JANUARY 2024

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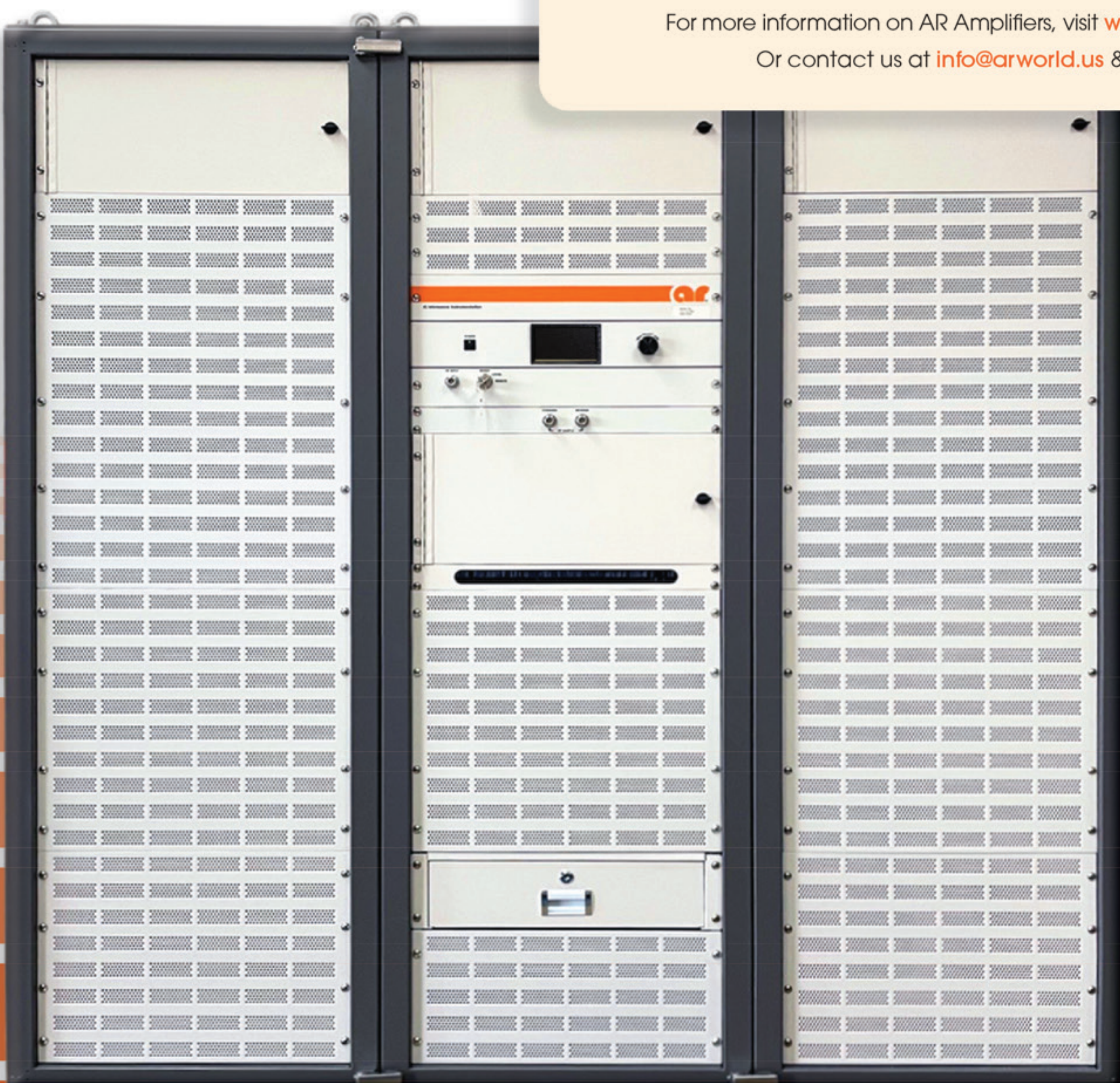

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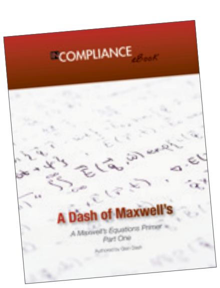

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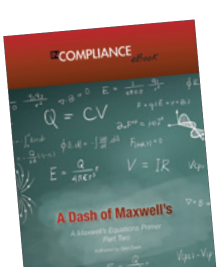

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FCC Launches Inquiry Into AI-Based Robocalls/Texts

The U.S. Federal Communications Commission (FCC) has voted to initiate a formal inquiry into how the use of artificial intelligence (AI) may impact illegal and unwanted robocalls and robotexts.

The FCC's Notice of Inquiry is an effort on the part of the Commission to gather information about how AI and AI-influenced technology will impact calling and texting processes and the extent to which such impacts may or may not compromise consumer privacy rights under the Telephone Consumer Protection Act (TCPA). Specific areas of inquiry include defining AI, detailing the current use of AI in calling and texting technologies, and discussing the potential impact of emerging AI technologies on consumer rights.

The FCC's inquiry into the impact of AI on robocalls is part of a larger effort by the Commission to fully explore and understand the opportunities and challenges posed by AI and machine learning to communications networks.

FCC "Modernizes" Amateur Radio Service Rules

The U.S. Federal Communications Commission (FCC) has adopted new rules that eliminate transmission rate limitations currently applicable in certain amateur radio bands.

According to a Report and Order issued by the Commission, the new rules replace limitations on the so-called baud rate applicable to data emissions in specific bands, establishing instead a 2.8 kHz bandwidth limitation. The Commission says that the changes are consistent with its treatment of other wireless radio services and will facilitate more efficient operations of amateur radio transmissions, especially in support of emergency response communications.

The action by the FCC won a prompt endorsement by the ARRL, the National Association for Amateur Radio, which acknowledges that the rule changes will also incentivize future innovation and experimentation in amateur radio bands by giving users the flexibility to use modern digital emissions.

Concurrently, the FCC also adopted a Further Notice of Proposed Rulemaking, seeking comment on a proposal to remove the current baud rate limitations on the VHF and UHF bands and in the 2200-meter and 630-meter bands, as well as recommendations on appropriate limitations in those bandwidths.

FCC Issues Proposed Rules to Prevent Digital Discrimination

As expected, the U.S. Federal Communications Commission (FCC) has implemented new rules that it says will help to prevent and eliminate discrimination in public access to broadband services.

The Commission provided details on its new rules in an extensive November Report and Order running more than 230 pages in length. In brief, the new rules:

- Directly address companies' policies and practices if they differentially impact consumers' access to broadband internet access service or are intended to do so;
- Apply these protections to ensure communities see equitable broadband deployment, network upgrades, and maintenance;
- Investigate possible instances of discrimination of broadband access, work to solve and, when necessary, penalize companies for failing to meet the obligations defined in the rules;
- Review consumer complaints of digital discrimination through an improved consumer complaint portal; and
- Help protect both current and prospective subscribers to a broadband internet service.

The Report and Order also includes several in-depth appendices providing detailed background on the Commission's position, along with lengthy statements by each of the FCC Commissioners regarding the new rules.

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Decoding the Invention of the Radio

An article explores the contributions of Marconi and other notable scientists in the evolutions of radio technologies

Most historians attribute the invention of radio technology to Guglielmo Marconi, an electrical engineer whose pioneering work in the late 19th century led to the creation of a wireless telegraph system and resulted in his being named a co-winner of the 1909 Nobel Prize in Physics.

But, like most things, the story behind the invention of radio technology is far more complex and reflects the contributions of other notable scientists, including James Maxwell, Nikola Tesla, and Alexander Popov. An interesting article recently published on the "Truth or Fiction" website, titled "Decoding the Invention of the Radio: A Scientific Retrospection," details the contributions of Maxwell, Tesla, Popov, and others in the development and evolution of modern radio technology.

The article gives due credit to Marconi, whose initial efforts to develop a wireless system to transmit Morse Code soon expanded to experiments involving voice transmissions. But it also acknowledges the work and the contributions of a number of other scientists and researchers, who worked tirelessly over the ensuing 100-plus years to perfect wireless radio communications technology, making it essential to all types of communications technologies in the 21st Century.

FUNDAMENTALS OF ELECTROMAGNETIC COMPLIANCE

A Practical Overview

Christopher Hare is a technical marketing engineer at Coilcraft. He received his Bachelor of Science degree in Physics from Northern Illinois University in 1986 and has been applying his long-developed understanding of physics, engineering, and marketing in various fields ever since. Hare can be reached at tech_support@coilcraft.com.

By Christopher Hare

Everyone enjoys the advantages of electronic devices and gadgets becoming smaller, lighter, and faster while providing longer battery life and ever-improving processing ability. Smaller devices require smaller electronic components — an advantage in reducing electromagnetic interference (EMI). However, a compact design also means smaller spacing between components, circuit traces, and enclosures, which can lead to increased field interactions, current loops, ground loops, crosstalk, and other potential sources of EMI.

We benefit from the convenience of televisions, cell phones, digital tablets, notebook computers, and IoT devices, all operating at the same time while appliance motors, lights, fans, and HVAC units are operating in the background to keep us comfortable. With multiple electrical and wireless electronic devices operating at the same time, signals must remain reliable in electromagnetically noisy environments.

The rapid growth of the electric vehicle (EV) and hybrid electric vehicle (HEV) market raises new electromagnetic compatibility (EMC) concerns as high-voltage batteries and chargers see increased use. High-voltage and high-frequency automotive electronics, if not properly designed, can lead to EMC compliance headaches. Focusing on design techniques that mitigate EMI will help ensure a low-emissions outcome.

High levels of electromagnetic (EM) noise lead to EMI, which is any undesired electrical disturbance (noise) that interferes with other circuits. Electromagnetic emissions occur when electrical or electronic equipment radiates or conducts EM noise that interferes with other devices. Electromagnetic compatibility is the ability of electronic equipment to function properly without interference from noise sources (immunity/susceptibility) and without causing disturbances to other electronic equipment (emissions). EMC is verified by testing in accordance with industry standards developed by regulating agencies described later in this discussion. These standards define specific test conditions and limits of noise emissions that may vary by location, application, and operating environment.

NOISE SOURCES

Noise might be of a transient or discontinuous nature, or it might be generated continuously. Potential sources of transient or discontinuous conducted emissions include automatic switches, temperature controllers, appliance controllers, other automatic controllers, motor controllers, and any other non-constant or event-driven on/off switching of voltage. Potential sources of continuously conducted emissions include electric motors, unshielded or poorly shielded data lines, switch-mode power converters, and any other constant steady-state switching of voltage. Improperly designed PCBs with power and signal areas too close together or having insufficient filtering can result in transient or steady-state conducted emissions.

MODES OF ELECTRICAL NOISE PROPAGATION

Noise is generally discussed as being either radiated or conducted. The solution to any noise problem requires identifying and understanding the nature of the noise. This can be complicated by the interaction between radiating and conducting modes. After all, any conducted electricity has the potential to generate radiating fields, and likewise, fields can cause electrical signals.

Designing and testing for EMC involves understanding how electric fields (E-fields) and magnetic fields (B-fields) propagate and interact. A fundamental understanding of antenna theory provides insights into how the size and design of electronic components, PCB traces, pads, and grounds relate to various frequencies and their associated wavelengths. Understanding the modes of electrical noise propagation and the methods of testing for EMC leads to design solutions that greatly improve the probability of passing EMC compliance tests in the earliest stages. Failing to design for EMC often results in expensive redesigns and PCB re-spins.

CONDUCTED EMISSIONS

Electrical noise can be transferred to "victim" equipment by field-coupling from source "aggressor" equipment through conducting input lines, cables, connectors, or traces to the equipment circuits. This mode of noise propagation and its effects on power quality are referred to as conducted emissions. Conducted emissions can be conducted directly into the circuit on the input lines, or they can be near-field energy that is capacitively coupled (E-field) or magnetically coupled (B-field) to a circuit unintentionally. Because conducted emissions may involve capacitively- or magnetically-coupled fields, they are essentially reactive (non-radiative) near-field effects that can generally be modeled using lumped resistive, inductive, and capacitive (RLC) elements. Conducted emissions are typically measured in the 150 kHz to 30 MHz frequency range.

DIFFERENTIAL AND COMMON MODE NOISE

Conducted emissions consist of differential mode (DM) currents and common mode (CM) currents. The dominant mode depends on the source of the noise. Differential mode noise currents are superimposed on the intended current that powers the circuit, traveling in a loop from the power source, through the circuit, and returning to ground or the intended source return node for non-grounded circuits.

DM currents include the typically lower-frequency desired fundamental signal and any higher-frequency harmonics. In some circuits, the fundamental frequency plus harmonics make up the desired waveform (AC), such as sine waves, square waves, or triangular waves. In others, the main current is DC, and the AC portion is noise to be filtered out. The cutoff frequency of a low-pass filter inductor, choke, or LC filter must be designed to filter out the high-frequency noise without significantly attenuating the intended signal.

CM currents travel in the same direction through one or more conductors toward a common return point that closes the current loop (e.g., ground). When the return path is not intentional, the CM current may be the result of energy capacitively or magnetically coupled to the common point. Common mode chokes are designed to create high impedance to such CM noise (Figure 1) while presenting low impedance to the desired differential signal.

RADIATED EMISSIONS

Near-field and far-field are terms associated with antennas. Why mention antennas in an EMC discussion? Unintentional transmitters are circuit elements that unintentionally radiate or scatter radiation. These are, in effect, "antennas" that were not intentionally designed to transmit energy. Unintentional transmitters cause radiated emissions, that is, electromagnetic noise propagated through the air that is received by other parts of the circuit or other devices.

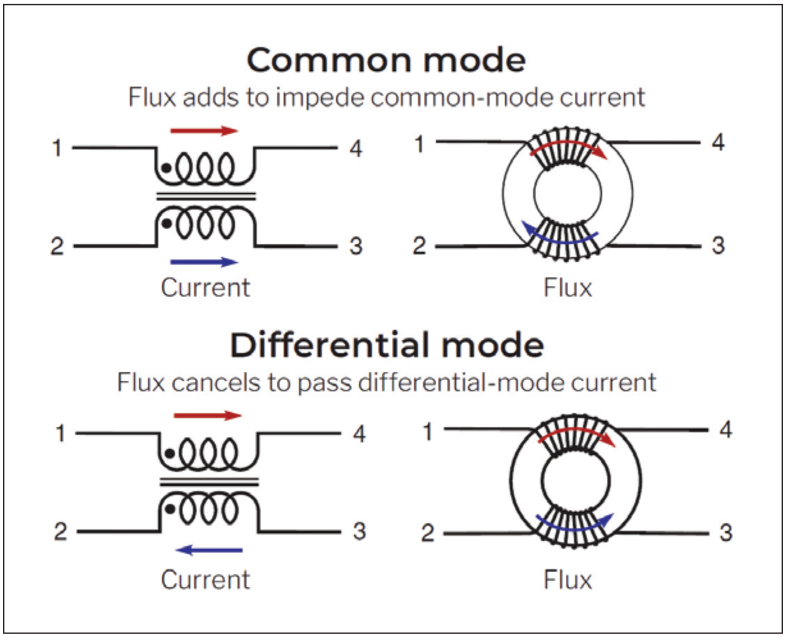

Figure 1: Common mode chokes create high impedance to CM noise (Source, Coilcraft)

Radiated emissions are essentially far-field at approximately two or more wavelengths distance from the source. The maximum dimension of an optimized antenna is about 1/4 wavelength of the intended signal being transmitted or received. When the size of an unintentional circuit transmitter, such as a PCB trace cable or slot behaving as an antenna, approaches about 4x the wavelength, the transmitted high-frequency energy can be modeled by distributed (transmission line) elements.

Wavelength and frequency have an inverse relationship. Therefore, at higher frequencies in which the corresponding wavelength approaches about 1/4 of the size of the unintended antenna or smaller, radiated emissions can be expected. Consequently, radiated emissions are tested at higher frequencies than conducted emissions, typically in the 30 MHz to 1 GHz range.

Potential sources of radiated emissions include switched wireless devices, IoT devices, radios, switching power supplies, electric motors, digital signal data lines, communications devices, motor drives, and any unshielded or radiating source with ineffective shielding. Some of these are also included as sources of conducted emissions because they can interact both on power cables and data lines as well as via radiation over the air.

EMC COMPLIANCE AGENCIES AND TEST METHODS

Following is a brief overview of EMC compliance agencies, test setups, methods, and standards. It also includes design hints for mitigating EMI and tips for EMC test troubleshooting.

EMC standards define specific test equipment, test set-ups, and pass/fail limits. EMC standards generally set limits on both peak (or quasi-peak) and average

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emissions levels vs. frequency range for the appropriate classification of the measured device. The equipment designed for measuring these levels is defined within the applicable product standard or within the referenced basic standard. EMC standards are continually under review due to new product types and applications. Therefore, the latest approved standard should be applied in any EMC test plan.

Figure 2 shows the test limits for FCC Part 15 (radio frequency devices) Subpart B radiated emissions limits for frequencies greater than 1 GHz for average measured values at 3 m and 10 m distances. Figure 3 shows the same for measured quasi-peak values.

Quasi-peak measurements apply a weighting factor based on the repetition frequency of the spectral components of the signal. Even if the emission is over a test limit when measured with peak detection, it can pass if the quasi-peak level is below the limit. For this standard, one must meet the limits for both average and quasi-peak measurements. Quasi-peak measurements require more time than peak measurements. If initial (faster) peak measurements pass, they will pass quasi-peak testing, and the slower quasi-peak test is not needed.

Basic EMC publications include definitions of terms and specific test set-ups and equipment requirements, such as those for line impedance stabilization networks (LISN) that stabilize the impedance of the source and provide isolation of the test equipment and circuit under test. EMC product standards and EMC product family standards refer to specific products and categories of products, while generic EMC standards apply where specific product or family categories do not exist. Product, product family, and generic EMC standards reference the more fundamental basic EMC standards.

Selecting appropriate EMC standards can be confusing, requiring a clear indication of the product category and markets, whether local, international, or both. Consulting an accredited EMC test laboratory can save much time and effort in determining the appropriate test standards and requirements for general or specific products and applications.

The following are the major EMC regulation agencies and examples of some of their basic product, product family, and generic standards currently in effect.

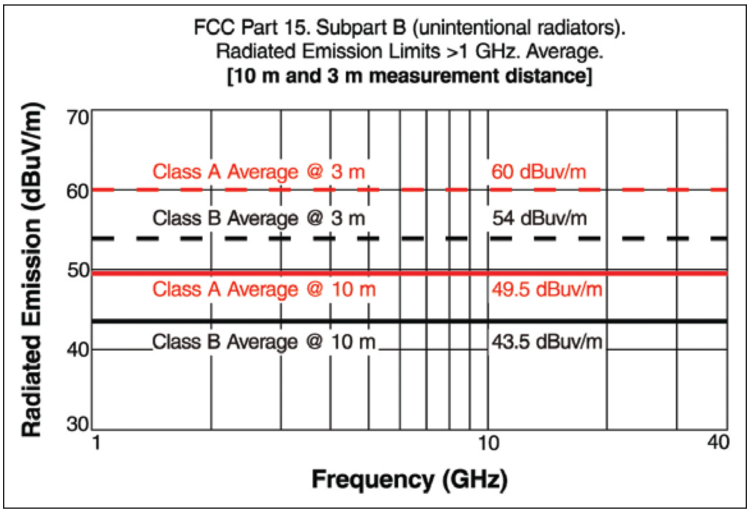

Figure 2: FCC Part 15, Subpart B, Radiation Emissions Limits > 1GHz - Average

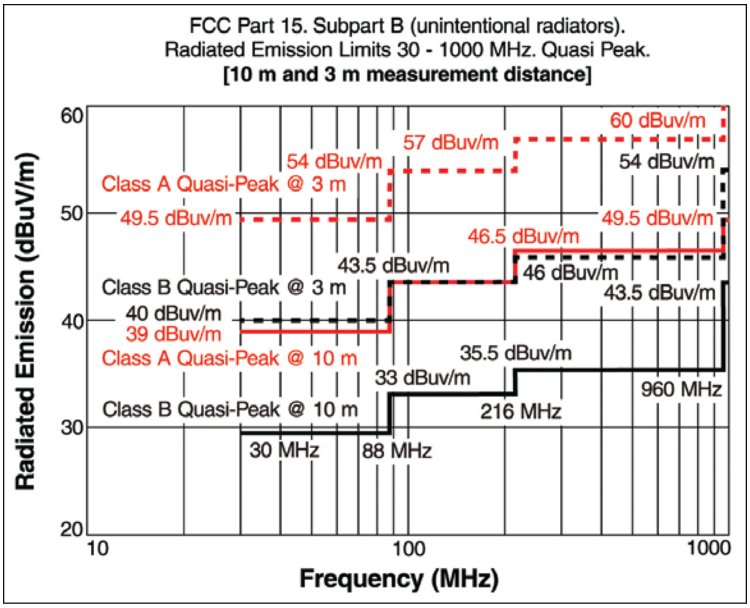

Figure 3: FCC Part 15, Subpart B, Radiation Emissions Limits 30 – 1000 MHz – Quasi-Peak

Major U.S. and Global EMC Regulating Agencies

The major regulating agencies that publish EMC standards include:

- FCC — Federal Communications Commission (USA / North America): Products designed for North American markets are generally tested to the basic compliance limits of the Federal Communications Commission (FCC) Part 15.
- IEC — International Electrotechnical Commission (International)
- CISPR — Comité International Spécial des Perturbations Radioélectriques (International): CISPR is part of the IEC.

Basic EMC Standards

The major basic EMC standards cover a wide range of devices and include:

- FCC Title 47 Part 15 — *Radio Frequency Devices* is a basic standard in the U.S. Under this standard, Class A digital devices are generally marketed for use in commercial, industrial, or business environments. Class B digital devices are generally marketed for residential environments but can include commercial, industrial, or business environments. Class B requirements are more stringent. Therefore, Class B devices can be used in Class A environments.
- IEC 61000 Series, Parts 1, 2, 4, 5, 6, and 9 define basic terminology, test and measurement methods, and installation and EMI mitigation guidelines.
- IEC 61000-3—The European (international) Standard for all electrical and electronic equipment that is connected to the public mains up to and including 16 A max.
- CISPR 16 — Defines measuring apparatus and methods for radio disturbance and immunity testing from 9 kHz to 1 GHz.

Product EMC Standards

Product EMC standards apply to specific products, such as electric vehicle conductive charging systems, power electronic converter systems, cables and connectors, or medical electrical equipment.

Examples of product-specific EMC standards include:

- IEC 61851-21 — *Electric vehicle conductive charging system – Part 21: Electric vehicle requirements for conductive connection to an AC/DC supply*

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- CS114 Bulk Cable Injection Conducted Susceptibility Test System **CST-CS114**
- CS115 Bulk Cable Injection Impulse Excitation Conducted Susceptibility Test System **TPS-CS115**
- CS116 Cables and Power Leads Damped Sinusoidal Transients Conducted Susceptibility **DOS-CS116**
- CS118 Personal Borne Electrostatic Discharge Test Equipment **EDS 30T**

Standard in compliant with: MIL-STD-461 CS106，CS114，CS115，CS116，CS118

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- IEC 62477-1 — *Safety requirements for power electronic converter systems and equipment – Part 1: General*
- IEC 61726 — *Cable assemblies, cables, connectors and passive microwave components – Screening attenuation measurement by the reverberation chamber method*
- IEC 60601-1-2 — *Medical electrical equipment – Part 1-2: General requirements for basic safety and essential performance – Collateral standard: Electromagnetic compatibility – Requirements and tests*

Product Family EMC Standards

Product family EMC standards apply to wider general product categories, such as vehicles, information technology equipment, and industrial, scientific, and medical equipment.

Examples of product CISPR EMC standards include:

- CISPR 25 — *Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers*. This is the go-to standard for automotive applications.
- CISPR 22 — *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement – High frequency conducted emissions standard*
- CISPR 11 — *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement – High frequency conducted emissions standard*
- CISPR 15 — *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*

Generic EMC Standards

Generic EMC standards are grouped as either residential, commercial and light industrial, or industrial. Industrial includes higher-power industrial and scientific and medical equipment. When a specific EMC standard does not exist for new products, a simplified generic EMC standard may be invoked. As with other product standards, they may refer to basic EMC standards for specific test methods.

Generic EMC standards examples include:

- IEC 61000-6-3 — *Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments*
- IEC 61000-6-4 — *Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments*

Designing to Mitigate EMI

Because higher-frequency harmonics are considered noise in conducted emissions testing, low-pass filters are purposely designed into electronic equipment to reduce this high-frequency noise to below the defined limits of the conducted emissions test. Series inductors and capacitors between line and neutral lines, such as X-caps between the power and neutral lines, are employed to reduce the high-frequency DM currents. Common mode chokes and Y-caps between the lines and chassis ground are used to reduce the CM noise.

When the source includes significant conducted noise, as with switching power supplies, additional elements may be needed to create higher-order LC filters that further reduce the DM and CM noise. Some good news is that the use of small surface mount (leadless) components reduces connection inductance and the length of traces that may contribute to higher EMI.

DESIGN HINTS FOR PASSING EMC PRE-COMPLIANCE AND COMPLIANCE TESTS

These design hints for passing EMC pre-compliance and compliance testing do not comprise an exhaustive list. However, following these guidelines will help ensure minimal generation of EMI.

1. Minimize the length of circuit traces to avoid making unintentional emitters/antennas. This is listed as #1 because it is most critical in preventing EMI. Minimizing trace length decreases the total stored reactive energy of the trace and reduces ringing due to parasitic inductance. This is especially critical in switched power converters.
2. Consider EMC in the earliest stages of the design process. It can save considerable time and help prevent time-consuming PCB redesigns.
3. Use simulation programs to design and simulate noise filters and use real measurements to verify them. Even accurate models may not fully capture some important parasitic interactions.
4. Use magnetically shielded inductors to minimize B field coupling unless your design

requires purposeful interaction with the inductor field (e.g., NFMI or RFID). Magnetic shielding is created by surrounding the inductor with a high-permeability, low-reluctance material (e.g., ferrite), creating a "closed" magnetic path. The purpose of magnetic shielding is to reduce the amount of magnetic flux generated outside the inductor, in turn reducing the likelihood of radiating energy to nearby components or circuit board traces, causing electromagnetic interference.

5. Avoid electrically conducting (metal) materials directly above, next to, or below inductors or high-frequency switches (e.g., switched power converters). When this can't be avoided, use raised inductors to increase the distance between the inductor and the conductors below.
6. Place the start winding of inductors closest to the high dv/dt side of switches.
7. Maintain spacing between components, generally 1.5x the largest x-y dimension.
8. Avoid or slow down sharp rising-edge and falling-edge waveforms (slew rate control). This can lead to reduced efficiency, so there are trade-offs and a balance must be struck.
9. Route clock lines and other high-speed traces away from power sources.
10. Avoid running high-speed lines across gaps in return lines.
11. Consider ground loops or return paths of reference planes as potential EMI sources.
12. Avoid discontinuous signal return paths, e.g., gaps in ground planes.
13. Utilize filtering or shielding to block coupling paths from energy sources.

Even the best design simulations can miss unanticipated field or wave interactions. Some failures may be unavoidable, but many are due to preventable design oversights.

14. Engage filter reference designs with proven performance and save design time.
15. A single pole (L or C) filter provides -20 dB/decade of frequency filtering. A two-pole (LC) filter has a more rapid attenuation rate of -40 dB/decade. A three-pole filter (e.g., LCL) gives -60 dB/decade attenuation. Therefore, a sharp cutoff frequency requires a high-order filter.
16. Consider spread-spectrum control methods to spread noise energy to lower levels over a range of frequencies.
17. Slope compensation requires a certain level of ripple current to maintain stability. If the ripple is too high, it can cause EMI. When using slope compensation, check that the ripple current is not a source of EMI.

EMC FILTER SIMULATIONS

Computer programs for designing noise filters speed up the design and analysis phase of electronic product development. Free programs are useful for designing and verifying the performance of LC filters. Physics-based three-dimensional EM (3D EM) simulation programs that use more advanced computational solver methods, such as FEM, FDTD, and MoM, are higher-priced and require more advanced knowledge. However, these advanced solver programs provide more geometry- and materials-related insights when attempting to understand EM field interactions.

COST-FREE PASSIVE COMPONENT FILTER SIMULATION PROGRAMS

There are no-cost programs available to help engineers design and simulate lumped-element filters and their effects on circuit behavior. It typically takes much less time to model and simulate a proposed circuit than to build and test the physical circuit, especially when performing "What if?" analyses that involve many iterations. Thus, SPICE-based and other circuit design and synthesis simulation programs provide fast insights while saving time in the initial stages of design and analysis.

3D ELECTROMAGNETIC SIMULATIONS

The major advanced 3-dimensional electromagnetic (3D EM) programs for simulating printed circuit boards (PCBs), electronic components, and circuits include Ansys - HFSS, AWR Axiem/Analyst, CST Studio Simulia, and Cadence Clarity. These programs use physical models that include materials and geometry details and advanced computational techniques for a better understanding of the effects of materials and spacings at various operating conditions.

PRE-COMPLIANCE TESTING

Even the best design simulations can miss unanticipated field or wave interactions. Intertek Testing Services NA, Inc., an accredited EMC test lab, has found that about 50% of EMC tests fail on the first try (note 5). Some failures may be unavoidable, but many are due to preventable design oversights, such as failure to apply EMC principles or to simulate predictable interactions between circuit components. Pre-compliance testing allows engineers to pre-verify EMC standard compliance so that no such surprises delay the release of a product due to necessary re-designs. When un-predicted EM noise is made visible by pre-compliance testing, there are methods that can be employed to identify the source and remediate the problem.

TIPS FOR EMC TEST TROUBLESHOOTING

1. Use E-field and B-field probes to locate sources of EMI on a PCB.
2. If inductors or capacitors are suspected, rotate inductors by 180 degrees and place nearby inductors and capacitors 90 degrees to each other.

If available, replace inductors that have side terminations with bottom-terminated inductors.

3. Use a spectrum analyzer to determine the frequency range and amplitude of noise sources.
4. Set the resolution bandwidth of the spectrum analyzer to that specified in the applicable emission standard.
5. Slower voltage rise times create higher-order harmonics of lower magnitude, and faster rise times lead to higher-magnitude, higher-order harmonics.
6. Lower duty cycle leads to lower-magnitude, higher-order harmonics, and higher duty cycle leads to higher-magnitude, higher-order harmonics.
7. Determine whether the noise is DM or CM. If the noise is suspected to be CM, select a CM choke for the offending frequencies. If the noise is reduced, the noise is CM (unless the choke is a combination choke). If the noise is not reduced, it is more likely DM noise.
8. If changing EMI filter components does not change the EMC test results, this points to a possible PCB layout issue.
9. A combination of too many circuit elements can lead to resonances that amplify unwanted harmonics. In such cases, removing a component, such as a capacitor, may improve EMC test results. This may seem counterintuitive. However, sometimes more is not better.
10. Is ringing in your switched mode power supply switching edges causing EMI? Use a simulation program to design an RC snubber circuit to reduce the ringing. Higher resistance dampens the ringing but can affect efficiency, so use simulation to optimize the trade-offs.

The continual increased use of electronics and electrical products has led to an environment filled with many signal and noise sources over a wide range of frequencies.

11. If the source issue is a strong E-field, a metal "Faraday cage" shield connected to ground provides a closed field path that shunts noise to ground.
12. Wrap thin copper completely around a noisy transformer and connect the copper to ground to create a Faraday cage shield.
13. Use copper tape in closed loops to create prototype shielding. Test with and without the shielding to determine whether it is needed.
14. Review the design hints above for additional insights into possible solutions.

CONCLUSION

The continual increased use of electronics and electrical products has led to an environment filled with many signal and noise sources over a wide range of frequencies. Understanding how fields interact to create intentional and unintended transmitters and receivers and applying EMI mitigation techniques when designing and testing can lead to positive outcomes in electromagnetic compliance testing.

DEFINITIONS AND TERMINOLOGY

CISPR — Comité International Spécial des Perturbations Radioélectriques

Common mode current (noise) involves currents flowing in the same direction to circuit ground at higher frequencies. It is also called asymmetrical or longitudinal current.

Conducted emissions are unintentionally conducted, capacitively coupled (E-field), or magnetically coupled (B-field) to the circuit. They are typically measured in the 150 kHz to 30 MHz frequency range.

Crosstalk occurs when a high-frequency (e.g., clock) signal couples into nearby analog circuits.

Differential mode (normal) noise involves currents flowing in opposite directions at lower frequencies, also called symmetrical or transverse current.

Electromagnetic (EM) field — A field of force that consists of both electric and magnetic components, resulting from the motion of an electric charge and containing a definite amount of electromagnetic energy.

Electromagnetic (EM) noise, a.k.a. electrical noise, is any unwanted electrical disturbance, not necessarily in the audible frequency range (audible noise).

EM emissions occur when equipment radiates or conducts electromagnetic noise.

EM immunity is the ability of the equipment to withstand outside sources of EM noise without adversely affecting functionality.

EM susceptibility is the sensitivity of equipment to function within an environment of EM noise.

An *aggressor* is equipment that emits EM noise. Aggressors conduct or radiate EM emissions.

A *victim* is equipment that is adversely affected by EM noise. Victims are susceptible to EM emissions.

EMC is *electromagnetic compatibility*. EMC is verified by testing to industry global and local standards.

EMI is *electromagnetic interference.* If EMI exists at a level that exceeds the applicable EMC testing standards, the equipment is not EMC-compliant.

Far-field — Involving a distance from the source in which the distributed element models are needed for high-accuracy far-field simulations. The transition from near-field to far-field exists at about 1/6 the wavelength of the signal (or noise).

FCC — Federal Communications Commission (U.S.)

FCC Title 47 Part 15 — Radio Frequency Devices is a basic EMC standard in the U.S. applicable to electromagnetic energy at any frequency in the radio frequency (RF) spectrum between 9 kHz and 3 GHz.

FDTD — Finite difference time domain - A powerful method of solving Maxwell's equations directly without requiring physical approximations.

FEM — Finite element method - An advanced method of numerically solving differential equations that, for example, define physical relationships over a geometric space.

IEC — International Electrotechnical Commission Intentional transmitters (antennas) purposely transmit EM waves for wireless charging and communications.

LISN — Line impedance stabilization network - Pi filter networks that stabilize the impedance of the test source and provide isolation of the test equipment and circuit under test.

MoM — Method of moments - Efficient full-wave numerical technique for solving open-boundary electromagnetic problems.

Near-field — Involving capacitively-coupled E fields or magnetically-coupled B fields. Lumped element models can be sufficient for near-field simulations.

Radiated emissions are the result of unintentional current loop paths that radiate EM noise from the circuit. They are typically measured in the 30 MHz to 1 GHz frequency range.

SMPS — Switched mode power supply (switching converter).

Unintentional radiator — A device that intentionally generates radio frequency energy for use within the device or that sends radio frequency signals by conduction to associated equipment via connecting wiring but which is not intended to emit RF energy by radiation or induction.

Unintentional transmitters unintentionally transmit EM waves as noise. The FCC defines this as an "incidental radiator" - A device that generates radio frequency energy during the course of its operation, although the device is not intentionally designed to generate or emit radio frequency energy.

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IT SERVER HARDWARE COMPLIANCE, PART 2

A Detailed Overview of Testing Requirements for Mainframes and Servers

This two-part series of articles focuses on hardware compliance aspects of specific information technology electronics equipment, which includes mainframes, server computers, and subcomponents. The goal of this series is to provide our readers with a better understanding of the requirements for executing hardware compliance testing and certification, as well as the technical details of every compliance discipline.

In Part 1 of this series (see *In Compliance Magazine*, December 2023), we provided a technical overview of server components and subcomponents and discussed specifics regarding product safety regulations and testing. Part 2 of this series will address additional areas of regulatory compliance, including electromagnetic compatibility and environmental concerns. We'll also discuss how IT equipment is tested and certified to compliance standards for worldwide shipments.

TESTING FOR ELECTROMAGNETIC COMPATIBILITY COMPLIANCE

EMC (electromagnetic compatibility) testing is a critical component of hardware compliance testing that evaluates a product's ability to function correctly in the presence of electromagnetic interference and to emit low levels of electromagnetic emissions.

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By John Werner, Rebecca Morones, and Arkadiy Tsfasman

This testing is necessary because information technology (IT) equipment, such as servers and server subcomponents, generates electromagnetic radiation and can be susceptible to interference from other devices and sources of electromagnetic radiation. The goal of EMC testing is to ensure that a product can operate without interfering with other devices and without being adversely affected by other devices or sources of electromagnetic radiation in the surrounding environment.

Applicable Standards

Servers and their subcomponents are subject to meeting the requirements detailed in multiple standards. As of the writing of this article, a product being certified (either the server or a subcomponent) typically needs to meet Federal Communications Commission (FCC) regulations in the United States, the Conformité Européene (CE) marking requirements in the European Union (EU), and standards of the International Special Committee on Radio Interference (CISPR). The product must also meet country-specific deviations of applicable standards to facilitate worldwide distribution and support. Finally, some companies require compliance with even more rigorous standards in addition to those already mentioned.

To ensure compliance with all the standards, a superset of worst-case test limits is utilized for each test case. If the worst-case limits are met, it can be safely assumed that the server or subcomponent meets all the requirements. Failure to meet these standards can result in interference with other electronic devices and legal consequences for manufacturers.

Types of EMC Testing

EMC testing typically involves two types of tests, emissions testing and immunity testing. In general, emissions testing measures the amount of electromagnetic radiation that a product emits when it is operating and includes radiated emissions testing, conducted emissions testing, and power line harmonics testing.

Immunity testing measures the product's ability to function correctly in the presence of electromagnetic interference. Immunity testing involves exposing the product to various sources of electromagnetic radiation while monitoring its performance. Immunity testing includes electrostatic discharge (ESD) testing, radiated RF electromagnetic field immunity (RES) testing, electrical fast transient (EFT) testing, surge testing, conducted immunity testing, power frequency magnetic field testing, voltage dip testing, and voltage interruption testing.

The work of EMC compliance begins during the product development stage of the server. Because of the cost and schedule impacts of releasing new hardware, it is up to the EMC engineer to attend design meetings, review both electrical and mechanical designs as early in the process as possible, and provide feedback for design improvements that will ensure that the final design passes all the requirements of the standards.

Some of the early work includes reviewing electrical schematics to assess wiring and other criteria, such as electrical filtering. Printed circuit board (PCB) layouts are reviewed to ensure critical nets do not cross splits in adjacent reference planes, return current vias are present near layer transition vias, critical nets are not too close to the edge of a reference plane or another critical net, power and ground traces have adequate width for current carrying capacity, and decoupling capacitor density and placement is sufficient.

The EMC boundary is evaluated early on 3D mechanical CAD models to ensure that there are no openings or seams that could radiate or become susceptibility concerns during immunity testing. Shielding effectiveness testing is performed on early mechanically good hardware in a reverb chamber, as shown in Figure 7.

This early-stage hardware does not have any functional electronics inside. So, to perform the testing, the reverb chamber is filled with energy, and a broadband loop antenna is placed inside the drawer to see what energy is able to make its way inside. Copper tape is used to cover openings and seams to view the impact on the overall shielding and to determine where design improvements can be made.

There are many configurations offered for each server or server subcomponent. Customers can choose a desired I/O configuration, memory configuration, processor configuration, and many other options that will result in different components being installed in their system. When hardware is available for the final EMC test, it is important that the correct configuration is selected.

Selecting a configuration for EMC testing requires consideration of multiple factors to satisfy different worldwide countries' requirements. The first consideration is to account for the typical/average client configuration, which is known from previous sales and projections. Second, every I/O card must be included up to the maximum quantity of the system if not covered by the typical/average configuration. If multiple vendors are supported for certain subcomponents, it must be ensured that hardware from each of those vendors is included in the configuration.

Radiated Emissions Testing

EMC radiated emissions testing serves the purpose of determining the level of unintentional electromagnetic radiation emitted by electronic devices. These emissions,

Figure 7: Shielding effectiveness testing in EMC reverb chamber

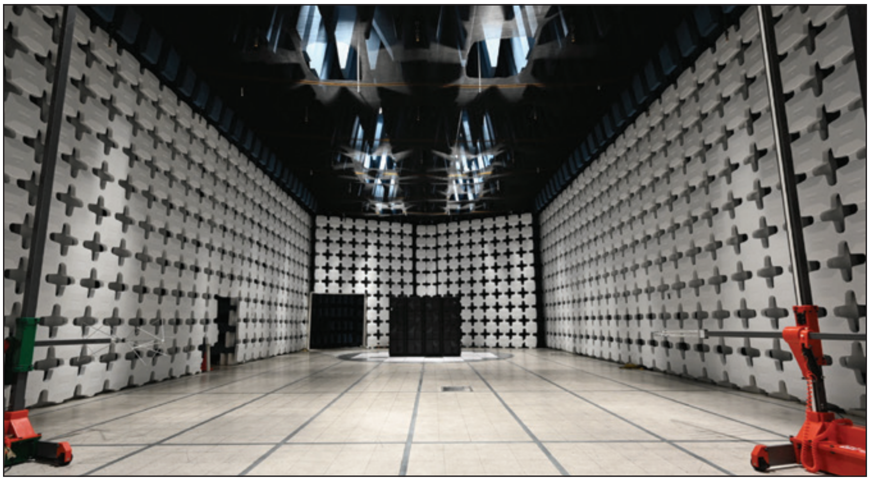

Figure 8: Radiated emissions test

if not controlled, can interfere with the proper functioning of other devices in the vicinity, leading to potential malfunctions or performance degradation. Emissions are tested across a broad frequency range of 30MHz to 40GHz to quantify the emitted electromagnetic energy and to compare it against the permissible limits defined by regulatory bodies. Testing is performed in a semi-anechoic chamber, as shown in Figure 8. The server is rotated 360 degrees on a turntable, and antennas are moved up and down from 1 to 4 meters and are positioned up to 10 meters away.

Conducted Emissions Testing

Conducted emissions testing is a process used to evaluate the level of unintentional electromagnetic radiation conducted through power and signal cables. Conducted emissions can interfere with the proper functioning of nearby electronic equipment, leading to performance issues, malfunctions, or data corruption. Impedance stabilization networks (ISNs) are used to capture and analyze the conducted emissions. The emissions generated by the server or server subcomponent are measured and analyzed over a frequency range from 150KHz to 30MHz while the device is operating.

Power Line Harmonics Testing

Power line harmonics testing is a process used to evaluate the harmonic distortion produced by electrical devices and systems when connected to the power grid. Harmonic distortion can result in several issues, including power quality problems, increased power losses, and interference with other equipment sharing the same power supply.

The objective of power line harmonics testing is to assess the level of harmonic distortion generated by the server or server subcomponent and to ensure compliance with regulatory standards and guidelines. Power analyzers are used to capture voltage and current waveforms, and harmonic analysis is performed to determine the harmonic content present in the system. The measured harmonic data is then analyzed to assess compliance with regulatory standards and guidelines.

ESD Testing

ESD testing is a process used to evaluate the susceptibility or resistance of the server and server subcomponents to electrostatic discharges. ESD occurs when two objects with different electrical potentials come into contact or close proximity with each other, resulting in the rapid transfer of an electric charge. ESD events can potentially damage or affect the functionality and reliability of electronic devices. The objective of ESD testing is to ensure that the server and server subcomponents can withstand and operate reliably in environments where ESD events may occur, such as in manufacturing, servicing, or normal usage scenarios.

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To perform the testing, an ESD simulator is used to generate and apply both air and contact electrostatic discharges to locations likely to be touched at varying energy levels up to 8kV. Discharges are applied to each test point 25 times for air discharges and 1000 times for contact discharges to ensure the system is tested at different operating points as the system is exercised.

The objective of EMC RES testing is to ensure that the server and server subcomponents can withstand and operate reliably in their intended environments, which may be subjected to various electromagnetic sources such as radio frequency (RF) signals, electrical transients, electrostatic discharges, or conducted disturbances. These disturbances can originate from nearby electronic devices, power lines, communication networks, or other external sources.

Signal generators, power amplifiers, and antennas are used to generate and apply the electromagnetic fields to the server and server subcomponents in the range of 80MHz to 5GHz while operating under typical conditions. The fields may vary in frequency, amplitude, modulation, and duration, simulating real-world electromagnetic disturbances. Performance and behavior are observed and monitored during the exposure. Any malfunctions, deviations from expected behavior, or degradation of performance are noted and analyzed. The data is compared with specified acceptance criteria or relevant standards to determine resistance to electromagnetic disturbances.

EFT Testing

EFT testing is a process used to evaluate the susceptibility or resistance of server and server subcomponents to electrical fast transients. Electrical fast transients are brief and high-energy bursts of electrical noise that can occur in power supply networks, typically caused by switching operations or sudden changes in current flow. These transients can adversely affect electronic devices, leading to malfunctions, performance degradation, or even damage.

An EFT generator is used to generate and apply electrical fast transients of varying energy levels, durations, and waveforms. Any malfunctions, deviations from expected behavior, or damage resulting from the transients are noted and compared with specified acceptance criteria or relevant standards to determine the resistance to electrical fast transients.

Surge Testing

Surge testing is a process used to evaluate the susceptibility or resistance of the server and server subcomponents to voltage surges or transients. A voltage surge refers to a sudden and temporary increase in the voltage level, often caused by lightning strikes, switching operations, or power grid disturbances. Surge events can potentially damage electronic components, disrupt the functionality of devices, or lead to data loss. The objective of surge testing is to ensure that electronic devices can withstand and operate reliably in environments where voltage surges may occur.

A surge is used to generate and apply controlled surge events of varying energy levels, waveforms, and durations. The surge generator applies surge impulses to the power supply lines or input/output (I/O) ports, simulating real-world surge disturbances that could occur in the operational environment. The DUT's performance and behavior are observed and monitored during and after each surge event.

Conducted Immunity Testing

Conducted immunity testing is a process used to evaluate the resistance or susceptibility of the server and server subcomponents to conducted disturbances or interference on their I/O lines. Conducted disturbances refer to unwanted electrical signals that can be coupled into electronic equipment through power supply lines, communication lines, or other conductive paths. The objective of conducted immunity testing is to ensure that electronic devices can withstand and operate reliably in the presence of conducted disturbances that may occur in their operational environment.

Signal generators, power amplifiers, and injection probes are used to generate and apply controlled conducted disturbances on power sources and I/Os. The disturbances may vary in frequency, amplitude, modulation, and duration, simulating real-world interference that could occur during operation. The performance and behavior are observed and monitored during and after each conducted disturbance and compared with acceptance criteria in the applicable standards.

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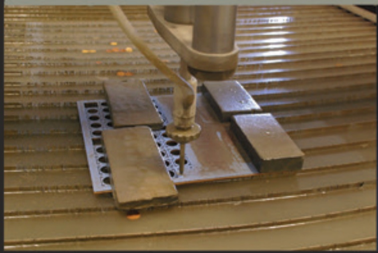

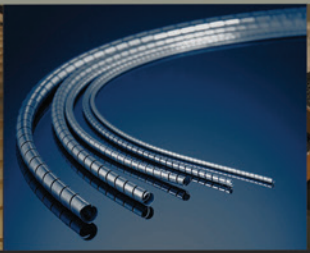

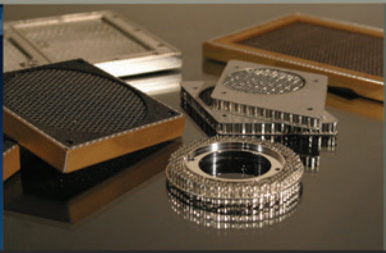

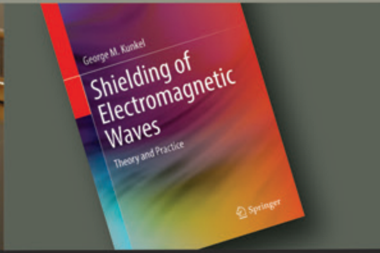

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EMC Voltage Dips/Interruptions Testing

EMC voltage dips and short interruptions testing is a process used to assess the susceptibility or resilience of electronic devices or systems to sudden changes or reductions in the supply voltage. Voltage dips refer to short-term decreases in voltage, while short interruptions indicate a complete loss of voltage for a brief duration. The objective of EMC voltage dips and short interruptions testing is to ensure that electronic devices can withstand and operate reliably when subjected to variations in the power supply voltage. These variations can occur due to faults in the power distribution network, switching operations, or other disturbances and may affect the performance, operation, or data integrity of electronic equipment.

Power sources are used to generate controlled voltage dips and interruptions that simulate real-world variations in the power supply. The power source applies transient changes to the power input, causing voltage reductions or interruptions of varying magnitudes and durations. The DUT's performance and behavior are observed and monitored during and after each voltage event.

In conclusion, EMC testing is a critical aspect of hardware compliance testing that evaluates a product's ability to function correctly in the presence of electromagnetic interference and to emit low levels of electromagnetic emissions. Conducting EMC testing confirms that a given product meets the applicable standards and regulations, reducing the risk of interference with other electronic devices and legal consequences.

Testing for Environmental Compliance

IT systems and devices are also subject to their share of environmental regulations. Compliance with these regulations will dictate whether or not a product can be marketed and/or sold in jurisdictions around the world. These environmental regulations do not just affect the electronic hardware itself but also supply chain issues and end-of-life management.

The EU has led the way with many regulations affecting IT equipment, and most EU regulatory agency labels include markings that directly connect with environmental compliance. The EU's Restriction of Hazardous Substances (RoHS) Directive and the EU's Waste Electrical and Electronic Equipment (WEEE) Directive are just some of the regulations and directives addressing environmental compliance issues that electronic companies must consider. However, there are other regulations not associated with labels and material declarations that companies must obtain from their supply chain partners.

Applicable Regulations

Let us dig a little more deeply into these regulations and directives. First, we will look at the differences in legislation within the EU. The EU has directives and regulations. A directive is a legislative act that sets a goal all EU countries must achieve, but each country can devise its own laws on how to reach the goal. An EU regulation is a binding legislative act and is applied entirely across the EU.

Enacted in 2003, the EU's RoHS Directive sets restrictions on substances (cadmium, mercury, hexavalent chromium, lead, polybrominated biphenyl (PBB) flame retardants, polybrominated diphenyl ether (PBDE) flame retardants) and phthalates unless an allowable exemption can be used. This allowable exemption gives the product manufacturer the ability to use a specific material in a specific situation for a specific category of product.

For example, while lead over 0.1% or 1,000 ppm by weight in the homogeneous material isn't allowed in general, one EU allowable exemption for IT equipment is "Lead (Pb) as an alloying element in aluminum containing up to 0.4% lead by weight."

To demonstrate conformity with the RoHS Directive, companies are required to have a Declaration of Conformity (DoC), a document stating that a given product is compliant with the Directive's requirements. The Directive also requires having a regulatory agency label for the equipment with a CE marking. Since the EU implemented RoHS, nearly 30 other countries and jurisdictions around the world (including some states in the United States) have adopted environmental requirements comparable to those in the EU's RoHS Directive.

The RoHS Directive works in conjunction with the EU's WEEE Directive, which came into force in 2012. The WEEE Directive's symbol on the agency label depicts a wheeled bin trash can with an X across it. The Directive focuses on the treatment of waste from electronic and electrical equipment, with the goal of minimizing the creation of electronic waste (e-waste) through the efficient use of resources and raw materials through reuse, recycling, and other recovery. It also focuses on improving environmental performance in the lifecycle of electronic equipment. The Directive's recovery target for Category 3 equipment (electronics) is listed as 80% recycled, meaning that the Directive looks to recycle 80% of an electronic product at the end of its useful life. The WEEE Directive is focused not so much on restriction but on the sustainability and the circular economy of electronic products.

Labeling Requirements

Energy Labeling

Moving on from some of the EU directives affecting labels, let's now turn our focus to energy. Energy labels are another common label seen on electronic equipment, which verify that a given product has been evaluated for its energy efficiency. One of the more common energy efficiency labels seen today is the ENERGY STAR Label, which affirms energy efficiency compliance with standards established by the U.S. Environmental Protection Agency (EPA).

Compliance with energy efficiency requirements is based on the results and outcomes of various tests. These include testing for power consumption in standby mode, energy consumption management, power management features (whether the system can be optimized for energy efficiency), testing the power consumption in off mode, and the availability of standby or power-savings functions (such as screen saver modes on electronic devices).

Some of the labels require the amount of electricity used over a period or for a given number of uses (cycles) to be listed in kilowatt hours (kWh). This can help users to better manage their energy usage in the long run. All energy labels have strict energy efficient requirements, and, if a product does not meet these requirements, the label cannot be applied to the product. Conformity with the requirements designated by these labels is verified by a third party as well.

California Proposition 65 Labeling

In addition to the use of restricted substances and energy efficiency, electronic products can display other labels to verify compliance, such as the warning label regulation linked to California Proposition 65 (sometimes referred to as CA Prop 65 or Prop 65). Officially implemented into law as California's Safe Drinking Water and Toxic Enforcement Act (1986), CA Prop 65 requires companies to inform consumers about products, including electronic products, that contain chemicals and substances known to cause cancer or reproductive harm. To date, no other country or jurisdiction in the world has enacted similar regulations.

CA Prop 65 requires companies to place warning labels on their products when the chemicals or substances found in the products exceed the state's legal limits. These limits are based on scientific research on chemical exposures. Companies handle compliance with these requirements in various ways. One way a company can show compliance with CA Prop 65 is to perform volatile organic chemical (VOC) emission testing. As previously mentioned, worst-case maximum configuration hardware undergoes VOC emission testing. This testing is all about capturing and identifying those chemicals that are "off-gassing" from the system, device, or component. The testing is performed using chambers and air sampling tubes. Once the tubes are analyzed, a risk assessment is

performed, and the results are compared to exposure limits specified in CA Prop 65 and OSHA regulations.

REACH Requirements

There are a few other regulations that impact electronics but do not have any labeling requirements. Two of those regulations are the Stockholm Convention and the EU's Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH).

Let's first look at the Stockholm Convention. The Stockholm Convention is a global treaty aiming to protect human health and the environment from the effects of persistent organic pollutants (POPs). The Convention entered into force on May 17, 2004, and has 186 signatory countries to date (the U.S. has not yet signed the Convention). Signatory countries agree to adopt and implement regulations that restrict the POPs listed. Signatory countries are also required under the Convention to provide financial resources and take measures to eliminate the production and use of intentionally-produced POPs. The provisions of the Convention also require signatory countries to eliminate, where possible, unintentionally produced POPs and to manage the safe disposal of POP-related waste.

There are three distinct categories for chemicals under the Stockholm Convention: elimination, restriction, and unintentional production. The specific category under which a chemical is classified determines the specific regulations that are applicable to that chemical. Elimination means that the chemical cannot be used in any form or for any use. Restriction means that a chemical can be used only in specified uses and circumstances. Unintentional production means that the chemical is a byproduct of a reaction or process.

There are currently 29 POPs listed within the Stockholm Convention. Regulations created by signatory countries to the Convention have mostly prohibited any of the chemicals from use unless there are unintentional trace contaminants of the substances. This includes substances, mixtures, and articles (an object which, during production, is given a special shape, surface, or design that determines its function to a greater degree than its chemical composition).

The requirements under the Stockholm Convention are not the only requirements or regulations restricting the use of a substance in a mixture or a product. The EU also restricts substances in mixtures or products under its REACH Regulation. The REACH Regulation has a few different aspects to it. REACH focuses on the production and use of chemical substances and their potential impacts on both human health and the environment. REACH, which took seven years to be approved in the EU and which finally entered into force in 2007, is the strictest chemical regulation to date.

Currently, any REACH-regulated substance for which production or importation exceeds one ton per year must be registered with the European Chemical Agency (ECHA). Each year, the ECHA and EU Member States conduct evaluations of the chemical substances that have been registered to determine the impacts on human health and the environment. At this point, the authorization and restriction aspects of the REACH Regulation come into play.

The authorization process focuses on substances of very high concern (SVHCs). This process looks to progressively replace these SVHCs with less dangerous substances or technologies where technically and economically feasible alternatives are available. The route to authorization starts when a Member State or the ECHA, at the request of the Commission, proposes a substance to be identified as an SVHC. Once it is identified, it is added to the Candidate List of SVHCs. Once on this authorization list, the substance can be restricted depending on the evidence regarding human health and the environment.

Restrictions are normally used to limit or ban the manufacture, the placing on the market (including imports), or the use of a given substance. But restrictions can also impose any relevant condition, such as requiring technical measures or specific labels. A restriction can apply to any substance, in a mixture or in an article, including those that do not require registration, for example, substances manufactured or imported below one ton per year.

All electronic systems and devices fall under at least one or more aspects of the REACH Regulation. Therefore, companies and their supply chain partners must pay attention to the requirements of the REACH Regulation in connection with products they produce or import into the EU.

The EU's Eco Design Directive

Another EU regulation that other countries are starting to incorporate in their legislation is the EU Eco Design Directive. This directive obligates manufacturers of energy-using products to reduce energy consumption and other negative environmental impacts occurring throughout the product life cycle. The Eco Design Directive requires companies to actively work during the product design stage to reduce the energy consumption and other potentially negative environmental impacts of their products. While the primary focus is on reducing energy use, the Directive also takes into account the longevity of electronic systems and products and the potential waste that will be left at the end of their useful life.

The Eco Design Directive bans the marketing or sale in the EU of systems and devices within ten different product groups that fail to meet its minimum requirements. IT-related products that fall under the scope of the Directive include network, data processing, and data storing equipment.

Material Declarations

Material declarations are how companies identify all of the potentially harmful substances in their systems, devices, and components to ensure compliance with RoHS requirements. Material declarations can range from full material declarations (a comprehensive list of substances within a particular product or material) to partial material declarations in which suppliers fill in what chemicals they use from an existing listing. These material declarations are how IT manufacturers manage their supply chains and determine for reporting regulations such as REACH what substances are in their products. Materials declarations come with a lot of data that must be managed. Seeing what is in the products helps to determine where products can be legally marketed or sold. Many times, material declarations are also tied to a company's product lifecycle management (PLM) tools. Tying into PLM tools allows a company to know what substances are in a specific product. As previously noted, this information is then tied back into declarations required by regulations and reporting requirements.

Compliance with environmental regulations and requirements requires quite a bit of work before a product can legally be released on the market. The biggest hurdle we face when doing environmental compliance is material declarations, which must include materials and substances used by supply chain partners. Most companies' largest struggle with environmental compliance is data management and visibility through the supply chain and the substances used by their suppliers.

CONTINUOUS MONITORING OF HARDWARE AND STANDARD CHANGES

Often in the IT industry, after the global launch of a product, hardware change requests come from the business due to various reasons (supply chain issues, cost reductions, redesign, etc.). In cases like this, the hardware compliance team must evaluate all the changes through the engineering change process and decide if and what re-testing/re-certification is required. In case of re-test/re-certification, the compliance team must repeat this cycle, considering the cost, the schedule, and the test equipment availability previously described.

In addition to hardware changes, new compliance regulations/standards may result in changes to the product plan. For example, this can occur during the release test cycle or post-product global availability. Depending on the timing of this change, support for new regulations may be included in the current test/certification cycle or may require re-test and re-certification later.

If a regulatory change occurs after global product availability and requires retesting and recertifying of the hardware, a halt on product shipments may be required to allow the compliance team to recertify the hardware to the new requirements.

CONTINUING YOUR PROFESSIONAL EDUCATION IN 2024

Welcome to 2024! Regardless of where you are in your career, your ongoing efforts to refresh or expand your technical knowledge and skills are essential to your continued professional and personal growth and success. So, as the new year begins, we've once again queried training resources throughout our industry to provide you with an overview of free or affordable solutions to meet your training goals and to help you on your journey to becoming your best self in the new year.

In this article, you'll find sources of compliance-related seminars, workshops, and other types of training, offered live, including both virtual and in-person options, as well as pre-recorded webinars and on-demand training offerings. We've also included a list of industry symposia, conferences, and exhibitions to be held in both the U.S. and around the world.

The information that follows is current as we go to press (early December 2023). But please note

Compiled by the *In Compliance Magazine* Staff

that dates for live in-person seminars, workshops, and symposia provided here are subject to change. So check the listed websites for the most up-to-date information on scheduling. Finally, we invite you to submit updates and corrections as well as suggestions for additional listings for our Events section. Please send your comments to us at editor@incompliancemag.com.

LIVE VIRTUAL AND IN-PERSON SEMINARS AND WORKSHOPS

The **American Council of Independent Laboratories (ACIL)** hosts occasional live virtual webinars related to the Council's wide range of activities, including technical subjects, ACIL Committee activities, and laboratory business practices. For more information, go to https://www.acil.org and click on the word "Education" at the top of the page. (Also see listing under "Recorded Webinars and On-Demand Training")

The **American Association for Laboratory Accreditation (A2LA)** WorkPlace Training portal offers both in-person and virtual classroom trainings featuring live instructor-led sessions. Currently, there are more than fifteen separate training offerings, covering areas including international standards, management systems, technical subjects, and soft skills. Course instructors are subject matter experts with many years of professional training experience. Additional details are available at https://www.a2lawpt.org/training. (Also see listings under "In-House/Custom Seminars and Workshops" and "Recorded Webinars and On-Demand Training")

Keith Armstrong of **Cherry Clough Consultants Ltd.** will be a featured presenter at the EMC & Compliance International 2024 event in Newbury, Berkshire (United Kingdom) on May 22-23, 2024, and will conduct the following training sessions:

- Essential EMC Design of Switching Power Converters
- Essential Circuit Design for Good, Quick EMC

For more information or to register, go to https://www.emcandci.com.

Along with his Associates Dr. Min Zhang, Andy Degraeve, and Chris Nicholas, Keith will also be conducting his EMC Design for Compliance courses in Australia and New Zealand in February 2024. Topics include:

- Essential & Advanced SI, PI, and EMC Design for Cost-Effective PCBs in 2024
- Design for EMC in 2024
- The Safe Design of Electrical Equipment in 2024

Additional information about locations and dates is available at https://www.emctech.com.au/keith-armstrong-design-compliance-emc-safety-2024. (Also see listings under "In-House/Customer Seminars and Workshops" and "Recorded Webinars and On-Demand Training)

The **Equipment Reliability Institute** offers several live, in-person public classes throughout the year, including courses on "Military Standard 810 Testing" and "Fundamentals of Random Vibration and Shock Testing." For complete information and 2024 training dates, go to https://equipment-reliability.com. (Also see listing under "In-House/Custom Seminars and Workshops")

The **EOS/ESD Association, Inc.** offers access to a wide variety of online and in-person educational opportunities throughout the year. These courses and certifications provide ESD professionals with the knowledge, tools, and credentials needed to meet the challenges of ESD in their companies. The Association holds courses at different locations throughout the year and with the annual EOS/ESD Symposium. Further, the Association publishes and distributes numerous educational materials on ESD and has pathways built to navigate training and certification programs and levels. For full details visit the Association's website at https://www.esda.org, and click on the links at the top of the home page for "Training & Education," "Certification," and "ESD Overview." (Also see listing under "Recorded Webinars and On-Demand Training")

ETS-Lindgren offers in-person and virtual training courses throughout the year as part of their popular ETS-U program. For information about course details and dates, visit the events page at https://www.ets-lindgren.com/about-us/news-events. (Also see listings under "In-House/Custom Seminars and Workshops" and "Recorded Webinars and On-Demand Training")

Eurofins York offers in-person classroom compliance training throughout the year at various locations in the United Kingdom. Find out more at https://www.yorkemc.com/services/training. (Also see listings under "In-House/Custom Seminars and Workshops")

Dr. Bogdan Adamczyk of **Grand Valley State University** (GVSU) will offer his two-day certificate course for industry on "Principles of Electromagnetic Compatibility" on April 18-19, 2024, and October 3-4, 2024, at the GVSU EMC Center in Grand Rapids, Michigan. Numerous measurements and demonstrations reinforce the course topics. The course is intended for both the practicing professionals and the new engineers entering the field. For additional details go to https://www.gvsu.edu/emccenter.

The **IEEE EMC Society** offers access to a number of live webinars on a variety of EMC-related subjects. Go to https://www.emcs.org/virtual-and-webinar-events.html for more information. (Also see listings under "Recorded Webinars and On-Demand Training" and "Industry Symposia, Conferences, and Exhibits")

Intertek offers live virtual and in-person public seminars and workshops throughout the year at various locations in the U.S. and around the world. Additional information is available at the company's "Knowledge and Education" portal at https://www.intertek.com/knowledge-education. (Also see listing under "Recorded Webinars and On-Demand Training")

Daryl Gerke of **Kimmel Gerke Associates, Ltd.** has provided EMC training to over 12,000 EMC professionals since 1992 and continues to offer his popular EMC trainings on a synchronous virtual basis. His three-day course on "Design for EMC" focuses on EMC problems and how to identify, prevent, and fix more than forty common EMI/EMC problems at the equipment level. His other course, "EMC in Military Systems," addresses issues stemming from four key EMC interfaces, grounding, shielding, power, and cables. For further details on these trainings, go to https://www.emiguru.com/seminars, or visit the website of the Applied Technology Institute (https://aticourses.com). (Also see listing under "In-House/Custom Seminars and Workshops")

Dr. Todd Hubing of **LearnEMC** offers a series of live, online courses covering EMC topics ranging from fundamentals to advanced design and modeling techniques. Courses include "Printed Circuit Board Design for EMC and Signal Integrity" and "Power Electronics Designs for Electromagnetic Compatibility." For additional details, go to https://learnemc.com.

Min Zhang of **Mach One Design** will offer his "High-Frequency Measurement and Benchtop EMC Test Course" on multiple dates in 2024. This 2-day, in-person workshop offers training for design engineers seeking a comprehensive understanding of high-frequency measurements and troubleshooting techniques to address EMI issues. The workshop emphasizes real-world applications and includes numerous demonstrations using state-of-the-art testing equipment and interactive hands-on training for participants. For workshop dates and additional information, go to https://mach1design.co.uk/practical.

The **Rohde & Schwarz** Technology Academy offers a comprehensive selection of live virtual and in-person courses on a wide variety of technical subjects dealing with EMC and RF testing and measurement. Visit https://www.rohde-schwarz.com/us/knowledge-center/technology-academy/ta-overview_256215.html

Many experts and training organizations offer standard and/or customized workshops and seminars on an in-house basis. These programs offer companies an opportunity to train multiple compliance personnel with a specialized approach designed for their needs.

for more information. (Also see listing under "Recorded Webinars and On-Demand Training")

Silent Solutions will offer several EMC courses during 2024, including "Applying Practical EMI Design and Troubleshooting Techniques," "Advanced PCB Design for EMC & SI, and "Mechanical Design for EMC." For training locations and dates, visit https://www.silent-solutions.com.

TÜV SÜD America offers live virtual public and private training courses and webinars that are enhanced by the real-life experiences of its auditing and testing teams, offering years of experience in the worldwide international standards arena. These courses can help prepare you for the most challenging compliance issues. To see the current offerings, visit the TÜV SÜD Resource Centre at https://www.tuvsud.com/en/resource-centre. (Also see listing under "Recorded Webinars and On-Demand Training")

UL is currently offering live events and seminars, virtual webinars, and other forms of training in the U.S. and locations around the world. The world's most progressive and safety-conscious companies rely on UL's educational programs for the expertise and tools required to design and install safer products, increase efficiency, realize improved speed to market, and advance their approach to prevention and compliance. A current listing of 2024 programs and dates is available at https://www.ul.com/events. (Also see listing under "Recorded Webinars and On-Demand Training")

Washington Laboratories offers a wide variety of live workshops and training sessions through its Washington Laboratories Academy. From EMC to Product Safety, and from Radio Frequency to Compliance and Environmental Design, these comprehensive webinars, seminars, and workshops combine in-depth technical information with practical, real-world engineering insights and solutions to meet today's engineering challenges. For more information, go to https://www.wll.com/emc-training.

Kenneth Wyatt of **Wyatt Technical Services, LLC** is an independent consultant specializing in EMC design, troubleshooting, and training services. Specialties include EMC troubleshooting, pre-compliance testing, and design reviews. For further information on his public seminar schedule for 2024, visit http://www.emc-seminars.com/page6/Schedule.html. (Also see listing under "Recorded Webinars and On-Demand Training")

IN-HOUSE/CUSTOM SEMINARS AND WORKSHOPS

Many experts and training organizations offer standard and/or customized workshops and seminars on an in-house basis. These training programs offer companies an opportunity to train multiple compliance personnel with a specialized approach designed for their needs. The following is a list of organizations and trainers that offer both virtual and in-person seminars and workshops for in-house presentation.

The **American Association for Laboratory Accreditation (A2LA)** also offers customized laboratory staff training on a number of topics. Go to https://www.a2lawpt.org/training for more information. (Also see listings under "Live Virtual and In-Person Public Seminars and Workshops" and "Recorded Webinars and On-Demand Training")

Vladimir Kraz of **BestESD Technical Services** provides customer-oriented classes and workshops on practical aspects of managing EMI, EOS, and ESD within the factory environment, using a results-based approach to provide participants with a fuller understanding of managed parameters. Classes and workshops are conducted on the customer premises and can include hands-on demonstrations and training on actual tools and processes in production. Specifics include overview and compliance with SEMI E.176 standard and current ESDA work on EOS. For additional information, go to https://www.bestesd.com.

Keith Armstrong and his Associates at **Cherry Clough Consultants Ltd.** offer an array of workshops and seminars, both in-person or virtual, for up to one thousand people at a time. Their extensive training portfolios cover a wide range of topics, and customized or more specialized training is also available. For more information, go to https://www.cherryclough.com. (Also see listings under “Live Virtual and In-Person Public Seminars and Workshops” and “Recorded Webinars and On-Demand Training”)

ETS-Lindgren offers customized trainings on various test and measurement topics for your engineers and test technicians. From standards updates and software education to how to perform an acoustic, 5G, or EMC test and more, these customized offerings can help increase the knowledge and productivity of your team. These customized trainings can be held at your facility, or at ETS-Lindgren’s headquarters facility where the lectures are complemented by hands-on demonstrations in their R&D test chambers. For more information and a custom training quote, contact sales@ets-lindgren.com. (Also see listings under “Live Virtual and In-Person Public Seminars and Workshops” and “Recorded Webinars and On-Demand Training”)

Equipment Reliability Institute also provides on-site training on a broad range of testing and design topics. Go to https://equipment-reliability.com for more information. (Also see listing under “Live Virtual and In-Person Public Seminars and Workshops”)

Eurofins York also offers customized, in-house training offerings in addition to their comprehensive schedule of public training programs. For additional details on their “bespoke” training options, go to https://www.yorkemc.com/services/training/on-site-training. (Also see listing under “Live Virtual and In-Person Public Seminars and Workshops”)

Daryl Gerke of **Kimmel Gerke Associates, Ltd.** also offers his synchronous virtual courses, “Design for EMC” and “EMC in Military Systems” on an in-house basis. For further details, visit https://www.emiguru.com/seminars. (Also see listing under “Live Virtual and In-Person Public Seminars and Workshops”)

StaticWorx provides in-person and online custom training on subjects involving electrostatic discharge. Topics focus on teaching architects and designers how to specify ESD flooring and include subjects such as: differentiating between conductive and dissipative floors; meeting ANSI/ESD S20.20 when working with ESD-sensitive electronic parts and assemblies; meeting DOD standards when handling explosives. Their CEU course qualifies for AIA credits. For additional information, go to https://staticworx.com/anti-static-flooring-basics-idec-accredited-course. (Also see listing under “Recorded Webinars and On-Demand Training”)

RECORDED WEBINARS AND ON-DEMAND TRAINING

Your time is valuable, and your schedule doesn’t always allow you to participate in live virtual and in-person presentations. But there are plenty of training options that you can take advantage of, right from the comfort of your daily workspace. Many organizations and training experts provide on-demand webinars, as well as books, podcasts, and e-learning programs. Here are a few options to get you started:

The **American Council of Independent Laboratories (ACIL)** also hosts an archive of previously recorded webinars that are available on-demand, covering EMC standards, key EMC committee meetings, and other EMC activities. For more information, go to https://www.acil.org and click on the word “Education” at the top of the page. (Also see listing under “Live Virtual and In-Person Public Seminars and Workshops”)

The **American Association for Laboratory Accreditation (A2LA)** offers a comprehensive suite of self-paced e-learning options through its WorkPlace Training portal. More than thirty different courses providing the equivalent of hundreds of hours of training are currently available, including online training on ISO/IEC 17025 compliance. More information is available at https://www.a2lawpt.org/e-learning. (Also see listings under “Live Virtual and In-Person Public Seminars and Workshops” and “In-House/Custom Seminars and Workshops”)

IEEE PSES 20TH ANNIVERSARY

IEEE ISPCE 2024

IEEE International Symposium on Product Compliance Engineering

REGISTRATION INFORMATION

Full Conference Registration Rates

CONFERENCE REGISTRATION	ADVANCED (THROUGH FEB 12, 2024)	REGULAR / ON-SITE (AFTER FEB 12, 2024)
PSES Members	$900	$1,000
IEEE Members	$1,000	$1,100
Non-Members	$1,100	$1,200
IEEE Life Members	$300	$325
Students	$100	$100

**Non-Members are persons who are not members of IEEE. To become an IEEE Member*

Exploring Product Compliance Careers Event Registration

Date: May 2, 2024

Time: 1:30 pm – 6:00 pm

This event is uniquely created for college students to explore the different career options offered as a Product Safety/Compliance engineer. Three dynamic speakers from varying industries will share how compliance engineering has shaped their careers. Capped off with a career fair where students can directly engage with hiring managers.

***FREE**

LIMITED AVALIBILITY (50 MAX)

**Registrants must provide provide proof of current student status at time of registration and upon checking in*

Daily Registration Rates

CONFERENCE REGISTRATION	ADVANCED (THROUGH FEB 12, 2024)	REGULAR / ON-SITE (AFTER FEB 12, 2024)
PSES Members	$400	$425
IEEE Members	$425	$450
Non-Members	$475	$450
Students	$40	$40

For further information concerning your registration, contact only the ISPCE 2023 manager:

Katherine Davies, Conference Catalysts, LLC
kdavies@conferencecatalysts.com

Keith Armstrong and his Associates at **Cherry Clough Consultants Ltd.** provide a wide range of training course modules for in-house webinars, and their PDF-formatted color course notes are available for immediate download at https://www.emcstandards.co.uk/emcacademy. A number of new on-demand training webinars are now being made available at https://emcstandards-shop.fedevel.education/index.html. (Also see listings under "Live Virtual and In-Person Public Seminars and Workshops" and "In-House/Custom Seminars and Workshops")

EMC Fast Pass provides comprehensive online training courses and short courses to assist electronic engineers, compliance specialists, and hardware manufacturers design and test products that pass EMC and RF certifications the first time. Course offerings include:

- EMC Design for Compliance: Immunity
- EMC Design for Compliance: Emissions
- Intrinsically Safe (IS) Hardware Design
- FCC Wireless (RF) Pre-Compliance
- EMC Technician Training

Additional information is available at https://emcfastpass.com.

The **EOS/ESD Association, Inc.**, in addition to its courses and certifications offered at events, has a wide variety of online classes, online certification programs, training videos, and educational resources at https://www.esda.org. Click on the links at the top of the home page for "Training & Education," "Certification," and "ESD Overview" for more information. (Also see listings under "Live Virtual and In-Person Public Seminars and Workshops" and "Industry Symposia, Conferences, and Exhibits")

ETS-Lindgren also offers a number of previously recorded webinars that are available on-demand covering topics such as EMC testing, wireless/5G testing, automotive testing (including e-motor and autonomous vehicles), ANSC C63® standards updates, and electro-magnetic protection. Visit http://www.ets-lindgren.com/services/education-training for more information about on-demand offerings. (Also see listings under "Live Virtual and In-Person Public Seminars and Workshops" and "In-House/Custom Seminars and Workshops")

The **IEEE EMC Society** also provides access to several on-demand recordings of recent presentations at Society and Chapter events. Further information is available at https://www.emcs.org/virtual-and-webinar-events.html. (Also see listings under "Live Virtual and In-Person Public Seminars and Workshops" and "Industry Symposia, Conferences, and Exhibits")

Intertek's extensive catalog of live and on-demand webinars complements the company's live virtual and in-person training options. Additional information is available at https://www.intertek.com/knowledge-education/webinars. (Also see listing under "Live Virtual and In-Person Public Seminars and Workshops")

NTS TESTalks provides access to free, on-demand videos on several aerospace and defense-related standards, including RTCA/DO-160, MIL-STD-810H, and MIL-STD-461G. The five-part video series on MIL-STD-461G covers key aspects of this important standard, including conducted and radiated emissions and susceptibility considerations. For more information, go to https://www.nts.com/nts-testalk.

Rohde & Schwarz offers a comprehensive selection of webinars, virtual demonstrations, videos, and other remote learning options covering a wide variety of technical subjects. Learn more by accessing the Rohde & Schwarz Technology Academy at https://www.rohde-schwarz.com/us/knowledge-center/technology-academy/ta-overview_256215.html. (Also see listing under "Live Virtual and In-Person Public Seminars and Workshops")

StaticWorx also offers a collection of over 60 brief, on-demand videos about static electricity that answer commonly asked questions, explain confusing technical terms, and help you mitigate the effects of static electricity. Visit the company's YouTube channel at https://www.youtube.com/c/staticworx to access their video library. (Also see listing under "In-House/Custom Seminars and Workshops")

The benefit of attending these annual symposia is that attendees can sample a vast array of workshops quickly and efficiently while connecting with colleagues and professionals with the same interests.

TÜV SÜD America also offers on-demand webinars covering various topics in the areas of product safety, EMC, management systems, and competency assessments. To learn more, go to the TÜV SÜD Resource Centre at https://www.tuvsud.com/en/resource-centre. (Also see listing under "Live Virtual and In-Person Public Seminars and Workshops")

UL also provides safety- and compliance-related training delivered via its extensive library of on-demand webinars. Topic areas include hazard-based safety engineering, global market access, and global directives, code compliance, conformity assessment, sustainability, responsible sourcing, social auditing, and many more. For additional details, visit https://www.ul.com/events/on-demand-webinars. (Also see listing under "Live Virtual and In-Person Public Seminars and Workshops")

Kenneth Wyatt of **Wyatt Technical Services, LLC** offers several webinar- and video-based trainings. Topics include EMC theory, product design for compliance, PC board design for low EMI, taming wireless self-interference, and benchtop EMC troubleshooting. For more information, visit http://www.emc-seminars.com/page6/Schedule.html. (Also see listing under "Live Virtual and In-Person Public Seminars and Workshops")

INDUSTRY SYMPOSIA, CONFERENCES, AND EXHIBITS

Annual symposia are an excellent resource for extensive technical training, as well as the exchange of new ideas and technical concepts. The benefit of attending these events is that attendees can sample a vast array of workshops quickly and efficiently while connecting with colleagues and professionals with the same interests. (The symposia listed below are planned as live in-person events unless otherwise noted. Please check the listed website for up-to-date information on dates and locations.)

DesignCon 2024
January 30-February 1, 2024 – Santa Clara, California (U.S.)
https://designcon.com

EMV 2024
March 12-14, 2024 – Cologne, Germany
https://emv.mesago.com/koeln/en.html

EuCAP 2024 – The 18th European Conference on Antennas and Propagation
March 17-22, 2024 – Glasgow, Scotland
http://www.eucap2024.org

A2LA Annual Conference 2024 (AnnCon24)
April 21-24, 2024—Denver, Colorado (U.S.)
https://a2la.org/annual_conference

2024 IEEE International Symposium on Product Compliance Engineering (ISPCE)
April 30-May 2, 2024 – Chicago, Illinois (U.S.)
http://2024.psessymposium.org

2024 International Applied Computational Electromagnetics Society (ACES) Symposium
May 19-23, 2024 – Orlando, Florida (U.S.)
http://www.aces-society.org/conference/Orlando_2024

2024 IEEE International Instrumentation and Measurement Technology Conference (I^2MTC)
May 20-23, 2024 – Glasgow, Scotland
http://i2mtc2024.ieee-ims.org

2024 IEEE Joint International Symposium on Electromagnetic Compatibility, Signal & Power Integrity and EMC Japan/Asia-Pacific International Symposium on Electromagnetic Compatibility
May 20-24, 2024 – Okinawa, Japan
https://www.ieice.org/~emc/2024

EMC & Compliance International Exhibition & Workshops
May 22-23, 2024 – Newbury, Berkshire, United Kingdom
https://www.emcandci.com

IMS 2024 – IEEE International Microwave Symposium
June 16-21, 2024 – Washington, D.C. (U.S.)
https://ims-ieee.org

Sensors Expo & Conference
June 24-26, 2024 – Santa Clara, California (U.S.)
https://www.sensorsexpo.com

2024 IEEE International Symposium on Antennas and Propagation & ITNC-USNC-URSI Radio Science Meeting
July 14-19, 2024 – Florence, Italy
https://2024.apsursi.org

2024 IEEE International Symposium on Electromagnetic Compatibility, Signal & Power Integrity (EMC + SIPI)
August 5-9, 2024 – Phoenix, Arizona (U.S.)
https://www.emc2024.org

EMC Europe 2024
September 2-5, 2024 – Bruges, Belgium
https://www.emceurope2024.org

46th Annual Electrical Overstress/Electrostatic Discharge Symposium
September 15-19, 2024 – Reno, Nevada (U.S.)
https://www.esda.org/events/46th-annual-eosesd-symposium-and-exhibits

European Microwave Week 2024
September 22-27, 2024 – Paris, France
https://www.eumweek.com

The Battery Show 2024, North America
October 7-10, 2024 – Detroit, Michigan (U.S.)
https://thebatteryshow.com

2024 San Diego Test Equipment Forum (SDTES)
October 2024—San Diego, California (U.S.)
https://www.atecorp.com/special-pages/sdtes/welcome-to-sdtes

46th Annual Meeting and Symposium of the Antenna Measurement Techniques Association (AMTA)
October 27-November 1, 2024 – Cincinnati, Ohio (U.S.)
https://2024.amta.org

EMCmini Symposium
dates to be announced (U.S.)
https://emcmini.us

IEEE EMC SOCIETY 2024 REGIONAL EVENTS

2024 Chicago IEEE EMC Mini Symposium
May 14, 2024 – Schaumburg, Illinois (U.S.)
http://www.emcchicago.org/sectfiles/events.htm

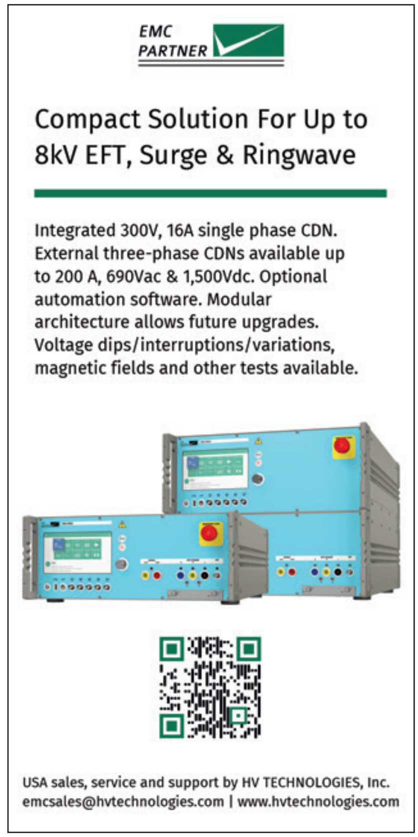
Southeastern Michigan EMC Fest 2024
May 16, 2024 – Livonia, Michigan (U.S.)
http://www.emcfest.org

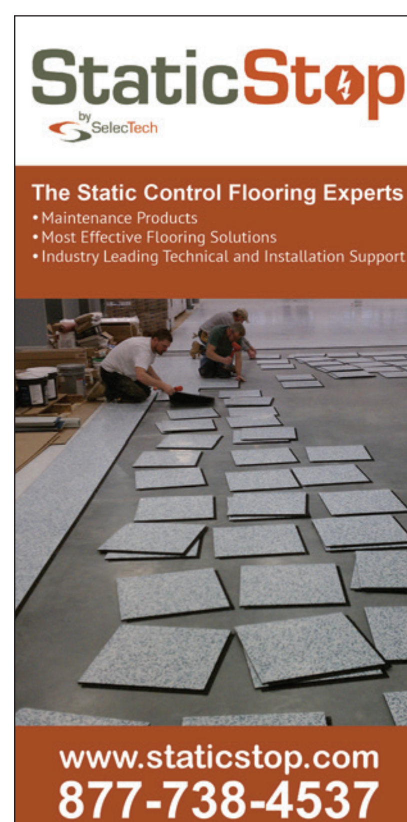
2024 Minnesota EMC Event
September 19, 2024 – Bloomington, Minnesota (U.S.)
https://www.mnemcevent.com

We hope this list will help you meet your professional development goals in 2024. Many additional trainings and events will be planned throughout the year, so be sure to check our events calendar at https://incompliancemag.com/event-directory to find the most up-to-date information. Another way to brush up on the basics and delve deep into advanced topics is by visiting our online resource center, the *In Compliance* **Electrical Engineering Resource Center** (**EERC**) at https://incompliancemag.com/eerc.

In the meantime, we hope that the year ahead brings only good health and happiness to you and your loved ones!

PRODUCT Showcase





IMPACT OF A DECOUPLING CAPACITOR AND TRACE LENGTH ON SIGNAL INTEGRITY IN A CMOS INVERTER CIRCUIT

By Bogdan Adamczyk and Mathew Yerian-French

This article describes a laboratory experiment that shows the impact of the decoupling capacitors and a PCB trace length on the signal integrity in a CMOS inverter circuit.

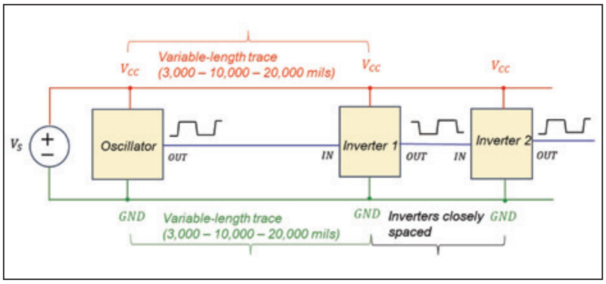


Figure 1: Block diagram of the switching circuit

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Mathew Yerian-French is an electrical engineer specializing in EMC design and diagnostic testing. He received his B.S.E in Electrical Engineering from Grand Valley State University. He focuses on preventing EMC issues through design reviews and early EMC pre-compliance testing and diagnostics. Mat participates in the industrial collaboration with GVSU at the EMC Center. He can be reached at mathew.french@e3compliance.com.

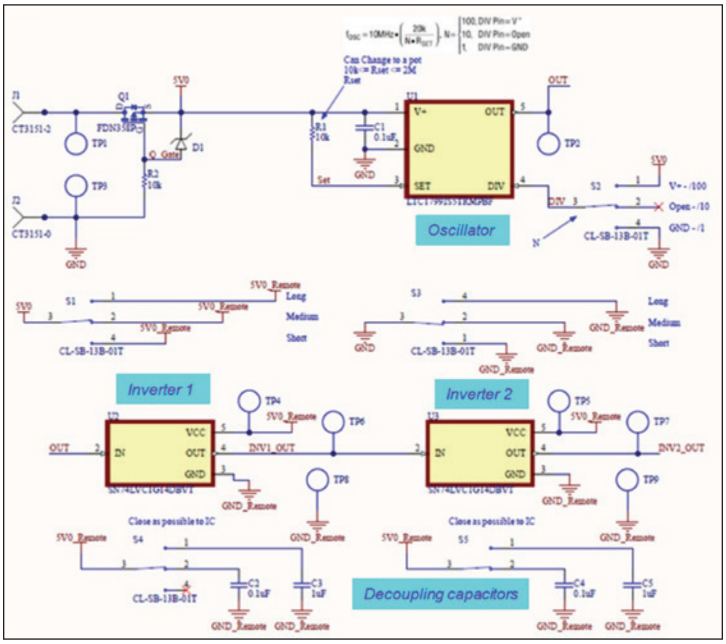

Figure 2: Schematic of the switching circuit

SWITCHING CIRCUIT DESCRIPTION

Figure 1 shows the block diagram of the switching circuitry.

A detailed schematic of the circuit is shown in Figure 2.

The PCB used in this experiment is shown in Figure 3.

The PCB used in this experiment is a newer version of the board used previously and described in [1]. This new PCB (designed by Mathew Yerian-French) contains several switches allowing the user to change the oscillator frequency, the length of power, and ground traces and choose whether to use the decoupling capacitors.

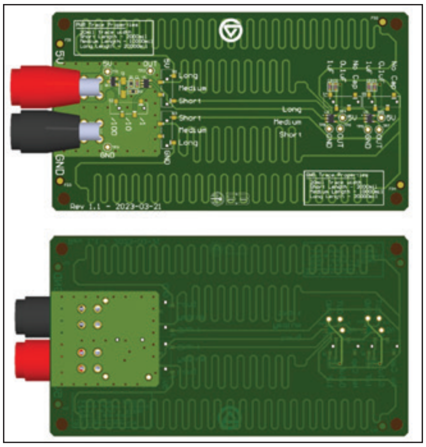

Figure 3: Both sides of the PCB

During switching, a transient current is drawn from the source. The inductance associated with the current loop causes the voltages at the power and ground pins to deviate from the desired values, as shown in the measurement section (see [1] for more details).

The board was purposely designed with very long traces to show the negative impact of the associated inductance while increasing the impact of a decoupling capacitor at the same time.

IMPACT OF THE TRACE LENGTH AND DECOUPLING CAPACITORS: MEASUREMENTS

The measurement setup is shown in Figure 4 (see [2] for the experiment details, Altium board files, and BOM).

Figures 5 and 6 show the voltages at the VCC pins of the inverters with respect to their GND pins. Figure 5 shows the results for short traces, while Figure 6 shows the results for long traces with no decoupling capacitors.

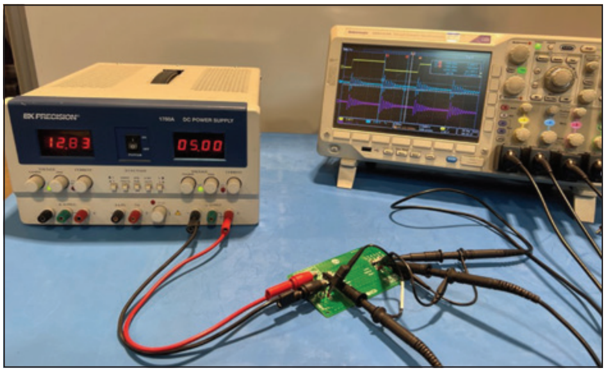

Figure 4: Measurement setup

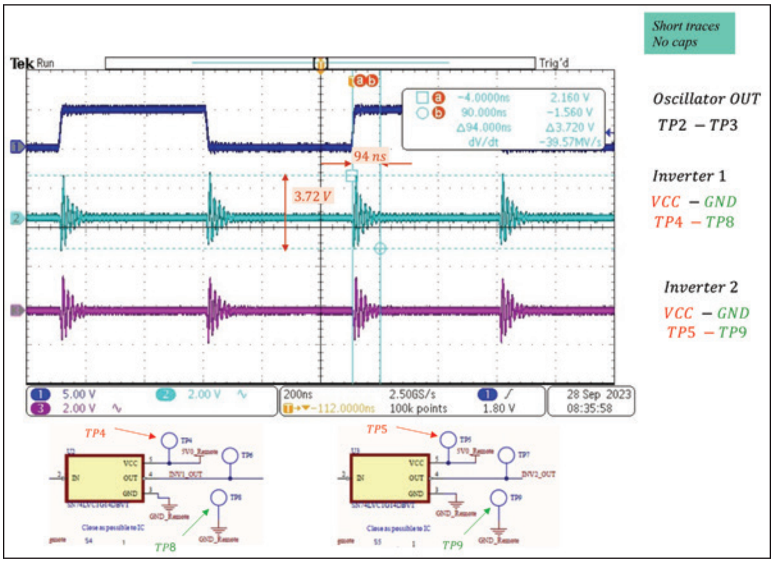

Figure 5: VCC-GND voltages – short trace, no decoupling capacitors

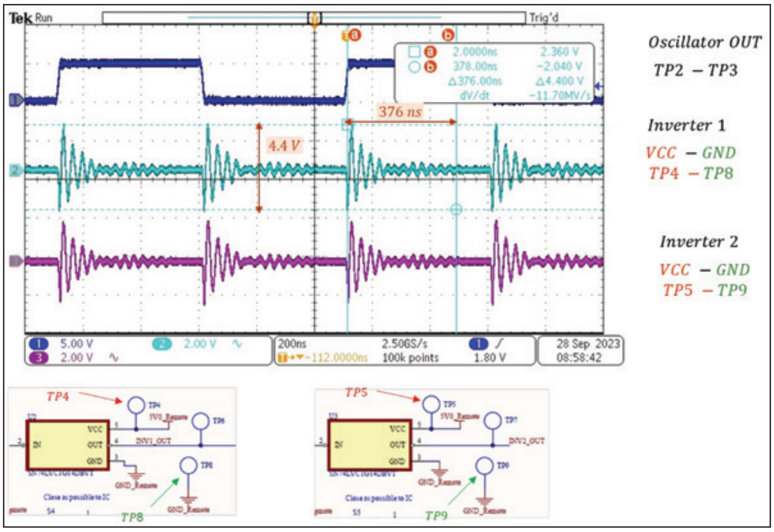

Figure 6: VCC-GND voltages – long trace, no decoupling capacitors

Observations: Both the amplitudes and duration of the ringing are larger for long traces as compared to short traces.

Figures 7 and 8 show the voltages at the VCC pins of the inverters with respect to their GND pins for short traces vs. long traces with a 0.1 µF decoupling capacitor at each inverter.

Observations: Decoupling capacitors dramatically reduce the ringing amplitudes and duration. The impact of the trace length is not as pronounced.

Figures 9 and 10 show the voltages at the GND pins of the inverters with respect to the main circuit input GND for short traces vs. long traces with no decoupling capacitors.

Observations: The duration of the ringing for long traces is significantly larger as compared to short traces. The amplitude of the ringing for long traces is, however, not as large as for short traces.

Figures 11 and 12 show the voltages at the GND pins of the inverters with respect to the main circuit input GND for short traces vs. long traces with a 0.1 µF decoupling capacitor at each inverter.

Observations: Decoupling capacitors dramatically reduce the ringing amplitudes and duration. The impact of the trace length is barely noticeable.

All measurement results are summarized in Table 1.

FUTURE WORK

The next column in the February issue describes the operation of an ideal difference amplifier.

The upcoming March 2024 column will discuss the impact of a decoupling capacitor and trace length on radiated emissions. Measurements will be performed in a semi-anechoic chamber,

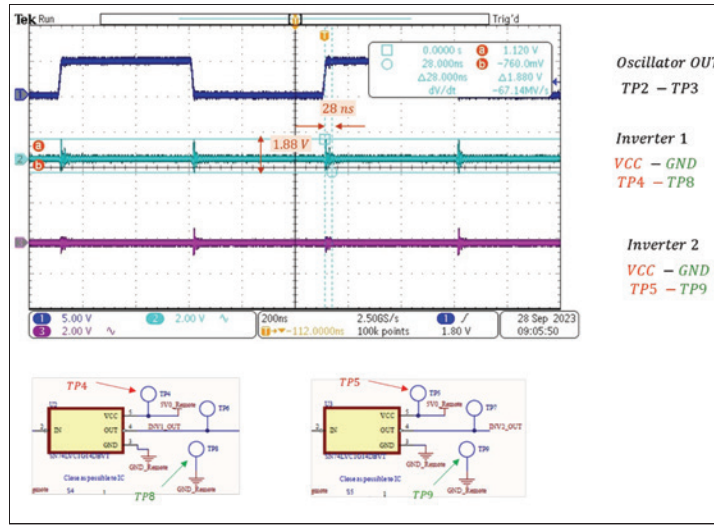

Figure 7: VCC-GND voltages – short trace, 0.1 µF decoupling capacitors

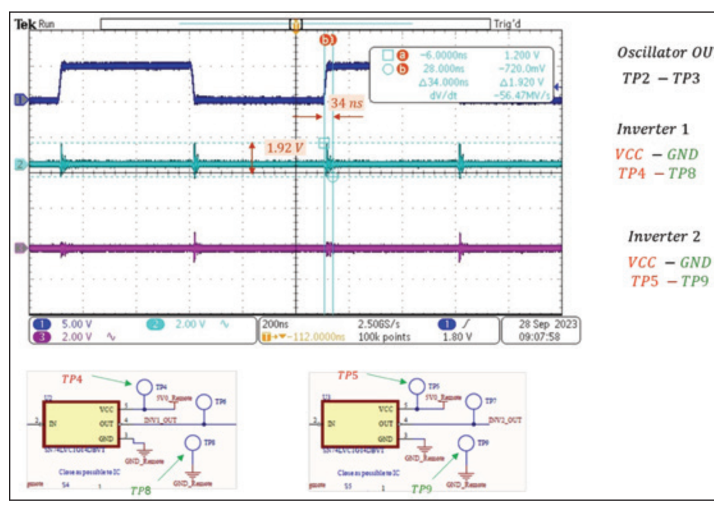

Figure 8: VCC-GND voltages – long trace, 0.1 µF decoupling capacitors

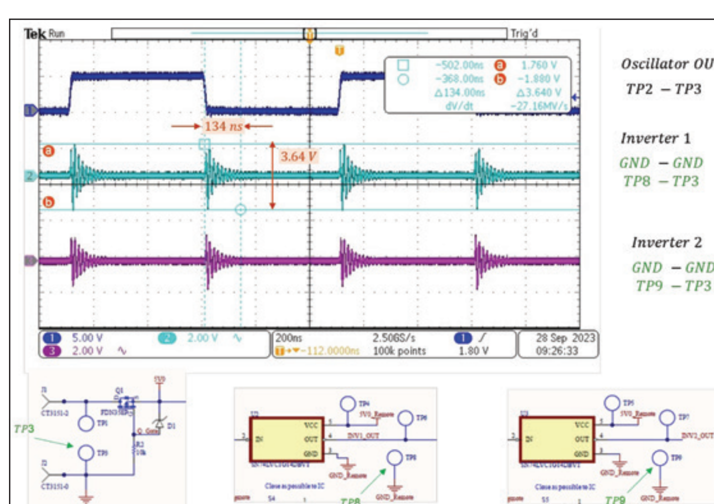

Figure 9: GND-GND voltages – short trace, no decoupling capacitors

in accordance with CISPR 25 Edition 5 automotive standard, a monopole antenna was used in the frequency range of 150 kHz – 30 MHz, a biconical antenna in the range of 30 MHz – 300 MHz, and a log-periodic antenna in the range of 300 MHz – 1GH.

The April 2024 column will be devoted to conducted emissions measurements in accordance with the same standard. Measurements will be performed in the same semi-anechoic chamber, both on the battery and ground lines in the frequency range of 150kHz – 108 MHz.

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1. Bogdan Adamczyk, "Impact of a Decoupling Capacitor in a CMOS Inverter Circuit," *In Compliance Magazine*, September 2019.
2. Bogdan Adamczyk, *Principles of Electromagnetic Compatibility: Laboratory Exercises and Lectures*, Wiley, 2023.

	VCC – GND ΔV [V]	VCC – GND Δt [ns]
Short trace, no caps	3.72	94
Long trace, no caps	4.4	376
Short trace, 0.1µF caps	1.88	28
Long trace, 0.1µF caps	1.92	34
	GND – GND ΔV [V]	GND – GND Δt [ns]
Short trace, no caps	3.64	134
Long trace, no caps	3.12	456
Short trace, 0.1µF caps	1.8	18
Long trace, 0.1µF caps	1.76	28

Table 1: Summary of the results

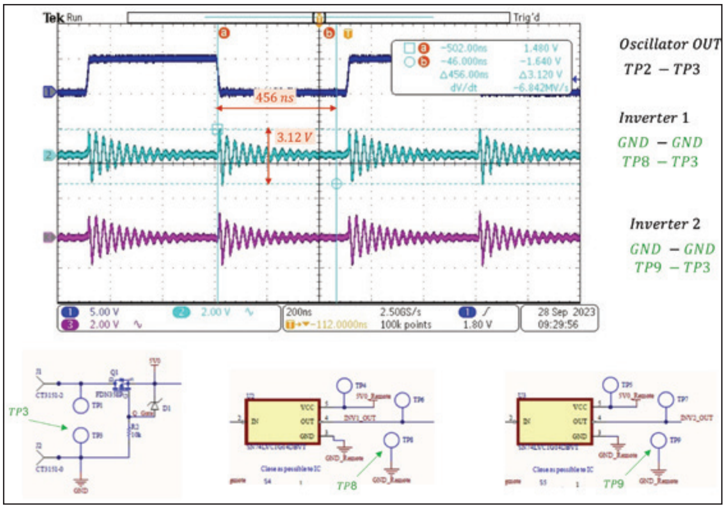

Figure 10: GND-GND voltages – long trace, no decoupling capacitors

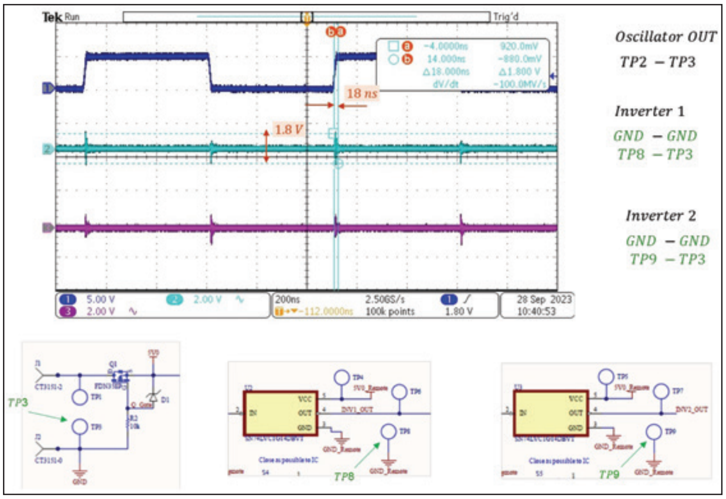

Figure 11: GND-GND voltages – short trace, 0.1 µF decoupling capacitors

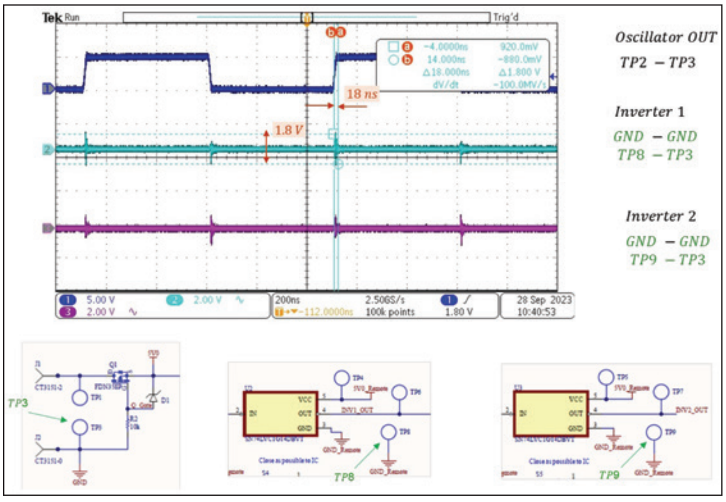

Figure 12: GND-GND voltages – long trace, 0.1 µF decoupling capacitors

INTEGRATING EMBEDDED ESD DETECTION, PART 3

By Jeffrey C. Dunnihoo, on behalf of EOS/ESD Association, Inc.

In Parts 1 and 2 of this series, we explored the opportunities for embedded on-chip and system-level ESD detection solutions. We introduced embedded detection technology and considerations for balancing ESD detection solutions with ESD protection requirements.

In Part 3, we will outline the steps to consider when embedding ESD detection capabilities into your system and overall design flow.

CHOOSING THE RIGHT TECHNOLOGY

Selecting the appropriate embedded ESD detection technology is crucial. On-chip, discrete, software detection, or a combination of strategies may be the best choice for your application. Consider the following factors:

1. **ESD Event Types**: Evaluate the types of ESD events your device will most likely encounter and what levels should be detected. Ensure that the chosen technology can detect and record or respond to these events effectively.
2. **ESD Failure Criteria:** Map out the expected ESD event failure mechanisms and recovery modes. Separate hard failures and soft upsets and how the device should respond to them, even if they are outside of the robustness limits for the product. For example, if your device's intended robustness level is exceeded and this is detected, should it do a recalibration or self-test, or should it "brick" itself and report potential malfunction? A medical or aerospace device may have a different "warranty" behavior than a low-cost consumer product.
3. **Speed Requirements**: Assess the speed at which ESD events need to be detected and responded to in your application. Some applications may have faster response times for safety or process than others.

Jeffrey Dunnihoo is the founder of Pragma Design in 1997, specializing in interface design architecture and ESD, EOS, and other transient analysis technologies. He has presented at IEEE EMC Society, the EOS/ESD Association, and ISTFA, and has co-authored a new textbook with other ESD experts on ESD co-design fundamentals, as well as a children's book series on technology and microelectronics. He has also been a contributor to industry groups and standards bodies, such as USB, IEEE 802.11, VESA/DisplayPort, ESD Industry Council, and has served on ESDA working groups.

Founded in 1982, EOS/ESD Association, Inc. is a not for profit, professional organization, dedicated to education and furthering the technology Electrostatic Discharge (ESD) control and prevention. EOS/ESD Association, Inc. sponsors educational programs, develops ESD control and measurement standards, holds international technical symposiums, workshops, tutorials, and foster the exchange of technical information among its members and others.

4. **Integration Complexity**: Evaluate the complexity of integrating the technology into your chip design versus adding discrete components to the system. Consider the data collection paths, such as fan-in registering, boundary scan chains, GPIO, or A/D multiplexers. Some solutions may require more extensive modifications to your design than others.
5. **Cost Considerations**: Compare the cost of implementing different embedded ESD detection technologies, factoring in both development and manufacturing costs.
6. **Compatibility with EDA Flow**: Collaborate with experienced library providers to guarantee the smooth integration of your chosen technology into your design process. Even if your primary expertise lies in making your application function effectively, it is important to acknowledge the numerous distinctive challenges that come with "rolling your own" ESD protection, not to mention the added complexity of ESD detection.

INTEGRATING EMBEDDED ESD DETECTION TECHNOLOGY

Once you've outlined your integrated or discrete protection and detection goals, it's time to implement them and eventually adapt the decision and optimization process into your design flow. Here's a step-by-step guide.

Step 1: Technology Selection

Begin by selecting the specific embedded ESD detection technology that aligns with your design requirements. If you've chosen embedded detection or similar technology, consult with the library provider for detailed integration guidelines. For discrete solutions, simulate the detector circuit options with appropriate ESD injection models and validate them with mock-ups in the ESD lab. A small evaluation board with LED or audio indicators for detector output are simple and convenient options in the ESD lab where you don't want to risk expensive oscilloscopes and IDE interfaces to ESD damage.

Step 2: Design Modifications

Adapt your chip design (and flow) or system PCB to accommodate the selected technology. This may involve:

- **Layout Adjustments**: Modify the chip/board layout to include ESD sensors at strategic locations. Ensure that these sensors are adequately connected to the monitoring and response circuitry, accounting for the noisy EMI environment expected during a strike.
- **Be the Bolt:** Identify the entry/exit vector(s) of concern. Find a place to attach a voltage, current, or near-field probe to the discharge path in order to trigger your detector. (See Figure 1.)
- **Circuit Modifications**: Integrate the technology's response mechanisms into your circuitry, ensuring that they can be triggered promptly upon ESD event detection.

Step 3: Simulation and Verification

Before moving to fabrication, perform simulations to validate the functionality of your embedded ESD detection system:

- **ESD Event Simulation**: Simulate ESD events of varying magnitudes and polarities to verify that the embedded detection system reliably detects and responds to them. Do not waste time inventing your own ESD pulse model. Select the appropriate one from the dozens of industry-developed ESD pulse spice models available in the literature.
- **Response Testing**: Ensure that the system's response time and level ranges meet the requirements of your application.
- **False Positive/Negative Analysis**: Evaluate the system's performance in terms of false positives (incorrectly detecting an ESD event due to non-ESD EMI, for example) and false negatives (failing to detect a genuine ESD event).

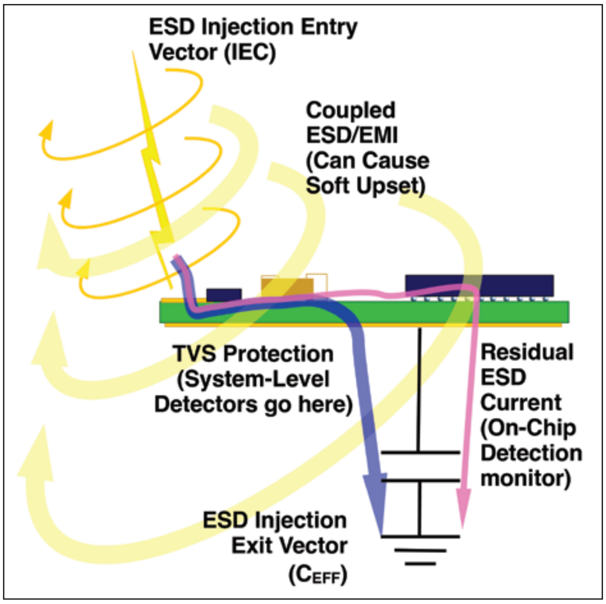

Figure 1: Consider the entry/exit vector and where to place the detectors.

Step 4: Layout Optimization

Optimize your chip or board's layout to minimize parasitic capacitance and ensure efficient signal routing. In many cases, the existing ESD protection can be used to trigger detection without any additional parasitic burden.

Step 5: Collaboration with EDA and Library Providers

Collaborate closely with EDA tool providers to facilitate the integration of the embedded ESD detection technology into your design flow. Ensure that simulation and verification tools are compatible

with other transient models from other device vendors in your system. Since this is a leading-edge technology, be persistent. Designing simple ESD protection systems remains a specialized area of expertise. Frontline support and application engineers may not have received training in ESD detection technologies yet.

Step 6: Documentation

Thoroughly document the integration process, including detection goals, limitations, layout modifications, circuit changes, and simulation results. This documentation will be invaluable for troubleshooting and future reference. **Don't forget to keep your firmware group in the loop!** Programmers do not like to be told that memory or program counters may suddenly change due to ESD in otherwise normal operation, so help them embrace this scary concept and give them a handle on how to identify the event (ISR or POR vector) and how to recover the hardware state after a detection event (Consider machine states such as Figure 2.)

VALIDATION AND TESTING

Validation and testing are critical phases in the implementation of embedded ESD detection. These steps help ensure that the technology performs as expected and provides the necessary protection for your design. Here's how to approach this phase.

Importance of Validation

Effective validation of the detectors is essential for building confidence in your embedded ESD detection system's reliability, but also the detection system can be used to help validate the on-chip and external system-level ESD protection robustness.

One problem of cutting-edge chip-level characterization has been the scarcity of early functional samples of "golden" qualification chips and early validation system boards. Many of these chips and evaluation boards are critically allocated to software development or other functional requirements and cannot be sacrificed for ESD or other potentially destructive transient testing.

Embedded transient scanning detectors may be designed to trigger at various levels of applied stress and may, therefore, provide an early "warning

Figure 2: What state are you in?[1]

track" of imminent failure. Traditional step-testing of a system can begin from a harmless starting point and be increased incrementally until near-destructive levels are detected, allowing testing to be aborted before damage occurs. The guardbanding of the target robustness level can be validated in this way without destroying the device.

Testing Methodologies

Consider the following testing methodologies for embedded ESD detection:

1. **ESD Generator Testing**: Use ESD generators to emulate ESD events and verify that the embedded detection system responds appropriately. Test under various conditions, including different magnitudes and polarities of ESD strikes. Carefully document the detector levels and ranges that correspond to different strike levels applied at different injection points.
2. **Multi-strike ESD Robustness Testing**: Subject the semiconductor chip to a series of ESD events to determine its robustness and ability to continue functioning under ESD stress. While some stress levels will precipitate instantaneous damage, other types of latent damage can accumulate after repeated strikes at much lower levels.[2]
3. **Temperature and Voltage Testing**: Test the embedded detection system under extreme temperature and voltage conditions to ensure its reliability across different operating environments.

Real-World Testing Scenarios

To ensure that your embedded ESD detection technology can handle real-world scenarios, consider testing in environments where ESD events are likely to occur. These could include testing during product handling, manufacturing, and everyday use. Additional telemetry of event severity and frequency across deployed products in the field can provide invaluable information on the actual application environment. This can reveal actual levels in the field that can help optimize or cost-reduce protection goals.

CONCLUSION

In Part 1 of this article series, we explored the critical need for embedded ESD detection in the context of advanced semiconductor nodes. The vulnerabilities of advanced ICs to ESD damage have necessitated the development of innovative solutions, such as embedded detection technology, to augment protection schemes. Embedded detection's real-time monitoring and response capabilities offer a new level of overall robustness and reliability by expanding the visibility of ESD events and effects.

In Parts 2 and 3, we've provided engineers and designers with an overview of embedding ESD detection in their products and processes. Embedded ESD detection gives you more visibility and flexibility, allowing you to optimize cost, enhance performance, and bolster robustness as semiconductor technology advances.

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1. J. Dunnihoo (author) and Simona Ceccarelli (illustrator), *TSSOP gets ZAPPED! with Static Electricity*, Pragma Media, 2019
2. I. Laasch, H-M. Ritter, and A. Werner, "Latent damage due to multiple ESD discharges," EOS/ESD Symposium, Anaheim, CA, 2009, pp. 1-6.

ANSI Z535.4 – SAFETY LABELS IN FOCUS

By Erin Earley

In our latest "On Your Mark" columns, we've been putting a spotlight on the American National Standards Institute (ANSI) Z535 standards. This family of six U.S. standards was created to enhance safety communication and promote consistent hazard recognition and understanding – making it important for manufacturers and workplaces across the country. These standards create a guide for the design, application, and use of signs, colors, and symbols intended to identify and warn against hazards and for other accident prevention purposes. Our theme of exploring each of these standards individually continues, this month focusing on ANSI Z535.4 – Product Safety Signs and Labels.

WHAT IS ANSI Z535.4?

ANSI Z535.4 is a standard developed by ANSI that relates specifically to product safety signs and labels. This standard – ANSI Z535.4 Product Safety Signs and Labels – provides guidelines and specifications for the design, use, and placement of safety signs and labels that are applied to products with the intention of conveying information about associated hazards.

It defines a "product safety sign or label" as a sign, label, cord tag, or decal affixed to a product that provides safety information about that product.

The standard outlines the main principles for creating effective safety signs and labels. That includes the use of symbols, colors, signal words, and other visual elements to communicate the severity of potential hazards and the actions that should be taken to avoid those hazards.

THE STANDARDS ORIGIN – AND LATEST UPDATES

How did the standardization of warning signs come about? According to ANSI.org, in the early 1900s, concerns over rising traffic-related injuries and deaths resulted in the emergence of warning signs, followed by complex safety sign systems in Europe and the U.S. These continued to evolve through Europe and North America in the following years.

Erin Earley, head of communications at Clarion Safety Systems, shares her company's passion for safer products and workplaces. She's written extensively about best practices for product safety labels and facility safety signs. Clarion is a member of the ANSI Z535 Committee for Safety Signs and Colors, the U.S. ANSI TAG to ISO/TC 145, and the U.S. ANSI TAG to ISO 45001. Erin can be reached at eearley@clarionsafety.com.

The development of the ANSI Z535 standards was part of a response to the growing need for standardized safety communication to better protect people across different environments and industries. ANSI Z535.4 was published for the first time in 1992, providing its core guidelines for safety labels. It was revised in 1998 when Annex A was added to explain the use of safety label components in collateral material used with the product. Annex B was added to provide principles and guidelines for the design of product safety signs.

Following that, revisions were made periodically, according to ANSI's cycle, including annexes to refer to ISO formats, signal word translations, and signal word selection assistance. In 2011, revisions were made to better harmonize with the .2, .5, and .6 standards; that year, a new type of product safety sign, the "safety instruction sign," was added to the standard, joining the existing types of signs, hazard alerting signs, and safety notice signs which were also more clearly defined and named in that edition. In 2017, the prior 2011 version was reaffirmed or republished without changes.

As for the next steps, a revision to Z535.4 is expected to be published shortly, focusing on further clarification of its usage with other standards, as well as new text, definitions, and minor modifications to its wording.

USING THE STANDARDS' GUIDELINES TO CREATE EFFECTIVE SAFETY LABELS

ANSI Z535.4 specifies that a product safety sign or label is made up of a signal word panel (the area

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of the sign or label that contains the signal word to communicate the level of seriousness of the hazard, as well as the safety alert symbol if used on a hazard alerting sign or label), plus a message panel.

"Hazard alerting" refers to signs and labels directly related to a hazard that identifies the hazard, the level of hazard seriousness, the probable consequence of involvement with the hazard, and how the hazard can be avoided.

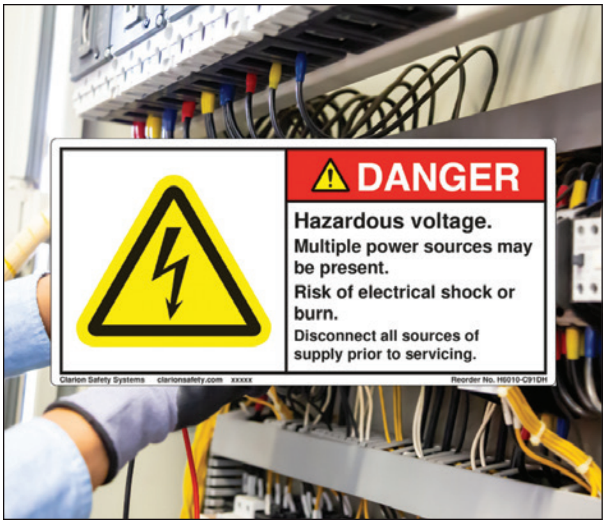
The message panel is the area of the safety sign or label that contains its word message. The word message, potentially along with a pictorial or safety symbol, is used to convey the nature of the hazard (such as its type: electric shock, cut, or burn), the consequence of interaction with the hazard, and how to avoid the hazard. A safety symbol panel can be used to communicate a part or all of the elements of a message panel.

The standard also lays out clear guidelines for the many specific aspects that need to be considered to create a safety label, including:

- Use of signal words
- Sign and label format
- Safety sign and label colors
- Letter style and size
- Sign and label placement
- Expected life and maintenance
- Safety symbols

In its introduction, ANSI Z535.4 notes that it "sets forth a system for presenting safety and accident prevention information through product safety signs and labels. It consolidates a number of previous graphic approaches into a common design direction selected to present product hazard information in an orderly and visually consistent manner. The basic mission and fundamental purpose of the ANSI Z535 committee is to develop, refine, and promote a single, uniform graphic system used for presenting safety and accident prevention information."

According to Angela Lambert, head of standards compliance at Clarion Safety Systems and an ANSI Z535 committee member, "While our goal



An example of a best practice hazard alerting product safety label, designed in line with ANSI Z535.4

absolutely is to offer tools to help individuals easily and efficiently create consistent signs and labels – in line with the development of a standardized, graphic system of signage which benefits comprehension and, overall, safety. However, putting this into practice is not without its challenges."

Lambert notes that one complexity is that Z535.4 is not meant to be looked at as a standalone standard. It's written as one part of the Z535 family; it's designed to be used alongside the .1 (Safety Colors) and .3 (Criteria for Safety Symbols) standards, and it's intended to complement the other standards in the Z535 series: .2 (Environmental and Facility Safety Signs), .5 (Safety Tags and Barricade Tapes for Temporary Hazards), and .6 (Product Safety Information in Product Manuals). When it comes to designing effective labels, it's also important to understand ANSI Z535.4's international counterpart, ISO 3864-2, may apply to the product or audience at hand and will need to be considered.

"While it may not always be a simple task to understand and apply the latest standards and best practices to your safety labels, the encouraging news is that, when it comes to safety, we've come so far by having these standardized tools and guidelines in place to use. And they'll continue to be revised, reviewed, and republished to be more relevant and harmonized."

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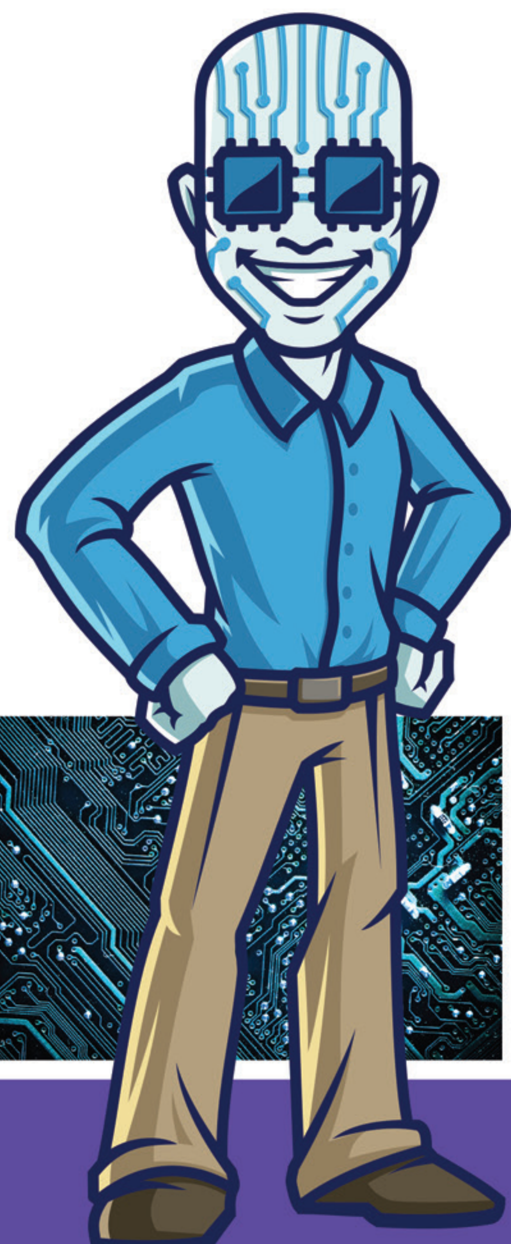

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