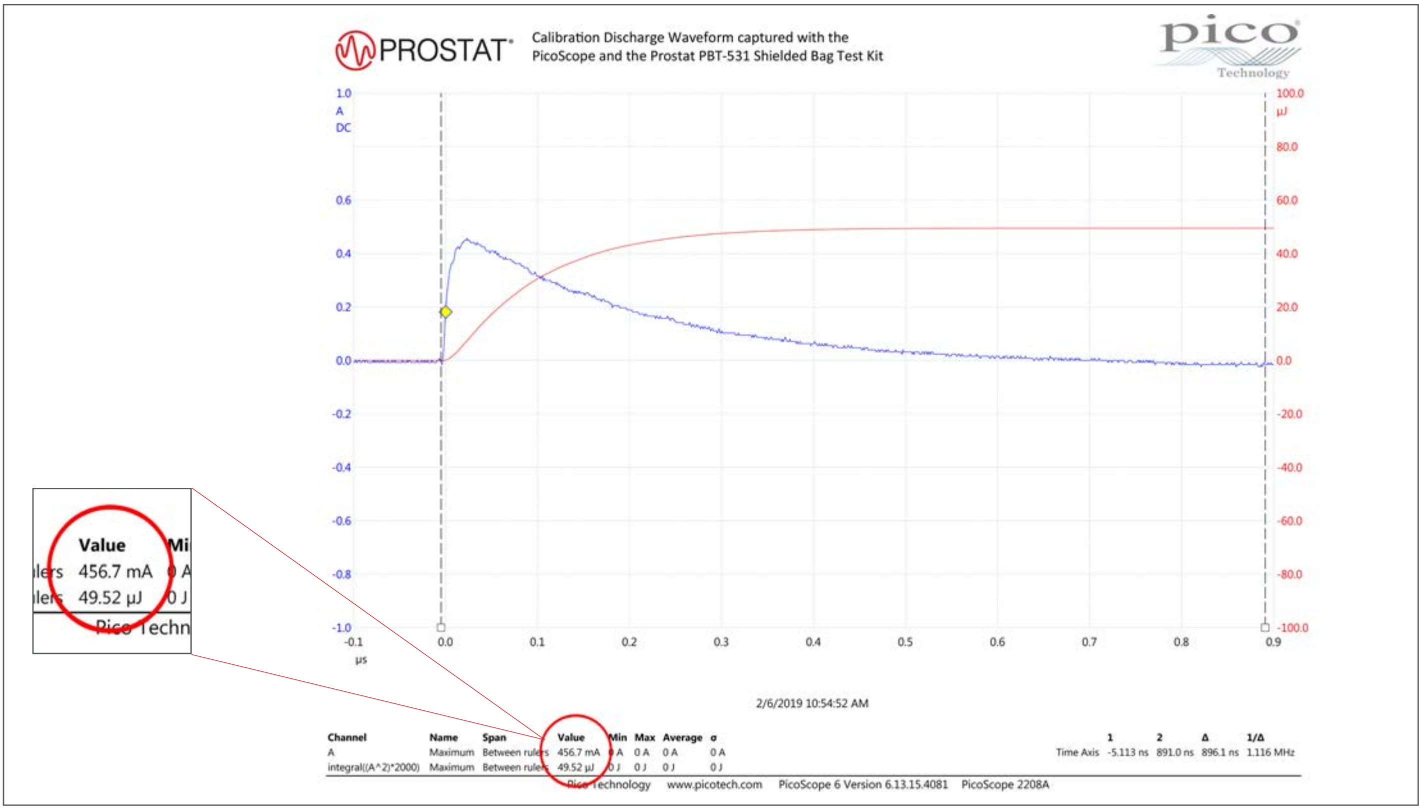

Figure 10 - The reader can view the calibration discharge curve of a calibration discharge (conducted without a bag) at 49.52uJ or 49,520nJ.

ESD Check Bag 1			ESD Check Bag 2			ESD Check Bag 3			ESD Check Bag 4			ESD Check Bag 5			ESD Check Bag 6		
Bag 1	nJ	HVD	Bag 2	nJ	HVD	Bag 3	nJ	HVD	Bag 4	nJ	HVD	Bag 5	nJ	HVD	Bag 6	nJ	HVD
1	5.53	1000v	1	6.47	1000v	1	5.29	1000v	1	5.45	1000v	1	4.43	1000v	1	4.63	1000v
2	5.39	1000v	2	6.44	1000v	2	5.38	1000v	2	5.45	1000v	2	4.43	1000v	2	4.75	1000v
3	5.41	1000v	3	6.47	1000v	3	5.27	1000v	3	5.45	1000v	3	4.43	1000v	3	4.75	1000v
4	5.44	1000v	4	6.47	1000v	4	5.41	1000v	4	4.43	1000v	4	4.43	1000v	4	4.99	1000v
5	5.38	1000v	5	6.34	1000v	5	5.42	1000v	5	4.43	1000v	5	4.43	1000v	5	4.99	1000v
6	5.50	1000v	6	6.28	1000v	6	5.45	1000v	6	4.43	1000v	6	4.43	1000v	6	5.07	1000v
Average	5.44		Average	6.41		Average	5.37		Average	4.94		Average	4.43		Average	4.86	
Median	5.43		Median	6.46		Median	5.39		Median	4.94		Median	4.43		Median	4.87	
Minimum	5.38		Minimum	6.28		Minimum	5.27		Minimum	4.43		Minimum	4.43		Minimum	4.63	
Maximum	5.53		Maximum	6.47		Maximum	5.45		Maximum	5.45		Maximum	4.43		Maximum	5.07	
St. Dev.	0.06	12%RH	St. Dev.	0.08	12%RH	St. Dev.	0.07	12%RH	St. Dev.	0.55	12%RH	St. Dev.	0.00	12%RH	St. Dev.	0.18	12%RH
ESD Check Bag 1			ESD Check Bag 2			ESD Check Bag 3			ESD Check Bag 4			ESD Check Bag 5			ESD Check Bag 6		
Bag 1	nJ	HVD	Bag 2	nJ	HVD	Bag 3	nJ	HVD	Bag 4	nJ	HVD	Bag 5	nJ	HVD	Bag 6	nJ	HVD
1	4.68	1000v	1	4.73	1000v	1	4.43	1000v	1	5.64	1000v	1	6.07	1000v	1	5.33	1000v
2	4.75	1000v	2	4.73	1000v	2	4.43	1000v	2	5.83	1000v	2	6.11	1000v	2	5.43	1000v
3	4.79	1000v	3	4.40	1000v	3	4.43	1000v	3	5.82	1000v	3	6.15	1000v	3	5.50	1000v
4	4.80	1000v	4	4.40	1000v	4	4.43	1000v	4	5.78	1000v	4	6.07	1000v	4	5.62	1000v
5	4.76	1000v	5	4.40	1000v	5	4.43	1000v	5	5.79	1000v	5	6.22	1000v	5	5.56	1000v
6	4.73	1000v	6	4.40	1000v	6	4.41	1000v	6	5.75	1000v	6	6.24	1000v	6	5.61	1000v
Average	4.75		Average	4.51		Average	4.42		Average	5.77		Average	6.14		Average	5.51	
Median	4.76		Median	4.40		Median	4.43		Median	5.78		Median	6.13		Median	5.53	
Minimum	4.68		Minimum	4.40		Minimum	4.41		Minimum	5.64		Minimum	6.07		Minimum	5.33	
Maximum	4.80		Maximum	4.73		Maximum	4.43		Maximum	5.83		Maximum	6.24		Maximum	5.62	
St. Dev.	0.04	50%RH	St. Dev.	0.17	50%RH	St. Dev.	0.01	50%RH	St. Dev.	0.07	50%RH	St. Dev.	0.07	50%RH	St. Dev.	0.11	50%RH

Table 10

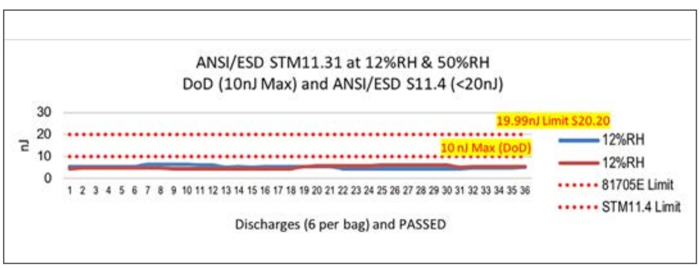

Table 11

The static shielding bag under test allowed <7.0nJ to penetrate the structure. Thus, the static shielding bags measured <20nJ and are ANSI/ESD S20.20 compliant.

In summary, the test methods utilized for formalized ESD qualification testing are as follows:

Testing Protocols	Results
Surface Resistance; inside and outside of bag per ANSI/ESD STM11.11at <1.0 x 10^{11} Ω	PASSED
Volume Resistance; inside of the bag to plate per ANSI/ESD STM11.12	PASSED
Electrostatic Decay per Mil-STD-3010C, Method 4046-2013 (5kV to 0 volts) at <2.0 Sec	PASSED
Charge Retention (Faraday Cup) per ESD Adv. 11.2-1995 at <1.0 n	PASSED
Static Shielding at 12%RH and 50%RH per ANSI/ESD STM11.31 at <20 nJ	PASSED

Table 12

In short, said testing methods for evaluation are traceable to ANSI/ESD S541 and MIL-STD-3010C, Method 4046.

This article clearly demonstrates that qualification of ESD control packaging as with any static control product from the USA, Europe, Mexico, Central and South America, and Asia-Pacific must follow a formalized qualification process. In this instance, the ESD bags are suitable for use inside and outside the ANSI/ESD S20.20-2014 ESD Protected Area. Moreover, ESD product qualification needs to be combined with periodic verification of incoming materials and packaging during the product life cycle to prevent substitution or downgrading of static control products. The ever increasing expansion of suspect counterfeit materials and packaging in the global supply chain demonstrates how important it is to use vetted ESD test labs that are credentialed and adhere to a code of ethics. Trust but verify a potential ESD test lab before issuing a purchase order as is done with other proven suppliers.

Author's Note: Special Thanks to Frank Coloccia of Prostat Corporation for providing the ESDcheck® Bag for Level 3 test specimens (fcoloccia@prostatcorp.com or 630.238.8883).

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3. ANSI/ESD S20.20
4. ANSI/ESD STM11.11
5. ANSI/ESD STM11.12
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7. MIL-STD-3010C, MTD 4046
8. ANSI/ESD S11.4 (Static Shielding Bag Standard Following ESD Materials Validation Process, Controlled Environments, Bob Vermillion, August 26, 2010
9. Pin Holes & Staples Lead to Diminished Performance in Metallized Static Shielding Bags, *In Compliance*, September 2013, pp 42-48, Bob Vermillion

ABOUT THE AUTHOR

Bob Vermillion, CPP, Fellow, is a Certified ESD & Product Safety Engineer-iNARTE with proven subject matter expertise in the mitigation of Triboelectrification for harsh environments and troubleshooting of robotics, systems and engineered materials (displays, flexible electronics, 3D materials) for aerospace & defense, medical device, pharmaceutical, biotechnology, automotive and the electronics sectors. Bob is the co-author of several ANSI level ESD documents. Vermillion formerly served on the BoD with iNARTE until its acquisition by Exemplar Global. Since 2014, Bob is an active participant of the NASA IAWG for ESD and Founder and Co-Chair of the SAE G19 Sub-Committee for Packaging of EEE parts.

In 2018, Bob Vermillion developed the exclusive and unique "hands on" instrument-driven aerospace and defense ESD training program in which the first class consisted of NASA ESD Program Managers, JPL, UC Berkeley Space Science Laboratory and a few primes who received the NEW iNARTE® Certified ESD Aerospace & Defense Engineer™ credential as developed by RMV with 3rd party international certification by Exemplar Global, an affiliate of American Society of Quality (ASQ). See https://inarte.org/certifications/esd-aerospace-defense-engineer-cert/

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EMC Laboratory Audit Items

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INTRODUCTION

In the last blog I provided the reader with a guide to some of the items that need to be looked at when auditing an EMC laboratory with an eye to placing the laboratory on your company's approved lab list. In this blog I'll go into some detail on a few of these items. This not an in depth look at each item but is based on my experiences auditing laboratories (both in-house and 3rd party) over a number of years.

IS THE LABORATORY TRULY CAPABLE OF PERFORMING YOUR NEEDED TESTS?

What are the standards to which your product must be tested? Not just the higher level product family standards, such as CISPR 32 or CISPR 35 for information Technology Equipment, but the basic standards called out in those product family standards. Not only which standards, but which version of the standards? When you issue the Declaration of Conformity it must be to the correct versions. And the test report from the laboratory must call out the correct versions. The latest version is not always the right answer.

EXAMPLES OF STANDARDS

- CISPR 35:2016 (Edition 1) calls out a number of basic standards to which you must test your product. And it uses specific versions of those standards. These are:

- IEC 61000-4-2:2008. This is the ESD testing standard. The 2008 edition is the latest edition of this standard.

- IEC 61000-4-3:2006 with Amendment 1:2007 and Amendment 2:2010. This is the radiated RF immunity test standard and with these amendments is the latest version of the standard.

- IEC 61000-4-4:2012. This is the electrical fast transient/burst immunity test standard. Again, this is the latest version of the standard.

- IEC 61000-4-5:2005. This is the surge immunity test standard. This is NOT the latest version of the standard. The latest version is IEC 61000-4-5:2014 with Amendment 1:2017. There are concerns in CISPR SC I with changes that were made by SC77B when they created the 2014 edition of IEC 61000-4-5 and as a result the 2005 version is still called out in the standard. Amendment 1 to CISPR 35:2016 will address these concerns, but don't look for it until about 2021 or 2022 (if it takes the typical length of time for an amendment to work its way through the IEC). CISPR SC I MT8 will be issuing a Committee Draft (CD) for this amendment later this spring, so for now the 2005 edition of IEC 61000-4-5 remains the proper version to use.

- IEC 61000-4-6:2008. This is the conducted RF immunity test standard. Again, this is NOT the latest version of the standard. The latest version is IEC 4-6:2013 with a 2015 corrigendum. Look for a possible change when the amendment to CISPR 35 is published in 2021 or 2022.

- IEC 61000-4-8:2009. This is the power frequency magnetic field immunity test standard. This is the latest edition of the standard.

- IEC 61000-4-11:2004. This is the voltage dips, short interruptions and voltage variations immunity tests standard. There is an amendment to this standard that was published in 2017, but the amendment is not called out in CISPR 35:2016 as it occurred after the current edition of CISPR 35 was published. Be aware of this when auditing a laboratory or reviewing a test report.

- IEC 61000-4-20:2010. This is the emission and immunity testing in transverse electromagnetic (TEM) waveguides test standard. Only the immunity portion of this standard would be used, and this is an option in place of IEC 61000-4-3:2006 with amendments called out above for certain tests.

- IEC 61000-4-21:2011. This is the reverberation chamber test methods standard and is also an option in place of IEC 61000-4-3:2006 with amendments called out above for certain tests.

Why do I call out these specific editions of the standards? Because CISPR 35, along with other standards, uses dated references in its normative standards list. This means that the laboratory must use these versions, and only these versions of the basic standards with testing in order to claim or show compliance with the higher level standard. The laboratory does not have the flexibility or authority to use a later edition if it exists, as in IEC 61000-4-5 and IEC 61000-4-6 as noted above. Sometimes the differences are minor, other times they are not.

The difference in how a dated reference is treated versus how an undated reference is treated is called out in IEC Guide 107:2014 (Edition 4.0). In its Informative Annex C it clearly states in article C.3.1 that if a dated reference is called out is it not permissible to use either an earlier or a later edition of the standard and that amendments to dated standards must be called out as used (see the example of IEC 61000-4-3 above), otherwise they are not used (see the example of IEC 61000-4-11 above).

An example from the past of a change that was significant was in CISPR 24:1997. This is the first edition of the ITE product family immunity test standard and it specifically called out IEC 61000-4-4:1995 for fast transient/burst testing. Labs were caught using IEC 61000-4-4:2004 after it was published. There was a significant change in the 2004 edition of IEC 61000-4-4 that changed the laboratory test setup for tabletop equipment and it was necessary to use the older setup. The auditor had to be aware of this change in order to ensure that the laboratory was using the older version of the basic standard. CISPR 24:2010 called out the updated IEC 61000-4-4:2004 and when it was adopted by regulatory agencies around the world this problem was resolved. But, in the meantime, laboratories had to understand the difference and test in accordance with the correct version. Other product family standards may very well have adopted the 2004 edition of IEC 61000-4-4 earlier than it was in CISPR 24, so a laboratory had to be equipped for both test setups and use the appropriate one as needed. Note that CISPR 35:2016 uses IEC 61000-4-4:2012, which is the latest edition of IEC 61000-4-4.

INSTRUMENTATION CALIBRATION RECORDS

Check the laboratory's quality system for how test equipment is to be calibrated and labeled. Some labs require that the expiration date of the calibration be included on calibration stickers, others do not. Find out the lab's requirement and check some instruments to see if the lab's own requirements are being followed. If an instrument does not have a calibration sticker on it, find out why. It may be legitimate, such as a controller for a turntable or antenna mast, or it may not be legitimate and the lab either forgot or it hiding something. Find out. How are antenna calibrations (among others) tracked? How are the new antenna factors loaded into measurement software and how does the lab ensure that the new factors were loaded correctly? The same goes for other items that require periodic calibration and loading of correction factors. A classic example is the insertion loss of antenna cables. Clearly a function of frequency and the loss file is unique to each cable. Are the cables labeled so the correct file is used for the correct cable?

HOW DOES THE LAB MAKE SURE THAT THE CORRECT VERSION OF A DOCUMENT IS USED?

Ask the laboratory personnel to show you how they check to make sure they are using the correct version of a test standard, and how they know that they are using the correct version of the laboratory's procedures, as called out in the quality manual. This is important and can tell you a great deal about the quality of the laboratory's results.

CONCLUSION

This is just a short, and non-comprehensive, list of items that have caused laboratories to have deficiencies written against them when being audited by someone other than an on-site assessor for a formal accreditation. Laboratories vary widely in their compliance with standards, and you must know the requirements in the standards at least as well as the laboratory you are considering using. They are your eyes and ears, but they must not be making the business decisions for you, as well. I could write a book on the errors I've found over the years, even in laboratories accredited by some well-known laboratory accrediting bodies. Some labs are better than others, but none have ever passed without at least one deficiency being written against them.

It is critical that you understand the standards to which your product will be tested when auditing a laboratory prior to selecting them. Laboratories are typically staffed by excellent technicians and engineers, but 3rd party labs typically test a wide variety of products and can make errors in selecting the correct versions of basic standard. You must know the standards that apply to your product so that you can ensure that the correct version is being used, even if it isn't the latest and greatest. Check the laboratory's quality manual and make sure they are following it. Make sure the laboratory personnel are using the correct version of the manual.

ABOUT THE AUTHOR

Ghery S. Pettit, NCE is the President of Pettit EMC Consulting LLC. He is a graduate of Washington State University and is a Life Senior Member of the IEEE. He has worked in the EMC world for the past 42 years in positions with the US Navy, Martin Marietta Denver Aerospace, Tandem Computers, Intel Corporation and now as an independent consultant. Mr. Pettit is a past President of the IEEE EMC Society and currently serves as Chair of CISPR Subcommittee I, which is responsible for emissions and immunity standards for broadcast receivers, ITE and multimedia equipment. He has designed and operated EMC laboratories, provided EMC analysis, design, troubleshooting and testing support for a variety of projects and contributed to various EMC standards such as ANSI C63.4, CISPR 22, CISPR 24, CISPR 32 and CISPR 35. Ghery may be reached at Ghery@PettitEMCConsulting.com or at (360) 790-9672.

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MAY 21 – 23 2019

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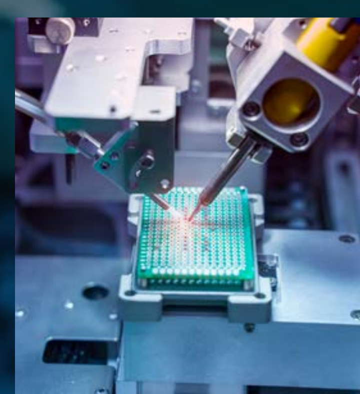

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EMC LIVE™ 2019 TECHNICAL PROGRAM

MAY 21 – 23 2019

TUESDAY | MAY 21, 2019

JOE DiBIASE | 11:00 am ET

Manager of EMC Applications and Systems, AR RF/Microwave Instrumentation

Improving EMC Test Lab Work Flow

Joe will discuss Improving EMC Test Lab Workflow. For those who set up a lab, or those making changes to a lab, this presentation will provide useful guidance to consider.

SCOTT LINDBERG | 11:50 am ET

Director of Sales and Marketing, Quell Corporation

Product Demo – Military Vehicle Passes RE102 EMC Test with Help of Connector Insert

EMC testing is expensive, failing in the chamber is the worst-case scenario. Learn how a military engineer passed their test using a connector insert.

TOM MULLINEAUX | 12:15 pm ET

RF Engineer / Educator, Self–Employed

Understanding the Interaction Between Radiated Fields and EMC Antennas

How exactly do EMC antennas ‘pick up’ radiated fields? And what is it about a radiated field that allows the antenna to do so? This webinar explains in plain language how the two interact.

MIKE VIOLETTE | 1:30 pm ET

President, Washington Laboratories

EMC Success Strategies for the Internet of Things

Mike will provide an introduction to the Internet of Things, including use cases and how the world of IoT is touching every part of our lives, our work, and our play.

CHRIS ARMSTRONG | 2:45 pm ET

Director of Product Marketing & SW Applications, Rigol Technologies North America

Comprehensive Pre-Compliance Analysis Throughout the Design Process

Learn how hardware, software, and setup can work together to eliminate blind spots in product development that often lead to wasted time and money in compliance testing and the late stage design changes they cause.

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WEDNESDAY | MAY 22, 2019

JORGE VICTORIA | **11:00 am ET**

Product Manager EMC Components, Würth Elektronik eiSos GmbH & Co. KG

EMC Shielding with Magnetic Absorbers

With the wide spread of wireless technologies through higher and lower frequencies, the continuous miniaturization of electronic devices and the development of powerful EMC measurement and simulation tools, EMC shielding is more useful and more challenging than ever.

FLYNN LAWRENCE | **11:50 am ET**

Senior Applications Engineer, AR RF/Microwave Instrumentation

Product Demo – Award-Winning Solid-State Field Generating Systems

These solid-state field-generating systems consist of an amplifier/antenna combination in a single housing which can generate field strengths up to 50 V/m with two band-specific models covering 18 to 40 GHz.

PAUL DUXBURY | **12:15 pm ET**

European Sales, Microwave Vision Group

The Challenges of Delivering Large Anechonic Chambers for Testing Large EUTs

During this presentation, Paul will overview a number of issues, such as interfacing to host building services, floor load capacity, chamber access, integrating turntables (and other systems), and anechoic design, showing the challenges which can be faced and, how they can be overcome.

MARKUS FUHRER | **1:30 pm ET**

Reinach, Schweiz, Ametek Compliance Test Solutions

Test Requirements of LV 123: Electrical Characteristics and Safety of High-Voltage Components in Road Vehicles

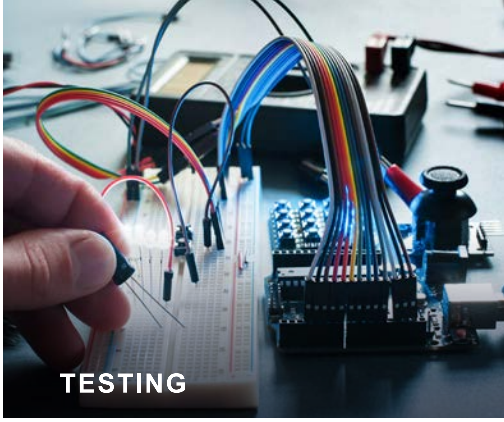
This presentation presents new test methods and methods developed from experiences with test houses in recent months, as the suppliers of electrical components from the German automotive manufacturers AUDI, BMW, Daimler, Porsche and Volkswagen are obliged to meet the requirements of LV 123 for HV components.

TOM MULLINEAUX | **2:45 pm ET**

RF Engineer / Educator, Self–Employed

How Equipment-Under-Test Creates Unwanted Radio Frequency Noise

In this webinar, Tom describes those conditions and the means by which the radio waves escape from the equipment housing the circuit.



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p: 610.382.5891

2019 Calendar of Events

The following is a partial listing of major EMC-related conferences planned for 2019. If your conference is not listed, please contact: info@interferencetechnology.com.

2019 ESA WORKSHOP ON AEROSPACE EMC

May 20th – 22nd, 2019

Budapest, Hungary

Aerospace industry is under the continuous pressure due to an increasing demand for new services and technologies, higher integration level of electronics and reducing overall mass and volume of systems. New technologies and trends are calling for new approaches and methods to achieve compatibility between a huge variety of equipment. In the view of traditional verification approach from equipment to subsystem to system level, the extended use of commercial off the shelf components and the miniaturization into the Cube Sat standards present new challenges to the EMC society. In order to avoid retesting, fixing or redesign of already integrated systems, EMC engineers are seeking to improve the means of forecasting possible compatibility issues and validating subsystem designs.

►https://atpi.eventsair.com/QuickEventWebsitePotal/2019-esa-workshop-on-aerospace-emc/emc2019

EMC LIVE 2019

May 21st – 23rd, 2019

Online Webinar

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►www.emc.live

2019 JOINT INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY AND ASIA-PACIFIC INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY, SAPPORO

June 3rd – 7th, 2019

Sapporo Convention Center, Sapporo, Hokkaido, Japan

EMC Sapporo & APEMC 2019 is the 8th "International Symposium on Electromagnetic Compatibility" organized by IEICE-CS, and the first joint symposium under technical co-sponsorship by Asia-Pacific EMC (APEMC). We would like to invite all engaged in research and development in the various fields of electromagnetic compatibility to participate in this Symposium. This EMC Symposium series has a long history and it has been held every 5 years. The first of its series was held in Tokyo in 1984, which was the first IEEE EMC Symposium held outside USA sharing sponsorship with IECE. Ever since the second in 1989, this symposium series has been sponsored by IEICE.

►http://www.ieice.org/~emc2019/

23RD IEEE WORKSHOP ON SIGNAL AND POWER INTEGRITY (SPI)

June 18th – June 21st, 2019

Chambery, France

Over the past two decades, the IEEE Workshop on Signal and Power Integrity (SPI) has evolved into a forum of exchange on the latest research and developments on design, characterization, modeling, simulation and testing for Signal and Power Integrity at chip, package, board and system level. The workshop brings together developers and researchers from industry and academia in order to encourage cooperation. In view of last year's success, the Committee is looking forward to the 23rd Edition which will convene in the French Alpes, in the charming town of Chambery, on the shores of the Bourget lake.

►spi2019@sciencesconf.org | ►www.spi2019.scienceconf.org

2019 IEEE INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPARABILITY, SIGNAL & POWER INTEGRITY

July 22nd – July 26th, 2019

New Orleans, Lousiana

The 2019 IEEE International Symposium on EMC+SIPI is the leading of EMC and Signal & Power Integrity techniques to engineers of all backgrounds. The Symposium features five full days of training, innovative sessions, interactive workshops & tutorials, experiments & demonstrations, and social networking events. And now you can pick how you'd like to attend – in person or online!

►www.emc2019.emcss.org

EMC EUROPE 2019

September 2nd – 6th, 2019

Barcelona, Spain

EMC Europe 2019 focuses on the high quality of scientific and technical contributions providing a forum for the exchange of ideas and latest research results from academia, research laboratories and industry from all over the world.The symposium gives the unique opportunity to present the progress and results of your work in any EMC topic, including emerging trends. Special sessions, workshops, tutorials and an exhibition will be organized along with regular sessions.

►www.emceurope2019.eu/

INTERNATIONAL CONFERENCE ON LIGHTNING & STATIC ELECTRICITY 2019 (ICOLSE 2019)

September 10th – 13th, 2019

Wichita, Kansas

ICOLSE, held every two years, focuses on lightning phenomenology, effects on and protection of aircraft and other air vehicles, and a wide variety of ground-based systems and facilities such as alternative energy (wind, solar), space launch, telecom, and recreational theme parks. Conference sessions will also address static electricity generation, effects, and protection for aerospace vehicles and industrial facilities that experience the effects of static electricity.

►www.ICOLSE.com

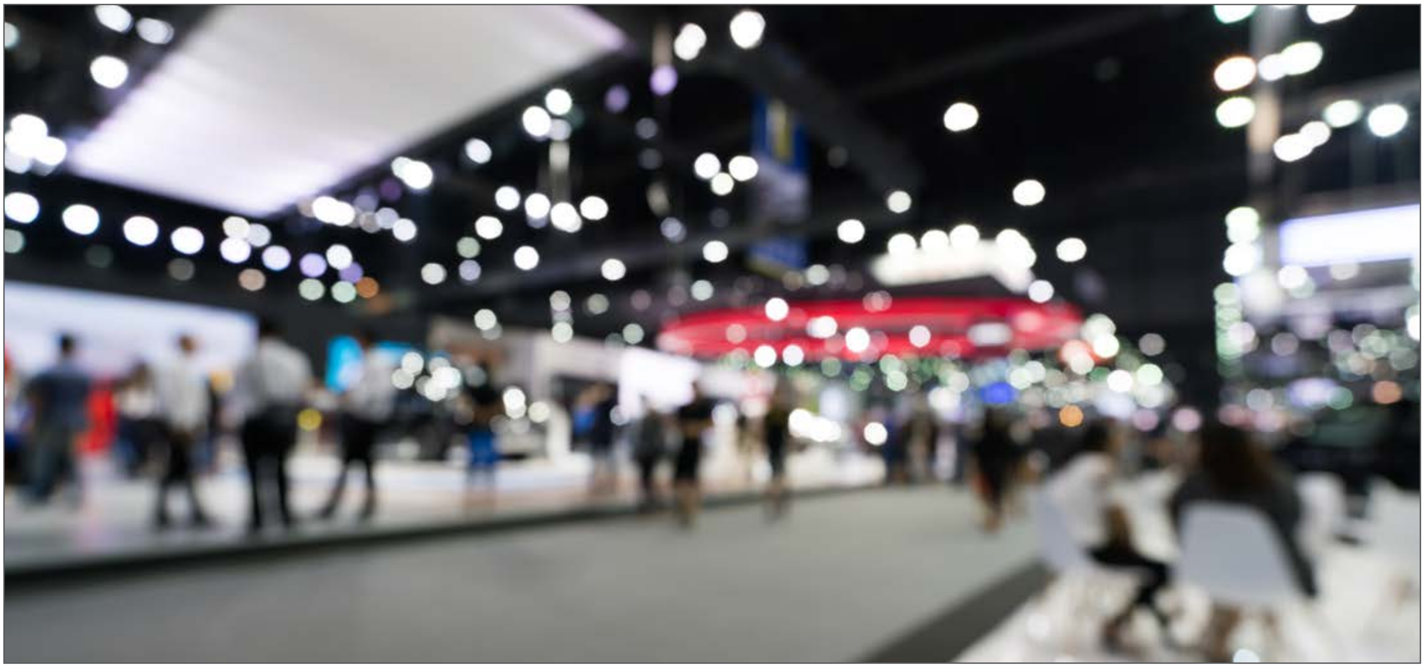
12TH IEEE INTERNATIONAL WORKSHOP ON THE ELECTROMAGNETIC COMPATIBILITY OF INTEGRATED CIRCUITS

October 21st – 23rd, 2019

Hangzhou, China

Since the first IC EMC Workshop is incepted in 1999 in Toulouse, France, www.emccompo.org, it has been held 10 times in Europe and one in Japan, the 12th EMC COMPO is the first time held in China. It will continue the EMC COMPO spirit and address the world-wide EMC issues primary in IC EMC community, the 12th EMC COMPO will serve as a broad exchange platform for both academia and industry. The symposium Technical Program Committee invites you to submit your original and unpublished papers in all aspects of electromagnetic compatibility (EMC) as well as signal and power Integrity (SI/PI), including but not limited to EMC/SI/PI design, modeling, management, measurements, and education. Please plan ahead and join this unique symposium, meet international colleagues, present your latest research findings, share your insight and perspectives, ask questions, learn from experts and innovators, explore collaborations, visit exhibitions and see new products.

►www.emcconf.org



2018/2019 Standards Review

Compliance with standards makes or breaks the launch of any new product. This section recaps new and revised national and international EMC standards over the last 12 months. The information below has been featured in our weekly Interference Technology eNews. Just go to InterferenceTechnology.com*, subscribe to the eNews, and you'll be updated on important changes in EMC standards weekly.*

REVIEW OF MIL-STD 461 CS115 IMPULSE EXCITATION; CS109 STRUCTURE CURRENT; RS105 TRANSIENT ELECTROMAGNETIC FIELD

March 27, 2019 – Steve Ferguson

I realized earlier that my reviews have covered most of the MIL-STD-461 test methods in the past year, so I decided to prepare this to capture those items that have been omitted in prior articles. Since this is a series close out and the topics have little in common, I'll take on each instead of using commonality to group multiple test methods.

To read the full article, please visit,
https://interferencetechnology.com/review-of-mil-std-461-cs115-impulse-excitation-cs109-structure-current-rs105-transient-electromagnetic-field/

REVIEW OF MIL-STD 461 CS103 INTERMODULATION, CS104 REJECTION OF UNDESIRED SIGNALS AND CS105 CROSS-MODULATION

March 7, 2019 – Steve Ferguson

Rapid technology advances in the wireless communications world makes test and evaluation of Radio Frequency (RF) devices a difficult subject. It seems that by the time a new device hits the market, it has been made obsolete by the next generation. I recall hearing from a major electronics manufacturer CEO that 90% of sales happen within 90-days of market release prompting the need for a successor. This applies to commercial products, but similar technology leaps will follow the military equipment demands from the propensity to use commercial-off-the-shelf (COTS) technology for DoD systems.

To read the full article, please visit,
https://interferencetechnology.com/review-of-mil-std-461-cs103-intermodulation-cs104-rejection-of-undesired-signals-and-cs105-cross-modulation/

REVIEW OF MIL-STD 461 CS117 LIGHTNING INDUCED TRANSIENTS, CABLES AND POWER LEADS

February 1, 2019 – Steve Ferguson

Lightning may produce a spectacular display when viewed, but the associated electromagnetic effects (EME) has the potential (pun intended) to severely damage electrical and electronic circuits. MIL-STD-461G added a new test method to evaluate device tolerance for induced current on equipment cables or insulation breakdown from the effects of indirect lightning. Although new to MIL-STD-461, the induced lightning tests have a background in civil aviation with similar test methods documented in RTCA/DO-160.

To read the full article, please visit,
https://interferencetechnology.com/review-of-mil-std-461-cs117-lightning-induced-transients-cables-and-power-leads/

REVIEW OF MIL-STD 461 CE106 CONDUCTED EMISSIONS, ANTENNA PORT

December 20, 2018 – Steve Ferguson

Let's take on the challenging evaluation of detection and measurement of antenna port emissions – the unintentional emissions that creep through the device circuitry and are presented to the world through an intentional wireless connection. We are NOT going into an in-depth study of antennas and we are NOT exploring what the unintentional signals may reveal. A simple discussion on getting measurements without overwhelming the test equipment while maintaining detection system sensitivity is the plan for this review.

To read the full article, please visit,
https://interferencetechnology.com/review-of-mil-std-461-ce106-conducted-emissions-antenna-port/

REVIEW OF MIL-STD-461 CS118 – ELECTROSTATIC DISCHARGE

October 12, 2018 – Steve Ferguson

MIL-STD-461G, released in December 2015, added a test for Personnel Borne Electrostatic Discharge (ESD). Prior to this release, this type of test for electronic systems and sub-systems was managed at the system level under MIL-STD-464C released in 2010. Both of these standards contain similar requirements. MIL-STD-461G provides the details on testing and MIL-STD-464C established the compliance requirements without detail on how to verify compliance.

To read the full article, please visit,
https://interferencetechnology.com/review-of-mil-std-461-cs118-electrostatic-discharge/

OVERVIEW OF THE DO-160 STANDARD

October 5, 2018 – Patrick Albersman

In aerospace, there is one standard that always seems to be popping up, DO-160. Aircraft suppliers are often complying with aviation authorities' regulations by testing their product to DO-160. DO-160 is a standard that was published by the industry group

Radio Technical Commission for Aeronautics known as RTCA. RTCA is not a government regulation, however the FAA, EASA and others will often cite RTCA/DO-160 as a means of compliance for certification. In fact, it is the de facto standard in aerospace environmental testing.

DO-160 includes both environmental plus EMC, but in this article, we'll provide an overview of just the EMC-related sections. In later blogs, we'll go through each section, describing the tests in more detail, along with specific challenges for each.

To read the full article, please visit,
https://interferencetechnology.com/overview-of-the-do-160-standard/

UNECE REGULATION 10: ELECTRONIC SUB-ASSEMBLY WITH IMMUNITY RELATED FUNCTIONALITY

September 14, 2018 – Stan Dolecki
In this special guest-installment for the series of blogs on UNECE Regulation 10, Revision 5, Amendment 1 (8 October 2016), written by Elite Electronic Engineering's Automotive Test Group Team Leader Stan Dolecki, we will look at electronic sub-assemblies with immunity related functionality.

Electronic sub-assemblies (ESA) utilized in the European Union require conformity assessment in accordance with UNECE Regulation 10 if the device has an immunity related function. The objective of testing is to assure the ESA operates reliability to support the safe operation of the vehicle. To confirm operations, a key set of Reg 10 tests are the ISO 7637 vehicle environment transients. In this article, we will review a few key aspects of vehicle transient tests and in particular those ISO 7637 tests for UNECE Regulation 10.

To read the full article, please visit,
https://interferencetechnology.com/unece-regulation-10-electronic-sub-assembly-with-immunity-related-functionality/

REVIEW OF MIL-STD 461 CS114– CONDUCTED SUSCEPTIBILITY, BULK CABLE INJECTION

July 27, 2018 – Steve Ferguson
This article discusses CS114, including the updates contained in MIL-STD-461 revision "G", the current revision and the associated nuances that lead to test errors. The fundamental idea behind CS114 testing is to simulate currents induced into cabling from electromagnetic (EM) fields from high level emissions, intentional or unintentional. This test allows an evaluation in the laboratory where cable length and low frequency radiator systems prevent coupling from or generation of the high-level field. When dealing with CS114, the engineer needs to keep in mind that the test goal is induce current in proportion to an associated radiated field. At the lower end of the test frequency range, conduction via power cables from noisy power sources can be the coupling path but inductive reactance of the wiring tends to attenuate the conducted interference.

To read the full article, please visit,
https://interferencetechnology.com/review-of-mil-std-461-cs114-conducted-susceptibility-bulk-cable-injection/

REVIEW OF MIL-STD 461 RS101– RADIATED SUSCEPTIBILITY, MAGNETIC FIELD AND RS103 RADIATED SUSCEPTIBILITY, ELECTRIC FIELD

June 8, 2018 – Steve Ferguson
This article discusses RS101 and RS103, including the updates contained in MIL-STD-461 revision "G", the current revision. These tests quantify the ability of a device to tolerate undesired signals present as a field at the device and associated cables. The field has the potential of coupling the interference into the device circuitry and cause performance degradation or device damage.

These test methods have been a part of the MIL-STD-461 test program from the onset using RS01 (Magnetic Field), RS02 (Magnetic Induction Fields), RS03 (14 kHz-10 GHz electric field) and RS04 (14 kHz-30 MHz Parallel Plate Electric Field) numbering. MIL-STD-461 assigned applicability and test levels for various applications. In addition, reference is made to MIL-HDBK-235 to determine the anticipated environment for establishing test levels for any particular application.

To read the full article, please visit,
https://interferencetechnology.com/review-of-mil-std-461-rs101-radiated-susceptibility-magnetic-field-and-rs103-radiated-susceptibility-electric-field/

RADIO EQUIPMENT DIRECTIVE, 2014/53/EU

February 1, 2017
Note: The Radio Equipment Directive (RED), 2014/53/EU, must be used for new products manufactured after June 13, 2016 and becomes mandatory for all products June 13, 2017.

Abstract
This article provides an update on changes occurring as a result of the new Radio Equipment Directive (RED) 2014/53/EU which can be used from June of 2016. It looks at the changes in the product and regulatory landscape and at what it means to equipment manufacturers. More detail on the history of the RED can be found in the article, Radio Equipment Directive, in the Interference Technology 2015 EMC Directory and Design Guide.

To read the full article,
https://interferencetechnology.com/radio-equipment-directive-201453eu/

REVIEW OF IEC 60601-1-2: 2014

(4th Edition)
February 22, 2017
IEC 60601-1-2:2014 Edition 4 was published February 2014 and replaces IEC 60601-1-2 Edition 3 published on 2007. It pertains to EMC for medical electrical equipment and medical electrical systems. The European version (EN60601-1-2:2015) is identical to its IEC counterpart with exception of references to the EN versions of the 61000-4-x series and the addition of an Essential Requirements annex.

The motivation behind the 4th edition was to create a safety standard that pertains to electromagnetic disturbances in order to align with the general requirements of IEC 60601-1 Edition 3. The previous version of IEC 60601-1-2 did not adequately address the safety aspects as related to electromagnetic interference. In addition, the differences between edition 3 and 4 with respect to immunity are substantial.

To read the full article,
https://interferencetechnology.com/review-iec-60601-1-2-2014-4th-edition/

CISPR 35 PUBLISHED – MULTIMEDIA IMMUNITY

September 7, 2016
Blog post by Ghery Pettit
Now that CISPR 35 is finally published, the questions that you want answered are: What is the same as CISPR 24? What has changed? What is new? To read the full blog post, click here.

FDA FINALIZES GUIDANCE IN SUPPORTING CLAIMS OF EMC

July 20, 2016
The U.S. Food and Drug Administration (FDA) has issued final guidance in supporting claims of electromagnetic compatibility (EMC) of medical devices. The document is recommended for use in conjunction with consensus standards, as well as other FDA guidance documents pertaining to specific devices.

Typically, the FDA reviews EMC information based on the risk of device malfunction and/or degradation if the device is exposed to electromagnetic interference by other devices near its intended electromagnetic environment. The proliferation of smartphones, wearables, home appliances, and other electronic devices poses a threat to safe performance of medical devices, and the FDA wants manufacturers to follow established standards and guidance documents to mitigate risks.

Manufacturers are recommended to follow device-specific guidance, such as one issued for Infusion Pumps Total Product Life Cycle, and cross-cutting guidances, such as Design Considerations for Devices Intended for Home Use.

In addition to following these FDA-recognized standards and guidance documents, and in order to support a claim of electromagnetic compatibility in premarket submissions, the FDA recommends in the final guidance that manufacturers include several items of information. The final guidance document applies to premarket approval (PMA) applications, humanitarian device exemption (HDE) applications, premarket notification [510(k)] submissions, investigational device exemption (IDE) applications, and de novo requests.

To learn more,
https://www.fda.gov/ucm/groups/fdagov-public/@fdagov-meddev-gen/documents/document/ucm470201.pdf

FCC RELEASES UPDATED LED LIGHTING EMC GUIDANCE

July 14, 2016
(June 17, 2016) Effective June 17, 2016, all RF LED lighting devices, including those that have been considered to operate on frequencies below 1.705 MHz, are now required to have Radiated Emissions measurements performed at a minimum from 30 MHz to 1000 MHz.

Radio frequency (RF) light-emitting diode (LED) lighting products are subject to FCC rules to ensure that devices do not cause harmful interference to radio communications services. This KDB publication clarifies how the FCC rules apply to these products, and outlines manufacturers' responsibilities for controlling interference. This publication does not address older legacy lighting technologies such as incandescent, fluorescent, and high intensity discharge (HID) lighting products.

For more, https://apps.fcc.gov/kdb/GetAttachment.html?id=K0pZdRE7biF3aqgO4XZ8cw%3D%3D&desc=640677%20D01%20RF%20LED%20LIGHTING%20v01&tracking_number=20518

ETSI RELEASES DRAFT STANDARD FOR LOW POWER MEDICAL IMPLANTS

July 14, 2016
(July 1, 2016) The present document together with ETSI EN 301 489-1 [1] covers the assessment of all radio transceivers associated with inductive Ultra Low Power Active Medical Implant (ULP-AMI) transmitters and receivers operating in the range from 9 kHz to 315 kHz and any associated external radio apparatus (ULP-AMI-Ps) transmitting in the frequency range of 9 kHz to 315 kHz including external programmers and patient related telecommunication devices in respect of ElectroMagnetic Compatibility (EMC). Non-radio parts of the above equipment may be covered by other directives and/or standards when applicable.

To download the draft, http://www.etsi.org/deliver/etsi_en%5C301400_301499%5C30148931%5C02.01.00_20%5Cen_30148931v020100a.pdf

IEC 60601-1-9 – ENVIRONMENTALLY CONSCIENCE DESIGN FOR MEDICAL EQUIPMENT

July 6, 2016
The standard for environmentally conscious design, IEC 60601-1-9, was published in 2007 (amended in 2013) as a collateral standard to IEC 60601, the widely accepted series of international standards for the basic safety and essential performance of medical electrical equipment. Compliance with the IEC 60601 series is required by regulatory bodies responsible for electrical medical equipment in many countries.

The requirements of IEC 60601-1-9 are based on practical experience made by reputable medical manufacturers which showed that the application of the standard may result in cost savings and marketing benefits.

Clients continue to increase pressure on manufacturers to develop medical devices with an environmentally conscious design, as it is seen as an aspect of an overall good design practice.

For more, http://www.intertek.com/medical/iec-60601-1-9/

MIL-STD-464C REVISION PROCESS UNDERWAY

May 26, 2016

US DoD has begun the process to revise MIL-STD-464C. Industry comments are welcome, and should be funneled through the two industry reps to the DoD Tri-Service Working Group: ken.javor@emccompliance.com and briand.lessard@lmco.com.

Format for comment submission is very specific and must be adhered to rigorously. The comment should provide change from, change to, and rationale. A suitable form is available from ken.javor@emccompliance.com.

ASSIST IS OFFICIAL ARCHIVE FOR MIL-STD DOCUMENTS

May 18, 2016

ASSIST is a web site used by standardization management to develop, coordinate, distribute, and manage defense and federal specifications and standards, military handbooks, commercial item descriptions, data item descriptions, and related technical documents prepared in accordance with the policies and procedures of the Defense Standardization Program (DSP).

Besides DoD-prepared documents, ASSIST also has selected international standardization agreements, such as NATO standards ratified by the United States and International Test Operating Procedures. Since it always has the most current information, ASSIST is the official source for specifications and standards used by the Department of Defense.

Find all archived copies of MIL-STD-461, http://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=35789

WHAT'S NEW: IEC 61000-4-5 SECOND EDITION VS. THIRD EDITION

April 28, 2016

by Jeff Gray, Chief Technology Officer, Compliance West USA

Introduction

IEC 61000-4-5 is part of the IEC 61000 series, which describes surge immunity testing caused by over-voltages from switching and lightning transients. The second edition of IEC 61000-4-5 was released in 2005 and has been in use for many years. The third edition was released as an EN standard in 2014. The general philosophy of the third edition is unchanged from the second edition. However there have been a number of refinements to the standard: additional explanation to clear up ambiguities, new descriptions that were not included in the second edition, and new (informative) Annexes that can be used to help in the application of the standard. The purpose of this article is to outline the changes and additions that are now part of IEC 61000-4-5 3rd edition.

Critical Transition Dates

Transition from the second edition to the third edition is already taking place within the EU according to the following dates:

> 19 Mar. 2015 – Date of Publication (dop): The third edition has to be implemented by publication of an identical national standard by CENELEC member countries.
>
> 19 June 2017 – Date of Withdrawal (dow): National standards that conflict with the third edition must be withdrawn (i.e. the second edition can no longer be used).

To read the full article, https://interferencetechnology.com/whats-new-iec-61000-4-5-second-edition-vs-third-edition/

HOW TO SELECT THE RIGHT EMC STANDARD FOR YOUR PRODUCT

April 20, 2016

Many companies developing products find it difficult to determine the appropriate EMC standard to comply with. The IEC (International Electrotechnical Commission) has developed a web page that explains EMC and offers a tabbed selection method for determining the right standard that applies to your product family.

You can then go to their web store and purchase downloadable standards applicable to your product.

For more information, http://www.iec.ch/emc/emc_prod/prod_main.htm

HOW THE IEC IS ORGANIZED FOR EMC

April 20, 2016

International EMC standards can be confusing to the newcomer. The IEC has posted a chart as to how the various standards organizations are organized.

The first level of organization is the committees, such as TC77, CISPR, and various product committees. These committees have liaisons with associated standards organizations, such as ISO, ITU, CENELEC, and many others. Many of these groups have working relationships with national, regional, and international organizations. In the U.S., for example, one of the primary standards organizations is ANSI.

For more information, http://www.iec.ch/emc/iec_emc/

MIL-STD-461G: THE "COMPLEAT" REVIEW

April 15, 2016

Ken Javor, EMC Compliance

MIL-STD-461G was released on 11 December 2015 and will become contractually obligatory on programs initiated after that date.

This account is more than a simple laundry list arrived at by performing a side-by-side “F” vs. “G” comparison. Instead, it is an insider account into the issues with which the Tri-Service Working Group (TSWG) was grappling, and the thought processes behind the changes, as well as, of course, the changes themselves. It also lists some of the issues brought to the table that were not incorporated in MIL-STD-461G, and why. It will greatly assist the reader if a copy of MIL-STD-461G is available as this account unfolds.

To read the full article, https://interferencetechnology.com/mil-std-461g-compleat-review/

WHY IS THERE AIR (IN MIL-STD-461G)?

April 14, 2016

Ken Javor, EMC Compliance January 2016 As noted in Javor's MIL-STD-461G review (https://interferencetechnology.com/mil-std-461g-compleat-review/), SAE Aerospace Information Report (AIR), AIR 6236, In-House Verification of EMI Test Equipment was written specifically to support MIL-STD-461G. Specifically, section 4.3.11 Calibration of measuring equipment has been reduced in scope to devices such as EMI receivers and spectrum analyzers, oscilloscopes and (RS103) electric field sensors. Section 4.3.11 now says, "After the initial calibration, passive devices such as measurement antennas, current probes, and LISNs, require no further formal calibration unless the device is repaired.

The measurement system integrity check in the procedures is sufficient to determine acceptability of passive devices." AIR 6236 was written to support the verification of proper operation of such devices in the EMI test facility using only test equipment commonly available in an EMI test facility. The idea behind the AIR was that if a measurement system integrity check was problematic, the AIR 6236 measurements would demonstrate whether or not there was a problem with a transducer. AIR 6236 was published in December 2015. Also, the procedures in the AIR can be used in-house to routinely self-check EMI test equipment, if desired.

This synopsis, by the AIR's author, discusses what's in it, and why, and includes a test procedure for one piece of equipment that was left out of the AIR.

The Introduction says that the AIR provides guidance on how to self-check the devices listed below, using equipment commonly found in EMI test facilities. The purpose is not to calibrate these devices, but to check that they have not varied significantly from manufacturer's specifications.

To read the full article,
https://interferencetechnology.com/air-mil-std-461g/

BLUE GUIDE FOR EU PRODUCT RULES AVAILABLE

April 12, 2016

The European Union's (EU) "Blue Guide" describes general rules for placing electronic products on the market within the EU.

It describes how the EU regulates the free movement of goods, when the harmonization rules apply, the product supply chain and their obligations, product requirements, conformity assessment, and accreditation. The document goes on to describe how market surveillance works and includes several informative annexes.

To download the guide,
http://ec.europa.eu/DocsRoom/documents/18027

NEW RADIO EQUIPMENT DIRECTIVE

March 30, 2016

As more products include wireless technology, designers need to specify wireless modules that meet the new Radio Equipment Directive (RED) 2014/53/EU, which was published on April 16, 2014. On June 13, 2016, the new Directive will become law and all products within its scope must meet the RED.

To learn more,
http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014L0053

CISPR PROVIDES "GUIDE TO EMC IN SMART GRID"

February 23, 2016

CISPR has prepared a "Guide to EMC in Smart Grid", which gives insight into issues which should be taken into consideration when designing and developing equipment for connection and inter-operation with the Smart Grid.

SmartGrid systems must be immune to sources of interference from a wide array of wanted RF signals and RF disturbances and other events which occur at SmartGrid component installations.

Among the issues that must be addressed is EMC, which is the ability to withstand the electromagnetic (EM) environment (have sufficient immunity) without causing interference (disturbances) primarily to radio reception, but also to other digital/electronic devices.

Electromagnetic disturbances of various types, from a variety of sources, have been reported and have caused performance degradation, outages, shutdowns and even large scale system failure to the power grid. EMC is thus an important factor for consideration in standards relating to the IEC SmartGrid program.

The SmartGrid needs to function properly and have full interoperability, with other electrical and electronic systems. To ensure this these systems and their components must be designed with due consideration for conducted electromagnetic emissions injected into the grid and for immunity to various electromagnetic phenomena originating from the grid. This needs to include devices that will be mounted on the outside of buildings and homes as well as in newly designed "SmartGrid enabled" appliances.

For more, and a copy of the guide,
http://www.iec.ch/emc/smartgrid/

A2LA AND ANSI RECOGNIZED BY NIST TO ACCREDIT NOTIFIED BODIES

February 16, 2016

A2LA and ANSI (American National Standards Institute) have been formally recognized by the National Institute of Standards and Technology (NIST) as an Accreditation Body offering Notified Body (NB) accreditation under ISO/IEC 17020:2012, ISO/IEC 17025:2005, and ISO/IEC 17065:2012. Currently, A2LA is the only accreditation body recognized by NIST to offer accreditation to all three conformity assessment standards.

These standards form the basis for NB accreditation based on Section 4 of NIST's Requirements & Application for U.S. Conformity Assessment Bodies Seeking EU Radio Equipment Directive (RED) 2014/53/EU Notified Body Status and Requirements & Application of U.S. Conformity Assessment Bodies Seeking

Electromagnetic Compatibility (EMC) Directive 2014/30/EU Notified Body Status, which both state that "The [organization] shall obtain formal accreditation for its Notified Body activities."

The newly published Directives become effective in a relatively short window of time, at which point the NB accreditation requirements come into place –April 20, 2016 for the EMC Directive, and June 13, 2016 for the RED.

To see more,
https://www.ansi.org/news_publications/news_story?menuid=7&articleid=5b8ca79c-a953-43b5-a1e5-009b28b9805f

ACMA RELEASES PRODUCT COMPLIANCE GUIDANCE FOR EMC

February 10, 2016

The electromagnetic compatibility (EMC) regulatory arrangements impose compliance labelling and record-keeping requirements for the supply of an extensive range of electrical and electronic products, vehicles and products with internal combustion engines. The Australian Communications and Media Authority (ACMA) has detailed new requirements in the:

Radiocommunications Labelling (Electromagnetic Compatibility) Notice 2008 (https://www.legislation.gov.au/Series/F2008L00262) (the EMC LN) made under section 182 of the Radiocommunications Act 1992.

The objective of the arrangements is to minimise the risk of unintentional electromagnetic interference from products which may affect the performance of other electrical products or disrupt radiocommunications services.

The EMC LN specifies, among other things, the form and placement of the compliance label, the compliance level, the applicable EMC testing and record-keeping requirements. The Radiocommunications (Electromagnetic Compatibility) Standard 2008 (https://www.legislation.gov.au/Series/F2008L00261) (the EMC Standard) specifies the technical standards that apply to a device.

The EMC regulatory arrangements require that, prior to supplying a product to the Australian market, a supplier must:

Assess applicability – establish whether the product is subject to the EMC regulatory arrangement (refer to Part 2 in the EMC LN) (https://www.legislation.gov.au/Series/F2008L00262)

Identify the applicable standards – identify the applicable EMC standard/s (http://www.acma.gov.au/Industry/Suppliers/Equipment-regulation/EMC-Electromagnetic-compatibility/emc-standards-list) as listed on the ACMA website.

Demonstrate compliance – ensure the product complies with the applicable standard/s at the specified compliance level (refer to section 4.3 of the EMC LN). Compliance can be demonstrated through testing and/or assessment of supporting documentation.

Complete a Declaration of Conformity (DoC) and maintain compliance records – the DoC (http://www.acma.gov.au/) is a declaration made by, or on behalf of the supplier that all products comply with the applicable standard/s. A compliance record (http://www.acma.gov.au/Industry/Suppliers/Equipment-regulation/EMC-Electromagnetic-compatibility/emc-record-keeping-requirements) is a collection of documents (that may include the DoC and test reports) that support the supplier's claim the product complies with the standard/s (refer to section 4.3A and Part 5 of the EMC LN).

Register on the national database – a supplier must register on the national database (https://equipment.erac.gov.au/Registration/) before affixing a compliance label to a compliant product (refer to sections 4.2 and 4.2A of the EMC LN).

Apply a compliance label – a compliance label indicates the device complies with the applicable standards (refer to Part 3 of the EMC LN). The compliance label consists of the Regulatory Compliance Mark (RCM).

The EMC LN:
(https://www.legislation.gov.au/Series/F2008L00262) and its associated explanatory statement is available on the Federal Register of Legislative Instruments through the ComLaw website.

For more info,
http://www.acma.gov.au/Industry/Suppliers/Product-supply-and-compliance/Steps-to-compliance/emc-regulatory-arrangements

FCC TO CHANGE EMC APPROVALS PROCESS

February 1, 2016

Ghery Pettit Consulting reports a change in the FCC approvals process starting July 13, 2016.

Up until now, manufacturers have had the choice of using "FCC Listed" test labs or "FCC Recognized Accredited Test Laboratories." After that date, only the latter test labs – and ONLY those located in countries with mutual recognition agreements (MRAs) with the FCC may be used for the "Certification" approval process. Countries with current MRAs include Australia, Canada, the EU, Hong Kong, Israel, Japan, South Korea, Singapore, and Taiwan. The country with the biggest impact will be those test labs in China, where an MRA does not yet exist.

These test labs (and others located in countries lacking an FCC MRA) will only be able to test products to the FCC's "Verification" process.

For more information,
http://pettitemcconsulting.com/what-has-changed-with-fcc-approvals/

FUNCTIONAL SAFETY STANDARD IEC 61508

January 26, 2016

With more electronic systems controlling human-machinery interfaces, functional safety for EMC is becoming an important consideration. IEC 61508 addresses functional safety for industrial-process measurement, control and automation. This standard was developed by IEC SC 65A and you can read various comments and changes by leading experts.

For more,
http://www.iec.ch/functionalsafety/?ref=extfooter

DIRECTORY OF WORLD POWER

Plugs for Travelers
January 26, 2016
There are 14 commonly-used power line plugs used in over 200 countries. The IEC has made available a useful directory of power line plug styles used across the world. This handy guide (http://www.iec.ch/worldplugs/?ref=extfooter) for travelers is tabulated by country or by clicking on a world map.

C63 COMMITTEE STANDARDS

Incorporated by FCC
January 11, 2016
IEEE, the world's largest professional organization dedicated to advancing technology for humanity, today announced that two Accredited Standards Committee on Electromagnetic Compatibility (ASC-C63®) standards have been 'incorporated by reference' into the updated U.S. Federal Communications Commission (FCC) rules by which telecommunications certification bodies (TCBs) authorize radio-frequency (RF) equipment.

The FCC's reference of the two ASC C63® standards impacts the work of wireless-device manufacturers, test laboratories, and trade associations globally. The two ASC C63® standards referenced in FCC 14-208, 'Authorization of Radiofrequency Equipment' (https://www.federalregister.gov/documents/2015/06/12/2015-14072/authorization-of-radiofrequency-equipment), propose procedures for testing the compliance of a wide variety of wireless transmitters. ANSI C63.4-2014 (http://standards.ieee.org/findstds/standard/C63.4-2014.html), American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz, defines measurement procedures for unintentional radiators such as computers and various digital electronic devices. ANSI C63.10-2013 (http://standards.ieee.org/findstds/standard/C63.10-2013.html), American National Stand≠ard of Procedures for Compliance Testing of Unlicensed Wireless Devices, for intentional radiators such as remote controls, cordless phones, hands-free microphones, some medical devices, security devices, and other unlicensed wireless devices.

'The rules we are adopting will facilitate the continued rapid introduction of new and innovative products to the market while ensuring that these products do not cause harmful interference to each other or to other communications devices and services,' as taken from FCC 14-208, which became effective 13 July 2015. Its rules in July 2016 will become mandatory for RF devices used in the United States.

For more, http://c63.org/news.htm

STANDARD FOR SPECTRUM CHARACTERIZATION AND OCCUPANCY SENSING

January 6, 2016
The IEEE has initiated a new standards working group, P802.22.3, whose purpose is to specify the operating characteristics of the components of a system to characterize and sense the occupancy of the radio spectrum.

For more, https://standards.ieee.org/develop/project/802.22.3.html

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Professional Societies

IEEE ELECTROMAGNETIC COMPATIBILITY SOCIETY

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Website: http://www.emcs.org

The Institute of Electrical & Electronics Engineers (IEEE), the world's largest professional engineering society, is a global organization of individuals dedicated to improving the understanding of electrical and electronics engineering and its applications to the needs of society. The parent organization has over 360,000 members, approximately 70 percent of whom belong to technical groups such as the EMC Society.

The EMC Society, which enjoys a membership of over 5000, functions through a Board of Directors elected by the Society membership. The Board includes 20 members-at-large who serve staggered 3-year terms. The Executive Board consists of the President, President-Elect, Immediate Past President, Secretary, Treasurer, and five Vice Presidents, who oversee the activities of standing and technical committees. The officers are elected by the Board of Directors. The annual IEEE International Symposium on Electromagnetic Compatibility is sponsored by the Board of Directors, which also coordinates activities of standing technical and ad hoc committees. Recently, the EMC Society has included the topic of Signal Integrity.

EMC Society publications include Transactions on EMC, a quarterly journal which features state-of-the-art papers on interference technology and EMC, and the EMC Society Newsletter, a quarterly newsletter of society activities, industry developments, practical papers, and notices of meetings, regulations, and new publications.

The EMC Society also has a group of distinguished lecturers who are available to present talks to IEEE and other organizations. The society subsidizes the lecturers' expenses, and organizations are encouraged to contact the society for further details.

IEEE PRODUCT SAFETY ENGINEERING SOCIETY

While product safety had been addressed in various committees over the years, there was never a professional society or symposium solely devoted to product safety engineering as a discipline until recently. The IEEE Product Safety Engineering Society (PSES) began operation on 1 January 2004.

The field of interest of the Society is the theory, design, development and implementation of product safety engineering for electronic and electro-mechanical equipment and devices. This includes the theoretical study and practical application of analysis techniques, testing methodologies, conformity assessments, and hazard evaluations.
The society's mission is to strive for the advancement of the theory and practice of applied electrical and electronic engineering as applied to product safety and of the allied arts and sciences.

The society provides a focus for cooperative activities, both internal and external to IEEE, including the promotion and coordination of product safety engineering activities among IEEE entities. In addition, the Society will provide a forum for product safety engineering professionals and design engineers to discuss and disseminate technical information, to enhance personal product safety engineering skills, and to provide product safety engineering outreach to engineers, students and others with an interest in the field. The Society is accepting members at any time during the calendar year, both full IEEE members and affiliate members. Membership is available at www.ieee.org/services/join/.

The IEEE Product Safety Engineering Society works closely with various IEEE Societies and Councils that also include product safety engineering as a technical specialty. Every year, the PSES hosts a Symposium on Product Compliance Engineering. Symposia will consist of Technical Sessions, Workshops, Tutorials and Demonstrations specifically targeted to the compliance engineering professional. Attendees will have the opportunity to discuss problems with vendors displaying the latest regulatory compliance products and services. For more information, visit www.psessymposium.org. Past papers from the Symposia are available in IEEE Xplore or on CD (for a fee).

In addition to hosting an annual conference, the PSES provides the opportunity for product safety engineers to publish technical papers in a newsletter.

See http://www.ieee-pses.org/newsletters.html.

For further information visit:
http://ewh.ieee.org/soc/pses/

DB SOCIETY

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This unique, interesting, and exclusive fraternity of EMC engineers was founded in 1975 by 10 eminent EMC engineers. The purpose of the dB Society is to open doors within the EMC community. Its primary objectives are to greet and to welcome new engineers, suppliers, vendors, and manufacturers to the EMC community and to assist them in establishing contacts in the EMC field.

The following membership requirements are unique and rigidly enforced:

Ten years of service to the EMC community, Five years of service to a recognized professional, EMC organization, Sponsorship by two Duo-Decade members, Favorable recommendations by three other recognized individuals in the EMC community, and Acceptance by the Admissions Board.

Business meetings and informal, relaxed get-togethers take place during major EMC functions. A formal evening social function is the highlight of each year and is usually conducted during the IEEE EMC Symposium. All meetings are for members and their spouses, only.

U.S. membership is limited to 100 EMC engineers. There are society affiliates in the United Kingdom, India, and Israel.

ESD ASSOCIATION

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Founded in 1982, the ESD Association is a professional voluntary association dedicated to advancing the theory and practice of electrostatic discharge (ESD) avoidance. From fewer than 100 members, the Association has grown to more than 2,000 members throughout the world. From an initial emphasis on the effects of ESD on electronic components, the association has broadened its horizons to include areas such as textiles, plastics, web processing, cleanrooms, and graphic arts. To meet the needs of a continually changing environment, the Association is chartered to expand ESD awareness through standards development, educational programs, local chapters, publications, tutorials, certification, and symposia.

Electromagnetic Discharge (ESD) Technology Roadmap – In the late 1970s, electrostatic discharge, or ESD, became a problem in the electronics industry. Low-level ESD events from people were causing device failures and yield losses. As the industry learned about this phenomenon, both device design improvements and process changes were made to make the devices more robust and processes more capable of handling these devices. With devices becoming more sensitive through the year 2010, it is imperative that companies begin to determine the ESD capabilities of their handling processes. The ESD Technology Roadmap can be downloaded at: www.esda.org

ANSI/ESD S20.20 Control Program Standard and Certification – A primary direction for the association is the continued implementation of a facility certification program in conjunction with ISO registrars. With the association's ESD control program standard, ANSI/ESD S20.20: Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices), the Association offers a means of independently assessing a company's ESD control program and of issuing a formal ANSI/ESD S20.20 certification.

The ANSI/ESD S20.20 standard covers the requirements necessary to design, establish, implement, and maintain an ESD control program to protect electrical or electronic parts, assemblies and equipment susceptible to ESD damage from Human Body Model (HBM) discharges greater than or equal to 100 volts. Developed in response to the Military Standardization Reform Act, ANSI/ESD S20.20 has been formally adopted for use by the U.S. Department of Defense.

Symposia, Tutorials, and Publicationsn – As part of its commitment to education and technology, the association holds the annual EOS/ESD Symposium, which places major emphasis on providing the knowledge and tools needed to meet the challenges of ESD. Scheduled for June 30-July 3, 2015, at the Conference Center, COEX in Seoul, KOREA, the annual Symposium attracts attendees and contributors from around the world. Technical sessions, workshops, authors' corners, seminars, tutorials, and technical exhibits provide a myriad of opportunities for attendees to expand their knowledge of ESD.

In addition to tutorials and seminars, the association offers a number of publications and reference materials for sale. These range from proceedings of past EOS/ESD Symposia to textbooks written by experts in the field of ESD.

SOCIETY OF AUTOMOTIVE ENGINEERS

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SAE International is a professional society of engineers dedicated to a broad spectrum of engineering disciplines within the aerospace and automotive fields. Under the SAE Aerospace Council, technical standards committees address disciplines ranging from electrical power to multiplex signal characteristics — and from fiber optic data transmission to electromagnetic compatibility. The many elements of EMC are handled by SAE Committee AE-4, Electromagnetic Compatibility, which was organized in 1942 under the Aerospace Council. The committee is composed of technically qualified members, liaison members, and consultants —all of whom are responsible for writing standards on electromagnetic compatibility.

Committee AE-4 provides assistance to the technical community through standardization, improved design and testing methodology, and technical forums for the resolution of mutual problems. Engineering standards, specifications, and technical reports are developed by the Committee and are issued by the Society for industry and governments worldwide. Objectives of Committee AE-4 are to advance the state of technology, to stabilize existing technology, to obtain a uniformity of EMC requirements among government agencies, and to further the interests of the EMC technical community. The theme of "design before the fact" for EMC is a guiding concept. Special attention is given to maintenance of EMI control requirements consistent with the rapidly advancing state-of-the-art.

SAE AE-4 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS

(E3 or EMC) Committee
The SAE AE-4 E3 Committee provides a technical, coordinating, and advisory function in the field of E3. The focus is on problem areas in which committee expertise can be effectively applied at the national and international levels. Electrical and electronic accessories are studied for compatibility within systems and with various communications media. Engineering standards, specifications, and technical reports are developed and are issued for the general information of industry and government.

In the past, subcommittees have included AE-4R, Aircraft Radiated Environments, and AE-4H, High Power RF Simulators and Effects. AE-4 E3 holds national meetings in conjunction with the IEEE EMC Society Symposium, usually held in August at various locations. Additional information about meetings or more specific information on the activities of the committee can be obtained by contacting the world headquarters at 1-724-776-4841. Visit the SAE's Technical Standards Committee Forum website at http://forums@sae.org.

INARTE

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iNARTE, Inc. (The International Association for Radio, and Telecommunications and Electromagnetics, Inc.) was founded as a non-profit membership/certification organization in 1982. With the advent of deregulation and the Federal Communications Commission's "encouragement/urging" private industry to establish certification standards to fill the licensing void, iNARTE initiated and developed a comprehensive certification program for telecommunications engineers and technicians.

In 1988, a Command of the United States Navy, seeking a credible and respected certification entity, selected iNARTE as the administrative agent for the certification of engineers and technicians in the field of electromagnetic compatibility (EMC).

ACIL—THE AMERICAN COUNCIL OF INDEPENDENT LABORATORIES

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The American Council of Independent Laboratories (ACIL) is the trade association representing independent, commercial engineering, and scientific laboratory, testing, consulting, product certifying and R&D firms; manufacturers' laboratories; related non-profit organizations; and consultants and suppliers to the industry. The organization was founded in 1937. All ACIL activities focus on its mission: to enhance members' success by providing advocacy, education, services, and mutual support and by promoting ethics, objectivity, independence, and free enterprise.

ACIL is a voluntary, non-profit membership organization. Programs are determined by members, administered by an elected Board of Directors, and supported by a professional staff operating from headquarters in Washington, D.C.

ACIL'S CONFORMITY ASSESSMENT SECTION

ACIL's Conformity Assessment Section consists of firms with wide and varied interests, all performing testing, listing, or labeling in accordance with applicable safety and performance standards, and/or materials testing and resolution of product and structural problems. Several committees have evolved within the Section to meet the needs of its diverse membership, including the EMC Committee, the U.S. Council of EMC Laboratories, and the Third-Party Product Certifiers Committee. In January 2005, the section sponsored a booth at the Consumer Electronics Show that advocated the advantages of independent third-party testing and the capabilities of ACIL member EMC laboratories.

ACIL'S EMC COMMITTEE

ACIL's EMC Committee was established in 1996 to address the common concerns of the ACIL EMC community. The Committee sponsors educational sessions at ACIL meetings that include both technical and policy issues such as mutual recognition agreements (MRAs). The Committee updates members on the latest developments, upcoming requirements, and activities in the field—both domestic and international.

In January 2002, ACIL published a 143-page document, Technical Criteria for the Accreditation of Electromagnetic Compatibility (EMC) and Radio Testing Laboratories, a checklist to assist both assessors and laboratories.

The Committee also formed the U.S. Council of EMC Laboratories (USCEL) in an effort to aid U.S. laboratories in addressing technical issues arising from the U.S./EU MRA and other global concerns. As the USCEL Secretariat, ACIL provides staff and supports volunteers active in this important area.

U.S. PRODUCT CERTIFIERS

Key U.S. product certifiers are ACIL members and are reaping many benefits, such as participation in the ACIL Third-Party Product Certifiers Committee ($3P^2C^2$). This Committee provides a forum for members to discuss and to act upon various issues of common interest. This committee formed the American Council for Electrical Safety to serve as a forum among testing laboratories, regulators, and electrical inspectors.

Government Directory

Need More Info?
Visit our EMC military channel at;
www.interferencetechnology.com for more information.

MILITARY

Branches

U.S. Air Force
www.af.mil

U.S. Army
www.army.mil

U.S. Coast Guard
www.uscg.mil
www.uscgboating.org

U.S. Marine Corps
www.marines.mil

U.S. Navy
www.navy.mil

National Guard
www.nationalguard.mil
www.nationalguard.com
www.goang.com

Agencies

U.S. Army Corps of Engineers
www.usace.army.mil

U.S. Fleet Forces Command
www.public.navy.mil/usff/Pages/default.aspx

U.S. European Command
www.eucom.mil

U.S. Central Command (CENTCOM)
www.centcom.mil

Defense Acquisition University
www.dau.mil

Defense Advanced Research Projects Agency (DARPA)
www.darpa.mil

Defense Commissary Agency
www.commissaries.com

Defense Contract Audit Agency
www.dcaa.mil

Defense Contract Management Agency
www.dcma.mil

Defense Department (DOD)
www.defense.gov

Defense Finance and Accounting Service (DFAS)
www.dfas.mil

Defense Finance and Accounting Service Out-of-Service Debt Mgmt. Center
www.dfas.mil

Defense Health Agency
www.health.mil/About-MHS/OASDHA/Defense-Health-Agency

Defense Information Systems Agency (DISA)
www.disa.mil

Defense Intelligence Agency (DIA)
www.dia.mil

Defense Logistics Agency (DLA)
www.dla.mil

Defense Nuclear Facilities Safety Board
www.dnfsb.gov

Defense Security Cooperation Agency (DSCA)
www.dsca.mil

Defense Security Service
www.dss.mil

Defense Technical Information Center (DTIC)
https://discover.dtic.mil

Defense Threat Reduction Agency (DTRA)
www.dtra.mil

Department of Defense (DOD)
www.defense.gov

Economic Adjustment Office
www.oea.gov

Fleet Forces Command
www.public.navy.mil/usff/Pages/default.aspx

Joint Chiefs of Staff
www.jcs.mil

Joint Forces Staff College
https://jfsc.ndu.edu

Joint Military Intelligence College
http://ni-u.edu/wp/

Joint Program Executive Office for Chemical and Biological Defense
www.jpeocbd.osd.mil/home

Missile Defense Agency
www.mda.mil

National Defense University
www.ndu.edu

National Geospatial-Intelligence Agency
www.nga.mil/Pages/Default.aspx

National Reconnaissance Office
www.nro.gov

National Security Agency
www.nsa.gov

Northern Command
www.northcom.mil

Pacific Command
www.pacom.mil

Pentagon Force Protection Agency
www.pfpa.mil

Southern Command
www.southcom.mil

Special Forces Operations Command
www.usa.gov/federal-agencies/u-s-special-operations-command

Strategic Command
www.stratcom.mil

Unified Combatant Commands
www.defense.gov

Uniformed Services University of the Health Sciences
www.usuhs.edu

Washington Headquarters Services
www.whs.mil

U.S.GOVERNMENT AGENCIES

A

Agency for Global Media
www.usagm.gov

Agency for Healthcare Research and Quality (AHRQ)
www.ahrq.gov

Agency for Toxic Substances and Disease Registry
www.atsdr.cdc.gov

Agricultural Marketing Service (AMS)
www.ams.usda.gov

Agricultural Research Service
www.ars.usda.gov

Agriculture Department (USDA)
www.usda.gov

Alcohol and Tobacco Tax and Trade Bureau
www.ttb.gov

Alcohol, Tobacco, Firearms and Explosives Bureau (ATF)
www.atf.gov

Amtrak (AMTRAK)
www.amtrak.com/home.html

Animal and Plant Health Inspection Service (APHIS)
www.aphis.usda.gov/aphis/home/

Archives, National Archives and Records Administration (NARA)
www.archives.gov

Arms Control and International Security
www.state.gov/t/

B

Bonneville Power Administration
www.bpa.gov/Pages/home.aspx

Bureau of Industry and Security (BIS)
www.federalregister.gov/agencies/economics-and-statistics-administration

Bureau of Labor Statistics
https://stats.bls.gov

Bureau of Land Management (BLM)
www.blm.gov

Bureau of Ocean Energy Management
www.boem.gov

Bureau of Safety and Environmental Enforcement
www.bsee.gov

Bureau of Transportation Statistics
www.bts.gov

C

Census Bureau
www.census.gov

Center for Food Safety and Applied Nutrition
www.fda.gov/AboutFDA/CentersOffices/OfficeofFoods/CFSAN/default.htm

Centers for Disease Control and Prevention (CDC)
www.cdc.gov

Central Intelligence Agency (CIA)
www.cia.gov/index.html

Chemical Safety Board
www.csb.gov

Chief Acquisition Officers Council
www.cao.gov/cao-home

Chief Financial Officers Council
https://cfo.gov

Chief Information Officers Council
www.cio.gov

Community Oriented Policing Services (COPS)
https://cops.usdoj.gov

Community Planning and Development
www.hud.gov/program_offices/comm_planning

Compliance, Office of
www.ocwr.gov

Computer Emergency Readiness Team (US CERT)
www.us-cert.gov

Congress—U.S. Senate
www.senate.gov

www.senate.gov/senators/leadership.htm

www.senate.gov/committees/index.htm

www.senate.gov/pagelayout/history/one_item_and_teasers/officers.htm

Congressional Budget Office (CBO)
www.cbo.gov

Congressional Research Service
www.loc.gov/crsinfo/about/

Consumer Product Safety Commission (CPSC)
www.cpsc.gov

www.recalls.gov

www.saferproducts.gov

Copyright Office
www.copyright.gov

Corps of Engineers
www.usace.army.mil

Council on Environmental Quality
www.whitehouse.gov/ceq/

Customs and Border Protection
www.cbp.gov

D

Department of Agriculture (USDA)
www.usda.gov

Department of Commerce (DOC)
www.commerce.gov

Department of Education (ED)
www.ed.gov

Department of Energy (DOE)
www.energy.gov

Department of Health and Human Services (HHS)
www.hhs.gov

Department of Homeland Security (DHS)
www.dhs.gov

Department of Housing and Urban Development (HUD)
www.hud.gov

Department of Justice (DOJ)
www.justice.gov

Department of Labor (DOL)
www.dol.gov

Department of State (DOS)
www.state.gov

Department of the Interior (DOI)
www.doi.gov

Department of the Treasury
https://home.treasury.gov

Department of Transportation (DOT)
www.transportation.gov

Director of National Intelligence, Office of
www.dni.gov

Drug Enforcement Administration (DEA)
www.dea.gov

E

Economic Development Administration
www.eda.gov

Economic Growth, Energy, and the Environment
www.state.gov/e/

Economics and Statistics Administration
www.usa.gov/federal-agencies/economics-and-statistics-administration

Education Department (ED)
www.ed.gov

Education Resources Information Center (ERIC)
https://eric.ed.gov

Energy Department (DOE)
www.energy.gov

Energy Star Program
www.energystar.gov

Environmental Protection Agency (EPA)
www.epa.gov

Equal Employment Opportunity Commission (EEOC)
www.eeoc.gov

European Command
www.eucom.mil

Export-Import Bank of the United States
www.exim.gov

F

Farm Service Agency
www.fsa.usda.gov

Federal Aviation Administration (FAA)
www.faa.gov

Federal Bureau of Investigation (FBI)
www.fbi.gov

Federal Bureau of Prisons (BOP)
www.bop.gov

Federal Citizen Information Center
www.usa.gov/explore/

Federal Communications Commission
www.fcc.gov

Federal Consulting Group
www.fcg.gov

Federal Emergency Management Agency (FEMA)
www.fema.gov

Federal Energy Regulatory Commission
www.ferc.gov

Federal Geographic Data Committee
www.fgdc.gov

Federal Highway Administration (FHA)
www.fhwa.dot.gov

Federal Housing Administration (FHA)
www.hud.gov/federal_housing_administration

Federal Labor Relations Authority (FLRA)
www.flra.gov

Federal Laboratory Consortium for Technology Transfer
www.federallabs.org

Federal Library and Information Center Committee
www.loc.gov/flicc/

Federal Maritime Commission
www.fmc.gov/default.aspx

Federal Mine Safety and Health Review Commission
www.fmshrc.gov

Federal Motor Carrier Safety Administration (FMCSA)
www.fmcsa.dot.gov

www.fmcsa.dot.gov/protect-your-move

Federal Protective Service
www.dhs.gov/topic/federal-protective-service

Federal Railroad Administration (FRA)
https://railroads.dot.gov

Federal Register
www.archives.gov/federal-register

Federal Trade Commission (FTC)
www.ftc.gov

www.consumer.ftc.gov/admongo/

www.consumer.ftc.gov/features/feature-0038-onguardonline

www.consumer.ftc.gov

Federal Transit Administration (FTA)
www.transit.dot.gov

FedStats
https://nces.ed.gov/FCSM/index.asp

Fish and Wildlife Service (FWS)
www.fws.gov

Food and Agriculture, National Institute of
https://nifa.usda.gov

Food and Drug Administration (FDA)
www.fda.gov

Food Safety and Inspection Service
www.fsis.usda.gov/wps/portal/fsis/home

Foreign Claims Settlement Commission
www.justice.gov/fcsc

Forest Service
www.fs.fed.us

Fossil Energy
www.energy.gov/fe/office-fossil-energy

G

General Services Administration (GSA)
www.gsa.gov

Geological Survey (USGS)
www.usgs.gov

Global Media, Agency for
www.usagm.gov

Government Accountability Office (GAO)
www.gao.gov

Government Ethics, Office of (OGE)
www.oge.gov

Government Publishing Office (GPO)
www.gpo.gov

Grain Inspection, Packers and Stockyards Administration
www.gipsa.usda.gov

H

Health and Human Services Department (HHS)
www.hhs.gov

Health Resources and Services Administration
www.hrsa.gov/

Homeland Security Department (DHS)
www.dhs.gov

House of Representatives
www.house.gov

www.house.gov/committees

www.house.gov/leadership

www.house.gov/the-house-explained/officers-and-organizations

Housing and Urban Development, Department of (HUD)
www.hud.gov

Housing Office
www.hud.gov/program_offices/housing

I

Immigration and Customs Enforcement (ICE)
www.ice.gov

Industry and Security, Bureau of (BIS)
www.federalregister.gov/agencies/economics-and-statistics-administration

Information Resources Center (ERIC)
www.usa.gov/federal-agencies/education-resources-information-center

Innovation and Improvement Office
https://innovation.ed.gov

Inspectors General
https://ignet.gov

Institute of Museum and Library Services
www.imls.gov

Interior Department (DOI)
www.doi.gov

Internal Revenue Service (IRS)
www.irs.gov

International Labor Affairs, Bureau of
www.dol.gov/agencies/ilab

International Trade Administration (ITA)
www.trade.gov/index.asp

International Trade Commission
www.usitc.gov

Interpol
www.justice.gov/interpol-washington

J

Job Corps
www.jobcorps.gov

Joint Chiefs of Staff
www.jcs.mil

Joint Fire Science Program
www.firescience.gov

Justice Department (DOJ)
www.justice.gov

L

Labor Department (DOL)
www.dol.gov

Labor Statistics, Bureau of
https://stats.bls.gov

Land Management, Bureau of (BLM)
www.blm.gov

Library of Congress (LOC)
www.loc.gov

M

Manufactured Housing Programs, Office of
www.hud.gov/program_offices/housing/rmra/mhs/mhshome

Marine Mammal Commission
www.mmc.gov

Maritime Administration (MARAD)
www.maritime.dot.gov

Marketing and Regulatory Programs
www.aphis.usda.gov/aphis/ourfocus/business-services

Marshals Service
www.usmarshals.gov//

Middle East Broadcasting Networks
www.alhurra.com

www.radiosawa.com

Migratory Bird Conservation Commission
www.fws.gov/refuges/realty/mbcc.html

Military Postal Service Agency
www.usa.gov/federal-agencies/military-postal-service-agency

Millennium Challenge Corporation
www.mcc.gov

Mine Safety and Health Administration (MSHA)
www.msha.gov

Mint
www.usmint.gov

Mississippi River Commission
www.mvd.usace.army.mil/About/Mississippi-River-Commission-MRC/

N

National Aeronautics and Space Administration (NASA)
www.nasa.gov

National Agricultural Statistics Service
www.nass.usda.gov

National Archives and Records Administration (NARA)
www.archives.gov

National Cancer Institute (NCI)
www.cancer.gov

National Geospatial-Intelligence Agency
www.nga.mil/Pages/Default.aspx

National Health Information Center (NHIC)
https://health.gov/nhic/

National Heart, Lung, and Blood Institute (NHLBI)
www.nhlbi.nih.gov

National Highway Traffic Safety Administration (NHTSA)
www.nhtsa.gov

National Institute of Food and Agriculture
https://nifa.usda.gov

National Institute of Occupational Safety and Health (NIOSH)
www.cdc.gov/niosh/

National Insts
www.nist.gov

National Institutes of Health (NIH)
www.nih.gov

National Laboratories
www.energy.gov/national-laboratories

National Nuclear Security Administration
www.energy.gov/nnsa/national-nuclear-security-administration

National Ocean Service
https://oceanservice.noaa.gov

National Oceanic and Atmospheric Administration (NOAA)
www.noaa.gov

National Park Foundation
www.nationalparks.org

National Park Service (NPS)
www.nps.gov/index.htm

National Railroad Passenger Corporation (AMTRAK)
www.amtrak.com/home.html

National Reconnaissance Office
www.nro.gov

National Science Foundation (NSF)
www.nsf.gov

National Security Agency (NSA)
www.nsa.gov

National Security Council (NSC)
www.whitehouse.gov/nsc/

National Technical Information Service
www.ntis.gov

National Telecommunications and Information Administration
www.ntia.doc.gov

National Transportation Safety Board
www.ntsb.gov/Pages/default.aspx

National Weather Service
www.weather.gov

Natural Resources Conservation Service
www.usa.gov/federal-agencies/natural-resources-conservation-service

Natural Resources Revenue, Office of
www.onrr.gov

Northern Border Regional Commission
www.nbrc.gov

Northwest Power and Conservation Council
www.nwcouncil.org

Northwest Power Planning Council
www.nwcouncil.org

Nuclear Energy, Office of
www.energy.gov/ne/office-nuclear-energy

Nuclear Regulatory Commission (NRC)
www.nrc.gov

O

Oak Ridge National Laboratory
www.ornl.gov

Occupational Safety and Health Administration (OSHA)
www.osha.gov

Ocean Energy Management, Bureau of
www.boem.gov

Office of Community Planning and Development
www.hud.gov/program_offices/comm_planning

Office of Compliance
www.usa.gov/federal-agencies/office-of-compliance

Office of Cuba Broadcasting
www.radiotelevisionmarti.com

Office of Environmental Management
www.energy.gov/em/office-environmental-management

Office of Fossil Energy
www.energy.gov/fe/office-fossil-energy

Office of Housing
www.hud.gov/program_offices/housing

Office of Management and Budget (OMB)
www.whitehouse.gov/omb/

Office of Natural Resources Revenue
www.onrr.gov

Office of Nuclear Energy
www.energy.gov/ne/office-nuclear-energy

Office of Policy Development and Research
www.huduser.gov/portal/home.html

Office of Science and Technology Policy
www.whitehouse.gov/ostp/

Office of Scientific and Technical Information
www.osti.gov

Office of the Director of National Intelligence
www.dni.gov

Office of the Federal Register
www.archives.gov/federal-register

www.archives.gov/federal-register

Overseas Private Investment Corporation
www.opic.gov

P

Pacific Northwest Electric Power and Conservation Planning Council
www.nwcouncil.org

Patent and Trademark Office
www.uspto.gov

Pipeline and Hazardous Materials Safety Administration
www.phmsa.dot.gov

Policy Development and Research
www.huduser.gov/portal/home.html

Postal Inspection Service
https://postalinspectors.uspis.gov

Postal Regulatory Commission
www.prc.gov

Postal Service (USPS)
www.usps.com

Power Administrations
www.energy.gov/offices

R

Radio Free Asia (RFA)
www.rfa.org/english/

Radio Free Europe and Radio Liberty (RFE/RL)
www.rferl.org

Radio Sawa
www.alhurra.com

www.radiosawa.com

Research and Innovative Technology Administration
www.transportation.gov/research-technology

Rural Business and Cooperative Programs
www.rd.usda.gov/about-rd/agencies/rural-business-cooperative-service

Rural Development
www.rd.usda.gov

Rural Utilities Service
www.rd.usda.gov/about-rd/agencies/rural-utilities-service

S

Safety and Environmental Enforcement, Bureau of
www.bsee.gov

Science and Technology Policy, Office of
www.whitehouse.gov/ostp/

Science Office
https://science.energy.gov

Scientific and Technical Information, Office of
www.osti.gov

Seafood Inspection Program
www.fisheries.noaa.gov/topic/seafood-commerce-certification#seafood-inspection

www.fishwatch.gov

Secret Service
www.secretservice.gov

Securities and Exchange Commission (SEC)
www.sec.gov

Selective Service System (SSS)
www.sss.gov

Senate
www.senate.gov

www.senate.gov/senators/leadership.htm

www.senate.gov/committees/index.htm

www.senate.gov/pagelayout/history/one_item_and_teasers/officers.htm

Small Business Administration (SBA)
www.sba.gov

Southeastern Power Administration
www.energy.gov/sepa/southeastern-power-administration

Southwestern Power Administration
www.swpa.gov

State Department (DOS)
www.state.gov

Supreme Court of the United States
www.supremecourt.gov

Surface Transportation Board
www.stb.gov/stb/index.html

T

Trade and Development Agency
www.ustda.gov

Transportation Department (DOT)
www.transportation.gov

Transportation Security Administration (TSA)
www.tsa.gov

Transportation Statistics, Bureau of
www.bts.gov

U

U.S. National Central Bureau - Interpol
www.justice.gov/interpol-washington

U.S. Transportation Command
www.ustranscom.mil

US-CERT (US CERT)
www.us-cert.gov

USAGov
www.usa.gov/explore/

W

Washington Headquarters Services
www.whs.mil

Weather Service
www.weather.gov

Weights and Measures Division
www.nist.gov/pml/weights-and-measures

Western Area Power Administration
www.wapa.gov/Pages/Western.aspx

White House
www.whitehouse.gov

Wireless Telecommunications Bureau
www.fcc.gov/wireless-telecommunications

US STATES AND PROVINCES

A

Alabama
www.usa.gov/state-government/alabama

Alaska
www.usa.gov/state-government/alaska

Arizona
www.usa.gov/state-government/arizona

Arkansas
www.usa.gov/state-government/arkansas

C

California
www.usa.gov/state-government/california

Colorado
www.usa.gov/state-government/colorado

Connecticut
www.usa.gov/state-government/connecticut

D

Delaware
www.usa.gov/state-government/delaware

F

Florida
www.usa.gov/state-government/florida

G

Georgia
www.usa.gov/state-government/

H

Hawaii
www.usa.gov/state-government/hawaii

I

Idaho
www.usa.gov/state-government/idaho

Illinois
www.usa.gov/state-government/illinois

Indiana
www.usa.gov/state-government/indiana

Iowa
www.usa.gov/state-government/iowa

K

Kansas
www.usa.gov/state-government/kansas

Kentucky
www.usa.gov/state-government/kentucky

L

Louisiana
www.usa.gov/state-government/louisiana

M

Maine
www.usa.gov/state-government/maine

Maryland
www.usa.gov/state-government/maryland

Massachusetts
www.usa.gov/state-government/massachusetts

Michigan
www.usa.gov/state-government/michigan

Minnesota
www.usa.gov/state-government/minnesota

Mississippi
www.usa.gov/state-government/mississippi

Missouri
www.usa.gov/state-government/missouri

Montana
www.usa.gov/state-government/montana

N

Nebraska
www.usa.gov/state-government/nebraska

Nevada
www.usa.gov/state-government/nevada

New Hampshire
www.usa.gov/state-government/new-hampshire

New Jersey
www.usa.gov/state-government/new-jersey

New Mexico
www.usa.gov/state-government/new-mexico

New York
www.usa.gov/state-government/new-york

North Carolina
www.usa.gov/state-government/north-carolina

North Dakota
www.usa.gov/state-government/north-dakota

O

Ohio
www.usa.gov/state-government/ohio

Oklahoma
www.usa.gov/state-government/oklahoma

Oregon
www.usa.gov/state-government/oregon

P

Pennsylvania
www.usa.gov/state-government/pennsylvania

R

Rhode Island
www.usa.gov/state-government/rhode-island

S

South Carolina
www.usa.gov/state-government/south-carolina

South Dakota
www.usa.gov/state-government/south-dakota

T

Tennessee
www.usa.gov/state-government/tennessee

Texas
www.usa.gov/state-government/texas

GOVERNMENT DIRECTORY

U

Utah
www.usa.gov/state-government/utah

V

Vermont
www.usa.gov/state-government/vermont

Virginia
www.usa.gov/state-government/virginia

W

Washington
www.usa.gov/state-government/washington

Wisconsin
www.usa.gov/state-government/wisconsin

Wyoming
www.usa.gov/state-government/wyoming

CAPITAL

Washington, D.C.
www.usa.gov/state-government/district-of-columbia

PROVINCES

Puerto Rico
www.usa.gov/state-government/puerto-rico

U.S. Virgin Islands
www.usa.gov/state-government/u-s-virgin-islands

Recommended EMC Books

ANDRÉ AND WYATT,
EMI Troubleshooting Cookbook for Product Designers
SciTech Publishing, 2014. Includes chapters on product design and EMC theory & measurement. A major part of the content includes how to troubleshoot and mitigate all common EMC test failures.

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

ARMSTRONG,
EMC Design Techniques For Electronic Engineers
Armstrong/Nutwood Publications, 2010. A comprehensive treatment of EMC theory and practical product design and measurement applications.

ARMSTRONG,
EMC For Printed Circuit Boards - Basic and Advanced Design and Layout Techniques
Armstrong/Nutwood Publications, 2010. A comprehensive treatment of PC board layout for EMC compliance.

ARRL,
The RFI Handbook
(3rd edition), 2010. Good practical book on radio frequency interference with mitigation techniques. Some EMC theory.

BOGATIN,
Signal & Power Integrity - Simplified
Prentice-Hall, 2009 (2nd Edition). Great coverage of signal and power integrity from a fields viewpoint.

BRANDER, ET AL,
Trilogy of Magnetics - Design Guide for EMI Filter Design, SMPS & RF Circuits
Würth Electronik, 2010. A comprehensive compilation of valuable design information and examples of filter, switch-mode power supply, and RF circuit design.

GOEDBLOED,
Electromagnetic Compatibility
Prentice-Hall, 1990. Good general text on EMC with practical experiments. May be out of print.

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

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

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.

OTT,
Electromagnetic Compatibility Engineering
Wiley, 2009. The “bible” on EMC measurement, theory, and product design.

REFERENCES

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.

SLATTERY AND SKINNER,
Platform Interference in Wireless Systems - Models, Measurement, and Mitigation
Newnes Press, 2008. The first publication to publicize the issue of self-interference to on-board wireless systems.

SMITH,
High Frequency Measurements and Noise in Electronic Circuits
Springer, 1993. A classic book on high frequency measurements, probing techniques, and EMC troubleshooting measurements.

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, encompassing both commercial and military EMC.

WITTE,
Spectrum and Network Measurements
(2nd edition), SciTech Publishing, 2014. The best text around explaining the theory and usage of spectrum and network analyzers.

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

WYATT AND JOST,
Electromagnetic Compatibility (EMC) Pocket Guide
SciTech Publishing, 2013. A handy pocket-sized reference guide to EMC.

WYATT AND GRUBER,
Radio Frequency (RFI) Pocket Guide
SciTech Publishing, 2015. A handy pocket-sized reference guide to radio frequency interference.

Common Commercial, Automotive, Medical, Wireless & Military EMC Standards

►COMMERCIAL STANDARDS

The following are some of the most common commercial EMC standards. Most standards have a fee associated and most on the list are linked back to the source where they're available. If you're purchasing the printed version of this guide, then refer to the Standards Organizations in the References section for standards purchase information. Note that many Euro Norm (EN) versions of IEC standards may be purchased at a considerable discount from the Estonian Centre for Standardization, https://www.evs.ee.

FCC

(https://www.ecfr.gov)

Electronic Code of Federal Regulations (e-CFR)
CFR 47 - Part 15 (Radio Frequency Devices)

ANSI

(http://webstore.ansi.org)

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

(https://webstore.iec.ch)

Document Number	Title
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 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 61000-4-2	Electromagnetic compatibility (EMC)- Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test
IEC 61000-4-3	Electromagnetic compatibility (EMC) - Part 4-3 : Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
IEC 61000-4-4	Electromagnetic compatibility (EMC) - Part 4-4 : Testing and measurement techniques – Electrical fast transient/burst immunity test

IEC 61000-4-5	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test
IEC 61000-4-6	Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
IEC 61000-4-7	Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto
IEC 61000-4-8	Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test
IEC 61000-4-9	Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Impulse magnetic field immunity test
IEC 61000-4-10	Electromagnetic compatibility (EMC) - Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field immunity test
IEC 61000-4-11	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests
IEC 61000-4-12	Electromagnetic compatibility (EMC) - Part 4-12: Testing and measurement techniques - Ring wave immunity test
IEC 61000-6-1	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 61000-6-7	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 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

CISPR

(https://webstore.iec.ch)

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 16-2-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-4: Methods of measurement of disturbances and immunity - Immunity measurements
CISPR TR 16-2-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-5: In situ measurements for disturbing emissions produced by physically large equipment
CISPR TR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports
CISPR TR 16-4-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-1: Uncertainties, statistics and limit modelling - Uncertainties in standardized EMC tests
CISPR 16-4-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modelling - Measurement instrumentation uncertainty
CISPR TR 16-4-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-3: Uncertainties, statistics and limit modelling - Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR TR 16-4-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-4: Uncertainties, statistics and limit modelling - Statistics of complaints and a model for the calculation of limits for the protection of radio services
CISPR TR 16-4-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-5: Uncertainties, statistics and limit modelling - Conditions for the use of alternative test methods
CISPR 17	Methods of measurement of the suppression characteristics of passive EMC filtering devices
CISPR TR 18-1	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena
CISPR TR 18-2	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits
CISPR TR 18-3	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 3: Code of practice for minimizing the generation of radio noise
CISPR 20	Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement
CISPR 22	Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement (Withdrawn and replaced by CISPR 32:2015)
CISPR 24	Information technology equipment - Immunity characteristics - Limits and methods of measurement
CISPR 25	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers
CISPR 32	Electromagnetic compatibility of multimedia equipment – Emission requirements
CISPR 35	Electromagnetic compatibility of multimedia equipment - Immunity requirements

►AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY STANDARDS

The following abbreviated 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. For a more complete list, refer to the link above. Permission to republish has been granted.

CISPR (AUTOMOTIVE EMISSIONS REQUIREMENTS)

(https://webstore.iec.ch)

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)

(https://www.iso.org)

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 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 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 11452-4	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 4: Bulk current injection (BCI)
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

SAE (AUTOMOTIVE EMISSIONS AND IMMUNITY)

(http://standards.sae.org)

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
J1113/4	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
J1113/26	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)
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
J551/15	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

(https://global.ihs.com)

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

(https://www.fordemc.com)

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

DaimlerChrysler

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

Automotive Electromagnetic Compatibility Standards From
(http://www.cvel.clemson.edu/auto/auto_emc_standards.html)

►MEDICAL STANDARDS

COLLATERAL STANDARDS

(https://webstore.iec.ch/)

Document Number	Title
IEC 60601-1-1	Safety requirements for medical electrical systems
IEC 60601-1-2	Electromagnetic disturbances - requirements and tests
IEC 60601-1-3	Radiation protection in diagnostic x-ray equipment
IEC 60601-1-6	General requirements for basic safety and essential performance - Usability
IEC 60601-1-8	General requirements for basic safety and essential performance - Alarm systems
IEC 60601-1-9	Requirements for environmentally conscious design
IEC 60601-1-10	Requirements for the development of physiologic closed-loop controllers
IEC 60601-1-11	Medical electrical equipment and medical electrical systems used in the home healthcare environment
IEC 60601-1-12	Medical electrical equipment and medical electrical systems used in the medical services environment

OTHER RELEVANT STANDARDS

(https://webstore.iec.ch/)

Document Number	Title
CISPR 11	Emission requirements for ISM equipment
IEC 60601-1	General requirements for basic safety and essential performance
IEC TR 60601-4-2	Electromagnetic immunity performance
IEC TR 60601-4-3	Considerations of unaddressed safety aspects in the third edition of IEC 60601-1
IEC TR 62354	General testing procedures for medical electrical equipment
ISO 14708-1	Active implantable medical devices

For more extensive listings of medical standards, download the 2017 Medical EMC Guide:
http://learn.interferencetechnology.com/2017-medical-emc-guide/

►COMMON WIRELESS STANDARDS

ETSI STANDARDS

(https://www.etsi.org)

Document Number	Title
ETSI EN 300 220	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25MHz to 1000MHz frequency range with power levels ranging up to 500mW
ETSI EN 300 328	Electromagnetic compatibility and Radio Spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques; Harmonized EN covering essential requirements under article 3.2 of the R&TTE Directive
ETSI EN 300 330	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 9kHz to 25MHz frequency range and inductive loop systems in the 9kHz to 30MHz frequency range
ETSI EN 300 440	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 1GHz to 40GHz frequency range
ETSI EN 301 489-3	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 3: Specific conditions for Short Range Devices (SRD) operating on frequencies between 9kHz and 40GHz
ETSI EN 301 489-17	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 17: Specific conditions for Wideband data and HIPERLAN equipment
ETSI EN 301 893	Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering essential requirements of article 3.2 of the R&TTE Directive
ETSI EN 303 413	GPS receivers
ETSI EN 303 417	Wireless Power Transfer

►COMMON MILITARY RELATED DOCUMENTS AND STANDARDS

The following references are not intended to be all inclusive, but rather a representation of available sources of additional information and point of contacts. Downloadable from: http://everyspec.com.

Document Number	Title
MIL-HDBK-235-1	Military Operational Electromagnetic Environment Profiles Part 1C General Guidance, 1 Oct 2010
MIL-HDBK-1857	Grounding, Bonding and Shielding Design Practices, 27 Mar 1998
MIL-STD-220C	Test Method Standard Method of Insertion Loss Measurement, 14 May 2009
MIL-STD-449D	Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973
MIL-STD-461F	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 10 Dec 2007
MIL-STD-461G	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 11 Dec 2015
MIL-STD-464C	Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010

REFERENCES

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-1605A	Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009
DoDI 3222.03	DoD Electromagnetic Environmental Effects (E3) Program, 24 Aug 2014

►AEROSPACE STANDARDS

AIAA Standards

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

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

RTCA Standards

https://www.rtca.org/

Document Number	Title
DO-160G	Environmental Conditions and Test Procedures for Airborne Equipment
DO-160G Change 1	Environmental Conditions and Test Procedures for Airborne Equipment
DO-233	Portable Electronic Devices Carried on Board Aircraft
DO-235B	Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band
DO-292	Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band
DO-294C	Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft
DO-307	Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance
DO-357	User Guide: Supplement to DO-160G
DO-363	Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft
DO-364	Minimum Aviation System Performance Standards (MASPS) for Aeronautical Information/ Meteorological Data Link Services
DO-363	Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft
DO-307A	Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

SAE Standards

http://www.sae.org/

Document Number	Title
ARP 5583A	Guide to Certification of Aircraft in a High Intensity Radiation (HIRF) Environment

EMC Standards Organizations & LinkedIn Groups

EMC STANDARDS ORGANIZATIONS

American National Standards Institute
http://www.ansi.org

ANSI Accredited C63
http://www.c63.org

Asia Pacific Laboratory Accreditation Cooperation (APLAC)
http://www.aplac.org

BSMI (Taiwan)
https://www.bsmi.gov.tw/wSite/mp?mp=2

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

CNCA (China)
http://www.cnca.gov.cn/cnca/cncatest/20040420/column/227.htm

Electromagnetic Compatibility Industry Association (UK)
http://www.emcia.org

FDA Center for Devices & Radiological Health (CDRH)
https://www.fda.gov/MedicalDevices/default.htm

Federal Communications Commission (FCC)
http://www.fcc.gov

Gosstandart (Russia)
https://gosstandart.gov.by/en/

IEC
http://www.iec.ch/index.htm

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

IEEE EMC Society Standards Development Committee (SDCOM)
http://standards.ieee.org/develop/project/electromagnetic_compatibility.html

Industry Canada (Certifications and Standards)
http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf06165.html

ISO (International Organization for Standards)
http://www.iso.org/iso/home.html

RTCA
https://www.rtca.org

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

VCCI (Japan, Voluntary Control Council for Interference
http://www.vcci.jp/vcci_e/

LINKEDIN GROUPS

Aircraft and Spacecraft ESD/EMI/EMC Issues

Automotive EMC Troubleshooting Experts

Electromagnetic Compatibility Automotive Group

Electromagnetic Compatibility Forum

Electromagnetics and Spectrum Engineering Group

EMC - Electromagnetic Compatibility

EMC Experts

EMC Jobs

EMC Testing and Compliance

EMC Troubleshooters

EMI and EMC Consultants

ESD Experts

iNARTE

Military EMC Forum

RTCA/DO-160 Experts

Signal & Power Integrity Community

Recommended Guides from INTERFERENCE TECHNOLOGY

►*(Free downloads available on www.interferencetechnology.com)*

2019 MILITARY & AEROSPACE EMC GUIDE

Includes articles and reference information related to military and aerospace EMC test and product design.

►**Download Here**

2018 EMC TESTING GUIDE

Includes articles and reference information related to EMC/EMI testing and how these tests are performed.

►**Download Here**

2019 COMPONENTS & MATERIALS GUIDE

Includes articles and reference information related to EMC components and materials.

►**Download Here**

2018 DIRECTORY & DESIGN GUIDE

Includes articles and reference information related to fundamental EMC product design concepts.

►**Download Here**

2019 EUROPEAN EMC GUIDE

Includes articles, reference information, changes in standards, upcoming events, new product distributors and more related to the European EMC market.

►**Download Here**

2018 EUROPE EMC GUIDE

Includes articles and reference information, related to European EMC/EMI standards, and more.

►**Download Here**

2018 EMC FUNDAMENTALS GUIDE

Includes articles and reference information related to fundamental EMC product design concepts.

►**Download Here**

2017 EMC TEST LAB DIRECTORY

Includes a complete list of EMC test labs, and their services from all over the globe separated by country, state, and city.

►**Download Here**

2018 AUTOMOTIVE EMC GUIDE

Includes articles and reference information related to automotive EMC.

►**Download Here**

2017 MEDICAL EMC GUIDE

Includes articles and reference information related to medical EMC product design and test.

►**Download Here**

2019 EMC Supplier Matrix

In this section, we provide a quick guide to some of the top suppliers in each EMC category - test equipment, components, materials, services, and more. To find a product that meets your needs for applications, frequencies, standards requirements, etc., please search these individual supplier websites for the latest information and availability. If you have trouble finding a particular product or solution, email info@item.media for further supplier contacts.

2019 EMC SUPPLIER MATRIX SPOTLIGHT

COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
ar	**AR RF/MICROWAVE INSTRUMENTATION** t: (215) 723-8181 e: info@arworld.us w: www.arworld.us	X	X	X				X									X	X				
Advanced Test Equipment Rentals	**ADVANCED TEST EQUIPMENT RENTALS** t: (800) 404-ATEC (2832) e: rentals@atecorp.com w: www.atecorp.com	X	X		X				X		X			X	X	X	X	X	X	X		
EXODUS ADVANCED COMMUNICATIONS	**EXODUS ADVANCED COMMUNICATIONS** t: (702) 534-6564 e: sales@exoduscomm.com w: www.exoduscomm.com	X	X	X													X					
F2 Labs	**F2 LABS** t: (877) 405-1580 e: sales@f2labs.com w: www.f2labs.com				X	X														X	X	X
RETLIF TESTING LABORATORIES	**RETLIF TESTING LABORATORIES** t: 631-737-1500 – Ext. 114 e: wpoggi@retlif.com w: www.retlif.com																			X	X	X
WL	**WASHINGTON LABORATORIES, LTD** t: (301) 216-1500 w: www.wll.com				X	X		X			X									X	X	X

SUPPLIER MATRIX

	COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
A	Aaronia AG	www.aaronia.com	X	X						X							X						
	Advanced Test Equipment Rentals (ATEC)	www.atecorp.com	X	X		X				X		X			X	X	X	X	X	X	X		
	A.H. SYSTEMS	www.ahsystems.com	X	X	X													X	X	X			
	Altair- US	www.altair.com					X		X														
A	American Certification Body Inc.	www.acbcert.com				X	X		X												X	X	X
	Ametek- CTS Compliance Test Solutions	www.ametek-cts.com	X	X														X		X			X
	Anritsu Company	www.anritsu.com															X	X		X	X		
	API Technologies	www.apitech.com						X			X												
	AR RF/Microwave Instrumentation	www.arworld.us	X	X	X				X									X	X				
	Astrodyne	www.astrodyneTDI.com									X												
B	Beehive Electronics	www.beehive-electronics.com																			X		
C	Captor Corpo	www.captorcorp.com									X												
	Coilcraft	www.coilcraft.com									X												
	CPI- Communications & Power Industries (USA)	www.cpii.com/emc	X																				
	CST of America (SIMULIA)	www.cst.com							X														
D	Delta Electronics (Americas) Ltd.	www.delta-americas.com									X												
	Dexmet Corporation	www.dexmet.com													X								
	DLS Electronic Systems, Inc.	www.dlsemc.com																				X	
	Don Heirman Consultants	www.donheirman.com					X																
E	Electro Rent	www.electrorent.com	X											X					X				
	Elite Electronic Engineering Co.	www.elitetest.com																				X	
	EMC Live	www.emc.live																					X
	EMC Partner	www.emc-partner.com																X					
	Empower RF Systems, Inc.	www.empowerrf.com	X																				
	EM TEST USA	www.emtest.com																X					
	Exemplar Global (iNarte)	www.exemplarglobal.org																					X
	EXODUS Advanced Communications	www.exoduscomm.com	X	X	X													X					

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F	F2 Labs	www.f2labs.com				X	X														X	X	X
F	Fischer Custom Communications	www.fischercc.com																		X			
F	FRANKONIA	www.frankonia-solutions.com													X	X		X				X	
G	Gauss Instruments	www.gauss-instruments.com								X													
H	Heilind Electronics, Inc	www.heilind.com									X												
H	Henry Ott Consultants	www.hottconsultants.com					X																
H	HV TECHNOLOGIES, Inc.	www.hvtechnologies.com	X	X						X		X				X	X	X		X			
I	Instrument Rental Labs	www.testequip.com	X							X							X		X				
I	Instruments For Industry (IFI)	www.ifi.com	X																				
I	Interference Technology	www.interferencetechnology.com																					X
I	Intertek	www.intertek.com																				X	
K	Keysight Technologies	www.keysight.com/us/en								X							X		X	X			
K	Krieger Specialty Products	www.kriegerproducts.com														X							
M	Master Bond Inc.	www.masterbond.com												X									
M	Microlease	www.microlease.com	X							X							X		X				
M	MILMEGA	www.ametek-cts.com	X																				
M	Montrose Compliance Services	www.montrosecompliance.com					X																
M	MVG Microwave Vision Group	www.mvg-world.com		X							X				X	X							
N	Narda Safety Test Solutions	www.narda-sts.com		X						X							X			X			
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N	NTS	www.nts.com																			X		
O	Ophir RF	www.ophirrf.com	X																				
P	Parker Chomerics	www.chomerics.com													X								
P	PPG Cuming Lehman Chambers	www.cuminglehman.com													X	X					X		
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Q	Quell Corp.	www.eeseal.com			X						X	X									X		
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	Rohde & Schwarz USA, Inc.	www.rohde-schwarz-usa.com	X	X						X					X	X	X	X					
S	Schaffner EMC, Inc.	www.schaffner.com						X			X										X	X	
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	Siglent Technologies	www.siglentamerica.com																X					
	SPIRA	www.spira-emi.com													X								
T	TekBox Technologies	www.tekbox.net	X																				
	TESEQ Inc.	www.teseq.com																X					
	Test Equity	www.testequity.com/leasing/	X							X							X		X				
	Thurlby Thandar (AIM-TTi)	www.aimtti.com								X							X						
	Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X						X							X						
	TPI	www.rf-consultant.com					X																
	Transient Specialists	www.transientspecialists.com																	X				
V	Vectawave Technology	www.vectawave.com	X																				
W	Washington Laboratories	www.wll.com				X	X		X			X									X	X	X
	Würth Elektronik eiSos GmbH & Co. Kg	www.we-online.com		X	X			X	X		X	X			X								
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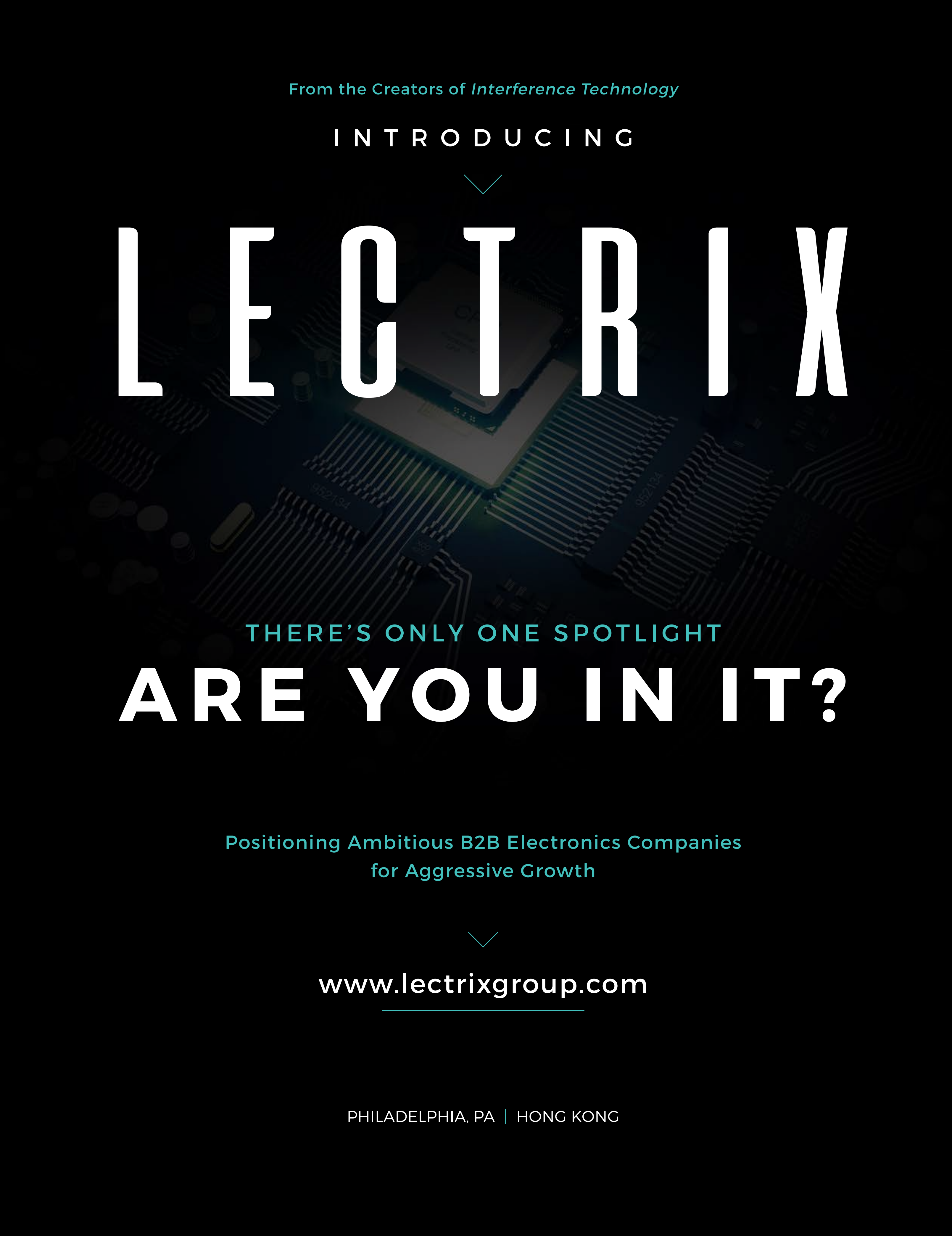
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