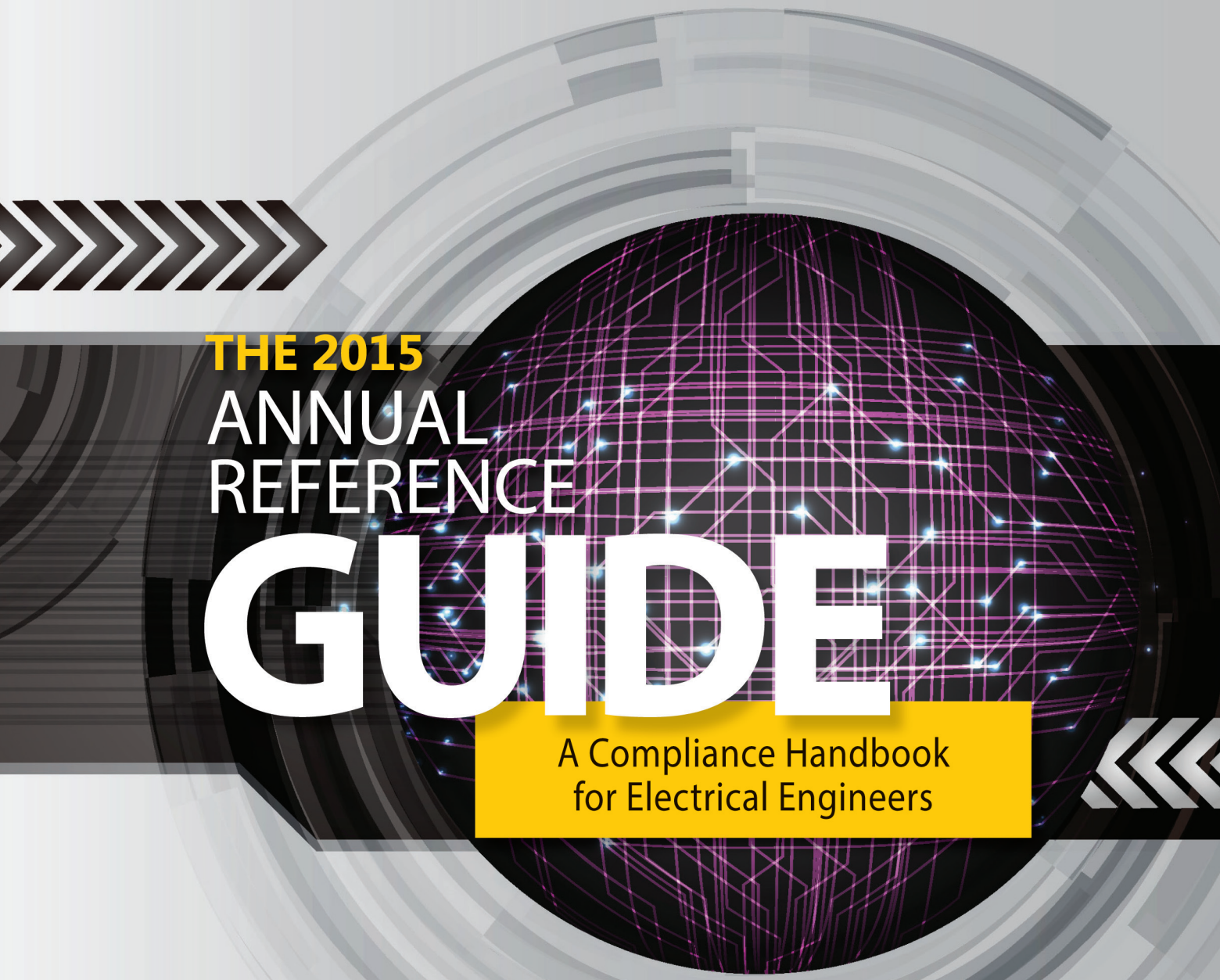
IN COMPLIANCE™

THE COMPLIANCE INFORMATION RESOURCE FOR ELECTRICAL ENGINEERS



THE 2015 ANNUAL REFERENCE GUIDE

A Compliance Handbook for Electrical Engineers

Just as Mount Rushmore was a monumental task to accomplish, so was building the world's first 50,000 Watt RF Solid State Amplifier.

From providing the absolute maximum power to the antenna to its indestructible design, we provide the most value for your money.

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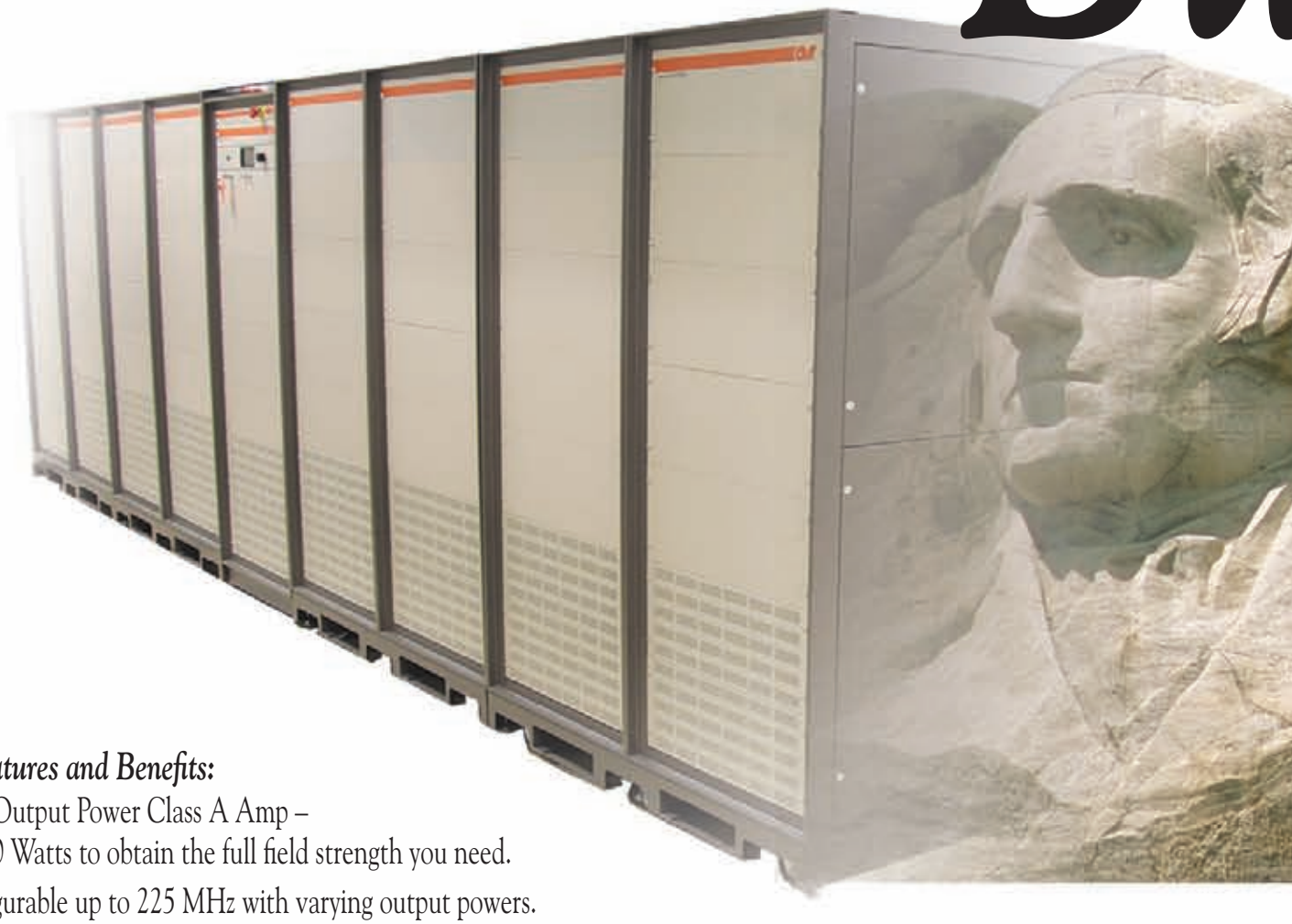

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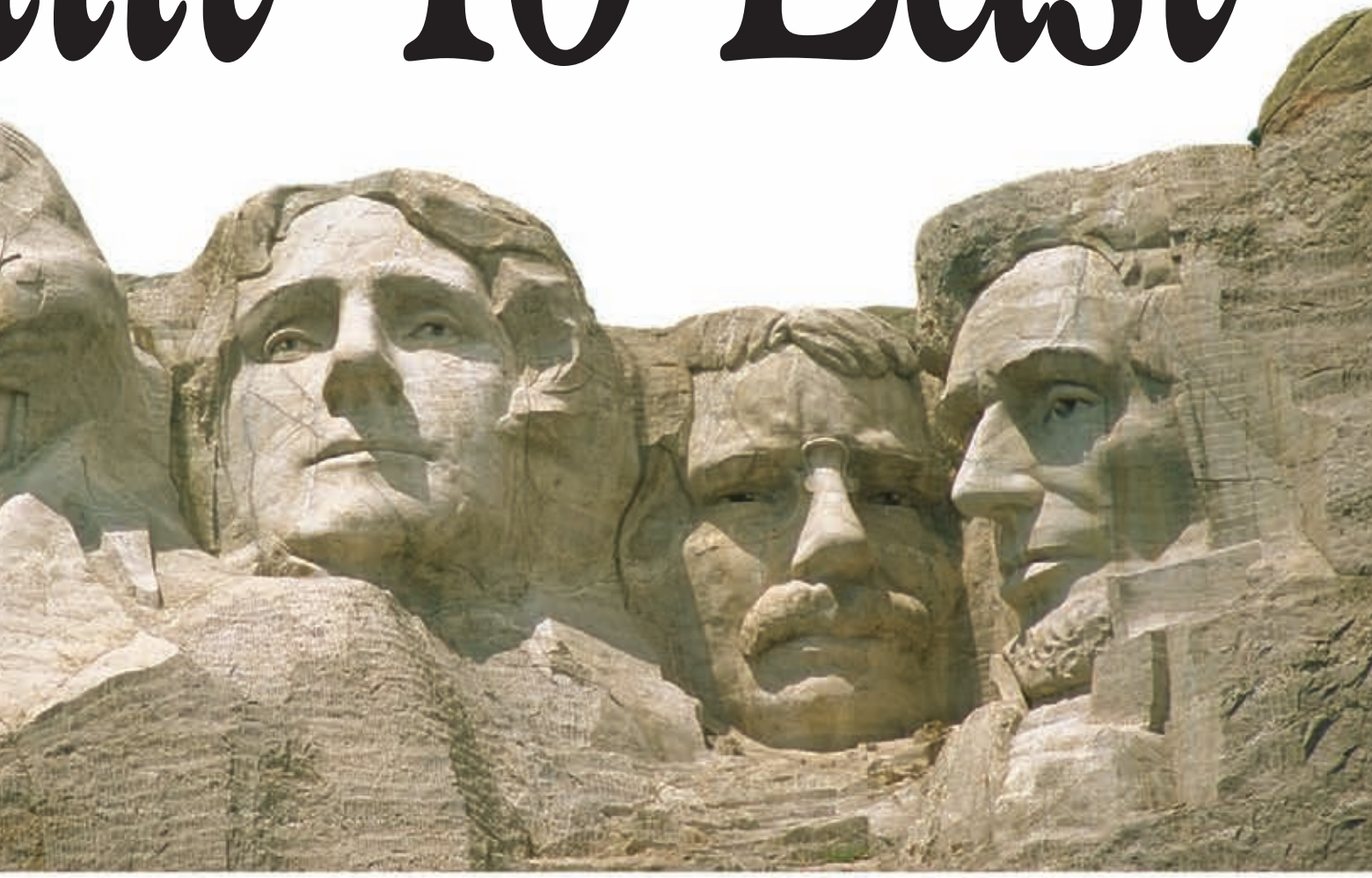

ection you can count on.

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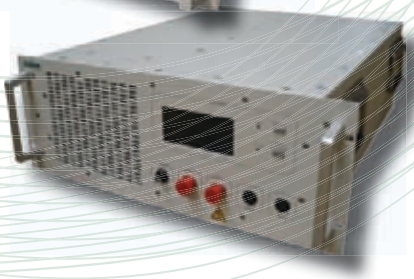

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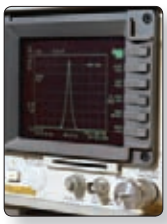

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continued on page 6


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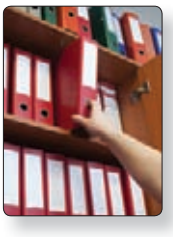

Letter from the editor

Welcome to the 2015 Annual Reference Guide

Dear Readers,

It is my pleasure to welcome you to *In Compliance Magazine's 2015 Annual Reference Guide*. This issue is devoted to bringing readers an invaluable collection of informative, fundamental engineering articles in the areas of EMC, Product Safety, ESD and Telecom and Wireless.

We live in an age of accelerated change. Our society places a high value on the ability to see the world through creative eyes. Pushing the boundaries of what was inspires us to explore what is possible for our future. Stories of new technologies, new products and new beginnings are posted to our website daily. The role of the compliance engineer in the creation and execution of these channels of change continues to expand. We salute you for your ability to see how things interrelate, your commitment to excellence and your unquenchable thirst for knowledge.

We know from many conversations with you throughout the year and from your feedback on our surveys that you continue to rely on print media as a means of information consumption. Let's face it, print is easily transportable, easy to put your hands on, and it's an experience that can't be replicated. In Compliance remains committed to providing our readers with the print experience every month. Just as you are committed to the excellence of your craft, we too remain committed to ours.

And so, it is in the spirit of sharing knowledge, practical implementation of engineering facts, and essential information in one, easy to use book, that we present our Sixth Edition of this classic annual Compliance Handbook.

Here's what you will find inside. Beginning on page 10, Compliance Solutions highlight companies with in-depth profiles detailing their areas of expertise. Technical articles, categorized by subject matter, run from page 22 to 179. Subject tabs appear in the outside margin to help you in easily navigating throughout the handbook. Toward the back of the Guide, the Directory section opens on page 177 with a Directory Index. Pages 187-189 provide a comprehensive index of all products and services listed in the Products and Services Directory. And a full industry Vendor Directory begins on page 218.

You also have full access to the information found in the Guide on our website www.incompliancemag.com and our online directory at www.incompliance-directory.com.

As always, your comments, requests and new ideas are welcome! Send your email message to editor@incompliancemag.com.

Until next time,

Lorie Nichols, Editor

IN COMPLIANCE

In Compliance Magazine
ISSN 1948-8254 (print)
ISSN 1948-8262 (online)
is published by

Same Page Publishing Inc.
531 King Street, Suite 5
Littleton, MA 01460-1279
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A.H. Systems is proud to know it is providing the highest quality products available. Quality problems arising in various areas are to be identified and solved with speed, technical efficiency and economy. We focus our resources, both technical and human, towards the prevention of quality deficiencies to satisfy the organizational goal of "right the first time... every time".

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We manufacture a complete line of affordable, reliable, individually calibrated EMC Test Antennas, Preamplifiers, Current Probes and Low-Loss, High-Frequency Cables. All Products are available directly from our facility in Chatsworth, CA and through our Distributors and Representatives worldwide. Our products keep on working, which enable us to give a 3-year warranty, the longest in our industry.

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How many times have you purchased several antennas and then you forget what department has them or where they are? You discover parts are missing and the data is lost. You are now frantic because you have a scheduled deadline for your testing. At A.H. Systems we bring portability to a new level. We specialize in Portable Antenna Kits and provide many models covering the broadband frequency range of 20 Hz to 40 MHz. Excellent performance, compact size and a lightweight package make each Antenna Kit a preferred choice for field-testing. Loss and breakage are virtually eliminated because each component has a specific storage compartment in the carrying case. When testing out in the field or traveling, keep them all in one case. Travel made easy!

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When you have a problem in the field during testing, you need fast answers to solve your problem. How many times have you called a company to speak to an engineer for a technical problem you are experiencing? And it takes many days to get a call back, let alone the answer to your problems. At A.H. Systems you get great personal service. A live person to talk to! We are here to assist customers with their EMC/EMI testing requirements. We try to solve your problems while you are experiencing them. Even before, during and after the Purchase Order. Our knowledge in EMC testing and antenna design enables us to offer unique solutions to specific customer problems. Not only do we solve your problems, we help you find the right antenna. Talking with our customers and hearing what they have to say enables us to provide better products, services and more options for our customers. Call us. We are here to make your problems, non-problems. For more information about our products visit our website at www.AHSystems.com.

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Providing Solutions for EMC Test and Measurement

ETS-Lindgren is one of the world's largest vertically integrated manufacturers of EMC systems and components. We are engaged in every aspect of the EMC industry; engineering, manufacturing, sales and support, calibration and repair. We are also committed to wireless, microwave, acoustic and medical technologies.

Company Roots

We trace our earliest roots to the 1930's when the Ray Proof Company began producing x-ray shielding for the medical market. In 1995, EMCO, Rantec and Ray Proof joined together to form EMC Test Systems, known then as ETS. Later, other companies were acquired; Euroshield Oy, Lindgren RF Enclosures, Holaday Industries, and Acoustic Systems. Today our company is known as ETS-Lindgren.

Global Scope

Headquartered in Cedar Park, Texas, ETS-Lindgren conducts business around the globe.

Our diverse and highly skilled global workforce consists of approximately 750 employees in North America, South America, Europe, and Asia. We have four manufacturing facilities in the US, and one each in Great Britain, Finland, and China.

Our sales network of more than 60 independent representative and distributor organizations provides knowledgeable sales, service and support around the world.

Commitment, Growth and Investment

ETS-Lindgren is committed to our industry and encourages our employees to participate in standards

committees, as speakers and session chairs at symposiums, and as authors and lecturers. It would be difficult to attend a symposium and not see an ETS-Lindgren team member in front of a podium, or read a journal or trade magazine without reading something authored by one of our engineers.

Our growth is propelled by meeting our customer's need for systems and components that provide reliable service, repeatable results, and value at a fair price. Our history of success and proven track record virtually eliminates risky outcomes for our customers.

ETS-Lindgren believes in making investments that enable us to serve our customers better. Our manufacturing facilities use efficient, cost reducing systems. Our engineers work with modern equipment. We continue to expand our locations to better service our customers, such as our newest office in Bengaluru, India.

Environment and Safety

As a company and as individuals, ETS-Lindgren take great pride in contributing to the communities where we live and work. Our efforts include the support of local charities, one of which benefits children with hearing disabilities. We also care about the environment and are proud of the many ways in which our employees work to safeguard it.

Our persistent efforts to improve on our safe work environment continue to pay off. We provide ongoing safety training and awareness, and a safe place to work.

Our Work Ethic

ETS-Lindgren recognizes the importance EMC has in a world increasingly dependent on electronic devices operating safely and compliance with regulatory standards. That's why our employees work daily to design, manufacture and support the systems and components our customers can depend on.

SOLUTIONS. SIMPLIFIED.

Keeping things simple makes you more productive. You get things done more quickly and with less effort when you have tools that are easy to use.

That's exactly how our solutions for RF test are designed – easy for operators to use, and requiring a lot less of your effort to design and implement.

We make it simple by providing test solutions that adapt to change, accept a choice of instrumentation, and operate with equal ease by engineers and lab technicians alike.

At project level, our in-house capabilities smooth the way with RF, mechanical and architectural engineering (including BIM), site surveys, local permitting (MEP), project management, system performance verification, operator training, assistance with agency certification, and ongoing support.

With us, you work with a single accountable partner with a proven track record of delivering on our promises, and a knack for making things simple.

See our solutions at the 2015 IEEE Symposium on Electromagnetic Compatibility & Signal Integrity at the Santa Clara, CA, Convention Center, March 15-21, 2015. We'll be in our Booth 402 at the front of the exhibit hall.

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The staff of HV TECHNOLOGIES, Inc. (HVT), in partnership with EMC-PARTNER, AG, Montena Technology, Prana, GAUSS INSTRUMENTS Innco Systems, and Pontis EMC, along with a wide selection of RF accessories, is focused on providingour clients with top quality, full compliance EMC test instruments at the most competitive prices. Our staff has been supporting the electro-magnetic compatibility (EMC) testing community by designing, producing, and distributing the best EMC test instruments for over two decades. Customers using our equipment receive the highest quality and the most accurate and repeatable waveforms and measurements. All equipment is backed and serviced by HVT. This is only possible through innovative product design and the deployment of unique leading-edge technologies. We have the products, delivery, and support you expect today and for years to come.

EMC/EMI transient test and measurement equipment

Our associate, EMC-PARTNER AG was founded by well-known EMC experts and complement our group with the most extensive lines of transient test equipment available.

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10 kHz up to 6 GHz with powers up to 12,000 Watts

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EMI Time Domain Receivers

Our partnership with GAUSS INSTRUMENTS, the developer and manufacturer of the TDEMI Measurement System, is revolutionizing how emissions testing is done. This advanced technology achieves processing and measurement speeds up to 64000 times faster than conventional EMI receivers.

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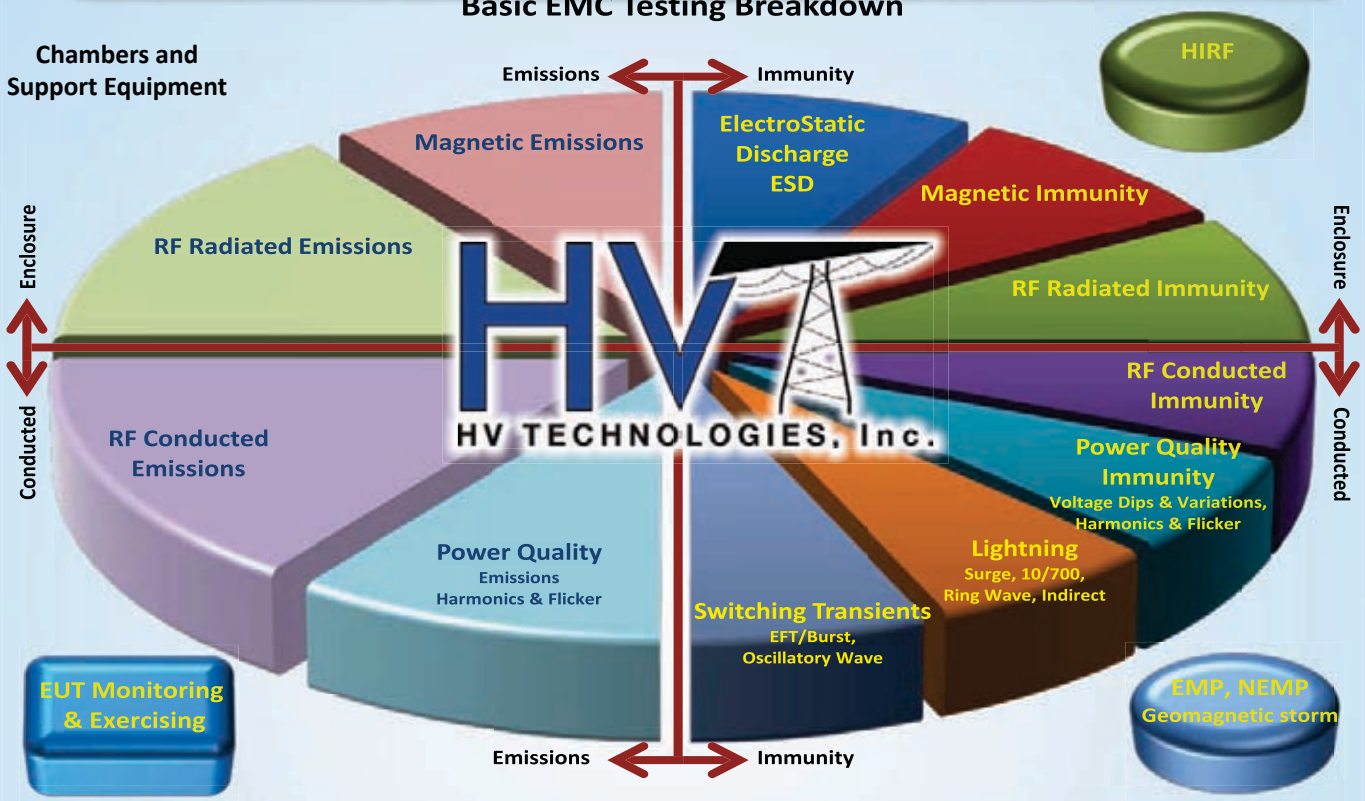
Basic EMC Testing Breakdown



Impulse Generators

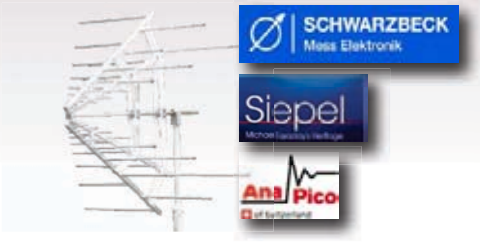
Power Amplifiers

Military Impulse Test Systems

EMI Time Domain Receivers

Positioners

EMI Hardened Links



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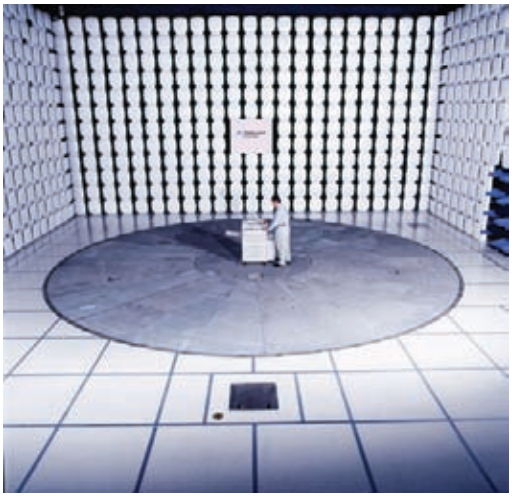
EMC Lab in Webster, N.Y.

TÜV Rheinland customers have access to a premier EMC test facility in Webster, N.Y. It is a 10,000-square-foot laboratory equipped with a 10-meter semi-anechoic chamber, with a 10-meter diameter turntable to test products up to 32 feet long, weighing up to 20,000 lbs. It is one of the largest capacity chambers commercially available in North America.

The state-of-the-art, ISO 17025-accredited laboratory provides complete EMC testing services to help electrical product manufacturers achieve global regulatory compliance, including the FCC, ICES and CE EMC requirements. Employing the 10-meter chamber and multiple dedicated test stations, several products can be tested at the same time, increasing productivity and reducing test time. Additionally, the Webster lab offers harmonics and flicker testing capability for high-power, three-phase products up to 63 Amps per phase according to the EN 61000-3-11 and EN 61000-3-12 standards.

TÜV Rheinland also offers EMC testing at four other locations throughout the US – Newtown, CT, Raleigh, NC, Pleasanton, CA and Santa Clara, CA – to help customers with all of their compliance needs.



10-meter semi-anechoic chamber in Webster, N.Y.

OpenSky

Organizations in the energy, medical device and Smart Grid industries will benefit from an extensive portfolio of services offered by TÜV Rheinland's division OpenSky. The services include transformational IT infrastructure, security and compliance. The partnership with OpenSky enables TÜV Rheinland's customers to quickly pick up on key IT security trends and innovations and implement them in a timely manner.

Medical Cybersecurity

With the rise of wireless, Internet and networking technologies employed in medical devices, the need for effective cybersecurity to assure device functionality and patient information security has become essential. Healthcare delivery organizations are expecting medical device makers to provide "securable" devices, and asking for evidence. Similarly, the FDA's new guideline on cybersecurity calls for changes to the risk analysis and should be followed for 510k submittals.

Product Safety Testing and Certification

TÜV Rheinland evaluates, tests and certifies the safety and quality of products in virtually all categories– from state-of-the-art computer equipment and wearable devices to heavy industrial machinery. With these services, you can:

- Ensure compliance with national and international regulatory requirements
- Gain quick access to the global market with streamlined and timely solutions
- Competitively position yourself with TÜV Rheinland's independent third-party certifications

International Approvals

Today, companies need more than ever seamless solutions for access to world markets with timely and accurate product certification management. Learn about the current rules and regulations for gaining market access to Argentina, Saudi Arabia, China, Japan, Korea, India, Brazil, and more. TÜV Rheinland experts advise on regulatory requirements for a wide range of product categories, including medical, Information Technology, wireless, audio/video, household, and machinery.

Small Businesses

Some laboratories are "friendlier" to small business operations than others. TÜV Rheinland provides a one-stop shop for small businesses, bundling services to make the regulatory and compliance puzzle much easier to manage. The staff are committed to making sure the customer understands what testing involves, providing a realistic timeline and outlining what items will need to be provided for testing.

Why TÜV Rheinland

At TÜV Rheinland, we embrace compliance as your partner from the very start. We invite you to challenge us with your questions and pledge to deliver individualized solutions based on expertise, years of experience and a worldwide network of laboratories.

TÜV Rheinland of North America, Inc.

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- ISO 13485

Accreditations

TÜV Rheinland is accredited as:

- Accredited Certification Body by the Standards Council of Canada (SCC) for ISO/IEC 17021:2011
- Health Canada Recognized Certification Body under the CMDCAS Program
- Accredited by the ZLG and ZLS for the EU directives (MDD, AIMD, IVD)
- Accredited by DAkkS for ISO/IEC 17021:2011

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Company Info:

Spira offers the finest and most reliable EMI/RFI shielding gaskets and honeycomb filters in the market, at very competitive prices. The company was founded by one of the leading EMI design engineers in the industry. Spira's commitment is to provide quality-engineered products, on-time delivery, superior customer service and technical support. Spira is **ISO-9001** and **AS9100** certified.

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Spira's patented EMI/RFI and environmental gaskets offer excellent solutions for both cost-sensitive and high-performance applications. The unique spiral design offers extremely low compression set, long life and high shielding. Gaskets meet requirements including ITAR, DFAR, RoHS, FCC, EC, HIRF, & TEMPEST. Configurations are available both in groove and surface mount options, in diameters from .034" up to 1.5".

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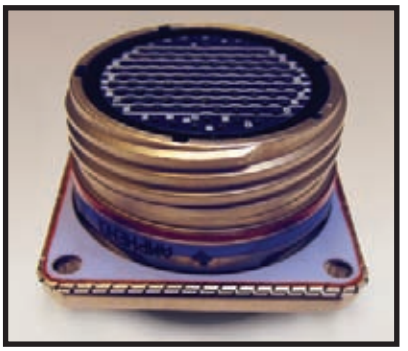

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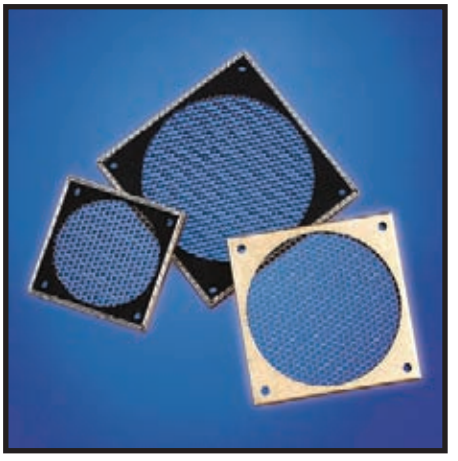

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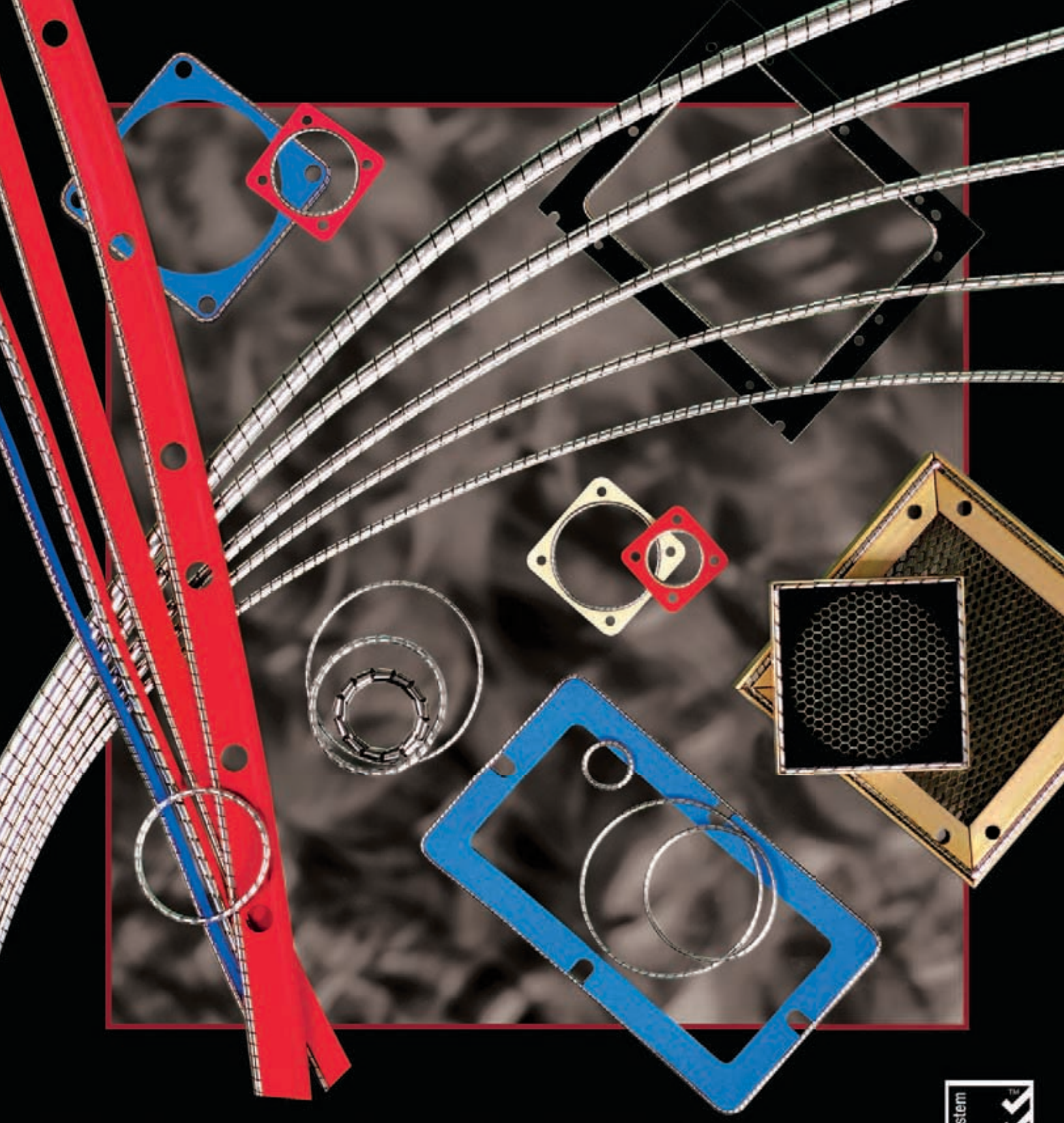

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EMI vs. EMC What's in an Acronym?

BY KEN JAVOR

Photo credit: ESA–A. Le Floc'h

"A rose by any other name would stink."
– Kenneth Adamson

We have all seen advertising copy for test equipment manufacturers' "EMC receivers" and "EMC test services" provided by commercial EMI test facilities. While we know what the aforementioned receiver does, and what sort of services the test facility supplies, the nomenclature is wrong and is symptomatic of a deeper problem.

In this article, we examine defense and aerospace EMC practices, and compare/contrast these processes with those of other market sectors. EMI vs EMC nomenclature is a good introduction.

Per ANSI C63.14 we control electromagnetic interference in order to achieve the desired state of electromagnetic compatibility:

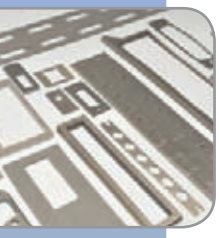
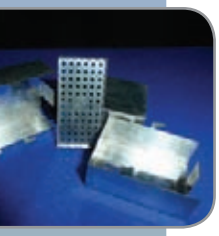
> EMI: "Any electromagnetic disturbance … that … degrades … performance of electronic or electrical equipment."
>
> EMC: "The capability of electrical and electronic systems, equipments, and devices to operate in their intended electromagnetic environment … without … unacceptable degradation as a result of electromagnetic interference."

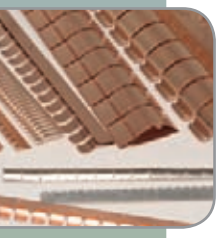
Requirements controlling EMI characteristics such as CISPR 22, CISPR 25, RTCA/DO-160 and MIL-STD-461 are *means to an end*. That end is electromagnetic compatibility between devices qualified to these standards and between them and radios. Conjointly, EMI requirements are *not* an end in themselves. Any device with an FCC Part 15 sticker has a disclaimer to the effect that, "This device may not cause harmful interference..." This is the desired end result - EMC. If the device does cause interference (despite having met its EMI requirements), the user is advised to separate culprit and victim, and as a last resort, shut the culprit off: the licensed user of the spectrum has priority over the unlicensed polluter.

The bottom line is that standards controlling EMI are one of the tools by which we achieve EMC and EMC is demonstrated, if at all, on the integrated system, which is typically a vehicle that drives, sails (above or below the sea) or flies (within or above the atmosphere). Equipment designed for use in homes, offices, and factories don't have a specific installation, and there is no EMC check for such equipment. EMI requirements to which they are subjected are the sole qualification relative to EMC. Hence, it is not surprising that this market segment most often fails to properly distinguish between EMI and EMC.

Integrated vehicles are functionally evaluated – EMC tested – ensuring that each subsystem operates properly as part of the greater whole, acting as neither a source of nor a victim to EMI within the vehicle. Separately, the entire vehicle is subjected to external stresses such as steady-state and transient electromagnetic fields, and the subsystems must operate properly. "Proper operation" might include graceful degradation, such as anti-lock brakes becoming purely hydraulic brakes with no electronic control.





Meeting the Challenge

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- **Conductive FR and Non-FR Foams** ideal for I/O gaskets and RFI Connectors (backplanes, Ethernet ports) available in five different thicknesses. Fire Rated and Non-FireRated
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- **Oriented Wire in Silicone** is available in both solid and sponge silicone, with aluminum or Monel embedded wires. It comes in sheet and strip forms or rule die cut with or without PSA. Custom orders upon request.
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Most importantly for this discussion, vehicle antennas will be interrogated by an EMI receiver looking for signals coupled to that antenna in-band to the receiver. On an automobile, that would mean 530 - 1710 kHz and 87.5 - 108 MHz at the point where the coaxial transmission line disconnects from the AM/FM receiver, and perhaps the "shark fin" antenna used for satellite reception. On a military aircraft, in contrast, there could be such measurements from 0.15-1.99 MHz (ADF), 2-30 MHz (hf), 30-88 MHz (vhf-FM), 108-152 MHz (vhf-AM, with both air navigation aids and communications residing in this band), 225-400 MHz (uhf-AM), 960-1215 MHz (TACAN), and perhaps others as well.

Such testing is the ultimate high fidelity EMC check, because the test set-up is the installation. All EMI standard test set-ups are approximations of expected installations, whether vehicle, home, office, or plant, and at best provide an upper bound of what would be expected to be measured *in situ*.

Along these lines, I like to quote a forerunner standard to MIL-STD-464, which is the present day military standard for electromagnetic effects that apply to a vehicle procurement. The 1967 vintage MIL-E-6051D, "EMC Requirements, Systems," paragraph 3.2.4.1, "Subsystems and Equipment," opens as follows: "Unless otherwise specified in the contract, subsystems/equipments shall be designed to meet the requirements of MIL-STD-461 and MIL-STD-462. Since some of the limits in these standards are very severe, the impact of these limits on system effectiveness, cost, and weight shall be considered…"

The importance of this paragraph cannot be overstated. The essence of system engineering – any engineering – is tradeoffs. In vehicle engineering, we can review EMI test data, and decide if out-of-tolerance signatures allow an acceptable level of EMC. Often we do that by test – for instance, by installing equipment with excessive radiated emissions (RE) in the vehicle and monitoring the antenna band wherein the offending signals reside to see if they do in fact couple into the receiver, or if the installation provides enough isolation via shielding, shading and distance between equipment and victim antenna to eliminate the potential for interference.

Vehicle EMC engineers can do all this because EMI qualification testing occurs after a contract has been signed between equipment vendor and integrator. Integrator and vendor can collaboratively find an optimal solution for "system effectiveness, cost, and weight" and schedule. The process can be bumpy, but it does work, especially within the military-industrial complex.

In the consumer marketplace, where FCC or European Norm or other national laws require passing EMI requirements before placing products on the market, there is no flexibility: the limit is the law. Therefore an extreme amount of attention is placed on measurement repeatability/uncertainty. A level playing field – irrespective of where a device is tested, or by whom – is an economic *sine qua non* (without which, nothing). Tight uncertainty requirements supporting repeatability requirements such as the +/- 4 dB normalized site attenuation for RE testing and the -0, +6 dB tolerance for the electric field immunity test uniform field area require more expensive test sites and more complex procedures than those required for equipments slated for vehicle usage. Two factors differentiating facility costs are the degree to which reflections are controlled, and separations between antenna and test sample, which drive chamber size.

It is commonplace to contrast military vs. commercial EMI test practices, but that is not a fundamental distinction. Commercial aerospace and automotive EMI test practices have much more in common with military practice than they do with qualification of consumer items on open area test sites (OATS) or in fully or semi-anechoic chambers (FAC/SAC). The fundamental difference is installation in a vehicle (usually metal) vs. equipment slated for use in homes, offices and industrial plants. EMI testing of equipment installed in vehicles requires acknowledgment of the immediate proximity of electrical ground (vehicle structure) and the possibility that vehicle antennas will be placed nearby culprit electrical noise generators. Neither of these are the case for non-vehicle equipment. Or more precisely, it is quite possible in the home, office or factory that someone may try to listen

to or watch a broadcast program or receive a wireless phone call and find that some device in the receiver's vicinity is causing interference. But it is under their control to increase culprit and victim separation, when the problem usually goes away. Separations up to three meters are deemed under the control of the Class B equipment end user, and separations up to ten meters are assumed under the control of the Class A end user.

Three or more meter separations coupled with RE control starting at 30 MHz and radiated immunity starting at 80 MHz happily allow for EMI measurements under far field, or nearly far field conditions.

Automobiles, aircraft and even large ships cannot guarantee such separations, and must impose one-meter RE measurements. Not all antenna-culprit separations will be precisely one meter, and while one-meter measurements are not scalable as are far field measurements, the vehicle EMC process does not stop at the one-meter measurement.

An example of the full vehicle EMC process offers insight into the fundamental differences between vehicle and non-vehicle EMI qualification. Medical devices designed for hospital use are needed in air ambulances. Part of ambulance qualification is EMI/EMC. The equipment in question already meets all medical device certifications, as it is commercially available and used in hospitals. But when re-qualified to aircraft EMI requirements, involving antenna-test sample separations of not three meters or more, but instead one meter, these devices often fail. Because the intent is to use existing off-the-shelf equipment, design modifications are undesirable and to be avoided, if at all possible.

When RE failures against the equipment limit are found, it is standard operating procedure to place the device in the aircraft and monitor aircraft antennas covering the failing frequencies with a spectrum analyzer, looking for evidence of excessive coupling. This is nothing new; the technique has been included in MIL-STD-464 since its inception in 1997. It is only the application to equipment neither designed for vehicle use, nor permanently installed in a fixed location within a vehicle that is different.

If the RFI signal measured at the aircraft antenna is deemed low enough to not be a problem, then the equipment-level EMI test failure does not force redesign. If the level measured at the vehicle antenna is too high, redesign is indicated

despite the previous far field qualification for hospital use. One-meter re-qualification is necessary despite the previous qualification involving far field testing (three or ten meter), despite persistent voices calling for a single unified far-field test approach for EMI testing, which comes from the OATS/FAC/SAC faction.

Were we to accept the oft-repeated superiority of OATS/SAC/FAC measurements and replace vehicle type one-meter measurements we would at our peril violate basic physical laws. While far field measurements are attractive for deriving analytical relationships between various circuit parameters and the resultant electromagnetic field, these predictions are not useful to vehicle integrators working in the near field.

Electric field structure is qualitatively, not just quantitatively different at one meter than at three and beyond. In close, we measure not only radiating signals, which are also picked up farther out, but in addition, inductive or quasi-static fields which do not propagate into the far field. On vehicles where the separation between culprit emitter and victim antenna is much closer than three meters, three meter and farther out measurements do not protect against interference.

The traditional automotive whip antenna used in the AM & FM broadcast bands is a good example. In the far field of a wire radiator, the electric field will be parallel to the wire, assuming the wire is long enough to develop a potential drop across its length. For other than a large ship or very large aircraft, this can't happen in the AM band, only at FM. But in close, whether AM or FM, there is a non-radiating electric field component that starts on the wire and ends on the ground plane beneath it, due to the potential on the wire relative to ground. It cannot propagate, because the magnetic field associated with that wire circulates around it, and is co-directional with it. Electromagnetic energy only propagates when electric and magnetic field vectors are at mutually non-zero angles (Poynting's theorem).

If that whip antenna can be one meter from a noisy cable, then the EMI test has to also place the antenna at one-meter separation.

Then there is the issue of separation between test sample and ground plane. In the typical vehicle installation, equipment bonds directly or indirectly to vehicle structure. The EMI test simulates this with a tabletop ground plane mounted 80-90 cm above floor height. On an OATS or in a SAC/ FAC, the test sample is 80 cm above the floor ground plane, with at most a green wire connection to it. Including a tabletop ground plane on an OATS or in a SAC/FAC destroys the anechoic properties of the facility, and those who advocate for OATS/SAC/FAC use also advocate for removal of the tabletop ground plane.

But the tabletop ground plane five centimeters below test sample attached cabling is worth up to 20 dB in reduced cable radiation efficiency for emission work, and something similar in terms of the effective aperture of test sample-connected cables during immunity/susceptibility testing. Especially for automotive use, where unshielded cables are the norm, meeting very stringent radiated limits one meter away in the absence of that ground plane is at best impractical.

It is presuming to insist on OATS and SAC/FAC type measurements in lieu of one-meter measurements for vehicle equipments. The comparison is apples and oranges. Considering not only (vehicle) equipment EMI testing, but also on-vehicle EMC assessment, including the super-hi fidelity check of RE coupling to vehicle antennas, it is clear that the overall vehicle EMI/EMC program efficiently does exactly what is needed.

Finally, there is the issue of protection of off-vehicle receivers. Automobile-level RE limits are imposed at ten meters to protect radios operating near roadways. Army ground vehicle-level RE limits impose control at one meter, to protect radios in a tactical operations center adjacent to which the vehicle might be parked. Some military aircraft impose RE control at one nautical mile to protect against aircraft detection by hostiles.

The simple conclusion is ***we test things the way we use them***. It is always better to separate noisemakers and sensitive receivers, and when we can separate them we do, but when we can't, then we have to assess the potential for EMI at the separations we expect in actual use.

To demand that vehicle equipment-level EMI testing adopt SAC/FAC/OATS type methods is akin to the old joke about looking for lost car keys not where they were dropped in a dark alley, but a block away under a street lamp, because it is easier to see there.

Ken Javor *has worked in the EMC industry over thirty years. He is a consultant to government and industry, runs a pre-compliance EMI test facility, and curates the Museum of EMC Antiquities, a collection of radios and instruments that were important in the development of the discipline, as well as a library of important documentation. Mr. Javor is an industry representative to the Tri-Service Working Groups that write MIL-STD-464 and MIL-STD-461 (the "G" effort presently underway). He has published numerous papers and is the author of a handbook on EMI requirements and test methods. Mr. Javor can be contacted at ken.javor@emccompliance.com.*

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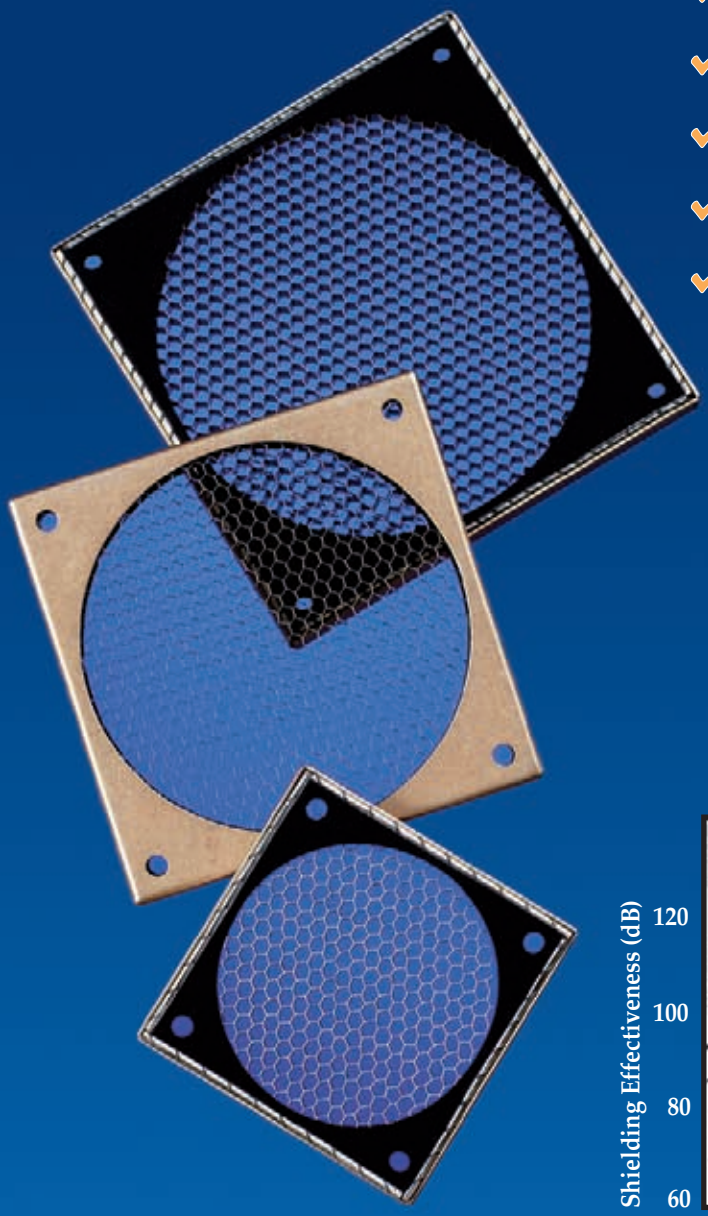

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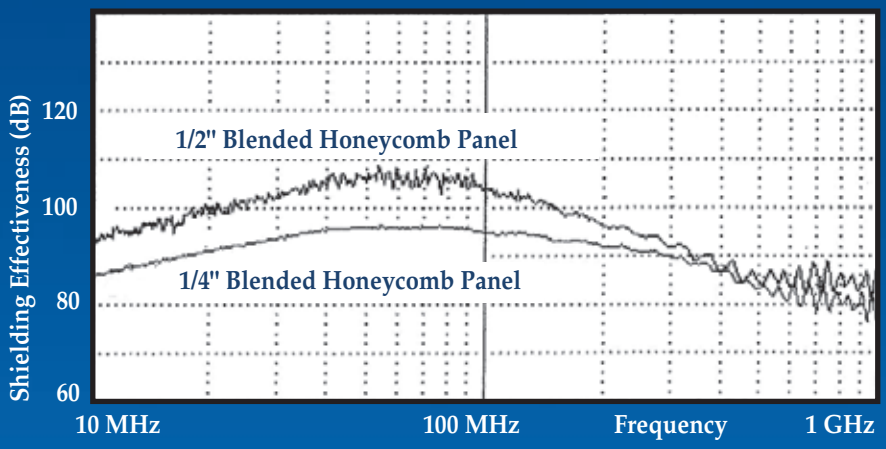

Typical Shielding Effectiveness Test Data of Spira Honeycomb Fan Filters

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A Challenge of Portable Radio Transmitters Used in Close Proximity

BY JOHN MAAS

Intentional RF transmitting devices seem to be everywhere. Smart phones, tablets and similar devices provide the ability for users to be connected to the internet any time, from any location using nearly any device. Other than the Boundary Waters Canoe Area Wilderness and the inner canyon of the Grand Canyon, it may be difficult to find any location without WiFi available. RFID tags and transponders are used for inventory in retail stores, monitoring the location of equipment of all kinds and tracking patients in medical settings. We even see active RFID tags imbedded in electronic equipment undergoing EMC testing. (The experienced EMC professional can probably imagine the challenge this practice creates during an RF emission test!)

A sampling of transmission systems is shown in Table 1.

No doubt, the great expansion of this technology has improved society in many ways. The benefits of these devices are quite significant. An unintended side effect of the proliferation of transmitting devices, however, is the increased potential for malfunctions of electronic equipment in operation close to where the transmitters are used. Not only are more transmitting devices in use in all environments, the separation between any given transmitter and equipment that may be affected is generally decreasing. The separation distance is often uncontrolled with separations of a few centimeters not being uncommon. Contrast this proximity with the several meters or more of separation typical in the days before the use of portable devices with transmitters became so prevalent.

The types of equipment that may be adversely affected is nearly endless, including desk-top computers, point-of-sale terminals, gas pumps, vehicle control systems, computer systems and other portable electronics, to name just a very few.

Transmission System	Frequency Range	Typical RF Power	Access Technique/ Modulation
TETRA/TETRAPOL	380 to 676 MHz (not continuous)	10 W (RMS)	TDMA, FDMA, DQPSK
GSM	824 to 1901 MHz (not continuous)	1 or 2 W	AM, PSK
DECT	1.88 to 1.9 GHz	250 mW	GMSK
UMTS	1.92 to 1.98 GHz	250 mW	QPSK
WLAN	2.4 to 2.835 GHz 5.15 to 5.725 GHz	100 mW 1 W	OFDM
Bluetooth	2.4 to 2.4835 GHz	100 mW	FHSS
LTE	790 to 862 MHz 2.5 to 2.69 GHz		OFDMA, SC-FDMA

Table 1: A sampling of transmission systems

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This new-world reality creates some interesting challenges and opportunities for EMC professionals. What are the devices we must consider as sources of interference? What devices need to be hardened against new or changing interferences? How do we determine adequate immunity levels? Are existing test methods and standards sufficient? If not, are wholesale modifications required, or can existing standards be used with some (minor?) modifications? Which characteristics of the transmitted signals are important to the evaluation of disturbance potential?

These questions, and more, are being considered in multiple segments of industry, including standards developing organizations and various user segments. This article will explore some of the aspects of this situation, including the possibility of developing a new international test standard focused on close proximity immunity. The challenges that will need to be addressed to provide repeatable, meaningful test results will be explored.

ANOTHER STANDARD?

One may ask why do we need a new test standard for this phenomenon. IEC 61000-4-3 covers immunity of electronic equipment to radiated RF electromagnetic energy, establishing both test levels and test procedures. The current edition of this standard even states "Particular considerations are devoted to the protection against radio-frequency emissions from digital radiotelephones and other RF emitting devices." [1]. IEC 61000-4-21 includes a detailed description for the test setup, chamber validation procedure and test procedures required to perform radiated immunity testing in a reverberation chamber [2]. IEC 61000-4-20 provides details for performing immunity tests on in-scope equipment in transverse electromagnetic (TEM) devices. [3]

These standards are excellent documents for their intended purposes and certainly can be used to simulate disturbances created by portable transmitters used at distance from equipment potentially suffering interference. They may not always produce a satisfactory characterization of equipment immunity to portable transmission sources used within a very short distance, say 20 cm or less. Test limits in the range of 3 to 10 volts/meter are typical when the disturbance source is a fair distance away. However, field intensities in close proximity to smart phones can be 100 volts/meter or more. Some equipment manufacturers and users reduce the risk of interference by specifying minimum separation distances that must be maintained between their equipment and portable transmitters. A typical specified separation distance is in the range of 1 to 3 meters. At the same time, we are seeing a move toward having service personnel use their smart phones very close to installed equipment while performing service. A practice gaining popularity is to place QR codes on equipment covers for service personnel to scan for accessing service information related to the equipment. Doing so while keeping smart phones 3 meters from the equipment would be, shall we say, a challenge.

Multiple industry segments have highlighted the problems of trying to use these existing standards to evaluate immunity of equipment to cell/smart phones used in close proximity. Notably, the automotive industry and the medical device industry have raised concerns with the suitability of existing test methods that could be used for this purpose. Groups within these industry segments reached the conclusion that the existing RF immunity test standards do not represent the close-proximity electric and magnetic field characteristics accurately enough and could produce results that are not fully in line with malfunctions created by interference sources used in close proximity in real-world situations.

The concerns raised by these groups helped initiate a new project in IEC to develop a new basic standard for immunity to devices used in close proximity. This project is in its early stages in Working Group 10 (WG10) of IEC SC77B.

WG10 is considering all aspects of interference caused by portable transmitting devices in close proximity and comparing them with characteristics of existing standards to determine where those standards are a good match and where they are not appropriate. The characteristics that need closer scrutiny include:

- Field strengths very close to cell/smart phone versus common test levels
- Input power levels required for achieve those very high field strengths
- The significance of using near field sources as opposed to far field sources
- The significance of the source type, such as electric field or magnetic field and
- Modulation schemes.

One of the first things we considered was whether the existing IEC standards could be used for this purpose, either wholly or in part.

EXISTING STANDARDS

The practice of using a linearly polarized antenna to create a uniform field area (UFA) in which the equipment being evaluated is immersed is described in IEC 61000-4-3. The standard states its test methods can be applied up to 6 GHz and that disturbances from portable transmitting devices such as cell phones have been given consideration. The method of independent test windows facilitates testing at frequencies greater than 1 GHz, the frequency typical for many types of portable transmitters. These factors certainly seem to

indicate this standard could be used to test for immunity to disturbances from portable RF transmitting devices. Some test labs have had good experience in doing just that. However, the input power levels required to establish field strengths on the order of 100 volts/meter can be quite large. They are possible to achieve, but large. For the independent windows method, the test distance between the transmitting antenna and EUT is 1 meter. Consequently, this method does not reproduce the near-field effects that exist in real-world close proximity situations. In some cases, not reproducing the near-field effects may not be an issue, particularly for equipment where the intensity of the disturbances is the predominant effect. In such cases, IEC 61000-4-3 could be applied. Where this is not so, a different test method and standard would be needed.

Reverberation chambers can be used to immerse the equipment under test (EUT) in a field that is statically isotropic, homogeneous, unpolarized and uncorrelated. As described in IEC 61000-4-21, the entire EUT is exposed to simulated disturbances without the need to rotate the EUT or to move the transmitting antenna to multiple, discrete positions. Fairly high field strengths can be generated using moderate input power levels, thereby avoiding input power level concern when testing according to IEC 61000-4-3. Similar to the practice of using a linear antenna to generate a uniform field area, the near-field effects that happen when the transmitting device is very close to the equipment experiencing interference are not reproduced in a reverberation chamber.

Based on the analysis that is summarized briefly here, the current position is that these standards certainly can be used to evaluate the immunity of equipment to interference from portable transmitting devices, including cell phones. However, they are best suited to evaluate situations when the transmitting device is far enough away that it would not be considered as being used in "close proximity." Therefore, an independent standard defining a test method that more fully replicates the particular characteristics of disturbances from transmitting devices used in close proximity to the equipment suffering interference and can be used when the test methods in the existing standards is not appropriate, adequate or sufficient should be developed.

TEST METHODOLOGY AND CHALLENGES

One of the challenges to be worked through is how to define what it means for the transmitting device to be in close proximity to the equipment experience the disturbance. We

could consider the transition from near field to far field, the intensity of the disturbance signal, an arbitrary physical separation or some other characteristic. However it is defined, this characteristic is important to establishing all the technical details in the standard.

An international standard must meet certain formal and informal criteria before it can be published and put into use. This requirement is especially true for a basic standard that is likely to be applied to a wide variety of equipment types. Test methods that are perfectly acceptable for a small, hand-held device may be totally impractical and produce questionable results for large industrial equipment. The people tasked with writing the standard must always keep in mind the bigger picture, considering how the standard may be used, the types of equipment that are likely to be evaluated against it and the state of the art in test equipment and the disturbance sources the standard intends to simulate.

The future standard is in the early stages of development. The work so far has identified some possible test methodologies as well as a number of issues that must be resolved before publication.

The test method being considered is based on the concept of a small RF coupler or antenna being scanned across the surface of the EUT. The coupler would be located some small distance away from the EUT surface, perhaps on the order of a few centimeters. To aid in repeatability of test results, the surface to be tested would be divided into a rectangular grid pattern and the coupler moved in discrete steps according to the size and shape of cells in that grid. See Figure 1 for an example of how the EUT may be partitioned into test grids. The RF coupler shown is intended to be of generic design and not an indication of what an actual coupler would be.

The test is conceptually simple, but some specific details are not quite so simple to develop. The details that need to be resolved before a useful basic test standard can be published include the following.

Defining the RF coupler

The coupler could be defined in terms of its electrical or mechanical parameters. It needs to be defined in a manner that allows commercial production by multiple suppliers. Facilitating construction by individual test laboratories could be considered as well. It must be able to withstand the input power needed to meet expected test levels. Some degree of uniformity of the field generated is also a must. Given the wide frequency range that must be considered, which could include approximately 800 MHz to 6 GHz, it is likely that multiple couplers would be needed. The definition would need to support this practical reality.

Calibration or verification of the RF coupler

Verifying that the RF coupler is functioning is not likely to be a major challenge. Defining a calibration procedure that will satisfy the rigors of laboratory accreditation requirements will probably be more difficult, not to mention essential to the reproducibility of test results.

Establishing a level-setting procedure

Given that the RF coupler will be placed very close to reflecting surfaces that may be very large relative to the size of the coupler, the effects of reflections from those reflecting surfaces must be considered. Can test levels be established in an environment with no reflecting surfaces nearby? Can forward power to the coupler be used as the test level without regard to effects from the reflecting surfaces under test?

Test time

Stepping the RF coupler across the surfaces to be tested will take some time. The amount of time, of course, depends on the size of the cells in the rectangular grid and the total size of the surfaces to be tested. Larger cells will reduce test time but must be balanced against the uniformity of the field radiated by the coupler. Add in a number of discrete frequencies or multiple frequency ranges, and the time required for the test can be very long, especially for large equipment being tested. One estimate for a full rack of computer or telecommunication equipment pegged test time in terms of days not hours.

Modulation schemes

Traditionally, amplitude modulation (AM) with a 1 kHz tone has been used for RF immunity testing. Evaluations and experiments have shown that AM sufficiently predicts performance for many other modulation signals. Is this still true given the large number of different modulation schemes being employed in RF transmitting devices today? If additional modulation schemes will be required, which ones need to be used and how do we decide how many difference schemes are necessary and sufficient?

CONCLUSION

Technology – isn't it grand? As technology evolves at a pace that seems only to get quicker, society reaps many benefits and improvements to daily life. For new technologies and applications to continue providing benefits, the unintended consequences must be considered. The test methods and associated standards for quantifying the effects of unintended consequences must also be examined and, in some cases, evolve along with the technology.

The proliferation of portable intentional RF transmitting devices is one of those shifts providing significant benefits

and the potential for undesired consequences. The standards community recognizes these consequences and the need for test standards to evolve to address them. The future standard for close proximity immunity testing will be one more tool in the EMC professional's toolkit to facilitate a seamless transition and enable progress well into the 21st century and beyond.

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2. IEC 61000-4-21:2011, *Electromagnetic compatibility (EMC) – Part 4-21: Testing and measurement techniques – Reverberation chamber test methods*
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Things You May Not Have Heard About Shielding

BY AL MARTIN

What determines how effective a cable shield is going to be? And how does the decision to ground or not ground a shield impact its effectiveness?

Fortunately there is a well-developed theory of shielding, which will be discussed as a way to get a general understanding of what can be expected of shield performance. But there's more to it. The manner in which the shield is terminated can significantly affect its effectiveness, as we shall see.

THE THEORY OF SHIELDING

A model of the physical environment

The theory of shielding starts with a model of the physical environment of the shield. The model assumes that the cable is jacketed, so that a shield is not in contact with a ground plane anywhere except possibly at the ends. That being the case, a transmission line is formed by whatever ground plane exists and the outside of the shield. Likewise the inside of the shield and the conductors enclosed also form a transmission line. Thus what we have is two transmission lines coupled by the leakage through the shield (see Figure 1).

The coupling of the inner and outer transmission lines is characterized by a mechanism called surface transfer impedance, Z_t. In most installations the shield, and hence the outer transmission line, is shorted to ground either at both ends or one end, shown schematically in Figure 2, by the switch SW being closed or open respectively.

The inner conductors are terminated at each end in some impedance, which when measurements are done, is generally an open, short or matched load.

A model of the electrical environment

If the shield is terminated at both ends, current can flow along the outside of the shield. This current can be due either to ground loops caused by the grounds at the ends of the cable being at different potentials (V_d), or it can be due to induction from external fields, or both. In either case the external

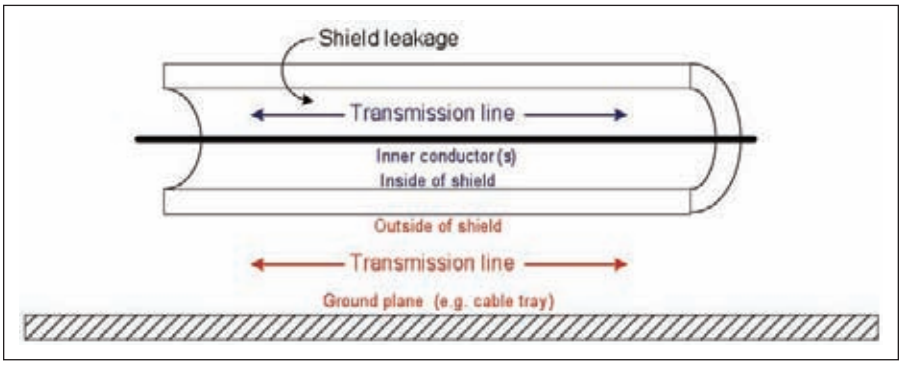

Figure 1: The basic model of the physical environment

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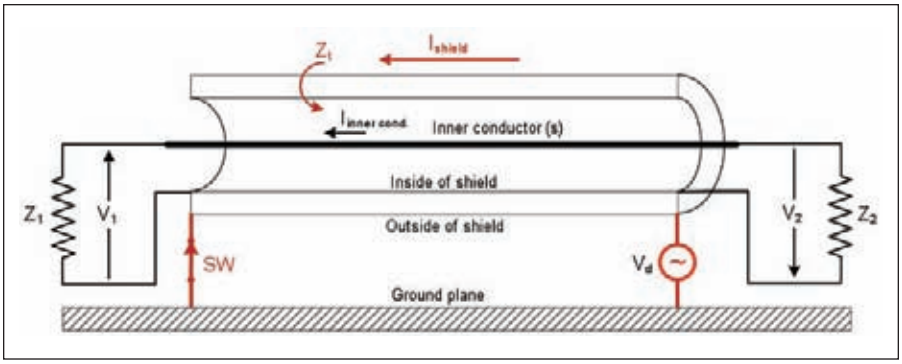

Figure 2: The model of the physical environment including terminations

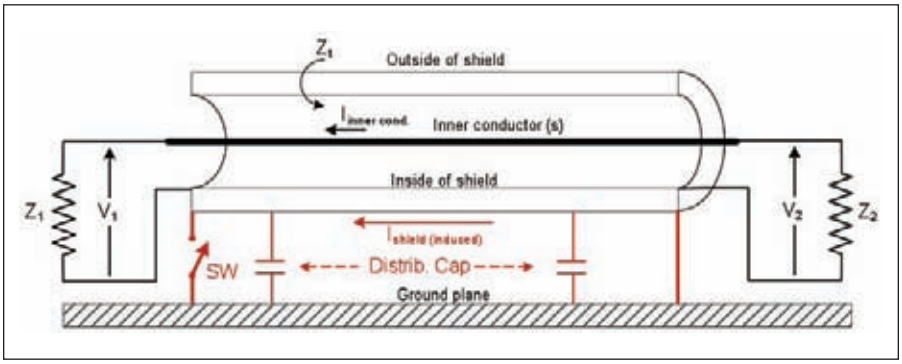

Figure 3: Model of a cable terminated at only one end

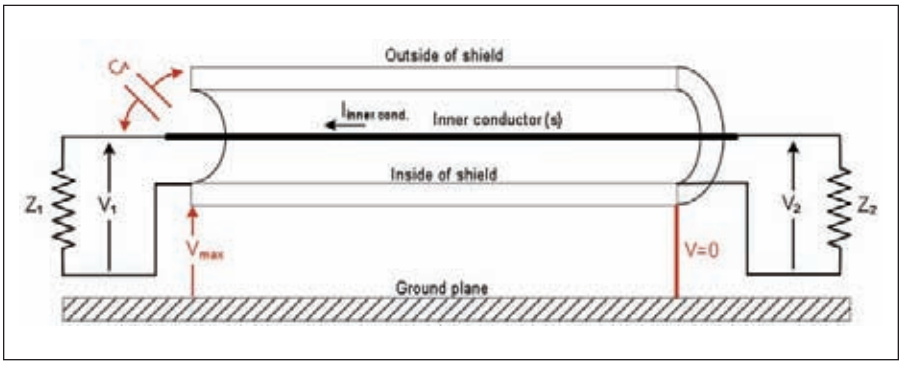

Figure 4: The basic schematic for coupling when one end of the shield is open-circuited

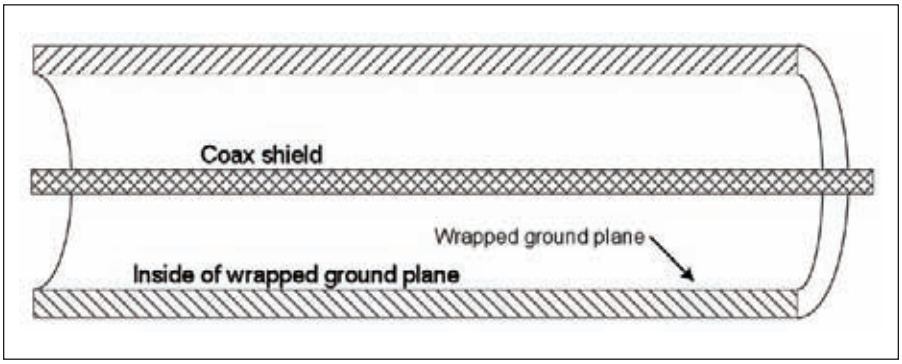

Figure 5: Basic configuration for calculating Z_t

shield current is coupled into the inner circuits via the surface transfer impedance, Z_t.

If the shield is terminated at only one end, the ground loop is broken. Current is limited to that which is induced to flow through the distributed capacitance between the outside of the shield and the ground plane (see Figure 3).

The induced current may be small, in which case the important quantity is the voltage distribution along the cable. The voltage is zero where the cable is terminated, but can be high at the open end for frequencies where the cable exceeds one-tenth of a wavelength, because, at that point, it becomes a very efficient antenna.

At the open end, there is capacitive coupling between the shield and the conductors of the cable due to the fringing capacitance C_f (see Figure 4). As the voltage across this capacitance can be high, a significant current can be coupled into the conductors of the cable through the fringing capacitance.

So far we have considered a model of the physical and electrical environment of a shield. Now we need to consider the characteristics of a shield's construction, and how that impacts shield performance.

Surface transfer impedance

To begin with, let's consider a cable grounded at both ends. To see how a cable grounded in that way works, we need to discuss surface transfer impedance. Simply stated, surface transfer impedance relates the voltage developed across circuits inside a shielded cable to currents flowing on the outside of the cable. Thus in Figure 2 with the switch closed, the current I_{shield} on the outside of the shield gives rise to V_1 and V_2 on the conductors inside the shield, via Z_t.

So how do we determine what Z_t is? Well, we can measure it, or we can calculate it. The measurement route has been described in [3], and an example will be shown later. The calculation route is worth discussing because it provides an insight to the physics involved.

We said earlier that the cable shield and the ground plane form a transmission line. We cannot say much about the general case of this, so for simplicity we'll consider a coax with a ground plane wrapped around it, as shown in Figure 5. In this case, the shield and the ground plane form a coax (so we have a coax within a coax, often called a triax). This configuration can be achieved in practice for a jacketed shielded cable by pulling a braid over the jacket; which is often done for measuring Z_t, as explained in [4].

Now let's suppose a current is flowing along the outside of the shield. From Maxwell's equations, this current will generate a travelling wave which has electric and magnetic fields, as illustrated in Figure 6. If the conductors have no resistance, the E-field (E_r) is radial, and the H-field (H_Θ) is circumferential (the TEM mode that some of you may be familiar with). However, since the shield has some resistance, the product of the current flowing on the shield and the shield resistance will generate an E-field E_Z in the Z direction, so that the resultant E-field is no longer radial but "tipped" as shown in Figure 7 (page 38).

Because the shield has a finite resistance, the E_Z field does not vanish in the shield, but has a strongly decaying value as a function of the penetration depth (related to the concept of

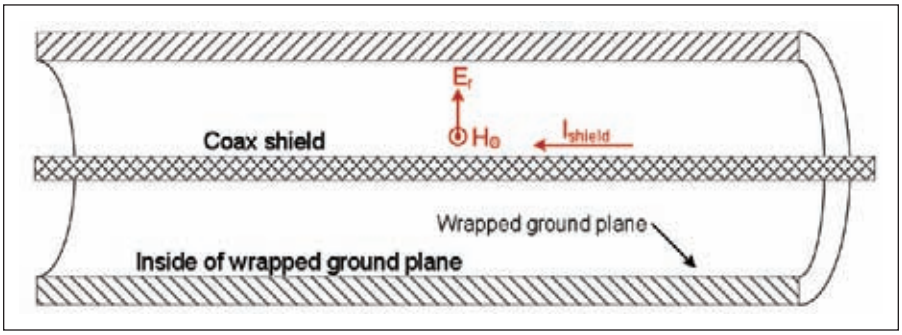

Figure 6: Shows the fields of the travelling wave

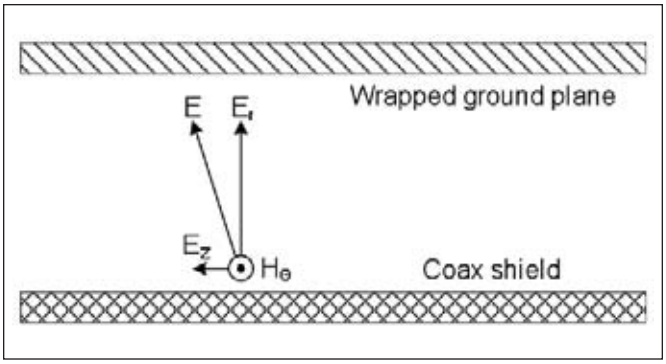

Figure 7: Orientation of the fields for calculating Z_t

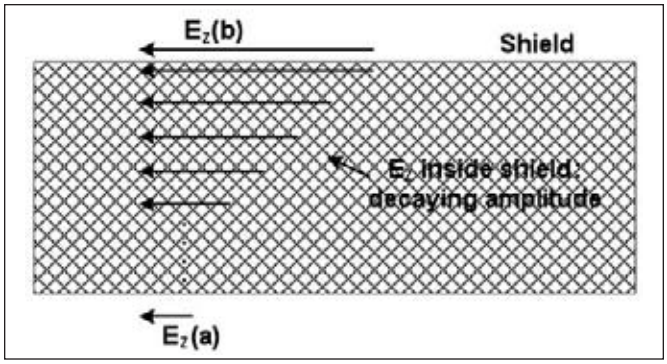

Figure 8: A wave with an $E_z(b)$ component travelling on the outside of a shield, having a decaying component in the shield, reaching $E_z(a)$ inside the shield

"skin depth"), shown schematically in Figure 8. The E_Z wave reaches some (greatly attenuated value) $E_Z(a)$ on the inside of the shield.

From circuit theory, $E_Z(a)$ is related to $E_Z(b)$ by the relations:

$$E_Z(a) = Z_{aa}I_a + Z_tI_b$$

$$E_Z(b) = Z_tI_a + Z_{bb}I_b$$

Where I_a is the current on the inside of the shield, I_b is the current on the outside of the shield, Z_{aa} is the surface impedance of the shield inside, and Z_{bb} is the surface impedance of the shield outside. Z_{aa}, Z_{bb} and Z_t can be calculated from the physical properties of the case, e.g. Schelkunoff [1].

Rearranging the equations on the previous slide, the $E_Z(a)$ field at the inside of the shield can be expressed in terms of the current I_b and voltage $E_Z(b)$ at the outside of the shield as:

$$E_Z(a) = \frac{Z_{aa}}{Z_t}E_Z(b) + \left[\frac{Z_t^2 - Z_{aa}Z_{bb}}{Z_t}\right]I_b$$

Ignoring the terms that are small

$$E_Z(a) = Z_tI_b$$

The calculation route for Z_t: Solid shields

A formula for calculating Z_t was given by Shelkunoff as

$$Z_t = \frac{UR_{DC}}{\sqrt{\cosh U - \cos U}}$$

$$U = 303t\sqrt{\mu_r\sigma_r f}$$

where R_{DC} is the dc resistance of the shield, t is the thickness of the shield in centimeters, μ_r is the permeability of the shield relative to air, σ_r is the conductivity of the shield relative to copper, and f is the frequency in megahertz. Notice that Z_t depends on frequency.

Inside the shield, $E_Z(a)$ drives a, basically, TEM wave (if the conductor resistance is small) that propagates along the conductors. The current I_a caused by the wave that travels inside the shield gives rise to voltages V_1 and V_2 across the terminations of the cable (see Figure 2). The amplitude of the current [and hence V1 and V2] depends on $E_Z(a)$ and Z_t.

To see whether Shelkunoff's formula actually works, we made a measurement on RG402, a solid-shield coax [3]. The results are shown in Figure 9, where the terms short-short and short-matched refer to two different methods of measuring surface transfer impedance. Figure 9 shows that Shelkunoff's formula is a good predictor of surface transfer impedance [and hence shielding effectiveness]. It also shows that, for a solid shield, shielding effectiveness keeps getting better as frequency increases.

The measurement route for Z_t: Cables with braided (wrapped) shields

Braided shields behave differently from solid ones, due to the holes in the shield created during the braiding process. The situation is similar for wrapped shields, which look like slot antennas. The holes or slot couple the fields outside the shield to the fields inside the shield by mutual inductance and capacitance. Surface transfer impedance can be calculated for this case, *e.g.* see [2]. But it's messy, in particular because it is hard to determine what the mutual capacitance and inductance are.

Generally what is done is to produce a sample of the braided or wrapped cable, and then measure its Z_t as a function of frequency (as a measure of shielding effectiveness). As an example, using a method developed to do this [3], we measured the Z_t of RG-58U, a widely used coaxial cable. The

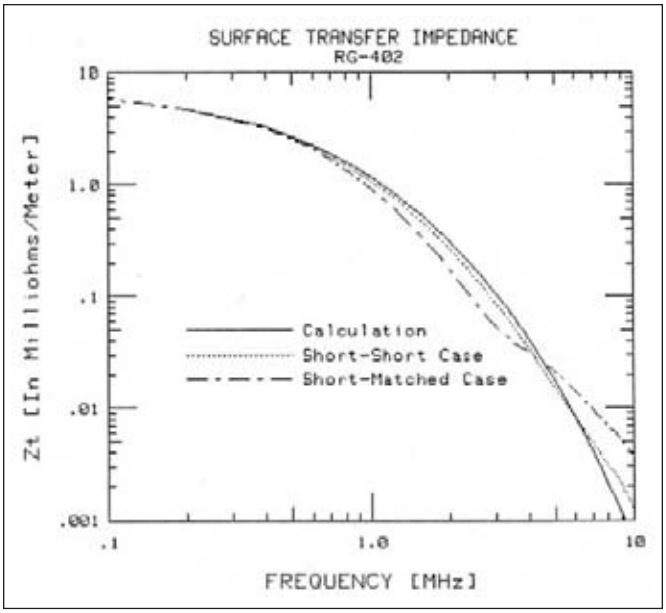

Figure 9: Example of Z_t for a solid shield

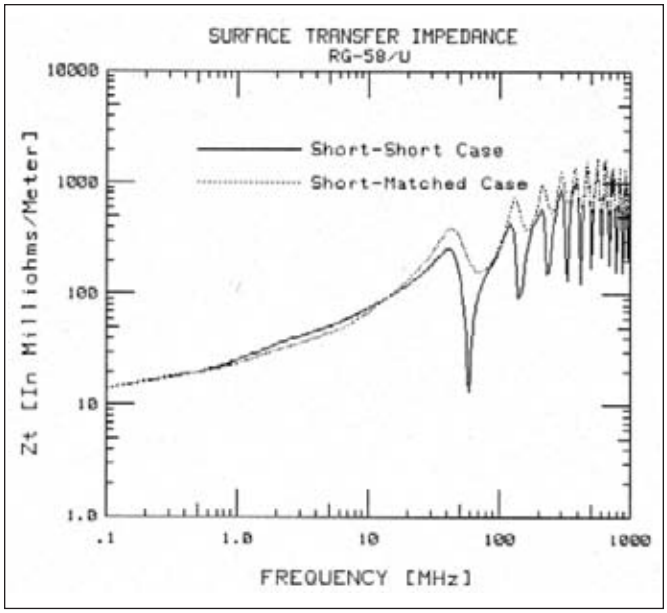

Figure 10: Example of Z_t for a braided shield

result is shown in Figure 10. Notice that, in contrast to solid shields, Z_t for a braided shield increases with frequency, and eventually becomes oscillatory. Wrapped shields in general show the same behavior as braided ones.

An important point, as explained in [5], is that Z_t increases to a first peak value as frequency is increased, and this peak is never exceeded as frequency is further increased. The frequency at which the first peak occurs depends on the length of the cable, and moves to lower frequencies as cable length increases. Indeed Z_t can be plotted against the product of frequency and cable length. For example, a plot like the one in Figure 11 can be generated by fitting a curve to the peak values of the data plotted in Figure 10.

Why this happens is explored further in [5] and [4], where the oscillatory behavior as a function of the length of the cable and frequency is discussed; and also why Z_t reaches a peak value at some frequency, and then decreases as frequency is further increased.

EFFECT OF A SHIELD ON WAVESHAPE

Regardless of how the braided or wrapped cable shield is terminated, it basically acts like a high-pass filter. The result is that a surge travelling on the inner conductors of a shielded cable will have a steeper rise-time than the inducing surge on the outside of the shield. As an illustration, the effect of a shield grounded at both ends on the frequency spectrum of a lightning surge is shown in Figure 12 (page 40). Here the frequency spectrum of a 4.5x77 negative first lightning surge has been multiplied by the Z_t spectrum shown in Figure 11, assuming a 10 m long cable. Figure 12 shows that the low-frequency components of the surge are suppressed. The result is that the surge appearing on the inner conductors of the cable will have a steeper rise time than the surge on the outside of the shield. Note that a similar effect would occur if the shield were grounded at only one end, since the resulting capacitive coupling also suppresses the low-frequency components of the surge.

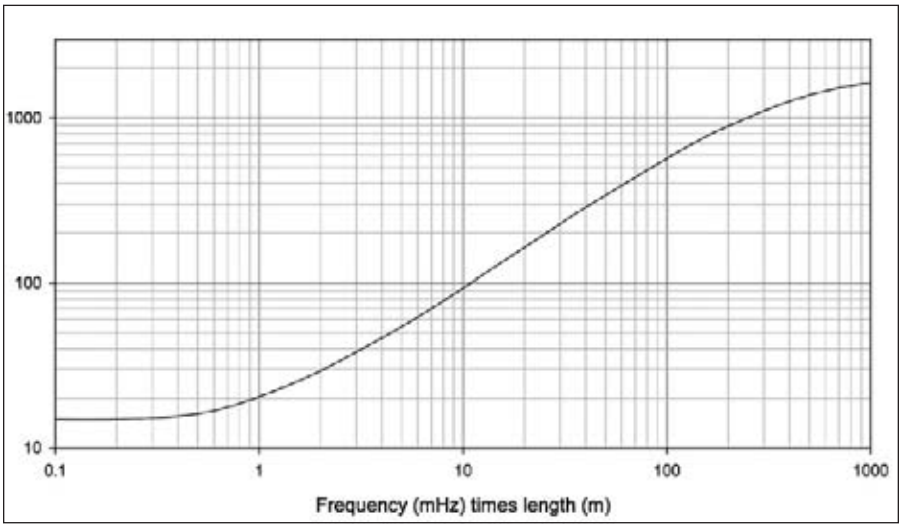

Figure 11: Z_t from Figure 10 plotted as the product of frequency and cable length

THE EFFECT OF SHIELD TERMINATION

Having looked at shielding theory, there is the practical matter of how to terminate the shield. This decision depends on the environment in which the cable is installed.

If a shield is terminated at only one end, a relatively high voltage may exist at the open end of the shield. Because a capacitance exists between the end of the shield and the cable conductors, electrical interference can be injected directly into the cable loads. The magnitude of this capacitance depends a lot on the installation, so it cannot really be calculated. The capacitive coupling is greatest at high frequencies, where the capacitive reactance is the lowest.

The argument has been made [6] that bonding a shield at only one end destroys its effectiveness, and there is some truth to it, especially at high frequencies, as shown in Figure 13 based on data in [7]. The implication of that remark is that a shield should never be bonded at one end only. But the remark was made in the context of saying that a properly designed system does not have ground loops – a condition that may not be achievable in practice.

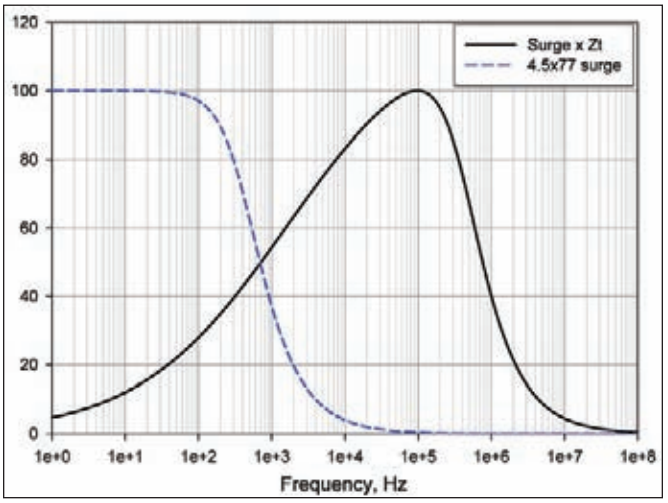

Figure 12: The effect of a 10 m RG-58 coax shield grounded at both ends on a 4.5x77 negative first lightning surge

As a note, the difference between the "no shield" and the "360° at one side" plots in Figure 13 is 18 dB at 1 mHz. Extrapolating this plot to 100 Hz [a pretty risky thin to do] leads to an estimated difference between the two curves of 63 dB. So a shield grounded at only one end may have reasonable performance at audio frequencies, but not at broadcast radio frequencies and higher.

Grounding a shield at both ends eliminates the capacitive coupling problem and is most effective when the potential difference between the two shield terminations is low. In this case, the ground loop currents will be small, and the shield will have its maximum effectiveness, provided it is terminated properly. As pointed out in [6], proper termination is for the shield to be bonded at each end with a 360° termination. Figure 14 shows two examples.

If that is not done, much of the benefit of terminating a shield at both ends may be diminished or lost; for example, as shown in Figure 15 from data in [7]. Note the loss of shielding effectiveness when pigtails are used (see also [8]).

CONCLUSIONS

Back to the original questions: What determines how effective a cable shield is going to be? And how does the decision to ground or not ground a shield impact its effectiveness?

The theory of shielding gives a general understanding of what can be expected of shield performance, but the manner in which the shield is terminated also has a significant impact on the effectiveness of the shield.

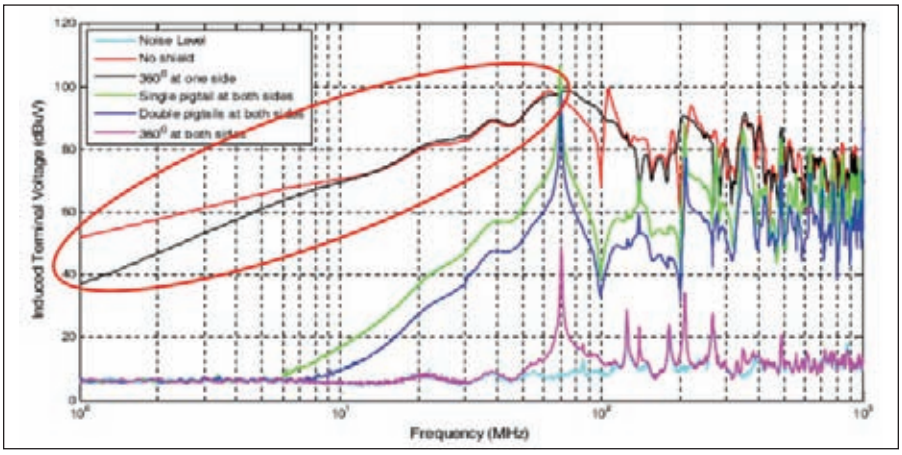

Figure 13: The effect of terminating a shield at only one end

An important factor to consider is whether or not the grounds at opposite ends of the cable are at close to the same potential. If they are, ground-loop currents will be minimal. In this case grounding both ends of the shield is likely to give the best shielding performance. If the grounds are at substantially different potentials, ground-loop currents could be a problem, and in this case leaving one end of the shield unterminated may give the best overall shielding performance, providing that shielding against high frequencies is not an issue.

The decision to terminate or not terminate depends on the application. Unfortunately, there is no rule that applies to all situations, and an experiment is often required to determine the best way to terminate the shield.

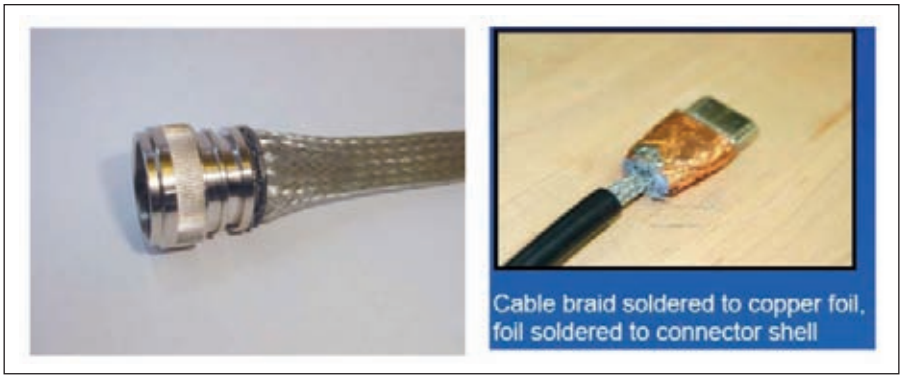

Figure 14: Two examples of 360° shield termination

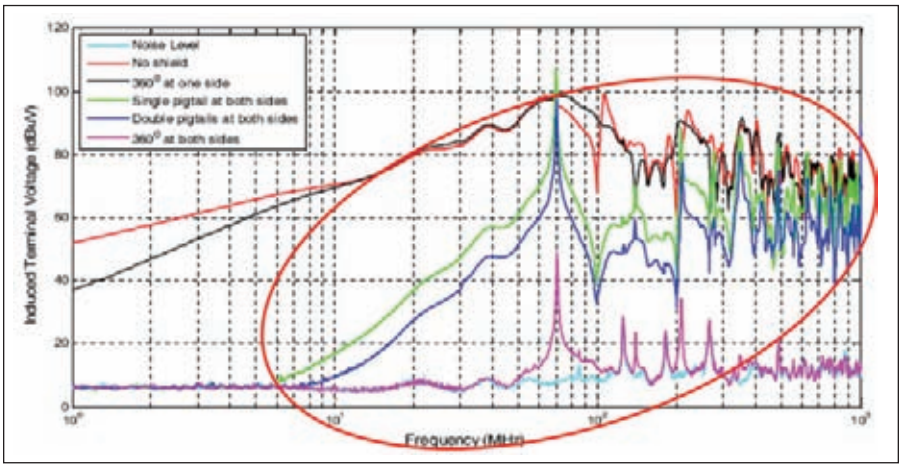

Figure 15: Loss of shielding effectiveness due to terminating the shield with pigtails

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I'm Partial to Partial Inductance!

BY BRUCE ARCHAMBEAULT

It is well known (but often forgotten) that the concept of inductance, without defining a complete loop of current, is *completely meaningless*!

Some books give *inductance* of a length or wire, some people talk about the *inductance* of a via, and still others talk about the *inductance* of ground braids, etc. All these discussions about *inductance* ignore the requirement for a complete loop before the *total* or *loop* inductance can be discussed in any meaningful way.

During our first electrical circuits classes as an undergraduate student in electrical engineering, we learn about the Kirchhoff's loop voltage law. This is a fundamental concept in electrical engineering where we sum the voltages around a loop. Partial inductance is a similar concept where we sum contribution around a loop to get the full answer. Recently, a well known EMC consultant told me that he felt the concept of partial inductance is too complex for the typical EMC engineer. I completely disagree! If someone understands Kirchhoff's voltage law, then the concept of partial inductance only adds a few extra terms.

Partial inductance allows a total loop to be broken into multiple branches. We can easily find the partial inductance of these individual branches based on the conductor dimensions. When assembled onto a closed loop, these branches contribute partial inductance, and the distances between branches contribute partial mutual inductances, and the complete loop inductance can easily be found, even if the various conductor sizes within the loop are different!

PARTIAL INDUCTANCE

The definition of inductance requires a current flowing in a loop. *Without a complete loop, there cannot be inductance.* Practical considerations, however, lead us to discuss the inductance of a part of the overall current loop, such as the (partial) inductance of a capacitor. This idea of discussing the inductance of only a portion of the overall loop is called partial inductance [4]. While the concept of inductance without a complete loop is meaningless, we can *assume* the current through a conductor will find a way to return to its source, even if we are not sure how that will happen initially, allowing us to calculate the partial inductance of that conductor.

Partial inductances can be combined to find the overall loop inductance. For the simple case of a rectangular loop of wire where sides 1 and 3 are parallel to each other and sides 2 and 4 are parallel to each other (see Figure 1), equation (1) can be used to calculate the total inductance from the partial inductances. Note that the partial inductances from each leg of the loop are added, while two

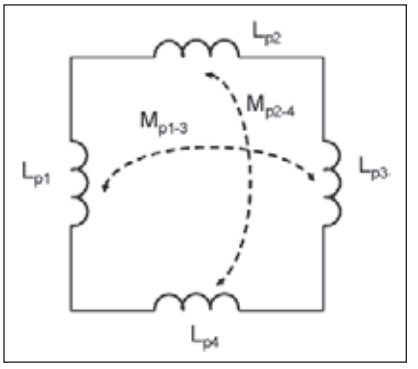

Figure 1: Partial Inductance Components of Simple Rectangular Loop

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times the partial mutual inductances are subtracted to find the total loop inductance.

$$L_{total} = L_{p1} + L_{p2} + L_{p3} + L_{p4} - 2M_{p13} - 2M_{p24} \quad (1)$$

In each portion of the loop we assign a partial inductance value as well as partial mutual inductance between all parts of the loop.[1] If the conductors have different sizes, that is not a problem to calculate the partial inductance values. Naturally, if the current follows a more complex path, additional partial inductances and partial mutual inductances will be needed.

The formulas to calculate the partial inductance and partial mutual inductance look a little messy (see appendix for the full formulas), if we make some simple assumptions that are typical of most cases, then the formulas are much simpler. When the length of the conductor is much longer than the wire radius, the partial inductance for a length of wire is given by (2). When the distance between the conductor is much longer than the conductor length, then the partial mutual inductance between a pair of parallel wires is given in (3).

$$L_p \cong 2 \cdot 10^{-7} \cdot l\left(\ln\frac{2l}{r_w} - 1\right) \quad l >> r_w \quad (2)$$

where

l is the length of the conductor in meters

r_w is the wire radius in meters.

$$M_p \cong 2 \cdot 10^{-7} \cdot l\left(\ln\frac{2l}{d} - 1\right) \quad l >> d \quad (3)$$

where

l is the length of the conductor in meters

d is the distance between wires in meters

USING PARTIAL INDUCTANCE

Examining equation (2), we can see that as the length of the conductor increases, so does the partial inductance associated with that conductor. Figure 2 shows how the partial inductance increases with wire length for a 1mm wire radius (calculated from (2)). Examining equation (3), we see the partial mutual inductance *increases* as distance between the wires *decrease*! Figure 3 shows examples of the partial mutual inductance (calculated from (3)) for 30 cm and 50 cm lengths of wire.

We can use these charts and formulas to help understand the usefulness of partial inductance in helping reduce the total loop inductance. For example, if we take a 50 cm long pair of wires that are closely spaced, we can assume the contribution of the short segments at each end is very small compared to the main length, and so we'll ignore them for this example. If

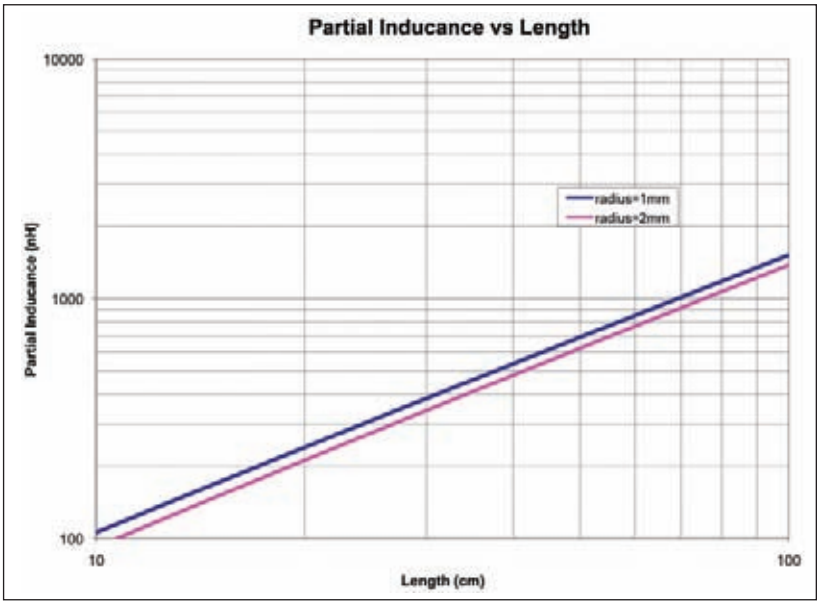


Figure 2: Partial Inductance vs Wire Radius

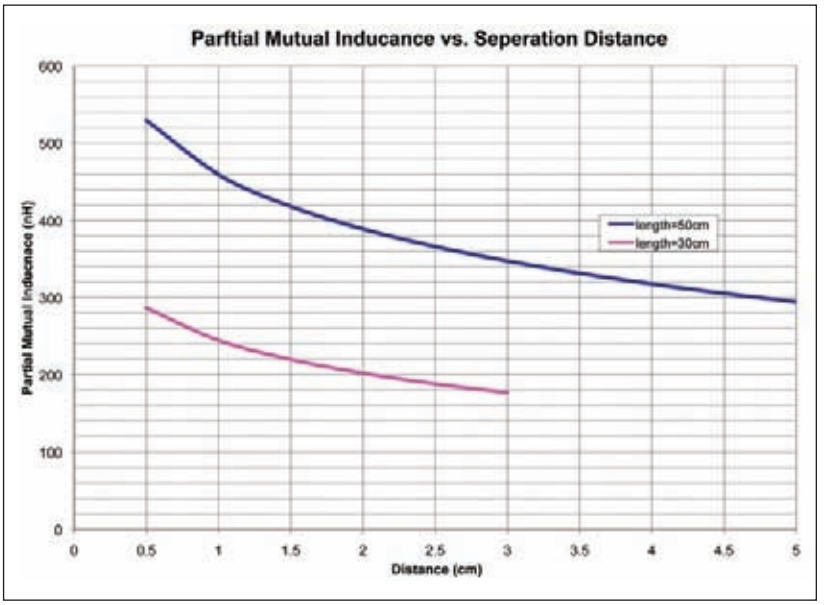
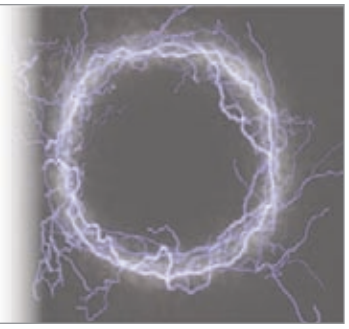


Figure 3: Partial Inductance vs Separation Distance

1. In this case, we only show the partial mutual inductance of the parallel sections, since perfectly perpendicular conductors will not have significant mutual inductance.

The concept of partial inductance is not difficult to understand and use. It is an extremely powerful concept that helps engineers more clearly think about inductance, and the contributions of conductor size and separation.



we start with both wires with a 1 mm radius, and separated by 5 cm, then we have the following:

$$L_{total} = L_{p1} + L_{p2} - 2 \cdot M_{p12} = 690 + 690 - 2 \cdot 294 = 792nH \quad (4)$$

If we increase the conductor radius for one of the wires to 2mm, we get the following:

$$L_{total} = L_{p1} + L_{p2} - 2 \cdot M_{p12} = 690 + 621 - 2 \cdot 294 = 732nH \quad (5)$$

Not a very impressive drop in total inductance after doubling the wire radius! However, if we go back to the initial wire radius, and decrease the separation between the wires to 2.5 cm, we get the following:

$$L_{total} = L_{p1} + L_{p2} - 2 \cdot M_{p12} = 690 + 690 - 2 \cdot 366 = 648nH \quad (6)$$

It should be no surprise that making the separation between the wires smaller, therefore reducing the loop area, had a more significant impact on the total inductance than dramatically increasing the wire radius. Partial inductance can be used to identify the impact of changing a portion of the overall current loop, thus allowing designers to have the greatest success in lowering total inductance.

APPENDIX

Full Formulas for Partial Inductance and Partial Mutual Inductance

$$L_{pi} = \frac{\mu_0}{2\pi} l \left[\log\left(\frac{l}{r} + \sqrt{\left(\frac{l}{r}\right)^2 + 1} \right) + \frac{r}{l} - \sqrt{\left(\frac{r}{l}\right)^2 + 1} \right]$$

(A1)

$$M_{P_{ij}} = \frac{\mu_0}{2\pi} l \left[\log\left(\frac{l}{d} + \sqrt{\left(\frac{l}{d}\right)^2 + 1} \right) + \frac{d}{l} - \sqrt{\left(\frac{d}{l}\right)^2 + 1} \right]$$

(A2)

where

l = length of wire (m)
r = radius of wire (m)
d = distance between parallel wires (m)

SUMMARY

The concept of partial inductance is not difficult to understand and use. It is an extremely powerful concept that helps engineers more clearly think about inductance, and the contributions of conductor size and separation. When the overall loop is more complex than the simple example shown here, partial inductance can be used to find the contributions of all the various portions of the loop. When very complex, a computer program is often needed to calculate the partial inductance components, but the concept of partial inductance remains quite simple and yet very powerful!

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Complying With the EU's EMC Directive Without 3rd Party Testing

BY KEITH ARMSTRONG

A common path to achieving compliance to the European Union's (EU's) EMC Directive 2004/108/EC (which I shall call the EMCD here) takes many manufacturers down the route of utilizing a third-party EMC test laboratory to obtain EMC test reports for their products. This process was detailed in the article "Heading for the EU? Get Your Compliance Passport Ready[1]" appearing in the May 2013 issue of *In Compliance*.

However, it is important to understand that the EMCD *contains no legal requirements for performing any EMC laboratory tests*.

This was also true of the original EMCD, 89/336/EEC, and will also be true for compliance with the future EMCD, 2014-30-EC, which replaces the current EMCD on 20 April 2016 (more on this below).

Manufacturers are required to affix the CE marking to their products, and to do that they must first have created and signed an EU EMC Declaration of Conformity (DoC) which is based on the evidence of EMCD compliance contained within a Technical Documentation File (TDF).

As I will show later, there are two routes to declaring EMC compliance (sometimes called conformity to the EMCD), and it is the manufacturer's choice whether his DoC relies entirely on all relevant harmonized standards (the *Standards Route*), or uses just a few or none of the relevant harmonized standards (the *EMC Assessment Route*).

Even when following the Standards Route, the DoC is effectively a legal statement by a manufacturer that: "***if my product was tested to these harmonized standards, it would probably pass.***"

How a manufacturer obtains sufficient confidence to make this legal declaration ***is entirely up to that manufacturer,*** and should be documented (amongst other things) in the TDF.

Compliance with the EMCD certainly does not require any test reports from third-party EMC test labs. This is what makes it possible for many manufacturers of electronic products around the world to save time and money by testing in their own EMC labs.

This also makes it possible for individual entrepreneurs, who might be working out of their garages (like Mr Hewlett and Mr Packard did when they first started)[3] to sell their products in the EU without the high costs associated with EMC testing to standards.

In fact, the same is true for most of the so-called CE Marking Directives – third-party testing is only a legal requirement in a very few EU Directives, and only then when dealing with especially dangerous products, e.g.

certain kinds of medical equipment; especially dangerous machinery such as chainsaws, bandsaws, etc.

I have often heard the EU's single market described in the USA as *Fortress Europe* – when the *exact opposite* has always been true: the EU's single market does not present any significant barriers of cost or delay to any equipment from anyone, anywhere.

OK, that's enough background. Let's get into the details!

To see how it is that manufacturers can comply with the EMCD without third -party testing, even without any testing at all, we need to understand how the EMCD works.

When we understand this, we will also understand that even passing third -party laboratory tests to all relevant EU harmonized EMC standards might not, on its own, ensure compliance with the EMCD.

APPLYING THE EMC DIRECTIVE

The EMCD[2] applies to both *apparatus* and *fixed installations*, with special legal meanings for both of these otherwise commonplace terms. Figure 1 shows that apparatus is treated very differently from fixed installations.

Apparatus is any electrical/electronic item that could cause or suffer EMI, *and* which is "made available for an end-user in the EU" for the first time (see later). It is important to understand that the EMCD applies to every individual item (e.g. individual serial numbers) – Chapter 2.2 in [4] and Chapters 1.2 and 3.2.2 in [5] provide much more detail on this.

The EMCD also has a special category of apparatus "… intended for incorporation into a given fixed installation, and not otherwise commercially available" (which most of us would call *custom*, *bespoke*, or *one-off* equipment) which can avoid having to be CE marked for EMC, although it then has to comply with other EMC activities.

EMC Benign equipment is excluded from the EMCD's scope, and the official guide [5] contains a list of what is currently considered to be EMC Benign. As a general rule, EMC Benign equipment never contains any operational semiconductors (rectifiers, transistors, ICs, etc.) or thermionic valves, or makes sparks.

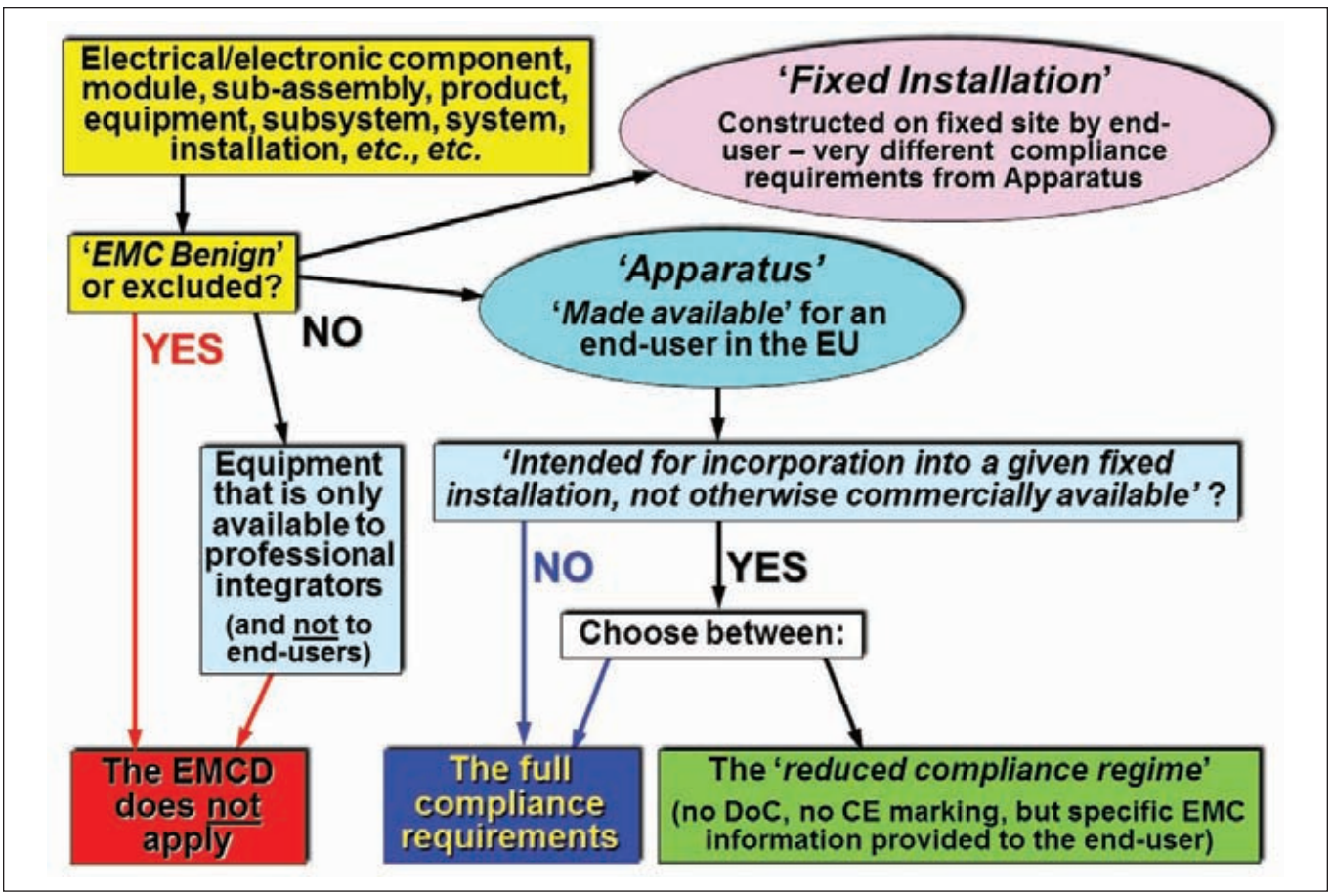

Figure 1: Applying the EMC Directive

Equipment that is only made available for the exclusive use of professional integrators in the construction of their own products, and which is not made available for end-users (even by distribution) is also excluded from the scope of the EMCD.

However, such equipment will almost certainly have to be CE marked for compliance with an EU safety directive, such as the Low Voltage Equipment Directive [6], Machinery Directive [7], etc. This is one reason why a manufacturer should never assume EMC compliance when purchasing a CE-marked third-party product for incorporation into another product, system or installation.

I have seen many large projects suffer greatly from major contractors making two big errors regarding EMC:

i. Mistakenly assuming that every item of equipment that carries a CE marking must perforce comply with the EMCD. This article describes three ways in which this assumption can be wrong, all of which are shown in Figure 1:
   a. When the equipment is *EMC Benign*
   b. When the equipment is only supplied to professional integrators, whether it is manufactured in volume or custom-designed (e.g. as a subcontract)
   c. When the equipment is custom-made for a particular end-user's Fixed Installation
ii. Mistakenly assuming that an EMC compliant final system merely needs EMC compliance for its constituent parts, often called the CE + CE = CE approach (see later).

Also exempt from the EMCD is radio amateur equipment that is not commercially available; aeronautical equipment covered by Regulation 1592/2002, and equipment covered by the R&TTE Directive (1999/5/EC).

The new Radio Equipment Directive 2014/53/EU will replace the R&TTE Directive from June 12, 2016, at which time some of the equipment that used to be covered by R&TTE will instead come under the EMCD [2] and the LVD [6].

Equipment that has EMC aspects addressed in specific product Directives (e.g. medical devices, automotive, etc.) is only exempt from the EMCD to the extent covered by those other Directives. Unfortunately, this is widely misunderstood to mean they are totally exempt from the EMCD.

Apparatus that must comply with the EMCD when made available for an end-user in the EU may be advertised or exhibited before it is EMC compliant – as long as it is clearly marked as being non-compliant with the EMCD, and as not (yet) being available to end-users in the EU.

EMC CONFORMITY OF APPARATUS

The EMCD requires all apparatus to:

i. Comply with the Protection Requirements
ii. Undergo a conformity assessment procedure
iii. Have a TDF prepared and readily available for inspection by enforcement officials
iv. Be supplied with specified User Information
v. Have a signed EC DoC
vi. Carry the CE marking

Items i - v in the above list must be complete before the CE marking is applied (item vi).

All of the items i - vi must be complete before the apparatus is made available for the first time to an end-user in the EU (see 2.2 in [4]).

It is important to note that being made available to an end-user for the first time in the EU, does not only mean new products. Used or second-hand products that are brought into the EU are *also made available for the first time in the EU*, and so have to comply with the EMCD no matter how old or how large they are.

As already mentioned, the only exclusion to full compliance with the EMCD is for apparatus intended for incorporation into a given fixed installation, and not otherwise commercially available (see later).

THE PROTECTION REQUIREMENTS

The Protection Requirements (Clause 1 of Annex I in [2]) state the essential legal requirements for compliance with the EMCD, using simple terminology in the hope (probably a vain one) that this will make it difficult for lawyers to interpret them in ways other than what was intended:

> "a shall be so designed and manufactured, having regard to the state of the art, as to ensure that:
>
> (a) The electromagnetic disturbance generated does not exceed the level above which radio and telecommunication equipment or other equipment cannot operate as intended;
>
> (b) It has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use."

Who would ever want their products not to comply with these Protection Requirements? The costs of dealing with the resulting complaints (and the loss of possible future sales) would eat into the financial bottom line, making a manufacturer less profitable.

So even if there was no EMCD, the Protection Requirements above should still be applied to help reduce financial risks.

CONFORMITY ASSESSMENT IN GENERAL

Conformity assessment is specified in Annex II of [2], and requires an EMC Assessment that results in a TDF that demonstrates how it is that a product can claim compliance with the Protection Requirements. The TDF should cover *all* operational modes and *all* intended use configurations, and (as described in [1]) the amount of verification work required can be reduced by identifying the *worst case* combinations of configuration and operational mode – i.e. the ones that would cause the highest emissions or are the most susceptible to interference. See 3.2.1 in [5] for more information.

As I said earlier, there are two routes to conformity with the EMCD:

i. The *Standards Route*, which uses harmonized EMC standards – see 3.2.2 in [5]
ii. The *EMC Assessment Route*, which can use any standards or none – see 3.2.3 in [5]

CONFORMITY ASSESSMENT BY USING HARMONIZED STANDARDS

When following this Standards Route, the product's DoC must list all of the relevant harmonized EMC test standards that apply to the product, which can be found in the official listing website at [8].

This route to EMC conformity requires that all these harmonized standards are *correctly applied* – but what does *correctly applied* actually mean?

Clearly, one way is to have a third-party test lab perform all of the tests exactly as described in the relevant standards, with the EMC test reports forming the bulk of the TDF. If the test lab is accredited by a national accreditation body to perform a particular test, there is more confidence that the test will be done correctly. Unfortunately my experience (and that of

many others) is that not all national accreditation bodies are equal.

Third-party testing has been very well described in [1], so I don't need to go into it here.

Some manufacturers (and not only the larger ones) have their own full-compliance EMC test labs, and some of them even have some/all of their tests accredited. These labs are generally best used just as if they were third-party labs, as described in [1].

(Interestingly, in-house test labs located in the same building as the design teams can pay back their original investment much more quickly than the usual business case predicts – I have seen one such lab payback in four months!)

However, as stated early on in this article, using the services of a third-party accredited test lab to *correctly apply* a harmonized standard to test exactly to the standard is not the only option when following the Standards Route.

The correct application of a harmonized standard, actually means that a manufacturer has done enough homework to have sufficient confidence that *if the product was fully tested in an EMC laboratory that was accredited to test to that standard – it would pass.*

Let's be perfectly clear on this: *correct application* does not mean that the product has actually been tested to that standard, only that – *if* it was tested at some future time – it would pass.

The EMCD leaves manufacturers totally free to decide on the amount and quality of EMC testing they do themselves, or have done for them, to have sufficient confidence to sign their DoC when using the Standards Route.

(It is important to understand that there are no absolute guarantees in the world of EMC – even with fully-accredited third-party testing, a product that passes in one test lab can fail when tested in another lab, even though nothing has changed in the product and the exact same cables are used with it. Some manufacturers take advantage of this by always using test labs that they find are more likely to give them a pass result!)

Here are four examples of when laboratory testing might not be required to correctly apply a harmonized radiated emissions standard such as EN 55022:

i. When the product emits a certain amount of RF power spread in a particular way over a particular frequency spectrum, and calculations/simulations show that if this emitted power was measured according to the relevant EMC test standard, it would be almost certain to pass (even when taking measurement uncertainty into account). For examples of this approach, see [9] [10] and [11].

ii. When the product is housed in a well-shielded and well-filtered enclosure that has been proven by shielding effectiveness testing and/or simulation to provide more than sufficient RF attenuation to ensure that if its emitted RF power was measured according to the relevant EMC test standard, it is certain to pass (even when taking measurement uncertainty into account).

    Many manufacturers purchase well-shielded/filtered overall enclosures, then ruin them with modifications, completely wasting their high cost, see Chapter 5 of [12]. So an expert assessment is usually required to have sufficient confidence in the final assembly.

iii. When a product fails in a test lab and a simple modification applied by hand makes it pass, and the same modification is applied on production units, there can be sufficient confidence that if a new production sample was retested, it would pass.

    In this context, 'the same modification' means physically and dimensionally the same – for example an additional shield bond made with a screw-fixing is not the same for EMC as an additional bond made in a different place, or made in the same place with a braid strap or piece of green/yellow wire instead of a screw.

iv. When a product has passed an equivalent or tougher radiated emissions test and has not been changed (either in its hardware, software, or components). A typical example is a product that has passed MIL STD 461 radiated emissions tests which set lower emissions limits than the relevant harmonized test standard, see [13].

Chapter 3.2.2 of [5] provides very good guidance on the Standards Route, and states that where a product follows this route there is no legal requirement in the EMCD to perform the EMC Assessment process outlined below.

Unfortunately, even when full testing is done in a lab that is accredited for that test, and passed, it might not ensure compliance with the Protection Requirements in real-life operation, which is, of course, what really matters for compliance with the EMCD – and also (more importantly) for financial success.

This is because no harmonized test standards cover all of the EM disturbances that could occur in real life. Also, it is because the tests have been specifically developed to ensure repeatability in testing, which can often mean they are simply not representative of real-life EM disturbances.

Also – given the inevitably slow pace of international standardization – all published standards are behind the times. For example: none of the harmonized immunity standards cover the very close proximity of cellphones, e-book readers, Wi-Fi transmitters, RFID transmitters (including active RFID tags), etc., even though such proximity is now a normal "…electromagnetic disturbance to be expected in its intended use…".

Immunity to the *near-fields* (see [14]) that can be created by portable RF transmitters in very close proximity is arguably now a necessity for legal compliance with the Protection Requirements, even though not tested by any harmonized standards.

"Big deal", you might say, "but I don't want to spend any more on legal compliance than I have to!" OK, but think for a minute about what I said earlier in the section on Protection Requirements – if products don't comply with them they are less likely to be financially successful. If they have big problems with EMC in real life, they could even do irreparable damage to a manufacturer's brand image and future profitability. Some companies have actually been bankrupted by real-life EMC problems.

The real reason we need to achieve EMC compliance, is to have products that work well enough in real life and don't upset customers. Achieving this is important to help control financial risks, and so what if we have to produce a few pages of legal documentation for EU sales, when it merely covers EMC work we have already done?

For these reasons, when following the Standards Route, in addition to correctly applying all relevant harmonized standards, I always recommend performing a full EMC Assessment as below, then doing *whatever else it takes* to ensure conformity to the Protection Requirements. This can sometimes be as quick and easy as a check for emissions or immunity using a close-field probe [15].

Note: When following the Standards Route, the DoC should not state that the listed harmonized standards have been tested and/or passed (unless they have been, of course!). Generally, it is better for the DoC to say something like: "The following standards have been applied."

CONFORMITY ASSESSMENT BY *NOT USING* HARMONIZED STANDARDS

This is the other route to EMC conformity permitted by the EMCD – the *EMC Assessment Route*.

When following the EMC Assessment Route, a manufacturer declares the EMC conformity of his apparatus directly to the EMCD's Protection Requirements, using just some of the relevant harmonized standards, or just some parts of some harmonized standards, or even ignoring all harmonized standards completely.

The EMC Assessment Route must follow a specified technical methodology to ensure that the Protection Requirements are met.

According to 3.2.3 in [5], the EMC Assessment Route is usually more appropriate than the Standards Route in the following situations:

- Where the Protection Requirements are not entirely covered by the application of the harmonized standards that are relevant for the product
- The apparatus uses technologies incompatible with, or not yet taken into account by, any harmonized standards
- The manufacturer uses test facilities not yet covered by harmonized standards
- The manufacturer prefers to apply other standards or specifications (even in-house specifications) that are not harmonized under the EMC Directive
- The apparatus is physically too large to be tested in the facility specified by a relevant harmonized standard, or where 'in-situ' testing is necessary (e.g. for systems or installations that are first assembled on the end-user's site) and is not adequately covered by a harmonized standard

Of course, a manufacturer may choose to follow the EMC Assessment Route simply to save time and money – which is often the case for start-up companies who cannot afford the cost of laboratory testing.

This alternative conformity route is essentially the old Technical Construction File (TCF) route under the first EMC Directive (89/336/EEC) – but with the significant difference that now there is no legal requirement for any TDFs to be assessed by a third-party (see Notified Bodies, later).

Non-harmonized methods of demonstrating conformity with the Protection Requirements, that may be able to be used, either singly or in suitable combinations, as part of an EMC Assessment Route include (but are not limited to):

i. Non-EU-harmonized but published EMC test standards (e.g., FCC, military, automotive, etc.)
ii. In-Situ / On-Site EMC tests [16]
iii. EMC tests or checks developed by the manufacturer that are not compliant with the harmonized test methods listed in [8]. These are often called 'pre-compliance' EMC tests and can vary from full-compliance tests that are just done a little more quickly than they should be, to close-field probing and a variety of other low-cost methods e.g. those described in [15], which might bear little resemblance to harmonized tests.
iv. Calculations (e.g. [9] [10] [11])
v. Validated computer simulations
vi. Comparisons with known EMCD-compliant products made by the same manufacturer, which use the same technologies, devices and construction methods (but beware – hardware and software technologies, and devices, change very rapidly – and so do their EMC characteristics!)

The EMC Assessment Route's technical methodology includes (but is not limited to)—

a. Assessing the EM environment(s) normally expected at the user(s) location(s), taking into account (see [17]):
   - The likely proximity to sensitive equipment that the product's emissions could interfere with;
   - The likely EM threats that could interfere with the product, plus the degradation of functional performance that the user will accept when it is interfered with.

b. Create the EMC specifications for the product. To help make life easier, these often use modified versions of harmonized standards, basic IEC test methods (see [1]), other EMC standards (automotive, military, aerospace, etc.), and/or guidance for systems and installations such as [12] [18] [19] or some of the many references they contain.

c. Verify and/or validate the product's design against the EMC specifications. Verification and validation techniques include – but are not limited to – EMC testing.

THE 3RD EDITION OF THE EMCD, 2014-30-EC, APPLIES FROM 20 APRIL 2016

All of the technical compliance issues discussed in this article, and in [1], are unaffected by the third edition of the EMCD [20]. Its changes are more to do with adapting the existing EMCD to the EU's New Legislative Framework (NLF, see Chapter 1.2 of [4]).

The changes wrought by the NLF are mostly concerned with extending legal compliance requirements to all *economic operators* through whose hands EMCD-compliant products pass, including: the manufacturer of the products (obviously), appointed agents, distributors, importers, etc.

CE + CE DOES NOT EQUAL CE

Constructing systems only from items that are CE-marked, and *mistakenly* assuming that *this alone* takes care of the EMC compliance of the overall system or installation, is often called the CE + CE = CE approach. Which simply doesn't work!

This incorrect approach is very widely used by system integrators, installers, and major contractors. However, it is easy to show that, technically and/or legally, this approach should never be relied upon, and Chapter 1.2.2 in the official guide [5] contains a specific warning against using it. More detailed information on this is given in Chapter 1.5 of [12], Chapter 2.3.4 of [18] and Chapter 2.3.3 of [19].

Note that the CE + CE = CE approach is also incorrect technically and/or legally for most, if not all other EU Directives, including [6] and [7].

CONCLUSIONS AND MORE INFORMATION

There's a great deal more I could write on complying with the EMCD, but I've covered the main issue of how to comply without using laboratory testing, and wandered off into some related issues as well.

To find out more about related issues, here are some excellent sources of free information:

- Employing Notified Bodies – see Chapter 6 of [5], [1] and [21]
- Creating and maintaining the TDF (Technical Documentation File) – see Chapter 3.3 of [5], [1] and [21]
- The EU EMC DoC (Declaration of Conformity) – see Chapter 3.3 of [5], [1] and [21]
- Correctly affixing the CE Marking – see Chapter 3.4 of [5] and [21]
- The EMC information legally required to be provided with each apparatus – see Chapter 3.4.4 of [5] and [21]
- Maintaining EMC compliance in serial or batch manufacture – see [21]

- Maintaining EMC compliance when the harmonized standards change – see Chapter 3.2.2 of [5], [1] and [21]
- EMC compliance of custom-designed 'apparatus intended for incorporation into a given fixed installation, and not otherwise commercially available' – see Chapter 2.5 of [18]
- EMC compliance of 'Fixed Installations' – see [18]
- Market Surveillance of EMC compliance by EU Member States – see Chapter 7 of [4]
- Compliance of used or second-hand apparatus – see Chapters 2.1, 2.4, 3.1 and 4.5.1.6 of [4]

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Magazine started, and unfortunately its archives are no longer available on-line. However, the author will be pleased to email anyone a copy of the revised version as published.

The above URLs are correct at the time of writing, however IT people regularly change their websites and break such links, in which case a good search engine, primed with the title and/or author and/or publication should find the document.

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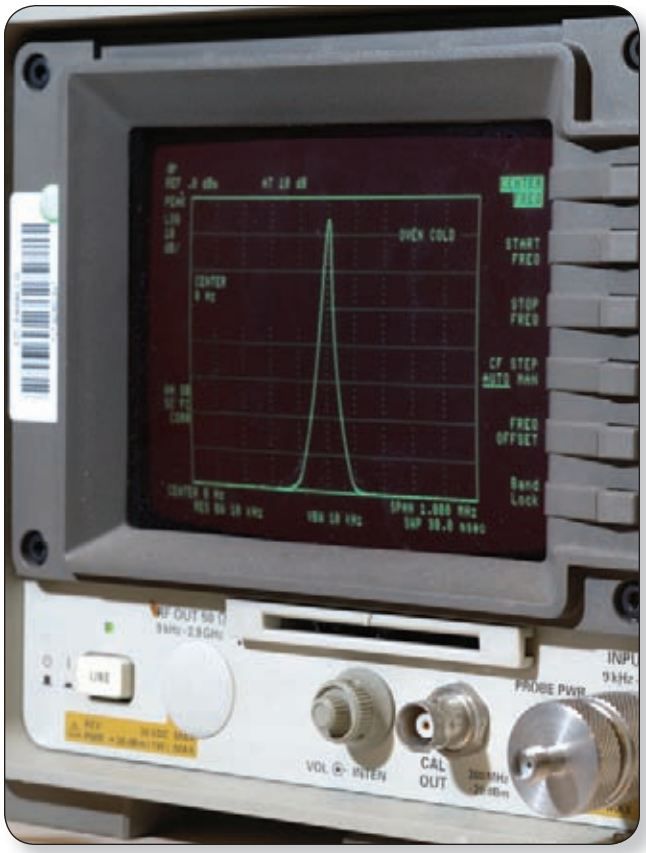
Keith's field-proven approach applies good EMC engineering techniques at every level of design to achieve: savings in design/development costs and timescales; quicker time to market; improved functional specifications with lower overall-cost-of-manufacture; greater reliability and reduced warranty costs. (Plus easy and quick compliance with EMC regulations, of course!)

Importance of Traceability in EMI Measurements

BY WERNER SCHAEFER



The recognition of the importance of measurement traceability significantly increased over the last 20 years, especially as part of the test and calibration laboratory accreditation programs that were established worldwide. The generally accepted quality system standard ISO/IEC 17025-2005 includes a set of requirements addressing the subject of traceability of measurement results. These requirements do also apply to EMC test laboratories. This article will introduce the concept of traceability, discuss the role an EMC test laboratory must assume to ensure traceability of test results and will introduce a future amendment to CISPR 16-1-1 which describes the requirements for calibration of EMI receivers and spectrum analyzers.

The definition of traceability that is globally accepted in the metrology community is included in the International Vocabulary of Metrology - Basic and general concepts and associated terms: "…property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty."

Traceability means that the result of a measurement, no matter where it was made, can be related to a national or international measurement standard, and that this relationship is documented. In addition, the measuring instrument must be calibrated by a measurement standard that is itself traceable. Traceability is thus defined as the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international, through an unbroken chain of comparisons all having stated uncertainties. It is essential to note that traceability is the property of the result of a measurement, not of an instrument or calibration report or a laboratory. It is not achieved by following a particular procedure or using special equipment.

The concept of traceability is important because it allows the comparison of the accuracy of measurements worldwide according to a standardized procedure for estimating measurement uncertainty.

Within a chain of traceability, the units of measurement with the highest accuracy are realized by international measurement standards. The value of the international standard is usually determined by comparison of national standards of the highest quality (or in the case of the kilogram by the mass of the International Prototype). National measurement standards, maintained in a national metrology institute or NMI (for example, NPL in the UK, NIST in the USA) must be compared with these international standards. The result of such comparisons, together with the precision and uncertainty of the national standard will be stated and will be available on, for example, the internet (see the BIPM

key comparison database at www.bipm.org/kcdb/). Then the national measurement standard serves as a reference for calibration of standards of lower precision. Reference standards are kept in a national metrology institute or in an accredited calibration laboratory for calibrations not requiring the highest accuracy. Again, the result and the uncertainty will be stated.

At each stage in such a chain of traceability, one loses a certain degree of precision. Thus the highest level standards are the international standards, known with the greatest level of precision, and the lower level standards will have been determined to a lower level of precision. This lower level of precision will be one which is acceptable or appropriate for the use of that particular standard.

For an EMC test laboratory to achieve traceability it is essential to use measuring equipment that is calibrated in a traceable manner and also meets the specifications called out in CISPR 16-1-1 to ensure that the expected measurement instrumentation uncertainty for conducted and radiated disturbance measurements or disturbance power measurements can be achieved. Since the EMC test laboratory is responsible for the selection and use of adequate measuring equipment, as well as the purchase of appropriate (meaning accredited or otherwise deemed suitable) calibration services to ensure traceability of test results, a clear understanding of the calibration requirements is essential. The determination of the necessary specifics of a calibration service in the purchasing process and the review of the obtained calibration service upon receipt of the equipment back from the calibration laboratory before it is placed back into service at the test laboratory are major tasks the test laboratory must complete in order to ensure the proper calibration of test equipment. The importance of test equipment calibration and traceability aspects was also acknowledged by CISPR subcommittee A which is in preparation of normative Annex to CISPR 16-1-1, defining calibration requirements for measuring receivers.

ROLE AND RESPONSIBILITIES OF THE EMC TEST LABORATORY

An accredited EMC test laboratory is required to specify the details of a calibration service to be purchased (technical and/or administrative aspects) to the calibration laboratory to ensure that a suitable calibration service is provided and the equipment is calibrated for the actual application. This

information can be included on a purchase order, be provided as a separate document as an attachment to a purchase order, be included in a general contract with a calibration laboratory or can be communicated in any other way. The following aspects must be considered when purchasing a calibration service:

- If a calibration standard is available for the calibration of a specific piece of test equipment like for a measuring receiver (i.e., CISPR 16-1-1) or for antennas (e.g., ANSI C63.5 or the future CISPR 16-1-6) the specification of the applicable standard must be included in the calibration request. In case the applicable standard does include multiple calibration methods (e.g., ANSI C63.5 or the future CISPR 16-1-6) the method to be used is to be included in the request as well.
- If no standard is available to calibrate a piece of test equipment like for spectrum analyzers or signal generators the EMC test laboratory should request the use of the equipment manufacturer's calibration process to ensure that compliance of the equipment under calibration with its specifications can be determined without ambiguity. It is essential to know for an EMC test laboratory that equipment still meets its specifications upon arrival at the calibration laboratory.
- Technical details like the required frequency range or amplitude range, if necessary, are to be specified if equipment is used in a limited fashion. For example, a spectrum analyzer is only used in a frequency range narrower than the capability of the instrument (e.g., the instrument covers the frequency range up to 26 GHz but the laboratory performs emission measurements under its scope of accreditation to 6 GHz only).
- The requirement for an accredited calibration envelopes all calibration parameters of the equipment to be calibrated under the scope of accreditation of the calibration laboratory. This is essential to ensure proper traceability of EMC measurement results.
- The test laboratory should also request the inclusion of the accreditation body's symbol on the calibration certificate for easy identification that an accredited calibration was performed.

When a measuring receiver is to be calibrated for the sole purpose of performing emission measurements, the EMC test laboratory has two choices: Either verification per CISPR 16-1-1 can be requested or a full calibration in accordance with the manufacturer's calibration procedure can be ordered. A calibration laboratory will perform the verification of the instrument by performing the measurements specified in CISPR 16-1-1. Parameters to be verified are summarized in Table 1 below, per identified sections in CISPR 16-1-1. If these measurements are performed under the calibration laboratory's scope of accreditation the EMC test laboratory will have a measuring receiver available for measuring emissions in a traceable manner. It is to be noted though that such a verification in accordance with CISPR 16-1-1 does not envelope all calibration parameters of a measuring receiver. For example, frequency accuracy, frequency stability, or displayed average noise level are not part of the CISPR 16-1-1 verification process. Therefore, if this instrument is also to be used for other purposes like measurements on intentional radiators (e.g., licensed or unlicensed transmitters) this verification will be insufficient and a complete calibration of the instrument in accordance with the manufacturer's calibration process is required. Compliance with the specifications of an instrument can only be determined if the manufacturer's calibration process is applied during the calibration process.

EMC test laboratories are also responsible for the selection of adequate calibration laboratories. Many accreditation bodies have established policies that define requirements related to the traceability of measurement results which very often call out the requirement for use of accredited calibration laboratories. It is to be noted that this requirement

Parameter	Subclause in CISPR 16-1-1	Suggested Frequencies
VSWR	4.2, 5.2, 6.2, 7.2	VSWR to be determined for 0 dB and ≥ 10 dB input attenuation at the following tuning frequencies: 100 kHz, 15 MHz, 475 MHz and 8,5 GHz
Sine wave voltage accuracy	4.3, 5.4, 6.4, 7.4	Verification at the following tuning frequencies: start frequency, stop frequency and center frequency of CISPR Bands A/B/C and D/E
Response to pulses	4.4, 5.5, 6.5, 7.5	Verification at the following tuning frequencies: start frequency, stop frequency and center frequency of CISPR Bands A/B/C and D/E
Selectivity	4.5, 5.6, 6.6, 7.6	Verification at the following tuning frequencies: center frequency of CISPR Bands A/B/C and D/E

Table 1: Verification parameter summary

is not included in ISO 17025-2005 but established by the accreditation bodies. Use of accredited calibration service providers is the easiest way to ensure traceability for a test laboratory. Today, almost all equipment used by an EMC test laboratory can be calibrated by an accredited calibration laboratory, assuming a suitable scope of accreditation. When selecting a calibration service provider the review of the scope of accreditation of a prospect calibration laboratory is an important step in the evaluation process. EMC laboratories must maintain records of such evaluations per ISO 17025-2005, clause 4.6.4.

Upon return of calibrated equipment from the calibration laboratory the EMC test laboratory must perform an incoming inspection of the received equipment before it is put back into service. This step is essential to avoid the use of equipment for testing work which may be improperly calibrated or may have ambiguous or unclear documentation. Only after a thorough review of the equipment should it be made available for measurements in the EMC test laboratory to avoid possible non-conforming work scenarios that could cause additional investigative work or even retests.

The incoming inspection of equipment received back from a calibration laboratory should address the following items, as applicable:

- Identification: The serial number, unique identification number (if used) and the calibration date/due date (if requested by the EMC test laboratory) on the certificate must match the information on the calibration sticker affixed to the equipment.
- Accuracy: The values provided on the certificate/report must be adequate for the intended use of the equipment.
- Traceability: The information which establishes traceability to national/international standards is to be verified. The presence of a symbol of the accreditation body, or reference to the accreditation status of the calibration laboratory is to be determined. Note: Traceability is not established merely by making a statement to that effect.
- Measurement uncertainty: The certificate must include an appropriate statement of measurement uncertainty and where applicable, the before and after data of the calibration in case an adjustment was required.
- Special instructions: If any special instructions were given to the calibration service provider for the calibration of test equipment, it must be verified that they were carried out.
- Documentation of In/Out of Tolerance information: It is to be verified that information is included on the certificate which states the condition of the test equipment (i.e., In Tolerance or Out of Tolerance) when received at the calibration laboratory and before shipment back to the EMC test laboratory.

- Tamper-resistant seals: If the calibration laboratory applied tamper-resistant seals it is to be verified that these seals are not broken. If this is the case the calibration is deemed void.
- Completeness: It is to be verified that a complete calibration of the test instrument was performed under the calibration service provider's scope of accreditation. The calibration documents are to be reviewed to determine if any calibration activities were performed outside the scope of accreditation (sometimes indicated by a foot note or a remark on the certificate).

When equipment was found to be out of tolerance, as stated on the calibration certificate, the test laboratory will have to use its non-conforming work process to determine how this out of tolerance situation may have impacted previous test results. Where necessary, technical evaluations (e.g., verification tests or an instrument self-test) are to be performed by the EMC test laboratory to establish that the equipment is functioning as expected.

CALIBRATION REQUIREMENTS FOR EMI RECEIVERS PER CISPR 16-1-1

The importance of equipment calibration and traceability of test results is recognized by CISPR. Since the calibration of measuring receivers (which are defined in CISPR 16-1-1 as an EMI receiver or spectrum analyzer without preselection) caused confusion in the international EMC community, CISPR subcommittee A is in preparation of a normative annex to CISPR 16-1-1 to outline the calibration requirements for measuring receivers. The following subjects will be addressed:

Calibration and verification

In CISPR 16-1-1 metrological calibration is defined as a set of operations that establishes, by reference to standards, the relationship that exists, under specified conditions, between an indication of an instrument under calibration and a result of a measurement using the corresponding traceable reference standard. Applied to the measuring receiver this means that a calibration procedure consisting of various steps is used to determine the actual values of calibration parameters like input VSWR or CW amplitude accuracy through measurements under specified environmental conditions, using measuring equipment that was calibrated by an accredited (or otherwise deemed appropriate) calibration laboratory to ensure traceability of the process. The results of these calibration measurements are used to determine if the instrument under calibration meets the specifications published by the manufacturer.

It is to be noted that the calibration process itself does not necessarily involve the instrument under calibration to be adjusted. However, adjustments may be required if the calibration process determines that the instrument does not meet the manufacturer's specifications. The goal of the instrument calibration process is the determination of compliance of the measuring receiver under calibration with its published specifications in a traceable manner.

Furthermore, *Verification* should not be confused with *intermediate checks* (also sometimes called *confidence checks* or *pre-checks*); the latter consists of a set of operations aimed at providing evidence of the proper functioning of a test instrument. An intermediate check of a measuring receiver can differ considerably from the calibration process because the purpose of these two activities is entirely different.

Calibration and verification specifics

The calibration of a measuring receiver requires a specific process that defines the various measurements to determine if the receiver meets its specifications. In general, this calibration process has also been used by the receiver manufacturer to establish the receiver specifications. Therefore, only the manufacturer's calibration process or verification process in accordance with CISPR 16-1-1 is to be applied by a calibration laboratory (or test laboratory performing its own calibrations) to determine whether the receiver meets its specifications at the time of calibration or the requirements called out in CISPR 16-1-1.

If a process different from the manufacturer's calibration process or verification process in accordance with CISPR 16-1-1 is used, the applied process must be verifiably validated to demonstrate technical feasibility and it must be stated in the issued calibration certificate that the process used deviates from the calibration process defined by the manufacturer.

The calibration process for measuring receivers is very important since it defines the following essential parameters that must be used for proper calibration:

a) the specific set-up of the receiver under calibration for each measurement in the calibration process (e.g. in the case of an EMI receiver or spectrum analyzer the tuning frequency, attenuator setting, resolution bandwidth setting, and other parameters, for each measurement to be performed);

b) the required test set-up for the measurement of a specific parameter (e.g. the use of power splitters for ratio measurements and any other required measuring equipment);

c) the required accuracy of measuring equipment used to perform the measurements of the calibration process (e.g. required amplitude accuracy and frequency accuracy);

d) the actual number of measurements to be performed and their sequence. For many types of measuring receivers

this sequence is mandatory and cannot be changed because the measurements of some parameters require the measurements of previous calibration parameters to be completed. In addition, it is possible that the interpretation of a test result for a calibration parameter is dependent on the test result of a previous measurement in the calibration sequence;

e) the required environmental conditions (e.g. required ambient temperature and relative humidity), if deemed necessary by the manufacturer.

Only if the manufacturer's calibration process is used can the results of the calibration measurements be compared to the published specifications. Consequently, the calibration laboratory or the test laboratory performing its own calibrations (also called internal calibrations) must use the manufacturer's calibration process for a specific measuring receiver. As stated before, an alternative process must be validated to determine its technical feasibility as a calibration process its use must be documented in the calibration certificate to indicate that it deviates from the calibration process defined by the manufacturer.

Measuring receiver specifics

CISPR 16-1-1 specifies measuring receiver requirements using a black box approach. This means that the instrument must show a specific response when a defined signal is applied to its input.

Therefore, the demonstration of compliance of measuring receivers with specifications defined in CISPR 16-1-1 does not require the application of the manufacturer's calibration process, and the procedures and measuring equipment defined in CISPR 16-1-1 are to be used. For example, the determination of intermodulation effects per 4.6 is to be performed using the test setup and input signals specified in the standard.

In case compliance of a measuring receiver is determined with the CISPR 16-1-1 specifications, the following minimum set of parameters shown in Table 1 are to be included in the verification process.

The parameters summarized in Table 1 are only applicable to the frequency ranges covered by the instrument under

verification and its implemented detector functions. Specifics described in the referenced subclauses apply in their entirety as well as the stated tolerances.

It is to be noted that the requirements called out in CISPR 16-1-1 constitute a subset of all the specifications the receiver manufacturer publishes. In addition, some requirements in CISPR 16-1-1 may be stated in a way that differs from the manufacturer's specifications (e.g. CW frequency accuracy in CISPR 16-1-1 versus a combination of absolute amplitude accuracy at a reference frequency and frequency response).

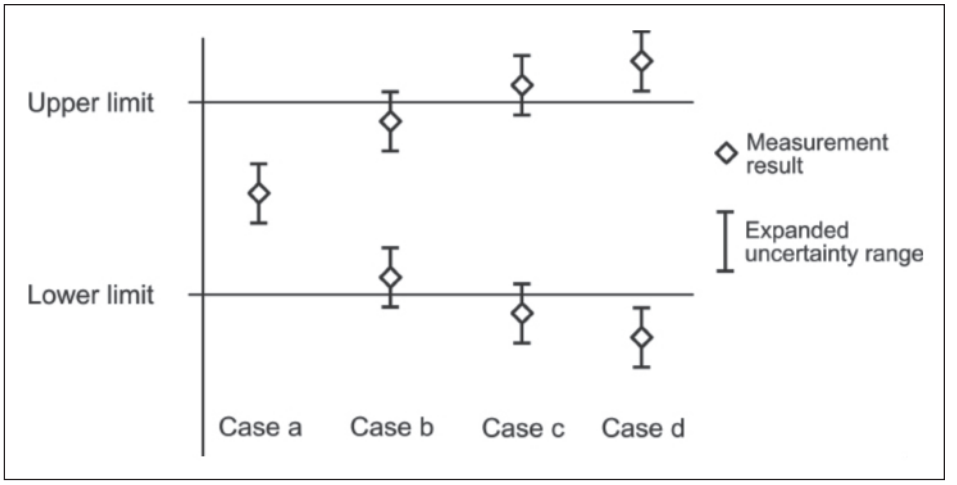


Figure 1: Compliance determination process with application of 276 measurement uncertainty

If evidence of compliance with the requirements presented in CISPR 16-1-1 cannot be directly provided through the manufacturer's calibration process, due to differences in form of the stated specifications, the verification of these requirements must be requested by the test laboratory in addition to the actual receiver calibration based on the manufacturer's calibration process.

Partial calibration of measuring receivers

Often times the complete functionality of a measuring receiver is not utilized when performing emission measurements. For economic reasons test laboratories therefore may decide to purchase a calibration service only for those functions that are actually used to perform measurements. Care must be taken when specifying such a partial or limited calibration service because the calibration of the identified functions may require calibration of other functions as a prerequisite. Such dependencies must be determined by the test laboratory or the calibration laboratory through a review of the manufacturer's calibration process. If the test laboratory does not have access to the manufacturer's calibration procedure, this review must be requested from the calibration laboratory as part of the calibration service purchase.

Determination of compliance of a measuring receiver with applicable specifications

Compliance of a measuring receiver with the specifications of the manufacturer or with the tolerances specified in CISPR standards requires that measurement results reported in calibration certificates are below an upper limit, or above a lower limit, or between an upper and lower limit. The uncertainty of the calibration or verification measurement has a direct impact on the pass/fail determination. Therefore, the measurement uncertainty must be taken into account when determining compliance of a measuring receiver with its stated specifications. The application of measurement uncertainty to a measurement result can lead to one of the four cases described as follows and depicted in Figure 1:

a) the measurement result is within the specified limit range by a margin larger than the expanded uncertainty value applicable to the calibration measurement;

b) the measurement result is within the specified limit range by a margin less than the expanded uncertainty value applicable to the calibration measurement;

c) the measurement result is outside of the specified limit range by a margin less than the expanded

d) uncertainty value applicable to the calibration measurement; or

e) the measurement result is outside of the specified limit range by a margin larger than the expanded uncertainty value applicable to the calibration measurement, and the specification is not met.

Per CISPR 16-1-1 the four cases in Figure 1 should be interpreted as follows:

a) the specification is met;

b) and c) the result is inconclusive, a definitive compliance statement is not possible;

d) specification is not met.

SUMMARY

Traceability and calibration requirements are also essential for EMC test laboratories. The interface between the test laboratory and external calibration laboratories can be complex, depending on the complexity of the equipment to be calibrated. Therefore, the EMC test laboratory is required to define the calibration requirements and communicate those

to the calibration laboratory. Through the selection of proper calibration laboratories traceability of EMC measurement results is established. Since the calibration requirements of measuring receivers is complex, CISPR subcommittee A is in the process of preparing an annex to CISPR 16-1-1 that summarizes the calibration requirements for such instruments. This will allow the EMC test laboratories to easily identify the required calibration requirements in order to perform traceable emissions measurements.

EMC test laboratories must also ensure that the provided calibration service is the one that was initially ordered. The step of an incoming inspection is performed upon receipt of the instrument back from the calibration laboratory and before the instrument is made available for measurements in the test laboratory. A thorough inspection will help avoid that improperly calibrated equipment or otherwise questionable calibration documentation causes non-conforming work situations later on which in turn can require considerable effort to determine the impact of such a situation on test results or can result in retesting of test samples.

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He was actively involved in the development of the new standard ANSI C63.10 and the latest revision of ANSI C63.4, mainly focusing on test equipment specifications, use of spectrum analyzers and site validation procedures.

Werner Schaefer is also a RAB certified quality systems lead auditor, and an iNARTE certified EMC engineer. He published over 50 papers on EMC, RF/uwave and quality assurance topics, conducted numerous trainings and workshops on these topics and co-authored a book on RF/uwave measurements in Germany.

Electromagnetic Analysis of Cable Harnesses in an Automotive Environment

BY M.H. VOGEL

This article shows how electromagnetic simulation tools can be used to investigate effects of high-speed signals in cable harnesses in a vehicle: cross talk, radiation and interference with a receiving antenna. Results are presented for two types of digital sequences and compared with standards. Cable shielding is designed to be adequate without adding unnecessary weight.

Vehicles are experiencing a continual growth in the number of electronic systems (*e.g.* cruise control, airbag deployment, power steering, "infotainment", *etc.*). These systems and their respective components are usually governed by digital logic on printed circuit boards. Signals are communicated through cables, which are bundled in complicated harnesses throughout the vehicle. Figure 1 illustrates only one of several harnesses that can easily contain more than a hundred cable instances and fifty connectors. Consequently, cross talk and electromagnetic compatibility (EMC) are major concerns.

This article demonstrates, by means of a case study, how simulation tools can help minimize the resources required for EMC testing, which is often time consuming and expensive.

CASE STUDY

A simplified yet representative example comprised of two cable bundles as well as an antenna integrated in the rear windshield is illustrated in Figure 2. The study was conducted with a commercial software package [1]. The cable

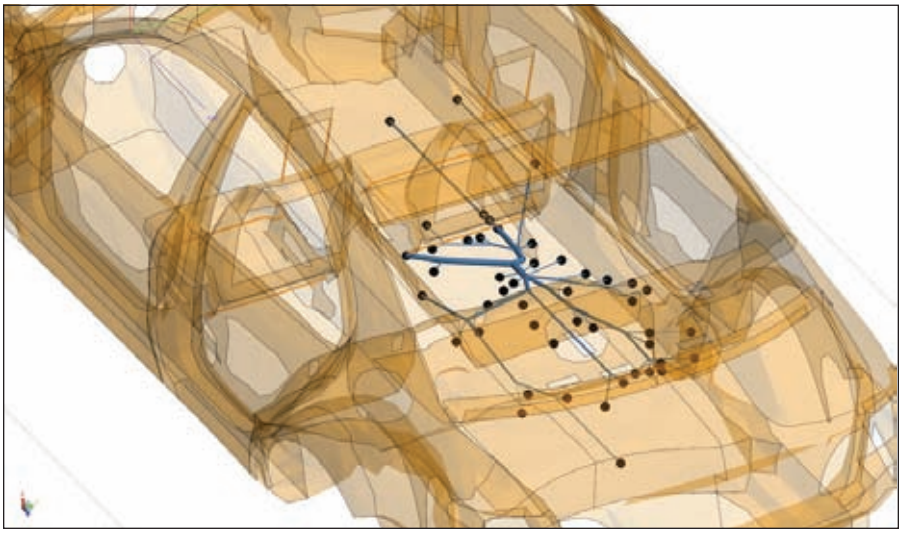

Figure 1: Example of a cable harness in a car model (Courtesy Daimler AG)

bundles each contain four signal wires as shown in Figure 3 where red and green indicate dielectric materials. Although a shield is shown in the figure, early simulations were done without cable shielding. The signal conductors can be used for both single-ended signaling and differential signaling, simply by adjusting the circuits in the software's integrated Schematic Views.

EMC engineers are concerned with cross talk within a bundle, cross talk between bundles, un-intended radiation to the environment, and interference with signals received by the antenna. Unintended radiation from electronic systems within a vehicle requires compliance with international regulations (*e.g.* CISPR 25) [2,3]. Unintended radiation from general electronic systems requires compliance with similar

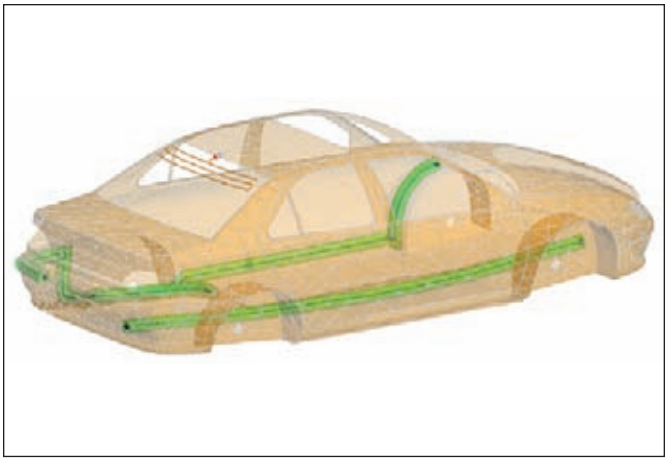

Figure 2: Model used in the case study

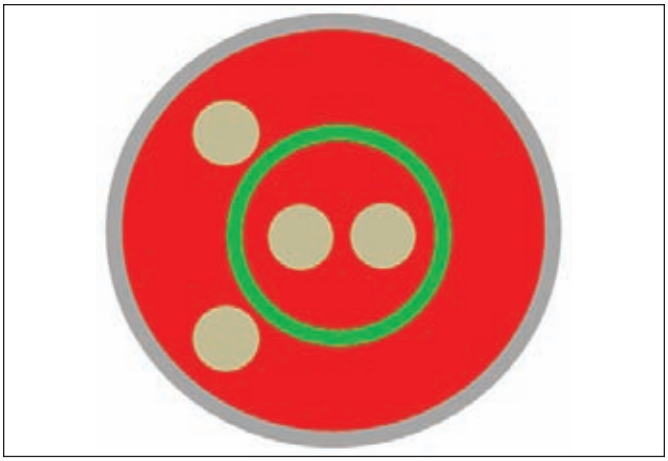

Figure 3: Cross section of a cable

regulations (*e.g.* FCC Part 15 [4]). To investigate compliance, proper accounting will have to be made for the spectrum of the digital signal.

CABLE ANALYSIS

For any cable-harness cross section, a 2D static finite element method (FEM) solver, determines the per-unit-length inductance, capacitance, resistance and conductance. Any complexity is possible, including twisted wires and shields inside shields. Cables can automatically be rearranged in the bundles to enable realistic simulation of the variations that may occur in practice. The link between fields outside and inside the cable harness is governed by the computed transfer impedance and transfer admittance.

The Multi-Conductor Transmission Line (MTL) theory is used to analyze complex cable problems. Simply put, a multi-conductor transmission line model is a distributed resistance, inductance, capacitance and conductance (RLCG) parameter network for an arbitrary cable cross section where the voltages and currents can vary in both magnitude and phase over the length of the cable. The transfer matrix links fields inside the cable with those outside. Cables can be radiating into their environment, be subject to irradiation from their environment, or both. Standard MTL technology is limited in application to situations where cables run close to a ground plane, where it is assumed that the current return path is in the ground plane directly below the cable. Combined Method of Moments (MoM)/MTL technology, is not restricted in this way and can solve problems with unrestricted cable paths.

CROSS TALK

The two signal conductors outside the center of the bundle in Figure 3 were excited with a 1-V differential signal (0.5 V per signal line). All terminations were 50 Ohm. Figure 4 shows the induced differential voltage on the other pair at both ends.

The cross talk is limited to 3 mV. For a digital signal with speed in the Mb/s range, differential signaling would be safe, unless dozens of differential pairs are packed in one bundle. Single-ended signaling, on the other hand, turned out to have an unacceptably large cross talk for signal speeds in the Mb/s range.

Figure 5 shows the cross talk between the two cable harnesses of in Figure 2 for the case of differential signaling. Note that the cross talk is mostly well below 1 mV, but several resonances occur. The first resonances are at 34 and 38 MHz. At 34 MHz, the aggressor radiates strongly while the victim is only moderately receptive. At 38 MHz the victim, which has a different electrical length, is highly susceptible while the aggressor radiates only moderately. For cross talk, three components are needed: an aggressor, a victim and a path between

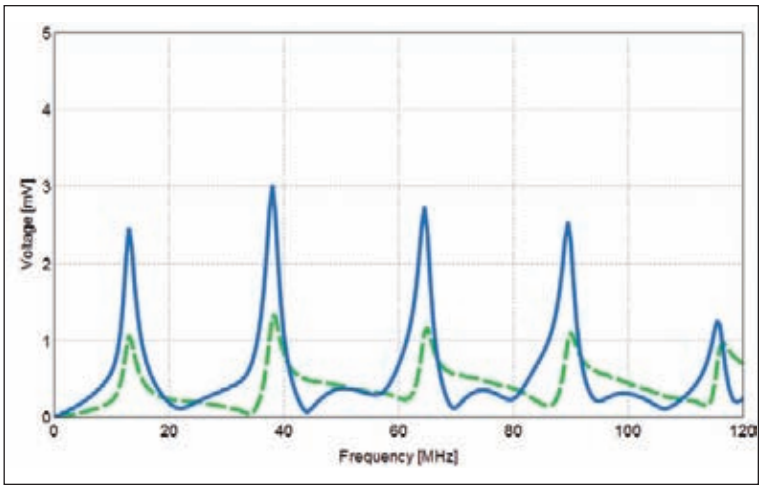

Figure 4: Cross talk between differential pairs in the same bundle. Blue: NEXT. Green: FEXT.

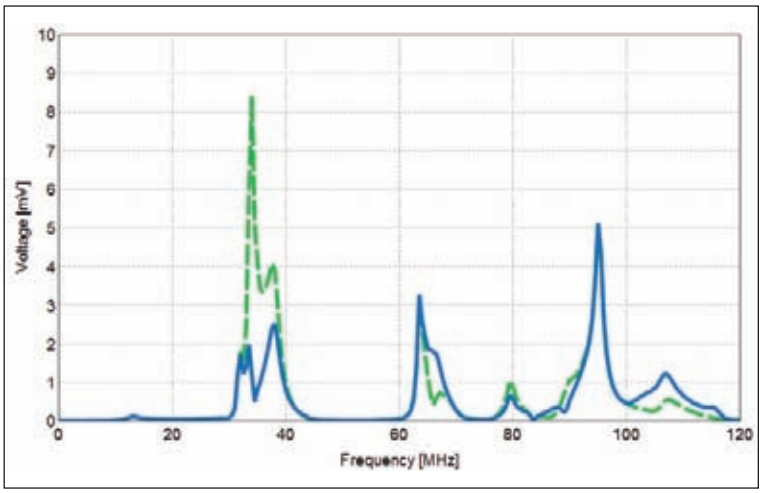

Figure 5: Differential cross talk between bundles. Blue: NEXT. Green: FEXT

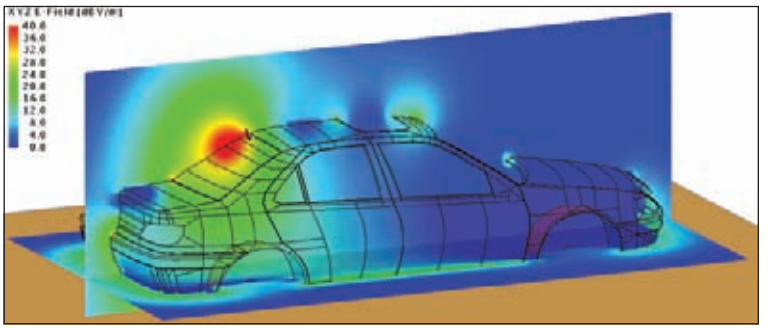

Figure 6: Fields at 34 MHz due to differential aggressor

them. In this case, a field plot is very revealing. Figure 6, in which no source is connected to the antenna, shows that the windscreen antenna is an essential part of the path.

This was verified by running the simulation again without the antenna present. Strikingly, while a cross talk of 8 mV was reached in Figure 5 with the receiving antenna present, the maximum (in the frequency range below 40 MHz) was only 0.025 mV when the antenna was removed, a reduction of 50 dB! While individual systems may appear safe, problems appear when the complete vehicle is analyzed. This underscores the need for EMC testing of the entire vehicle. Since EMC measurements of the complete vehicle can only be done late in the design process, identifying and addressing EMC problems with software simulations early in the design process can minimize costly modifications.

RADIATION AND COMPLIANCE WITH EMC REGULATIONS

Figure 7 shows the maximum electric-field magnitude at 10 m as a function of frequency, based on an excitation with a differential voltage of 1 V (0.5 V per signal line) at every frequency. In order to compare this result with regulations, it needs to be weighed with respect to the spectrum of the actual signal on the differential line.

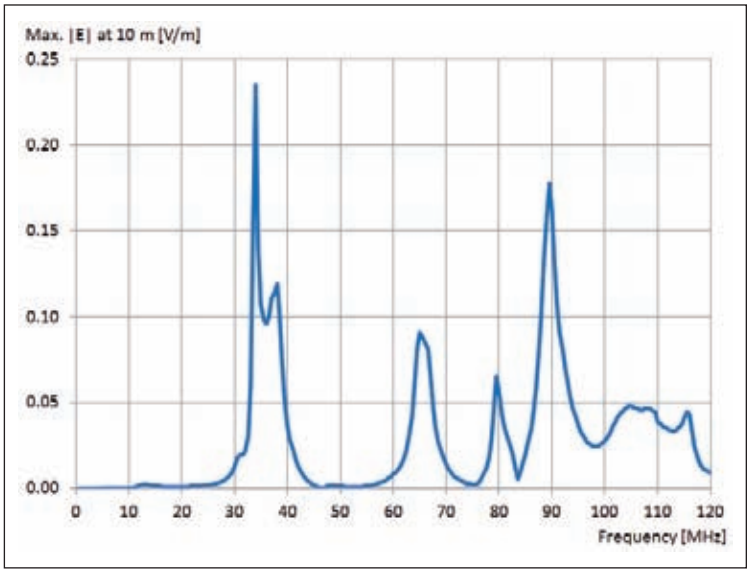

Figure 7: Maximum E field at 10 m distance as a function of frequency

Let the signal on the differential transmission line be a 2 Mbit/s digital signal with a rise and fall time of 100 ns. The resulting spectrum depends strongly on whether the signal is a regular stream of bits, like a clock pulse, or an irregular stream of bits, like a pseudo-random binary sequence (PRBS). In the first case, the spectrum is a set of delta functions ("spikes") at the odd harmonics of the bit rate, while in the second case, the spectrum is continuous. The equations can be found in [5].

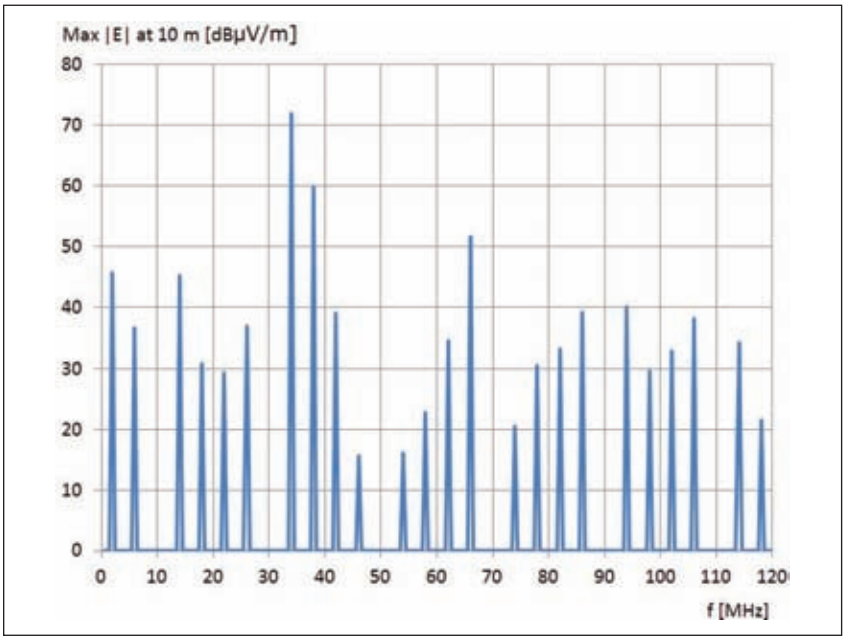

Figure 8: Maximum |E| at 10 m for a 5V differential clock signal

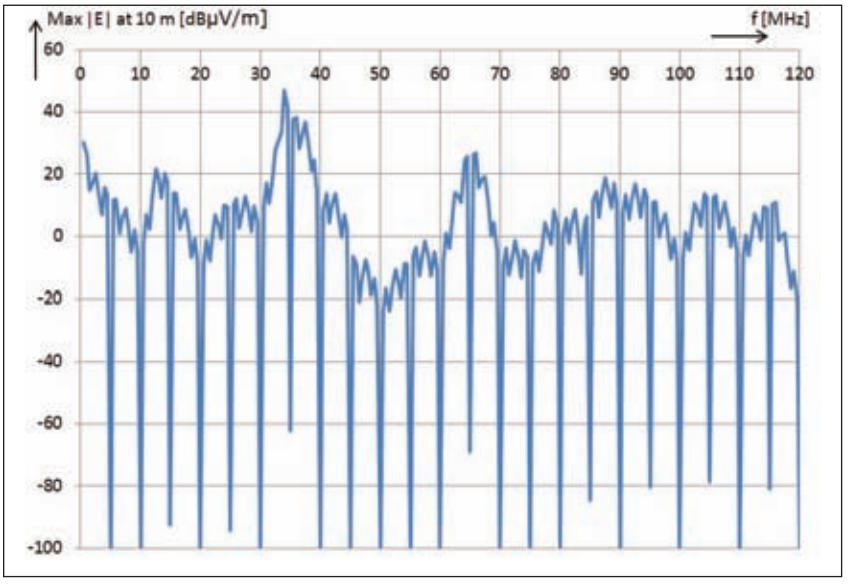

Figure 9: Maximum |E| at 10 m for a 5V differential PRBS

For a 5 V differential clock signal (2.5 V per signal line), the resulting radiated field at 10 m is presented in Figure 8. Note that the spikes occur at the odd harmonics of 2 MHz. Also note that no harmonics are visible at 10, 30, 50, … MHz. This is due to a sinc function involving the rise time.

While Figure 7 shows little radiation below 30 MHz, Figure 8 shows significant spikes below 30 MHz because most of the signal's spectral content is there. Above 30 MHz, the signal has less spectral content but the cable radiates more effectively. The radiation at 34 MHz, a resonance due to the electrical length of the cable, exceeds the radiation at all other frequencies in both plots. The FCC Class A limit at 34 MHz is 39 dBµV/m at 10 m. Clearly, the limit is exceeded by a significant amount.

For a 5 V differential PRBS signal (2.5 V per signal line), the resulting radiated field at 10 m is presented in Figure 9. The straight application of the equations for the continuous spectrum gives a field in units of V/(m Hz), i.e. Volts per meter per Hertz bandwidth. To obtain V/m, we have to specify a receiver bandwidth. To produce Figure 9, a receiver bandwidth of 120 kHz [2] has been used.

The radiated emissions of the PRBS are a lot less worrisome than those of the regular pulse, simply because the PRBS spreads its radiated power over all frequencies. Still, at 34 MHz the limit of 39 dBµV/m is exceeded.

In order to comply with regulations, the cables will need to be shielded. The main benefit of these simulations is that they reveal how much shielding is needed to achieve first-pass success in tests. This is important, since repeated testing is expensive, while adding too much shielding to all the cable harnesses in a vehicle adds a lot of weight and reduces the routing flexibility.

Several types of shielding can be specified: selected from a database of popular cable types, solid shields with a specified material and thickness, user-defined by means of the frequency-dependent impedance transfer matrix, and braided shields. For a braided shield (Figure 10) one specifies the relevant parameters and materials of the

In order to comply with regulations, the cables will need to be shielded. The main benefit of these simulations is that they reveal how much shielding is needed to achieve first-pass success in tests.

weave pattern, upon which the frequency-dependent transfer matrix is determined using the Kley formulation [6, 7]. This formulation accurately models the coupling mechanism due to the field penetration through the shield apertures.

With a shield of 32 carriers of seven 0.12-mm filaments each around each cable, which, for a shield radius of 5 mm leaves openings, the radiation is reduced sufficiently (see Figure 11) to satisfy the FCC regulations, if they were applied to vehicles. While CISPR-25 applies to automotive systems, it is used more for individual systems and harnesses than for radiation from entire cars. CISPR-25 limits between 30 and 54 MHz range from 22 to 46 dBµV at 1 m distance, depending on the class, which corresponds to 2 to 26 dBµV at 10 m distance. The individual system with harness might well pass in a standard test, while with the windshield antenna present the radiation, as shown in Figure 11, might be too high.

The difference in levels between Figures 8 and 11 (without and with shielding) varies with frequency. One reason for the frequency dependence is that the shielding factor is frequency dependent; another reason is that with the added shield the cross section of the cable has changed, so the amount of crosstalk to other signal lines in the cable has changed. The latter is strongly frequency dependent.

INTERFERENCE WITH SIGNALS RECEIVED BY THE ANTENNA

Windscreen antennas are typically embedded in a number of dielectric layers of varying dielectric properties. For such

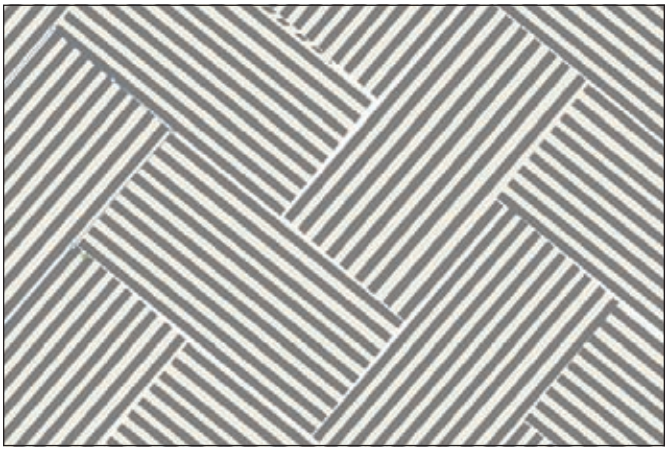

Figure 10: Braided shield

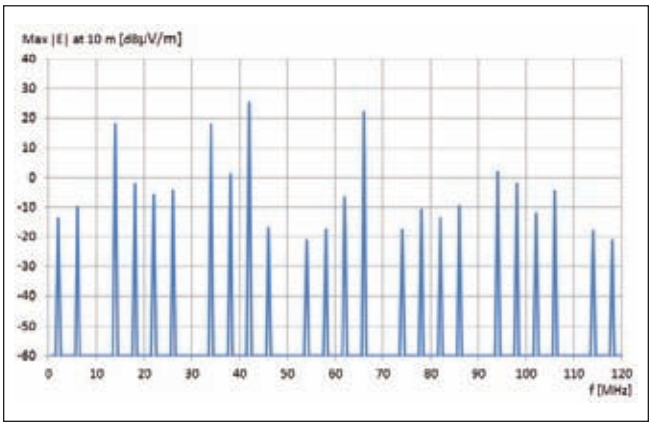

Figure 11: Maximum |E| at 10 m for a 5V differential clock signal in a shielded cable

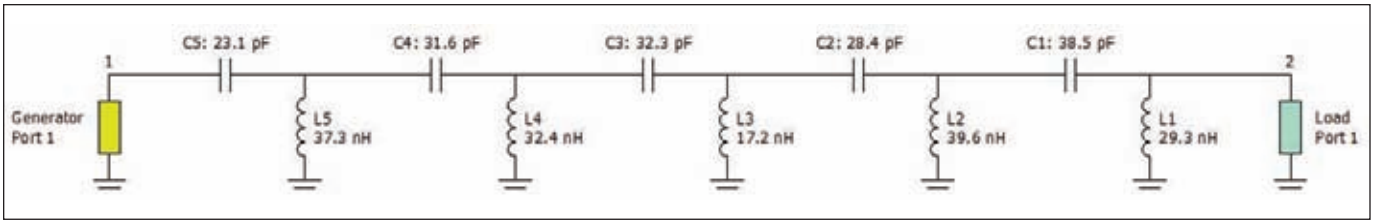

Figure 12: Matching circuit designed with Optenni Lab and integrated in the model

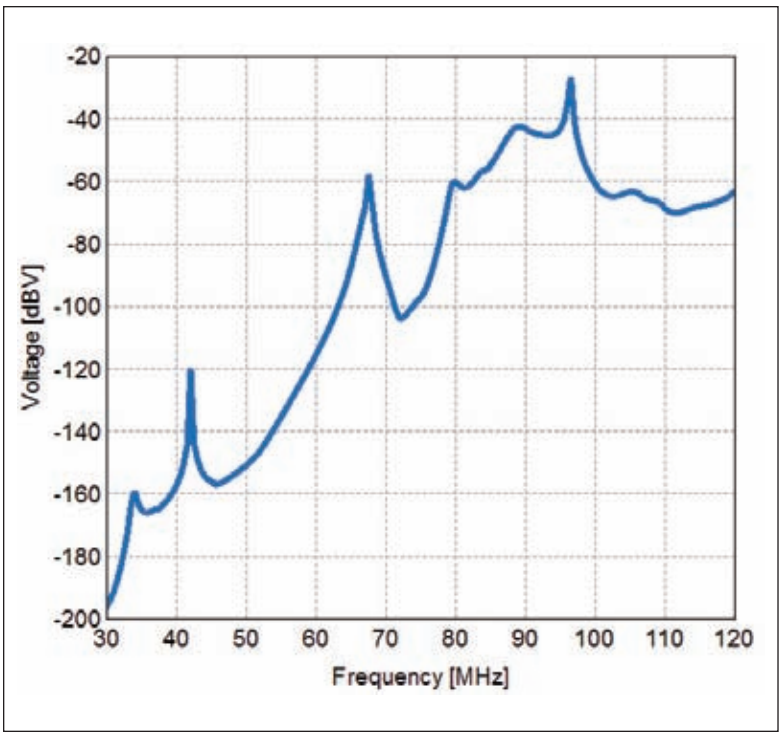

Figure 13: Voltage received by antenna with matching circuit

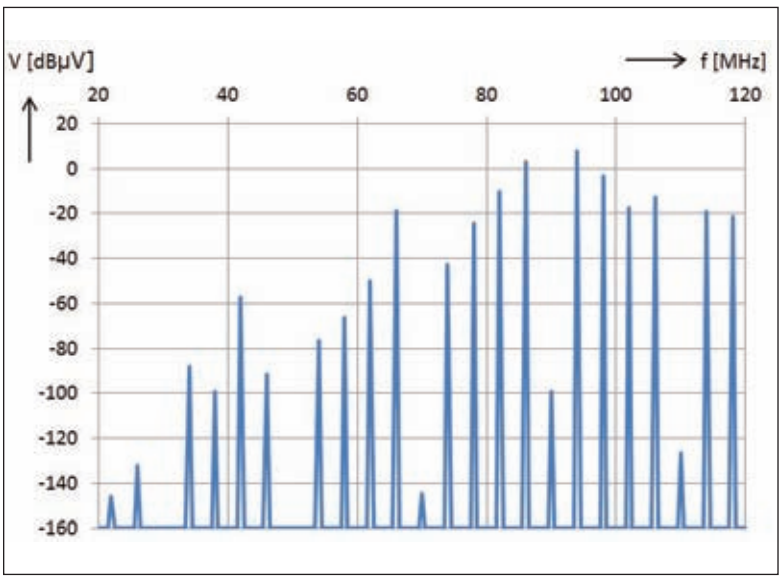

Figure 14: Voltage received by antenna and passed by the matching circuit

antennas a Method-of-Moments based formulation that meshes only the metallic antenna elements in a windscreen antenna, while rigorously taking all dielectric layers into account with special methods is used. This avoids having to mesh the layers with a triangle size of the order of the layer thickness, which would require impractical simulation times.

The antenna is connected to a ten-element matching circuit, which provides an excellent match ($S_{11} \leq$ -23 dB) between 89 and 91 MHz.

A 5-V differential signal was connected to a pair of signal lines inside a shielded cable. The resulting voltage on the receiving antenna terminals, after passing through the matching circuit, is illustrated in Figure 13.

Note that the peak at 34 MHz in Figure 13 is weak compared to Figure 7, due to the matching circuit. The results for a shielded cable, illustrated in Figure 13, do not indicate a peak at 90 MHz, while Figure 7 does show a peak for the unshielded case. In addition to reducing radiated fields, a shield also changes the characteristic impedances "seen" by the signals and the coupling between the two pairs of signal lines.

Figure 14 shows the received voltage that passes the matching circuit when the differential signal is a 5-V regular binary pulse with repetition frequency 2 MHz and with rise- and fall times of 100 ns. The maximum is 8 dBµV. CISPR-25 specifies a maximum of 6 dBµV. Therefore, engineers are required either to shield the bundles better, or work with a lower voltage, or ensure that this kind of signal can never travel on this cable.

CONCLUSION

Cross talk, radiation and interference for a vehicle with cable harnesses and a windshield antenna have been analyzed. Instrumental in this case study were the capabilities to include radiating

and irradiated cable harnesses of arbitrary complexity, and to model windshield antennas efficiently. Taking the spectra of digital signals into account, comparisons with regulatory standards were made.

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Prepping for EMI Testing

BY WILLIAM D. KIMMEL, PE AND
DARYL D. GERKE, PE

Like it or not, most electronic designs today are subject to formal EMI testing. So even if you are new to EMI/EMC (electromagnetic interference/ compatibility), you need to understand what is involved and how to best prepare for a trip to the EMI test lab.

Like any trip, good preparations are key. We'll look at three phases — *pretest, test,* and *post test*. Try to anticipate problems, and don't overlook contingencies. Most EMI tests are not successful the first time. As engineers we always need to have "Plan B" ready, and maybe even "Plan C."

Before we begin, however, a little philosophy. Too often designers take EMI failures personally. So change your mind set — think *verification*, not testing.The goal is not to criticize your designs, but rather to assure your designs will work in the field. Make it a positive experience. As we learn, we improve — even us grumpy old EMC consultants.

PHASE 1 - PRETEST

The first step is to write a plan. If you are working in the defense industry, a test plan is usually a contract requirement. We find an EMI test plan very useful for communicating among the design team, the test lab, and the customer.

But even if not required, a test plan is still a good idea as it forces one to address critical issues ahead of time. Here is a summary, which you can even use as a checklist.

Identify necessary tests. If you are not sure what tests are needed contact your test lab prior to your visit. Nothing is worse than showing up without knowing what needs to be done. You should also determine the test configuration for each test, which is usually defined in the relevant test specification.

Define failure criteria. With emissions, this is easy. Are the levels above or below the limits? But with immunity/ susceptibility, however, you may need to define failures. For example, is a reset with recovery acceptable? How much perturbation can you withstand in an analog sensor?

Depending on the equipment under test, the failure criteria are already specified. Other times you have more flexibility. The different failure levels prescribed in the European Union EMI specifications are a useful place to start. Be sure to include this in your plan, and to get advance agreement on the failure criteria.

Determine failure monitors. Again, with emissions this is easy - just watch the spectrum analyzer. Immunity/ susceptibility are not as easy. How will you determine a failure? Special software? Or special hardware, such as a blinking "heartbeat" detector? Or maybe just indicators on the EUT (equipment under test) via a video camera.

Determine equipment hardware. What specific equipment will you test? Are peripherals needed? What about memory or I/O configurations? Probably best to test a "worst case" configuration, which assumes that lesser configurations will have lesser EMI issues.

Determine equipment software. Will you need special test or diagnostic software? Some software may even be prescribed. For example, the prescribed emissions test software for personal computers includes reading/writing to hard drives and peripherals, along with a "scrolling H" test pattern for monitors. Not fair to let the system idle - you need to exercise the hardware.

For immunity/susceptibility, how will you monitor, recognize, and report failures? Will the standard software do it, or do you need additional special software? Will that software run on the EUT, or on remote equipment?

Determine support hardware. Passive peripherals, or active exercisers? Will you need to develop special hardware (and associated software?) Are there special power or cooling needs?

Don't forget about cables and connectors. If shielded, make sure they are properly terminated. If necessary, how will the cables penetrate the test chamber? You may need to develop a special test fixture for this.

We've see too many problems with cables — check them out *before* going to the lab. We still recall one engineer admonishing his colleague with, "I thought we brought the *good* cables."

Put together a tool kit and spares. As a minimum, you should bring spare boards. Better yet, bring an extra system or two. There is nothing worse than having equipment break during the tests, with no backup. Bring backup software too.

You may also want to include some spare parts - ferrites, small caps, EMI copper tape, and a roll of heavy duty aluminum foil. A soldering station can be useful too if you need any minor board modifications. Much of this may be available at the lab, but better to be prepared.

Consider multiple configurations. For cost sensitive designs, we often recommend three test samples (ABC method.)

The first step is to write a plan. A test plan is a good idea as it forces one to address critical issues ahead of time. If you are working in the defense industry, a test plan is usually a contract requirement.

The A unit has minimal modifications (management's dream); the C unit has all the EMI fixes you can think of (the EMI engineer's dream): and the B unit is somewhere in between (the designer's dream.).

If you're an optimist, start with A. If you pass, life is great! If you are a pessimist, start with C. If you fail, you're still in trouble. In most cases, you'll be somewhere in between, which is where the B unit comes into play. But this approach lets you quickly bracket things. It also means you have spares on hand if needed, and that can be modified as needed.

Schedule your tests. With all this preparation, don't forget to call your test lab for scheduling. Test labs can get pretty busy, so don't expect to get in right away. The more advance time you can give the lab, the better. They will appreciate your courtesy. But for emergencies and panic situations, most labs will do their best to accommodate you. Just don't make every test a panic.

PHASE 2 - TESTING

All your planning and prepping is done, and you are now at the lab. Regardless of your overall responsibilities, somebody from your company should attend the tests. Don't just throw the design over the wall to the lab. Yes, it is done but very often is not effective, particularly if problems arise.

Many EMI tests take a week or less. In that time, not only will you learn a lot, but by being on site you'll also save your company time and money. After all, you know the design, how it works, and how to fix it if it breaks. Here are some issues to consider.

Setup the EUT. Do the basic stuff - connect power, peripherals, ventilation (if needed), etc. Run a diagnostic to be sure everything is working as it should.

Start a test log. Note date, time, test configuration, and summary results. Keep it simple but organized, as you will get a full set of data at the end of the tests. This is very useful if you start troubleshooting. Without it, you will soon be confused as to what has been tried. Photos are a good idea too.

Baseline tests. For emissions, run an ambient test (power to the EUT off.). This is normally done anyway, but make sure it happens. For immunity, run a pre-scan. This verifies proper operation before you begin subjecting the EUT to the EMI torture chamber. This is the time to catch any glitches in the test setup. Note and record the results.

Dealing with test failures. Unless you are incredibly lucky, you will encounter test failures, particularly with initial tests. Expect two or three trips to the lab before achieving full success. Even with the best design techniques, there are always unknown factors. That is why we test - it is still the most cost effective way to assure EMC, and ultimate successful operation of our equipment in the field.

If you fail a test, don't just stop and give up. Do some quick troubleshooting instead. If you are lucky, you may fix the problem right away. If not, at least gather enough information to narrow the possible failure mechanisms. Think like a doctor trying to diagnose an illness.

Do the simple stuff first. Add ferrites to cables, or better yet pull cables to see if emissions drop (or immunity improves.) If you think the box is leaking, wrap the EUT in aluminum foil, sealing the seams in copper tape. You did bring your ferrites, aluminum foil, and tape with you, right? If not, the lab probably has a supply, but better to be prepared.

For immunity, back off the test levels to determine the actual failure levels. How bad is the problem, anyway? If you are close, maybe a ferrite will fix things. But if you are a long way from success, more serious fixes may be needed. You need to know this.

Ask for suggestions. Your test engineers and technicians have seen a lot of problems, and may have some ideas to try. Be polite, and don't be a hot shot trying to impress everyone. Worst of all, do NOT blame the test lab or question their equipment or abilities. Wish we didn't have to include this last piece of advice, but we've seen it happen.

Verify operation. Finally, regularly check to see if the EUT is still working right. This is particularly important with immunity tests that might cause damage or subtle changes, such as ESD or power transients. But even random equipment failures can invalidate your test data.

How often to verify? The answer is how much data are you willing to discard. If you are willing to lose a day's data, then once a day is enough. For a half day, then twice a day suffices. Test time is expensive, so we usually recommend revalidating every two to four hours, assuming the revalidation does not take a lot of time.

PHASE 3 - POST TEST

If all has gone well, you've passed the necessary tests. If not, hopefully you have gathered enough data and ideas to fix things for the next round of testing. Rest assured - eventually you *will* achieve test success. So what now?

Test report. It is not enough to just pass the tests — you need to document the results. For military designs, the test report is another contractually required document. As such, it can be quite formal and detailed. For commercial products, the test report can be less formal, but should still contain enough relevant data to show that you have, in fact, passed the tests.

You can have the test lab prepare the test report, or you can do so yourself. Since most engineers do not like to write reports, we usually recommend paying the test lab to provide the report. With their experience and templates, they can do so in a cost effective manner. Either way, keep the test report on file in case there are future questions about the tests.

Raw data. Before leaving the lab, it is a good idea to leave with raw data — graphs, tables, and photographs. Of course, you have your lab notes too , right?

In addition, we like to record other relevant data — test equipment, serial numbers, calibration dates, etc. That will be included in formal reports, but it only takes a few minutes to gather.

Last, but not least, thank everyone for their help. Not only is this courteous but will be very much appreciated. You will also find youself welcomed back on your next trip to the EMI lab.

IN CONCLUSION

We hope this makes your next trip to the EMI test lab both easier and more enjoyable. EMI testing is an important step to assure our equipment will work properly in its intended environment. The ultimate goal is a better design, which is what we all want as engineers.

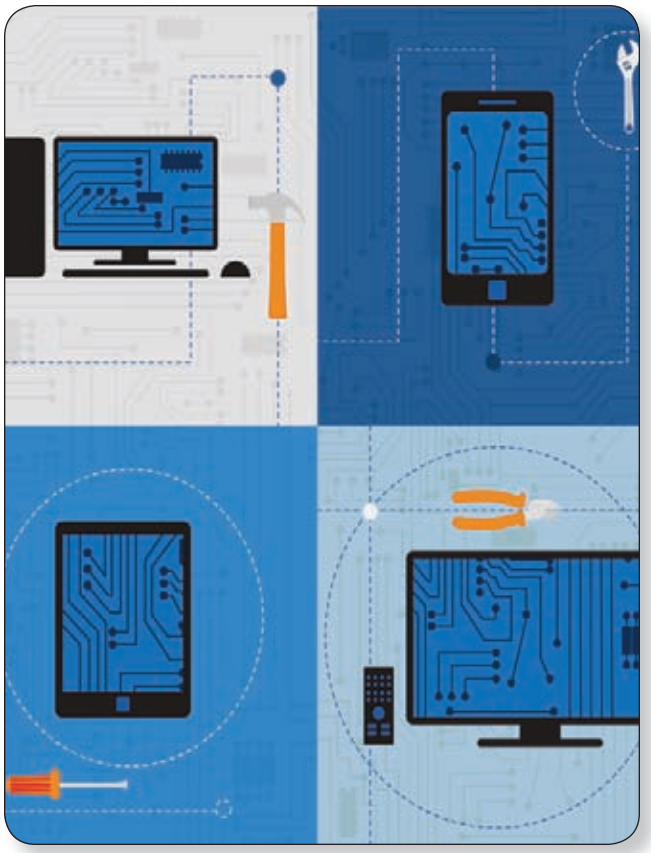
Daryl Gerke, PE and Bill Kimmel, PE *are the founding partners of Kimmel Gerke Associates, Ltd. The firm specializes in EMC consulting and training, and has offices in Minnesota and Arizona. The firm was founded in 1978 and has been in full time EMC practice since 1987.*

Daryl and Bill have solved or prevented hundreds of EMC problems in a wide range of industries - computers, medical, military, avionics, industrial controls, vehicular electronics and more. They have also trained over 10,000 designers through their public and in-house EMC seminars.

Daryl and Bill are both degreed Electrical Engineers, registered Professional Engineers, and NARTE Certified EMC Engineers. Between them, they share over 80 years of industry experience. For more information and resources, visit their web site at www.emiguru.com.

Using EMC Tools to Help Designs Pass the First Time

BY BRUCE ARCHAMBEAULT



This is a true story. When I first joined IBM as an EMC engineer, my new manager handed me a document titled 'EMC Design Process at IBM' and asked me to comment. I quickly read the short document that basically said that the EMC engineer would provide the design engineers a list of EMC rules, which would be largely ignored.

The product would be built and when tested in the EMC laboratory it would fail. The EMC engineer would then spend anywhere from a week to a month to try various band-aid fixes (not the term used in the document, of course) before making recommended changes back to the design team. The changes (or some of the changes) would be implemented, and a new version of the product built. Testing would be repeated, and this process might need 2-3 iterations before completed and the product was ready to ship.

I handed the document back to my brand new manager, and asked if he had fired this EMC engineer yet? He was shocked, and told me this was one of the more senior EMC engineers! I told him that if I told my boss I expected to fail every time I *should* be fired. Of course, this was not the design process that was desired, but rather the one that had evolved.

Using software tools helped IBM turn this process around completely. So now, instead of failing the first time, every time, products usually pass the first time in the EMC chamber! Using these tools (along with education of the design engineers) made all the difference!

There is a variety of tools available and they operate at different levels. This article will discuss using these tools and point out the benefits and where they can be used most effectively in the design process. Many people had told me they have no time to learn how to use new tools. I equate this to a story a friend of mine told me years ago. A woodsman is tasked to clear five acres of forest in a very short time. He begins with his double-bladed axe and is working hard when someone tries to show him a new invention, called a chain saw. The woodsman replies that he has no time to learn new tools! He is busy with a short deadline!

BEFORE THE DESIGN BEGINS – SIMULATION

There are many EMC rules, and some of them are in direct conflict with each other! These rules need to be evaluated to see which ones will work for your particular product family. For example, EMC rules for large main frame computers may or may not apply to a small hand held device where large metal shields and finger stock can not be used. Furthermore, some published EMC design rules do not follow physics! All rules need to be examined to make sure that they make sense, and are appropriate for your product types.

One of the best ways to validate rules is to use full wave simulation software. There are a variety of vendors offering a variety of different software simulation tools. These tools use a variety of different simulation techniques, each having areas

where they excel and areas where they are not the best tool for the job. A tool box approach is strongly recommended so the user will have a variety of tools at their disposal and can optimize their particular simulation for the type of problem at hand. Figure 1 shows a number of different possible problems[1] that might be simulated and represent only a small number of examples possible for simulation tools. However, each of these problems are very different, and so a different simulation technique would be best for some of the problems. There is no *one size fits all* in the world of simulation techniques.

For example, the heatsink in Figure 1A would usually require an open boundary condition and would likely be easiest to simulate using Finite-Different Time Domain (FDTD), Finite Integration Technique (FIT), or the Method of Moments (MoM). PCB problems often require dielectric materials to be included as well as open boundaries, so FDTD or FIT might be best suited. If the PCB problem includes many discrete components (such as capacitors, equivalent inductances, etc.) then the Partial Element Equivalent Circuit (PEEC) would probably be the most efficient way to perform the simulation. Internal shielded air vents (Figure 1C) could easily be solved with FDTD, FIT, or the Finite Element Method (FEM). Problems such as the coax cable in Figure 1D might be optimized using FEM, since it is a problem with metal boundaries (open boundaries not needed) and the non-rectangular shape of the grid can be well suited to curved surfaces.

Very seldom is a single simulation run to determine pass/fail of a system. Usually there are a family of simulations, each with something slightly different, to help define the grey area between the absolutes. A classic example would be to determine how many posts are required to connect the heatsink in Figure 1A to the ground-reference plane in order to

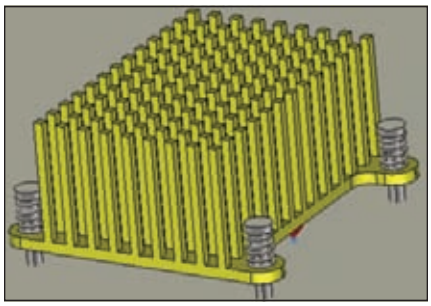


Figure 1A: Heatsink example

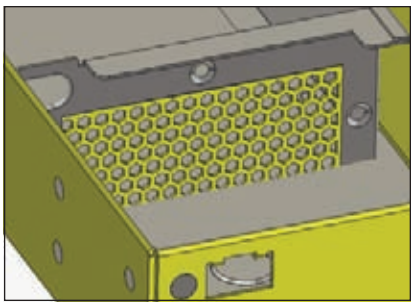


Figure 1C: Internal shielded air vent example

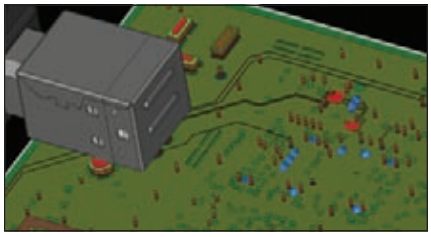


Figure 1B: PCB example

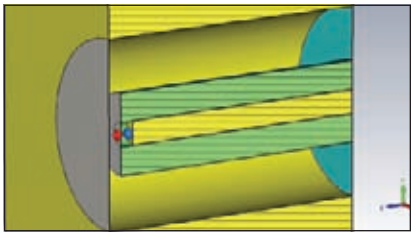


Figure 1D: Coax cable example

1 Courtesy of CST

Training is an important part of the preparation for the coming design project. While there are a number of training seminars available, it is important to make sure that it is not just a listing of EMC design rules collected over the years.

reduce the emissions over a certain frequency range. In this example, a number of simulations would be performed, each with a different number of grounding posts, to observe the frequency range where the emissions are reduced. Using these multiple simulations, a set of design guidelines can be created that are optimized for the specific type of product that is to be designed.

A word of caution should be mentioned here. Simulation tools are very powerful and useful. They can help fill in the grey areas, and also help understanding of the engineers and non-engineers who often must be convinced to implement a certain design rule even though it might add a little cost, weight, etc. to the product. However, all simulations should be validated. The software vendors spend a lot of time to insure their tools give an accurate answer to whatever question was asked. However, the user is often the primary source of error. A good rule of thumb about validating simulations: if you have never made a mistake in your life, you might be safe to ignore the recommendations for validation!

One of the primary potential sources of error are the types of source used in the simulation. Wave ports are an easy source of error. If the boundaries of the wave port are too close to a microstrip (for example), then the fields will interact with the perfect electrical conductor boundary and incorrect wave modes are established (see Figure 2).

Validation can take many forms. Probably the most common, and often the most difficult is to use measurements to validate the simulation. After all, measurements are a great emotional comfort! However, there are a lot of measurement artifacts that may or may not be included in the simulation. Antenna patterns, ground plane reflections, and equipment input impedance loading for direct measurements can all make it difficult to compare measurements and models unless all these effects are included in the simulation.

Another popular way to validate simulations is to use a completely different simulation technique. For example, using FDTD and MoM for the same problem will use very different physics for the simulation. Of course, this means the simulation must be run twice, but if both simulations give the same results, then the user must have understood the problem well enough to create models for the different simulation techniques, and the results are probably good.

BEFORE THE DESIGN BEGINS – TRAINING

Training is an important part of the preparation for the coming design project. While there are a number of training seminars available, it is important to make sure that it is not just a listing of EMC design rules collected over the years, but rather training that explains how the physics work, why the rule is important, and how to determine if the rule is appropriate for this product/project or not. This does not mean that a lot of heavy math is required! We can leave the math for the universities and those who love to solve equations. Understanding the physics means that the students should learn the fundamentals of how current flows, the true

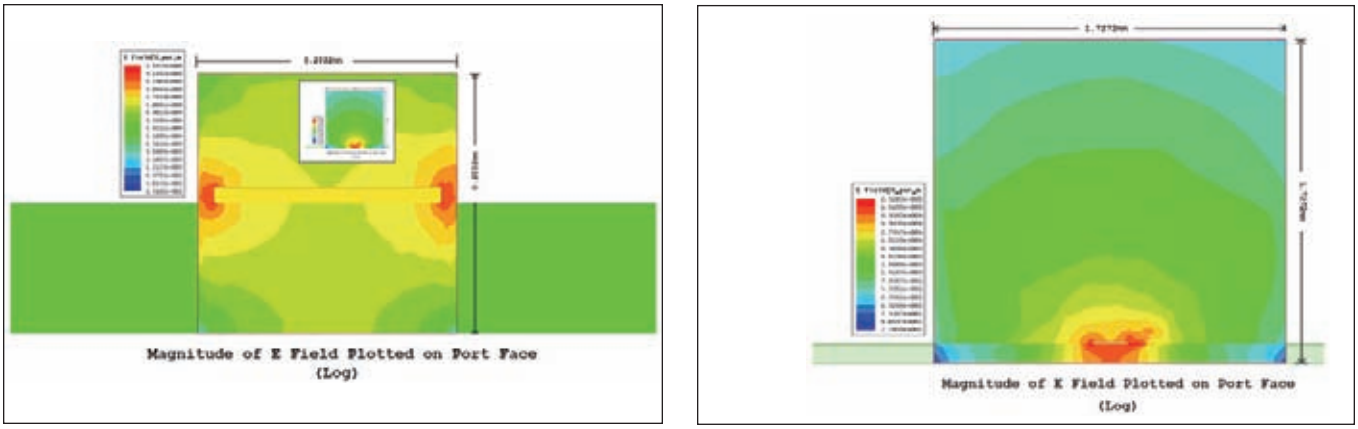


Figure 2: Incorrect and correct electric fields in wave port

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THE CLASSIC RESOURCE

clas·sic (klăs ĭk)
adj.
1.
a. Belonging to the highest rank or class.
b. Serving as the established model or standard: a classic example of colonial architecture.
c. Having lasting significance or worth; enduring.

There are software tools available that can read the PCB CAD design file, quickly check against a wide variety of EMC and Signal Integrity design rules, and highlight the areas where design rule violations occur.

nature of ground vs. return current path, how shielding really works, and especially a good understanding of inductance concepts. Remember, once the seminar is completed, the student/engineer must rely on the knowledge gained during the seminar to be able to know when a rule must be enforced, when the rule can be bent a little (and how far) or when a rule does not make sense for the product under design.

DURING THE DESIGN – RULE CHECKING SOFTWARE

Once the design has begun, there is seldom time to do multiple simulations, etc. The design rules that were vetted prior must be used since time is usually short. When designing many layer high speed printed circuit boards (PBCs), it can be impossible for an engineer to double check all the proper design rules were followed. There are software tools available that can read the PCB CAD design file, quickly check against a wide variety of EMC and Signal Integrity (SI) design rules, and highlight the areas where design rule violations occur.

These software EMC/SI design rule checking tools usually include a variety of rules that are more complex than the simple manufacturability Design Rule checkers (DRCs) that are included in PCB layout CAD tools. For example, a typical EMC design rule is that high speed traces must not cross a split in the nearby reference plane. However, depending on the data rate, rise time, etc. for the signal on that trace, a stitching capacitor might be used to allow the return current

to cross from one plane to the other *if* the capacitor is located within a certain specified distance from the crossing point. Complex rules, such as this one, are too complex for the DRC in the CAD tools.

One of the major advantages of these EMC/SI rule checking tools is that they will highlight the area where the violation occurs, turning on only the PCB layers involved, and often even drawing a box around the violation to draw the engineer's eyes to the right location quickly. Figure 3 shows an example screen shot[2] of a violation of the trace crossing a split reference plane rule.

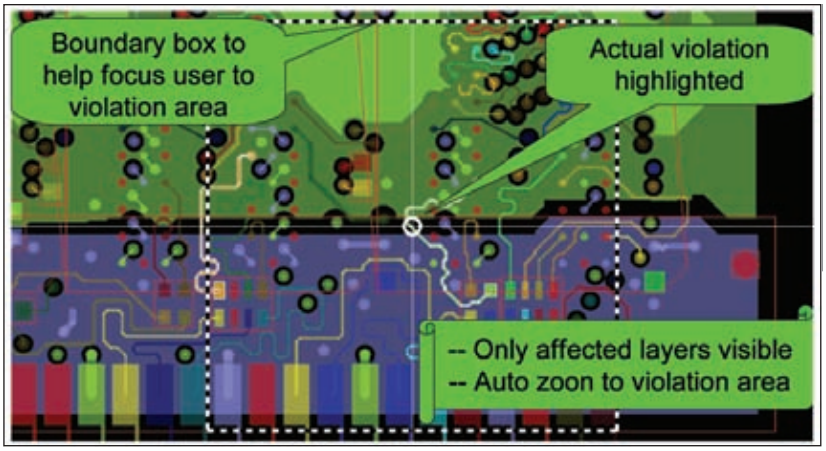

Figure 3: Example of EMC Rule checking tool Violation Viewing

Typical rules for printed circuit boards cover a wide range of potential violation, including distance from decoupling capacitor (and IC) pads to vias, decoupling capacitor density, traces close to the edge of a PCB, distance from signal via to return current via, and many more. Users can tailor the limits for the various rules depending on the product specific requirements, data rates etc.

Rule checking software tools are usually very fast, doing an entire high speed PCB in minutes or at most, tens of minutes. This is in contrast to most full wave simulations which typically take hours or even days to complete. The full wave simulation gives a complete solution to Maxwell's equations, vs. a relatively simple geometry checking against a rule. Therefore the rule checking tools can be incorporated into the typical product design process easily and quickly. The visual aid of the violation viewing allows the engineer to quickly evaluate which violations are important and to make the necessary changes before building the hardware and possibly failing during EMC testing.

AFTER THE DESIGN IS COMPLETED

Once the product has been successfully designed, built, and passed the EMC testing, feedback into the EMC rules can help the next product development as well as help reinforce the importance of the tools used before and during the design process. Of course, if the product happens to fail during initial EMC testing, once the offending portion of the product is determined, the feed back into the EMC rule checking tool will tighten the appropriate rule limits as necessary.

SUMMARY

A variety of software tools are available to design engineers that can help increase the probability of passing EMC requirements the first time. Full wave tools are most useful to help understand the shades of grey for various design approaches, and are less useful to predict the pass/fail performance directly (due to the excessive amount of details required and excessive simulation run times for such complex models).

Rule checking software tools are very fast, accurate and helpful to identify potential design issues for high speed complex PCBs. The engineer still must make a decision about the relative importance of the violation and whether or not it must be corrected. The visual feedback and focusing on a violation allows engineers to make quick and informed decisions.

The bottom line is that none of these tools replace the need for the engineer to have a fundamental understanding of the physics of high frequency electromagnetics. These are simply tools to help the engineer, not replace the engineer! Imagine taking your auto to a repairman who knows nothing about engines, but has a full set of mechanics tools. Equally absurd!

In this time of short design cycles, product cost pressures, and increasing RF noise from wireless devices etc., no one can afford to *not* use these tools to their fullest potentials. Don't be like the woodsman and ignore things that will help you be successful!

2 Courtesy of CST

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A Primer on Global Regulatory Requirements for ITE

BY JOHN MAAS AND
MARIEL ACOSTA-GERALDINO

Sellers and importers of Information Technology Equipment (ITE) must comply with a vast array of hardware regulations when marketing their products in today's world. The scope of hardware regulations includes the following basic disciplines:

- Product Safety
- Electromagnetic Compatibility (EMC)
- Homologation of wired and wireless telecommunication devices
- Energy Efficiency
- Environmental
- Chemical

Such regulations are established at many levels, including national, regional, state, province and even individual cities or towns. In many cases, hardware regulations carry the force of law. Hence, a complete and in-depth understanding of the regulations applicable to any particular product is needed to avoid running afoul of the law. Being aware of all the regulations that apply to a product can be challenging enough, even before understanding all the details.

REGULATORY FUNDAMENTALS

Regardless the discipline, all hardware regulations encompass a common set of basic elements.

- Technical evaluation, which may include testing or engineering analysis
- Documentation of results, often in the form of a test report
- Conformity assessment procedures, including Declaration of Conformity (DoC), verification and certification
- Product and packaging marking
- Information to the user, with required language translations
- Market surveillance and on-going compliance
- Registration to the government and follow up (registering laser devices with the FDA, for example)

It should be noted that some regulations may not require explicit action on all of these elements. For example, certain regulations do not require a statement of compliance to be included in the documentation provided to the end user of the product. Other elements may be included as well, such as an audit of procedures and capabilities of manufacturing factories.

The technical evaluation typically includes either testing a sample of the product against some defined standard or set of standards or an engineering analysis or assessment. Restrictions or rules on who can perform the testing or evaluation vary. In some cases, the test or assessment may be performed by the product's manufacturer, while other regulations for the same basic discipline may require the use of an independent third party. If testing to standards is required, the lab performing the testing may need to be approved by the regulatory agency or accredited through a designated lab accrediting agency. With the wide possibility

of requirements on who can perform the evaluation and what specifically is required or allowed, it is easy to see why in-depth knowledge of the applicable regulations is essential for successful compliance.

Once the technical evaluation is completed, the results must be documented. The old adage of the work not being done until the paperwork is completed definitely applies in hardware compliance. Without adequate documentation of the evaluation, one cannot truly demonstrate compliance with the requirements. What product was evaluated/tested? What configuration was evaluated/tested? How was the evaluation/test performed? Who did the work, and were they properly qualified to do it? If the company is accredited to perform the work, is their accreditation through an organization that is accepted or recognized by the regulatory body? The list of content that must be included in a test report can be quite extensive. Consider the following example.

1. Test Report Cover Page stating the regulation the report encompasses
2. Test standard and test method that were applied and any deviations from the specified procedures
3. Classification of the product with respect to the regulation (for example, Class A or Class B for EMC emissions test results)
4. Description of the device being tested for approval, including marketing designation or model number
5. Product specification sheet describing its functions and capabilities
6. Functional block diagram
7. Specific identification of the device that was tested, including serial number and detailed list of all hardware content
8. Description of software used to exercise the unit being tested
9. Measuring equipment used in performing the test, including make, model, serial number and calibration details
10. Test results
11. Description of any changes made to the device during testing to meet the test limits
12. Photographs of the test setup
13. Photographs of the device being tested
14. Diagram of the physical arrangement and configuration of the unit tested
15. Drawing or photograph of the product label showing required marking(s) and location of label on the device

The conformity assessment procedures define the specific process steps that must be followed to satisfy the regulation and include things such as filing a report with an agency versus keeping it on file to be made available if requested These procedures can be placed into three basic categories:

- Certification
- Suppliers Declaration of Conformity
- Verification

Certification generally requires filing specific documentation with the agency and receiving a certificate in return. Required documentation may include a test report or detailed technical assessment of the equipment being certified, description of the equipment, instructions furnished to the user of the equipment and information about the manufacturer importer. To ensure the manufacturer does not swap parts for inferior/lower cost substitutes after the product is certified, all components that are considered critical are included in the certification documents. Agency representatives may audit the manufacturer to verify the product continues to be built as originally tested. Quarterly audits are a common practice

for Product Safety certifications. Changes in the hardware considered critical would drive recertification.

In a Suppliers Declaration of Conformity procedure, the supplier (typically the product's manufacturer) completes a form attesting, or declaring, that the device complies with the required regulation. The method used for demonstrating compliance is often listed on the declaration. In some cases, the declaration is distributed with the product to the end user; while in other cases, it is kept on file to be made available upon request.

Verification is the simplest form of conformity assessment in which the supplier creates documentation to verify that the product meets the requirements. Typically, this documentation would be a test report that is kept on file and made available upon request.

Laws and regulations from different countries drive the manufacturer to choose the specific method that will make marketing a product feasible. In the USA for example, OSHA clause 1910.399 and national Electric Code (NEC) clause 90.7 drive the IT industry into using the certification method. In the European Union, DoC is widely accepted. In terms of cost and work by the manufacturer, the DoC would be considered the preferred methodology as it eliminates the third party certification agency. Certification via a third party agency adds delays to the certification cycle, it relies on the availability of the agency and adds costs for initial certification, manufacturer's audits, recertification and annual fees to place the agency's mark on the product. DoC requires all the documentation to be available; so, the manufacturer would still be required to do all the testing and keep the documentation on file.

Product marking involves placing a mark or statement on the product. Product's information labels are usually used as a venue to distribute regulatory information. Some of that information includes the following items.

a) Trademark, Model Designation, Certification Marks and Statements: Information on product certificates should match information provided on the label. For rebranding agreement, where the company's trademark shown on the label does not match the original manufacturer (owner of the certification), a number may be included below a certification mark, which can be used to relate the product back to the original manufacturer.

b) Manufacturing Location and Country of Origin: This information, historically required for trade and customs, is becoming more and more important in the regulatory area, because some countries are starting to require certification is done per manufacturing site. That means, when submitting a sample for testing, assuming you have two potential manufacturing locations, you would need to submit samples from each location to be able to ship from both manufacturing locations.

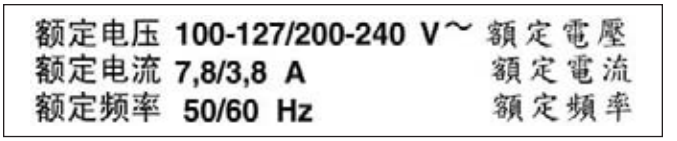

Figure 1: Product rating information shown with required translations of test into simplified Chinese and traditional Chinese

c) Translations: For certain categories of products, specific information on the label needs to be translated. Figure 1 is an example where both simplified and traditional Chinese text are included, to meet requirements for China and for Taiwan.

Different regulations require the marking is placed on the product or on both the product and the packaging. Other regulations allow alternatives of placing the product marking on the packaging or in the user manual.

Information to the user is generally a statement that the product complies with the regulation. It may also include caution or warning statements describing types of locations where the device is, or is not, allowed to be used. This information may have to be provided in more than one language. For example, in Canada, text-based statements targeting the end user have to be provided in both English and French.

Market surveillance includes any activities undertaken by the authorities to verify that products being sold do, in fact, comply with all applicable regulations. Market surveillance activities take many forms and may include checking products at retail outlets to ensure proper labeling; requesting copies of test reports, DoCs or certificates from the manufacturer or importer; or performing the tests defined by the standards or regulations on samples acquired from manufacturers, importers or retail outlets.

Compliance verification by Customs officials at the time of importation is another form of market surveillance. Verification by Customs typically involves document inspection to see if all the paperwork accompanying a shipment is in order. Noncompliances discovered during Customs verification typically result in delayed product deliveries to customers, as the noncompliant product (or suspected noncompliant product) will likely be held by Customs until compliance can be demonstrated or obtained. Even simple errors in documentation, such as the model number shown on the commercial invoice not matching the information on the certificate issued for the product, can create problems at the time of importation. Therefore, attention to detail is very important. This practice seems to be gaining in popularity among national agencies. Recently, the Customs Union of Russia, Belarus and Kazakhstan announced their customs authorities would begin checking imports of equipment in certain product categories to verify

compliance with the EMC requirements prescribed by the EuroAsian Economic Commission (EAC). South Korea has been executing a similar verification process for several years.

EMC

Let us now explore EMC regulations around the globe.

A device's ability to exist in its intended operating environment without causing electromagnetic interference with other electronic equipment (emissions) or without suffering undue interference from other equipment (immunity) is regulated in some 50 countries.

Fortunately for manufacturers, importer and other responsible parties, these regulations reference a much smaller set of common standards, as shown in Table 1.

This referencing of common standards substantially reduces the testing burden, although changes and revisions to the reference standards are not always adopted on uniform schedules by the various regulations. A recent example of the variations that can happen in adoption is the roll out of the CISPR 22 limits on radiated emissions between 1 and 6 GHz. Compliance with these limits became mandatory in October 2010 for the Republic of China (Taiwan), in March 2011 for the Peoples Republic of China, and October 2011 in Australia, the European Union and Japan. Depending on the changes introduced in subsequent editions of a standard, the effect of nonuniform implementation schedules can range from simply referencing the correct edition in test reports to testing a single product multiple times to accommodate the technical differences between versions if the standard.

Now that the new CISPR 32 standard for emissions from multimedia equipment has been published, it will be interesting to see how the various jurisdictions incorporate the standard into their requirements.

Even with the use of these common standards to establish the test conditions and limits that must be met, the industry must understand and correctly apply differences in the conformity assessment details between various global EMC regulations. A sampling of these details is summarized in Table 2 (page 86). Note that some regulations include multiple conformity assessment procedures, usually based on the type of product or product classification.

CONCLUSION

Many countries around the world have hardware regulations that must be met before ITE is marketed, sold or imported into those countries. These regulations exist for valid reasons and generally are intended to protect something: people, other equipment or the environment. Meeting the technical details of hardware regulations is only one step in satisfying the regulations. Satisfying the administrative elements of the conformity assessment process that need to be completed after the technical analysis or testing is finished can be more challenging and time consuming than the test or analysis itself.

Effective regulatory compliance engineers must have a solid technical background to understand the intricate details of product designs and the related test standards and evaluation criteria. They must also stay current on the ever-evolving test and analysis standards, related test equipment,

Type of Test	Base Standard
Conducted and Radiated Emissions	CISPR 22
	FCC Part 15 Rules
Power Line Harmonic Emissions	IEC 61000-3-2
	IEC 61000-3-12
Voltage Fluctuations and Flicker	IE C 61000-3-3
	IEC 61000-3-11
Immunity	CISPR 24

Table 1: Common standards serve as the basis for global EMC regulations

laboratory performance and approval criteria, accreditation requirements, import rules and the rules for the declaration and certification regimes of multiple regulatory agencies throughout the world. These skills must then be applied with meticulous attention to detail.

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Geography	Test Type	Conformity Assessment Procedure	Submit Test Report	Product Label	User Manual Statement	Lab Accreditation or Approval
Australia	Emissions	DoC	No	Yes	No	Recommended
Brazil	Emissions Immunity	Certification	Yes	Yes		Yes
Canada	Emissions	Verification	No	Yes	Yes	No
China	Emissions Harmonics Flicker	Certification	Yes	Yes	Yes	Yes
European Union	Emissions Immunity Harmonics Flicker	DoC	No	Yes	Yes	No
Japan	Emissions	DoC	No	Yes	Yes	Yes
South Korea	Emissions Immunity	Certification	Yes	Yes	Yes	Yes
New Zealand	Emissions	DoC	No	Yes	No	Recommended
Customs Union (Russia, Belarus and Kazakstan)	Emissions Immunity Harmonics Flicker	Certification DoC	Yes	Yes	Yes	Yes
Taiwan	Emissions	Certification DoC	Yes	Yes	Yes	Yes
Turkey	Emissions Immunity Harmonics Flicker	DoC	No	Yes	Yes	No
USA	Emissions	Verification Certification DoC	No Yes No	Yes	Yes	No No Yes
Vietnam	Emissions	Certification	Yes	Yes	No	Yes

Table 2: Sampling of compliance details for EMC regulations

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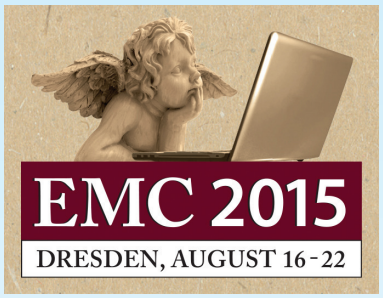

IEEE International Symposium on Electromagnetic Compatibility and EMC Europe:
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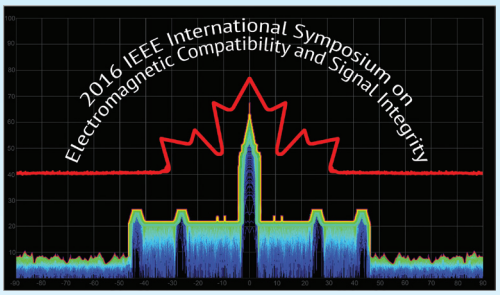

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A Primer on Automotive EMC for Non-EMC Engineers

BY GARY FENICAL

The automotive industry has changed drastically in recent years. Advancements in technology paired with tighter federal fuel and emissions regulations have resulted in the need to place more electrical systems into vehicles. This in turn places a greater emphasis on keeping the Electromagnetic Interference (EMI) of these systems from interfering with each other through radiated and conducted emissions, as well as crosstalk between the multitudes of on-board systems.

In addition to the sources within the vehicle, there are external sources of EMI that could interfere with vehicle electronic systems. These sources include, but are not limited to, cell phone towers, commercial broadcast signals of all sorts, remote entry devices as well as RADAR near airports and other such places. There are devices brought on board by passengers such as Bluetooth® devices, DVD players, video games and pretty much anything else you or your children can think of that must also be taken into consideration by automakers.

Before discussing the best solutions for common EMI issues, it is helpful to understand EMI; its influences on vehicle EMC (Electromagnetic Compatibility) and where EMI shielding is often used in automobiles. Once engineers have all the information and have considered all of the factors affecting EMI, then they can choose the proper shielding material for their need.

WHAT IS EMI?

EMI is a process by which disruptive electromagnetic energy is transmitted from one electronic component or device to another via radiated or conducted paths, or both. There are always both paths there but many times one is more prevalent than the other. In an automotive electronic system, EMI can adversely affect the performance of an integrated circuit internally, as well as that of other electronic components in close proximity.

There is a root cause to most EMI noise. In a digital system, clock pulses are generated to operate the logic. As these clock pulses are developed, they have a given rise time. The rise time, as it gets shorter, has a tendency to create a broadband energy pulse on the leading edge. This is commonly known as overshoot and/or ringing.

The energy present in the overshoot and ringing is the basis for generating other higher frequencies called harmonics. These higher frequencies are multiples of the clock frequency. Both odd and even multiples (harmonics) exist. In most cases, the odd harmonics (observed at 3, 5, 7, and 9 etc. times the fundamental of the clock frequency) create most of the EMI noise problems. However, even harmonics do exist and must not be ignored.

Placing more and more electronic systems into the confined spaces of vehicles poses a potential EMI problem. If not properly addressed, the interference can cause each system to malfunction or even fail. Current trends and technology advancements are introducing new electronic systems, and with that, new potential EMI issues into vehicles at a rapid pace. And, of course, every new device or system must meet all mandatory EMC requirements that give a reasonable assurance that the device or system will operate as intended and will not cause any other devices or systems to not operate as intended. This is especially critical where safety is concerned.

CURRENT TRENDS INFLUENCING VEHICLE EMI

As the automotive industry has progressed, there have been several factors external to the business which have influenced the evolution of today's vehicle. Between increased fuel and emissions standards by the federal government to the consumer's interest in additional convenience and entertainment options, the automotive industry must address these trends and the additional potential sources for EMI.

With the new fuel efficiency standards issued by the Transportation Department and Environmental Protection Agency stating vehicles must get an average of 35.5 miles per gallon by 2016, automakers are increasing the use of electronic engine controls. These electronic controls allow more precise control of the engine and therefore, fuel use, helping to achieve the increased fuel efficiency standards. The use of these controls also means additional electronics introduced into the car, resulting in potential EMI issues.

As fuel efficient automobiles become a focus, hybrid and electric vehicles are gaining popularity with consumers. These types of vehicles feature some degree of electronic drive systems, introducing new EMI issues for engineers, which must be dealt with to maintain the "mission critical" systems. These types of drives are high current devices. As current increases in a circuit, emissions increase. Therefore it becomes more difficult to meet radiated emission standards.

Additionally, consumers have become more interested in the optional convenience and entertainment systems available in vehicles today. These options include rear-view cameras, back-up radar and complicated infotainment systems. As more electronic applications are added to vehicles, additional EMI shielding for these systems is necessary to ensure the safety and functionality of the automobile. And let us not forget the PEDs (Portable Electronic Devices) many of us like to bring into the vehicle. Although the PEDs must meet FCC radiated and conducted emissions, these devices have not been specifically tested for use in an automotive system. Generally, conducted emission will not matter because there are only requirements for conducted emission on the AC mains.

SHIELDING

Shielding is the practice of reducing the electromagnetic field in an environment by blocking it, or isolating it from the "outside world" with some type of conductive or magnetic material. The amount of reduction depends on the material used, thickness of the shield, amplitude and the frequency of the fields. Shielding is noninvasive and does not affect high-speed operation of components and systems. Other solutions such as filters, ferrites and/or absorbers can change the signal characteristics and affect circuit operation. Shielding can be a stand-alone solution, but is more cost effective when combined with other suppression techniques such as filtering, absorbers, grounding and, most importantly, proper design. The use of shielding can take many forms, from RF gaskets to board level shielding (BLS) and there are several factors to consider when choosing shielding material.

Vehicle electronics must be designed for extremely high reliability at the lowest possible cost. If EMI is not considered at the beginning stages of the design process, it becomes more difficult and expensive to deal with later.

SELECTING PROPER MATERIALS

There are many factors that affect the proper selection of RF gasket materials. The following list identifies some of the key issues that must be considered when choosing a material.

- Operating frequency
- Materials compatibility
- Corrosive considerations
- EMC compliance specification
- Operating environment (In the passenger compartment, under the hood, etc.)
- Load and forces
- Cost
- Attenuation performance
- Storage environment
- Oil and fuel resistance
- Cycle life
- Electrical requirements
- Materials thickness/alloy
- Space and weight considerations
- Product safety
- Recyclability

WHERE IS EMI SHIELDING USED ON A VEHICLE?

As stated previously, there are both internal and external sources of EMI to vehicles. The automotive electromagnetic environment is very complex, requiring automakers to consider both these external and internal sources prior to production of vehicles.

Internal EMI problems can range from simple static on the radio to a loss of control of the vehicle. Internal electrical systems that can affect the vehicle function include:

- Collision avoidance radar
- Navigation-radio combination
- Power steering module
- Airbag inflator
- Adaptive cruise control
- Infotainment systems
- Tire pressure monitor, etc.

Vehicles' electronics can be affected by harsh external EMI environments. EMI can be generated from power transients, radio frequency interference, electrostatic discharge and power line electric and magnetic fields. These external sources can include:

- Garage door openers
- Remote entry devices
- Cell phones
- Bluetooth devices
- Third party navigation
- DVD players
- Pretty much anything that uses electricity but especially digital devices

Vehicle electronics must be designed for extremely high reliability at the lowest possible cost. If EMI is not considered at the beginning stages of the design process, it becomes more difficult and expensive to deal with later. All these issues have to be overcome through optimal electromagnetic compliance (EMC) design and the correct EMI shielding materials selection.

There is a wide variety of solutions available to automakers to help solve EMI issues. It is important to remember that considering EMI early in the design process is not only more cost-effective, but also more efficient.

EXAMPLES OF EMI SHIELDING USED IN VEHICLES

EMI shielding can be found in virtually any electronic system in a vehicle. Because of the confined space and the number of electronic systems within a vehicle, engineers often use EMI shielding as an efficient and cost-effective means of addressing interference issues.

Audio Systems – Audio and entertainment systems can be one of the largest sources of EMI in vehicles due to AM/FM radios and additional electronics including GPS and navigation or satellite radio. Other considerations include in-car entertainment options such as televisions and DVD players and the convenience of after-market items including multi-programmable wireless controls. Common shielding solutions used in these systems include board-level shielding, metal fingerstock, conductive Fabric-over-Foam and spring gaskets.

Interior Systems – These systems include the lighting (which is only a problem during turn-on and turn-off unless it is electronic lighting), power modules, rearview mirrors and display screens found in most cars today. These electronics are more vital to the function of the vehicle and EMI issues should be carefully considered. Typical solutions used in these systems include board-level shields, metal fingerstock, spring gaskets, Form-in-Place gaskets and conductive elastomers. For example, in a rearview mirror with a camera, a board-level shield could be used to prevent crosstalk among components on the circuit board. For a system that is exposed to the elements, conductive elastomers are a good choice as it is an environmental seal as well as an EMI gasket.

Safety and Security Systems – These systems, often considered "mission critical", include cruise control, driver information systems, tire pressure monitors, blind spot detectors and night vision systems. If these systems fail, then the safety of passengers is immediately at risk. Often engineers will use board-level shields, fingerstock, spring gaskets and microwave absorbers to mitigate the EMI in these systems. Microwave absorbers are used in some blind-spot detectors and side-view radar to help alleviate cavity resonance and reduce crosstalk between boards and elements. As frequencies get higher, absorbers become a more efficient solution. It is difficult to put a number on just when to rely on absorbers as opposed to the shielding but in the low gigahertz region is a good rule of thumb.

EMI SHIELDING OPTIONS FOR AUTOMAKERS

There is a wide variety of solutions available to automakers to help solve EMI issues. The following discusses the shielding options most often used in vehicles. It is important to remember that considering EMI early in the design process is not only more cost-effective, but also more efficient. Automakers and design engineers should consider all factors when choosing the proper EMI material for their needs.

Fingerstock and Spring Contacts

Metal RF gaskets are made from various materials. The standard product is offered in Beryllium Copper (BeCu), but phosphor bronze and stainless steel are also available.

The metal must be conductive and have good spring properties. The metal RF gaskets generally have the largest physical compression range and high shielding effectiveness holding steady across a wide frequency range. BeCu is the most conductive and has the best spring properties. Fingerstock and spring contact products are ideal for high cycling applications requiring frequent access. Hundreds of standard shapes are available, as well as cut-to-length and modified standards. Fingerstock and spring contacts offer superior performance at elevated temperatures, often a concern in automotive applications. Metal fingerstock can be used from as low as 20% to 90% or more depending upon the geometry and material.

Fabric-over-Foam (FoF)

FoF EMI gaskets offer high conductivity and shielding attenuation and are ideal for applications requiring low compression force. The FoF profiles are available in a UL 94V0 flame retardant version and offer high abrasion and shear resistance. Typical FoF EMI gasket applications include shielding or grounding of automotive electronic equipment seams and apertures.

There are a wide range of shapes and thickness to meet any design need. Compression of the gasket from 30% to as high as 75% can be allowed depending on the geometry and FoF material, thereby accommodating the tolerances of many systems.

Form-in-Place (FiP)

Form-in-Place (FiP) EMI gaskets can be dispensed onto any conductive painted, plated, or metallic surface of an electronics enclosure that requires environmental sealing. It can be applied on complex or rounded surfaces as well as miniature devices requiring a precision gasket. In return FiP gaskets protect the enclosure against internally and externally radiated interference and environmental elements.

These EMI gaskets save costs in the form of raw materials, labor and assembly time. FiP gaskets allow for more critical packaging space for board-level components. Room temperature curing gasket materials eliminate the need for costly heat curing systems because single-component compounds eliminate ingredient mixing, thus shortening production cycles. They have shielding effectiveness in excess of 70-100 dB to 18 GHz and beyond.

Electrically Conductive Elastomers

Conductive elastomers are ideal for automotive applications requiring both environmental sealing and EMI shielding. Compounds can be supplied in molded or extruded shapes, sheet stock, and custom extruded or die-cut shapes to meet a wide variety of applications. Conductive elastomers provide shielding effectiveness up to 120dB at 18GHz and beyond and come with many different material choices for both the conductive filler and elastomer compound.

Conductive Foam

Conductive foam (CF) offers unlimited compression performance while providing a relatively soft Compression Load Deflection (CLD) curve. Lower CLD properties further reduce the potential distortion in the application. CF can be die cut into or supplied as gaskets or in sheet stock.

Board-Level Shielding (BLS)

When electrical and electronic circuits are in nonconductive enclosures, or when it is difficult or impossible to use RF gasketing, BLS provides the best option for EMI suppression. It is well known that the closer you are to the source of an EMI problem, the more efficient and less expensive it is to fix, and using a board-level shield is as close as you can get to the problem.

If done well, PCB level shielding can be the most cost-efficient means of resolving EMI issues. The approaches involve proper shield selection and optimal circuit design including partitioning, board stack-up, as well as high-frequency grounding of the board and filtering techniques. Generally, shielding on a PCB is some form of conductive cover mounted over one or more components. In some applications, a shielding barrier separates board components to prevent crosstalk.

Heat can be an issue when using PCB shields. Ventilation holes are usually an adequate way to address this problem. However, if ventilation holes do not provide enough heat dissipation, PCB shields are available with integral heat sinks or other thermal dissipation systems.

For extremely high frequency applications board level shields are available for use in conjunction with microwave absorbers.

As a low cost and common shielding method, a variety of board-level metal can-type shields have been used to eliminate EMI radiation from entering or exiting sections of a PCB. This method has primarily employed solder-attached perforated metal cans being attached and soldered to the ground trace on a PCB directly over the electrical components that need to be shielded. The can-type-shields

are often installed in a fully automated fashion via a surface mount technology process at the same time the components themselves are installed onto the PCB using wave soldering, or solder paste and a reflow process. Such cans offer very high levels of shielding effectiveness, are typically very reliable, and are widely used in the industry. But remember that a board level shield is only five sides. The manufacture (PCB designer) must provide the sixth side in the form of a solid layer within the board with properly spaced vias to attach the BLS.

CONCLUSION

With the advancements in technology and the increased emphasis on fuel efficiency, the automotive industry has placed more and more electrical systems into cars than ever before. These electrical systems present a greater need to control the EMI issues they often present in the vehicle environment. If EMI issues are not addressed, automakers risk the proper functionality of basic and complex systems within the car, and even passenger safety.

Automakers must take into consideration a number of factors when choosing materials for their EMI needs, including internal and external sources of EMI and cost. Engineers should always consider the potential EMI issues in the beginning phases of the design process, as it will be more efficient and more cost-effective.

There are a number of potential EMI shielding solutions for the automotive industry. With a variety of shapes, sizes, material options and mechanical factors, however, there is a product that will fit virtually any need.

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Basics of EMI Troubleshooting

BY WILLIAM D. KIMMEL, PE AND
DARYL D. GERKE, PE

Sooner or later, anyone involved with EMI will be involved in troubleshooting an EMI problem, wherever it may surface. Most commonly, the problems will be uncovered during EMI testing, generally very late in the product design cycle, resulting in costly patches and schedule delays. It is best if preliminary EMI testing is done early in the design stage - EMI problems can be uncovered early enough that corrective action can be done in a timely fashion, ideally at the circuit board level. On the back end, EMI problems are often encountered in the field - perhaps because the environment is harsher than that expected by the regulatory agencies or because of an installation problem.

In each of these situations, there are a wide variety of problems that can occur: there may be multiple problems co-existing, and there is usually more than one way to fix the problem. Considering the range of problems, it would seem that EMI troubleshooting is a hit-or-miss situation. Nevertheless, a reasonable methodology can be formulated to minimize the false starts. There will never be a sure fire approach to running down problems, but the process can be minimized.

This article will categorize the basic EMI problems, where they are likely to occur, and the tools available for running the problem to earth.

A REVIEW OF EMI PROBLEMS

Let's start by summarizing the problems likely to be encountered, as evidenced by modern EMI test requirements. The US military formulated the basic terminology: emissions and susceptibility, and both radiated and conducted paths: RE, RS, CE, CS. (In more recent times, the term "susceptibility to interference" is commonly replaced by "immunity to interference,")

So, there are basically two considerations: emissions vs susceptibility and conducted vs radiated. A closer look at these will give clues as to how to proceed.

Problems uncovered during EMI testing are definitive, with specific frequencies and levels being readily available. Problems uncovered in the field are much more elusive, as the cause of the problem may not be obvious. In this case, it will be necessary to identify the cause before effective remedial action can be taken.

Let's start with a summary of these four basic issues, how they occur, and when they occur.

Emissions

Emissions from electrical and electronic equipment are almost exclusively uncovered during EMI testing, and are perhaps the most common of EMI test failure: the limits are set to prevent interference to sensitive nearby radio receiving equipment. Emissions are generally too low to pose a threat to nearby ordinary electronic equipment. Accordingly, emission problems are rarely encountered in the field.

Since radio receiving equipment operates on continuous waves, the source will also be periodic waves and their harmonic frequencies, most commonly oscillators and switching power devices.

In the field, heavy starting loads and inductive kick from turn-off in your equipment may affect other equipment - these won't typically be uncovered during EMI testing, another reason for uncertainty in the field.

Immunity (or susceptibility)

External interference sources assaulting the equipment are varied, as evidenced by the array of susceptibility tests: conducted and radiated RFI, power transients, lightning and ESD, to mention the most common. In addition to radio sources, transients from nearby equipment, notably power loads, become an issue, as does lightning.

This is basically the opposite of emissions (interference getting into the box as opposed to interference getting out of the box) and, as such, the fixes are largely reciprocal.

Conducted or radiated EMI

Interference may enter or leave the enclosure by conduction via a data or power cable or by radiation, which may be directly through the enclosure or via a data or power cable. The culprit needs to be identified, as it is a necessary path to a solution. To understand why, we first need to understand what facilitates radiation.

Effective radiation requires a suitable antenna to receive or transmit, which requires a metallic element that is a significant fraction of a wavelength. So the first order of business is to establish the wavelength, which is calculated from the offending frequency:

$\lambda = 300/f$,

where f is frequency in MHz and λ is wavelength in meter.

For continuous waves, frequency is determined by test. For transients, use the bandwidth of the pulse, which is $1/(\pi * t_r)$. As an example, ESD has a rise time of 1 ns, providing a bandwidth of about 300 MHz.

Having determined the wavelength, look for metallic members greater than about 1/20 wavelength. In actuality, resonances occur at 1/4 or 1/2 wavelength, where radiation is near optimal, so anything approaching 1/4 wavelength becomes significant. This applies to dipole antennas (like cables), slot antennas (openings in metallic enclosures), and loops (internal cables and circuit board traces).

Table 1 gives some representative dimensions as a function of frequency.

The bottom line is, low frequencies don't radiate effectively, as there are few metallic members large enough to make a good antenna. At 30 MHz, where commercial radiated emission tests start, the only metallic elements long enough to serve as effective antennas are cables. Enclosure dimensions, being much smaller, don't become a consideration until about 300 MHz.

Alternately, high frequencies don't conduct well, due to lead inductance in wires and cables, so conducted EMI is largely a low frequency issue. Overall, common radiated RFI frequencies tend to be a few hundreds of MHz, which puts cables as primary suspects. Low frequencies, such as from switched mode power supplies (SMPS) and motor drives, tend to dominate at conducted frequencies, below 30 MHz. Yes, these are rules of thumb - there will certainly be radiated problems below 30 MHz and conducted problems above 30 MHz. Military standards test with a considerable frequency overlap.

Transients vs continuous waves

As mentioned above, transients don't show up in emissions testing. For immunity, both transients and continuous waves may cause problems. Transients tend to create digital errors while continuous waves tend to cause analog input errors. Further, emissions tend to originate from low impedance circuits such as output drivers and switching power circuits. Immunity tends to attack high impedance circuits, such as op amp inputs and feedback circuits in voltage regulators

Frequency	1/20	1/4	1/2
1 MHz	15 meter	75 meter	150 meter
10 MHz	1.5 meter	7.5 meter	15 meter
30 MHz	50 cm	2.5 meter	5 meter
100 MHz	15 cm	75 cm	1.5 meter
300 MHz	5 cm	25 cm	50 cm
1 GHz	1.5 cm	7.5 cm	15 cm

Table 1: Dimensions for Effective Radiation

FAT-ID

All interference problems have three common elements: There is always a source of interference, a receptor of interference and a path linking the source to the receptor. It is usually not possible to eliminate the source or the receptor, so the remaining choice is to attack the path. Table 2 shows some possibilities. Depending on the problem, the source or receptor (or both) may be apparent, but, if not, they will need to be identified.

We have an acronym that we use in identifying the key parameters during the design phase, FAT-ID - frequency - amplitude - time - impedance - dimensions. The acronym is useful for troubleshooting, as well. Once the source and receptor has been identified (perhaps tentatively), the next steps are to identify these parameters:

Frequency - identifying the problem frequencies is the first step in troubleshooting - all remedial steps depend on this information, Lacking this, you are reduced to guessing, and this is not a productive approach. Test results will provide this information but with field problems you may need to hunt, or guess.

Amplitude - what is the amplitude relative to expectations? Is the problem modest, in which case mild fixes may be adequate? Or will major efforts be required?

Time - this can have several aspects. During EMI testing, it may be during a particular operational state of the equipment. If in the field, it may be a particular time of day or season.
Impedance - this will be a factor with I/O and filter design.

Dimensions - depending on the problem frequencies, potential antennas may be found in cable length or enclosure openings.

STARTING WITH FIELD PROBLEMS

Problems that surface in the field are almost always harder to run down than test lab problems. In a test lab, the failure problems are specifically identified with calibrated data, and the efficacy of the fixes can be readily evaluated.

In the field, the source of the problem is often unknown, and may well be intermittent: the failure may occur at seemingly random times and there may be no apparent sources. So the problem is to figure out what caused the failure, patch in fixes, then to be confident that the problem has been fixed.

Handling Field Problems - Identifying the Source

The first order of business is to identify the cause of the problem, recognizing that the cause may not be directly found. At the site, look for possible causes. Here are the common possibilities:

Sources	Paths	Receptors

• Microprocessors
• Video Drivers
• ESD
• Transmitters
• RF Heaters
• Power Disturbances
• Lightning
	• Radiated
	  ○ EM Fields
	  ○ Crosstalk
	  ▪ Capacitive
	  ▪ Inductive
	• Conducted
	  ○ Signal
	  ○ Power
	  ○ Ground
		• Digital
		  ○ Microprocessors
		  ○ Reset
		  ○ Other Logic
		• Low Level Analog
		• Receivers

Table 2: Interference Involves a Source, a Path, and a Receptor

Radio sources - Possible sources are nearby radio and TV transmitters, fixed base commercial and emergency transmitters. Internal to the facility, look for RF heaters, arc welders, and use of hand held radios - these are mobile and sporadic. If vehicles may be stopped in a garage, consider on-board radio transmitters.

Power disturbances - look for heavy equipment, large motors, etc., common in industrial facilities and often found in commercial office buildings (elevators and air conditioners, for example). Depending on the geographical area and the season, lightning strikes may be a factor.

Electrostatic Discharge - ESD can be a problem any time the humidity is low, particularly in the heating season. There may be static generators within the facility, such as conveyer belts and paper or plastic film rolling. In extreme cases, ESD below the human threshold of feeling (about 2 kV) may cause equipment anomalies.

Handling Field Problems - Forcing the Failure

Running down a field problem is nearly impossible without being able to evaluate whether your corrective action is effective. To do this, it is vital to be able to force the failure, which requires some external equipment. Formal test equipment is desirable, but often not available or permissible.

ESD guns are readily available, are portable, and relatively inexpensive. ESD applied directly to the equipment carries some risk of damage, and this can be especially problematic in the field, as the equipment may be in actual operation at the time in question. So if ESD is a possibility, test with extreme caution, starting with indirect discharge if possible, followed by very low level direct contact. Inexpensive ESD sensors are useful in detecting possible ESD sources.

Handheld radios can often be used to identify suspected radio interference. E field can be estimated by: E = 5.5*SQRT(P)/R. For a one watt transmiter, an E field of 10 v/m will be achieved at a distance of about ½ meter. Start by irradiating cables - analog sensor inputs are most vulnerable, followed by power cables. If possible, employ a handheld radio in use at the facility, usually from security or maintenance people. Common radio bands run at about 150 and 450 MHz. Hold the radio parallel to the cables, starting at a distance of maybe two meters, and closing in until a failure is observed. Then proceed to the equipment enclosure itself, repeating the procedure.

Power disturbances are difficult to simulate in the field, due to operating constraints in the field - injection of a transient may adversely affect nearby equipment sharing the same power source. If you have access to a power transient generator, you can proceed much as you would in the test lab. A power quality monitor is useful for identifying transient effects. Connect to the power line and let it run, preferably long enough to observe the failure. Cycling nearby equipment may force a failure, expediting this process.

A chattering relay might be used to inject transients into the power line: the relay coil is connected in series with the normally closed contact - the relay doesn't know if it should be on or off, so it chatters. It generates copious amounts of noise into the power line, perhaps too much for comfort.

Another possibility is to inject a transient into the power line. Tape an 18 inch length of wire to the power cord, ground one end of the wire and discharge into the other end. This will inject a fast transient into the power cord. Sneak up on the level, much as with the ESD test procedure described above.

STARTING THE TROUBLESHOOTING/FIXING

We'll start by assuming you know, or have a reasonable handle on the interference source and recipient. This would definitely be true if you are working with test lab data, but may or may not be true with field problems.

1. Start with FAT-ID. This will provide initial insight to the nature of the problem. Knowledge of frequency helps you to identify significant metallic members and impedance of critical paths.
2. Minimize the system. Remove all unneeded cables and power down unneeded equipent. The goal is to start with as few variables as possible. Where cables are necessary, use clamp-on ferrites to minimize cable effects. Establish a baseline failure, compare with that of the unmodified set-up. If there is still a failure, it's time to work on the system as is - power input is a good place to start.
3. As improvements occur, remove the ferrites and continue by adding cables. Evaluate and fix as you progress. If your enclosure is non-conductive, you will need to attack at the circuit boards. If accessible, apply fixes at the board boundary, typically with filters.
4. If you can't eliminate the problem by working the cables or if the problem persists even with a minimum system, turn to the enclosure. If you have a metallic enclosure, close the seams for effect, using conductive copper tape or wrap in aluminum foil.

Knowing the problem frequencies gives some clues as to where to start. Frequencies below about 30 MHz are usually conducted, often power line related. Above 30 MHz, problems are usually cable related. Above about 300 MHz, enclosures and circuit boards start to become contributors.

FIXES

First to note, when troubleshooting, there may well be more than one problem, and those may be handled by the same fix, or a combination of fixes. In particular, with a continuous wave frequency range, the same problem may show up at a number of frequencies. Here, it is usually best to start by attacking the lowest frequencies first - often the higher problem frequencies will diminish as well.

Second, the fixes you try during troubleshooting will usually be different than you would have used during the design phase. As a general rule, you design your equipment from the inside out, and you fix it from the outside in. This is simply a recognition that when you uncover a problem during testing, you have fewer options - you generally prefer to avoid spinning the board, so you try to find fixes at the box level. Of course, if the enclosure is non-conductive, this goal may not be realistic, so you will need to proceed to internal fixes.

Once you have identified potential problem areas, it is time to come up with some fixes. Here are some common remedies:

Cable Fixes

Since cables are very often part of the problem, let's start there. Again, your options depend on your enclosure. If you have a shielded cable, the connector termination is the biggest suspect. The termination at cable shield to connector, connector to mating connector and mating connector to bulkhead all need to be well done, or the cable will leak. The termination must be circumferential at each junction - pigtail terminations and single point grounding is not acceptable. Especially note: purchased cables are rarely terminated well.

You can put in a temporary fix using copper tape to close possible gaps in the connector area. If this is not feasible, use aluminum foil to make a temporary shield over the cable

shield, grounding the foil to the housing at each end. If the patch works, look for the breach in the shield - often a pigtail termination or, worse yet, the shield is grounded at only one end (and sometimes not grounded at either end).

And don't forget to check to make sure the mating surfaces are fully conductive.

If your cable is filtered but not shielded, make sure the filter assembly is circumferentially terminated to the housing or to the cable connector, whichever is applicable.

If you don't have a shielded enclosure, you will probably need to work on the circuit board, discussed below.

Enclosure shield fixes

For shielded enclosures, the principal issue is the openings and penetrations. The cable penetrations were discussed above, leaving switches, indicators, and fastener penetrations to deal with. The openings include seams, ventilation, and displays.

The penetrations are primarily a problem with ESD, and these can generally be localized by ESD testing. Discharge to switches, edges of touch panels and indicators and screw threads are prime suspects. Discharge near seams will couple energy to internal cables located near the seams. The problem with plastic enclosures is quite different. As there is no metal to which discharge can occur, the arc can only penetrate through openings in the enclosure, however small and indirect - ESD can travel surprising distances to find metal. Generally, the only option is to prevent discharge from penetrating to the internals.

For radiated emissions and immunity, seams and openings need to be closed, typically starting with the largest opening and those near cables. For immunity, you can check suspect openings with handheld radios. For emissions, sniffer probes and a spectrum analyzer will help identify possibilities.

Depending on the opening, you can close them with copper tape and aluminum foil. Closing openings like ventilators or displays may need to be covered with conductive screen or possibly perforated aluminum foil. If there are a number of suspect openings, it may be better to close up all of them by wrapping the entire box, then remove patches of foil one at a time while evaluating results.

Circuit board fixes

If you have no external shields to work with, your only option is to work at the circuit board, often at the board/cable boundary. Handheld radios can be used to force failures, especially at power and data cables. Sniffer probes and spectrum analyzers can help isolate an emission issue - typically by tuning to a problem frequency, then moving the probe around the board. The smaller probes are more selective but less sensitive. H-field probes work best on traces and cables, E-field probes work best on open connectors and chips. If you want to get really local, connect a high impedance scope probe to the spectrum analyzer input to get right down to the pin.

Most emission and immunity problems will be traced to the board boundary to the cables, using filters, transient protectors or a combination, whether this is radiated or conducted, emissions or susceptibility. If your problem is emissions, you have the additional option of filtering power and signals on-board, and using on-board shields.

Circuit board problems are best uncovered during pre-test, when you have some circuit board design flexibility.

SUMMARY

Troubleshooting EMI is an uncertain process, and usually takes more than one iteration to run down even a single problem, not to mention cases where multiple problems exist.

A methodical approach can reduce the number of false trails. Start by gathering information, establishing a list of probable causes, deciding what tools and components will be needed, minimizing the system, trying fixes until results are satisfactory.

Daryl Gerke, PE *and* ***Bill Kimmel, PE*** *are the founding partners of Kimmel Gerke Associates, Ltd. The firm specializes in EMC consulting and training, and has offices in Minnesota and Arizona. The firm was founded in 1978 and has been in full time EMC practice since 1987.*

Daryl and Bill have solved or prevented hundreds of EMC problems in a wide range of industries - computers, medical, military, avionics, industrial controls, vehicular electronics and more. They have also trained over 10,000 designers through their public and in-house EMC seminars.

Daryl and Bill are both degreed Electrical Engineers, registered Professional Engineers, and iNARTE Certified EMC Engineers. Between them, they share over 80 years of industry experience. For more information and resources, visit their web site at www.emiguru.com.

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Growing the Engineer's Toolkit:

Project Management Tips and Techniques

BY MARK MAYNARD

"If you are not willing to learn, no one can help you.
If you are determined to learn, no one can stop you". – Author Unknown

In today's fast-paced product development cycles, the pressure to compress testing and certification schedules is constantly increasing, with global competitors all rushing to get their new technology to market first. Mistakes made in compliance testing and certification processes can have huge financial impacts if product releases are delayed, or lead to later stop-ships or recalls. Utilizing project management techniques can provide great benefits by improving the efficiency and quality of compliance projects.

WHAT'S IN YOUR TOOLKIT?

As regulatory compliance professionals, we are expected to stay current on the latest international standards and test methods, keep up with the latest regulatory requirements for our company's market countries, and keep pace with the constantly changing technology in both products and test equipment. But what tools do you have to keep track of your assigned projects, and what do you do when things don't go as you've planned? When you find yourself in a ditch, what do you do to get out?

I will provide a few effective project management techniques that can help increase your efficiency, lower your stress, and help to ensure more success with your compliance projects. This is not a comprehensive overview of all aspects of project management, but rather provides some exposure to the benefits of the subject, and to encourage additional study of this topic.

FASTER, CHEAPER…BETTER?

After a decade working of working in the compliance field at one of the largest ITE companies, I noticed that I kept running into the same types of problems with my product certification projects, and that my colleagues were having similar issues. As an engineer who was also involved with quality management systems, I knew there had to be a "root cause" for these glitches that kept showing up. As I examined the project data, I saw that these issues weren't related to a lack of knowledge of the regulations or agency processes, nor were they related to a lack of technical knowledge such as operating test hardware or software, or the current prescribed test methods. Instead, they all seemed to be related to the internal processes for product development, the assumptions used to build schedules, and miscommunication.

THE BIG ELEPHANTS IN THE ROOM

This led me to the discovery of the field of project management. I was astounded to learn that not only were my issues fairly common, but there already existed a huge

The Elephant in the Room: Project Management

Project management is a huge field, and has many parts and dependencies required for the full implementation of the methodology, but there are some vital tools that can be applied which will help to make your work more manageable.

number of books, magazines, websites, and on-demand videos, all dedicated to these tools and concepts. I quickly realized how beneficial this information would be to increasing my project success and on-time completions. Over the next five years I dove into the study of the best practices of project management, taking formal classes, and culminating with my certification as a Project Management Professional (PMP)
by the Project Management Institute (www.pmi.org).

Please don't get nervous; I'm not recommending that you also spend five years of concentrated study on this subject. I just wanted to share the path that led me to identifying the most common non-technical issues with product compliance and certification projects, which I dive into below; the two "Big Elephants" that we don't normally talk about in compliance engineering: project management and communications.

Elephant #1: Project Management

As mentioned, project management is a huge field, and has many parts and dependencies required for the full implementation of the methodology, but there are some vital tools that can be applied which will help to make your work more manageable. In this section I'm going to cover three very effective project management tools, those being project planning, risk management, and deliverables.

Defining and Planning Your Projects

Before I started learning about project management, I just accepted whatever schedules came with my assigned projects, and hoped that I could somehow run fast enough to keep up with them. I came to realize that these schedules were developed by well-meaning planners in product groups, who were working from "one-size-fits-all" templates and applying them to very different types of ITE projects, without accounting for the required resources. To have realistic schedules, you must understand your product requirements and the amount of resources needed, in order to develop your own specific compliance schedule, and you must actively work with the project team so your requirements can be grafted into the overall project schedule.

The "Golden Triangle" is an excellent tool for understanding the interplay between scope, schedule, and resources involved in a project, and is a key project management concept (Figure 1). Scope refers to the totality of the features and abilities of the product; for example, if we are making a printer, for our compliance work we would need to define the printing technology (laser? Ink jet?), the data input and output connections (USB? Wi-Fi?), the market country list (US only? EU? Worldwide?), and other pertinent regulated features. The schedule part we are interested in is how much time is allotted for the various product compliance activities, such as EMC and product safety testing, report writing, agency submittals and certification timelines, and every other scheduled activity in our process to cover all of the items specified in the scope. And resources refers to the employees, product samples, test equipment, agency and lab fees, and any other expenditure required to complete the project.

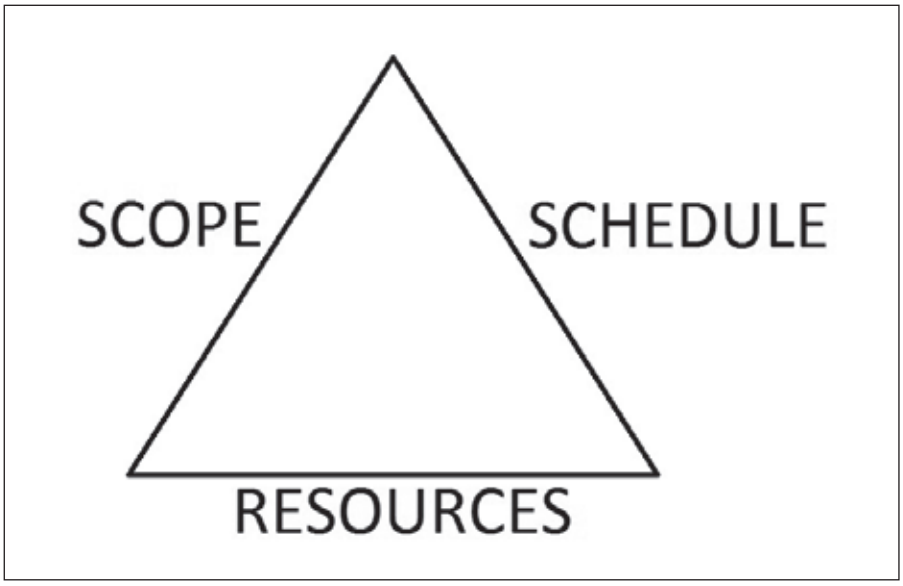

Figure 1: The "Golden Triangle" of Project Management

In formal project management, scope, schedule, and resources will define the major factors in the project, and how well they are defined can determine the success or failure of a project. You need to have a solid understanding of all of the processes and activities required to complete the compliance work covered by these three terms. If you are a new engineer, you need to seek out more experienced staff members who can provide this information, and help to mentor you through your first projects. In clarifying and documenting all three areas, compromise and trade-offs will be involved. If your company wants to speed up the schedule, it will take more resources, and you may have to drop some features from the scope.

Once you have completed your compliance "Golden Triangle," it is vital that this information is incorporated into the overall product definitions and schedule, as you are the project team's expert on these certification activities. Just think of scope, schedule and resources like the law of conservation of energy; you can't give to one without taking from another, and you can't magically create one out of thin air.
The mantra of "Faster, Cheaper, Better" I used to hear in the 1990s was a denial of this reality, and would almost without fail result in products that were late to market, with high cost overruns, and de-featured so they could be shipped, to the point of making them undesirable.

Have a Plan B

In compliance engineering, as in life, it's always good to have a backup plan. Market conditions change, technology advances, and suppliers can go out of business, so identifying the most critical links in your project processes is important in preparing alternatives for when things don't go as expected. In project management terms, this is called risk management.

Think of the most critical paths on your project compliance schedule, such as product testing, agency submittals, and department members. You will realize some things you will have control over, such as where and when you perform EMC tests, and others you don't have control over, like how long it will take for BSMI to review your submitted test reports. So for risk management, we will focus on the items where we have some control, such as choosing which test lab to use, and we will document the items we don't have control over, like creating an estimated timeline for BSMI approvals, based on historical averages.

The time to address risk management is well before you have an issue. If you've just delivered your new product samples to your favorite test lab you've been using exclusively for ten years, and it is put out of business by a freak flood the next day, that is not the time to realize you have no plan B. Frantically calling labs all over the country to find out if anybody can fit you in right away so you can still meet your schedule is not risk management, it's a crisis.

While most large and medium sized companies have disaster recovery plans, most of these are focused on overall infrastructure issues, such as finding new offices, restoring power, and rebuilding IT and communications networks, and are not specific to the needs of the individual departments, such as compliance engineering. You are the experts on what is needed to operate your group, so it is up to you to define and make these alternative plans in advance of issues, so you can quickly implement them with as little impact to your projects as possible.

It is a good idea to have a team made up of several compliance staff members when formulating these plans. Having different levels of experience and backgrounds will help in developing a better overall plan, which will address the most critical areas presenting the highest levels of risk. You can start by brainstorming on the biggest risks, then following that up by rating each item for the potential impacts to a project, and the likelihood it could occur. Then you could create an ordered listing, from highest risk to lowest, and choose the top ten items to address in your risk management plan. Over time you can add in more risks to address, and you should also periodically review your risk management plan to make sure it is still addressing the likely major risks.

Here's some examples of common compliance items needing contingency plans:

1. Having internal test labs
2. Losing key staff members
3. Project load increases with a hiring freeze
4. Regulatory documentation and certificates data storage
5. Test equipment failures
6. In-country representatives
7. Product recalls
8. Critical component suppliers

Once you have made your plans, they need to be documented, and the compliance team will need to receive training. There will also need to be someone designated as being in charge of these plans, making sure they are complete, periodically reviewed, and kept current. My experience has been if the attitude is "everybody is in charge" of the risk planning, then nobody is in charge.

The purpose of risk management is to lower the possibility of catastrophic impacts to the project by being ready to quickly implement prepared contingencies on the areas where you have choices and influence. Once you get into this mindset, you will start seeing the possible risks in other areas of your compliance work, and you'll be able to make those processes more robust. Start by evaluating your own situation, and develop your own plan B.

The purpose of risk management is to lower the possibility of catastrophic impacts to the project by being ready to quickly implement prepared contingencies on the areas where you have choices and influence.

Deliverables

Deliverables is simply project management-speak for your work product. In our world, that means compliance test reports, agency submittal forms and applications, and other required documentation supporting product certification and approval activities. This can be a key area for finding efficiencies, lowering costs, and increasing accuracy in submittal documentation, depending on the current processes in place at your company. Here's the story of one of my experiences.

One of the first jobs I was assigned when I started my quest to learn about project management was the task of looking at our internal EMC compliance report writing process. I was at a global ITE development and manufacturing company, and we sold our products into over 200 countries, so we were dealing with a lot of regulatory agencies. We were receiving critical feedback, rejected reports, and complaints from almost every agency, mostly due to inconsistent report formats, and the large number of errors in the reports. Also, our EMC engineers were complaining, because the multitude of compliance reports they had to write for each product they were assigned was taking up an ever-larger portion of their workday, keeping them from their engineering duties. All of this was giving management a king-size headache; I couldn't find anybody who was happy with the status quo.

I started off by interviewing agency contacts and our own EMC engineers, to document all of the issues, and to also define what actually needed to be accomplished to support the intended outcome of successful EMC agency approvals. The EMC agencies main complaint was that every report they received had a different format; they might receive one with radiated measurements in the front part of the report, followed by the conducted data, then concluding with the written portion of the analysis and summary, and the next day they would receive another with a totally different design and organization with sections covering combined radiated and conducted measurements for different voltages. They wanted a consistent standard report format to reduce the amount of time necessary for their reviews and so they could more easily identify errors in the reports.

In my interviews with the thirty EMC engineers we had in our regulatory compliance group, I discovered that each engineer was using their own individual report design, and thus I found the agencies had a valid complaint. We were, in fact, submitting thirty different versions of EMC reports. As to the errors contained in the reports, this seemed to be related to an overload of work and the reports were not being reviewed internally to catch mistakes prior to being sent out. For each assigned product, the engineer had to write eight different types of EMC reports. This could take more than a week to complete because the engineers had to gather the data, samples, photos, and everything else required for the submittals and also complete all of the agency application paperwork. Between this and their normal engineering duties, reviewing reports was not a priority, so it wasn't happening. After analyzing the agency requirements for the reports, I could see that we were wasting a huge amount of engineering time and resources with this system, as well as hurting our reputation and relationships with the agencies. I determined that a large part of the report preparation did not need an engineer to construct it, but how could this be addressed?

Our solution was to use this as a cross-training opportunity for our EMC technicians. This would free up our engineers to focus on engineering tasks, as well as implementing three levels of critical reviews of the reports. The EMC report templates were reduced to eight standard types, covering all of our worldwide market countries, and the product information, test data, and photographs added in by the technicians. The technicians would then review their work, checking against the original data. Next the EMC engineer assigned to this project would add in his or her engineering analysis, conclusions, and summary, then review the entire report for completeness and accuracy. The final report review would be conducted by another EMC engineer outside of this department. Each of the three reviewers would sign the report, and, to ensure accountability for the task of report reviews, their annual performance review included a metric for report accuracy.

Your situation is probably different, but ask yourself some questions about how you generate your deliverables:

1. Can you automate any part of the process?
2. Do you use standard templates?
3. Who's doing the data entry?
4. Who reviews reports?
5. Have you sought feedback from regulatory agencies?

The Elephant in the Room: Communication & CLEs

In over two decades of product development projects, every project I have observed or participated in that was canceled, late, over budget, or in some other category of failure, had one thing in common: somewhere a critical communication was not delivered.

Elephant #2: Communication & CLEs

In over two decades of product development projects, every project I have observed or participated in that was canceled, late, over budget, or in some other category of failure, had one thing in common: somewhere a critical communication was not delivered. Sometimes it wasn't sent, other times it was not received, but the root cause I attribute to these transmission failures are assumptions. Assumptions may be human nature, but they kill effective communication.

In formal project management, the term stakeholder is used to mean anyone that is involved in a project, or affected by the outcome of a project. In the product compliance field, our stakeholders are our product development teams, management, regulatory agencies, and our customers, among others. Having constant and timely communications with our stakeholders is vital to having successful projects (Figure 2). Remember that communication is a two-way process; both sending and receiving, and to increase your chances at success you need to listen to your stakeholders a lot more than you talk at them. Regular communication with stakeholders also makes it more likely they will return the favor and keep you in the loop on any relevant information they receive.

At the beginning of your project, you should find out who is on the project team. This will be the group of stakeholders that you are in contact with the most. Find out their requirements and intended uses for project information; such as how often, and how much detail is needed. Next, do the same for stakeholders outside of this team who will need to know about any changes as quickly as possible, such as management (who can help when you run into obstacles), and your customers who will actually use the product (or marketing, as the customer's representative). Provide project updates frequently, which might be weekly updates, but for critical issues daily updates may be required. The important point is to be out in front of the news cycle, meaning you are the one providing the latest updates, not the company rumor mill.

This up-front communication is important in keeping everyone informed so the current information can be used when making team decisions, but it is invaluable for those times when bad things happen to your project. If the project team hasn't heard a peep out of you in the first three months of the project, and then you speak up for the first time proclaiming that the compliance submittals have all crashed and burned and there is no way the approvals will be received by the ship date, you will just have killed your credibility for future projects. If you had been providing those weekly updates, there would have been earlier indications of issues and someone else on the team could have stepped in to assist you to keep it on track. Don't get the reputation for only being a bearer of bad news; we in the compliance field have a hard enough time as it is. Make sure you are reporting the good news when everything is going well.

Figure 2: Constant communication is the key to successful projects

One of the stronger impulses in humans is to try to hide bad news when it is received, hoping it can be fixed before anyone finds out, but this is another project killer. Usually by the time the truth comes out (and believe me, it will come out) the small, solvable problem has become a huge crisis and can be the death of a project. Stay open and honest, keep the constant communications open, and keep your integrity. This will open up the possibility for novel solutions from other team members and leaves open a path for you to recover your good name.

So speaking of bad news, let's talk about something called a "Career-Limiting Event," or CLE. I first learned about CLEs from my first compliance manager, and later mentor, Dave Staggs, who also taught me how to recover from them, which I'll outline next. As a human, you will make mistakes from time to time, and every once in a while, they will be an error of monumental proportions. When we are talking about a product development project, this can have huge financial impacts which can result in a questionable employment future, hence the term Career-Limiting Event. If you've been keeping up the constant communication with your stakeholders prior to this event, I have advice to share with you on redeeming yourself. But if you haven't, your time might be better spent on Monster.com.

First, you want to be the first to admit your mistakes. But before you do, you need to do some work, and do it quickly. Research what happened, and why it happened. Next, develop recovery plan options (more than one). This is vital, and the best single piece of advice I ever got from anyone about business: you have to come with solutions, not just talk about the problems. If you only talk about the problems, you're being a victim. Don't be a victim; they don't have long careers.

Once you have all of this information, prepare and practice your presentation. Yes, just like any other presentation, you need to practice to make sure you can clearly and concisely deliver your message. This is not the time to "wing it" and hope for the best; your job security and future prospects may well be riding on this. Stick to the facts and focus on the issues; this is also not the time to start pointing fingers and spreading around the blame. You're an adult, you made a mistake and you can take the consequences.

As soon as possible, deliver the news. Don't delay this presentation. Be transparent, direct, positive, and truthful. Don't dig a deeper hole by guessing or making assumptions. At the end of your presentation, ask for feedback, and take notes on what is said and asked. Answer the questions you can at this time. If you don't know the answer, state that you don't know, and promise to find the answer and get back to them.

Follow up on your commitments, implement the selected recovery plan, and then follow up to verify the results. Ensure frequent constant communications with your stakeholders during this recovery phase. Thank your stakeholders for allowing you the opportunity to recover; now is not the time to let pride or ego get in your way.

Admittedly, this is not a pleasant process, and it is not easy, but I haven't found anything else that works better while also allowing me to feel good about myself. There is a way to avoid this, however.

To avoid your own future CLE, follow this process:

1. Learn from the mistakes of others; note what they did right, and what they did wrong
2. Learn from your own previous mistakes; and don't repeat them
3. Keep your skills current, be a permanent student
4. Stay transparent and open; don't have hidden agendas
5. Assumptions: Don't make any; communicate instead
6. Projects: Verify, review, evaluate, check, re-check

Additional material on project management and communications are available from a wide variety of sources. In addition to the Project Management Institute (PMI) mentioned earlier, which has monthly meetings at local chapters throughout the world, there are many groups on LinkedIn, as well as a host of project management education providers available on the Internet. The IEEE Communications Society is also another great resource, also with monthly chapter meetings that are great for learning, networking, and finding experienced mentors. The only limitations are the ones you set on yourself, so don't hold yourself back, and keep learning!

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Usability Engineering

Observe Users, Improve Product Safety

BY FRANK O'BRIEN

Up until now there's been much emphasis on designing to make a product "idiot proof". This has provided some benefit, but what Usability Engineering is reminding us is that it is the designers who are sometimes viewed as idiots by the users. It is the users who are the experts (in usability).

For those involved in product safety, we could perhaps congratulate ourselves. Based on my testing experience over the last three decades, it is my view that products have become safer. No longer is it common to see products cause electrical shocks, burns, fires, or crushing/cutting injuries. We continue to see where we need improvements, particularly when we see new technologies, such as recent events associated with rechargeable lithium batteries. Tragic events associated with energies and materials in electrical products occur, but they have become quite remote.

The focus of this article will be on Usability Engineering for medical devices. We will look at the present state of medical device safety. The data will show poor usability is to blame for more preventable deaths than traffic collisions and firearms combined. We'll look at new Usability Engineering process requirements and provide an overview on how we can better control the risks associated with poor usability. Even though the focus of this article is on medical devices, the principals hold for all products. Poor usability represents the low lying fruit for safer products.

THE PRESENT STATE OF MEDICAL DEVICE SAFETY

As reported by the post-market surveillance group of the U.S. Food and Drug Administration (FDA), between 2005 and 2009, there were 56,000 adverse events (undesirable experience) involving infusion pumps, resulting in at least 700 deaths. There were 87 manufacturer initiated product recalls. In March 2010, the FDA ordered Baxter to recall 200,000 infusion pumps because of "numerous flaws". Other pump manufacturers took note, and voluntarily instituted their own product design reviews and, where necessary, recalls.

Based on a new study, "A New, Evidence-based Estimate of Patient Harms Associated with Hospital Care" by John T. James, PhD, published in the *Journal of Patient Safety* in September 2013, it is estimated that between 210,000 and 440,000 patients die in US hospitals due to preventable medical errors; a four-fold increase over 1999 estimates. The study also estimates that medical errors cause serious harm (e.g. loss of limb, sight, hearing), ten-fold to twenty-fold more common than lethal harm. The study details how better analysis of four past studies justifies the new estimates. These medical errors include those caused by medical and in vitro devices (IVD), both active and non-active, and the administration of pharmaceutical drugs.

Prior to this recent study, the best estimate of preventable medical errors that cause death had been an Institute of Medicine article from 1999, "To Err Is Human". This older study extrapolated data from hospitals in CO/UT, and NYC, and estimated at least 44,000 people, and perhaps as many as 98,000 people, die in hospitals each year as a result of preventable medical errors (adverse events).

Figure 1 shows the midpoint of the 210,000 to 440,000 estimated deaths due to medical error, alongside deaths due to traffic collisions and firearms.

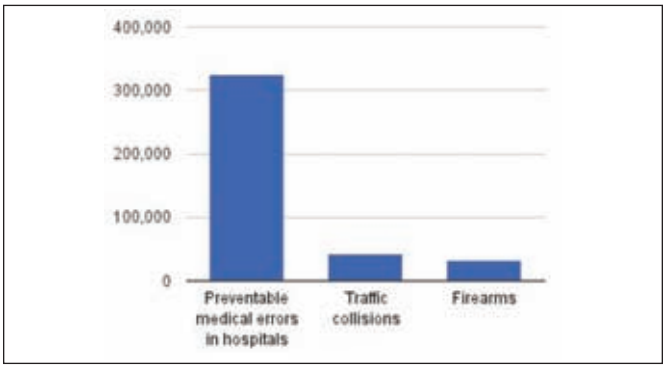

Figure 1: USA Deaths from Medical Errors (Adverse Events) in Perspective

The best source for aggregate medical device adverse incident/event data seems to be the UK based Medicines and Healthcare Products Regulatory Agency (MHRA). In Europe (including the UK), an adverse incident, causes, or has the potential to cause, unexpected or unwanted effects involving the safety of device users (including patients) or other persons.

The chart shown in Figure 2 shows adverse incidents by year, based on MHRA (UK) Annual Adverse Incident Reports from 2007 (which includes data back to 2001, and 2010

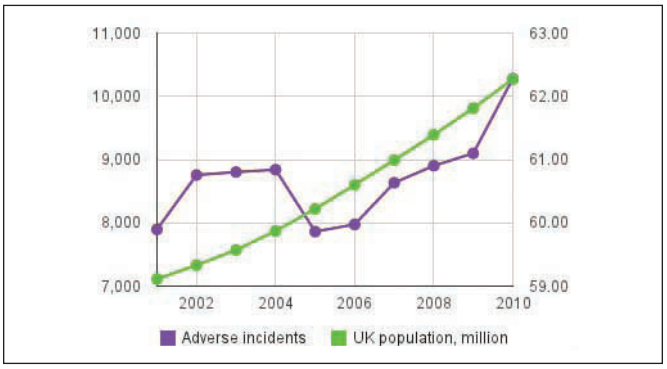

Figure 2: UK Adverse Incident and Population Trends

(which includes data back to 2008). We see the upward trend of adverse incidents. As this could be due to an increase in medical devices in use, I plotted as well UK population, based on World Bank data. From the population data, we begin to see some correlation between the two increases.

To better look at adverse incidents to population, I charted in Figure 3 adverse incidents per 1 million persons. I also broke out death and near death, from other adverse incidents having less severe outcomes.

Figure 4 shows adverse incidents by device type.

In Figure 4, the Other category includes (each with less than 5%) Surgical consumables, Aids for daily living, Syringes/needles, Disinfection/sterilization/disposal, Drainage/Suction, Beds/mattresses, Hoists, Artificial limbs, Walking aids, Physiotherapy equipment, and Orthoses.

Only some of reported adverse incidents are investigated by MHRA. Of those chosen for investigation, Figure 5 shows to whom responsibility for the incident was assigned. In assigning responsibility MRHA uses the following system:

- Healthcare facility, Use: After delivery; use errors, performance and/or maintenance failures and degradation
- Manufacturer: Before delivery; design, manufacture, quality control and packaging
- Unknown: intermittent faults (use error, software, EMC) or couldn't investigate

In looking at the adverse incident data one needs to be wary of reaching any definitive conclusions. Problems with the data include:

- Increase real? Or due to better reporting?
- Need to know adverse incident per devices in use
  - Are high adverse incidents for a device type due to in use numbers, device complexity, or other?

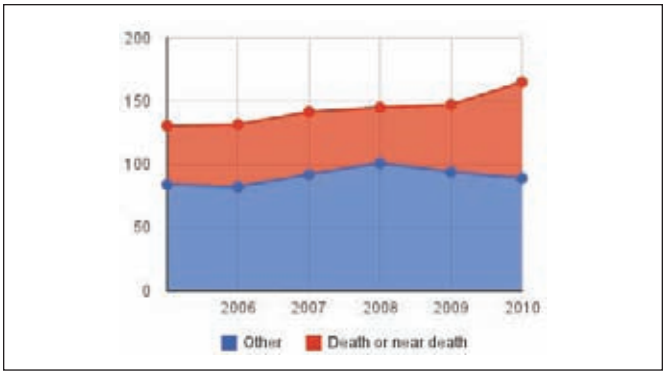

Figure 3: UK Adverse Incidents per 1 Million Persons

- Cause investigations should target use error specifically
  - Don't lump in with performance and/or maintenance failures and degradation by healthcare facility
  - Differentiate use error due to inadequate training by healthcare facility, etc; from insufficient usability by device manufacturer
  - Categorize by device failure mode (e.g. transformer, switch, software, EMC), or use error
- Increase in unknown causes results in less useful data (e.g. assigned causes)
  - Pull out suspected use error, software, EMC causes

Hats off to MHRA for providing aggregate data, even if not perfect. It would be nice to see FDA publish aggregate data annually, and/or make their databases a bit more accessible (they're searchable, but for aggregate data, not easy to download and reconstruct the relational tables).

Problems aside, one could reach the following qualified conclusions:

- 26% more adverse incidents per capita
- 29% more death or near death

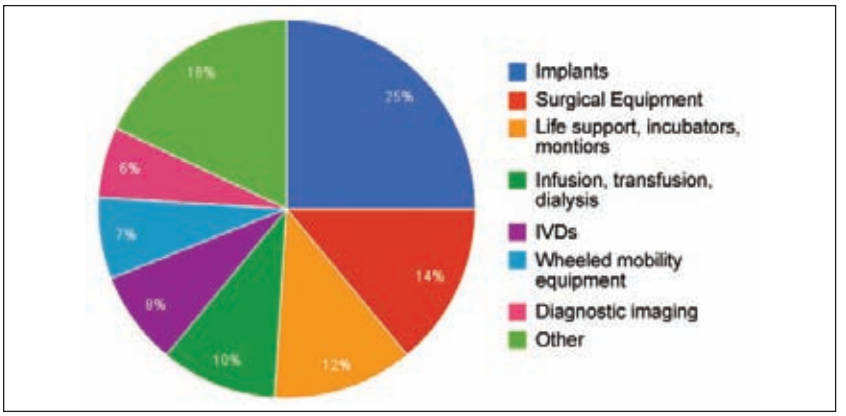

Figure 4: Adverse Incidents by Device Type

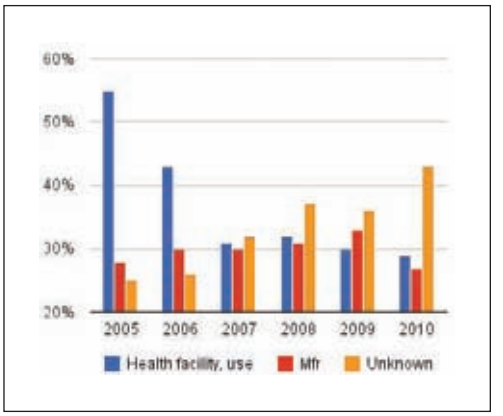

Figure 5: Cause of Investigated Adverse Incidents

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NBM-580 Meter shown here with multiple field sensors

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- 82% involve more complicated equipment, such as implants, surgical, patient monitors, infusion pumps, IVDs, wheelchairs, imaging, and similar
- During 2005-06, majority of cause was health facility, use
- During 2007-10, cause was shared between healthcare facility, use; and manufacturer design, controls

DO NO HARM

The latin phrase, *Primum non nocere,* "first, do no harm", is attributed to to Thomas Sydenham (1624–1689) in a book by Thomas Inman (1860), *Foundation for a New Theory and Practice of Medicine*. Putting things in the terminology of modern risk management, (e.g. ISO 14971:2007), where a medical device has an unacceptable risk of harm, a designer needs to implement effective risk control measures.

With the above adverse incident/event data in mind, take a look at Figure 6. What's the most likely hazard or failure mode that could result in harm? Hopefully everyone recognizes that it's the User Interface. As designers we need to recognize that this is an important, and perhaps the most important, design responsibility.

USABILITY ENGINEERING

Usability Engineering, or as FDA refers to it, Human Factors Engineering, is the process to identify where user interactions with a medical device have the potential for harm, and to implement effective risk control measures. The Usability Engineering process touches all design aspects; the hardware interface, the software interface, product markings, and any user documentation. Considered is usability associated with the full product life cycle, from transport, normal use, maintenance, to decommissioning.

Key standards to guide a manufacturer's Usability Engineering process:

- IEC 62366:2007 + A1/FDIS:2013, Medical devices - Application of usability engineering
- IEC 60601-1-6:2010, Medical electrical equipment -- Part 1-6: General requirements for basic safety & essential performance - Collateral standard: Usability
- ISO 14971:2007, Medical devices - Application of risk management
- ANSI/AAMI HE75, 2009 Edition - Human factors engineering—Design of medical devices
- Medical Device Use-Safety: Incorporating Human Factors Engineering into Risk Management, issued 2000
- Apply Human Factors and Usability Engineering to Optimize Medical Device Design, issued 2011 (draft)

The IEC and ISO standards have EN (CENELEC) versions for Europe, and are harmonized to the essential requirements of the Medical Device Directive related to ergonomics and information supplied by manufacturer. All are in the U.S. FDA recognized consensus standards database. They become the means to provide a presumption of compliance with essential requirements and a reasonable assurance of safety and effectiveness, with regards to acceptable usability.

All these standards are consistent with each other. The scope of IEC 62366 (which I consider the high level process standard) is all medical devices, including the more prevalent non-active devices like tubing sets, luer connectors, syringes, dental implants, sterile drapes; as well as electrical equipment like surgical equipment, patient monitors, in vitro diagnostic equipment, and non-implantable accessories to active implants. IEC 60601-1-6:2010, the medical electrical equipment collateral standard for usability, contains essentially only a normative reference to IEC 62366. The AAMI HE75 is useful as it has more specific guidance and examples. FDA guidance documents are also written to provide more specific examples, use FDA terminology, and provide references for further reading. Think of the AAMI HE75 and FDA guidance documents as informative annexes to IEC 62366.

In the remainder of this article we focus on IEC 62366.

IEC 62366 tells us that users want good usability:

- Effectiveness
- Efficiency
- Ease
- Satisfaction

Figure 7: It's all about the User Interface

With these user motivations and taking into account the use environment we can anticipate and investigate user actions (or interactions) such as pushing a button, toggling a switch, sliding a door, turning a screw, tapping a menu item, speaking into a microphone, filling a reservoir, or connecting a leadset.

Figure 8 provides terminology to refer to user actions (or interactions). Discussions are helped when we all use the same terminology. Note that ideally medical devices are desired to result in what we call, Correct Use; the designers

IEC 60601, Medical Equipment Term	Mapping to IEC 62366, Usability Term
Normal Use	Correct Use
Reasonably Foreseeable Misuse	Use Error (Slip, Lapse, Mistake)
Normal Use + Reasonably Foreseeable Misuse	Normal Use

Table 1

intent; the device fulfilling its intended clinical purpose/use. As designers we must also anticipate Use Error, (or reasonably foreseeable misuse), which can be Slips, Lapses, or Mistakes. Slips are due to buttons or menu items being too close together such as the maximize and close buttons in Windows. Lapses are due to too much complexity for the use environment. Slips and Lapses are unintentional. These should be fairly routine to anticipate and control.

Mistakes are more interesting. A designer needs to anticipate and investigate (assisted by user input and observation) where a user might default to behavior suggested by the user interface, or seek a shortcut. Mistakes are always intentional.

I like to think of mistakes as something Homer Simpson might do. Homer has good intentions, but nonetheless, somehow always seems to find himself in trouble.

Homer in the episode where he becomes "Max Power", says to Bart, "There's the right way, the wrong way, and the Max Power way."

Bart asks, "Isn't that the wrong way?"

Homer explains, "Yeah, but faster."

I think this sums up the new mentality that designers need to adopt.

Abnormal use is intentional and beyond any further reasonable means of risk control by the manufacturer. Think Pete Townshend from The Who and what he used to do to guitars after a concert (for young readers; he smashed them into bits and pieces). As reducing risk from abnormal use is beyond further reasonable means, a manufacturer has no further responsibility to reduce this risk.

For those versed in the terminology of the medical equipment safety standard series, IEC 60601, Table 1 provides a quick mapping.

We can see the intent of IEC 62366 is to remind us that reasonably foreseeable misuse or use error needs to be considered "normal". This is true of both IEC 60601 (clause 4.1) and IEC 62366, but IEC 62366 adds emphasis by using the term *normal use* for both correct and use error.

Consider as well that the term *use error* is NOT called *user* error. Use of the word *use* instead of *user* is intentional to emphasize that it is the designer's responsibility to risk control use error where it could result in harm. Use error should not be considered the user's fault.

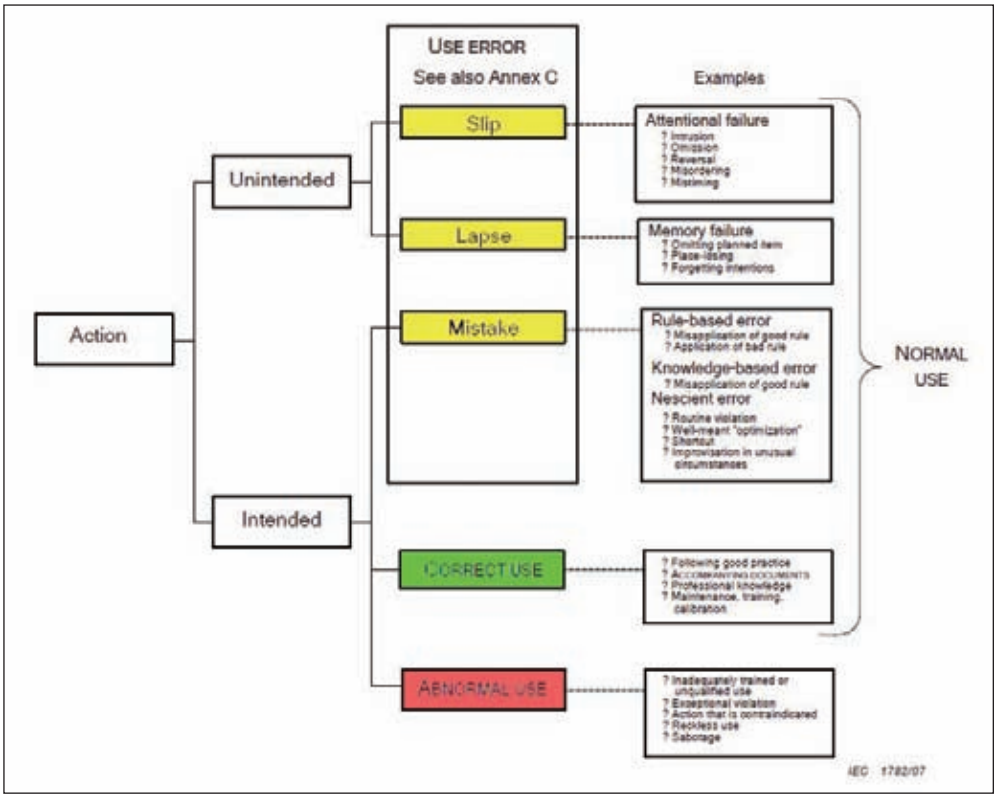

Figure 8: User action (interaction) categories (IEC 62366:2007, Figure B.1)

Verification can be carried out by engineering, as usability risk control measures such as the color, or blink rate, volume, or spacing to adjacent buttons can be verified. Validation necessarily involves users, as detailed in validation plan.

Figure 9 illustrates well that the Usability Engineering process has continuous improvement provided by its post-market surveillance feedback. This is much like a quality management system with its customer feedback, process metrics, and internal auditing, feeding into the management review and CAPA (corrective action, preventative action) process. A risk management process has post-market surveillance as feedback for risk control improvement.

Key aspects of a Usability Engineering process during the design phase:

- Application specification
- Frequently used functions
- Usability hazards (user input & observation)
- Primary operating functions
- Usability specification
- Validation plan
- Design & implementation
- Verification
- Validation (*user input & observation*)

The Usability Engineering process starts with a documented list of what the device is intended to do -- the application specification. We analyze and investigate this list to determine frequently used and otherwise primary operations related to safety -- frequently used and primary operating functions.

Based on our analysis and investigations, where use error could result in unacceptable risk, we add risk controls. These risk controls are defined in the Usability Specification. These can be included with other design requirements related to customer, business, and device failure risk controls, but there needs to be a means (e.g. a flag), to identify those related to usability risk controls, as these are inputs for the usability validation plan. The usability risk analysis process is repeated as the design becomes more detailed.

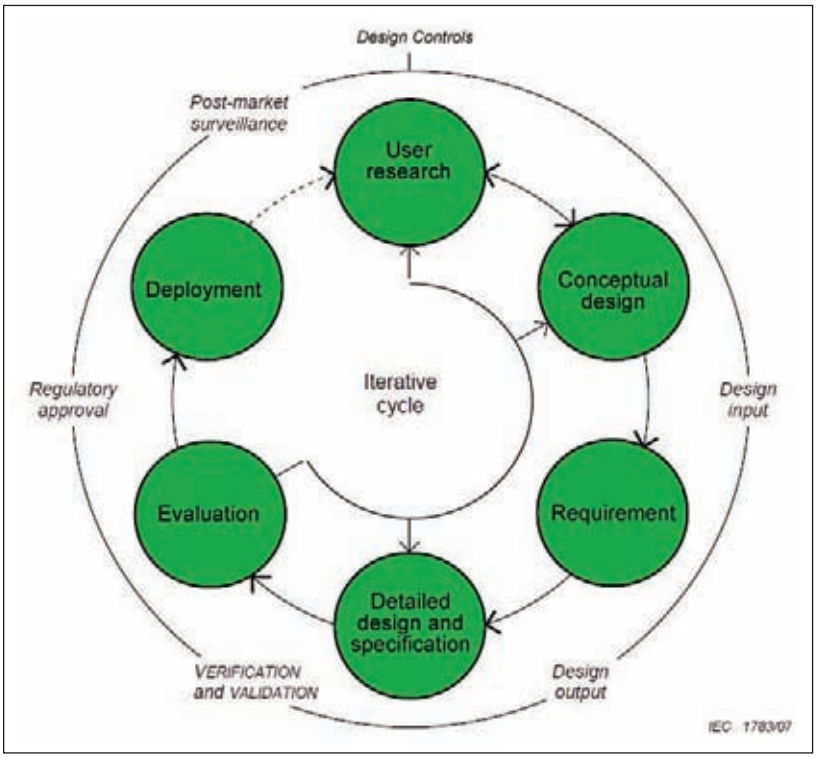

Figure 9: Usability Engineering process (IEC 62366:2007, Figure D.1)

A validation plan needs to be formulated to define the method(s), (e.g. test user population profile, interviews, simulated clinical use, actual clinical use, etc.), and criteria for usability validation. The testing method(s) and compliance criteria allow a validation of the effectiveness of the risk control measures.

Verification can be carried out by engineering, as usability risk control measures such as the color, or blink rate, volume, or spacing to adjacent buttons can be verified. Validation necessarily involves users, as detailed in validation plan.

USABILITY TRENDS IN OTHER PRODUCT SECTORS

Not only the medical device sector recognizes the importance of Usability Engineering. With the newest version of the safety standard for equipment for measurement, control, and laboratory use, IEC 61010-1:2010, 3rd ed, we have a new clause 16, which mandates

With both risk management and usability engineering, unacceptable risk is mitigated with risk control measures, defined by design requirements, in turn verified and validated. Post-market surveillance provides feedback.

that reasonably foreseeable misuse and ergonomic issues be addressed with risk assessment (analysis, evaluation, and where needed, effective risk control). Risk assessment is a new clause 17.

In the newest version of the safety standard for information technology equipment, IEC 60950-1:2005 + A1:2009 + A2:2013 (consolidated ed 2.2), in the principles for safety it mentions the need to consider foreseeable misuse. There is no separate clause for this hazard. But, as with all product safety standards, (i.e. the physical requirements for enclosures) foreseeable misuse is taken into account.

In the newly published, but as yet not widely used, safeguards based standard IEC 62368-1:2010, *Audio/video, information and communication technology equipment - Part 1: Safety requirements*, the term *reasonably foreseeable misuse* is defined. However its use is limited to the normative Annex on batteries and fuel cells. Nonetheless, having the term defined will facilitate useful safety discussions.

RISK MANAGEMENT AND USABILITY ENGINEERING

With both risk management and usability engineering, unacceptable risk is mitigated with risk control measures, defined by design requirements, in turn verified and validated. Post-market surveillance provides feedback.

With risk management, hazards are identified and risks defined by the design team including clinical application specialists.

With usability engineering, usability hazards are identified and risks are defined by *user input and observation*. Validation explicitly requires a formal plan to define how and by what criteria *user input and observation* will be sought and evaluated. It is this emphasis on user input and observation that Usability Engineering brings to existing quality system design controls and risk management.

USABILITY ENGINEERING FOR LEGACY DEVICES

User interfaces and user manuals for legacy devices are already designed. We cannot very well go back and follow a Usability Engineering Process without having to go back and effectively undertake the whole design process again -- something that isn't going to make business sense for products that have good experience in the market. This is much like off-the-shelf software, or what IEC 62304, the software safety standard, calls Software of Unknown Provenance (SOUP).

With the forthcoming Amendment 1 to IEC 62366, we now have what we call, User Interface of Unknown Provenance (UOUP). As with legacy hardware and SOUP, with UOUP, we have a practical process for conducting a sufficient review of UOUP, taking into account our new appreciation for the importance of good usability.

Amendment 1, Annex K, anticipated in first quarter 2014, provides a UOUP process for legacy devices:

- Relook at Application specification (K.2.1); develop list of Frequently used functions (K.2.2); Primary operating functions (K.2.3)
- Relook at Post market information (K.2.4)
- Relook at Hazard, Risk Analysis records (K.2.5);
- Consider need for any additional Usability risk control measures (K.2.6)

Figure 10: Cause and effect related to risk

TAKE AWAYS

Designers need to anticipate and investigate use error (reasonably foreseeable misuse):

- Optimize Usability (effectiveness, efficiency, ease, satisfaction)
- Risk control behavior that could result in unacceptable risk of harm

Users are the experts:

- User input and observation needed by design team, including clinical application specialists
- Users validate effectiveness of usability specification (risk control measures)

Based on a review of aggregate medical device adverse incident/event data, use error would seem to be a significant contributor.

Usability Engineering represents a new tool to help us design safer products. Manufacturers who adopt a Usability Engineering process will create safer products. Greater reliance on user input and observation makes intuitive sense if we are to reduce risk associated with use error.

Finally, with better adverse incident/event data collection, we will have the data to assist with root cause analysis, identify areas for improvement, and evaluate our performance.

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Frank O'Brien *teaches a best selling training course in IEC 60601, the medical electrical equipment family of standards for basic safety and essential performance, with locations in San Jose, Boston, Galway, and Amsterdam. His Boston based consulting firm is O'Brien Compliance Management, obcompman.com. He participates on IEC TC62 committees. He worked 24 years at Underwriters Laboratories where he evaluated literally 1000's of medical devices. In the past Frank has called home, San Jose, Frankfurt Germany, Long Island NY, and Syracuse NY. Frank has a Bachelor of Science in Electrical Engineering from Clarkson College, NY; and a Master of Science in Technology Management from SUNY Stony Brook, NY. When not busy with work, he enjoys time with his fiancee in Ireland, grandkids on Long Island, his family camp in Maine, exchanging stories over a pint of Guinness, a baseball game at Fenway, quiet moments with a cup of coffee, and solving puzzles.*

Your Guide to Effective Product Safety Labels

BY GEOFFREY PECKHAM

Of all the responsibilities product engineers are tasked with, safety labeling cannot be overlooked. Why? Because the bottom line is: if safety matters, your labels matter. This month, we'll explore the key elements to consider in creating the most effective labels possible.

It's a new year – a time for new beginnings, fresh starts, and getting refocused. It's a fitting opportunity to revisit the fundamentals in visual safety communication that can help to create safer products and workplaces. A critical part of the overall safety of your products and equipment is their safety labels. In this article, we'll outline the best practices in developing effective labels that can help to prevent injuries and save lives.

THE GOAL OF YOUR LABELS

Let's first review the goal of today's product safety labels. There are three essential purposes that an effective safety label should meet, and that product safety engineers *must* understand: 1) to communicate hazards to protect those who interact with your product during its anticipated lifecycle (delivery, installation, use, service, decommissioning, and disposal) 2) to enable companies to comply with their intended markets' codes and regulations (ie., CE marking, UL-compliance, and WEEE/RoHS) and 3) to provide a legal defense in the event of an accident. Here, it's important to note that "inadequate warnings" and "failure to warn" are two of the most common allegations found in liability lawsuits in the U.S. today.

DEFINING TYPES OF LABELS TO MEET YOUR GOALS

Now that we've revisited the vital function your safety labels must perform, let's look at the types of product safety labels that can help to achieve these goals. There are three main[1] kinds of product safety labels.

Hazard alerting labels communicate potential personal injury hazards and how to avoid them. This kind of label includes the signal word "DANGER," "WARNING" or "CAUTION" to indicate the proper risk severity level.

Safety instruction labels communicate explanatory information like safety procedures (such as lockout/tagout instructions).

Notice labels communicate information considered important but not directly hazard-related (such as maintenance information).

1. A secondary type of label identifies function and control. Refer to *In Compliance Magazine*'s January 2012 *On Your Mark* column regarding "The Grounding Symbols" for more information on this topic.

DESIGNING AN EFFECTIVE LABEL

So, where does the engineer start in designing an effective label? There are several main building block elements that should be considered.

- **Know the type of content to go on the label.** The ANSI Z535.4 standard makes it very clear what content should be conveyed on a label.[2] (See Figure 1 for an example of an ANSI-formatted product safety label.)
- **Know your intended audience.** The intended audience and intended market must be taken into account. This includes factors like: is the product shipped to a foreign country; what is the education level of your anticipated product users and how much training will be given; and is there a product safety manual available for communicating more detailed safety information?

The product risk assessment process is a critical element here. When it's not practical to design out or guard against a particular hazard, a best practice label can be designed to communicate the risk.

Figure 1: Example of an ANSI 2011 Z535.4 electrical hazard product safety label. (Design ©2014 Clarion Safety Systems. All rights reserved.)

2. Compliance with the ANSI Z535.4 product safety label standard is voluntary. However, over the past 20 years of U.S. case law, state and federal courts have repeatedly used the ANSI standards as the benchmark to judge adequacy of warnings.

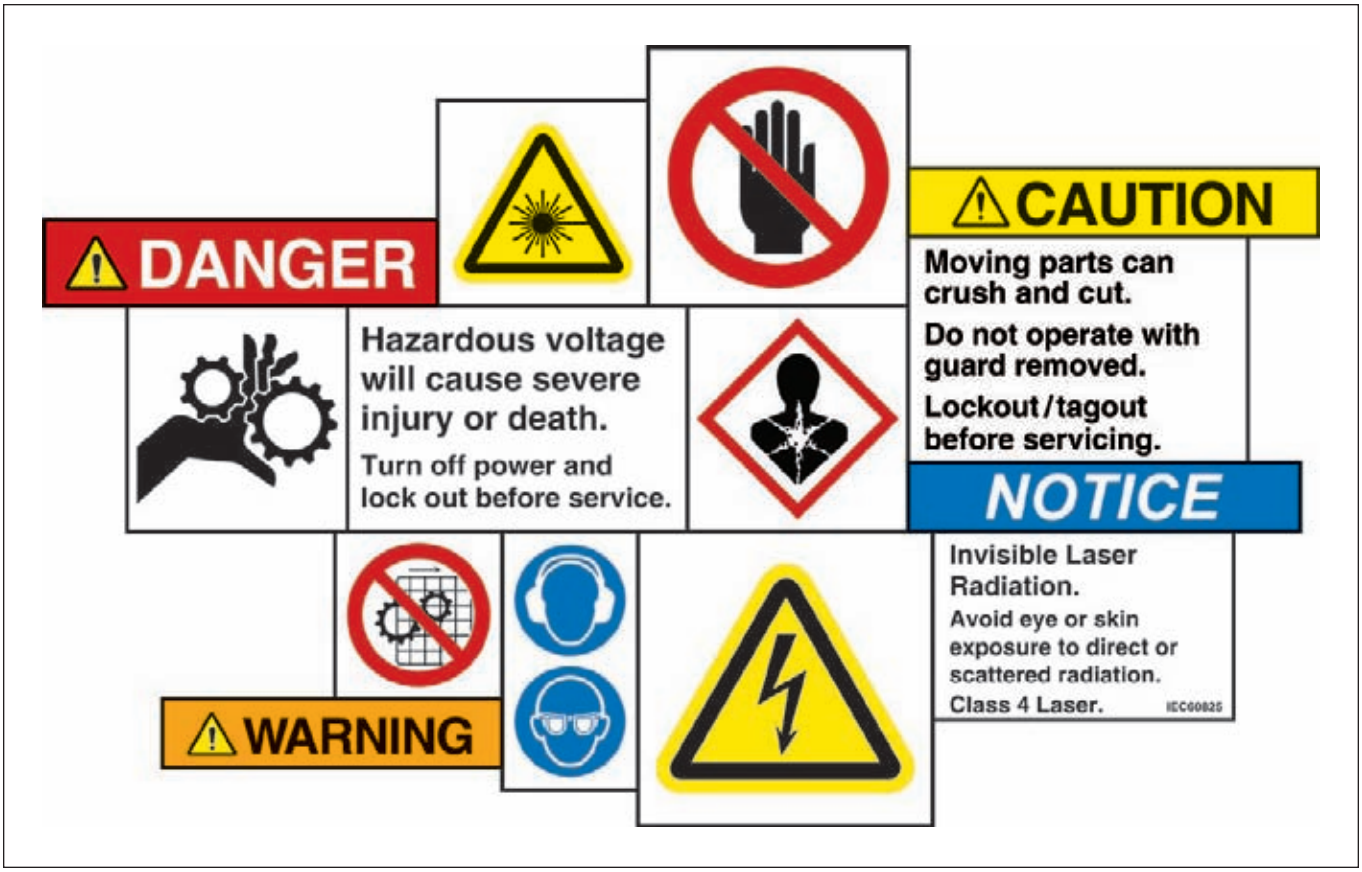


Figure 2: A compilation of all the different elements (from signal words to text messages to symbols) that must be considered, and brought together cohesively, when designing effective product safety labels.

- **Use the latest standards and best practices in considering the elements of your label.** This includes:
  - **Colors** – using uniform color standards developed by ANSI and ISO will help to speed visual recognition of your safety markings.
  - **Formats/text/content** – clear and concise messaging, as well as visual consistency, enables your product safety labels to be more easily seen and understood.
  - **Symbols** – symbols communicate efficiently and across language barriers. To be effective, they should come from the most up-to-date standards or be drawn using standards-based illustration techniques.
  - **Materials** – a label's performance is only as good as the materials that go into its manufacture. It's important to have an understanding of environmental and surface conditions, as well as the latest high-quality material options available, to achieve your durability objectives.
  - **Location** – the final critical factor to the design of an effective safety label is its placement. Consideration must be given to its anticipated viewing distance, legibility, and whether placing the label in multiple locations is necessary for both visibility and repetition of messaging purposes to ensure compliance.

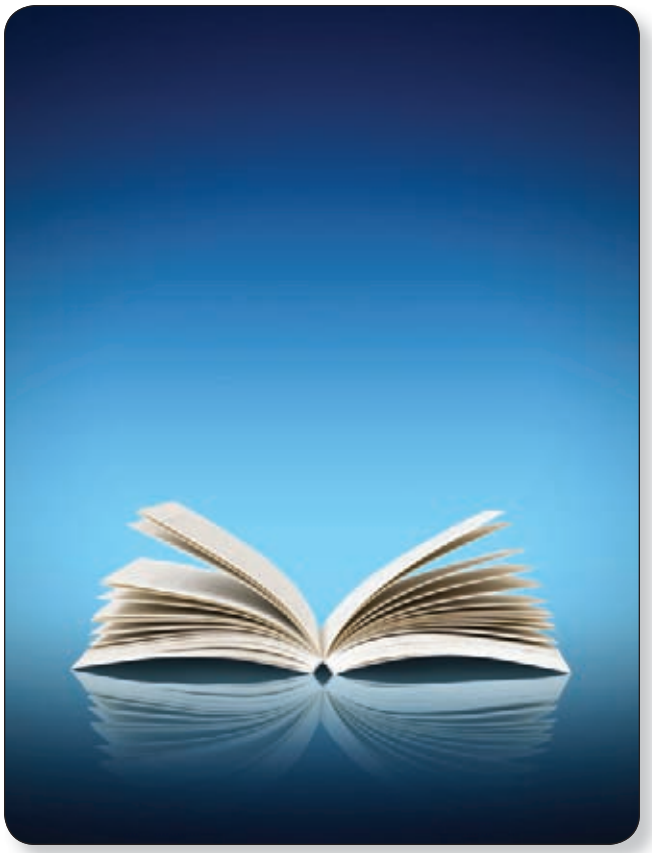
Designing effective safety labels can be a complex task. (See Figure 2 for a snapshot of the many elements that make up labels.) It's also one that is never completely finished; you must periodically reevaluate your labels in light of changes to the standards, new symbols that have become codified, and the latest available product safety and accident information related to your product and its industry. Symbols, content, and risk severity levels are the core elements that must be thoughtfully considered to be able to achieve the goal: effective hazard communication that helps prevent accidents and saves lives from tragedy.

Geoffrey Peckham *is CEO of Clarion Safety Systems and chair of both the ANSI Z535 Committee and the U.S. Technical Advisory Group to ISO Technical Committee 145-Graphical Symbols. Over the past two decades he has played a pivotal role in the harmonization of U.S. and international standards dealing with safety signs, colors, formats and symbols.*

CPSC Mandates Safety Programs for Manufacturers and Retailers

The History Behind the CPSC's Action

BY KENNETH ROSS



Since its inception, the U.S. Consumer Product Safety Commission (CPSC) has encouraged companies to implement active product safety management programs. Since 2010, however, the CPSC has made this a bit more official. Requirements for the establishment of safety compliance programs have appeared in a final rule of factors to be considered for civil penalties, in a number of consent decrees and settlement agreements for civil penalties, in letters from the CPSC where they decided not to seek civil penalties, and finally in a proposed interpretive rule.

This article will examine the CPSC's previous guidance on safety programs, describe the new requirements and proposed rules and discuss what they might mean for product manufacturers.

PRIOR GUIDANCE ON SAFETY PROGRAMS

The CPSC first published the *Handbook for Manufacturing Safer Consumer Products* in the 1970s, shortly after the agency was created. The last edition of this handbook came out in 2006 and discusses product safety policies, organization, and training as well as all aspects of design, manufacturing, quality, corrective actions, etc. In other words, it discusses safety procedures that it believes are appropriate for any company making consumer products in all aspects of design, production, sales, and post-sale.

At the beginning of the handbook, it says:

> *"Manufacturers must assure the safety of consumer products. This is achieved through the design, production and distribution of the products they manufacture. It is best accomplished by a comprehensive systems approach to product safety, which includes every step from the creation of a product design to the ultimate use of the product by the consumer. The basic concepts for a comprehensive systems approach for the design, production and distribution of consumer products are discussed in this Handbook."*

In addition, the CPSC's Recall Handbook, in existence for many years but updated in March 2012, has had sections on the appointment of a Recall Coordinator, development of a company recall policy and plan, and extensive suggestions for the creation and retention of records to support a recall.

The safety processes advocated in these handbooks are just suggestions and not legal requirements. In addition, they are similar to those procedures employed by companies who have a well-functioning safety effort. So, there is nothing particularly onerous here that a company shouldn't already be doing.

NEW REQUIREMENTS FOR SAFETY COMPLIANCE PROGRAMS

Recently, however, new requirements for safety compliance programs have been inserted by the CPSC into various documents.

Factors to Consider for Civil Penalties

First, on March 31, 2010, the CPSC published in the *Federal Register* a final rule of factors that its staff is expected to consider when deciding whether to seek civil penalties. The rule (16 CFR §1119.4(b)(1)) clearly states that product safety programs are one of the factors to be considered by the staff in assessing civil penalties:

> *"The Commission may consider, when a safety/compliance program and/or system as established is relevant to a violation, whether a person had at the time of the violation a reasonable and effective program or system for collecting and analyzing information related to safety issues. Examples of such information would include incident reports, lawsuits, warranty claims, and safety-related issues related to repairs or returns. The Commission may also consider whether a person conducted adequate and relevant premarket and production testing of the product at issue; had a program in place for continued compliance with all relevant mandatory and voluntary safety standards; and other factors as the Commission deems appropriate. The burden to present clear, reliable, relevant, and sufficient evidence of such program, system, or testing rests on the person seeking consideration of this factor."*

In addition, the Commissioners released a statement dated March 10, 2010 concerning these new factors that said in part:

> *"The safety/compliance program factor takes into account the extent to which a person (including an importer of goods) has sound, effective programs/systems in place to ensure that the products he makes, sells or distributes are safe. Having effective safety programs dramatically lessens the likelihood that a person will have to worry about the application of this civil penalty rule. Any good program will make sure that there is continuing compliance with all relevant mandatory and voluntary safety standards. This is not the same as saying if one's product meets all mandatory and voluntary standards that the Commission will not seek a civil penalty in appropriate cases. The Commission expects companies to follow all mandatory and voluntary safety standards as a matter of course."*

Daiso consent decree

At the same time that the new civil penalty factors were being finalized, the establishment of a product safety management program was included for the first time in a consent decree for civil penalties. In a March 4, 2010 agreement, Daiso Holding, a U.S. subsidiary of a Japanese company, agreed to pay a little more than $2 million in fines for violating various laws and regulations concerning the sale of toys and children's products.

The consent decree required Daiso to hire a product safety coordinator approved by the CPSC to do, in part, the following:

- Create a comprehensive product safety program
- Conduct a product audit to determine which of Defendants' merchandise requires testing and certification of compliance with the FHSA, the CPSA, and any other Act enforced by the CPSC
- Establish and implement an effective and reasonable product safety testing program in compliance with the FHSA, the CPSA, and any other Act enforced by the CPSC
- Create guidance manuals for managers and employees on how to comply with product safety requirements
- Establish procedures to conduct product recalls
- Establish systems to investigate all reports of consumer incidents, property damage, injuries, warranty claims, insurance claims and court complaints regarding products under the jurisdiction of the CPSC that Defendants imported into the United States

The consent decree contains many more specific requirements, and also includes the following monitoring requirements:

> *"At the end of the first year of the monitoring period and at the end of any 180-day extension of the monitoring period under this paragraph, the Coordinator shall provide a written report to the Office of Compliance. If the Coordinator certifies Defendants are in compliance as described in this paragraph, the monitoring period will end. If the Coordinator cannot certify that Defendants meet each of the compliance requirements listed below, the monitoring period shall continue for an additional 180 days, at the end of which the Coordinator shall provide an updated written report to the Office of Compliance."*

Daiso retained an independent consultant to certify compliance, and the CPSC sent its staff to Daiso facilities to audit compliance. Daiso passed and the monitoring was ultimately discontinued.

Safety requirements in civil penalty settlement sgreements

The CPSC did nothing further to impose safety requirements until they were inserted into civil penalty settlement agreements starting in February 2013. In the first such

agreement, Kolcraft agreed to pay a $400,000 civil penalty. In addition, they agreed to the following language:

"Kolcraft shall maintain and enforce a system of internal controls and procedures designed to ensure that: (i) information required to be disclosed by Kolcraft to the Commission is recorded, processed and reported in accordance with applicable law; (ii) all reporting made to the Commission is timely, truthful, complete and accurate; and (iii) prompt disclosure is made to Kolcraft's management of any significant deficiencies or material weaknesses in the design or operation of such internal controls that are reasonably likely to adversely affect in any material respect Kolcraft's ability to record, process and report to the Commission in accordance with applicable law.

"Upon request of Staff, Kolcraft shall provide written documentation of such improvements, processes, and controls, including, but not limited to, the effective dates of such improvements, processes, and controls. Kolcraft shall cooperate fully and truthfully with Staff and shall make available all information, materials, and personnel deemed necessary by Staff to evaluate Kolcraft's compliance with the terms of the Agreement.

"Kolcraft shall implement and maintain a compliance program designed to ensure compliance with the safety statutes and regulations enforced by the CPSC that, at a minimum, contains the following elements (i) written standards and policies; (ii) a mechanism for confidential employee reporting of compliance-related questions or concerns to either a compliance officer or to another senior manager with authority to act as necessary; (iii) effective communication of company compliance-related policies and procedures to all employees through training programs or otherwise; (iv) senior manager responsibility for compliance; (v) board oversight of compliance (if applicable); and (vi) retention of all compliance-related records for at least five (5) years and availability of such records to CPSC upon request."

Then, Chairman Tenenbaum and Commissioner Adler issued a joint statement in connection with this agreement, stating their concern that Kolcraft had had a dozen recalls since 1989 and that some further action was required. They said:

"The failure of a company to have an effective means of detecting and addressing serious or continuous safety issues with its products is contrary to the expectations of consumers and is unacceptable to this Commission. While we certainly understand that even the most responsible companies can make mistakes, the failure of a company to have in place an effective compliance program and internal controls is irresponsible. Thus, going forward, we expect those 2companies that lack an effective compliance program and internal controls to voluntarily adopt them. If not, we will insist that they do so."

The Commissioners also made it clear in their statement that having an adequate safety program does not let a company off the hook for failing to report a safety problem in a timely manner.

Then, in May 2013, Williams-Sonoma agreed to pay $987,500 in civil penalties for failing to report a safety problem to the CPSC in a timely manner. The three paragraphs from the Kolcraft opinion quoted above were also inserted in the Williams-Sonoma agreement. In addition, Commissioner Nord submitted a statement on the Williams-Sonoma agreement that questioned the piecemeal creation of a mandate for such programs through enforcement. Commissioner Adler responded to Commissioner Nord's concern and signaled his views on the future use of such safety requirements. He said, in part:

"Far from viewing this settlement as punishment, I view it as the Commission and the company mutually agreeing to a set of reasonable measures designed to lead to safer products and fewer recalls in the future. Indeed, I suspect that the reason that companies agree to such language is their sense that any conscientious, responsible firm should follow such procedures in their approach to compliance. And to the extent that their past practices might have fallen short of these goals, they are eager to demonstrate that their future approach will be one of strict adherence to such provisions…

"…The fact that the Commission has sought similar language in the two settlements says little at this point about whether there has been a shift in agency policy in the future. Even if it did, there is nothing improper about implementing the policy in individual case settlements. That said, I do not rule out asking for such clauses in future non-civil penalty settlement agreements nor do I rule out future expansions of the Commission's voluntary recall policies."

Since May 2013, every settlement agreement for civil penalties has had some compliance requirements. Based on this history, it is virtually certain that future settlement agreements will also contain some type of requirement for the establishment of more robust safety compliance programs. However, it is still an open question as to how compliance will be audited and monitored, and when the CPSC will require that additional processes and procedures be established. In addition, it is unknown what the CPSC would do if a firm failed to fully comply with these requirements.

Or, let's say the firm complies and then is charged again with late reporting. Will their new safety programs reduce the likelihood of penalties or reduce the amount of penalties? This is a concept that has already been adopted by the Department of Justice in connection with the Federal Sentencing Guidelines for Organizations. The establishment

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of a compliance program is taken into account when deciding whether to defer prosecution or the amount of penalties to seek.

SAFETY REQUIREMENTS IN OTHER AGREEMENTS

As signaled by then Commissioner Adler in his statement above, even if the CPSC decides not to seek civil penalties, it might ask companies to set up more robust programs. In September 2013, I received a letter from the CPSC saying that a decision not to proceed with a civil penalty would be conditional upon the firm agreeing to take a variety of corrective measures similar to those in the above settlement agreements.

I have heard from other lawyers that they have also seen such requests in letters of this type. However, one recent letter used the word "encourage" rather than "required" concerning such programs. And some of these letters make it clear that the manufacturer still has a duty to report new information, and that they can again be subject to civil penalties for late reporting or for failing to report.

SAFETY REQUIREMENTS IN CORRECTIVE ACTION PLANS

The last CPSC action concerning compliance programs is contained in a Notice of Proposed Rulemaking published in the November 21, 2013 *Federal Register*. This rule deals with voluntary recall notices, but also allows the CPSC to mandate compliance programs as part of corrective action plans (CAPs). The requirements for safety programs are the same as those in the civil penalty settlement agreements described above.

This proposed interpretative rule also provides that the corrective action, including an agreement to establish a safety program, is legally binding. Therefore, if this rule is approved, the CPSC would be able to legally enforce the compliance program if a company fails to comply.

It is unclear how the CPSC will be able to evaluate the procedures and controls of the manufacturer or product seller and determine whether they are insufficient or ineffectual. Who will do it? When will they have time to do it? What is the basis of their determination? Will the recall be postponed until this analysis is done?

The comment period for this Notice of Proposed Rulemaking ended in February 2014. As of this writing, we are waiting to see what the CPSC Commissioners and staff decide to do.

CONCLUSION

It is certainly possible for a company that has a robust safety program to fail to notify the CPSC of certain potentially reportable information because it does not believe that there is a product defect or substantial product hazard. Indeed, reasonable minds may differ in such matters. However, the open question is whether the CPSC is justified in imposing new procedures on a manufacturer that may already have sufficient safety programs in place. It will be interesting to see whether, going forward, companies that have good safety programs are able to keep these provisions out of future agreements, and whether such programs will enable them to escape all civil penalties or negotiate lower civil penalties.

In the meantime, product manufacturers should consider all of these requirements and evaluate their own programs. They should also consider the new ISO standard (ISO 10377) that sets forth some "best practices" in safety management, as well as other studies and reports on what is an effective product safety management program. (See articles in www.productliabilityprevention.com discussing the new ISO standard and other product safety management best practices.)

Most companies don't do a good enough job in monitoring product safety issues and incidents, especially when they are selling their products globally. Therefore, it would be prudent for every company to pull their safety program out of the file cabinet and review it with a fresh eye.

The responsible course of action is to be proactive about complying with these requirements before a safety problem arises. Dealing with such issues after the fact only increases the risk of their becoming a much bigger problem, both for your products and for your company.

Kenneth Ross *is a former partner and now Of Counsel in the Minneapolis, Minnesota office of Bowman and Brooke LLP, where he provides legal advice to manufacturers and other product sellers in all areas of product safety, regulatory compliance and product liability prevention, including safety management, recalls and dealing with the CPSC. He can be reached at 952-933-1195 or kenrossesq@comcast.net. Other articles by Mr. Ross can be accessed at www.productliabilityprevention.com.*

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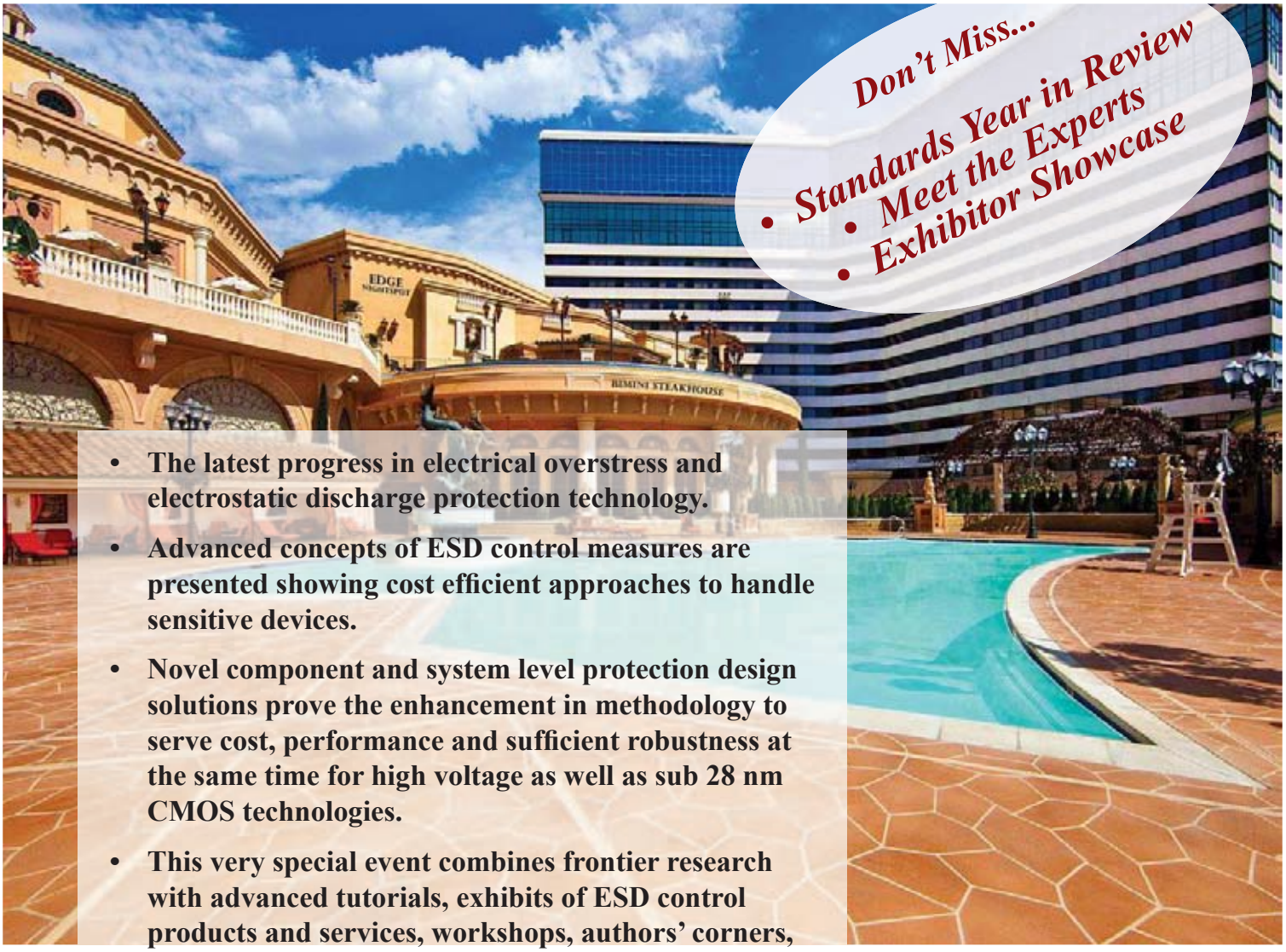

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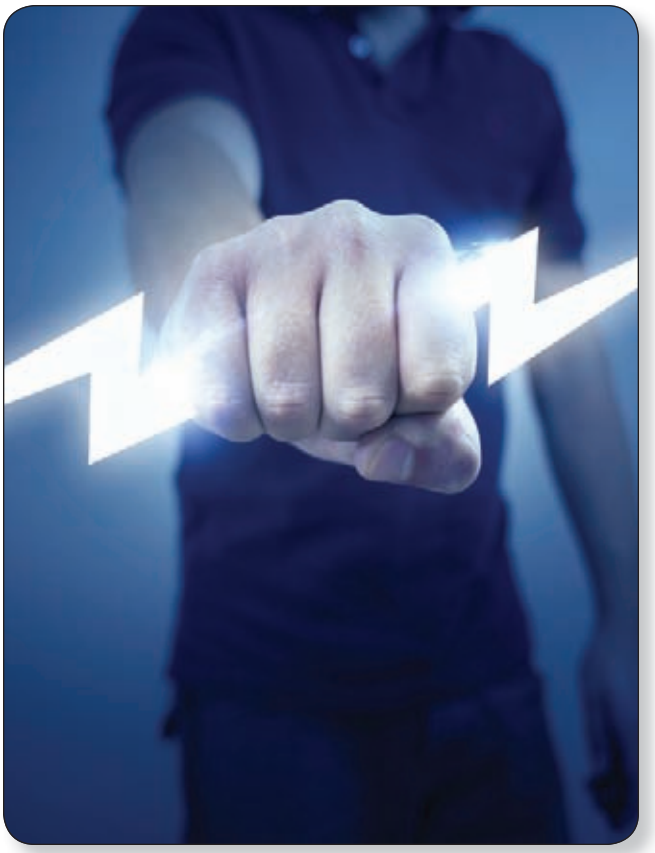
Fundamentals of Electrostatic Discharge
Part 1

An Introduction to ESD

BY THE ESD ASSOCIATION



HISTORY & BACKGROUND

To many people, Electrostatic Discharge (ESD) is only experienced as a shock when touching a metal doorknob after walking across a carpeted floor or after sliding across a car seat. However, static electricity and ESD has been a serious industrial problem for centuries. As early as the 1400s, European and Caribbean military forts were using static control procedures and devices trying to prevent inadvertent electrostatic discharge ignition of gunpowder stores. By the 1860s, paper mills throughout the U.S. employed basic grounding, flame ionization techniques, and steam drums to dissipate static electricity from the paper web as it traveled through the drying process. Every imaginable business and industrial process has issues with electrostatic charge and discharge at one time or another. Munitions and explosives, petrochemical, pharmaceutical, agriculture, printing and graphic arts, textiles, painting, and plastics are just some of the industries where control of static electricity has significant importance. The age of electronics brought with it new problems associated with static electricity and electrostatic discharge. And, as electronic devices become faster and the circuitry getting smaller, their sensitivity to ESD in general increases. This trend may be accelerating. The ESD Association's "Electrostatic Discharge (ESD) Technology Roadmap", revised April 2010, includes "With devices becoming more sensitive through 2010-2015 and beyond, it is imperative that companies begin to scrutinize the ESD capabilities of their handling processes". Today, ESD impacts productivity and product reliability in virtually every aspect of the global electronics environment.

Despite a great deal of effort during the past thirty years, ESD still affects production yields, manufacturing cost, product quality, product reliability, and profitability. The cost of damaged devices themselves ranges from only a few cents for a simple diode to thousands of dollars for complex integrated circuits. When associated costs of repair and rework, shipping, labor, and overhead are included, clearly the opportunities exist for significant improvements. Nearly all of the thousands of companies involved in electronics manufacturing today pay attention to the basic, industry accepted elements of static control. ESD Association industry standards are available today to guide manufacturers in establishing the fundamental static charge mitigation and control techniques (see Part Six – ESD Standards). It is unlikely that any company which ignores static control will be able to successfully manufacture and deliver undamaged electronic parts.

STATIC ELECTRICITY: CREATING CHARGE

Definitions for Electrostatic Discharge Terminology are in the ESD ADV1.0 Glossary which is available as a complimentary download at www.ESDA.org. *Electrostatic charge* is defined as "electric charge at rest". Static electricity is an imbalance of electrical charges within or on the surface of a material. This imbalance of electrons produces an electric field that can be measured and that can influence other objects. *Electrostatic discharge (ESD)* is defined as "the rapid, spontaneous transfer of electrostatic charge induced by a high electrostatic field. Note: Usually, the charge flows through a spark between two bodies at different electrostatic potentials as they approach one another".

Electrostatic discharge can change the electrical characteristics of a semiconductor device, degrading or destroying it. Electrostatic discharge also may upset the normal operation of an electronic system, causing equipment malfunction or failure. Charged surfaces can attract and hold contaminants, making removal of the particles difficult. When attracted to the surface of a silicon wafer or a device's electrical circuitry, air-borne particulates can cause random wafer defects and reduce product yields.

Controlling *electrostatic discharge* begins with understanding how *electrostatic charge* occurs in the first place. Electrostatic charge is most commonly created by the contact and separation of two materials. The materials may be similar or dissimilar although dissimilar materials tend to liberate higher levels of static charge. For example, a person walking across the floor generates static electricity as shoe soles contact and then separate from the floor surface. An electronic device sliding into or out of a bag, magazine or tube generates an electrostatic charge as the device's housing and metal leads make multiple contacts and separations with the surface of the container. While the magnitude of electrostatic charge may be different in these examples, static electricity is indeed formed in each case.

Creating electrostatic charge by contact and separation of materials is known as "triboelectric charging." The word "triboelectric" comes from the Greek words, *tribo* – meaning "to rub" and *elektros* – meaning "amber" (fossilized resin from prehistoric trees). It involves the transfer of electrons between materials. The atoms of a material with no static charge have an equal number of positive (+) protons in their nucleus and negative (-) electrons orbiting the nucleus. In Figure 1, Material "A" consists of atoms with equal numbers of protons and electrons. Material B also consists of atoms with equal (though perhaps different) numbers of protons and electrons. Both materials are electrically neutral.

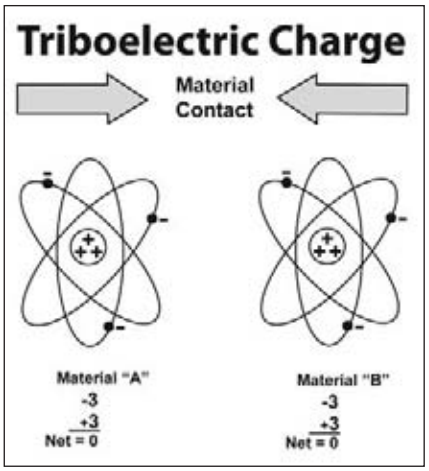


Figure 1: The Triboelectric Charge: Materials Make Intimate Contact

When the two materials are placed in contact and then separated, negatively charged electrons are transferred from the surface of one material to the surface of the other material. Which material loses electrons and which gains electrons will depend on the nature of the two materials. The material that loses electrons becomes positively charged, while the material that gains electrons is negatively charged. This is shown in Figure 2.

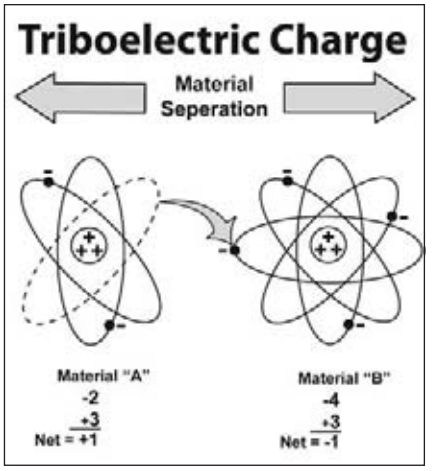


Figure 2: The Triboelectric Charge: Separation

Static electricity is measured in coulombs. The charge "q" on an object is determined by the product of the capacitance of the object "C" and the voltage potential on the object (V):

$$q = CV$$

Commonly, however, we speak of the electrostatic potential on an object, which is expressed as voltage.

This process of material contact, electron transfer and separation is a much more complex mechanism than described here. The amount of charge created by triboelectric generation is affected by the area of contact, the speed of separation, relative humidity, and chemistry of the materials, surface work function and other factors. Once the charge is created on a material, it becomes an electrostatic charge (if it remains on the material). This charge may be transferred from the material, creating an electrostatic discharge or ESD event. Additional factors, such as the resistance of the actual discharge circuit and the contact resistance at the interface between contacting surfaces also affect the actual charge that is released. Typical charge generation scenarios and the resulting voltage levels are shown in Table 1. In addition, the contribution of humidity to reducing charge accumulation is also shown. It should be noted however that static charge generation still occurs even at high relative humidity.

An electrostatic charge also may be created on a material in other ways such as by induction, ion bombardment, or contact with another charged object. However, triboelectric charging is the most common.

HOW MATERIAL CHARACTERISTICS AFFECT STATIC CHARGE

Triboelectric Series

When two materials contact and separate, the polarity and magnitude of the charge are indicated by the materials' positions in a *triboelectric series*. The triboelectric series tables show how charges are generated on various materials. When two materials contact and separate, the one nearer the top of the series takes on a positive charge, the other a negative charge. Materials further apart on the table typically generate a higher charge than ones closer together. These tables, however, should only be used as a general guide because there are many variables involved that cannot be controlled well enough to ensure repeatability. A typical triboelectric series is shown in Table 2.

Virtually all materials, including water and dirt particles in the air, can be triboelectrically charged. How much charge is generated, where that charge goes, and how quickly, are functions of the material's physical, chemical and electrical characteristics.

Insulative materials

A material that prevents or limits the flow of electrons across its surface or through its volume is called an insulator. Insulators have an extremely high electrical resistance, **insulative materials** are defined as "materials with a surface resistance or a volume resistance equal to or greater than 1×10^{11} ohms." A considerable amount of charge can be generated on the surface of an insulator. Because an insulative material does not readily allow the flow of electrons, both positive and negative charges can reside on insulative surface at the same time, although at different locations. The excess electrons at the negatively charged spot might be sufficient to satisfy the absence of electrons at the positively charged spot. However, electrons cannot easily flow across the insulative material's surface, and both charges may remain in place for a very long time.

Means of Generation	10-25% RH	65-90% RH
Walking across carpet	35,000V	1,500V
Walking across vinyl tile	12,000V	250V
Worker at bench	6,000V	100V
Poly bag picked up from bench	20,000V	1,200V
Chair with urethane foam	18,000V	1,500V

Table 1: Examples of Static Generation - Typical Voltage Levels

Conductive materials

A conductive material, because it has low electrical resistance, allows electrons to flow easily across its surface or through its volume. Conductive materials have low electrical resistance, less than 1×10^4 ohms (surface resistance) and 1×10^4 ohm (volume resistance) per Glossary ESD ADV1.0. When a conductive material becomes charged, the charge (i.e., the deficiency or excess of electrons) will be uniformly distributed across the surface of the material. If the charged conductive material makes contact with another conductive material, the electrons will be shared between the materials quite easily. If the second conductor is attached to AC equipment ground or any other grounding point, the electrons will flow to ground and the excess charge on the conductor will be neutralized.

Electrostatic charge can be created triboelectrically on conductors the same way it is created on insulators. As long as the conductor is isolated from other conductors or ground, the static charge will remain on the conductor. If the conductor is grounded the charge will easily go to ground. Or, if the charged conductor contacts another conductor, the charge will flow between the two conductors.

Static dissipative materials

Static dissipative materials have an electrical resistance between insulative and conductive materials ($1 \times 10^4 < 1 \times 10^{11}$ ohms surface or volume resistance). There can be electron flow across or through the dissipative material, but it is controlled by the surface resistance or volume resistance of the material.

As with the other two types of materials, charge can be generated triboelectrically on a static dissipative material. However, like the conductive material, the static dissipative material will allow the transfer of charge to ground or other conductive objects. The transfer of charge from a static dissipative material will generally take longer than from a conductive material of equivalent size. Charge transfers from static dissipative materials are significantly faster than from insulators, and slower than from conductive material.

Electrostatic fields

Charged materials also have an electrostatic field and lines of force associated with them. Conductive objects brought into the vicinity of this electric field will be polarized by a process known as *induction* Figure 3 (page 126). A negative electric field will repel electrons on the surface of the conducting item that is exposed to the field. A positive electric field will attract electrons to near the surface thus leaving other areas positively charged. No change in the actual charge on the item will occur in polarization. If, however, the item is conductive or dissipative and is connected to ground while polarized, the charge will flow from or to ground due to the charge imbalance. If the electrostatic field is removed and the ground contact disconnected, the charge will remain on the item. If a nonconductive object is brought into the electric field, the electrical dipoles will tend to align with the field creating apparent surface charges. A nonconductor (insulative material) cannot be charged by induction.

+ Positive	
	Rabbit fur
	Glass
	Mica
	Human Hair
	Nylon
	Wool
	Fur
	Lead
	Silk
	Aluminum
	Paper
	COTTON
	Steel
	Wood
	Amber
	Sealing Wax
	Nickel, Copper, Brass, Silver
	Gold, Platinum
	Sulfur
	Acetate Rayon
	Polyester
	Celluloid
Negative -	Silicon
	Teflon

Table 2: Typical Triboelectric Series

ESD DAMAGE: HOW DEVICES FAIL

Electrostatic damage is defined as "change to an item caused by an electrostatic discharge that makes it fail to meet one or more specified parameters" and can occur at any point from manufacture to field service. Typically, damage results from handling the devices in uncontrolled surroundings or when poor ESD control practices are used. Generally damage is classified as either a catastrophic failure or a latent defect.

Catastrophic failure

When an electronic device is exposed to an ESD event, it may no longer function. The ESD event may have caused a metal melt, junction breakdown, or oxide failure. The device's circuitry is permanently damaged causing the device to stop functioning totally or at least partially. Such failures usually can be detected when the device is tested before shipment. If a damaging level ESD event occurs after test, the part may go into production and the damage will go undetected until the device fails in final test.

Latent defect

Per ESD ADV1.0 latent failure is "a malfunction that occurs following a period of normal operation. The failure may be attributable to an earlier electrostatic discharge event.

The concept of latent failure is controversial and not totally accepted by all in the technical community." A latent defect is difficult to identify. A device that is exposed to an ESD event may be partially degraded, yet continue to perform its intended function. However, the operating life of the device may be reduced. A product or system incorporating devices with latent defects may experience premature failure after the user places them in service. Such failures are usually costly to repair and in some applications may create personnel hazards.

It is relatively easy with the proper equipment to confirm that a device has experienced a catastrophic failure. Basic performance tests will substantiate device damage. However, latent defects are extremely difficult to prove or detect using current technology, especially after the device is assembled into a finished product.

BASIC ESD EVENTS: WHAT CAUSES ELECTRONIC DEVICES TO FAIL?

ESD damage is usually caused by one of three events: direct electrostatic discharge *to* the device, electrostatic discharge *from* the device or field-induced discharges. Whether or not damage occurs to an ESD sensitive item (ESDS) by an ESD event is determined by the device's ability to dissipate the energy of the discharge or withstand the voltage levels involved. The level at which a device fails is known as the device's ESD sensitivity or ESD susceptibility.

Discharge to the device

An ESD event can occur when any charged conductor (including the human body) discharges to an item. A cause of electrostatic damage could be the direct transfer of electrostatic charge from the human body or a charged material to the ESDS. When one walks across a floor, an electrostatic charge accumulates on the body. Simple contact (or close proximity) of a finger to the leads of an ESDS or assembly which is typically on a different electrical potential can allow the body to discharge, possibly causing ESD damage. The model used to simulate this event is the Human Body Model (HBM). A similar discharge can occur from a charged conductive object, such as a metallic tool or fixture. From the nature of the discharge, the model used to describe this event is known as the Machine Model (MM).

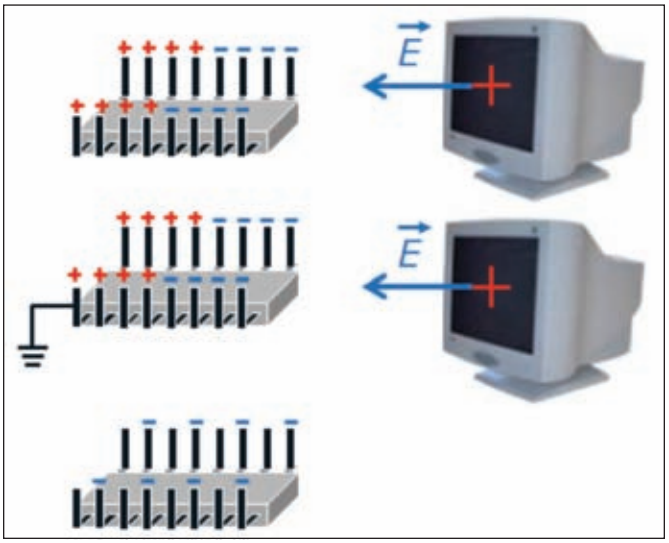


Figure 3: Induction

Discharge from the device

The transfer of charge *from* an ESDS to a conductor is also an ESD event. Static charge may accumulate on the ESDS itself through handling or contact and separation with packaging materials, work surfaces, or machine surfaces. This frequently occurs when a device moves across a surface or vibrates in a package. The model used to simulate the transfer of charge from an ESDS is referred to as the Charged Device Model (CDM). The capacitances, energies, and current waveforms involved are totally different from those of a discharge to the ESD sensitive item, resulting very likely in different failure modes.

The trend towards automated assembly would seem to solve the problems of HBM ESD events. However, it has been shown that components may be more sensitive to damage when assembled by automated equipment. A device may become charged, for example, from sliding down the feeder. If it then contacts the insertion head or any other conductive surface, a rapid discharge occurs from the device to the metal object.

Field induced discharges

Another electrostatic charging process that can directly or indirectly damage devices is termed Field Induction. As noted earlier, whenever any object becomes electrostatically charged, there is an electrostatic field associated with that charge. If an ESDS is placed in that electrostatic field, a charge may be induced on the item. If the item is then grounded while within the electrostatic field, a transfer of charge from the device occurs as a CDM event. If the item is removed from the region of the electrostatic field and grounded again, a second CDM event will occur as the charge (of opposite polarity from the first event) is transferred from the device.

HOW MUCH ESD CONTROL PROTECTION IS NEEDED?

Damage to an ESDS by the ESD event is determined by the device's ability to dissipate the energy of the discharge or withstand the voltage levels involved—as explained previously these factors determine the parts ESD sensitivity or susceptibility. Test procedures based on the models of ESD events help define the sensitivity of components to ESD. Although it is known that there is very rarely a direct

correlation between the discharges in the test procedures and real-world ESD events, defining the ESD sensitivity of electronic components gives some guidance in determining the degree of ESD control protection required. These procedures and more are covered in Part Five of this series.

The ESD withstand voltage is "the highest voltage level that does not cause device failure; the device passes all tested lower voltages." Many electronic components are sensitive or susceptible to ESD damage at relatively low voltage levels. Many are susceptible at less than 100 volts, and many disk drive components withstand voltages even below 10 volts. Current trends in product design and development pack more circuitry onto these miniature devices, further increasing their sensitivity to ESD and making the potential problem even more acute. Table 3 indicates the ESD sensitivity of various types of components.

SUMMARY

In this "An Introduction to ESD", we have discussed electrostatic charge and discharge, the mechanisms of creating charge, materials, types of ESD damage, ESD events, and ESD sensitivity. We can summarize this discussion as follows:

1. Virtually all materials, including conductors, can be triboelectrically charged.
2. The amount of charge is affected by material type, speed of contact and separation, humidity, and several other factors.
3. Charged objects have electrostatic fields.
4. Electrostatic discharge can damage devices so a parameter fails immediately, or ESD damage may be a latent defect that may escape immediate detection, but may cause the device to fail prematurely.
5. Electrostatic discharge can occur throughout the manufacturing, test, shipping, handling, or operational processes, and during field service operations.
6. ESD damage can occur as the result of a discharge **to** the device, **from** the device, or from charge transfers resulting from electrostatic fields. Devices vary significantly in their sensitivity or susceptibility to ESD.

Protecting products from the effects of ESD damage begins by understanding these key concepts of electrostatic charges and discharges. An effective ESD control program requires an effective training program where all personnel involved understand the key concepts. See Part Two for the basic concepts of ESD control.

REFERENCES

1. *ESD-ADV 1.0, Glossary*, ESD Association, Rome NY.
2. *ESD TR20.20, Handbook*, ESD Association, Rome, NY.
3. *ESD ADV 11.2, Triboelectric Charge Accumulation Testing*, ESD Association, Rome, NY.
4. *ANSI/ESD S20.20—Standard for the Development of Electrostatic Discharge Control Program*, ESD Association, Rome, NY.

Device or Part Type
Microwave devices (Schottky barrier diodes, point contact diodes and other detector diodes >1 GHz)
Discrete MOSFET devices
Surface acoustic wave (SAW) devices
Junction field effect transistors (JFETs)
Charged coupled devices (CCDs)
Precision voltage regulator diodes (line of load voltage regulation, <0.5%)
Operational amplifiers (OP AMPs)
Thin film resistors
Integrated circuits
GMR and new technology Disk Drive Recording Heads
Laser Diodes
Hybrids
Very high speed integrated circuits (VHSIC)
Silicon controlled rectifiers (SCRs) with Io <0.175 amp at 10°C ambient
*Specific Sensitivity Levels are available from supplier data sheets

Table 3: ESD Sensitivity of Representative Electronic Devices - Devices or Parts with Sensitivity Associated with HBM and CDM*

Fundamentals of Electrostatic Discharge
Part 2

ESD Control Program Development

BY THE ESD ASSOCIATION

In Part One of this series, Introduction to ESD, we discussed the basics of electrostatic charge and discharge, the mechanisms of creating charge, materials, types of ESD damage, ESD events, and ESD sensitivity. We concluded our discussion with the following summary:

1. Virtually all materials, including conductors, can be triboelectrically charged.
2. The amount of charge is affected by material type, speed of contact and separation, humidity, and several other factors.
3. Charged objects have electrostatic fields.
4. Electrostatic discharge can damage devices so a parameter fails immediately, or ESD damage may be a latent defect that may escape immediate detection, but may cause the device to fail prematurely.
5. Electrostatic discharge can occur throughout the manufacturing, test, shipping, handling, or operational processes, and during field service operations.
6. ESD damage can occur as the result of a discharge **to** the device, **from** the device, or from charge transfers resulting from electrostatic fields. Devices vary significantly in their sensitivity or susceptibility to ESD.

Protecting products from the effects of ESD damage begins by understanding these key concepts of electrostatic charges and discharges. An effective ESD control program requires an effective training program where all personnel involved understand the key concepts. Armed with this information, you can then begin to develop an effective ESD control program. In Part Two we will focus on some basic principles of ESD control and ESD control program development.

BASIC PRINCIPLES OF STATIC CONTROL

Controlling electrostatic discharge (ESD) in the electronics manufacturing environment is a formidable challenge. However, the task of designing and implementing ESD control programs becomes less complex if we focus on just six basic principles of static control. In doing so, we also need to keep in mind the ESD corollary to Murphy's law, "no matter what we do, static charge will try to find a way to discharge."

Design in protection

The first principle is to *design products and assemblies to be as resistant as reasonable* from the effects of ESD. This involves such steps as using less static sensitive devices or providing appropriate input protection on devices, boards, assemblies, and equipment. For engineers and designers, the paradox is that advancing product technology requires smaller and more complex geometries that often are more susceptible to ESD. The Industry Council on ESD Target Levels and the ESD Association's "Electrostatic Discharge (ESD) Technology Roadmap", revised April 2010, suggest that designers will have less ability to provide the protection levels that were available

in the past. Consequently, the ESD target levels are reduced to 1000 volts for Human Body Model robustness and 250 volts for robustness against the Charged Device Model, with tendency to reduce these values further. Those target values are considered to be realistic and safe levels for manufacturing and handling of today's products using basic ESD control methods as described in international industry standards as e.g. ANSI/ESD S20.20 or IEC 61340-5-1. When devices with lower ESD target levels must be used and handled, application-specific controls beyond the principles described here may be required.

Define the level of control needed in your environment

What is the most sensitive or ESD susceptible ESDS you are using and what is the classification of withstand voltage of the products that you are manufacturing and shipping? In order to get an idea of what is required, it is best to know the Human-Body Model (HBM) and Charged-Device Model (CDM) sensitivity levels for all devices that will be handled in the manufacturing environment. ANSI/ESD S20.20 and IEC 61350-5-1, both published in 2007, define control program requirements for items that are sensitive to 100 volts HBM; future version of those standards will most likely address also items that are sensitive to 200 volts CDM. With documentation, both standards allows requirements to be tailored as appropriate for specific situations.

Identify and define the electrostatic protected areas (EPA)

Per Glossary ESD ADV1.0 an ESD protected area is "A defined location with the necessary materials, tools and equipment capable of controlling static electricity to a level that minimizes damage to ESD susceptible items". These are the areas in which you will be handling ESD sensitive items and the areas in which you will need to implement the basic ESD control procedures including bonding or electrically connecting all conductive and dissipative materials, including personnel, to a known common ground.

Reduce electrostatic charge generation

If projections of ESD sensitivity are correct, ESD protection measures in product design will be increasingly less effective in minimizing ESD losses. The fourth principle of control is to *reduce electrostatic charge generation and accumulation* in the first place. It's fairly basic: no charge – no discharge. We begin by eliminating as many static charge generating processes or materials, specifically high-charging insulators such as common plastics, as possible from the EPA work environment. We keep conductive/dissipative materials at the same electrostatic potential using equipotential bonding or attaching to equipment ground. Electrostatic discharge does not occur between materials kept at the same potential. In the EPA, ESD control items should be used in place of more common factory products such as worksurface mats, flooring, smocks, etc. which are to be attached to ground to reduce charge generation and accumulation. Personnel are grounded via wrist straps or a flooring/footwear system. While the basic principle of "controlling static electricity to a level that minimizes damage" should be followed, complete removal of charge generation is not achievable.

Dissipate and neutralize

Because we simply can't eliminate all generation of electrostatic charge in the EPA, our fifth principle is to *safely dissipate or neutralize those electrostatic charges* that do occur. Proper grounding and the use of conductive or dissipative materials play major roles. For example, personnel starting work may have a charge on their body; they can have that charge removed by attachment to a wrist strap or when they step on ESD flooring while wearing ESD control footwear. The charge goes to ground rather than being discharged into a sensitive part. To prevent damaging a charged device, the magnitude of the discharge current can be controlled with static dissipative materials.

For some objects, such as common plastics and other insulators, being non-conductors grounding cannot remove an electrostatic charge because there is no pathway which is conductive enough to reduce the charge in a reasonable time. If the object cannot be eliminated from the EPA, ionization can be used to neutralize charges on these insulators. The ionization process generates negative and positive ions. The like charged ions are repelled from a charged object while the opposite charged ions are attracted to the surface of a charged object, therefore neutralizing the object (see Figure 1). If the ionizer is balanced, the net charge is zero.

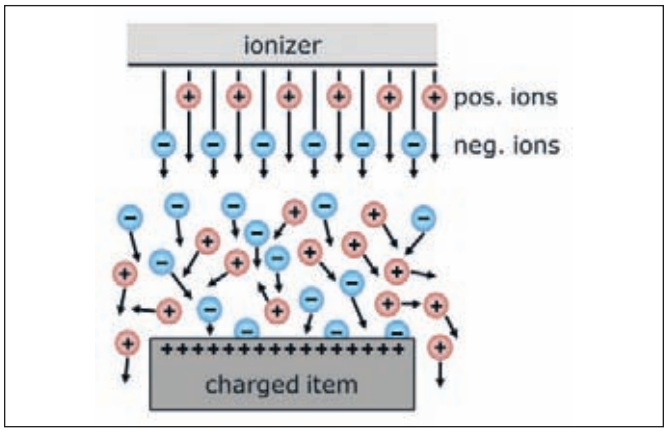


Figure 1: Principle of neutralization of a charged object by an ionizer that generates negative and positive ions. The like charged ions are repelled from a charged object while the opposite charged ions are attracted to the surface of a charged object, neutralizing the object.

No single procedure or product will do the whole job; rather effective static control requires a full ESD control program. How do we develop and maintain a program that puts these basic principles into practice?

Protect products

Our final ESD control principle is to *prevent discharges that do occur from reaching susceptible parts and assemblies*. There are a variety of ESD control packaging and material handling products to use both inside and outside the EPA. One way is to protect ESD sensitive products and assemblies with proper grounding or shunting that will "dissipate" any discharge away from the product. A second method is to package, to store, or to transport ESD sensitive products in packaging that is low charging and are conductive/dissipative so can remove charges when grounded. In addition to these properties, packaging used to move ESD sensitive items outside the EPA should have the ESD control property of "discharge shielding". These materials should effectively shield the product from charges and discharges, as well as reduce the generation of charge caused by any movement of product within the container.

Figure 2: Six critical elements of a successful ESD control program

ELEMENTS OF AN EFFECTIVE ESD CONTROL PROGRAM

While these six principles may seem rather basic, they can guide us in the selection of appropriate materials and procedures to use in effectively controlling ESD. In most circumstances, effective programs will involve all of these principles. No single procedure or product will do the whole job; rather effective static control requires a full ESD control program.

How do we develop and maintain a program that puts these basic principles into practice? How do we start? What is the process? What do we do first? Ask a dozen experts and you may get a dozen different answers. But, if you dig a little deeper, you will find that most of the answers center on similar key elements. You will also find that starting and maintaining an ESD control program is similar to many other business activities and projects. Although each company is unique in terms of its ESD control needs, there are at least 6 critical elements to successfully developing, implementing, and maintaining an effective ESD control program (see Figure 2).

Establish an ESD coordinator and ESD teams

A team approach particularly applies to ESD because the problems and the solutions cross various functions, departments, divisions and suppliers in most companies. ESD team composition includes line employees as well as department heads or other management personnel. The ESD team may also cut across functions such as incoming inspection, quality, training, automation, packaging, and test. ESD teams or committees help assure a variety of viewpoints, the availability of the needed expertise, and commitment to success. An active ESD team helps unify the ongoing effort.

Heading this ESD team effort is an ESD program coordinator ("ESD coordinator"). Ideally, this responsibility should be a full-time job. However, we seldom operate in an ideal environment and you may have to settle for the function to be a major responsibility of an individual. The ESD coordinator is responsible for developing, budgeting, and administering the program. The ESD coordinator also serves as the company's internal ESD consultant to all ESD control programs areas.

Assess your organization, facility, processes and losses

Your next step is to gain a thorough understanding of your environment and its impact on ESD. Armed with your product quality loss and ESD sensitivity data, you can evaluate your facility, looking for areas and procedures that may possibly cause ESD problems. Be on the lookout for things such as static generating materials, personnel handling procedures for ESD sensitive items, and contacts of ESD sensitive devices to conductors.

Document your processes or work instructions. Observe the movement of people and materials through the areas. Note

An ESD program requires the support of your top management, at the highest level possible. Prepare a short corporate policy statement on ESD control. Have top management co-sign it with the ESD coordinator.

those areas that would appear to have the greatest potential for ESD problems. Remember, that ESD can occur in the warehouse just as it can in the assembly areas. Then conduct a thorough facility survey or audit. Measure personnel, equipment, and materials to identify proper resistance ranges and the presence of electrostatic fields in your environment.

Before seeking solutions to your problems, you will need to determine the extent of your product quality losses to ESD. These losses may be reflected in receiving reports, Quality Assurance and Quality Control records, customer returns, in-plant yields, failure analysis reports, and other data that you may already have or that you need to gather. This information not only identifies the magnitude of the problem, but also helps to pinpoint and prioritize areas that need attention. Where available, the potential for future problems as a result of technology roadmaps and internal product evolution should be considered.

Document your actual and potential ESD losses in terms of defective components, rework, customer returns, and failures during final test and inspection. Use data from outside sources or the results of your pilot program for additional support. Develop estimates of the savings to be realized from implementing an ESD control program.

You will also want to identify those items (components, assemblies, and finished products) that are the most sensitive to ESD noting the classification or withstand voltage. Note that two functionally identical items from two different suppliers may *not* have similar ESD ratings.

Establish and document your ESD control program plan

After completing your assessment, you can begin to develop and document your ESD control program plan. The plan should cover the scope of the program and include the tasks, activities and procedures necessary to protect the ESD sensitive items at or above the ESD sensitivity level chosen for the plan. Prepare and distribute written procedures and specifications so that all departments have a clear understanding of what is to be done. Fully documented procedures will help you meet the administrative and technical elements of ANSI/ESD S20.20 or IEC 61340-5-1 and help you with ISO 9000 certification as well.

Build justification to get the top management support

To be successful, an ESD program requires the support of your top management, at the highest level possible. What level of commitment is required? To obtain commitment, you will need to build justification for the plan. You will need to emphasize quality and reliability, the costs of ESD damage, the impact of ESD on customer service and product performance. It may be useful to conduct a pilot program if the experience of other companies is not sufficient and you have an expectation that you can show meaningful results in the pilot.

Prepare a short corporate policy statement on ESD control. Have top management co-sign it with the ESD coordinator. Periodically, reaffirm the policy statement and management's commitment to it. Published articles such as "The 'Real' Cost of ESD Damage" by Terry Welsher should be provided to top management.

Develop and implement a training plan

Train and retrain your personnel in ESD control and your company's ESD control program and procedures. Training should include testing or other method to verify comprehension. Proper training for line personnel is especially important. They are often the ones who have to live with the procedures on a day-to-day basis. A sustained commitment and mind set among all employees that ESD prevention is a valuable, on-going effort by everyone is one of the primary goals of training. Please be aware that it might be necessary to tailor the ESD training to the education of the trainees.

ANSI/ESD S20.20 requires a written training plan, however, your company has the flexibility to determine how best to design the plan.

Develop and implement a compliance verification plan

Developing and implementing the program itself is obvious. What might not be so obvious is the need to continually

review, audit, analyze, obtain feedback and improve. Auditing is essential to ensure that the ESD control program is successful. You will be asked to continually identify the return on investment of the program and to justify the savings realized. Technological changes will dictate improvements and modifications. Feedback to employees and top management is essential. Management commitment will need reinforcement.

Include both reporting and feedback to management, the ESD team, and other employees as part of your plan. Management will want to know that their investment in time and money is yielding a return in terms of quality, reliability and profits. ESD team members need a pat on the back for a job well done. Other employees will want to know that the procedures you have asked them to follow are indeed worthwhile. It is helpful to integrate the process improvement process into the overall quality system and use the existing quality tools such as root cause analysis and corrective action reports. As you find areas that need work, be sure to make the necessary adjustments to keep the program on track.

Conduct periodic evaluations of your program and audits of your facility. You will find out if your program is successful and is giving you the expected return. You will spot weaknesses in the program and shore them up. You will discover whether the procedures are being followed.

ANSI/ESD S20.20 and IEC 61340-5-1 require a written compliance verification plan, however, your company has the flexibility to determine how best to design the plan. Test procedures are described in ESD TR53-01-06 Compliance Verification of ESD Protective Equipment and Materials which is available as complimentary download from www.ESDA.org. The objective is to identify if significant changes in ESD equipment and materials performance have occurred over time. Each user will need to develop their own set of test frequencies based on the critical nature of those ESD sensitive items handled and the risk of failure for the ESD protective equipment and materials.

CONCLUSION

Six principles of ESD control and six key elements to ESD control program development and implementation are your guideposts for effective ESD control programs.

The six basic principles of static control are:

1. Design in protection
2. Define the level of control needed in your environment
3. Identify and define the electrostatic protected areas (EPA)
4. Reduce electrostatic charge generation
5. Dissipate and neutralize
6. Protect products

Six key elements to to ESD control program development and implementation are:

1. Establish an ESD Coordinator and ESD teams
2. Assess your organization, facility, processes and losses
3. Establish and document your ESD control program plan
4. Build justification to get the top management support
5. Develop and implement a training plan
6. Develop and implement a compliance verification plan

In Part Three, we'll take a close look at specific procedures and materials that become part of your ESD control program.

FOR ADDITIONAL INFORMATION

- *ANSI/ESD S20.20-2007 – Standard for the Development of Electrostatic Discharge Control Program*, ESD Association, Rome, NY.
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- ESDA Technology Roadmap, March 2013
- IEC 61340-5-1, ed. 1.0, *"Electrostatics – Part 5.1: Protection of electronic devices from electrostatic phenomena – General requirements*", IEC, Geneva, Switzerland, 2007-08.
- Terry Welsher, "The 'Real' Cost of ESD Damage," *In Compliance Magazine*, May 2010.

Fundamentals of Electrostatic Discharge
Part 3

Basic ESD Control Procedures and Materials

BY THE ESD ASSOCIATION

In Part Two, *Principles of ESD Control – ESD Control Program Development,* we introduced six principles of static control and six key elements of ESD program development and implementation. In Part Three, we will cover basic static control procedures and materials that will become part of your ESD control program. First, we review the principles.

BASIC PRINCIPLES OF STATIC CONTROL

We suggested focusing on just six basic principles in the development and implementation of effective ESD control programs:

1. **Design in protection** by designing products and assemblies to be as robust as reasonable from the effects of ESD.
2. **Define the level of control** needed in your environment.
3. **Identify and define** the electrostatic protected areas (EPAs), the areas in which you will be handling ESD sensitive parts (ESDS).
4. **Reduce Electrostatic charge generation** by reducing and eliminating static generating processes, keeping processes and materials at the same electrostatic potential, and by providing appropriate ground paths to reduce charge generation and accumulation.
5. **Dissipate and neutralize** by grounding, ionization, and the use of conductive and dissipative static control materials.
6. **Protect products from ESD** with proper grounding or shunting and the use of static control packaging and material handling products.

At the facility level our ESD control efforts concentrate on the last five principles. Here in Part Three, we will concentrate on the primary materials and procedures that reduce electrostatic charge generation, remove charges to ground, and neutralize charges to protect sensitive products from ESD.

IDENTIFYING THE PROBLEM AREAS AND THE LEVEL OF CONTROL

One of the first questions we need to answer is "How ESD sensitive are the parts and assemblies we are manufacturing or handling?" This information will guide you in determining the various procedures and materials required to control ESD in your environment.

How do you determine the sensitivity of your parts and assemblies or where can you get information about their ESD classification or withstand voltage? A first source would be the manufacturer or supplier of the component itself or the part data sheet. It is critical that you obtain both Human Body Model (HBM) and Charged Device Model (CDM) ratings. You may find that you need to have your specific device tested for ESD sensitivity. However, be aware that the correlation between voltages used for device qualification and static voltages measured in the field is weak.

The second question you need to answer is "Which areas of our facility need ESD protection?" This will allow you to define your specific electrostatic protected areas (EPAs), the areas in which you will be handling sensitive parts and the areas in which you will need to implement the ESD control principles. Often you will find that there are more areas that require protection than you originally thought, usually wherever ESDS devices are handled. Typical areas requiring ESD protection are shown in Table 1.

Receiving
Inspection
Stores and warehouses
Assembly
Test and inspection
Research and development
Packaging
Field service repair
Offices and laboratories
Clean rooms

Table 1: Typical Facility Areas Requiring ESD Protection

GROUNDING

Grounding is especially important for effective ESD control. It should be clearly defined, and regularly evaluated.

The equipment grounding conductor provides a path to bring ESD protective materials and personnel to the same electrical potential. All conductors and dissipative materials in the environment, including personnel, must be bonded or electrically connected and attached to a known ground, or create an equipotential balance between all items and personnel. ESD protection can be maintained at a charge or potential above a "zero" voltage ground reference as long as all items in the system are at the same potential. It is important to note that insulators, by definition non-conductors, cannot lose their electrostatic charge by attachment to ground.

ESD Association Standard ANSI/ESD S6.1-*Grounding* recommends a two-step procedure for grounding EPA ESD control items.

The first step is to ground all components of the workstation and the personnel (worksurfaces, equipment, etc.) to the same electrical ground point, called the "common point ground." This common point ground is defined as a "system or method for connecting two or more grounding conductors to the same electrical potential."

This ESD common point ground should be properly identified. ESD Association standard ANSI/ESD S8.1 – Symbols, recommends the use of the symbol in Figure 1 to identify the common point ground.

The second step is to connect the common point ground to the equipment grounding conductor (AC ground) or the third wire (typically green) electrical ground connection. This is the preferred ground connection because all electrical equipment at the workstation is already connected to this ground. Connecting the ESD control materials or equipment to the equipment ground brings all components of the workstation to the same electrical potential. If a soldering iron used to repair an ESDS item were connected to the electrical ground and the surface containing the ESDS item were connected to an auxiliary ground, a difference in electrical potential could exist between the iron and the ESDS item. This difference in potential could cause damage to the item.

Any auxiliary ground (water pipe, building frame, ground stake) present and used at the workstation must be bonded to the equipment grounding conductor to minimize differences in potential between the two grounds. Detailed information on ESD grounding can be found in ESD Association standard ANSI/ESD S6.1, Grounding, and the ESD Handbook ESD TR20.20, and/or CLC/TR 61340-5-2 User guide.

CONTROLLING STATIC CHARGE ON PERSONNEL AND MOVING EQUIPMENT

People can be one of the prime generators of static electricity. The simple act of walking around or the motions required in repairing a circuit board can generate several thousand volts of electrostatic charge on the human body. If not properly controlled, this static charge can easily discharge into an ESD sensitive device – a typical Human Body Model discharge. Also, a person can transfer charge to a circuit board or other item making it vulnerable to Charged Device Model events in a subsequent process.

Figure 1: Common Point Ground Symbol

Even in highly automated assembly and test processes, people still handle ESDS… in the warehouse, in repair, in the lab, in transport. For this reason, ESD control programs place considerable emphasis on controlling personnel generated electrostatic discharge. Similarly, the movement of mobile equipment (such as carts or trolleys) and other wheeled equipment through the facility also can generate substantial static charges that can transfer to the products being transported on this equipment.

WRIST STRAPS

Typically, wrist straps are the primary means of grounding personnel. When properly worn and connected to ground, a wrist strap keeps the person wearing it near ground potential. Because the person and other grounded objects in the work area are at or near the same potential, there can be no hazardous discharge between them. In addition, static charges are removed from the person to ground and do not accumulate. When personnel are seated on a chair which is not EPA appropriate, they are to be grounded using a wrist strap.

Typically, wrist straps are the primary means of grounding personnel. When properly worn and connected to ground, a wrist strap keeps the person wearing it near ground potential.

Wrist straps have two major components, the wristband that goes around the person's wrist and the ground cord that connects the wristband to the common point ground. Most wrist straps have a current limiting resistor molded into the ground cord on the end that connects to the wristband. This resistor is most commonly one megohm, rated at least 1/4 watt with a working voltage rating of 250 volts.

Wrist straps have several failure mechanisms and therefore should be tested on a regular basis. Either daily testing at specific test stations or using a continuous monitor at the workbench is recommended.

FLOORING, FLOOR MATS, FLOOR FINISHES

A second method of grounding personnel is a Flooring/Footwear System using ESD flooring in conjunction with ESD control footwear or foot grounders. This combination of conductive or dissipative floor materials and footwear provides a safe ground path for the dissipation of electrostatic charge, thus reducing the charge accumulation on personnel. In addition to dissipating charge, some floor materials (and floor finishes) also reduce triboelectric charging. The use of a Flooring/Footwear System is especially appropriate in those areas where increased personnel mobility is necessary. In addition, floor materials can minimize charge accumulation on chairs, mobile equipment (such as carts and trolleys), lift trucks and other objects that move across the floor. However, those items require dissipative or conductive casters or wheels to make electrical contact with the floor, and components to be electrically connected. When used as the personnel grounding system, the resistance to ground including the person, footwear and floor must be the same as specified for wrist straps (<35 megohms) and the accumulation body voltage in a standard walking voltage test (ANSI/ESD STM97.2) must be less than 100 volts.

SHOES, FOOT GROUNDERS, CASTERS

Used in combination with ESD flooring, static control shoes, foot grounders, casters and wheels provide the necessary electrical contact between the person or object and the flooring. Insulative footwear, casters, or wheels prevent static charges from flowing from the body or mobile equipment to the floor to ground and, therefore, have to be avoided.

CLOTHING

Clothing is a consideration in some ESD protective areas, especially in cleanrooms and very dry environments. Clothing materials, particularly those made of synthetic fabrics, can generate electrostatic charges that may discharge into ESDS or they may create electrostatic fields that may induce charges. Because clothing usually is electrically insulated or isolated from the body, charges on clothing fabrics are not necessarily dissipated to the skin and then to ground. Static control garments may suppress or otherwise affect an electric field from clothing worn underneath the garment. Per ANSI/ESD S20.20 and the Garment standard ANSI/ESD STM2.1, there are three categories of ESD garment:

- ESD Category 1 garment; a **static control garment** without being attached to ground. However, without grounding, a charge may accumulate on conductive or dissipative elements of a garment, if present, resulting in a charged source.
- ESD Category 2 garment; a **groundable static control garment,** when connected to ground, provides a higher level of suppression of the affects of an electric field from clothing worn underneath the garment.
- ESD Category 3 garment; a **groundable static control garment system** also bonds the skin of the person to an identified ground path. **The total system resistance including the person, garment and grounding cord shall be less than 35 megohms.**

WORKSTATIONS AND WORKSURFACES

An ESD protective workstation refers to the work area of a single individual that is constructed and equipped with materials and equipment to limit damage to ESD sensitive items. It may be a stand-alone station in a stockroom, warehouse, or assembly area, or in a field location such as a computer bay in commercial aircraft. A workstation also may be located in a controlled area such as a cleanroom. The key ESD control elements comprising most workstations are a static dissipative worksurface, a means of grounding personnel (usually a wrist strap), a common point ground, and appropriate signage and labeling. A typical workstation is shown in Figure 2.

The workstation provides a means for connecting all worksurfaces, fixtures, handling equipment, and grounding devices to a common point ground. In addition, there may be provision for connecting additional personnel grounding devices, equipment, and accessories such as constant or continuous monitors and ionizers.
Static protective worksurfaces with a resistance to ground of 1 megohm to 1 gigohm provide a surface that is at the same electrical potential as other ESD control items at the workstation. They also provide an electrical path to ground for the controlled dissipation of any static charges on materials that contact the surface. The worksurface also helps define a specific work area in which ESDS are to be handled. The worksurface is connected to the common point ground.

CONTINUOUS OR CONSTANT MONITORS

Continuous (or constant) monitors are designed to provide ongoing testing of the wrist strap system. While a number of technologies are utilized, the goal remains consistent: electrical connections are tested between the ground point, ground cord, wristband and person's body while the wearer handles ESDS. Continuous monitors may also provide a monitoring circuit for the ESD worksurface or other equipment connection to the ground reference.

Typical test programs recommend that wrist straps that are used daily should be tested daily. However, if the products that are being produced are of such value that knowledge of a continuous, reliable ground is needed, and then continuous monitoring should be considered or even required. Daily wrist strap testing may be omitted if continuous monitoring is used.

PRODUCTION EQUIPMENT AND PRODUCTION AIDS

Although personnel can be the prime generator of electrostatic charge, automated manufacturing and test

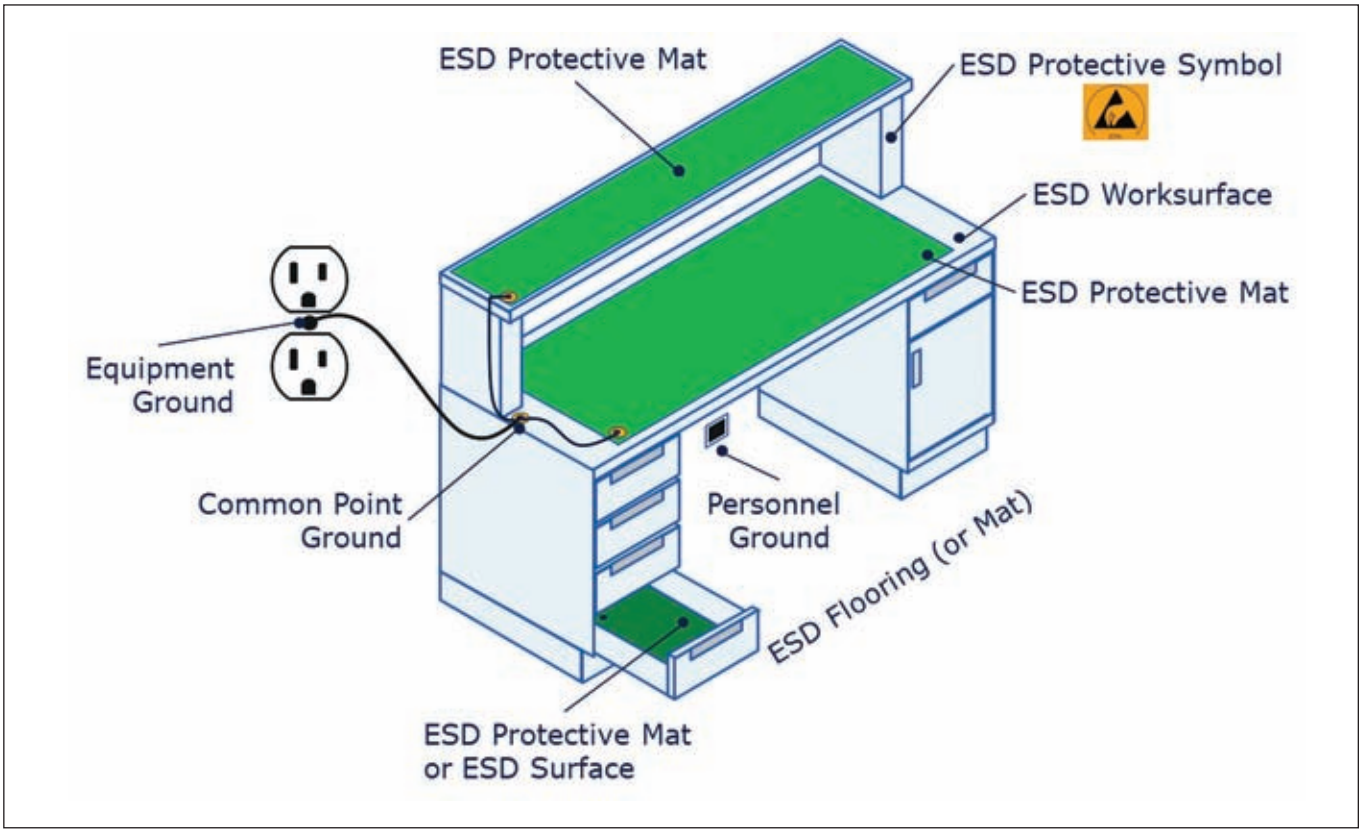


Figure 2: Typical ESD Workstation

equipment also can pose an ESD problem. For example, an ESDS device may become charged from sliding down a component part feeder. If the device then contacts the insertion head or another conductive surface, a rapid discharge occurs from the device to the metal object — a Charged Device Model (CDM) event. If charging of the ESDS cannot be avoided – which is quite often the case in modern assembly lines due to the insulative IC packages – charge storage should be reduced by the use of ionizers. In addition, various production aids such as hand tools, tapes, or solvents can also be ESD concerns.

Grounding is the primary means of controlling static charge on equipment and many production aids. Much electrical equipment is required by the National Electrical Code to be connected to the equipment ground (the green wire) in order to carry fault currents. This ground connection also will function for ESD control purposes. All electrical tools and equipment used to process ESD sensitive hardware require the 3 prong grounded type AC plug. Hand tools that are not electrically powered, i.e., pliers, wire cutters, and tweezers, are usually grounded through the ESD worksurface and the grounded person using the conductive/dissipative tools. Holding fixtures should be made of conductive or static dissipative materials when possible. Static dissipative materials are often suggested when very sensitive devices are being handled. A separate ground wire may be required for conductive or dissipative fixtures not in contact with an ESD worksurface or handled by a grounded person. For those items that are composed of insulative materials, the use of ionization or application of topical antistats may be required to control electrostatic charge generation and accumulation of static charges.

GLOVES AND FINGER COTS

Certainly, grounded personnel handling ESDS should not be wearing gloves or finger cots made from insulative material. If gloves or finger cots are used, the material should be dissipative or conductive. Compliance Verification ESD TR53 provides test procedures for measuring the electrical resistance of gloves or finger cots together with personnel in a system.

PACKAGING AND MATERIAL HANDLING

Inside the EPA packaging and material handing containers are to be low charging and be dissipative or conductive. Outside the EPA packaging and material handing containers are to also have a structure that provides electrostatic discharge shielding.

Direct protection of ESDS devices from electrostatic discharge is provided by packaging materials such as shielding bags, corrugated boxes, and rigid or semi-rigid plastic packages. The primary use of these items is to protect the product when it leaves the facility, usually when shipped to a customer. In addition, materials handling products such as tote boxes and other containers primarily provide protection during inter- or intra-facility transport.

The main ESD function of these packaging and materials handling products is to limit the possible impact of ESD from triboelectric charge generation, direct discharge, and in some cases electrostatic fields. The initial consideration is to have low charging materials in contact with ESD sensitive items. For example, the low charging property would control triboelectric charge resulting from sliding a board or component into the package or container. A second requirement is that the material can be grounded so that the resistance range must be conductive or dissipative. A third property required outside the EPA is to provide protection from direct electrostatic discharges that is discharge shielding.

Many materials are available that provide all three properties: low charging, resistance, and discharge shielding. The inside of these packaging materials have a low charging layer, but also have an outer layer with a surface resistance conductive or dissipative range. Per the Packaging standard ANSI/ESD S541, a low-charging, conductive or dissipative package is required for packaging or material handling within an EPA. Outside the EPA, the packaging must also have the discharge shielding property. Effectiveness, cost and device vulnerability to the various mechanisms need to be balanced in making packaging decisions (see ANSI/ESD S541, the ESD Handbook ESD TR20.20, and/or CLC/TR 61340-5-2 User guide for more detailed information).

Resistance or resistivity measurements help define the material's ability to provide electrostatic shielding or charge dissipation. Electrostatic shielding attenuates electrostatic fields on the surface of a package in order to prevent a difference in electrical potential from existing inside the package. Discharge shielding is provided by materials that have a surface resistance equal to or less than 1 kilohm when tested according to ANSI/ESD STM11.11 or a volume resistivity of equal to or less than 1×10^3 ohm-cm when tested according to the methods of ANSI/ESD STM11.12. In addition, effective shielding may be provided by packaging materials that provide a sufficiently large air gap between the package and the ESDS contents. Dissipative materials provide charge dissipation characteristics. These materials have a surface resistance greater than 10 kilohms but less than 100 gigohms when tested according to ANSI/ESD STM11.11 or a volume resistivity greater than 1.0×10^5 ohm-cm but less than or equal to 1.0×10^{12} ohm-cm when tested according to the methods of ANSI/ESD STM11.12. The ability of some packages to provide discharge shielding may be evaluated using ANSI/ESD STM11.31 which measures the energy

transferred to the package interior. A material's low charging properties are not necessarily predicted by its resistance or resistivity.

IONIZATION

Most static control programs also deal with isolated conductors that are not grounded, or insulating materials (e.g., most common plastics) that cannot be grounded. Topical antistats may provide temporary ability to dissipate static charges under some circumstances.

More frequently, however, air ionization is used to neutralize the static charge on insulated and isolated objects by producing a balanced source of positively and negatively charged ions. Whatever static charge is present on objects in the work environment will be reduced, neutralized by attracting opposite polarity charges from the air. Because it uses only the air that is already present in the work environment, air ionization may be employed even in cleanrooms where chemical sprays and some static dissipative materials are not usable.

Figure 3: ESD Susceptibility Symbol

Figure 4: ESD Protective Symbol

Air ionization is one component of a complete ESD control program, and not a substitute for grounding or other methods. Ionizers are used when it is not possible to properly ground everything and as backup to other static control methods. In cleanrooms, air ionization may be one of the few methods of static control available.

See Ionization standard ANSI/ESD STM3.1, ANSI/ESD SP3.3, and ESD TR53 for testing offset voltage (balance) and discharge times of ionizers.

CLEANROOMS

While the basic methods of static control discussed here are applicable in most environments, cleanroom manufacturing processes require special considerations.

Many objects integral to the semiconductor manufacturing process (quartz, glass, plastic, and ceramic) are inherently charge generating. Because these materials are insulators, this charge cannot be removed by grounding. Many static control materials contain carbon particles or surfactant additives that sometimes restrict their use in cleanrooms. The need for personnel mobility and the use of cleanroom garments often make the use of wrist straps difficult. In these circumstances, ionization and flooring/footwear grounding systems become key weapons against static charge.

IDENTIFICATION

A final element in our ESD control program is the use of appropriate symbols to identify ESD sensitive items, as well as specialty products intended to control ESD. The two most widely accepted symbols for identifying ESDS parts or ESD control protective materials are defined in ESD Association Standard ANSI/ESD S8.1 — ESD Awareness Symbols.

The ESD Susceptibility Symbol (Figure 3) consists of a triangle, a reaching hand, and a slash through the reaching hand. The triangle means "caution" and the slash through the reaching hand means "Don't touch." Because of its broad usage, the hand in the triangle has become associated with ESD and the symbol literally translates to "ESD sensitive stuff, don't touch."

The ESD Susceptibility Symbol is applied directly to integrated circuits, boards, and assemblies that are ESD sensitive. It indicates that handling or use of this item may result in damage from ESD if proper precautions are not taken. Operators should be grounded prior to handling. If desired, the sensitivity level of the item may be added to the label.

The ESD Protective Symbol (Figure 4) consists of the reaching hand in the triangle. An arc around the triangle replaces the slash. This "umbrella" means protection. The symbol indicates ESD protective material. It is applied to mats, chairs, wrist straps, garments, packaging, and other items that provide ESD protection. It also may be used on equipment such as hand tools, conveyor belts, or automated handlers that is especially designed or modified to provide ESD control properties (low charging, conductive/dissipative resistance, and/or discharge shielding).

SUMMARY

Effective ESD control programs require a variety of procedures and materials. The ESD coordinator should release and control regularly a list of the specific EPA ESD control products permitted to be used in the program. We have provided a brief overview of the most commonly used

products. Additional in-depth discussion of individual materials and procedures can be found in publications such as the ESD Handbook (ESD TR20.20) published by the ESD Association or the CLC/TR 61340-5-2 User guide.

Your program is up and running. How do you determine whether it is effective? How do you make sure your employees follow it? In Part Four, we will cover the topics of Auditing and Training.

FOR ADDITIONAL INFORMATION

ESD Association Standards

- *ANSI/ESD S1.1: Wrist Straps*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM2.1: Garments-Characterization*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM3.1: Ionization*, ESD Association, Rome, NY 13440
- *ANSI/ESD SP3.3: Periodic Verification of Air Ionizers*, ESD Association, Rome, NY 13440
- *ANSI/ESD S4.1: Worksurfaces-Resistance Measurements*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM4.2: ESD Protective Worksurfaces - Charge Dissipation Characteristics*, ESD Association, Rome, NY 13440
- *ANSI/ESD S6.1: Grounding,* ESD Association, Rome, NY 13440
- *ANSI/ESD S7.1: Resistive Characterization of Materials-Floor Materials*, ESD Association, Rome, NY 13440
- *ANSI/ESD S8.1: Symbols-ESD Awareness*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM9.1: Footwear-Resistive Characterization*, ESD Association, Rome, NY 13440
- *ESD SP9.2: Footwear-Foot Grounders Resistive Characterization*, ESD Association, Rome, NY 13440
- *ANSI/ESD SP10.1: Automated Handling Equipment*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM11.11: Surface Resistance Measurement of Static Dissipative Planar Materials*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM11.12: Volume Resistance Measurement of Static Dissipative Planar Materials*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM11.13: Two-Point Resistance Measurement*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM11.31: Evaluating the Performance of Electrostatic Discharge Shielding Bags*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM12.1: Seating-Resistive Measurement*, ESD Association, Rome, NY 13440
- *ESD STM13.1: Electrical Soldering/Desoldering Hand Tools*, ESD Association, Rome, NY 13440
- *ANSI/ESD SP15.1: In-Use Resistance Testing of Gloves and Finger Cots, ESD Association, Rome, NY 13440*
- *ANSI/ESD S20.20: Standard for the Development of an ESD Control Program*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM97.1: Floor Materials and Footwear - Resistance in Combination with a Person*, ESD Association, Rome, NY 13440
- *ANSI/ESD STM97.2: Floor Materials and Footwear - Voltage Measurement in Combination with a Person*, ESD Association, Rome, NY 13440
- *ANSI/ESD S541: Packaging Materials for ESD Sensitive Devices, ESD Association, Rome, NY 13440*
- *ESD ADV1.0: Glossary of Terms, ESD Association, Rome, NY 13440*
- *ESD ADV11.2: Triboelectric Charge Accumulation Testing*, ESD Association, Rome, NY 13440
- *ESD ADV53.1: ESD Protective Workstations*, ESD Association, Rome, NY 13440
- *ESD TR20.20: ESD Handbook*, ESD Association, Rome, NY 13440
- *ESD TR53: Compliance Verification of ESD Protective Equipment and Materials*, ESD Association, Rome, NY 13440

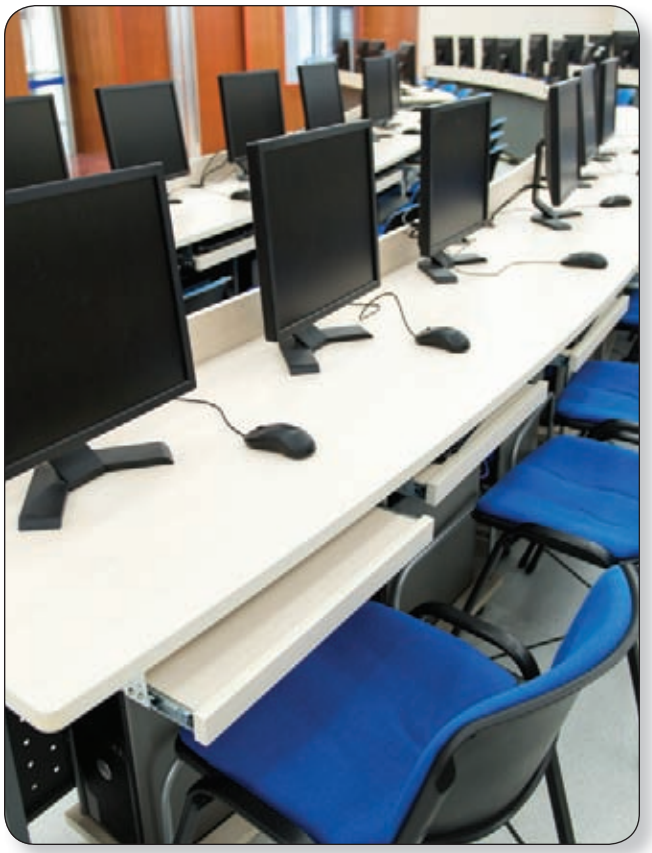
Other Resources

- System Reliability Center, 201 Mill Street, Rome, NY 13440
- *ANSI/IEEE STD142, IEEE Green Book*, Institute of Electrical and Electronics Engineers
- *ANSI/NFPA 70, National Electrical Code*, National Fire Protection Association, Quincy, MA
- *CLC/TR 61340-5-2 User guide,* European Committee for Electrotechnical Standardization, Brussels

Fundamentals of Electrostatic Discharge
Part 4

Training and Compliance Verification Auditing

BY THE ESD ASSOCIATION



Your static control program is up and running. How do you determine whether it is effective? How do you make sure your employees follow it? In Part Three, we covered basic static control procedures and materials of your ESD control program. In *Part Four*, we will focus on two ESD control program plan requirements: training and compliance verification auditing. Per ANSI/ESD S20.20 and IEC 61340-5-1, the written ESD control plan is to include a training plan and a compliance verification plan.

PERSONNEL TRAINING

The procedures are in place. The materials are in use. But, your ESD control program just does not seem to yield the expected results. Failures declined initially, but they have begun reversing direction. Or perhaps there was little improvement. The solutions might not be apparent in inspection reports of incoming ESD protective materials. Nor in the wrist strap log of test results. In large companies or small, it is hard to overestimate the role of training in an ESD control program. ANSI/ESD S20.20 and IEC 61340-5-1 ESD Control Program standards cite training as a basic administrative requirement within an ESD control program.

There is significant evidence to support the contribution of training to the success of the program. We would not send employees to the factory floor without the proper soldering skills or the knowledge to operate the automated insertion equipment. We should provide them with the same skill level regarding ESD control procedures.

ELEMENTS OF EFFECTIVE TRAINING PROGRAMS

Although individual requirements cause training programs to vary from company to company, there are several common threads that run through the successful programs.

Successful training programs cover all affected employees

Obviously we train the line employees who handle ESD sensitive devices and typically test their wrist straps or place finished products in static protective packaging. But we also include department heads, upper management, and executive personnel in the process. Typically they are responsible for the day-to-day supervision and administration of the program or they provide leadership and support. Even subcontractors and suppliers should be considered for inclusion in the training program if they are directly involved in handling your ESD sensitive components, sub-assemblies or products.

Because ESD control programs cover such a variety of job disciplines and educational levels, it may be necessary to develop special training modules for each organizational entity. For example, the modules developed for management,

engineering, assembly technicians and field service could differ significantly from one another because their day-to-day concerns and responsibilities are much different. Also, the different education and skills should be considered.

Effective training is comprehensive and consistent

Training not only covers specific procedures, but also the physics of the problem and the benefits of the program as well. Consistent content across various groups, facilities, and even countries (adjusted for cultural differences) reduces confusion and helps assure conformance. The training content should include topics such as the fundamentals of static electricity and electrostatic discharges, the details of the organization's ESD Control Program plan, and each person's role in the plan.

Use a variety of training tools and techniques

Choose the methods that will work best for your organization. Combine live instruction with training videos or interactive computer-based programs. You may have in-house instructors available, or you may need to go outside the company to find instructors or training materials. You can also integrate industry symposia, tutorials, and workshops into your program. Consider using this "Fundamentals of ESD" series of articles.

Effective training involves employees in the process. Reinforce the message with demonstrations of ESD events and their impact. Bulletin boards, newsletters, and posters provide additional reminders and reinforcement.

Maintaining a central repository for educational ESD control materials will help your employees keep current or answer questions that may occur outside the formal training sessions. Materials in such a repository might include

- Material from initial and recurring training sessions
- ESD Association or internal bulletins or newsletters
- DVDs or CDs
- Computer based training materials
- Technical papers, studies, standards (e.g. ESD Association, IEC, JEDEC), test methods and technical reports
- ESD control material and equipment product technical data sheets

In addition, a knowledgeable person in the organization should be available to answer trainee questions once they have begun working.

Test, certify and retrain

Your training should assure comprehension, material retention and emphasize the importance of the effort. If properly implemented, testing and certification motivates and builds employee pride. Retraining or refresher training is an ongoing process that reinforces, reminds, and provides opportunities for implementing new or improved procedures. Establish a system to highlight when employees are due for retraining, retesting, or recertification.

Feedback, compliance verification, and measurement

Motivate and provide the mechanism for program improvement. Sharing yield or productivity, quality, and reliability data with employees demonstrates the effectiveness of the program and their efforts. Tracking these same numbers can indicate that it is time for retraining or whether modifications are required in the training program.

Design and delivery of an effective ESD training program can be just as important as the procedures and materials used in your ESD control program. Without an effective personnel training program, investments in ESD materials can be wasted. A training program that is built on identifiable and measurable performance goals helps assure employee understanding, implementation and success.

A key method of training effectiveness is observation of the operator in the EPA following ESD control procedures and precautions. Non-compliance with required ESD control program practices should be treated in the same manner of other impermissible actions that are handled through the company's disciplinary process. This includes verbal warnings, re-training, written warnings, and eventually re-assignment or termination.

COMPLIANCE VERIFICATION AUDITING

Developing and implementing an ESD control program itself is obvious. What might not be so obvious is the need to continually review, verify, analyze, feedback and improve. You will be asked to continually identify the program's financial return on investment and to justify expenditures with the cost savings realized. Technological changes will dictate improvements and modifications. Feedback to employees and top management is essential. Management commitment will need continuous reinforcement.

Like training, regular program compliance verification and auditing becomes a key factor in the successful management of ESD control programs. The mere presence of the auditing process spurs compliance with program procedures. It helps strengthen management's commitment. Program compliance verification reports should trigger required corrective action and help foster continuous improvement.

The benefits to be gained from regular compliance verification of ESD control procedures are numerous.

- Prevent problems before they occur rather than always fighting fires.
- Identify problems and take corrective action.
- Identify areas in which our programs may be weak and provide us with information required for continuous improvement.
- Leverage limited resources effectively.
- Determine when our employees need to be retrained.
- Improve yields, productivity, and reliability.
- Bind our ESD program together into a successful effort.

An ESD control program compliance verification audit measures performance to the ESD Control Program Plan's required limits. Typically, we think of the ESD program compliance verification as a periodic review and inspection of the ESD protective area (EPA) verifying the correct use of packaging materials, wearing of wrist straps, following defined procedures, and similar items. Auditing can range from informal surveys of the processes and facilities to the more formal third-party audits for ISO 9000 or ANSI/ESD S20.20 certification.

REQUIREMENTS FOR EFFECTIVE COMPLIANCE VERIFICATION

Regardless of the structure, effective compliance verification revolves around several factors. First, the *existence of a written and well-defined ESD Control Program Plan* with defined required limits for each EPA ESD control item. It is difficult to measure performance if you do not have anything to measure against. Yet, you quite frequently hear an auditor ask, "Some people say you should measure less than 500 volts in an EPA, but others say you should measure less than 100 volts. What's acceptable when I audit the factory floor?" Obviously, this question indicates a lack of a formal ESD Control Program Plan defined required limits and test procedures, and the audit will be relatively ineffective.

Second, the *taking of some measurements* – typically measuring resistance and detecting the presence of charge or fields. Therefore, you will need *test equipment* to conduct EPA compliance verification. As a minimum, you will need an *electrostatic field meter*, a *high range resistance meter*, a *ground AC outlet tester,* and appropriate electrodes and accessories.

Third, *include all areas in which ESD control is required* to protect electrostatic discharge sensitive (ESDS) items. Typically included are receiving, inspection, stores and warehouses, assembly, test and inspection, research and development, packaging, field service repair, offices and laboratories, and cleanrooms. All of the areas listed in the ESD Control Program Plan are subject to compliance verification.

Even the areas that are excluded from the plan need to be reviewed to ensure that unprotected ESDS devices are not handled in those areas. In the event that devices do enter those areas (e.g. Engineering and Design), mechanisms must be put in place to ensure that the devices are handled as non-conforming product. Similarly, we need to audit all of the various processes, materials, and procedures that are used in our ESD control programs – personnel, equipment, wrist straps, floors, clothing, worksurfaces, continuous monitors, seating, training, and grounding.

Fourth, we need to conduct compliance verification audits *frequently and regularly*. However, the user must determine the frequency (and if sampling is appropriate). Per Compliance Verification ESD TR53 ANNEX A Test Frequency "The objective of the periodic test procedures listed in this document is to identify if significant changes in ESD equipment and materials performance have occurred over time.

Test frequency limits are not listed in this document as each user will need to develop their own set of test frequencies based on the critical nature of those ESD sensitive items handled and the risk of failure for the ESD protective equipment and materials.

Following are examples of how test frequencies are considered. Daily wrist strap checks are sufficient in some applications, where in other operations constant wrist strap monitoring may be used for added operator grounding reliability. Packaging checks may depend on the composition of the packaging and its use. Some packaging may have static control properties that deteriorate more quickly with time and use, and some packaging may be humidity dependent and may have limited shelf life.

Some materials, such as ESD floor finishes, may require more frequent monitoring because of their lack of permanency. Other materials, such as ESD vinyl floor covering, may require less monitoring. The testing of a floor should also be considered after maintenance on the floor has been performed."

The actual frequency of compliance verification audits depends upon your facility and the ESD problems that you have. Following an ESD Control Program initial audit, some experts recommend auditing each department once a month if possible and probably a minimum of six times per year. If this seems like a high frequency level, remember that these regular verification audits are based upon a *sampling* of work areas in each department, not necessarily *every* workstation. Once you have gotten your program underway, your frequency of audit will be based on your experience. If your audits regularly show acceptable levels of conformance and performance, you can reduce the frequency and the sampling. If, on the other hand,

ESD Control Program Compliance Verification audits verify that program procedures are followed and that ESD control materials and equipment are within required limits or are functioning properly.

your audits regularly uncover continuing problems, you will want to increase the frequency and the sampling.

Fifth, we need to *maintain trend charts and detailed records and prepare reports*. They help assure that specified procedures are followed on a regular basis. The records are essential for quality control purposes, corrective action and compliance with ISO-9000.

Finally, upon completion of the compliance verification audit, it is essential to *implement corrective action* if deficiencies are discovered. Trends need to be tracked and analyzed to help establish corrective action, which may include retraining of personnel, revision of requirement documents or processes, or modification of the existing facility.

TYPES OF AUDITS

There are three types of ESD audits: *program management* audits, *quality process* checking, and *ESD Control Program compliance verification* (*work place)* audits. Each type is distinctively different and each is vitally important to the success of the ESD program

Program management audits measure how well a program is managed and the strength of the management commitment. The program management audit emphasizes factors such as the existence of an effective implementation plan, realistic program requirements, ESD training programs, regular compliance verification audits, and other critical factors of program management. The program management audit typically is conducted by a survey specifically tailored to the factors being reviewed. Because it is a survey, the audit could be conducted without visiting the site. The results of this audit indirectly measure workplace compliance and are particularly effective as a means of self-assessment for small companies as well as large global corporations.

Quality process checking applies statistical quality control techniques to the ESD process and is performed by operations personnel. This is not a periodic verification audit, but rather tracking daily effectiveness of the program. Visual and electrical checks of the procedures and materials, wrist strap testing, for example, are used to monitor the quality of the ESD control process. Checking is done on a daily, weekly or monthly basis.

Trend charts and detailed records trigger process adjustments and corrective action. They help assure that specified procedures are followed on a regular basis. The records are essential for quality control purposes, corrective action and compliance with ISO-9000.

ESD Control Program Compliance Verification audits verify that program procedures are followed and that ESD control materials and equipment are within required limits or are functioning properly. Compliance Verification audits are performed on a regular basis, often monthly, and utilize sampling techniques and statistical analysis of the results. The use of detailed checklists and a single auditor assures that all items are covered and that the audits are performed consistently over time.

BASIC AUDITING INSTRUMENTATION

Special test equipment will be required to conduct EPA compliance verification. The specific test equipment will depend on what you are trying to measure, the precision you require and the sophistication of your static control and material evaluation program. However, as a minimum, you will need an *electrostatic field meter*, a *high range resistance meter*, a *ground/AC outlet tester,* and appropriate electrodes and accessories. Additional test equipment might include a charged plate monitor, footwear and wrist strap testers, chart recorders/data acquisition systems and timing devices, discharge simulators, and ESD event detectors.

Although this equipment must be accurate and calibrated according to the vendor's recommendations, it needs not be as sophisticated as laboratory instruments. The compliance verification audit is intended to verify basic functions and not for product qualification of ESD control equipment or materials. The compliance verification audit is intended to verify basic functions and not as a product qualification of ESD control items or materials. You want the right tool for the job. Just as you would not buy a hammer if you are were planning to saw wood, you would not purchase an electrometer to measure static voltages on a production line. Remember, many of the test equipment you might choose for compliance verification are good indicators, but not suitable for precise evaluation of materials. However, be sure that you can correlate the measurements obtained on the factory floor with those obtained in the laboratory. If you are

making measurements according to specific standards or test methods, be sure the instrumentation meets the requirements of those documents.

With a hand-held **electrostatic field meter,** you can measure the presence of electrostatic fields in your environment allowing you to identify problems and monitor your ESD control program. These instruments measure the electrostatic field associated with a charged object. Many electrostatic field meters simply measure the gross level of the electrostatic field and should be used as general indicators of the presence of a charge and the approximate level of electrical potential of the charge. Others will provide more precise measurement for material evaluation and comparison.

For greater precision in facility measurements or for laboratory evaluation, a **charged plate monitor** is a useful instrument that can be used in many different ways; for example to evaluate the performance of flooring materials or measuring the offset voltage (balance) and discharge times of ionizers.

Because grounding is so important, resistance is one of the key factors in evaluating ESD control materials. A high range **resistance meter** becomes a crucial instrument. Most resistance measurements are made using a 100 volt or 10 volt test voltage. The resistance meter you choose should be capable of applying these voltages to the materials being tested. In addition, the meter should be capable of measuring resistance ranges of 10^3 to 10^{12} ohms. With the proper electrodes and cables, you will be able to measure the resistance of flooring materials, worksurfaces, equipment, furniture, garments, and some packaging materials.

The final instrument is a **ground/AC outlet tester.** With this device, you can measure the continuity of your ESD grounds, check the impedance of the equipment grounding conductor (3^{rd} wire AC ground) as well as verify that the wiring of power outlets in the EPA is correct.

AREAS, PROCESSES, AND MATERIALS TO BE AUDITED

Previously we stated that ESD protection was required "wherever unprotected ESD sensitive devices are handled." Obviously, our audits need to include these same areas. Table 1 indicates some of the physical areas that may be part of the ESD Control Program Plan and, therefore, will be involved in Compliance Verification Audits. Remember, some areas may be excluded from the Plan depending on the Scope of the Plan.

Similarly, we need to conduct Compliance Verification audits of all the various requirements that are used in our ESD Control Program Plan. Some of these are shown in Table 2.

Receiving
Inspection
Stores and Warehouses
Assembly
Test and Inspection
Research and Development
Packaging
Field Service Repair
Offices and Laboratories
Cleanrooms

Table 1: Typical Facility Areas Requiring ESD Protection

Personnel
Wrist Straps
Floors, Floor Mats, Floor Finishes
Shoes, Foot Grounders, Casters
Garments
Mobile Equipment (Carts, trolleys, lift trucks)
Workstations
Worksurfaces
Packaging and Materials Handling
Ionization
Grounding
Continuous Monitors
Seating
Production Equipment
Tools and Equipment (Soldering irons, fixtures, etc.)
Marking
Purchasing Specifications and Requisitions
ESD Measurement and Test Equipment
Personnel Training

Table 2: Typical Processes, Materials and Procedures

CHECKLISTS

Checklists can be helpful tools for conducting Compliance Verification audits. However, it is important that ESD control program requirements are well documented and accessible to avoid the tendency for checklists becoming *de facto* lists of requirements. Table 3 indicates the questions and information that might be included in an auditing checklist. Other checklists are in the ESD Handbook ESD TR20.20 section 4.3.3. Your own checklists, of course, will be based on your specific needs and program requirements. They should conform to your actual ESD control procedures and specifications, and they should be consistent with any ISO 9000 requirements you may have. For ANSI/ESD S20.20 based ESD Control Programs, the recognized Certification Bodies (Registrars) use a formal checklist supplied by the ESD Association to aid in conducting the Certification Audit.

In addition to checklists, you will use various forms for recording the measurements you make: resistance, voltage generation, etc. Part of your compliance verification audit will also include the daily logs used on the factory floor such as those used for wrist strap checking.

REPORTING AND CORRECTIVE ACTION

Upon completion of the compliance verification auditing process, Reports should be prepared and distributed in a timely manner. Details of the audits need to be fully documented for ISO-9000 or ANSI/ESD S20.20 certification. As with all audits, it is essential to implement corrective action if deficiencies are discovered. Trends need to be tracked and analyzed to help establish corrective action, which may include retraining of personnel, revision of requirement documents or processes, or modification of the existing facility.

Function/Area Audited: Facilities			
Date: By:			
Audit Questions	Y	N	Comments
1. Where ESD protective flooring is used for personnel grounding, are ESD footwear worn?			
2. Where ESD floors and footwear are used for personnel grounding, do personnel check and log continuity to ground upon entering the EPA?			
3. Are personnel wearing grounded wrist straps at the ESD protective workstations (if required)?			
4. Are personnel checking wrist straps for continuity or using a continuous monitor?			
5. Where continuous monitors are not used, are wrist straps checked and logged routinely and at frequent intervals?			
6. Are wrist strap checkers and continuous monitors checked and maintained periodically?			
7. Are wrist strap cords checked, on the person, at the workstation?			
8. Are disposable foot grounders limited to one time use?			
9. Are test records for wrist straps and foot grounders kept and maintained?			
10. When required, are ESD protective garments correctly worn?			
11. Are nonessential personal items kept out of the EPA?			
12. Are personnel working in the EPA currently certified or escorted?			
13. Are ESD Control requirements imposed on visitors to the EPA?			

Table 3: Partial Audit Checklist ESD Control Program

CONCLUSION

Compliance verification and personnel ESD control training are key ANSI/ESD S20.20 and IEC 61340-5-1 requirements to maintain an effective ESD control program. They help assure that ESDS handling procedures are properly implemented and can provide a management tool to gauge program effectiveness and to make continuous improvement.

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Fundamentals of Electrostatic Discharge
Part 5

Device Sensitivity and Testing

BY THE ESD ASSOCIATION

In *Part Two* of this series ("Principles of ESD Control – ESD Control Program Development"), we indicated that a key element in a successful static control program is the identification of those items (components, assemblies, and finished products) that are susceptible (ESD sensitive devices, ESDS) to ESD and to know the level of their sensitivity. Susceptibility of an ESDS to an ESD event is determined by the device's ability to dissipate or shunt the energy of the discharge or withstand the current and voltage levels involved. Although energy or (peak) current are the most important parameters, the ESD sensitivity or ESD susceptibility is typically classified by its withstand voltage. The withstand voltage is defined by the voltage which causes the discharge, not the voltage which can be measured at the ESDS. Part Two included:

> Define the level of control needed in your environment. What is the most sensitive or ESD susceptible ESDS you are using and what is the classification of withstand voltage of the products that you are manufacturing and shipping? In order to have a complete picture of what is required, it is best to know the Human-Body Model (HBM) and Charged-Device Model (CDM) sensitivity levels for all devices that will be handled in the manufacturing environment. ANSI/ESD S20.20 defines control program requirements for items that are sensitive to 100 volts HBM.

Some devices may be more readily damaged by discharges occurring within automated equipment, while others may be more prone to damage from handling by personnel. In this Part Five we will cover the models and test procedures used to characterize, determine, and classify the sensitivity of components to ESD. Today, these test procedures are based on the two primary models of ESD events: Human Body Model (HBM) and Charged Device Model (CDM). The models used to perform component testing cannot replicate the full spectrum of all possible ESD events and there is no direct correlation between discharges in the field and in a test system. Nevertheless, these models have been proven to be successful in reproducing over 99% of all ESD field failure signatures and typically the ESD withstand voltages obtained by models in test systems are worst-case compared to real-world events with the same discharge voltage. With the use of standardized test procedures, the industry can:

- Develop and measure suitable on-chip protection.
- Enable comparisons to be made between devices.
- Provide a system of ESD sensitivity classification to assist in the ESD design and monitoring requirements of the manufacturing and assembly environments.
- Have documented test procedures to ensure reliable and repeatable results.

HUMAN BODY MODEL (HBM) TESTING

One of the most common causes of electrostatic discharge damage is the direct transfer of electrostatic charge from the human body or from a charged material to the electrostatic discharge sensitive item. When one walks across a floor, an

electrostatic charge accumulates on the body. Simple contact (or even close proximity) of a finger to the leads of an ESDS or assembly allows the body to discharge, possibly causing device damage. The model used to simulate this event is the Human Body Model (HBM).

The Human Body Model is the oldest and most commonly used model for classifying device sensitivity to ESD. The HBM testing model represents the discharge from the fingertip of a standing individual delivered to the device. It is modeled by a 100 pF capacitor which is charged by a high-voltage supply through a high-ohmic resistor (typically in the megohm regime) and then discharged through a switching component and a 1.5 kW (1,500 ohms) series resistor through the component to ground or to a lower potential. This model, which dates from the nineteenth century, was developed for investigating explosions of gas mixtures in mines. It was adopted by the military in MIL-STD-883 Method 3015, and is referenced in ANSI/ESDA-JEDEC JS-001*: Electrostatic Discharge Sensitivity Testing – Human Body Model*. This document replaces the previous ESDA and JEDEC methods, STM5.1-2007 and JESD22-A114F, respectively. The simplified Human Body Model circuit without any parasitics from the test system is presented in Figure 1.

A typical HBM waveform has a rise time of 2–10 ns, a peak current of 0.67 amps/kilovolts and a double-exponential decay with a width of 200 ns. Typically, the decisive parameter which causes the failure is the energy of the HBM pulse.

Testing for HBM ESD susceptibility is typically performed using automated test systems. The device is placed in the test system and contacted through a relay matrix. One pin is contancted to the HBM network ("zap pin"), and one or several other pins are connected to tester ground ("ground pins"). With today's high-pin count devices, a full test of all possible stress combinations is no longer possible, thus pin combinations have to be selected which guarantee a sufficient coverage to detect weak stress combinations. These pin combinations which have to be stressed are defined in the current HBM standard. Electrostatic discharges (ESD) are applied with a waveform generated by a Human Body Model network. A device is determined to have failed if it does not meet the datasheet parameters using parametric and functional testing.

One has to state clearly that the Human Body Model according to JS-001 addresses *handling issues*.

Sometimes, the well-known IEC 61000-4-2 is also called "Human Body Model", but that model addresses ESD events *in a system* under different operating conditions and, therefore, should be applied to *systems only*. The waveform and the severity of the IEC 61000-4-2 and the JS-001 cannot be compared. For handling issues, only JS-001 is meaningful.

CHARGED DEVICE MODEL (CDM) TESTING

The transfer of charge *from* an ESDS to a conductive surface at a lower potential is also an ESD event. A device may become charged, for example, from sliding down the part feeder in automated handling equipment. If it then contacts the insertion head or another conductive surface, which is at a lower potential, a rapid discharge may occur from the device to the conductive surface. This discharge event is known as the Charged Device Model (CDM) event and can be more damaging than the HBM for some devices. Although the duration of the discharge is very short – often less than one nanosecond – the peak current can reach several tens of amperes, causing significant voltage drops in the device and eventually resulting in breakdown of dielectrics (e.g. gate oxides) due to the excessive voltage.

The device testing standards for *CDM (ESD STM5.3.1: Electrostatic Discharge Sensitivity Testing - Charged Device Model and JEDEC Standard JESD22-C101: "Field-Induced Charged-Device Model Test Method for Electrostatic-Discharge-Withstand Thresholds of Microelectronic Components")* were originally published in 1999 and 2000, respectively. The test procedure involves placing the device on a field plate with its leads pointing up, then charging it and discharging the device. All pins are treated equally and are discharged after positive and negative charging. Figure 2 illustrates a typical CDM test circuit with direct charging o the device. The CDM 5.3.1

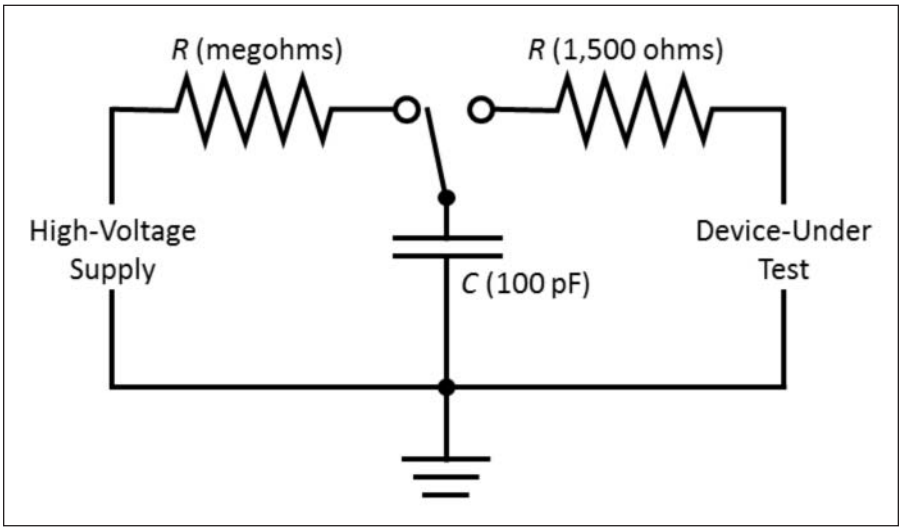

Figure 1: Typical (simplified) Human Body Model Circuit

ESDA document was last published in 2009. A joint JEDEC/ANSI/ESDA CDM standard (JS-002-2014) is about to be released.

OTHER TEST METHODS

Machine Model (MM) testing

A discharge also can occur from a charged conductive object, such as a metallic tool, or an automatic equipment or fixture. Originating in Japan as the result of trying to create a worst-case HBM event, the model is known as the Machine Model. This ESD model consists of a 200 pF capacitor discharged directly into a component with no series DC resistor in the output circuitry. The discharge waveform can be oscillating, rise time and pulse width are similar to HBM. The Machine Model typically addresses the same physical failure mode as the Human Body Model, although at significantly lower levels.

Testing of devices for MM sensitivity using ESD Association standard *ESD S5.2: Electrostatic Discharge Sensitivity Testing – Machine Model* is similar in procedure to HBM testing. The basic test equipment and the stress combinations are the same, but the test head is very different. The MM version does not have a 1,500 ohm resistor, but otherwise the test board and the socket are often the same as for HBM testing. The series inductance, as shown in Figure 3, is the dominating parasitic element that shapes the oscillating machine model wave form. The series inductance is indirectly defined through the specification of various waveform parameters like peak currents, rise times and the period of the waveform. However, the inductance is not well defined. Hence, for different testers the MM withstand voltage might differ by at least a factor of 2–5, although both test systems comply with the current standard. The lack of reproducibility of test results and the fact that the well reproducible HBM addresses the same failure mode as HBM are the main reasons that the industry only rarely is using MM today. JEDEC and ESDA do not recommend to qualify products with Machine Model, but qualifiying with HBM and CDM instead. The ANSI/ESDA MM 5.2 document was last published in 2013, however, with the arguments discussed in Industry Council White Paper 1, "A Case for Lowering Component Level HBM/MM ESD Specifications and Requirements," the test procedure was reclassified from a Standard to a Standard Test Method. Machine Model testing of integrated circuits (ICs) should be limited to failure analysis without correlation of withstand voltages and charging in the field.

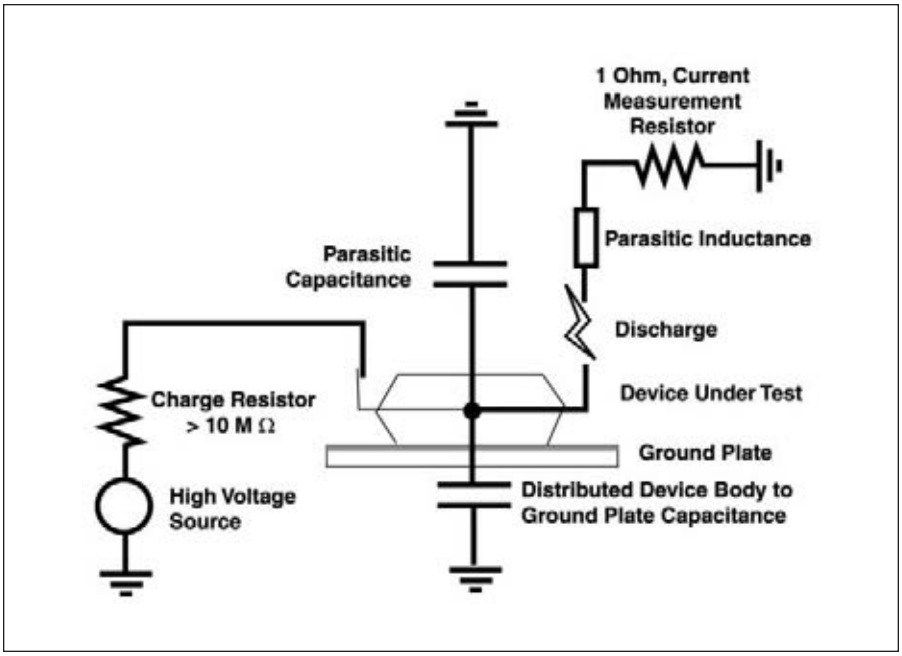

Figure 2: Typical Charged Device Model Test

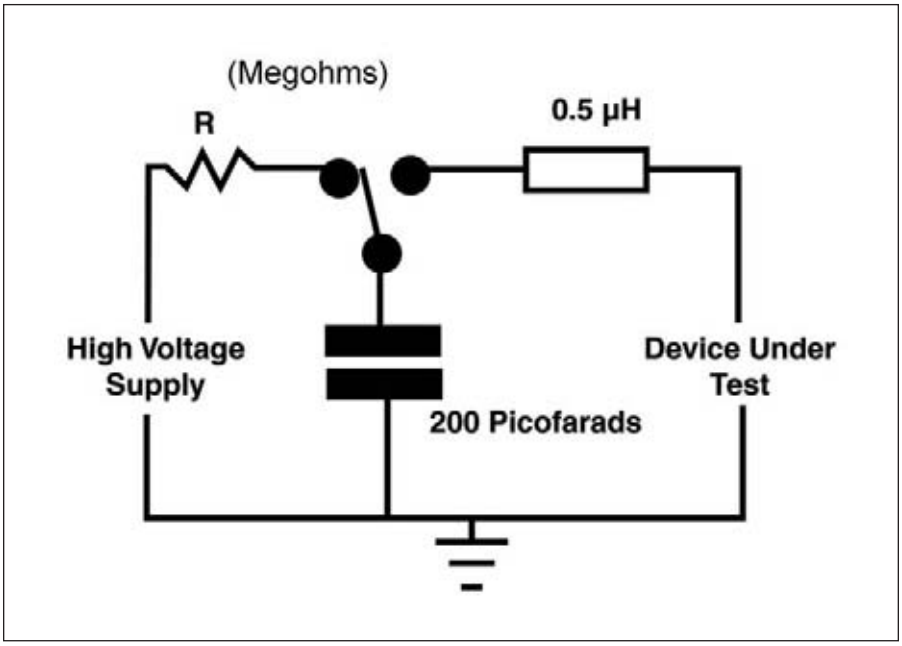

Figure 3: Typical Machine Model Circuit

Socketed Device Model (SDM) testing

This model was originally intended to provide an efficient way to do CDM testing. The device is placed in a socket, charged from a high-voltage source and then discharged through the relay to ground. However, a correlation with the CDM standard cannot be guaranteed and there was too great a dependency on the specific design of the SDM tester. Furthermore, today there is no commercial SDM test system available anymore. A Standard Practice (SP) document (SP), SDM-5.3.2, was first published in 2002, and republished in 2013. A technical report, *ESD TR5.3.2 (formerly TR08-00) Socket Device Model (SDM) Tester* which discusses the pros and cons of SDM is also available from the ESD Association.

DEVICE SENSITIVITY CLASSIFICATION

The HBM and CDM methods include a classification system for defining the component sensitivity to the specified model (See Tables 1 and 2). These classification systems have a number of advantages. They allow easy grouping and comparing of components according to their ESD sensitivity and the classification gives you an indication of the level of ESD protection that is required for the component.

The current HBM and standards divide the Class 0 classification into two withstand voltage levels with class 0A being less than 125 volt sensitivity, and class 0B being 125 to less than 250 volts.

If handling class 0A items, or less than 125 volts, program improvements are called for. Basically, to control the environment to decrease the probability of ESD damage in class 0A situations, involves increasing ESD protective redundancies by adding EPA ESD control items and ensuring that they are working properly by increasing the frequency of compliance verifications of those ESD control items perhaps to more stringent required limits.

A component should be classified using both the Human Body Model, and the Charged Device Model. This would alert a potential user of the component to the need for a controlled environment, whether assembly and manufacturing operations are performed by human beings or automatic machinery.

A word of caution; however, these classification systems and component sensitivity test results function as guides, not necessarily as absolutes. The events defined by the test data produce narrowly restrictive data that must be carefully considered and judiciously used. The two ESD models represent discrete points used in an attempt to characterize ESD vulnerability. The data points are informative and useful, but to arbitrarily extrapolate the data into a real world scenario can be misleading. The true utility of the data is in comparing one device with another and to provide a starting point for developing your ESD control programs.

SUMMARY

Device failure models and device test methods define the ESD susceptibilty of the electronic devices and assemblies to be protected from the effects of ESD. With this key information, you can design more effective ESD control programs. However, do expect devices to become more susceptible. The ESD Association's White Paper "Electrostatic Discharge (ESD) Technology Roadmap – Revised April 2010" includes "With devices becoming more sensitive through 2010-2015 and beyond, it is imperative that companies begin to scrutinize

Classification	Voltage Range (V)
0A	< 125
0B	125 to < 250
1A	250 to < 500
1B	500 to < 1000
1C	1000 to < 2000
2	2000 to < 4000
3A	4000 to < 8000
3B	≥ 8000

Table 1: ANSI/ESDA/JEDEC JS-001 Table 3 - HBM ESD Component Classification Levels

Classification	Voltage Range (V)
C0A	< 125
C0B	125 to < 250
C1	250 to < 500
C2A	500 to <750
C2B	750 to < 1000
C3	≥ 1000

Table 2: ANSI/ESDA/JEDEC JS-002 Table 3 - CDM ESD Component Classification Levels

the ESD capabilities of their handling processes. Factory ESD control is expected to play an ever-increasing critical role as the industry is flooded with even more HBM (Human Body Model) and CDM (Charged Device Model) sensitive designs. For people handling ESD sensitive devices, personnel grounding systems must be designed to limit body voltages to less than 100 volts."

FOR FURTHER REFERENCE

- ANSI/ESDA/JEDEC JS-001 *Electrostatic Discharge Sensitivity Testing – Human Body Model,* ESD Association, Rome, NY.
- *ESD STM5.2-2009: Electrostatic Discharge Sensitivity Testing – Machine Model,* ESD Association, Rome, NY.
- *ESD STM5.3.1-2009: Electrostatic Discharge Sensitivity Testing – Charged Device Model,* ESD Association, Rome, NY.
- ANSI/ESDA/JEDEC JS-002 *Electrostatic Discharge Sensitivity Testing – Charged Device Model,* ESD Association, Rome, NY.
- *ESD TR 5.3.2-2013 (formerly TR08-00): Socket Device Model (SDM) Tester,* ESD Association, Rome, NY.
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Fundamentals of Electrostatic Discharge
Part 6

ESD Standards

BY THE ESD ASSOCIATION

The electronics industry is continually shifting. Device circuitry density and technology is more complex. Electronics manufacturing is more heavily reliant on out-sourcing. The ESD industry seems to have jumped into this swirling eddy headfirst. ESD control programs have mushroomed. Black has been replaced by green, blue and gold. Shielding bags dominate the warehouse. Ionizers exist alongside wrist straps and ground cords. An early history of "smoke and mirrors," magic and lofty claims of performance is rapidly being relegated to the past.

Today, more than ever, meeting the complex challenge of reducing ESD losses requires more than reliance on faith alone. Users require a way to legitimately evaluate and compare competing brands and types of products and ESD protection strategies. They need objective confirmation that their ESD control program provides effective solutions to their unique ESD problems. Contract manufacturers and OEM's require mutually agreed-upon ESD control programs that reduce duplication of process controls.

That's where standards come into play. They provide information in developing programs that effectively address ESD process control. They help define the sensitivity of the products manufactured and used. They help define the performance requirements for various ESD control materials, instruments, and tools. Standards are playing an ever-increasing role in reducing marketplace confusion in the manufacture, evaluation, and selection of ESD control products and programs.

THE WHO AND WHY OF STANDARDS

Who uses ESD standards? Manufacturers and users of ESD sensitive devices and products, manufacturers and distributors of ESD control products, certification registrars, and third party testers of ESD control products.
Why use ESD standards? They help assure consistency of ESD sensitive products and consistency of ESD control products and services. They provide a means of objective evaluation and comparison among competitive ESD control products. They help reduce conflicts between users and suppliers of ESD control products. They help in developing, implementing, auditing, and certifying ESD control programs. And, they help reduce confusion in the marketplace.

In the United States, the use of standards is voluntary, although their use can be written into contracts or purchasing agreements between buyer and seller. In most of the rest of the world, the use of standards, where they exist, is compulsory.

KEY STANDARDS AND ORGANIZATIONS

Just twenty-five years ago, there were relatively few reliable ESD standards and few ESD standards development organizations. Today's ESD standards landscape is not only witnessing an increase in the number of standards, but also increasing cooperation among the organizations that develop them.

Today's standards fall into three main groups. First, there are those that provide ESD program guidance or requirements. These include documents such as *ANSI ESD S20.20 – Standard for the Development of an ESD Control Program, IEC 61340-5-1 – Protection of electronic devices from electrostatic phenomena – General requirements, ANSI/ESD S8.1 – Symbols-ESD Awareness,* or *ANSI/ESD TR20.20 – ESD Handbook.*

A second group covers requirements for specific products or procedures such as packaging requirements and grounding. Typical standards in this group are *ANSI/ESD S6.1 – Grounding* and *ANSI/ESD S541 –Packaging Materials for ESD Sensitive Items*.

A third group of documents covers the standardized test methods used to evaluate products and materials. Historically, the electronics industry relied heavily on test methods established for other industries or even for other materials (e. g., *ASTM-257 – DC Resistance or Conductance of Insulating Materials*). Today, however, specific test method standards focus on ESD in the electronics environment, largely as a result of the ESD Association's activity. These include standards such as *ANSI/ESDA-JEDEC JS-001– Device Testing, Human Body Model* and *ANSI/ESD STM7.1: Floor Materials – Resistive Characterization of Materials*.

WHO DEVELOPS STANDARDS?

Standards development and usage is a cooperative effort among all organizations and individuals affected by standards. There are several key ESD standards development organizations.

Military standards

Traditionally, the U.S. military spearheaded the development of specific standards and specifications with regard to ESD control in the U.S. Today, however, U.S. military agencies are relying on commercially developed standards rather than developing standards themselves. For example, the ESD Association completed the assignment from the Department of Defense (DoD) to convert MIL-STD-1686 into a commercial standard called ANSI/ESD S20.20 which was adopted by the DoD July, 7, 2000.

ESD Association

The ESD Association has been a focal point for the development of ESD standards in recent years. An ANSI-accredited standards development organization, the Association is charged with the development of ESD standards and test methods. The Association also represents the US on the International Electrotechnical Commission (IEC) Technical Committee 101-Electrostatics.

The ESD Association has currently 32 standards documents available and 30 Technical Reports. These voluntary standards cover the areas of material requirements, electrostatic sensitivity, and test methodology for evaluating ESD control materials and products. In addition to standards documents, the Association also has published a number of informational advisories. Advisory documents may be changed to other document types in the future.

ESD Association standards classifications and definitions

There are four types of ESD Association standards documents with specific clarity of definition. The four document categories are consistent with other standards development organizations. These four categories are defined below.

Standard: A precise statement of a set of requirements to be satisfied by a material, product, system or process that also specifies the procedures for determining whether each of the requirements is satisfied.

Standard Test Method: A definitive procedure for the identification, measurement and evaluation of one or more qualities, characteristics or properties of a material, product, system or process that yields a reproducible test result.

Standard Practice: A procedure for performing one or more operations or functions that may or may not yield a test result. Note: If a test result is obtained, it may not be reproducible between labs.

Technical Report: A collection of technical data or test results published as an informational reference on a specific material, product, system, or process.

As new documents are approved and issued, they will be designated into one of these four categories. Existing documents have been reviewed and have been reclassified as appropriate. Several Advisory Documents still exist and may be migrated to either Technical Reports or Standard Practices in the future.

International standards

The international community, led by the European-based International Electrotechnical Commission (IEC), also develops and publishes standards. IEC Technical Committee 101 has released a series of documents under the heading IEC 61340. The documents contain general information regarding electrostatics, standard test methods, general practices and an ESD Control Program Development Standard IEC 61340-5-1 that is technically equivalent to ANSI/ESD S20.20. A Facility Certification Program is also available. Global companies can seek to become certified to both ANSI/ESD S20.20 and to IEC 61340-5-1 if they so choose. Japan also has released its proposed version of a national electrostatic Standard, which also shares many aspects of the European and U.S. documents.

Organizational cooperation

Perhaps one of the more intriguing changes in ESD standards has been the organizational cooperation developing between various groups. One cooperative effort was between the ESD Association and the U.S. Department of Defense, which resulted in the Association preparing ANSI/ESD S20.20 as a successor to MIL-STD-1686. A second cooperative effort occurred between the ESD Association and JEDEC, which started with an MOU and resulted in the development of 2 documents: a joint Human Body Model document was published in 2010; a joint Charged Device Model document will be published in 2014.

Internationally, European standards development organizations and the ESD Association have developed working relationships that result in an expanded review of proposed documents, greater input, and closer harmonization of standards that impact the international electronics community.

For users of ESD standards, this increased cooperation will have a significant impact. First, we should see standards that are technically improved due to broader input. Second, we should see fewer conflicts between different standards. Finally, we should see less duplication of effort.

SUMMARY

For the electronics community, the rapid propagation of ESD standards and continuing change in the standards environment mean greater availability of the technical references that will help improve ESD control programs. There will be recommendations to help set up effective programs. There will be test methods and specifications to help users of ESD control materials evaluate and select ESD control products that are applicable to their specific needs. And there will be guidelines for suppliers of ESD control products and materials to help them develop products that meet the real needs of their customers.

Standards will continue to fuel change in the international ESD community.

Principal ESD standards

U.S. Military/Department of Defense

MIL-STD-1686: Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
This military standard establishes requirements for ESD Control Programs. It applies to U.S. military agencies, contractors, subcontractors, suppliers and vendors. It requires the establishment, implementation and documentation of ESD control programs for static sensitive devices, but does NOT mandate or preclude the use of any specific ESD control materials, products, or procedures. It is being updated and converted to a commercial standard by the ESD Association. Although DOD has accepted the new ANSI/ESD S20.20 document as a successor, it has not yet taken action to cancel STD-1686

MIL-HBDK-263: Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
This document provides guidance, but NOT mandatory requirements, for the establishment and implementation of an electrostatic discharge control program in accordance with the requirements of MIL-STD-1686.

MIL-PRF 87893 — Workstation, Electrostatic Discharge (ESD) Control
This document defines the requirements for ESD protective workstations.

MIL-PRF-81705—Barrier Materials, Flexible, Electrostatic Protective, Heat Sealable
This documents defines requirements for ESD protective flexible packaging materials.

MIL-STD-129—Marking for Shipment and Storage
Covers procedures for marketing and labeling ESD sensitive items.

ESD Association

Standards Documents

ANSI/ESD S1.1: Evaluation, Acceptance, and Functional Testing of Wrist Straps
A successor to EOS/ESD S1.0, this document establishes test methods for evaluating the electrical and mechanical characteristics of wrist straps. It includes improved test methods and performance limits for evaluation, acceptance, and functional testing of wrist straps.

ANSI/ESD STM2.1: Resistance Test Method for Electrostatic Discharge Protective Garments
This Standard Test Method provides test methods for measuring the electrical resistance of garments used to control electrostatic discharge. It covers test methods for measuring sleeve-to-sleeve and point-to-point resistance.

ANSI/ESD STM3.1: Ionization
Test methods and procedures for evaluating and selecting air ionization equipment and systems are covered in this standard. The document establishes measurement techniques to determine offset voltage ion balance and discharge neutralization time for ionizers.

ANSI/ESD SP3.3: Periodic Verification of Air Ionizers
This Standard Practice provides test procedures for periodic verification of the performance of air ionization equipment and systems (ionizers).

ANSI/ESD SP3.4 Periodic Verification of Air Ionizer Performance Using a Small Test Fixture
This standard practice provides a test fixture example and procedures for performance verification of air ionization used in confined spaces where it may not be possible to use the test fixtures defined in ANSI/ESD STM3.1 or ANSI/ESD SP3.3.

ANSI/ESD S4.1: Worksurfaces – Resistance Measurements
This Standard establishes test methods for measuring the electrical resistance of worksurface materials used at workstations for protection of ESD susceptible items. It includes methods for evaluating and selecting materials, and testing new worksurface installations and previously installed worksurfaces.

ANSI/ESD STM4.2: Worksurfaces – Charge Dissipation Characteristics
This Standard Test Method provides a test method to measure the electrostatic charge dissipation characteristics of worksurfaces used for ESD control. The procedure is designed for use in a laboratory environment for qualification, evaluation or acceptance of worksurfaces.

ESDA-JEDEC JS-001: Electrostatic Discharge Sensitivity Testing – Human Body Model
This Standard Test Method updates and revises an existing Standard. It establishes a procedure for testing, evaluating and classifying the ESD sensitivity of components to the defined Human Body Model (HBM).

ANSI/ESD STM5.2: Electrostatic Discharge Sensitivity Testing Machine Model
This Standard establishes a test procedure for evaluating the ESD sensitivity of components to a defined Machine Model (MM). The component damage caused by the Machine Model is often similar to that caused by the Human Body Model, but it occurs at a significantly lower voltage.

ANSI/ESD STM5.3.1: Electrostatic Discharge Sensitivity Testing – Charged Device Model – Non-Socketed Model
This Standard Test Method establishes a test method for evaluating the ESD sensitivity of active and passive components to a defined Charged Device Model (CDM).

ANSI/ESD SP5.3.2: Electrostatic Discharge Sensitivity Testing – Socketed Device Method (SDM) – Component Level.
This standard practice provides a test method generating a Socketed Device Model (SDM) test on a component integrated circuit (IC) device.

SOURCES OF STANDARDS

ESD Association, 7900 Turin Road, Building 3, Rome, NY 13440. Phone: 315-339-6937. Fax: 315-339-6793. **http://www.ESDA.org**

IHS Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112. Phone: 800-854-7179. Fax: 303-397-2740. **http://global.ihs.com**

International Electrotechnical Commission, 3, rue de Varembe, Case postale 131, 1211 Geneva 20, Switzerland. Fax: 41-22-919-0300. **http://www.iec.ch**

Military Standards, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120. **https://assist.dla.mil**

JEDEC Solid State Technology Association, 3103 North 10th Street, Suite 240-S, Arlington, VA 22201-2107. **http://www.jedec.org**

ANSI/ESD STM5.5.1: Electrostatic Discharge Sensitivity Testing – Transmission Line Pulse (TLP) – Component Level.
This document pertains to Transmission Line Pulse (TLP) testing techniques of semiconductor components. The purpose of this document is to establish a methodology for both testing and reporting information associated with TLP testing.

ANSI/ESD SP5.5.2: Electrostatic Discharge Sensitivity Testing – Very Fast Transmission Line Pulse (VF-TLP) – Component Level
This document pertains to Very Fast Transmission Line Pulse (VF-TLP) testing techniques of semiconductor components. It establishes guidelines and standard practices presently used by development, research, and reliability engineers in both universities and industry for VF-TLP testing. This document explains a methodology for both testing and reporting information associated with VF-TLP testing.

ANSI/ESD SP5.6: Electrostatic Discharge Sensitivity Testing – Human Metal Model (HMM) – Component Level
Establishes the procedure for testing, evaluating, and classifying the ESD sensitivity of components to the defined HMM.

ANSI/ESD S6.1: Grounding
This Standard recommends the parameters, procedures, and types of materials needed to establish an ESD grounding system for the protection of electronic hardware from ESD

damage. This system is used for personnel grounding devices, worksurfaces, chairs, carts, floors, and other related equipment.

ANSI ESD STM7.1: Floor Materials – Resistive Characterization of Materials
Measurement of the electrical resistance of various floor materials such as floor coverings, mats, and floor finishes is covered in this document. It provides test methods for qualifying floor materials before installation or application and for evaluating and monitoring materials after installation or application.

ANSI ESD S8.1: ESD Awareness Symbols
Three types of ESD awareness symbols are established by this document. The first one is to be used on a device or assembly to indicate that it is susceptible to electrostatic charge. The second is to be used on items and materials intended to provide electrostatic protection. The third symbol indicates the common point ground

ANSI/ESD S9.1: Resistive Characterization of Footwear
This Standard defines a test method for measuring the electrical resistance of shoes used for ESD control in the electronics environment.

ESD SP9.2: Footwear – Foot Grounders Resistive Characterization
This standard practice was developed to provide test methods for evaluating foot grounders and foot grounder systems used to electrically bond or ground personnel as part of an ESD Control Program. Static Control Shoes are tested using ANSI/ESD STM9.1.

ANSI/ESD SP10.1: Automated Handling Equipment
This Standard Practice provides procedures for evaluating the electrostatic environment associated with automated handling equipment.

ANSI ESD STM11.11: Surface Resistance Measurement of Static Dissipative Planar Materials
This Standard Test Method defines a direct current test method for measuring electrical resistance. The Standard is designed specifically for static dissipative planar materials used in packaging of ESD sensitive devices and components.

ANSI/ESD STM11.12: Volume Resistance Measurement of Static Dissipative Planar Materials
This Standard Test Method provides test methods for measuring the volume resistance of static dissipative planar materials used in the packaging of ESD sensitive devices and components.

ANSI/ESD STM11.13: Two-Point Resistance Measurement
This Standard Test Method provides a test method to measure the resistance between two points on an items surface.

ANSI ESD STM11.31: Evaluating the Performance of Electrostatic Discharge Shielding Bags
This Standard provides a method for testing and determining the shielding capabilities of electrostatic shielding bags.

ANSI/ESD S11.4: Static Control Bags
This standard establishes performance limits for bags that are intended to protect electronic parts and products from damage due to static electricity and moisture during common electronic manufacturing industry transport and storage applications.

ANSI/ESD STM12.1: Seating-Resistive Characterization
This Standard provides test methods for measuring the electrical resistance of seating used to control ESD. The test methods can be used for qualification testing as well as for evaluating and monitoring seating after installation. It covers all types of seating, including chairs and stools.

ANSI/ESD STM13.1: Electrical Soldering/Desoldering Hand Tools
This Standard Test Method provides electric soldering/desoldering hand tool test methods for measuring the

electrical leakage and tip to ground reference point resistance and provides parameters for EOS safe soldering operation.

ANSI/ESD SP15.1: Standard Practice for In-Use Testing of Gloves and Finger Cots
This document provides test procedures for measuring the intrinsic electrical resistance of gloves and finger cots as well as their electrical resistance together with personnel as a system.

ANSI ESD S20.20: Standard for the Development of an ESD Control Program
This Standard provides administrative, technical requirements and guidance for establishing, implementing and maintaining an ESD Control Program.

ANSI/ESD STM97.1: Floor Materials and Footwear – Resistance in Combination with a Person.
This Standard Test Method provides for measuring the electrical resistance of floor materials, footwear and personnel together, as a system.

ANSI/ESD STM97.2: Floor Materials and Footwear Voltage Measurement in Combination with a Person
This Standard Test Method provides for measuring the electrostatic voltage on a person in combination with floor materials and footwear, as a system.

ANSI/ESD S541: Packaging Materials for ESD Sensitive Items
This standard describes the packaging material properties needed to protect electrostatic discharge (ESD) sensitive electronic items, and references the testing methods for evaluating packaging and packaging materials for those properties. Where possible, performance limits are provided. Guidance for selecting the types of packaging with protective properties appropriate for specific applications is provided. Other considerations for protective packaging are also provided.

Advisory Documents and Technical Reports

Advisory Documents and Technical Reports are not Standards, but provide general information for the industry or additional information to aid in better understanding of Association Standards.

ESD ADV1.0: Glossary of Terms
Definitions and explanations of various terms used in Association Standards and documents are covered in this Advisory. It also includes other terms commonly used in the ESD industry.

ESD ADV3.2: Selection and Acceptance of Air Ionizers
This Advisory document provides end users with guidelines for creating a performance specification for selecting air ionization systems. It reviews four types of air ionizers and discusses applications, test method references, and general design, performance and safety requirements.

ESD ADV11.2: Triboelectric Charge Accumulation Testing
The complex phenomenon of triboelectric charging is discussed in this Advisory. It covers the theory and effects of tribocharging. It reviews procedures and problems associated with various test methods that are often used to evaluate triboelectrification characteristics. The test methods reviewed indicate gross levels of charge and polarity, but are not necessarily repeatable in real world situations.

ESD TR5.4-04-13 Transient Latch-up Testing
This document defines transient latch-up (TLU) as a state in which a low-impedance path, resulting from a transient overstress that triggers a parasitic thyristor structure or bipolar structure or combinations of both, persists at least temporarily after removal or cessation of the triggering condition. The rise time of the transient overstress causing TLU is shorter than five μs. TLU as defined in this document does not cover changes of functional states, even if those changes would result in a low-impedance path and increased power supply consumption.

ESD TR53: Compliance Verification of ESD Protective Equipment and Materials.
This technical report describes the test procedures and test equipment that can be used to periodically verify the performance of ESD protective equipment and materials.

ESD TR20.20: ESD Handbook
ESD handbook provides detailed guidance for implementing an ESD control program in accordance with ANSI/ESD S20.20.

The FCC TCB Program: A Government and Industry Cooperative

BY MARK MAYNARD

"Great discoveries and improvements invariably involve the cooperation of many minds. I may be given credit for having blazed the trail, but when I look at the subsequent developments I feel the credit is due to others rather than to myself." – Alexander Graham Bell

As a compliance engineer it is easy to develop a "victim" mentality after working with a multitude of government agencies and bureaucracies, having to adjust and adapt to whatever regulatory roadblocks are set up in your path. It can seem as though some of the rules and compliance criteria are arbitrary and random, and I have wished on more than one occasion that I was able to talk and work directly with the agencies, and be able to better understand and influence the requirements and processes.

I was finally granted that wish when I became involved with the United States (US) Federal Communications Commission (FCC) Telecommunications Certification Bodies (TCB) program. My initial exposure to this government and private industry initiative was a decade ago, while I was working at an ITE manufacturer, and more recently I've observed it from a different perspective while working at a third-party compliance test lab that is an authorized TCB. TCBs are private industry independent organizations, which have been authorized under this FCC program to issue grants to electronic product manufacturers for the certification of specific types of telecommunications equipment covered under the program scope.

Please note that this article is intended as an overview of the TCB program based on my work experiences, and I am not speaking in any official capacity for the FCC, the National Institute of Standards and Technology (NIST), the Telecommunications Certification Body Council (TCBC), or any other agency. The opinions and views provided are my own, and you should utilize the FCC, NIST, TCBC and other official resources provided at the end of this article for the program details, requirements, and publications before applying for product approvals.

So let's start with some background on how this program came to be.

CREATING A GOVERNMENT-INDUSTRY PARTNERSHIP

Prior to the TCB program, certification for telecommunication equipment required a grant of authorization issued directly from the FCC. These "new equipment authorizations" were legal documents, which were issued based on exhibits demonstrating compliance to the FCC rules and regulations, such as test reports from the FCC

Prior to the TCB program, certification for telecommunication equipment required a grant of authorization issued directly from the FCC. These "new equipment authorizations" were legal documents, which were issued based on exhibits demonstrating compliance to the FCC rules and regulations.

lab, or a FCC authorized test lab. The FCC grant certificate has several purposes: to define the device operating modes, features, and ratings; the allowed uses and environments for the device, and to show that the product was properly tested according to the applicable FCC rules and regulations, including worst cases configurations, so that it can be sold and placed on the US market.

With momentum from a wider effort in the United States to reduce the size of government agencies by turning more regulatory activities over to private enterprises, the legislative framework for the TCB was established at the end of 1998, when the FCC GEN Docket Report and Order No. 98-68 was adopted. For the FCC, this was seen as a method to reduce the number of applications filed directly with them, reducing their workload, so they could focus on enforcement activities. The program also allowed TCBs outside of the US to participate, by establishing procedures for government-to-government Mutual Recognition Agreements (MRA); for example, the MRA between the US and the European Union (EU) governments allows accredited US TCBs to certify radio and telecom products for the EU markets, and reciprocally allows accredited EU TCBs to certify radio and telecom products for the US market. Another driver for this program was industry, who had encountered occasional bottlenecks at the FCC in obtaining certification, especially prior to seasonal selling periods such as the Christmas holidays, and wanted faster options for US certification and regional labs outside of Washington D.C, which would match the US efforts with foreign MRA partners to expand the certification options.

The criteria for TCB accreditation and designation was further defined in FCC Public Notice DA 99-1640 issued on August 17, 1999. The program officially started on June 2, 2000, with the publication of FCC Public Notice DA 00-1223, which listed the 13 initial designated TCBs, along with their specific scope of accreditation for licensed radio service equipment, unlicensed radio frequency devices, and telephone terminal equipment. Another major revision for TCB rules for designation and requirements was published in ET Docket No. 03-201 (FCC 04-165), which was officially adopted on July 8, 2004.

BECOMING A TCB

To become an accredited Telecommunications Certification Body, an independent third-party lab must be accredited to ISO/IEC 17065 (2012), titled *Conformity assessment-Requirements for bodies certifying products, processes and services,* ISO/IEC Standard 17025 (2005), titled *General requirements for the competence of testing and calibration laboratories,* and also incorporate the applicable FCC rules and regulations. In the US the TCB accreditation process is managed by NIST, which has qualified two US accreditation bodies as being in compliance with the standard ISO/IEC 17011 (2004), *Conformity assessment - General Requirements for Accreditation bodies accrediting conformity assessment bodies,* and therefore authorized to accredit TCBs: the American National Standards Institute (ANSI) and the American Association for Laboratory Accreditation (A2LA). The FCC Office of Engineering and Technology (OET) has oversight authority for the TCB accrediting process, and will coordinate frequently with ANSI and A2LA to confirm and verify that the veracity of their programs meets acceptable standards for performance. The FCC has a very strong vested interest in keeping this program performing effectively, and will perform frequent assessments to check for any issues or to find areas for improvement in the authorized program accreditation bodies.

In turn, ANSI and A2LA will accredit qualifying US TCBs that meet the requirements of both the TCB certification program requirements, which are defined and set by NIST, and the ISO/IEC 17065 (2012) standard. Also, as mentioned, foreign certification bodies (non-US) can become a recognized TCB for issuing FCC grant certificates if a government-to-government MRA is in effect between the US and the foreign country. However it will be up to the designated accrediting authority in the foreign country to assess the TCB and evaluate it to determine the competency of the organization, and this accrediting authority must meet the criteria found in the standard ISO/IEC 17011 (2004).

The TCBs will select the specific products they choose to certify, which will define the scope of their TCB accreditation. There are three scopes covering unlicensed radio service

equipment (Scope A), unlicensed radio frequency devices (Scope B), and telephone terminal equipment (Scope C). Scopes A and B each have four sub-categories, which can be seen in Table 1. The TCB may be accredited for all scopes and sub-categories, or a limited set, depending on their preferences and capabilities, so prospective customers should always verify that their equipment type falls under one of the accredited scope for the specific TCB.

However wide or narrow the scope of the TCB accreditation, each TCB is required to have the essential competency to perform the mandated set of tests for each scope and sub-category of scope selected. This will be verified during the ISO/IEC 17025 (2005) accreditation process.

WHAT DOES A TCB DO?

So if you are a product manufacturer seeking FCC certification for a device that falls under the scope of the TCB program, you probably are interested in finding out more about the process and requirements. It is important to find a TCB that you are comfortable working with, as there will be a need for frequent interactions and exchanges of information throughout the process, especially if this is your first experience with certifying a product.

The TCB is responsible for testing, evaluating, and reviewing the product, to verify that it meets all of the applicable FCC rules and regulations. To do this, the manufacturer needs to provide fully functioning device samples, technical documentation, and operating instructions that will enable to fully investigate the operating abilities and parameters, so that they can render a valid and fair decision on the conformity of the product.

As mentioned, the compliance testing has to be performed in a test lab facility that has been accredited as meeting the requirements of ISO/IEC 17025. The test data and results are incorporated into an evaluation test report, which plays a big part in the review process. The decision to certify the product will be based on the examination of the test report, to verify compliance with the FCC requirements for the specific

TCB Scope A - Unlicensed Radio Frequency Devices	
A1	Low power transmitters operating on frequencies below 1 GHz (with the exception of spread spectrum devices). emergency alert systems, unintentional radiators (e.g., personal computers and associated peripherals and TV Interface Devices) and consumer ISM devices subject to certification (e.g., microwave ovens, RF lighting and other consumer ISM devices)
A2	Low power transmitters operating on frequencies about 1 GHz, with the exception of spread spectrum devices
A3	Unlicensed Personal Communication Service (PCS) Devices
A4	Unlicensed National Information Infrastructure (UNI) devices and low power transmitters using spread spectrum techniques
TCB Scope B - Licensed Radio Service Equipment	
B1	Commercial Mobile Services in 47 CFR Parts 20, 22 (cellular), 24, 25, and 27
B2	General Mobile Radio Services in 47 CFR Parts 22 (non-cellular), 73, 74, 90, 95, and 97
B3	Maritime and Aviation Radio Services in 47 CFR Parts 80 and 87
B4	Microwave Radio Services in 47 CFR Parts 27, 74, and 101
TCB Scope C - Telephone Terminal Equipment	
C1	Telephone terminal equipment in 47 CFR Part 68

Table 1: List of TCB Scope of Accreditation Categories

product type, along with the review of any other relevant supporting documentation. If the device is then deemed to be in compliance, then the test lab can render their decision to certify. If it is not found to be in compliance, then the test lab should review the results and shortcomings with the client, so any necessary product changes can be made and incorporated before retesting the product.

If the ISO/IEC 17025-accredited test lab facility is also a TCB accredited to ISO/IEC 17065 (2012), then there must be separation of responsibilities at the TCB between those that are performing the evaluation of a device, and those that are making the decision to certify the device. This is to ensure an autonomous review process takes place to impartially review the findings, so a correct ruling can be made based on the findings. The ISO/IEC 17065 standard requires that the individuals that perform the TCB evaluation functions, such as type-testing, report generation, and assessing the supporting documentation to verify compliance with the applicable FCC rules and regulations, must not be the same individuals that perform the TCB certification functions of reviewing all of the provided information and documentation, and then making the decision to certify the product.

A TCB is required to be impartial, meaning that they are responsible for making sure that any other activities it is involved in with other related groups or organizations does not impact or influence the fairness, neutrality, or confidentiality concerning their ruling on certification for the product. In addition, the TCB is not allowed to give guidance or provide consulting services to the client concerning techniques for resolving the issues which prevent the specific certification that is being sought.

While the FCC allows for a wide range of different types of devices to be certified under the TCB program, it still requires certain specific functions to be performed solely by the FCC, which it does not allow TCBs to perform. As defined in the Title 47 of the Code of Federal Regulations (CFR), TCBs are not allowed to grant waivers to FCC rules, nor certify devices that don't have applicable FCC rules, or take action on any rules that are not clear. Also, TCBs can not authorize the transfer of control for a grant, and are not allowed to interpret any FCC rules or regulations.

Previously there was a "TCB Exclusion List," which specifically detailed types of products that TCBs were not allowed to certify. However, this has changed under a FCC procedure known as Permit-but-Ask. The intent of this option is to allow the TCBs to expand the types of devices for which they can issue grants, while allowing the FCC to have oversight for new technology devices that do not have specific FCC guidance available, or for cases where the client is planning to demonstrate compliance by using some alternative to the published procedures or guidelines.

RESOURCES FOR USING THE FCC TCB PROGRAM

If you are a manufacturer wanting to obtain FCC certification for equipment that falls under the scope of the TCB program, my strongest advice is for you to first learn all you can about the program requirements, and to learn from the experience of others who have already been through this process. There are two great resources available to you on the Internet, the first is on the FCC website, and the other is for a TCB industry organization called the Telecommunications Certification Body Council (TCBC). Let's start with the FCC.

THE FCC KNOWLEDGE DATABASE

The FCC rules and regulations are famous for being complex and sometimes ambiguous, and it is hard to find all of the specific information and details that will help to ensure the compliance of your product. To help this situation, the FCC created the Knowledge Database (KDB) system (**apps.fcc.gov/oetcf/kdb/index.cfm**), which is a part of the FCC website, in order to provide additional guidance and assistance to manufacturers, TCBs, test labs, and other interested stakeholders.

KDB publications are created by FCC staff members, and are intended to provide clearer guidance and explanations on specific topics, outside of the FCC rules and regulations. While the KDB is intended to assist the public in following FCC requirements, the KDB publications do not constitute FCC rules; the guidance is not binding on the FCC, and it will not prevent them from making a conflicting or different ruling on any issue that comes to them for resolution.

You can search for whatever topic you are interested in, with the available keyword search engine, or use the more advanced search options. Currently there are about 200 active KDB publications available, with popular topics such as the Permit-but-Ask procedure, DFS/UNII requirements, and test procedures. One warning; there doesn't seem to be a logical order for the numbering system for the KDB publications and revision levels, so make sure you verify that you are utilizing the most current version, as updates can be frequent for certain categories. Most KDB documents have a 6-digit code, and if you know the code you can search for it by just using the code. Also know that you will usually have to reference several KDB publications to find all of the information or guidance you are seeking; it is not common to find everything in one document.

You may notice that there are two areas in the KDB, one is public and accessible by anyone on the Internet, but the other is restricted to TCBs only. The KDBs available on the public

Anyone that is interested can become a member of the TCB Council. Membership is extended to a company, and any employees of the member company can receive TCBC membership benefits without any additional cost.

site usually give FCC guidance or interpretation of the rules for a general category or technology, and do not cover specific applications or devices, because of rules on confidentiality.

THE TELECOMMUNICATIONS CERTIFICATION BODY COUNCIL

The TCBC is a not-for-profit industry consortium of TCBs, the FCC and other government regulators, accrediting bodies, test laboratories, equipment manufacturers, product developers, consultants, and other interested stakeholders. The purpose of the TCB Council, as stated on their website, is to "provide a forum for periodic dialogue between the FCC and the TCB's and to facilitate on-going activities geared toward the improvement of TCB technical and administrative performance."

The TCBC has a website (www.tcbcouncil.org) containing general information on the organization and benefits of joining. The members of this organization have a wealth of experience in all aspects of the TCB program, and members also have access to monthly conference calls with the FCC, training materials, and discounted registrations for the twice-yearly training workshops on the latest compliance requirements featuring presenters from the FCC, Industry Canada, the European Union, and other international government regulators, in addition to the TCBs.

Anyone that is interested can become a member of the TCB Council. Membership is extended to a company, and any employees of the member company can receive TCBC membership benefits without any additional cost. Any FCC designated TCB can join as a full TCB council member, and any other company of individual can join as an associate member.

My hope is you now have enough background for an understanding of the TCB program and requirements to get started on the certification process. You will still have a lot more to learn, but with the provided Internet resources you have connections to the sources that can help you to obtain FCC approvals for your products.

INTERNET RESOURCES

FCC Telecommunications Certification Bodies (TCB) System
http://apps.fcc.gov/tcb/index.html
FCC Knowledge Database (KDB) System
http://apps.fcc.gov/oetcf/kdb/)

National Institute of Standards and Technology (NIST) EMC and Telecommunications Mutual Recognition Agreements (MRA)
http://gsi.nist.gov/global/index.cfm/L1-4/L2-16

American National Standards Institute (ANSI) Accreditation Services
http://www.ansica.org/wwwversion2/outside/PROgeneral.asp?menuID=1

American Association for Laboratory Accreditation (A2LA)
http://www.a2la.org

International Electrotechnical Commission (IEC)
http://www.iec.ch/

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

ANSI Document Store (ISO/IEC documents are available at the ANSI website)
http://webstore.ansi.org/ansidocstore/default.asp

The Telecommunications Certification Body Council (TCBC)
http://www.tcbcouncil.org

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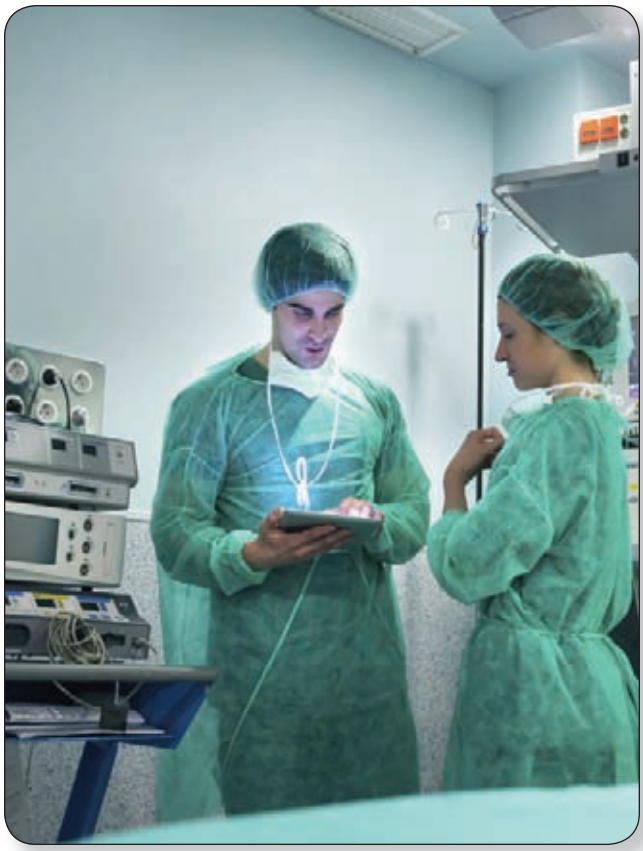
Medical Devices in a Wireless World

What You Need to Know About Medical Device Manufacturing, Wireless Technologies and Compliance

BY IVAYLO TANKOV



While wireless technology is now an integral component of a wide variety of manufactured products, factors unique to the medical device market have kept wireless from making inroads there. However, the tide is turning to the point where manufacturers can now offer wireless benefits to North American practitioners, patients and payers, as long as the medical device manufacturers can meet the standards established by different and unrelated regulatory bodies.

This article will define the regulatory bodies involved, the criteria important to each of them, and the steps a medical device manufacturer needs to take to sell wireless medical devices in North America.

THE POWERS THAT BE

There are basically two regulatory bodies that impact compliance for wireless medical devices in the United States: the Food & Drug Administration (FDA) and the Federal Communications Commission (FCC).

All medical device manufacturers are familiar with the FDA regulations for placing a medical device on the US market. Although the agency was not known by its present name until 1930, its roots go back to 1848, and its modern regulatory functions began with the passage of the 1906 Pure Food and Drugs Act.

The FCC is no stranger to those of us who live here in the world of compliance. Since its formation by the Communications Act of 1934 "…for the purpose of promoting safety of life and property through the use of wire and radio communications" among other things, the FCC has established a broad base of rules and standards that have impacted virtually every American in one way or another.

Every medical device using wireless technology must comply with both the FDA and FCC requirements. As the primary function of the device is medical, the FDA requirements are considered primary with the FCC requirements considered supplementary. Both, however, are mandatory. The FDA expects a wireless product to comply with FCC requirements before its compliance with the FDA regulations is demonstrated.

Further, the FDA just recently updated its recommendations for medical devices using/integrating wireless technologies. While full compliance with the new regulations is not yet mandated, the agency has made it quite clear that it expects to see its recommendations addressed.

FCC RULES OF COMMUNICATION

As most *In Compliance* readers already know, typically a wireless medical device must follow the FCC rules particular to the type of wireless technology it employs. The rules

Every medical device is considered unique in its functionality and as such, needs to be evaluated individually to determine the best regulatory approach to take it to market. The FDA's generic requirements apply to all devices

consider various frequencies, power and other radio features. The FCC's main requirements for this product type are presented in Title 47 of the Code of Federal Regulations, which contains more than 100 parts; each part regulating a specific technology or combination of technologies using the same radio spectrum.

The type and scope of testing will also depend on the type of radio used in a given device. Manufacturers can use the FCC pre-certified radio modules, which still require limited testing on the system level to show compliance of the finished device. Using them saves time and money. Alternatively, companies can design and manufacture their own radios to incorporate into a product, which will require a full scope of wireless testing to certify the radio and the product.

THE FDA'S EXPECTATIONS

Every medical device is considered unique in its functionality and as such, needs to be evaluated individually to determine the best regulatory approach to take it to market. The FDA's generic requirements apply to all devices, but the manufacturer and testing laboratory need to choose the most applicable technical standards to which the product will be tested. Each technology performs differently, and the choice of technology automatically impacts a product's performance and also has bearing on the device's security and susceptibility to interference from other electronic devices. Generally, the FDA mandates that a medical device be tested to satisfy the FDA's and international minimal requirements for safety and electromagnetic compatibility (EMC).

"Radio Frequency Wireless Technology in Medical Devices - Guidance for Industry and Food and Drug Administration Staff" is the main document governing the use of wireless technology in medical devices. The document was originally published in 2007, and the most recent revision, published in August 2013, outlined several new recommendations for medical device manufacturers to follow. While at this point the recommendations are only suggestions, the FDA is on file as having urged manufacturers to demonstrate that they have considered the recommendations in their application for approvals. The specific recommendations suggest the medical device manufacturer:

1. Explain clearly why and how it selected a specific wireless technology.
2. Prove that the quality of the wireless service has been considered.
3. Show that its product can co-exist with other radio equipment in the vicinity without generating any problems; the intent being to minimize the possibility of a technology error where decisions about people's well-being are made in an environment full of wireless cell phones, tablets and laptops.
4. Illustrate how the security of wireless signals and data has been addressed to protect confidential patient information.
5. Demonstrate how other electronic devices might interfere with the radio portion of the medical device; i.e. EMC performance of the wireless technology.
6. Provide clear operations instructions in the user documentation for both the medical staff and patients.
7. Offer detailed maintenance and care instructions for the medical device.

The FDA also wants medical device manufacturers to perform risk management as part of their quality system under Title 21 CFR Part 820. When preparing pre-market submissions for the FDA, manufacturers should know that in the risk-based approach to verification and validation section, the agency will expect to be given information about:

1. Quality of wireless service: With wireless technology, a medical device might experience a delay in administering or terminating therapy. This depends on how fast data is transferred back and forth between a medical device in question and other medical or IT infrastructure equipment.
2. Wireless coexistence: A device's radio channel might interfere with other wireless devices nearby. Multiple devices in a hospital use various wireless technologies and might interfere with each other on the radio portion of the spectrum.
3. Security of wireless signals and data: When patient information is transferred over the air and is not properly encrypted, it can be intercepted. Unauthorized access or harmful interference (such as maliciously altering data) will compromise patient's private records and might impact healthcare delivery.

In order to demonstrate compliance, the medical device manufacturer must develop a list of the product's key functions and associated risks, and this list would be used to determine if the product is in a pass or fail status during and after the test.

4. EMC of the wireless technology: Yet another consideration is how susceptible a medical device's interface is to the electromagnetic interference (EMI) from nearby devices that do not use radio transmission, such as computers. For example, a pacemaker worn by a patient might be affected by a PC of the nurse who is checking him in.

INTERNATIONAL COMPLIANCE

From an international perspective, medical devices are covered by the International Electrotechnical Commission's (IEC) 60601 standard. IEC 60601-1 addresses basic safety and essential performance (BS&EP) criteria. The BS&EP criteria describe the product's intended use and operation and any of its features or functions that might cause harm or injury to the users, patients and surroundings. Degradation of features and functions is allowed, provided it does not affect essential performance and safety of the product.

In order to demonstrate compliance, the medical device manufacturer must develop a list of the product's key functions and associated risks, and this list would be used to determine if the product is in a pass or fail status during and after the test. From this, the manufacturer will develop an essential performance document. During immunity testing, degradation of performance that affects essential performance would not be acceptable. Some examples of these situations include:

- Changes in programmable parameters,
- Distortion of image/data,
- Change/interruption of intended operating mode,
- Unintended operation/movement,
- Component failures, and
- False alarms.

EMC TESTING ACCORDING TO IEC 60601-1-2

EMC testing according to IEC 6060-1-2 can be broken into two parts: emissions and immunity. The emissions test evaluates the RF energy the product emits, while immunity testing determines product performance according to its EP & BS criteria under the electromagnetic effects. All operational modes should be considered for testing in full or partially to determine compliance for the overall system. The summary of the EMC tests to be performed is listed below:

EMISSIONS (Class AB, Group 1/2)

- Conducted
- Radiated
- Harmonics
- Flicker

IMMUNITY (EP & BS, Life-Supporting/Non-Life Supporting)

- ESD
- Radiated Immunity
- Conducted Immunity
- Surge
- EFT/Burst
- Voltage Dips/Interrupts
- Magnetic Fields

Group 1: All equipment that does not fall into Group 2.

Group 2: All equipment that intentionally generates and uses, or only uses, radio-frequency energy in the range of 9 kHz to 400 GHz in the form of electromagnetic radiation, inductive and/or capacitive coupling, for the treatment of material or inspection /analysis purposes.

Class A: Equipment suitable for use in all establishments except domestic and establishments directly connected to a low voltage power network supplying residential buildings.

Class B: Equipment suitable for use in domestic establishments and in establishments directly connected to a low voltage power supply network which services residential buildings.

Life Supporting or Non-Life Supporting: Based on this classification, some immunity test strengths would be higher for Life-Supporting equipment due to the inherent risks associated with the use of this equipment.

Determining the correct product class and group is essential in that the limits for various classes and groups are defined differently in the standard. For example, conducted emissions limit (the main terminal disturbance voltage limit) between 5-30 MHz for Class A, Group 1 product is 73 dB(µV)- Quasi Peak & 60 dB(µV)-Average. If the product is a Class B, Group 1 type, the limit between 5-30 MHz is 60 dB(µV)- Quasi Peak and 50 dB(µV)-Average, regardless of the rated input power. The summary matrix of tests mandated by the IEC60601-1-2 standard is featured in Figure 1.

WHAT ELSE IS INVOLVED IN THE STANDARD?

The medical device manufacturer's responsibility for EMC is not limited to testing. Per 60601-1-2, the product-related risks and warnings are to be clearly indicated and explained to the user, patient and others so they can take necessary actions to limit any interruption. Some warnings must be placed in an obvious location on the product itself and in related files and documentation. A summary is listed below:

Warnings & Markings:

- Non-ionizing radiation use for diagnosis or treatment
- ESD sensitive port
- Interference warning
- Minimum amplitude of the patient's physiological signals and consequence of use below specified standard limits
- If tested in-situ, the list of frequencies tested and a warning that some frequencies specified by the standard were omitted due to the specifics of the in-situ testing

Environment Use:

- Shielded location,
- Domestic, hospital, etc. use,
- Potential electromagnetic site survey at the installation location, and
- An EMC site survey might be needed for EMC sensitive products; if EMC noise level is too high, preventive actions need to be taken.

Limitation of Use:

- Use by healthcare professionals only
- Interaction with adjacent equipment
- Distance to RF communication equipment (tables)
- Floor specification
- Mains power quality
- UPS use for respiratory devices

Safety Instructions for Accessories:

- Cable types and lengths
- Specifications for replacement parts of the manufacturer-provided cables, accessories and components

Justification for Lower Immunity Levels:

- Due to physical, technological or physiological limits of the device; for example, Radiated Immunity tested at 1V/m between 150-160MHz.

OTHER GLOBAL ACCESS CONSIDERATIONS

Above and beyond the above-mentioned considerations, medical devices also face the same hurdles as most every other product intended for sale in foreign markets. For example, the product will need to be designed to meet all mandatory base certifications and safety deviations peculiar to each individual country, which may be different from those in the US, Canada and EU. In addition, certain countries require the applicant to be a legal entity in that country, while some require the actual testing to be done in-country, meaning manufacturers need to assure samples are

<table>
<tr><th>60601-1-2</th><th>Magnetic Immunity</th><th>Radiated Immunity</th><th>ESD</th><th>Conducted Immunity</th><th>SURGE</th><th>EFT/B</th><th>DIPS & INT</th><th>Radiated Emissions</th><th>Conducted Emissions</th></tr>
<tr><td rowspan="2">Non Life Supporting</td><td>3 A/m</td><td>3 V/m</td><td rowspan="3">6/8 kV</td><td>3V</td><td rowspan="3">1 kV/2 kV DM, CM</td><td rowspan="3">1 kV/2 kV I/O, AC</td><td>0%V
0.5 cycle
& 5 sec</td><td rowspan="3">Class A/B, Group 1/2</td><td rowspan="3">Class A/B, Group 1/2</td></tr>
<tr><td></td><td></td><td></td><td>40%V
5 cycle</td></tr>
<tr><td>Life Supporting</td><td>3 A/m
50 & 60 Hz</td><td>10 V/m</td><td>3V 10V for ISM</td><td>70%V
25 cycle</td></tr>
</table>

Figure 1

available in sufficient quantities and timeliness. Translation of user documentation can also pose problems.

Further, some countries have specific EMC regulations that may have more stringent limits than the US, Canada or the EU, while other countries may not allow the use of certain radio frequencies.

The bottom line is that garnering international approvals can be difficult enough for any type of product; getting approvals for a medical device is only more difficult. However, choosing the right testing partner can help a medical device manufacturer lower its level of difficulty. The right testing laboratory will help a medical device manufacturer identify legal requirements and harmonized standards, make sure properly configured product samples are available, coordinate shipping, assure appropriate documentation and language, and execute pre-tests to assure compliance.

BRAVING THE NEW WIRELESS WORLD

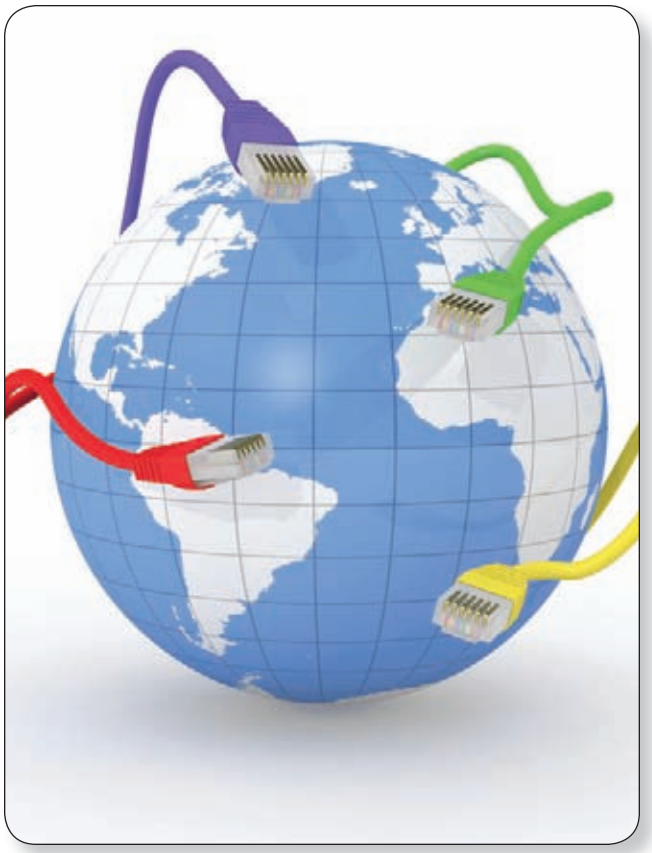
While wireless technologies have opened up a seemingly unlimited world of potential, many medical device manufacturers face a delayed introduction for their products utilizing wireless technologies due to the additional compliance requirements. Unfortunately for those manufacturers, a delayed product launch in a hotly contested market such as that for medical devices can have severe downstream ramifications in terms of market adoption and acceptance, resulting in lower share-of-market opportunities and lost revenues.

The easiest way for medical device manufacturers to mitigate the likelihood of compliance-caused launch delays is to involve the testing laboratory as early in the product development cycle as possible. While the product is still in the concept stage a testing laboratory can advise the manufacturer about the general regulatory requirements and suggest wireless technology options suitable from the point of view of technical certification. When the manufacturer has a clear idea of what the product looks like, the test lab can determine exact requirements based on technical specifications. This approach introduces a significant degree of confidence into the regulatory compliance process, increasing the odds that the product passes the tests and gets to market on time and on budget.

Ivaylo Tankov *is Director of Competence Center, Information and Communication Technologies (ICT) and Wireless Products at TÜV Rheinland. Tankov's focus is on ICT and use of licensed and unlicensed wireless technologies in manufacturing, commercial products, consumer electronics and healthcare sectors.*

Market-driven Standardization and IEEE 802.3™ Ethernet Innovation

BY DAVID LAW



Ethernet's success in the marketplace is undeniable, and market-driven standardization has been instrumental in its success. It's a cycle of synergistic innovation and market growth that has been spinning for decades.

Ethernet has become entwined with almost every pattern and process of every-day life around the world. Whether a personal computer (PC) has a direct connection to a router or an indirect connection through a "Wi-Fi®" access point, it is highly likely that Ethernet is providing the connection to the Internet. In one way or another, Ethernet networks are used in, or in support of, data centers, PCs, laptops, tablets, smartphones and now, power infrastructure and smart meters, personal medical devices, the Internet of Things, connected cars and a sprawling array of established and emerging technologies. The Internet, Wi-Fi, Big Data, cloud computing, in-vehicle networking and infotainment, the smart grid, computer gaming, eHealth and numerous other high-tech applications all are supported by Ethernet—oftentimes, imperceptibly so.

As Bob Metcalfe, Ethernet co-inventor and now Professor of Innovation at The University of Texas at Austin, described at the Ethernet Alliance blog in August 2013: "Ethernet began as a very high-speed packet-switching local area network (LAN) for extending the Internet into buildings to reach personal computers and their servers. However, Ethernet has been evolving and re-invented for some 40 years, making it so much more than just a networking technology or a means for connecting computers together. At its heart, Ethernet is a brand—an innovation brand. Brands make promises, so it's entirely appropriate to ask what promises Ethernet makes … such as the promise of openness, interoperability, and higher speeds at lower costs. Ethernet's promises also come in the form of open (de) jure standards; owned rather than open source implementations; and fierce competition but interoperability among competing products. It also means preservation and backward compatibility with the installed base and the rapid evolution of IEEE standards based on market engagement. Long live Ethernet!"[1]

Market-driven development and refinement of the IEEE 802.3™ "Standard for Ethernet" has been, and continues to be, integral to Ethernet's ongoing innovation, allowing increasingly complex technologies to be cost-effectively developed and deployed. A full-fledged, standards-driven ecosystem has flourished around Ethernet over its 40 years on the scene. Serving this is a standards development community, its participants being driven by real-world marketplace needs to take the technology to places and capabilities that its creators could not have possibly imagined.

1. http://www.ethernetalliance.org/blog/2013/08/22/ethernet-for-the-ages-a-discussion-with-bob-metcalfe/

STANDARDIZATION'S ROLE IN ETHERNET'S SUCCESS

Ethernet has already penetrated a wide swath of the various ways humanity lives, works and plays. The technology's applications continue to diversify and grow. In fact, Ethernet is so pervasive and dependable that its presence is increasingly overlooked. Ethernet has become an invisible, enabling infrastructure of every-day life in developed and developing areas of the globe.

Standardization is a key and long-running narrative within Ethernet's rich history. Seven years after the concept of Ethernet technology was first documented, IEEE started Project 802 (1980) to standardize local area networks (LANs), and 10 years after the idea, on 23rd June 1983, IEEE 802.3 "Standard for Ethernet" (http://standards.ieee.org/findstds/standard/802.3-2012.html) was first approved as an IEEE standard. Over the three decades since, IEEE 802.3 has evolved from its roots of standardizing connectivity devices inside a LAN to deliver increased capacities and connect more devices, users, media and protocols across more types of networks.

Throughout the years, IEEE 802® has blossomed into a family of standards that, along with a host of others from other standards-development organizations (SDOs), are foundational to the Internet. The IEEE 802.3 Ethernet standard, the IEEE 802.11™ wireless local area network (WLAN) standard[2] (the basis for Wi-Fi), the International Telecommunication Union (ITU) Optical Transport Network (OTN) standards and the 3rd Generation Partnership Project (3GPP) standards—layered upon by the Internet Engineering Task Force (IETF) Internet Protocol (IP) standards—are among those that provide the communications foundation of the Internet we know today. Application-level standards such as browser standards from the World Wide Web Consortium (W3C) as well as e-business and web service standards from the Organization for the Advancement of Structured Information Standards (OASIS) figure prominently in the Internet, as well.

The technological advancements for the Internet resulting from collaboration of those SDOs have been no less than historic. Today, regardless of where you are in the world, connecting a device to the Internet is an easy and familiar process. The consistent interoperability enabled by IEEE 802.3 and other standards comprise a big reason why. Fundamentally, new ways in how societies live, work and play—border-crossing e-commerce, information sharing and community operations, etc.—have emerged with the Internet's proliferation. Business models that didn't exist before now exist because of the Internet. A brand-new engine for worldwide economic opportunity has been established. The Internet works because of an array of complementary, market-driven standards, and the result is that billions of people around the world have been positively impacted.

The success story of Internet standardization speaks to the necessity of borderless collaboration in accelerating innovation. Across traditional national and technical borders, the global engineering community—driven by customer desire and market opportunity—has collaborated in creating the standards and technologies on which today's Internet continues to thrive.

Such an environment demands global coordination building on and/or harmonizing with each other's efforts wherever possible—if return on industry investment in standards is to be maximized and innovation is to be accelerated. Such

2. IEEE 802.11™-2012 "Standard for Information technology-Telecommunications and information exchange between systems Local and metropolitan area networks-Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications"

The IEEE 802.3 Ethernet standard has steadily evolved in response to changing market needs. There is the never-ending demand for increased bandwidth, as well as the move from half duplex to switched operation.

SDO collaboration has certainly taken place in Ethernet standards development.

IEEE 802.3 maintains key relationships with the International Organization for Standardization (ISO), ITU, the Optical Internetworking Forum (OIF) and Telecommunications Industry Association (TIA). The symbiotic cooperation among those standards communities has ensured standards innovation in Ethernet keeps moving forward. It is a complex, layered system of standards built upon standards. As just one example of many, ISO/IEC 11801 "Generic cabling for customer premises standard specifies cabling referenced throughout the IEEE 802.3 standard, but this standard, in turn, is built upon the wire and connector standards of the International Electrotechnical Commission (IEC). And many standards are built on the IEEE 802.3 Ethernet standards; one such example is IEEE 1904.1™ "Standard for Service Interoperability in Ethernet Passive Optical Networks (SIEPON)" (http://standards.ieee.org/findstds/standard/1904.1-2013.html).

MARKET-DRIVEN, GLOBALLY OPEN

Collaboration among standards organizations is central to the market-driven model of standards development and adoption that has fueled Internet innovation.

In 2012, five standards organizations—IEEE, the Internet Architecture Board (IAB), IETF, the Internet Society and W3C—worked together to document the market-driven standardization principles that have fueled the Internet's success and consolidate them in an easily extendible paradigm. The "OpenStand" principles are:

- respectful cooperation among standards organizations, "whereby each respects the autonomy, integrity, processes, and intellectual property rules of the others;"
- adherence to the principles of due process, broad consensus, transparency, balance and openness;
- "collective empowerment," which encompasses a commitment by standards organizations to strive for "standards that are chosen and defined based on technical merit, as judged by the contributed expertise of each participant; provide global interoperability, scalability, stability, and resiliency; enable global competition; serve as building blocks for further innovation; and contribute to the creation of global communities, benefiting humanity;"
- availability of standards "to all for implementation and deployment;" and
- voluntary adoption of standards, the success of which "is determined by the market."

INCESSANT INNOVATION

In the case of the IEEE 802.3 Ethernet family, it is the IEEE-SA that has provided the globally open forum through which standards innovation thrives. It is the open and transparent development process through which the standards come to exist that is the common, lasting factor in the decades of success that IEEE 802.3 Ethernet has demonstrated.

A proven, formal, rigorous process underpins development of IEEE 802.3 and other IEEE standards.

Consensus, due process, openness, right to appeal and balance are the building blocks on which the IEEE-SA process is built. Balloters on a draft IEEE standard vote to approve, disapprove or abstain; every comment received by the standards-development project's working group must be considered, and a 75-percent response from the ballot group—with 75 percent of those voting to approve—is required for the standard to be approved.

Participation in the development of an IEEE 802 standard is open to anyone globally, with all stakeholders invited to *directly* participate in the process. In the case of IEEE 802.3, thousands of individuals from markets around the globe have participated in the creation and refinement of the standards family. Often, those individuals have been affiliated with competitors. Individuals affiliated with both well-established and startup companies alike have participated.

The IEEE 802.3 Ethernet standard has steadily evolved in response to changing market needs. There is the never-ending demand for increased bandwidth, as well as the move from half duplex to switched operation. Along with this, IEEE 802.3 progressed to support the large installed base of telephony-

The IEEE 802.3 Ethernet standards make an ideal case study in the context of OpenStand, as they are constantly evolving and expanding as driven by real-world market needs and are openly developed and deployed/accepted on a global scale.

type wiring as well as single mode and multimode fiber, and more recently backplanes, and point-to-multipoint fiber in passive optical networks (PON). There has been market demand for additional functionality; Power over Ethernet (PoE) and energy-efficient Ethernet (EEE) are two prime examples. IEEE 802.3 continues to grow into subscriber access, into data centers and now into automotive and industrial applications. Application areas such as smart grid, supercomputing, mobile-communications infrastructure, healthcare and medical-device communications as well as entertainment are fast-growing areas for IEEE 802.3 Ethernet.

Innovation in the standards family is incessant. For example, three new standards-development projects as well as an IEEE-SA Industry Connections activity—all intended to expand the capabilities and relevance of IEEE 802.3—were announced in January 2014:

- The IEEE P802.3br Interspersing Express Traffic project (http://standards.ieee.org/develop/project/802.3br.html) is addressing the market need in emerging IEEE 802.3 Ethernet application areas such as audio/video, automotive, industrial automation and transportation (aircraft, railway and heavy trucking) to cost-effectively converge low-latency and best-effort traffic streams on the same physical connections.

- PoE continues to be a fast-growing application space for the IEEE 802.3, and two standards-development projects are underway to enhance its capabilities and efficiency. The IEEE P802.3bt DTE Power via MDI over 4-Pair project (http://standards.ieee.org/develop/project/802.3bt.html) is underway to deliver the boosts in PoE power and efficiency that are sought in areas such as pan/tilt/zoom security cameras, Internet Protocol (IP) videophones, kiosks, point-of-sale (POS) terminals, thin clients, multi-radio wireless nodes and access points, laptop computers, radio frequency identification (RFID) readers and building management. The IEEE P802.3bu 1-Pair Power over Data Lines project (http://standards.ieee.org/develop/project/802.3bu.html) meanwhile, is extending PoE to single-pair data interfaces. The availability of power on the single-pair data interface would remove the need for separate power wiring for applications in emerging Ethernet markets such as automotive, transportation and industrial automation.

- Access is one of those application spaces for which Ethernet was not originally intended. It has gradually evolved and is now widely deployed. Ethernet Passive Optical Network (EPON) infrastructure is popular for a number of applications, including residential and commercial subscriber access (for voice, video and data) and mobile backhaul, and equipment vendors and network operators—especially in Asia and North and South America—are interested in exploring the technologies available for the next generation of EPON. Consequently, the IEEE 802.3 Industry Connections NG-EPON Ad Hoc (http://www.ieee802.org/3/ad_hoc/ngepon/index.html) has been launched to explore the market potential and technology options for a next generation of Ethernet Passive Optical Networks operating at data rates beyond 10 Gigabit per second (10Gbps). IEEE-SA Industry Connections activities such as these are valuable to industry because they allow like-minded organizations and individuals to come together quickly, effectively and economically to build consensus at strategic points in a technology's lifecycle, perhaps even before that technology area is ready for formal standardization.

The IEEE 802.3 Ethernet standards make an ideal case study in the context of OpenStand, as they are constantly evolving and expanding as driven by real-world market needs and are openly developed and deployed/accepted on a global scale.

David Law *is a distinguished engineer for HP Networking and has worked on the specification and development of Ethernet products since 1989. In this role, Law has held a number of leadership positions as a member of the IEEE 802.3 Ethernet Working Group. He served as the vice-chair of IEEE 802.3 from 1996 to 2008 and in 2008 was elected to chair of IEEE 802.3. Law has been a member of the IEEE-SA Standards Board since 2005 and is also chair of the IEEE-SA Standards Board Patent Committee (PatCom). Law has received several awards, including the IEEE-SA Standards Medallion in 2000, IEEE-SA Standards Board Distinguished Service Award in 2009 and IEEE-SA International Award in 2012. Law holds a Bachelor of Engineering (Honours) in Electrical and Electronic Engineering from Strathclyde University in Glasgow, Scotland.*

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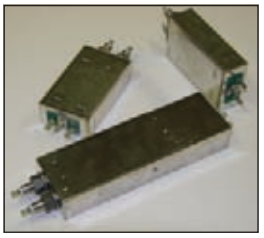

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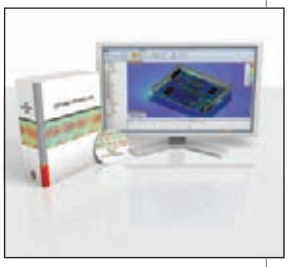

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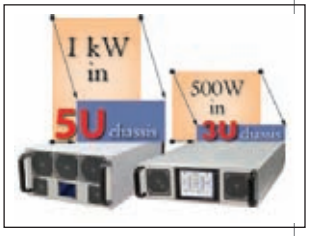

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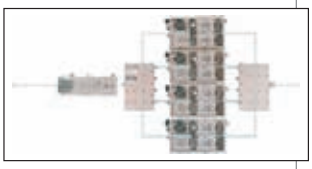

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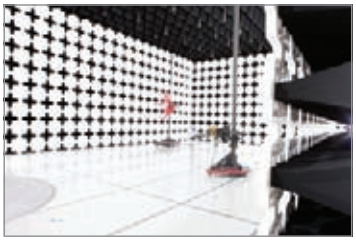

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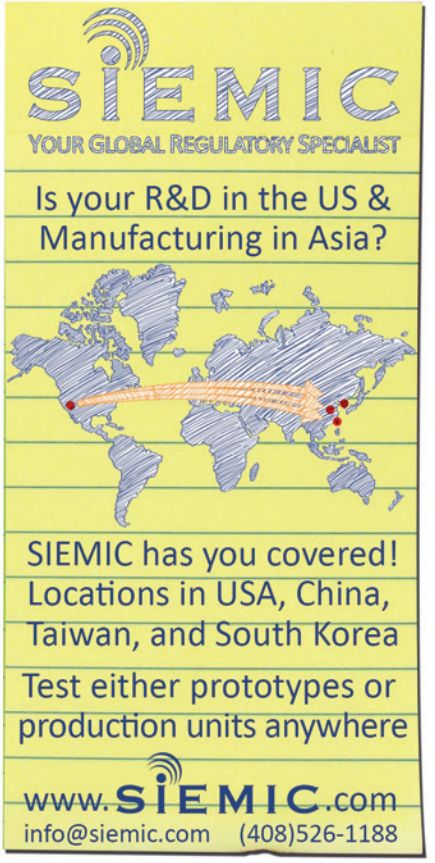

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Teseq Inc.

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Teseq Inc.

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Mag Daddy, LLC

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CST of America
dB Instruments Co.
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ETS-Lindgren
Fair-Rite Products Corp.
Mag Daddy, LLC

Tunable Dipole

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Laird

Whip Antennas

Laird

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Electronic Instrument Associates
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MAJR Products
Microwave Vision Group
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TDK RF Solutions
TechDream, Inc.

Honeycomb RF

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Microwave Vision Group
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TDK RF Solutions

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HV TECHNOLOGIES, Inc.
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Panashield LLC
QAI Laboratories
Raymond EMC Enclosures Ltd.

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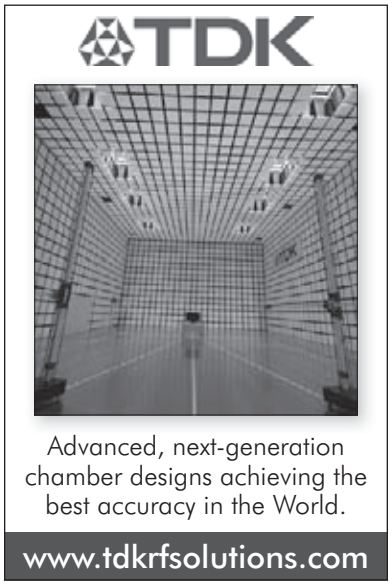

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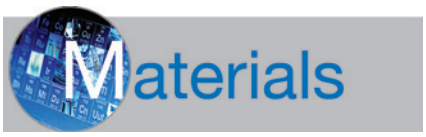

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Safe Engineering Services & technologies
SIEMIC
SILENT Solutions LLC
TÜV SÜD America - Tampa, FL
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL Knowledge Solutions
Wyatt Technical Services LLC

Training Courses

A2LA

André Consulting, Inc.

ARC Technical Resources, Inc.

Cherry Clough Consultants Ltd

CLMI Safety Training

D. C. Smith Consultants

D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

DG Technologies

Don HEIRMAN Consultants

Electronic Instrument Associates

Equipment Reliability Institute (ERI)

ETS-Lindgren

Exemplar Global

Henry Ott Consultants

Hoolihan EMC Consulting

Jastech EMC Consulting LLC

Kimmel Gerke Associates Ltd. - Arizona

Laboratory Accreditation Bureau (L-A-B)

Lewis Bass International Engineering Services

Montrose Compliance Services

NTS - Boxborough, MA

NTS - Corporate Calabasas, CA

NTS - El Segundo, CA

NTS - Fullerton, CA

NTS - Pittsfield, MA

NTS - Plano, TX

NTS - Rockford, IL

NTS - Silicon Valley Fremont & Newark, CA

O'Brien Compliance Management

RTF Compliance

Safe Engineering Services & technologies

SILENT Solutions LLC

TÜV SÜD America - Tampa, FL

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Holland, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America Inc. - San Diego, CA

TÜV SÜD America- Fremont, CA

TÜV SÜD America- Plymouth, MI

TÜV SÜD America- Portland, OR

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL Knowledge Solutions

University of Oxford Continuing Professional Development - Technology Programme

Washington Laboratories

Wyatt Technical Services LLC

Videos

ARC Technical Resources, Inc.

ESD Association

Keysight Technologies Inc.

Washington Laboratories

Webinars

Cherry Clough Consultants Ltd

Eisner Safety Consultants

ESD Association

Go Global Compliance Inc.

Keysight Technologies Inc.

NTS - Boxborough, MA

NTS - Corporate Calabasas, CA

NTS - El Segundo, CA

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Rockford, IL

NTS - Silicon Valley Fremont & Newark, CA

Safe Engineering Services & technologies

SIEMIC

TÜV SÜD America - Tampa, FL

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Holland, MI

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America Inc. - San Diego, CA

TÜV SÜD America- Fremont, CA

TÜV SÜD America- Plymouth, MI

TÜV SÜD America- Portland, OR

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL - Fremont, CA

Publications

Books

EMI/EMC Books

André Consulting, Inc.

Cherry Clough Consultants Ltd

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Montrose Compliance Services

Product Safety Books

Lewis Bass International Engineering Services

Magazines

In Compliance Magazine

Standards Resellers

ESD Association

Safety +

Eyes, Face, and Head

HEMCO Corporation

Safety & Warning Labels

Abstraction Engineering Inc.

Clarion Safety Systems

Coast Label

Enerdoor

HM Cragg

InfoSight Corporation

Lewis Bass International Engineering Services

Calibration & Repair

A.H. Systems, Inc.
ARC Technical Resources, Inc.
Avalon Equipment Corporation Rentals
Electronic Instrument Associates
EM TEST United States of America
ETS-Lindgren
Excalibur Engineering Inc.
Fischer Custom Communications, Inc.
HAEFELY HIPOTRONICS
IFI
Keysight Technologies Inc.
Liberty Labs, Inc.
MI Technologies
MILMEGA
Pearson Electronics, Inc.
Ross Engineering Corp.
SE Laboratories a Trescal Company
Solar Electronics Co.
TDK RF Solutions
TESEO SpA
Teseq Inc.
Trescal
VEROCH - Testing Equipment USA

Codes, Standards & Regulations

A2LA
American National Standards Institute
ConvergePoint: Compliance Software on SharePoint
DG Technologies
Eisner Safety Consultants
Enerdoor
Grund Technical Solutions, LLC
InfoSight Corporation
Laboratory Accreditation Bureau (L-A-B)
Phoenix Technical Group
UL Knowledge Solutions

Consulting

Cleanroom/Static Control

Advanced ESD Services +
Bennett and Bennett
BestESD Technical Services
Bystat
Protective Industrial Polymers

EMC Consulting

André Consulting, Inc.
Atlas Compliance & Engineering
Cherry Clough Consultants Ltd
CKC Laboratories, Inc.
Compliance & More Inc.
CSIA, LLC
D. C. Smith Consultants
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Dayton T. Brown, Inc.
DG Technologies
Don HEIRMAN Consultants
Enerdoor
ESDEMC Technology LLC
G&M Compliance, Inc.
Go Global Compliance Inc.
Grund Technical Solutions, LLC
Henry Ott Consultants
Hoolihan EMC Consulting
International Certification Services, Inc.
Jastech EMC Consulting LLC
JDM LABS LLC
Kimmel Gerke Associates Ltd. - Arizona
Kitagawa Industries, America, Inc.
LS Research
Montrose Compliance Services
Northwest EMC Inc. - Texas
Northwest EMC, Inc. - Oregon
NTS - Boxborough, MA
NTS - Corporate Calabasas, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
Panashield LLC
RTF Compliance
SIEMIC
SILENT Solutions LLC
Southwest Research Institute
Spectrum EMC Consulting, LLC
Test Site Services Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
Wave Scientific Ltd
WEMS Electronics
Wyatt Technical Services LLC

ESD Consulting

Conductive Containers Inc.
ESDEMC Technology LLC

Government Regulations

BMSI (Korea) Regulatory Consulting

Atlas Compliance & Engineering
Compliance & More Inc.
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Go Global Compliance Inc.
NTS - Corporate Calabasas, CA
NTS - Silicon Valley Fremont & Newark, CA
RTF Compliance

EU (Europe) Regulatory Consulting

ACEMA
André Consulting, Inc.
Atlas Compliance & Engineering
CKC Laboratories, Inc.
Compliance & More Inc.
Compliance Worldwide, Inc.
D.L.S. Electronic Systems, Inc. - Conformity Assessment
D.L.S. Electronic Systems, Inc. - Environmental Testing

EU (Europe) Regulatory Consulting (continued)

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Eisner Safety Consultants

Go Global Compliance Inc.

International Certification Services, Inc.

Kimmel Gerke Associates Ltd. - Arizona

Montrose Compliance Services

NTS - Corporate Calabasas, CA

NTS - Rockford, IL

NTS - Silicon Valley Fremont & Newark, CA

RTF Compliance

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

Wyatt Technical Services LLC

FCC (U.S) Regulatory Consulting

André Consulting, Inc.

Atlas Compliance & Engineering

CKC Laboratories, Inc.

Compliance & More Inc.

Compliance Worldwide, Inc.

D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Go Global Compliance Inc.

International Certification Services, Inc.

Kimmel Gerke Associates Ltd. - Arizona

Montrose Compliance Services

NTS - Corporate Calabasas, CA

NTS - Silicon Valley Fremont & Newark, CA

RTF Compliance

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

GOST (Russia) Regulatory Consulting

Compliance & More Inc.

Go Global Compliance Inc.

NTS - El Segundo, CA

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

RTF Compliance

VCCI Consulting

Atlas Compliance & Engineering

CKC Laboratories, Inc.

Compliance & More Inc.

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Go Global Compliance Inc.

Lightning Protection

André Consulting, Inc.

Captor Corporation

D. C. Smith Consultants

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Dexmet Corporation

HM Cragg

NexTek, Inc.

NTS - Boxborough, MA

NTS - Corporate Calabasas, CA

NTS - Fullerton, CA

NTS - Pittsfield, MA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

UL Knowledge Solutions

Medical Device

André Consulting, Inc.

D. C. Smith Consultants

D.L.S. Electronic Systems, Inc. - Conformity Assessment

D.L.S. Electronic Systems, Inc. - EMC Testing

D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing

Darryl Ray EMC Consultants LLC

Eisner Safety Consultants

G&M Compliance, Inc.

Kimmel Gerke Associates Ltd. - Arizona

Montrose Compliance Services

NTS - Boxborough, MA

NTS - Corporate Calabasas, CA

NTS - El Segundo, CA

NTS - Fullerton, CA

NTS - Plano, TX

NTS - Silicon Valley Fremont & Newark, CA

O'Brien Compliance Management

Orbis Compliance LLC.

Product Safety Consulting

Test Site Services Inc.

TÜV Rheinland of North America - Newtown, CT

TÜV Rheinland of North America - Pleasanton, CA

TÜV Rheinland of North America - Santa Clara, CA

TÜV Rheinland of North America - Webster, NY

TÜV Rheinland of North America - Youngsville, NC

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI

TÜV SÜD America - Holland, MI

TÜV SÜD America - New Brighton, MN

TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - Tampa, FL

TÜV SÜD America Inc. - Headquarters Peabody, MA

TÜV SÜD America Inc. - San Diego, CA

TÜV SÜD America- Fremont, CA

TÜV SÜD America- Plymouth, MI

TÜV SÜD America- Portland, OR

TÜV SÜD Canada - Gormley, ON

TÜV SÜD Canada - Newmarket, ON

UL Knowledge Solutions

Product Safety Consulting

CASE Forensics
Compliance & More Inc.
Compliance inSight Consulting Inc.
CSIA, LLC
D.L.S. Electronic Systems, Inc. - Conformity Assessment
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
Eisner Safety Consultants
Evans Regulatory Certification Consulting
G&M Compliance, Inc.
Go Global Compliance Inc.
InfoSight Corporation
Intertek
Lewis Bass International Engineering Services
NTS - Boxborough, MA
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
O'Brien Compliance Management
Orbis Compliance LLC.
Product EHS Consulting LLC
Product Safety Consulting
Test Site Services Inc.
TJS Technical Services Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL Knowledge Solutions
VEROCH - Testing Equipment USA

Quality

Eisner Safety Consultants
InfoSight Corporation
Spectrum EMC Consulting, LLC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
UL Knowledge Solutions

Telecom

CSIA, LLC
CV. DIMULTI
D. C. Smith Consultants
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
FPX, LLC
Go Global Compliance Inc.
Nolato Silikonteknik AB
NTS - Boxborough, MA
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
Orbis Compliance LLC.
UL Knowledge Solutions

Tempest

D. C. Smith Consultants
Dayton T. Brown, Inc.
Kimmel Gerke Associates Ltd. - Arizona

Transient

André Consulting, Inc.
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Dayton T. Brown, Inc.
Grund Technical Solutions, LLC
NexTek, Inc.
SILENT Solutions LLC

Design

André Consulting, Inc.
Conductive Containers Inc.
CST AG
CST of America
D. C. Smith Consultants
DG Technologies
EMS-PLUS
Jastech EMC Consulting LLC
LS Research
Montrose Compliance Services
NTS - Albuquerque, NM
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Camden, AR
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - Detroit, MI
NTS - El Segundo, CA
NTS - Europe
NTS - Fullerton, CA
NTS - Indianapolis, IN
NTS - Los Angeles, CA
NTS - Pittsfield, MA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Rustburg, VA
NTS - San Bernardino, CA
NTS - Santa Clarita, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tempe, AZ
UL Knowledge Solutions
VEROCH - Testing Equipment USA
Videon Central, Inc.
Washington Laboratories
WEMS Electronics
Wyatt Technical Services LLC

Other

Conductive Painting Services

Nolato Silikonteknik AB

VTI Vacuum Technologies, Inc.

Shielded Enclosure Design

3Gmetalworx Inc.

Conductive Containers Inc.

Dexmet Corporation

Magnetic Shield Corporation

Panashield LLC

Raymond EMC Enclosures Ltd.

VTI Vacuum Technologies, Inc.

Site Survey Services

Dayton T. Brown, Inc.

Electronic Instrument Associates

ETS-Lindgren

Spectrum EMC Consulting, LLC

Wave Scientific Ltd

Rentals

See Test Equipment Rentals

Shielding

Architectural Shielding Products

ETS-Lindgren

MAJR Products

Metal Textiles Corporation

Fingerstock

3Gmetalworx Inc.

Laird

Metal Textiles Corporation

Parker Chomerics

Tech-Etch

Shielded Air Filters

Alco Technologies, Inc.

Ja-Bar Silicone Corp

MAJR Products

P & P Technology Ltd

Parker Chomerics

Spira Manufacturing Corporation

Tech-Etch

Shielded Cable Assemblies & Harnesses

Alco Technologies, Inc.

EM Software & Systems (United States of America) Inc.

Magnetic Shield Corporation

MAJR Products

Shielded Coatings

ARC Technologies, Inc.

Parker Chomerics

VTI Vacuum Technologies, Inc.

Shielded Compounds

Ja-Bar Silicone Corp

Parker Chomerics

Shielded Conduit

Electri-Flex Company

Magnetic Shield Corporation

Shielded Connectors

Alco Technologies, Inc.

Gemini Electronic Components, Inc.

Isodyne Inc.

Metal Textiles Corporation

METZ CONNECT USA

Spira Manufacturing Corporation

Tech-Etch

Shielded Enclosures

3Gmetalworx Inc.

Comply Tek, Inc.

Comtest Engineering Inc.

Cuming-Lehman Chambers, Inc.

ETS-Lindgren

Lionheart Northwest

Magnetic Shield Corporation

The MuShield Company Inc.

Panashield LLC

Raymond EMC Enclosures Ltd.

Select Fabricators, Inc.

VTI Vacuum Technologies, Inc.

Shielded Tubing

Electri-Flex Company

Magnetic Shield Corporation

Shielded Wire & Cable

Alco Technologies, Inc.

Dexmet Corporation

Isodyne Inc.

Magnetic Shield Corporation

Metal Textiles Corporation

METZ CONNECT USA

Shielding Gaskets

3Gmetalworx Inc.
Alco Technologies, Inc.
Ja-Bar Silicone Corp
Kitagawa Industries, America, Inc.
Laird
MAJR Products
Metal Textiles Corporation
Nolato Silikonteknik AB
P & P Technology Ltd
Parker Chomerics
SAS Industries, Inc.
Spira Manufacturing Corporation
Tech-Etch
VTI Vacuum Technologies, Inc.
W. L. Gore & Associates, Inc.

Shielding Materials

EMI/RFI Shielding Materials

Alco Technologies, Inc.
Bal Seal Engineering
Cuming-Lehman Chambers, Inc.
Dexmet Corporation
Fabritech, Inc.
Fair-Rite Products Corp.
Isodyne Inc.
Ja-Bar Silicone Corp
Kitagawa Industries, America, Inc.
Laird
MAJR Products
Metal Textiles Corporation
P & P Technology Ltd
Panashield LLC
Schlegel Electronic Materials
Spira Manufacturing Corporation
Swift Textile Metalizing LLC

VTI Vacuum Technologies, Inc.
W. L. Gore & Associates, Inc.

Magnetic Field Shielding Materials

3Gmetalworx Inc.
Cuming-Lehman Chambers, Inc.
Dexmet Corporation
MAJR Products
The MuShield Company Inc.

Shielding, Board-Level

3Gmetalworx Inc.
Conductive Containers Inc.
Faspro Technologies
Laird
MAJR Products

EMC Simulation Software

Altair Development SA (Pty) Ltd
ANSYS Inc.
CST AG
CST of America
Delcross Technologies
Electro Magnetic Applications, Inc. (EMA)
EMS-PLUS
LS Research
Moss Bay EDA
Reliant EMC LLC
Rohde & Schwarz, Inc.
TechDream, Inc.
TESEO SpA
Wave Computation Technologies, Inc.

ESD/Static Control Software

ACL Staticide Inc.
DESCO INDUSTRIES Inc.
Monroe Electronics

Lab Control Software

TESEO SpA

Product Safety Software

O'Brien Compliance Management
OnRule

Signal Integrity & EMC Analysis Software

Altair Development SA (Pty) Ltd
CST AG
CST of America

Delcross Technologies
Keysight Technologies Inc.
Remcom
Rohde & Schwarz, Inc.
TDK RF Solutions

Wireless Propagation Software

Altair Development SA (Pty) Ltd
Delcross Technologies

Static Control

Air Ionizers

Simco-Ion

Clothing & Accessories

Footwear

Amstat Industries, Inc.
Lubrizol Engineered Polymers

Wrist Straps

Amstat Industries, Inc.
Lubrizol Engineered Polymers

Containers

Conductive Containers Inc.
Lubrizol Engineered Polymers

ESD Tape

Conductive Containers Inc.
Polyonics

Flooring

Carpet

Ground Zero
Protective Industrial Polymers

Floor Coatings

ACL Staticide Inc.
Arizona Polymer Flooring

Ground Zero
Protective Industrial Polymers

Tiles

Ground Zero

Packaging

Conductive Containers Inc.
CST AG
CST of America
Lubrizol Engineered Polymers

Simulators

EMP Simulators

CST AG
CST of America
Fischer Custom Communications, Inc.
Grund Technical Solutions, LLC

ESD Simulators

Comply Tek, Inc.
CST AG
CST of America
EM TEST United States of America
ESDEMC Technology LLC
Kikusui America Inc.
TechDream, Inc.

Lightning Simulators

Comply Tek, Inc.
CST AG
CST of America
EM Software & Systems (United States of America) Inc.
EM TEST United States of America

Transient Detectors & Suppressors

Fischer Custom Communications, Inc.
NexTek, Inc.

Workstations

ACL Staticide Inc.
Conductive Containers Inc.
HEMCO Corporation
Lubrizol Engineered Polymers
MI Technologies

Test and Measure

Accelerometers

Clark Testing
SE Laboratories a Trescal Company

Amplifiers

Amplifier Modules

AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Empower RF Systems
IFI
MILMEGA
OPHIR RF

Prana
TREK, Inc.

Low Power Amplifiers

A.H. Systems, Inc.
AMETEK Compliance Test Solutions
IFI
MILMEGA
TREK, Inc.

Microwave Amplifiers

AMETEK Compliance Test Solutions
Applied Systems Engineering, Inc.
AR RF/Microwave Instrumentation
Empower RF Systems
Giga-tronics Incorporated
HV TECHNOLOGIES, Inc.
IFI
MILMEGA
OPHIR RF
Prana
Wave Scientific Ltd

Power Amplifiers

AE Techron, Inc.

AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Associated Power Technologies
CPI, Inc.
Empower RF Systems
HV TECHNOLOGIES, Inc.
IFI
Lionheart Northwest
MILMEGA
OPHIR RF
Prana
Rohde & Schwarz, Inc.
TechDream, Inc.
TESEO SpA
TREK, Inc.

RF Amplifiers

A.H. Systems, Inc.
AMETEK Compliance Test Solutions
Avalon Equipment Corporation Rentals
CPI, Inc.
Empower RF Systems
EMSource
ETS-Lindgren
HV TECHNOLOGIES, Inc.
IFI
MI Technologies
MILMEGA
OPHIR RF
Prana
US Microwave Laboratories
Wave Scientific Ltd

Solid State Amplifiers

AMETEK Compliance Test Solutions
AR RF/Microwave Instrumentation
Comply Tek, Inc.
CPI, Inc.
Empower RF Systems
IFI
MILMEGA
OPHIR RF
Prana
TREK, Inc.

Traveling Wave Tube Amplifiers

AR RF/Microwave Instrumentation
Avalon Equipment Corporation Rentals
Comply Tek, Inc.
CPI, Inc.
IFI
OPHIR RF

Analyzers

EMI/EMC, Spectrum Analyzers

Cobham (formerly Aeroflex)
Electro Rent Corporation
Electronic Instrument Associates
EMSource
Excalibur Engineering Inc.
Keysight Technologies Inc.
Narda Safety Test Solutions GmbH
Rigol Technologies
Rohde & Schwarz, Inc.
Signal Hound

Flicker Analyzers

EM TEST United States of America
HV TECHNOLOGIES, Inc.
Kikusui America Inc.
Lionheart Northwest
Reliant EMC LLC
SE Laboratories a Trescal Company
Teseq Inc.

Harmonics Analyzers

EM TEST United States of America
HV TECHNOLOGIES, Inc.
Kikusui America Inc.
Reliant EMC LLC
SE Laboratories a Trescal Company
Teseq Inc.

Network Analyzers

Cobham (formerly Aeroflex)
Electro Rent Corporation
Excalibur Engineering Inc.
Keysight Technologies Inc.
LS Research

Power Quality Analyzers

Electro Rent Corporation
Excalibur Engineering Inc.
Lionheart Northwest
SE Laboratories a Trescal Company

Audio & Video

Audio Systems

Audivo GmbH
Videon Central, Inc.

CCTV

Audivo GmbH
TDK RF Solutions
TESEO SpA
Videon Central, Inc.

Automatic Test Sets

ARC Technical Resources, Inc.
EM TEST United States of America
IFI
MILMEGA
NTS - Albuquerque, NM

Avionics Test Equipment

AMETEK Compliance Test Solutions
Cobham (formerly Aeroflex)
EM TEST United States of America
HV TECHNOLOGIES, Inc.
IFI
MILMEGA
NTS - Albuquerque, NM
NTS - San Bernardino, CA

Burn-in Test Equipment

OPHIR RF

Data Acquisition Monitoring Systems

DG Technologies
MI Technologies

Fiber-Optic Systems

DG Technologies
Excalibur Engineering Inc.
HV TECHNOLOGIES, Inc.
Michigan Scientific Corp.
MITEQ Inc.
Ross Engineering Corp.
TESEO SpA

Flow Meters

Advanced Test Equipment Rentals
VEROCH - Testing Equipment USA

Generators

Arbitrary Waveform Generators

AE Techron, Inc.
AMETEK Compliance Test Solutions
Applied Physical Electronics, L.C. (APELC)
EM TEST United States of America
Keysight Technologies Inc.
Teseq Inc.

EMP Generator

EMSource
HV TECHNOLOGIES, Inc.

ESD Generators

AMETEK Compliance Test Solutions
ARC Technical Resources, Inc.
EM TEST United States of America
EMSource
Grund Technical Solutions, LLC
HAEFELY HIPOTRONICS
HV TECHNOLOGIES, Inc.
Teseq Inc.

Fast/Transient Burst Generators

AE Techron, Inc.
AMETEK Compliance Test Solutions
ARC Technical Resources, Inc.
Comply Tek, Inc.
EMSource
HAEFELY HIPOTRONICS
HV TECHNOLOGIES, Inc.
Teseq Inc.

Impulse Generators

AMETEK Compliance Test Solutions
Applied EM Technology
Applied Physical Electronics, L.C. (APELC)
EM TEST United States of America
EMSource
Grund Technical Solutions, LLC
HAEFELY HIPOTRONICS
HV TECHNOLOGIES, Inc.
Solar Electronics Co.
Teseq Inc.

Interference Generators

AMETEK Compliance Test Solutions
EM TEST United States of America
IFI
MILMEGA
Teseq Inc.

Lightning Generators

ARC Technical Resources, Inc.
Avalon Equipment Corporation Rentals
EM TEST United States of America
HAEFELY HIPOTRONICS
HV TECHNOLOGIES, Inc.
Solar Electronics Co.

Signal Generators

Applied EM Technology
Cobham (formerly Aeroflex)
Electro Rent Corporation
Excalibur Engineering Inc.
Giga-tronics Incorporated
Keysight Technologies Inc.
Kikusui America Inc.
Teseq Inc.

Surge Transient Generators

ARC Technical Resources, Inc.
Avalon Equipment Corporation Rentals
EM TEST United States of America
HAEFELY HIPOTRONICS
HV TECHNOLOGIES, Inc.
Solar Electronics Co.
TechDream, Inc.
Teseq Inc.
Thermo Fisher Scientific

Meters

Field Strength Meters

AR RF/Microwave Instrumentation
Monroe Electronics
Narda STS, USA
SE Laboratories a Trescal Company
TREK, Inc.

Megohmmeters

ACL Staticide Inc.
Amstat Industries, Inc.
Chroma Systems Solutions, Inc.
Monroe Electronics
Ross Engineering Corp.

Radiation Hazard Meters

ETS-Lindgren

RF Power Meters

AR RF/Microwave Instrumentation
Cobham (formerly Aeroflex)
Electro Rent Corporation
Giga-tronics Incorporated
Keysight Technologies Inc.
OPHIR RF
SE Laboratories a Trescal Company

Static Charge Meters

ACL Staticide Inc.
Monroe Electronics
TREK, Inc.

Static Decay Meters

Monroe Electronics
TREK, Inc.

Monitors

Current Monitors

Grund Technical Solutions, LLC
Pearson Electronics, Inc.

EMI Test Monitors

DG Technologies

ESD Monitors

Monroe Electronics

Ionizer Balance Monitors

Monroe Electronics
TREK, Inc.

Static Voltage Monitors

Michigan Scientific Corp.
TREK, Inc.

Oscilloscopes & Transient Recorders

Avalon Equipment Corporation Rentals
Electro Rent Corporation
Keysight Technologies Inc.
Lionheart Northwest
Reliant EMC LLC
Rohde & Schwarz, Inc.
SE Laboratories a Trescal Company
Teledyne LeCroy

Probes

Current/Magnetic Field Probes

A.H. Systems, Inc.
ETS-Lindgren
Fischer Custom Communications, Inc.
Pearson Electronics, Inc.
Prana
Solar Electronics Co.

Electric Field Probes

Enerdoor
ETS-Lindgren
TREK, Inc.

Voltage Probes

EM TEST United States of America
Fischer Custom Communications, Inc.
Ross Engineering Corp.
Solar Electronics Co.

Receivers

EMI/EMC Receivers

Comply Tek, Inc.
EMSource
Excalibur Engineering Inc.
GAUSS INSTRUMENTS GmbH
HV TECHNOLOGIES, Inc.
Keysight Technologies Inc.
MITEQ Inc.
Reliant EMC LLC

Rohde & Schwarz, Inc.
SE Laboratories a Trescal Company
TechDream, Inc.

RF Receivers

MI Technologies
Reliant EMC LLC

RF Leak Detectors

AR RF/Microwave Instrumentation

Safety Test Equipment

Advanced Test Equipment Rentals
AEMC Instruments
AR RF/Microwave Instrumentation
Chroma Systems Solutions, Inc.
ED&D
HAEFELY HIPOTRONICS
Kikusui America Inc.
O'Brien Compliance Management
Product Safety Consulting
VEROCH - Testing Equipment USA

SAR Testing Equipment

ART-MAN

Shock & Vibration Testing Shakers

Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
NTS - San Bernardino, CA

Susceptibility Test Instruments

AMETEK Compliance Test Solutions
ARC Technical Resources, Inc.
DG Technologies
EM TEST United States of America
ESDEMC Technology LLC
Grund Technical Solutions, LLC
IFI
MILMEGA
OPHIR RF

Susceptibility Test Instruments

(continued)

TDK RF Solutions

TechDream, Inc.

Teseq Inc.

Telecom Test Equipment

Advanced Test Equipment Rentals

AE Techron, Inc.

AMETEK Compliance Test Solutions

Avalon Equipment Corporation Rentals

Cobham (formerly Aeroflex)

CSIA, LLC

Electro Rent Corporation

EM TEST United States of America

EMSCAN

Fischer Custom Communications, Inc.

HAEFELY HIPOTRONICS

IFI

MILMEGA

TechDream, Inc.

Test Equipment Rentals

Advanced Test Equipment Rentals

AMETEK Compliance Test Solutions

Avalon Equipment Corporation Rentals

Barth Electronics, Inc.

CSZ Testing - Ohio

Electro Rent Corporation

EM TEST United States of America

ESDEMC Technology LLC

Excalibur Engineering Inc.

Grund Technical Solutions, LLC

IFI

Lionheart Northwest

Michigan Scientific Corp.

MILMEGA

TechDream, Inc.

TestWorld Inc.

Transient Specialists, Inc.

VEROCH - Testing Equipment USA

Testers

Current Leakage Testers

Associated Research, Inc.

Barth Electronics, Inc.

Chroma Systems Solutions, Inc.

ESDEMC Technology LLC

Kikusui America Inc.

Ross Engineering Corp.

Slaughter Company, Inc.

Dielectric Strength Testers

Associated Research, Inc.

Chroma Systems Solutions, Inc.

EM TEST United States of America

Slaughter Company, Inc.

Electrical Safety Testers

Associated Research, Inc.

Chroma Systems Solutions, Inc.

Kikusui America Inc.

O'Brien Compliance Management

Slaughter Company, Inc.

EMC Testers

AE Techron, Inc.

AMETEK Compliance Test Solutions

Detectus AB

DG Technologies

EM TEST United States of America

EMSCAN

EMSource

ESDEMC Technology LLC

Grund Technical Solutions, LLC

HAEFELY HIPOTRONICS

IFI

Langer EMV-Technik GmbH

MILMEGA

OPHIR RF

Rohde & Schwarz, Inc.

Teseq Inc.

Ground Bond Testers

Associated Research, Inc.

Chroma Systems Solutions, Inc.

Slaughter Company, Inc.

Ground Resistance Testers

Associated Research, Inc.

Atlas Foundation Company

Slaughter Company, Inc.

Hipot Testers

Applied Physical Electronics, L.C. (APELC)

Associated Research, Inc.

Chroma Systems Solutions, Inc.

Electro Rent Corporation

Kikusui America Inc.

Ross Engineering Corp.

Slaughter Company, Inc.

Thermocouples

Applied Physical Electronics, L.C. (APELC)

VEROCH - Testing Equipment USA

Used & Refurbished Test Equipment

Avalon Equipment Corporation Rentals

Electro Rent Corporation

Vibration Controllers

Excalibur Engineering Inc.

Accredited Registrar

Excalibur Engineering Inc.

Green Mountain Electromagnetics, Inc.

Laboratory Accreditation Bureau (L-A-B)

LS Research

Northwest EMC Inc. - Minnesota

Northwest EMC Inc. - Texas

Northwest EMC Inc.- California

Northwest EMC Inc.- Washington

Northwest EMC, Inc. - Oregon

QAI Laboratories

TÜV SÜD America - Alpharetta, GA

TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON

CE Competent Body

D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Elite Electronic Engineering
QAI Laboratories
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories

CE Notified Body

American Certification Body
CKC Laboratories, Inc.
Clark Testing
Compatible Electronics, Inc.
CSIA, LLC
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Elite Electronic Engineering
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC Inc.- Washington
Northwest EMC, Inc. - Oregon
QAI Laboratories
SIEMIC
TESEO SpA
Test Site Services Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - UK (Ashwood Park)
Washington Laboratories

Environmental Testing & Analysis Services

Boeing Technology Services
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
CSZ Testing - Ohio
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Dayton T. Brown, Inc.
DNB Engineering, Inc.
Elite Electronic Engineering
NTS - Boxborough, MA
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - San Bernardino, CA
Professional Testing (EMI), Inc.
QAI Laboratories
Retlif Testing Laboratories
Test Site Services Inc.
Trace Laboratories, Inc.
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories

Homologation Services

CSIA, LLC
Jacobs Technology
Lewis Bass International Engineering Services
MET Laboratories, Inc.
Orbis Compliance LLC.
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Pre-Assessments

A2LA
CertifiGroup Inc.
Clark Testing
Compatible Electronics, Inc.
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Eisner Safety Consultants
Elite Electronic Engineering
F2 Labs
International Certification Services, Inc.
Jastech EMC Consulting LLC
Laboratory Accreditation Bureau (L-A-B)
Lewis Bass International Engineering Services
Product Safety Consulting
SILENT Solutions LLC
Spectrum EMC Consulting, LLC
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Wyatt Technical Services LLC

Product & Component Testing Services

ART-MAN
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
Compliance Testing, LLC
Dayton T. Brown, Inc.
Diversified T.E.S.T. Technologies, Inc.
DNB Engineering, Inc.
Elite Electronic Engineering
F2 Labs
Green Mountain Electromagnetics, Inc.
International Certification Services, Inc.
MI Technologies
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Huntsville, AL Nuclear
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
Product Safety Consulting
Retlif Testing Laboratories
SIEMIC
Southwest Research Institute
Trace Laboratories, Inc.
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Testing Laboratories

Accelerated Stress Testing

Boeing Technology Services
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
Core Compliance Testing Services
CSZ Testing - Ohio
D.L.S. Electronic Systems, Inc. - Environmental Testing
Dayton T. Brown, Inc.
Elite Electronic Engineering
Intertek
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Los Angeles, CA
NTS - Plano, TX

NTS - San Bernardino, CA
NTS - Santa Clarita, CA
NTS - Tempe, AZ
NTS - Tinton Falls, NJ
Product Safety Consulting
Professional Testing (EMI), Inc.
Radiometrics Midwest Corporation
Trace Laboratories, Inc.
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Videon Central, Inc.

Acoustical Testing

Boeing Technology Services
Clark Testing
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Conformity Assessment
Dayton T. Brown, Inc.
DNB Engineering, Inc.
Electronic Instrument Associates
Intertek
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Europe
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Rustburg, VA
NTS - San Bernardino, CA
NTS - Santa Clarita, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
Retlif Testing Laboratories

BSMI Compliant Certification Testing

Atlas Compliance & Engineering
Compliance Worldwide, Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
Elite Electronic Engineering
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC Inc.- Washington
Northwest EMC, Inc. - Oregon
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Silicon Valley Fremont & Newark, CA
TestingPartners.com
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

CB Test Report

D.L.S. Electronic Systems, Inc. - Conformity Assessment
Elite Electronic Engineering
EMC Integrity Inc.
Intertek
NTS - Baltimore, MD
NTS - Chicago, IL
Professional Testing (EMI), Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
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TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
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UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

CE Marking

Abstraction Engineering Inc.
Atlas Compliance & Engineering
CertifiGroup Inc.
CKC Laboratories, Inc.
Compatible Electronics, Inc.
Compliance Worldwide, Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Conformity Assessment
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Dayton T. Brown, Inc.
DNB Engineering, Inc.
Elite Electronic Engineering
F2 Labs
G&M Compliance, Inc.
Green Mountain Electromagnetics, Inc.
H.B. Compliance Solutions
International Certification Services, Inc.
Intertek
Lewis Bass International Engineering Services
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC, Inc. - Oregon
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
Professional Testing (EMI), Inc.
Retlif Testing Laboratories
TESEO SpA
Test Site Services Inc.
TestingPartners.com
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
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UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Walshire Labs, LLC

China Compulsory Certification

CSIA, LLC
D.L.S. Electronic Systems, Inc. - Conformity Assessment
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
G&M Compliance, Inc.
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC Inc.- Washington
Northwest EMC, Inc. - Oregon
NTS - Baltimore, MD
NTS - Chicago, IL
TestingPartners.com
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
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TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON

Electrical Safety Testing

Abstraction Engineering Inc.
Boeing Technology Services
CertifiGroup Inc.
Coilcraft CPS
D.L.S. Electronic Systems, Inc. - Conformity Assessment
Dayton T. Brown, Inc.
DNB Engineering, Inc.
Elite Electronic Engineering
F2 Labs
G&M Compliance, Inc.
Green Mountain Electromagnetics, Inc.
H.B. Compliance Solutions
Intertek
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
Orbis Compliance LLC.
Professional Testing (EMI), Inc.

TestingPartners.com
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TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL LLC

EMC Testing

Abstraction Engineering Inc.
AHD
APREL Inc.
ART-MAN
Atlas Compliance & Engineering
Boeing Technology Services
CKC Laboratories, Inc.
Clark Testing
Compatible Electronics, Inc.
Compliance Worldwide, Inc.
Core Compliance Testing Services
CSIA, LLC
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
DNB Engineering, Inc.
Electronics Test Centre
EMC Integrity Inc.
EMC Testing Laboratory Inc.
F2 Labs
G&M Compliance, Inc.
Global EMC Inc.
Green Mountain Electromagnetics, Inc.
H.B. Compliance Solutions
International Certification Services, Inc.
Intertek
Jacobs Technology
Jastech EMC Consulting LLC
LS Research
MET Laboratories, Inc.
National Institute for Aviation Research
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC Inc.- Washington
Northwest EMC, Inc. - Oregon

NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - Europe
NTS - Fullerton, CA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Rustburg, VA
NTS - San Bernardino, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tempe, AZ
NTS - Tinton Falls, NJ
Parker Chomerics
Professional Testing (EMI), Inc.
Qualtest, Inc.
Radiometrics Midwest Corporation
Retlif Testing Laboratories
SIEMIC
Southwest Research Institute
Spes Development Co
Test Site Services Inc.
TestingPartners.com
Timco Engineering, Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories
WEMS Electronics
Wyatt Technical Services LLC
Yazaki Testing Laboratory

Energy Efficiency Testing

Boeing Technology Services
MET Laboratories, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - San Bernardino, CA
NTS - Silicon Valley Fremont & Newark, CA
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Environmental Simulation Testing

Boeing Technology Services
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
CertifiGroup Inc.
Coilcraft CPS

Core Compliance Testing Services
CSZ Testing - Ohio
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
DNB Engineering, Inc.
H.B. Compliance Solutions
MET Laboratories, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Camden, AR
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - Detroit, MI
NTS - El Segundo, CA
NTS - Europe
NTS - Fullerton, CA
NTS - Huntsville, AL Nuclear
NTS - Indianapolis, IN
NTS - Los Angeles, CA
NTS - Pittsfield, MA
NTS - Plano, TX
NTS - Rockford, IL
NTS - San Bernardino, CA
NTS - Santa Clarita, CA
NTS - Tempe, AZ
NTS - Tinton Falls, NJ
Professional Testing (EMI), Inc.
Retlif Testing Laboratories
Trace Laboratories, Inc.
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

ESD Testing

Compliance Worldwide, Inc.
ESDEMC Technology LLC
H.B. Compliance Solutions
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC Inc.- Washington
Northwest EMC, Inc. - Oregon
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA

EuP Directive Compliance

NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA

GOST R Certification

G&M Compliance, Inc.
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC Inc.- Washington
Northwest EMC, Inc. - Oregon
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
NTS - Silicon Valley Fremont & Newark, CA
TestingPartners.com
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL LLC

Green Energy Compliance

CertifiGroup Inc.
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

GS Mark Certification

NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Halogen Testing

NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
Trace Laboratories, Inc.
UL - UK (Kingsland Park)

Lithium-Ion Battery Testing

Boeing Technology Services
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
CSZ Testing - Ohio
MET Laboratories, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Camden, AR
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - Detroit, MI
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - San Bernardino, CA
NTS - Santa Clarita, CA
Trace Laboratories, Inc.
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA

Lithium-Ion Battery Testing (continued)

TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Marine Electronics Testing

Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
CertifiGroup Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - Military and Aerospace Testing
Green Mountain Electromagnetics, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Fullerton, CA
NTS - Plano, TX
NTS - San Bernardino, CA
NTS - Silicon Valley Fremont & Newark, CA
Retlif Testing Laboratories
Trace Laboratories, Inc.
UL - Research Triangle Park, NC

National Recognized Testing Laboratory (NRTL)

CertifiGroup Inc.
MET Laboratories, Inc.
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
Product Safety Consulting
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Network Equipment Building System (NEBS) Testing

International Certification Services, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - El Segundo, CA
NTS - Europe
NTS - Fullerton, CA
NTS - Plano, TX
NTS - San Bernardino, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
UL - Fremont, CA
UL - Research Triangle Park, NC

Product Pre-Compliance Testing

ART-MAN
Atlas Compliance & Engineering
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
CASE Forensics
CertifiGroup Inc.
Coilcraft CPS

Compatible Electronics, Inc.
Compliance Worldwide, Inc.
Core Compliance Testing Services
D.L.S. Electronic Systems, Inc. - Conformity Assessment
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
DNB Engineering, Inc.
F2 Labs
G&M Compliance, Inc.
Green Mountain Electromagnetics, Inc.
H.B. Compliance Solutions
International Certification Services, Inc.

Lewis Bass International Engineering Services
Northwest EMC Inc. - Minnesota
Northwest EMC Inc. - Texas
Northwest EMC Inc.- California
Northwest EMC Inc.- Washington
Northwest EMC, Inc. - Oregon
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Camden, AR
NTS - Chicago, IL
NTS - Detroit, MI
NTS - El Segundo, CA
NTS - Europe
NTS - Fullerton, CA
NTS - Huntsville, AL Nuclear
NTS - Indianapolis, IN
NTS - Los Angeles, CA
NTS - Pittsfield, MA
NTS - Plano, TX
NTS - Rockford, IL
NTS - Rustburg, VA
NTS - San Bernardino, CA
NTS - Santa Clarita, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tempe, AZ
NTS - Tinton Falls, NJ
O'Brien Compliance Management
Product Safety Consulting
Professional Testing (EMI), Inc.
Test Site Services Inc.
TestingPartners.com
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories
Wyatt Technical Services LLC

Product Safety Testing

Abstraction Engineering Inc.
Bharat Test House
Boeing Technology Services
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
CASE Forensics
CertifiGroup Inc.
Coilcraft CPS
Compatible Electronics, Inc.
Core Compliance Testing Services
CSA Group
D.L.S. Electronic Systems, Inc. - Conformity Assessment
D.L.S. Electronic Systems, Inc. - Environmental Testing
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
DNB Engineering, Inc.
F2 Labs
G&M Compliance, Inc.
Green Mountain Electromagnetics, Inc.
Lewis Bass International Engineering Services
MET Laboratories, Inc.
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - El Segundo, CA
NTS - San Bernardino, CA
NTS - Silicon Valley Fremont & Newark, CA
NTS - Tinton Falls, NJ
Product Safety Consulting
Professional Testing (EMI), Inc.
SIEMIC
TestingPartners.com
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories

Radio Performance & Functionality Testing

Applied Physical Electronics, L.C. (APELC)
D.L.S. Electronic Systems, Inc. - Wireless Compliance Testing
D.L.S. Electronic Systems, Inc. - EMC Testing
H.B. Compliance Solutions
Northwest EMC Inc.- California
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
Orbis Compliance LLC.
Radiometrics Midwest Corporation
SIEMIC
Test Site Services Inc.
UL - Fremont, CA

Radio Performance & Functionality Testing (continued)

UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC
Washington Laboratories

RoHS Directive Compliance

D.L.S. Electronic Systems, Inc. - Conformity Assessment
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
Trace Laboratories, Inc.
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)

Shock & Vibration

Boeing Technology Services
Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
Clark Testing
Coilcraft CPS

CSZ Testing - Ohio
D.L.S. Electronic Systems, Inc. - Environmental Testing
DNB Engineering, Inc.
EMC Integrity Inc.
Fiarex testing laboratory Inc.
MET Laboratories, Inc.
NTS - Baltimore, MD
NTS - Boxborough, MA
NTS - Camden, AR
NTS - Chicago, IL
NTS - Corporate Calabasas, CA
NTS - Detroit, MI
NTS - El Segundo, CA
NTS - Europe
NTS - Fullerton, CA
NTS - Huntsville, AL Nuclear
NTS - Indianapolis, IN
NTS - Los Angeles, CA
NTS - Plano, TX
NTS - Rustburg, VA
NTS - San Bernardino, CA
NTS - Santa Clarita, CA
NTS - Tinton Falls, NJ
Professional Testing (EMI), Inc.
Retlif Testing Laboratories
Trace Laboratories, Inc.
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA
TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Research Triangle Park, NC
UL LLC
WEMS Electronics

Standards Council of Canada Certification Body

CertifiGroup Inc.
NTS - Baltimore, MD
NTS - Chicago, IL
NTS - San Bernardino, CA
TÜV Rheinland of North America - Newtown, CT
TÜV Rheinland of North America - Pleasanton, CA
TÜV Rheinland of North America - Santa Clara, CA
TÜV Rheinland of North America - Webster, NY
TÜV Rheinland of North America - Youngsville, NC
TÜV SÜD America - Alpharetta, GA
TÜV SÜD America - Auburn Hills, MI
TÜV SÜD America - Holland, MI
TÜV SÜD America - New Brighton, MN
TÜV SÜD America - Rancho Bernardo, CA

TÜV SÜD America - Tampa, FL
TÜV SÜD America Inc. - Headquarters Peabody, MA
TÜV SÜD America Inc. - San Diego, CA
TÜV SÜD America- Fremont, CA
TÜV SÜD America- Plymouth, MI
TÜV SÜD America- Portland, OR
TÜV SÜD Canada - Gormley, ON
TÜV SÜD Canada - Newmarket, ON
UL - Fremont, CA
UL - India
UL - Italy
UL - Japan Inc. (Yokawa EMC Laboratory)
UL - Japan, Inc. (Ise Head Office)
UL - Japan, Inc. (Shonan EMC Laboratory)
UL - Japan, Inc. (Yamakita)
UL - Korea Ltd.
UL - New Zealand
UL - Novi, MI
UL - Research Triangle Park, NC
UL - UK (Ashwood Park)
UL - UK (Kingsland Park)
UL LLC

Telecommunications Testing

Cascade TEK - Colorado
Cascade TEK - Oregon Pacific Northwest
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