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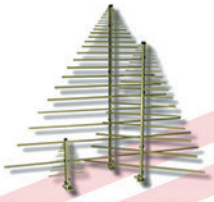

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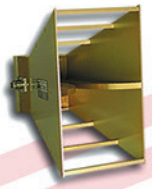

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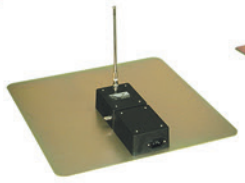

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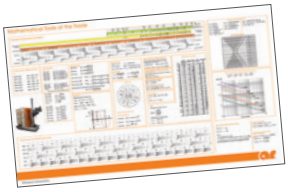

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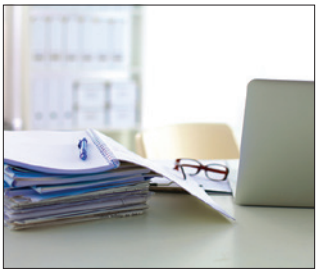

EU Commission Updates Standards for Certain Electrical Equipment

The Commission of the European Union (EU) has updated its list of harmonized standards that can be used to demonstrate conformity with the safety requirements of the EU's Radio Equipment Directive (2014/35/EU, or RED).

Commission Implementing Decision (EU) 2022/713 specifically updates harmonized standards originally detailed in Annexes I, II, and III of Commission Implementing Decision (EU) 2019/1956. Compliance with the requirements of applicable harmonized standards in (EU) 2019/1956 confers a presumption of conformity with RED requirements.

New harmonized standards addressed in the update cover a short list of specific electrical and electronic products, including battery chargers, appliances for heating liquids, instantaneous water heaters, thermal-storage room heaters, toilets, and certain other electrical equipment designed for use within certain voltage limits.

FCC Addresses International Robocall Scammers

As part of its ongoing battle against robocall scamming activity, the U.S. Federal Communications Commission (FCC) is now taking steps to stop illegal robocalls originating from outside of the U.S.

In a Sixth Report and Order, the FCC moved to implement new rules applicable to so-called gateway providers, the key pathway for international call traffic. The rules require them to institute compliance measures and procedures to ensure compliance with the FCC's STIR/SHAKEN caller ID authentication protocols and to take additional steps to validate the true identity of the providers they service, including efforts to trace illegal robocalls to their source.

According to the FCC, international robocall scams represent a disproportionately large number of robocall and spoofing activities in the U.S. It cites statistics from the Industry Traceback Group that estimates that 65% of service providers found to be transmitting illegal robocalls were either based outside of the U.S. or were gateway providers.

Electro-Pollution: A Potential Source of Sleep Deprivation and Stress

Modern life would be very different without access to state-of-the-art wireless technologies. But the benefits of these technologies may be offset by the adverse impact that continuous exposure to "electromagnetic pollution" has on our physical and mental health.

That's the conclusion of an article written by researcher and author Trevicia Williams and recently published on the website of *Psychology Today*. According to the article, environmental factors including exposure to electricity, electromagnetic field (EMF) radiation, and other forms of electro-pollution can directly affect the body's own electrical and biochemical response mechanisms, leading to imbalances in how we feel and think.

The problem is exacerbated when we sleep with EMF radiation-emitting devices in close proximity. Reportedly, the human pineal gland interprets EMF radiation as a form of light, thereby interfering with the production of melatonin which helps us to sleep. And EMF radiation also disrupts our circadian rhythms, impacting our ability to stay asleep.

The article offers a short list of suggestions for minimizing the impact of electro-pollution, including removing electronics from your sleeping area, use of a battery-powered alarm clock instead of your smartphone, and replacing wireless forms of connected devices with wired alternatives.

FCC Regulatory Process: Safety is Just One Consideration

The regulatory development process often devolves into a debate over competing interests

Many people believe that the U.S. Federal Communications Commission (FCC) focuses primarily on public safety considerations when developing regulations to address radio spectrum allocation issues. But, in reality, the regulatory development process often devolves into a debate over competing interests, with safety being just one factor that's considered.

This perspective is shared in detail in an insightful article published on the IEEE Spectrum website, written by Mitchell Lazarus, an engineer and telecommunications attorney.

While the FCC's established rulemaking process appears open and transparent, Lazarus argues that extensive engineering studies submitted by both proponents and opponents of new frequency usage and allocations are often based on different assumptions about transmitter and receiver characteristics and the interaction between the two. As a result, these opposing perspectives can produce significant differences in the results.

Further, according to Lazarus, study outcomes rarely result in a "binary yes/no," but "as differing probabilities for various degrees of interference." As a result, the FCC is faced with the task of evaluating a range of conflicting uncertainties, typically leading to a solution that attempts to balance both sides of the dispute, with safety just one of several considerations.

Lazarus cites several examples of the regulatory process complexity. These include the recent debate over whether the widespread introduction of 5G services could interfere with aircraft radar altimeters, putting planes and their passengers at risk. He also discusses in detail the controversy over the FCC's proposal to add Wi-Fi to the 6-GHz band, and the basis for the differing conclusions offered by proponents and opponents of the proposal.

A BIAS TEE FOR BROADBAND MEASUREMENT OF POWER ELECTRONIC COMPONENTS

By Michael Fuchs, Christoph Maier, and David Pommerenke

Editor's Note: *The paper on which this article is based was originally presented at the 2021 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMC, SI & PI), where it received recognition as the Best Symposium Paper. It is reprinted here with the gracious permission of the IEEE.*

INTRODUCTION

In many EMC applications, passive components need to be characterized to provide simulation models and physical insight into the dominant processes within these components. Passive filters consist of inductors and capacitors, some of which are 3- or 4-terminal devices, such as common-mode chokes. For small signals, these components can be considered linear with respect to voltage and current. However, in many applications, non-linear effects must be considered and characterized. This can be achieved with a time-domain large-signal approach or by linearization around certain bias points. Linearized characterization of potentially non-linear devices such as filter inductors or capacitors requires simultaneous excitation of the small-signal evaluation signal and the large-signal bias, which is current for inductors and voltage for capacitors. The most commonly used method relies on a vector network analyzer (VNA) and a bias network to apply the large signal bias.

For higher current or voltage levels, external bias tees must be used for VNA measurements. In particular, when these span a wide frequency range, here from 9 kHz to 500 mHz, they present the following challenges:

- The calibration plane is moved away from the VNA to a position after the bias tee. The basic assumption of the VNA calibration is time invariance. Any changes in the path from the VNA to the calibration plane that occur after the time of calibration are not corrected. Thermal expansion, such as in inductors, and saturation due to current or capacitance changes caused by the bias voltage can change the RF characteristics of the bias tee. Therefore, a thermally well-designed, highly linear bias tee is required.
- The bias tee will influence the RF path. It connects inductors for the DC feed to the RF path and it interrupts the RF path to block the DC voltage from reaching the VNA. In principle, the VNA calibration compensates for these effects. Even if these effects were completely time invariant, they would reduce the dynamic range of the test system if the calibration had to correct for large changes in the RF path through the bias tee. Thus, the RF path through the capacitor and the decoupling through the inductors requires a design that minimizes the effects on the RF path and thus does not require strong compensation by the calibration.
- The energy stored in mH inductors at 10 A current can endanger the VNA if the current path to the DUT is suddenly interrupted. Simply adding transient voltage suppression (TVS) diodes to the VNA is difficult because large diodes are required to handle the energy, but they have larger capacitances that will negatively impact the RF path. A distributed protection solution is therefore required.

This paper shows design details of a linear bias tee for a frequency range of 9 kHz - 500 mHz which can handle 10 A continuously, or 30 A for 10 minutes and can be biased up to 500 V. Although there are countless publications on bias tees for high frequency applications, there are relatively few in the low frequency range and even fewer suited for high DC currents and voltages. In [1] it is stated that *"The proposed Bias-T was designed for the target values* I_{DCmax} = 1 A *and* U_{DCmax} = 150 V *at the lower frequency* f_{min} = 2 mHz *and at the current minimum bandwidth of*

B_{min} *of* 100 mHz" while in [2] the targeted frequency range reaches from 300 kHz to 100 mHz with a maximum DC current of 3A. Both publications do not present any considerations regarding the protection concept and also target lower bandwidth and smaller DC currents and voltages. In [2], coils with iron core are used, which probably results in the need to make several calibrations for different DC current values to account for the influence of saturation effects. However, no information was given in this respect.

For very low frequencies there are also interesting active solutions for bias tees [3], which again cannot be used for higher frequencies. However, the bias tee published in this paper is intended to be used primarily for the measurement of conducted electromagnetic emissions, for which a lower frequency limit of 9 kHz is quite adequate. A passive solution is therefore preferred.

Although some of the concepts described regarding the construction of the individual components are already known in the literature, to the best of the authors' knowledge, there are no publications yet on such a composition for the construction of a bias tee. The particular advantage of this special form of bias tee is the possible use for small-signal characterization of power electronic components while maintaining high large-signal bias currents and voltages. By measuring the S-parameters of various power electronic components and measuring the changes due to bias over a large frequency range, valuable data can be easily obtained for modeling the behavior of these components under large signal bias. Measurements of this configuration show good results regarding important properties of the tee, like insertion loss, return loss and temperature behavior.

DESIGN OF THE BIAS TEE

Figure 1 shows four common bias tee consisting of a DC block capacitor and an RF decoupling inductor. The general topology of a bis tee is maintained in this design. The core challenge is the design of the components for the needed inductance, capacitance, voltage and current values and their physical arrangement in a bias tee such that four of those bias tees can be arranged to form a 4-port measurement system, like depicted. The schematic of the proposed bias tee is shown in Figure 2 and discussed in detail in the following sections.

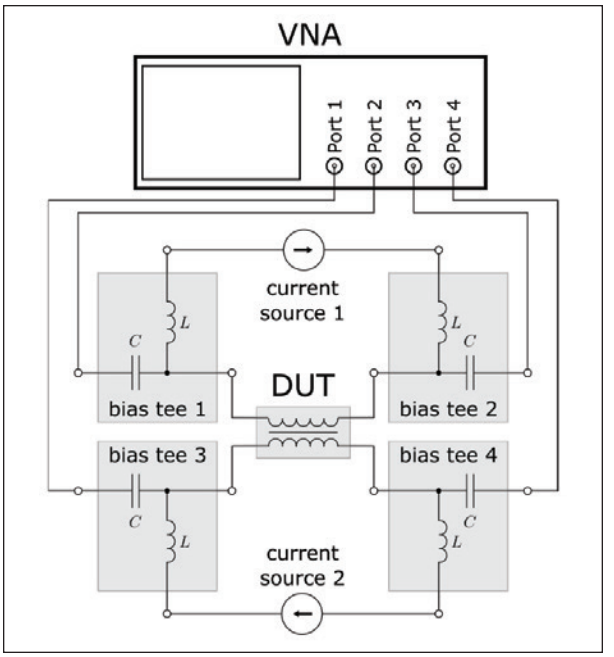

Figure 1: Possible test setup for measuring a common mode choke

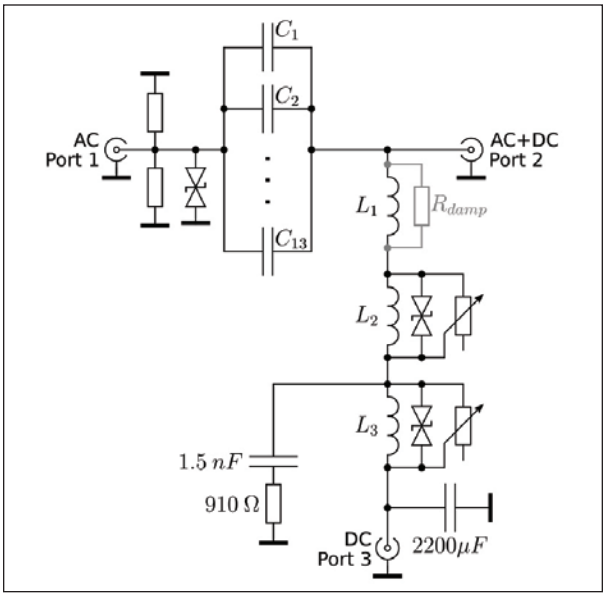

Figure 2: Schematic of the proposed bias tee

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Capacitors

The capacitor in a bias tee acts as a DC block, allowing RF currents to pass in the frequency range of interest. Lower minimum frequencies require larger capacitance values to avoid influencing the RF path. If 2 Ω is set as upper impedance limit for the capacitor a value of 8.8 µF is needed at 9 kHz. Linearity requirements up to 500 V exclude the usage of high K ceramics or electrolytic capacitors. This constraint increases the size of the capacitors such that the upper frequency limit becomes a challenge. The parasitic inductances and parasitic capacitances of the capacitor arrangement needs to be utilized to obtain low RF losses in the RF path. This is realized by a distributed arrangement of the capacitors seen in Figure 3.

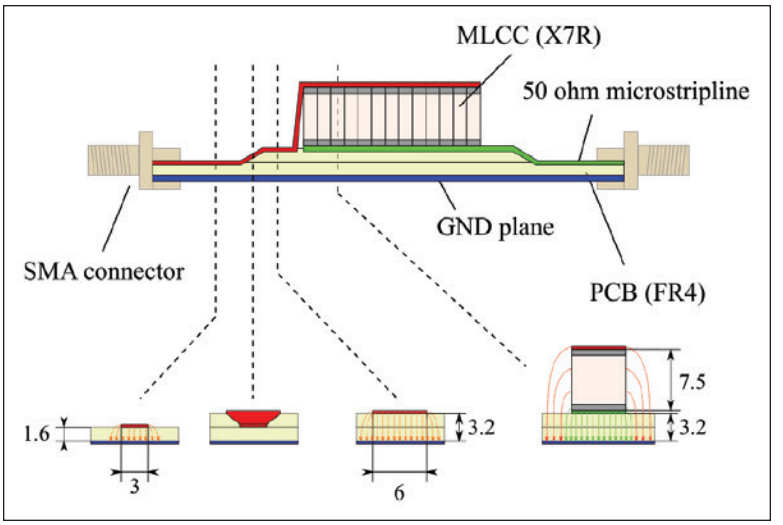

Figure 3: Design of the DC block capacitor with 50 Ω characteristic impedance. Copper layer thickness is not to scale. All dimensions are in mm.

To obtain a constant characteristic impedance of 50 Ω along the capacitor arrangement the structure must maintain a cross section that provides 50 Ω including the parasitic effects of the capacitors. To obtain the needed capacitance of about 8.8 µF a total of 13 capacitors of size 0.68 µF have been placed in parallel [4]. The capacitor has a width of 6 mm.

On a 1.6 mm FR-4 board a 3 mm wide trace leads to a 50 Ω characteristic impedance. To distribute the capacitances along the transmission line, thus to allow for a undisturbed TEM wave the capacitors are placed vertically, like it is shown in Figure 3. To match the trace width to the width of the capacitors two layers of 1.6 mm FR-4 are used creating a 6 mm wide microstrip line which allows placement of the capacitors without interrupting the RF path. Two carefully designed transitions guide the RF signal from the 3 mm wide trace to the 6 mm wide trace. Figure 4 shows the results of the designed microstrip line using a TDR measurement with a bandwidth of 14 GHz. It can be seen that the capacitive coupling of the TVS diodes used to protect the VNA, as discussed in the section “Protection Concept,” have an influence on the line. This influence can be counteracted by changing the diameter of the microstrip line at the point where the diodes are connected.

Although the capacitors are voltage-dependent due to their dielectric (X7R), this only has a negative effect on the behavior of the bias tee in the lowest frequency range, where large capacitance plays a decisive role. Class 2 X7R capacitors promise a maximum capacitance change of 15 % at nominal voltage.

Inductors

For the calculation of the necessary inductance values, a minimum impedance of 43 dBΩ (referred to 1 Ω) was aimed at. At the minimum frequency of 9 kHz this results in a necessary minimum inductance of about 2.5 mH. The needed bandwidth and current

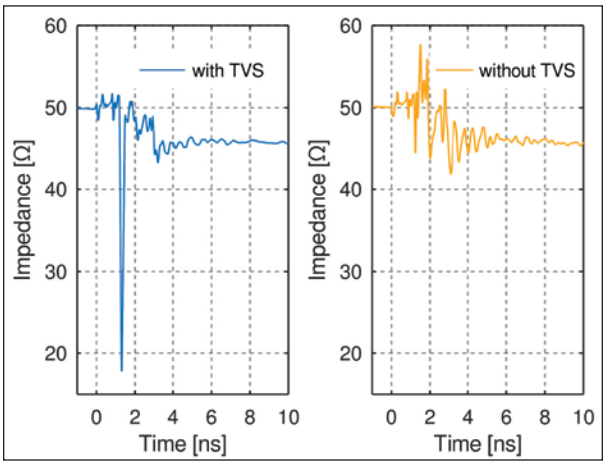

Figure 4: TDR measurement of the designed capacitor with and without TVS diodes as protection device

carrying capability poses several problems for the inductor design. High currents require thick wires which adds parasitics at high frequencies; not being able to use cores because of saturation effects increases the inductor size, which again is detrimental to the RF performance and the use of large value inductors increases the difficulty of over-voltage protection of the VNA in case the DUT current is suddenly interrupted. In addition, large coils have greater DC resistance and thus higher power dissipation, which leads to increased temperatures in the package (see the section "Temperature Behavior").

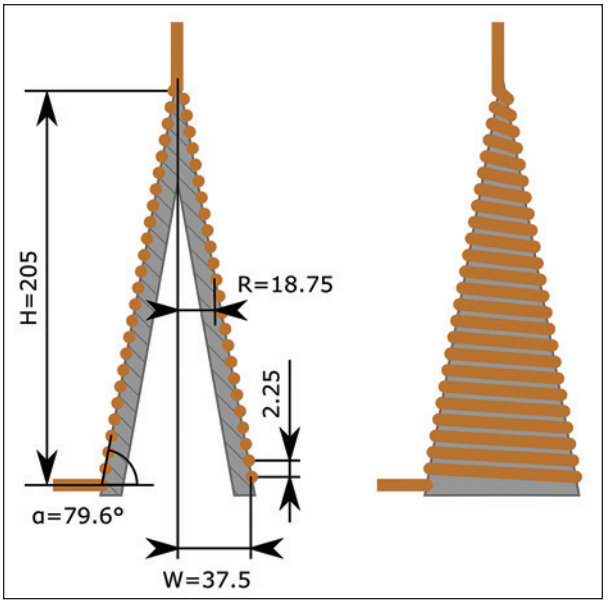

Figure 5: Design of the conical inductor with dimensions in millimeters

In order to optimize the behavior at high frequencies, a conical coil (L_1), shown in Figure 5, was used. Following the design in [5] the conical inductor was connected to the 50 Ω microstrip line that holds the DC block. The advantages of a conical design over a cylindrical inductor can be seen in Figure 6. The conical shape improves the RF performance however, it offers less inductance compared to a cylindrical inductor having the same number of turns and length. Both inductors in the plot have the same

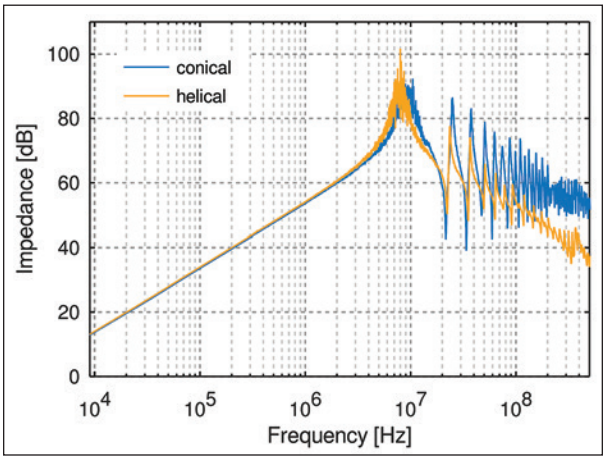

Figure 6: Comparison of the frequency characteristic of a conical and a helical inductor

After the first resonance, the conical inductor shows a series of resonances maintaining in average higher impedance relative to its cylindrical partner.

inductance and do not use a magnetic core. Up to the resonance, no differences are visible. However, after the first resonance, the conical inductor shows a series of resonances maintaining in average higher impedance relative to its cylindrical partner. The distribution of these additional resonances depends on details of the winding, the wire diameter and the distance between the wires. The higher the frequency, the more important is the design of the tip of the conical inductor and its connection to the 50 Ω trace. According to [6] the inductance of the conical inductor can be derived from the inductances of related cylindrical and spiral inductors. The inductance of a spiral inductor in µH is given by Equation 1 where R is the mean radius of the inductor in mm, W is the radius difference on both cone ends in mm and N is the number of windings.

$$L_S = \frac{1}{25.4} \cdot \frac{(N \cdot R)^2}{8R + 11W} \quad (1)$$

The inductance of a cylindrical (helical) inductor is given by Equation 2, where H is the coil height in mm and again R and N are the mean radius and the number of windings respectively.

$$L_H = \frac{1}{25.4} \cdot \frac{(N \cdot R)^2}{9R + 10H} \quad (2)$$

Using L_S and L_H the inductance of a conical inductor can be obtained by Equation 3 where α is the angle of the conical inductor, being 0° for a totally flat inductor.

$$L = \sqrt{(L_H \cdot sin(\alpha))^2 + (L_S \cdot cos(\alpha))^2} \quad (3)$$

For this coil an inductance of about 63 µH is calculated with the geometrical values given in Figure 5. For achieving an inductance value of 2.5 mH the conical inductor would need to be more than three times as long, which is why two further coils of higher inductance (L_2 = 0.27 mH and L_3 = 2.2 mH) had to be connected in series behind it to reach the desired inductance value. The coils have a total DC resistance of 300 mΩ and thus dissipate 30 W at 10 A DC current.

Dampening

The coil assembly forms a complex system of the nominal coils and parasitic capacitances between the windings, to the enclosure and between the coils. This leads to a multitude of resonances, which was already shown in Figure 6 for the conical inductor itself. These resonances have a threefold negative effect on the system performance:

- The anti-resonances may reach low impedance values. Those are placed in parallel to the 50 Ω trace, thus, at those frequencies the S12 of the RF path is diminished. This requires stronger correction during calibration.
- Even if they could be compensated by calibration, they must remain time invariant. Small geometrical changes, e.g., thermally induced may move the resonances. The higher the Q-factor is, the stronger small changes will impact the impedance.
- The inductors will warm up to 60 °C at 10 A current. This increases the wire resistance which increase damping. If the calibration would be based on high Q resonance even this small change may lead to an inaccurate correction during measurements by the stored calibration values.

Thus, it is advisable to introduce losses that dampen the resonances. This will reduce the impedance at resonances and increase the impedance at anti-resonances. Of the several available damping methods, electrically lossy material placed near the conical inductor was used for the first stage inductor, represented by R_{damp} in Figure 2. Magnetically lossy material would pose the risk of introducing non-linear behavior due to the large DC current. Placing a resistor across the conical inductor would add parasitic capacitance to the connection point at the DC block

on the RF path. The disadvantage of the electrically lossy material is its blocking effect on the cooling of the coil.

For the other inductors adjustable resistors have been placed in parallel to allow for a smooth impedance behavior which leads to a smooth loss characteristic show in Figure 8.

Protection Concept

A maximum permissible direct current of 10 A will store about 126.5 mJ of energy in the inductors. This energy is divided among the three inductors (E_{L1} = 3 mJ, E_{L2} = 13.5 mJ, E_{L3} = 110 mJ).

Without protection, a sudden interruption of current flow through the DUT, e.g., a solder joint breaks, will dissipate the stored energy into the VNA (RIP). Protective devices such as transient voltage suppressor (TVS) diodes are well suited to protect the VNA. If they are placed directly in the RF path, their capacitance needs to be kept small to avoid further disturbances on the RF path. However, those diodes cannot handle the energy. The problem is resolved by distributing diodes across the inductors. The high value inductors store most of the energy, but their electrical function is limited to lower frequencies, thus TVS having larger capacitance of about 100 pF can be used [7]. No TVS is placed across the conical inductor, instead 2.5 pF TVS are placed on the RF path [8].

A second protection problem arises from the 1.1 J stored in the DC block capacitors. If the DUT is suddenly shorted to GND the 8.8 µF charged at 500 V would be discharged into the VNA (RIP). The low capacitance diodes placed to protect against the energy in the conical inductor cannot handle the energy. A second level protection is needed. This is realized by placing polymer based snap back devices from the RF path to GND [9]. These devices offer very low capacitance < 0.05 pF, a fast turn on of 0.1 ns. After internal breakdown within the component, they clamp at about 25 V DC. The amount of energy in the DC block capacitor can destroy them and the TVS devices, but they protect the VNA in case of a short circuit.

Internal DC Block of the VNA

An additional problem for this circuit is the internal DC block of the VNA. Since it has a small capacitance

compared to the DC block of the bias tee, a capacitive voltage divider is created, which means that at high DC voltages, a voltage would always be present at the input of the VNA and could destroy it. Therefore, two parallel 10 kΩ resistors are connected between internal and external DC block against ground. These dissipate a slowly changing DC current until the large capacitor of the external DC block is full and the internal DC block can no longer be charged.

The Complete Bias Tee

After initial measurements, discussed in the following section, an additional capacitor with 1.5 nF and resistor with 910 Ω was inserted between L_1 and L_2, as shown in Figure 2, to further flatten the insertion loss curve. Furthermore, an additional capacitor of 2200 µF was added to the DC port to ensure a well-defined impedance to ground which is independent of the impedance of the DC source. Figure 7 shows the complete bias tee with all components. These were installed in a die- cast aluminum housing, which on the one hand reduces the susceptibility to interference and on the other hand ensures temperature stability.

MEASUREMENTS AND VERIFICATION

The verification covers linear frequency response, temperature behavior and linearity check at high currents and voltages.

Frequency Response

To verify the linear behavior the S-parameters of two identically built bias tees have been measured. Because of the well-defined impedance due to the large capacitor at the DC port, port 3 can be left open during calibration. In Figure 8 an insertion loss measurement of the two bias tees is depicted, which shows very satisfying results from 9 kHz up to a frequency of about 500 mHz with an insertion loss of less than 1 dB and an insertion flatness of about 0.5 dB. Above 500 mHz, the insertion loss increases to 2 dB at 1 GHz, largely due to the high frequency characteristics of the conical inductor. Measurements using conical coils with thinner wire showed better properties here but cannot pass the DC current. It can also be seen from the return loss measurement in Figure 9, that even though the two shown bias tees are built identically, their return loss differs quite significantly. This is the effect of slightly different coils and potentiometer settings. In general, one could create an S-parameter set for each bias tee and use this for de-embedding. Even though this procedure would

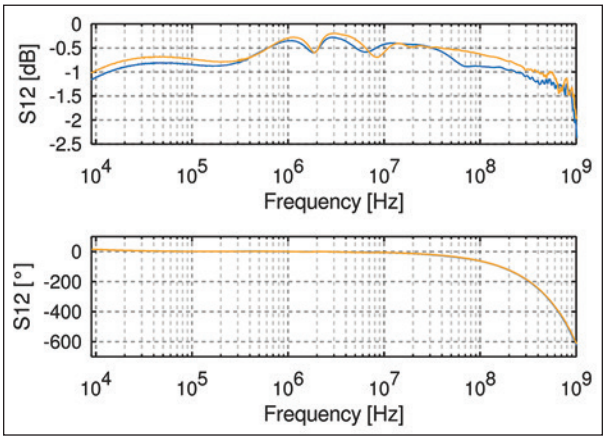

Figure 8: Insertion loss of two identically built bias tees

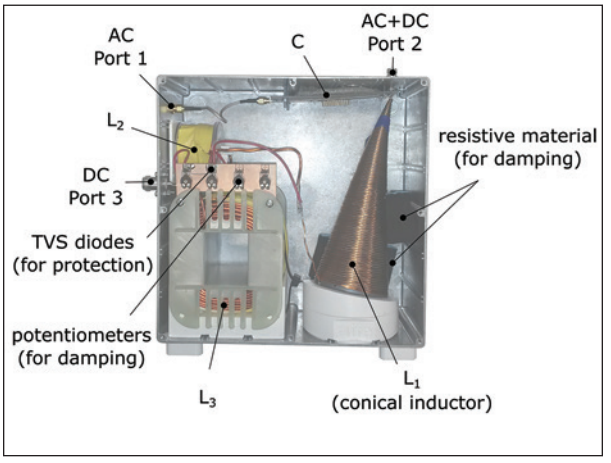

Figure 7: Picture of the bias tee in aluminum housing

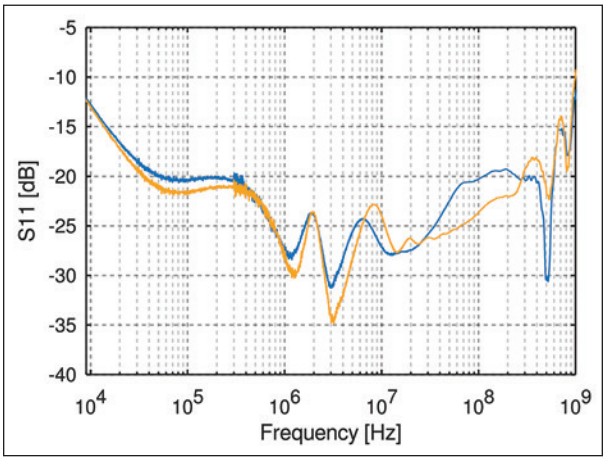

Figure 9: Return loss of two identically built bias tees

result in better measurement performance, one would need the de-embedding profiles for each individual tee and must never interchange the bias tees for each measurement. Instead, a self-made calibration kit with previously measured de-embedding parameters was used. Two bias tees and the self-made calibration kit (TOSM) was used for calibration, which works regardless of the arrangement of the bias tees. For the final measurement, shown in Figure 1 a four-port calibration has to be done. In general, all calibration methods can run into the same limitations, which are small remaining non-linearities or mechanical changes due to heat or mechanical instability.

Temperature Behavior

The DC resistance of the coils (R_{L1} = 0.1 Ω, R_{L2} = 0.04 Ω, R_{L3} = 0.16 Ω) leads to internal heating at high currents. A stress test of the bias tee was carried out in the course of an initial test. The bias tee was loaded with 10 A DC current for 30 minutes causing the temperature at the tip of the conical inductor to increase to 60 °C. No forced cooling was applied. No significant heating was detected elsewhere in the enclosure.

Protection Circuit Response

The maximum voltage at the input of the VNA in the event of a fault is specified by the manufacturer as 30 V. The protection circuit, described in Sec. II-D was tested by connecting two bias tees in series and a fuse with 10 A rated current which should simulate a sudden interrupt of current flow. A DC current of 25 A was applied to the test setup with a 50 Ω dummy load and a small capacitor as DC block instead of the VNA. The resulting voltage at the dummy VNA did not exceed the maximum allowed voltage of 30 V and the resulting energy of about 125 µJ does not pose any danger to the input of the VNA.

The presented bias tee shows good frequency response over a wide frequency range and can be loaded with high DC currents and voltages. Measurements show that the behavior of the bias tee is not influenced by DC bias currents.

Linearity Check

Figure 10 shows an S12 measurement of two bias tees connected in series at different DC bias currents. It can be seen that the DC bias current causes practically no difference in the behavior of the tees up to 25A.

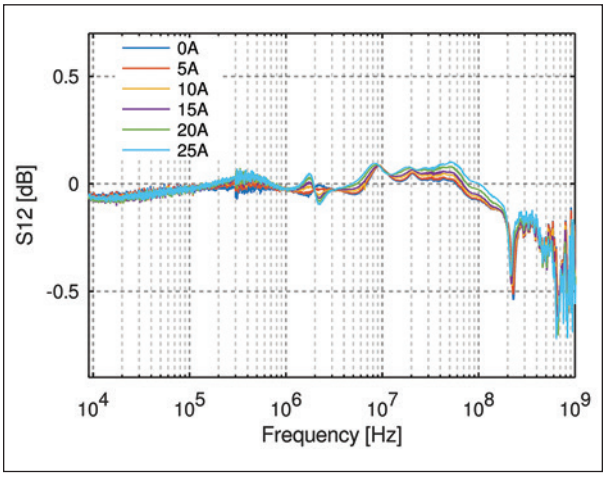

Figure 10: Insertion loss of two bias tees in series

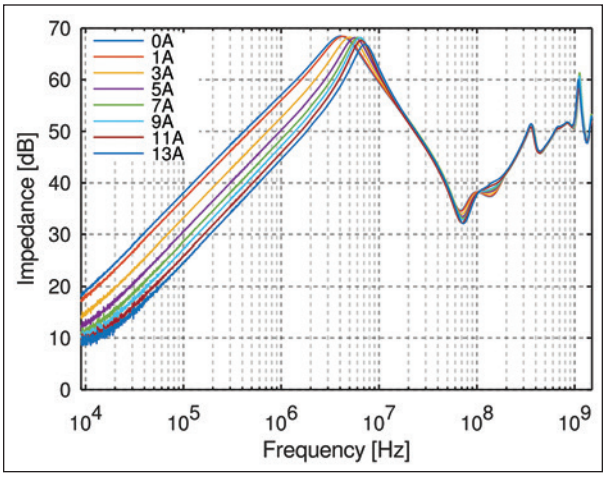

Figure 11: Measurement of an inductor with different DC bias currents.

Measurement of an Inductor

Figure 11 shows a test measurement of an inductor [10] at different DC bias currents between 0 A and 13 A. Saturation effects due to the DC bias current can be observed in the lower frequency range by a shift towards the right. At higher frequencies not much changes due to the bias current, since the permeability of the material has reduced to a level at which the flux cannot reach saturation levels.

CONCLUSION

This paper shows a way to build a bias tee for power electronics applications. Especially if saturation effects of coils or larger filter elements in a low frequency range are to be investigated, this bias tee offers a possibility to tackle this problem with the help of vector network analysis. This allows to measure a device under test in magnitude and phase to gain detailed conclusions about its frequency behavior. The data can then be used to optimize filter circuits in real application situations, or to generate load-dependent models of these filters. The presented bias tee shows good frequency response over a wide frequency range and can be loaded with high DC currents and voltages. Measurements show that the behavior of the bias tee is not influenced by DC bias currents. When these bias currents are abruptly interrupted, the presented protection circuit serves to protect the measurement equipment.

ACKNOWLEDGEMENT

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Why the Growing Interest in Reverberation Chambers?

Reverberation chambers have been in use for decades with usage largely limited to automotive and aerospace test applications. Now, with the ongoing development of increasingly complex electronic/electrical systems, reverberation chambers are seen as a robust alternative for EMC and Wireless testing for an increasing range of products.

What are you seeing in terms of electronics and electrical systems becoming increasingly complex?

In the automotive and aerospace industries, the sensing, control, and communication electronics have become increasingly interconnected to provide automated, advanced, and autonomous features. In these cases, the consequences of interruption or interference may be catastrophic or even life threatening. For example, in the automotive industry, lane keeping assistance and adaptive cruise control rely on the input of several sensors such as RADAR, camera, and in some cases LIDAR. These features may be integrated with the automatic control of acceleration, breaking, and steering – an interruption anywhere in the communication chain could cause problems. Similarly in the aerospace industry, autopilot is commonly used; this feature and the new emergency auto-land capability may be vulnerable to interference from other radiating sources. For example, we're seeing the potential concerns with 5G and aircraft radio altimeters.

What are the new applications of reverberation chambers for EMC and Wireless testing?

In the automotive industry, small component sized reverb chambers have been in use for system-level immunity testing to several international and manufacturer standards for decades; more recently, work has begun on a new standard to extend this to full vehicle immunity testing. An early draft of ISO 11451-5 introduces several enhancements to traditional reverb chamber methods to improve reliability, accuracy, and flexibility. A goal is to provide an alternative to the direct illumination methods in an anechoic chamber so that the multiple interconnected systems commonly seen can be immersed in the RF test fields in a manner representative of real exposure threats. Wireless device tests also typically performed in an anechoic chamber have seen alternate test standards under CTIA and 3GPP which describe reverb-based methods. ANSC C63® is also working on using reverb chambers as a method of measuring spurious emissions of wireless devices.

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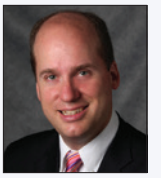
Can a reverberation chamber provide useful data compared to an anechoic chamber method for new applications, such as testing wireless devices?

Wireless tests in an anechoic chamber are usually centered on antenna pattern measurements from which the performance metrics such as TRP/TIS/EIRP and other related parameters are derived. The pattern measurement provides spatial information, the accuracy of which depends on the positioning resolution of systems used. In most cases, this has a direct impact on overall measurement time. In contrast, the reverb environment samples the temporal power density in the chamber which is directly related to the total power radiated by the device to provide an indication of overall peak or average radiated power. This testing can potentially be performed much faster in a reverb chamber that is less costly than an anechoic chamber so it is has attractive advantages. Chamber comparison results so far are very encouraging.

THE RISE OF TIME-SENSITIVE NETWORKING (TSN) IN AUTOMOBILES, INDUSTRIAL AUTOMATION, AND AVIATION

IEEE Standards Association advances new TSN application profiles as adoption increases across industry sectors

Glenn Parsons is the chair of the IEEE 802.1Working Group and a principal standards advisor for Ericsson. Parsons is an internationally known expert in networking, including mobile transport and Ethernet, and is currently involved in 5G transport standardization efforts with the IEEE SA and ITU-T. Parsons was also the founding Editor-in-Chief of IEEE Communications Standards Magazine. He can be reached at glenn.parsons@ericsson.com.



By Glenn Parsons

Ethernet is one of the most widely adopted technologies for the transmission of data between devices and is used in many industries because of its speed, affordable cost, and versatility. Over the years, Ethernet standards have evolved to meet increasing needs to transmit more data faster. However, in addition to speed, a key performance factor – determinism – is influencing the increasing need for time-sensitive networking (TSN).

A deterministic system is a system in which no randomness is introduced in future states of the system, thus allowing a deterministic network to exchange packet data in a precise manner with a defined latency. Because data exchange in Ethernet networks lacks determinism with its packet buffering and varying queuing delays, deterministic data exchange in Ethernet has, until recently, only been possible with proprietary solutions.

TSN, a relatively new technology, is making Ethernet bridged networks deterministic by design – guaranteed data transport with bounded low latency, low delay variation, and extremely low loss. Today, TSN is notably leveraged in industries where deterministic communication is important, such as automotive, manufacturing, aerospace, transportation, and utilities applications.

TSN STANDARDS

TSN is the focus of a series of standards from the IEEE Standards Association (IEEE SA) under development by the IEEE 802.1™ Working Group's Time-Sensitive Networking Task Group. The standards define mechanisms for the time-sensitive transmission of data over deterministic Ethernet networks. TSN is not addressed in a single standard. Rather, its collection of capabilities are governed and managed by several separate IEEE standards. TSN uses a profiles approach, which defines the specific set of features, options, configurations, and protocols appropriate for a particular set of TSN applications. Some profiles are well defined, while others are still works in progress.

TSN IN THE AUTOMOTIVE INDUSTRY

Functionality advancements and driver features in today's automotive systems require high-bandwidth and low-latency in-vehicle communications. Innovation in automotive technology is focused on both hardware and software for an increasing number of applications, including but not limited to adaptive cruise control with stop-and-go, lane departure warning, blind-spot warning, traffic sign recognition, night vision, active headlight system, parking automation, efficient dynamics, hybrid engines, internet access, telematics, online services, Bluetooth integration, local hazard warning, personalization, SW update, and smartphone apps.

This list goes on and continues to grow with the pace of new, innovative features and, of course, the advent of autonomous vehicles.

Embedded software is a key enabler for advanced functionality and features in automotive systems, which is becoming more complex and requiring increasing amounts of source code. And software complexities lead to more challenges such as requirements for timing predictability and the distribution of software over electronic control units (ECUs), just to name two.

In the automobile sector, Ethernet is the answer for several reasons, including:

- Data needs such as raw camera data, data logging, map data, backbone aggregation, high-resolution displays, and in-vehicle Wi-Fi hotspot (carrier link aggregation) wired backhaul;

To leverage Ethernet, the TSN protocol can precisely guarantee the time certainty of the key signals of automotive Ethernet.

- Latency requirements, with the minimum need determined by hardware and the maximum determined by software;
- Services, including precise time awareness, redundancy/fail-over, and security;
- More challenging standards for fuel economy, oftentimes by pioneering and using lighter weight materials; and
- Reduced costs for vehicle manufacture, an underlying reason that cannot be ignored.

To leverage Ethernet, the TSN protocol can precisely guarantee the time certainty of the key signals of automotive Ethernet. Accurate timing and guaranteed data delivery are critical in the automotive environment. IEEE 802.1AS™ provides timing accuracy in the sub-microsecond range, which is required as Ethernet usage grows within the vehicle. In addition, other IEEE and TSN standards provide secure, ultra-reliable, bounded low-latency communications throughout the vehicle at multiple data rates.

Cabling is the third highest cost component in a car, with the engine being first followed by the chassis. Wire harnesses are constructed one at a time, with half of the cost coming from labor. And the wire harness also is the third heaviest component in a car. We can clearly see that reducing the cable weight in a vehicle will directly impact its fuel economy. Thus, because the in-vehicle wiring plant is a tremendous challenge with regards to weight and space coupled with higher throughput requirements for automotive sensors, various PHYs targeting automotive are available today, including 2-wire 10 Mb/s (IEEE 802.3cg™), 100 Mb/s (IEEE 802.3bw™), 1 Gb/s (IEEE 802.3bp™) and 2.5/5/10 Gb/s (IEEE 802.3ch™).

Previously known as the audio video bridging (AVB) series of standards, which are successfully used in automotive infotainment systems today, AVB has evolved into time-sensitive networking in order to reflect the expanded scope of work toward autonomous driving.

In the automotive sector, TSN is leveraged to achieve:

- *Time synchronization*—IEEE 802.1AS maintains synchronized time (+/- 500 nsec worst case) and supports scheduling-bounded low-latency traffic through the network where required while also allowing asynchronous traffic.
- *Very low jitter*—IEEE 802.1AS reduces jitter associated with audio/video, command, sensor, and control packet delivery to upper layers.
- *Bounded low latency*—Time scheduled traffic (IEEE 802.1Qbv™) and preemption (IEEE 802.1Qbu™) are combined with no need to compress video and other advanced driver assistance systems (ADAS) data (since speeds up to 10 Gbit/s allow multiple channels of high-definition video). As a result, the use of TSN avoids the latency and processing power penalties associated with compressions and decompression.
- *Ultra-reliability*—TSN provides reliability in the network (IEEE 802.1CB™ - frame replication and elimination), protection from errant devices (ingress policing), and backup for network timing master (standby GM).
- *Security*—Authentication of installed devices (IEEE 802.1AR™ - secure device identity), segregation of traffic types and flows between authorized devices, message integrity, and authenticity are possible.
- *Fast startup*—Preconfigured values for timing and bandwidth reservation allows quick startup followed by an optional transition to negotiated values for dynamic adjustments.
- *Faster updates*—Firmware updates are quicker with Ethernet's higher speed.
- *Information sharing*—A homogeneous Ethernet network allows instant sharing of information between allowed devices without the delays and security risks associated with interconnecting different bus types through gateways.

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- Order free samples directly
- Direct access to product datasheets
- Comfortable and clear component selection

While there are several proprietary solutions available, TSN can help standardize real-time Ethernet across the industry.

TSN IN MANUFACTURING

A prevalent need for deterministic Ethernet can be found in industrial automation in the ongoing quest to achieve fast, deterministic, and robust communication. While there are several proprietary solutions available, TSN can help standardize real-time Ethernet across the industry.

IEEE 802.1 TSN is an enabler of Industry 4.0, such as the smart factory of cyber-physical systems. TSN is the foundation that provides connectivity and real-time quality of service to time and mission-critical industrial applications on converged networks of operations technology and information technology and converging multiple independent applications in one network, enabling real-time communication on the same infrastructure (cables, bridges). TSN meets these requirements by providing interoperability via open standards. TSN provides synchronization and supports real-time communication, for example, closed loop control over a single standard Ethernet network.

IEEE SA and the International Electrotechnical Commission (IEC) have established a joint project, the IEC/IEEE 60802™ Time-Sensitive Networking Profile for Industrial Automation, so that the right mix of experts is involved in defining the use of TSN for industrial automation. By selecting TSN features and describing their use including configurations and defaults, the IEC/IEEE 60802 standard aims to benefit vendors offering and/or developing TSN products as well as the users of industrial automation technologies.

In smart factories, TSN provides guaranteed data transport with bounded low latency, low jitter, and extremely low data loss. In the manufacturing sector, TSN is leveraged to achieve:

- *Time synchronization*—IEEE 802.1AS maintains synchronized time (+/- 500 nsec worst case) end-to-end, i.e., including the devices running the control applications. Time synchronization is the basis of multiple TSN quality of service (QoS) solutions, e.g., time-based scheduling.
- *Bounded low latency*—TSN includes multiple solutions to provide bounded low latency, e.g., time-scheduling, preemption, and traffic shaping mechanisms. Time synchronization and TSN QoS solutions can reduce packet delay variation (jitter).
- *Resource management*—Standard protocols, data models, and interfaces to dedicate resources for time and mission-critical traffic.
- *Zero congestion loss*—TSN provides zero congestion loss via the bounded low latency and the resource management solutions.
- *High availability/ultra-reliability*—TSN provides ultra-reliability and high availability in the network up to seamless communication over redundant paths (frame replication and elimination), protection from errant devices (ingress policing), and backup for network timing master (standby grandmaster).
- *Security*—Authentication of installed devices, segregation of traffic types and flows between authorized devices, message integrity, and authenticity are possible.
- *Converged network*—TSN supports multiple traffic classes that may have very different requirements. Thus, control data traffic in real-time and multiple independent applications using the same network can be carried together with best-effort traffic in the same network infrastructure, increasing the economic feasibility of the network.
- *Interoperability*—TSN leverages the benefits of existing IEEE 802.3 Ethernet, e.g., diagnostics; thus, TSN is applicable in brownfield deployments. A common information model for the network resources enables common TSN engineering and diagnostics. The harmonized interfaces and the protocols for stream set-up support interoperability. Variants should be limited by a harmonized TSN profile for industrial automation, i.e., IEC/IEEE 60802, to enable multi-vendor networking to interconnect different bus types used in end stations.

TSN IN THE AVIATION INDUSTRY

In the aviation sector, high-bandwidth and low-latency communications are required for technology-rich modern aircraft for avionics, sensors, communications, and entertainment systems, all of which rely on on-board networks. For many years, Ethernet has been the network infrastructure protocol of choice. More recent innovations, notably on commercial aircraft, include advanced avionics systems, onboard Wi-Fi, in-flight entertainment, and connectivity (IFEC) systems, global position system (GPS) data, and more.

IEEE P802.1DP™ / SAE AS6675 is a joint project of IEEE 802 and SAE Avionics Networks AS-1 A2 to define TSN profiles for aerospace. This work will provide a jointly developed standard that serves as both an SAE and an IEEE standard. This standard specifies profiles of IEEE 802.1 TSN and IEEE 802.1 security standards for aerospace onboard bridged IEEE 802.3 Ethernet networks. The profiles select features, options, configurations, defaults, protocols, and procedures of bridges, end stations, and local area networks facilitate the design of deterministic networks for aerospace onboard communications.

Additionally, this standard specifies profiles for designers, implementers, integrators, and certification agencies of deterministic IEEE 802.3 Ethernet networks that support a broad range of aerospace onboard applications, including those requiring security, high availability and reliability, maintainability, and bounded latency.

CONCLUSION

As TSN continues to gain interest and use across multiple industries, so too does the demand for an increasing number of profiles – the selection and use of TSN tools for specific applications.

Join us in this initiative! The IEEE 802.1 Working Group welcomes participants from academia, government, and industry. We invite those interested in the noted application spaces or in new ones. For more information or to join the standards activity, please visit the TSN webpage at https://1.ieee802.org/tsn. To learn more, follow the latest news about our work at https://1.ieee802.org/category/latest-news.

CONTINUITY AND CHANGE IN INTERNATIONAL WIRELESS APPROVALS

Reflections on the Last 15 years

Michael Cassidy founded and runs MC Global Access LLC. He has left the Bay Area for his home state of Minnesota, where he lives with his wife, daughters, and adopted California dog that doesn't like winter. Cassidy can be reached at mcassidy@mcglobalaccess.com.

By Michael Cassidy

In 2007, before the cratering of the global economy, I began a job with Intertek's Global Market Access program. While job losses in the US accelerated, so did my early career. "I'll get laid off," I figured, "I'm an untrained newbie in a collapsing market." But I never did. I credited this to my low salary and Intertek's book of business. However, the truth was that manufacturers knew the headwinds and were still willing to export globally. I kept getting product certifications, and the flow never stopped. Fifteen years later, on the brink of another inflation-induced, war-torn, sanction-driven, and pandemic-fueled recession, the companies I represent are still looking ahead. They are still developing new products to introduce in new markets.

Macroeconomics aside, the process of certifying a wireless device across the globe hasn't changed much. New regulations continuously emerge while regulatory bodies add or drop burdens and requirements. Although these details are important, the big picture remains similar, and cooperation between countries, or the emergence of regulatory blocks, remains rare. Technology is making applications easier, but we have yet to see a reduction in regulatory burdens.

For example, if we compare today's Wi-Fi certification process in 30 major countries with the processes that were in place fifteen years ago, little has changed in terms of manufacturer requirements. (This is true of other wireless technologies as well). Even if the countries themselves have since eased or bolstered certain requirements, the average work required of a manufacturer has not evolved. For many countries, you can submit test reports prepared in support of US Federal Communications Commission (FCC) or European Union (EU) approvals. But you may still need to send samples for in-country testing to obtain approval in a handful of other countries. Many still require that a local representative or importer act as the applicant. Documentation and label requirements have been consistent.

The article explores a few key aspects of international approvals to illustrate areas of increasing and decreasing difficulty, as well as areas with little change.

MODULAR APPROVAL

During my first meeting with an industrial manufacturing client, a compliance engineer asked me, "can we get 'modular approval' in any country?" What he meant was, "if we have eight devices that all use the same model of module, can we just certify that module in any country?" By doing this, he would be getting one certification instead of eight. In this hypothetical scenario, the module likely already had FCC, Industry Canada, and EU compliance approvals but not approval or certification in other global markets. Now, 15 years later, modular approvals are facing increasing restrictions. Let's look at two major markets for US exporters, Brazil and Mexico.

Instituto Federal de Telecomunicaciones (IFT), Mexico's telecom authority, moved to restrict modular approvals in January 2021. As a result, a manufacturer's end-product must comply with Mexico regulations and certification requirements. The manufacturer can no longer leverage certification for the RF component or any modular approval.[1,2] This generally means the manufacturer must complete testing in Mexico.

In-country testing has long been an IFT requirement for common wireless products. So, in that regard, we see continuity. The difference is that the Mexico testing laboratory now needs to test the end-product. Although the IFT does allow family groupings in some instances, the additional requirement of testing end-products can be burdensome, especially for medical or other manufacturers of expensive products.

The following question has remained relevant and necessary for the past 15 years. Can a manufacturer apply for wireless approval as a foreign manufacturer/entity, or does the application need to come from a local representative in the country?

Going back to the previous example, an industrial manufacturer may not be able to simply certify its module. But it may be able to test one model of its end units and add the other models to the certificate. Mexico's added requirements are noteworthy but not representative of a sea-change in the global certification sphere.

The Wireless Planning & Coordination Wing (WPC) of India has moved away altogether from allowing modular certifications and is limiting the use of module test reports. Any device falling under WPC regulations that is manufactured outside India must obtain equipment type approval (ETA), or follow a self-declaration procedure, at the system or end-unit level.[3] Further, my partners in India have told me the product must have its own wireless reports. You cannot seek end-unit approval while leveraging reports from its module—even if the product has its own safety and EMC reports. Many other countries still allow module wireless test reports as part of the application for the final product.

LOCAL REPRESENTATION

The following question has remained relevant and necessary for the past 15 years. Can a manufacturer apply for wireless approval as a foreign manufacturer/entity, or does the application need to come from a local representative in the country? Based on my experience and research, it seems the same countries that required local representatives in 2007 still require them today, with few exceptions.

I've seen further continuity about the question of local representation in the lack of communication between US/EU manufacturers and their overseas partners. Many foreign applicants have local offices in the countries they wish to enter. Yet I still hear that they cannot get that office to respond to queries. For instance, we need a basic form signed by the local office, and the office refuses on various grounds or wants to escalate the issue to the corporation's legal department. In such cases, my advice to those who want to use their local offices is to coordinate with them early in the process.

I also see the opposite situation. That is, the local office is eager to help but is thinking that the product is ready for sale immediately or in the near future. They may be unaware that the product has yet to undergo conformity assessment or testing and that the country may have a lead-time of weeks or months to issue the approval, even if the testing goes according to plan.

The option to use a locally based, third-party representative remains. If a country requires local representation and the manufacturer doesn't have one, they can use a third-party representative. The notable exception is if the country requires the local representative to also serve as the importer and/or distributor of the product. In that case, a third party cannot act as the applicant unless they are officially authorized to import the product (which is possible in some cases). Mexico has recently added this requirement, and while it has been common practice for some time in other countries, it appears as though we are trending toward increased global regulation.

IN-COUNTRY TESTING: THE BIG PICTURE

A bigger question than the requirements regarding local representation is whether a country requires local testing. That is, can you apply for approval or certification in a given country with existing EU or FCC reports, or do you need to send product samples to an in-country testing laboratory.

Of course, obtaining wireless certification with existing reports would be preferable for most manufacturers. In this regard, I've seen the burdens decrease slightly. In a few dozen non-EU countries, you can expect to send samples to mostly the same locations as you did in 2007. The exception is the increasing use of accredited foreign testing laboratories. For example, Vietnam has been allowing test reports from its curated list of accredited labs instead of requiring samples. This list of countries has grown.[4]

The use of mutual recognition agreements (MRAs) has also increased with regulators in other countries. Korea allows more testing in foreign labs. Japan's Ministry of Internal Affairs and Communications (MIC) has a relatively small list of certified accreditation bodies (CABS)[5], but these CABS may move to accept reports from other testing laboratories, increasing the available locations for testing if a CAB still certifies the product.

ONLINE OR STREAMLINED APPLICATIONS

Online portals have expedited the wireless approval process in several countries. I don't recall any clear, well-functioning online application processes for type approval back in 2007. Today, we see many countries, especially those in the Middle East, offering a clear, online path to certification. A foreign applicant can create an account, upload documents, and watch the process.

This still takes time and some knowledge of the procedure, and no one has gone to any lengths to simplify this. It is, however, a positive trend and one that I hope continues. In many situations, having a trusted agent in-country to correspond with the wireless authority is valuable or necessary, especially with language barriers. One should always check if there is an online or direct route to certification before engaging a local contact.

Today, countries still have label requirements, and logos, images, or certification numbers can fill up a small or even medium device. Manufacturers may not like the aesthetics of a certification mark even if their unit has room.

DOCUMENTATION AND LABEL REQUIREMENTS

Perhaps no other aspect of international approvals has remained as consistent as the documentation requirements. In trying to prepare their companies in advance of a global launch, project managers may provide a checklist or discuss the required documents. The list is remarkably similar fifteen years into my time in this industry. The primary documents required are the test reports. Applicable standards are updated regularly, but the covered areas remain consistently the same, that is, EMC, safety, and wireless, as well as specific absorption rate (SAR), in some cases.

Other documents, user manuals, specifications sheets, ISO certificates, and photos are a must. Block diagrams and schematics are still needed in some countries, and no one likes providing them today any more than they did in 2007. I can't blame them. At the time of this writing, I can't think of any major items added to or removed from a hypothetical certification checklist over the past 15 years. (If you can think of one, let me know.)

Labeling remains a key concern for globally certified products. Today, countries still have label requirements, and logos, images, or certification numbers can fill up a small or even medium device. Manufacturers may not like the aesthetics of a certification mark even if their unit has room. Countries often exempt especially small products from logo requirements, but for anything bigger, even something the size of a baseball, you may be stuck putting logos on the product depending on which countries you want to enter.

Some countries don't care if you have other certifications and your label space is filling up, taking the position that their requirements are as important as those of other countries. We are seeing advances in the increased acceptance of e-labeling and countries allowing labeling on the user manual or packaging. But, until we enter a label-free world, it is crucial to understand requirements in advance of your product launch.

US TESTING LABORATORIES: INCREASED COMMODIFICATION

To obtain international wireless approvals, you first need test reports for the product itself—a process that is becoming increasingly commoditized. Typically, manufacturers cover FCC and EU-required testing and then turn their attention to the rest of the globe. And many manufacturers submit FCC or EU-required test reports, along with other documents, to dozens of countries for type approval.

I've seen some manufacturers become indifferent to the test laboratory they use. Many test engineers, when asked which testing laboratory they want to work with, will often remark that they have no preference since all are pretty much the same. (This attitude seems especially prevalent in the San Francisco Bay area, which has a high concentration of testing labs and a high turnover of test engineers.)

The increased commodification of testing services offers benefits and drawbacks. Manufacturers open to using any lab often receive multiple quotes for testing and/or certification. This can drive down costs and improve timing or testing laboratory availability. The downside is that a given laboratory may not be familiar with the product's technical specifications and operation or with the customer's compliance planning.

There are, of course, exceptions to this trend. Some manufacturers maintain strong ties with third-party test laboratories and will only use that testing lab. The stated reason for sticking with a given lab is typically "they provide good service, response time, and understand our product line." Ultimately, product testing and

certification remains a service business. Just as with a restaurant or any other business offering services to customers, the principle is still the same: treat your customers well and they will keep coming back.

WHAT DO THE NEXT 15 YEARS HOLD?

While the relative continuity of the past 15 years suggests things may stay the same for the foreseeable future, it is, of course, impossible to predict what will actually happen. What I can say with certainty is that we will need to be on alert for country-specific changes. Recent revisions to the regulatory approval process like those in Mexico and other countries have major impacts on a company's compliance plan, exports, or in-country distribution. Even changes to label requirements may be a headache if you do not anticipate them.

Will we see increased cooperation or recognition of compliance between countries? Brexit, sanctions, and rising nationalist movements indicate the opposite may be in store. I may not be working in international wireless certifications at the next 15-year mark in 2037, but I'm betting they will still be required across the globe, and our jobs as manufacturers and compliance professionals are going to look the same.

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PREPARING FOR AND IMPLEMENTING PRODUCT RECALLS IN 2022

New Guides Provide Recall Assistance

Kenneth Ross is a Senior Contributor to *In Compliance Magazine*. He provides legal and practical advice to manufacturers and other product sellers in all areas of product safety, regulatory compliance, and product liability prevention, including contracts, risk assessment, design, warnings and instructions, safety management, litigation management, recalls, dealing with the CPSC, and document management. His previous articles for *In Compliance Magazine* can be accessed at https://incompliancemag.com/author/kennethross. Ross can be reached at kenrossesq@gmail.com.

By Kenneth Ross

Recalls have received lots of attention recently by government agencies and industry as they try to determine how to help manufacturers be better prepared to undertake a recall and then how to implement the recall once one is started. Given the growing importance of this subject, there has been a recent proliferation of guides, standards, and best practices developed in the U. S. and elsewhere. Taken together, these can significantly help a manufacturer establish procedures and personnel necessary to meet its legal and practical obligations.

This article will discuss the ways in which a company can be organized and prepared to meet its post-sale duties and to undertake a field corrective action program or a recall.

GUIDES FOR PREPARING FOR AND IMPLEMENTING A RECALL

Many guides have been developed by government agencies and standards-setting organizations both in the U.S. and in foreign countries. The U.S. Consumer Product Safety Commission (CPSC) published a recently updated planning and recall handbook, while the Food and Drug Administration (FDA) issued, in March 2022, a guidance for industry and staff on the initiation of voluntary recalls. The U.S. Department of Agriculture has recall guidelines for food, and the National Highway Traffic Safety Administration has one for motor vehicles and accessories. Therefore, if you are selling regulated products in the United States, you should look at the relevant agency's recall guidelines for help. This article will focus on new guides that apply to consumer products.

The CPSC revised its 2012 Recall Handbook in September 2021 and now calls it the "Product Safety Planning, Reporting, & Recall Handbook" ("the CPSC Handbook").[1] The CPSC added a new section titled "Plan Ahead: Compliance Programs and Designating Responsibility for Product Safety Issues" and added an appendix on how to develop a compliance program. In addition, they added a number of templates of documents as appendices, including several for Health Canada and one for communicating recalls on social media. Some details of this new handbook will be discussed below.

The next new guide comes from the newly formed UK Office for Product Safety & Standards. The guide is entitled "Product recall and other corrective actions – Code of practice" (PAS 7100:2022) and was licensed and published by the British Standards Institution (BSI).[2]

A PAS is defined as follows:

> *"The PAS process enables a code of practice to be rapidly developed in order to fulfil an immediate need in industry. A PAS can be considered for further development as a British Standard or constitute part of the UK input into the development of a European or International Standard."*

This document makes it clear that it is not a British standard and that it supersedes an earlier version of PAS 7100, which was issued in 2018. This document also states that "this PAS is to be read in conjunction with PAS 7050:2022, which supports businesses and regulators in complying with their relevant legal duties relating to placing safe products on the market."[3]

The new PAS 7100 is a partial revision of the 2018 version and includes the following main changes:

- Incorporates changes regarding UK's exit from the European Union;
- Better aligns with the revised version of PAS 7050; and
- Adds new sections for online marketplaces and for repair and refurbishment.

As with the CPSC Handbook, PAS 7100 contains guidance and recommendations. Neither of these documents constitutes legal requirements, and therefore, compliance may not provide any legal immunity. However, the PAS says:

> *"Users may substitute any of the recommendations in this PAS with practices of equivalent or better outcome. Any user claiming compliance with this PAS is expected to be able to justify any course of action that deviates from its recommendations."*

In 2013, the International Organization for Standardization (ISO) issued a new standard, ISO 10393, providing guidelines for consumer product recalls. This standard does a good job of describing the types of personnel who should be involved in the establishment of a product recall team, as well as the procedures that should be in place so that the company is prepared to undertake consumer product recalls. It also talks about how to develop a recall strategy, recall objectives, and a recall process as well as how to develop a communication plan. All aspects of a comprehensive recall program are contained in this ISO standard.

Lastly, the European Union and the governments of Canada and Australia have developed various recall guides, especially for consumer products. Some of these guides may be useful in structuring your recall program in the U.S. There are great similarities between all of these guides, especially in the guidances on how to develop a compliance program. Therefore, the CPSC's Handbook, the new BSI PAS 7100, and ISO 10393 should provide sufficient guidance for recall programs established by companies selling consumer products in the U.S., Canada, and Europe.

DEVELOPING A COMPLIANCE PROGRAM

The CPSC Handbook contains detailed suggestions on setting up a compliance program. The focus should be on developing a culture of safety, communicating to employees that culture and the process of product safety and recall preparedness, and continuous improvement.

The CPSC Handbook gives an example of a sample compliance program:

1. Identify who in senior management is responsible for product safety issues at the company;
2. Research and create written policies and procedures to respond to product safety issues, including:
    a. Identify and centralize data for availability and review by the product safety team;
    b. Establish regular data reviews and, as appropriate, specific incident reviews;
    c. Establish or refine supplier qualifications and audits;
    d. Incorporate CPSC reporting requirements and recall execution plans into policies; and
    e. Establish a protocol for specific follow-up action;
3. Establish a records-retention policy. CPSC staff recommends retaining records for at least five years;
4. Train staff regularly; and
5. Routinely reevaluate and update compliance policies and training.

PAS 7100 calls their compliance program a product safety incident plan ("PSIP") which should include the following, where appropriate:

1. Management commitment
2. Product and customer traceability plan
3. Product safety monitoring plan
4. Legal notification plan
5. Risk assessment plan
6. Corrective action decision plan
7. Communications plan
8. Training plan
9. Testing plan
10. Review plan

Both of these guides and the ISO standard have more detailed information on the development of a compliance program, and these should be consulted. However, in the next two sections of this article, I will discuss pre-sale preparation and post-sale implementation from my experience of helping manufacturers in these areas for over 40 years.


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PRE-SALE PREPARATION

Some of the most significant elements to build into the product's design, manufacture, and distribution processes are product marking and traceability procedures that are used before manufacture, during manufacture, and during distribution. To the extent possible, products, especially safety-critical components, should be marked or coded so that anyone, including customers, can easily identify a recalled product and remove the component to be returned or repaired.

This is not easy to do and many manufacturers, especially those who have never had to recall their products, will wonder if the effort is worth it. Of course, in the event of a recall, this traceability will allow a manufacturer of the finished product or component part to narrow the affected population and allow customers to more easily identify whether their product is subject to the recall. A customer might even be able to return the affected part and replace it with a new one. In that case, everyone benefits, from the manufacturer to the retailer to the consumer.

The next important consideration is for the manufacturer, in cooperation with all entities in the distribution chain, to design and maintain an effective database so that different types of entities, including product users, can be identified. These databases must be updated periodically.

There are new and interesting ways in which this can be accomplished. In the past, manufacturers have relied on the customer sending in a warranty registration card. This hasn't worked well. Today, the customer's ability to quickly register their product online with the manufacturer has made it a lot easier. The enormous growth of retailer customer loyalty programs and membership retailers has also made it much easier to track products to specific customers. And QR codes can be programmed so that scanning the code with your smartphone will automatically send your contact information to the manufacturer.

One of the most important and difficult tasks is for the manufacturer to set up a communications network before sale, so that appropriate safety information is received. A manufacturer has a number of readily available sources of information anywhere its product is sold. Personnel should be trained to ensure that sufficient information is gathered concerning warranty claims, injury or damage claims, accidents, near misses, and customer complaints so that potential problems can be identified as early as possible.

Personnel should be trained to identify and clarify the information received so that it is accurate and substantiated. A manufacturer does not want to gather and maintain inaccurate and overstated complaints and claims that make it appear that a problem exists when, in fact, it doesn't. In addition, a company must decide which claims to follow up on and how to do so. Do they need to see and analyze the product? Do they need to interview the product user or claimant?

Post-sale information, some of it unsubstantiated or even incorrect, can be posted by consumers and others on the Internet. This information needs to be monitored and followed up where necessary. Ignoring such information can be risky, but following up on all alleged safety issues can be time-consuming, fruitless, and misleading. The goal is to separate the valid information from all the information that is available and received.

A manufacturer must understand all legal reporting and recall requirements applicable in each country in which its product is being sold. The requirements have increased recently and are different from country to country. The result is that there may be a reporting responsibility in one country and not another, with a recall being required in one place but not another. In addition, there may be differences in the ways in which different government agencies expect the manufacturer to announce and implement the recall. Coordinating reports and recalls in multiple jurisdictions is a significant challenge that can be very detailed and time-intensive.

Entities in the supply chain must consider contracts in anticipation of potential recalls or other corrective actions. Therefore, any company buying safety-critical products or services for inclusion in their product needs to consider which entity is financially and procedurally responsible in case that component part or service is defective. In addition, every entity within the distribution chain - dealer, distributor, and retailer - is potentially responsible for any accidents involving products that should have been recalled. Therefore, the contracts between these sellers and the manufacturer are critical in establishing the duties, obligations, and responsibilities of each of these parties in the event of safety problems in the field.

Unfortunately, most of the time, purchase and sales contracts deal with warranty matters, extra-contractual damages, and remedies, but rarely recalls. Marketing personnel from the manufacturer don't mind discussing warranties with their customers but discussing the possibility of the product being recalled and who is responsible for that is not something that is considered helpful during the sales process. In addition, buying component parts from a small company can be difficult if that company believes that it will be fully financially responsible for any defects in that component part. And many times, it is not clear what caused the problem - the component part itself, the selection of the part, the installation of the part, or the use of the part.

One other issue that should be considered before you start to sell products that could create a large financial risk if recalled is whether your company should consider purchasing recall insurance. The market for such insurance has grown significantly in the last ten years, and there are many options. Recall insurance is designed to cover first-party costs related to a recall that are excluded by most comprehensive general liability policies. Coverage is usually triggered by a voluntary safety recall or by government-ordered recall where the product has caused or is likely to cause bodily injury or property damage.

Some of the costs that might be reimbursed are those involving pre-recall and recall costs, business interruption and extra expenses, brand rehabilitation expenses, extortion costs, and consultant's costs. Limits, self-insured retentions, and coverage vary from company to company and are largely dependent on the underwriter's analysis of future risk. Any interested company must obtain an evaluation of their situation conducted by a broker experienced with recall insurance and get a recommendation on what type of policy might be best for them.

POST-SALE PREPARATION

Every entity in the supply chain needs to expect that a recall may be necessary at some point. Importantly, they need to have experienced technical and legal personnel who routinely evaluate post-sale data and information and decide whether to report to the government and undertake a corrective action or to undertake a corrective action even if no government agency is involved. If adequate pre-sale planning has occurred, gathering and analyzing the information, and implementing the program will be less difficult and more organized than if no planning has occurred. Everyone will know what to do and when to do it.

Virtually every manufacturer should have a functioning product safety committee whose main job is to evaluate post-sale information and to make decisions concerning reporting to government agencies and undertaking corrective actions such as recalls. Decisions in this area are multi-functional and lend themselves to the kind of brainstorming that can be accomplished in a committee meeting. This is particularly true because information about post-sale issues comes into different parts of the company. Therefore several members of the committee might have information relevant to the post-sale analysis that will need to be discussed.

There should be well-defined procedures for the product safety committee as well as a list of the people who should always participate and those who will participate on an as-needed basis. It is important to decide what power the committee has in making decisions concerning corrective actions. For example, can they make the final decision, or are they merely making recommendations to upper management?

A company's legal counsel should be a member of this committee since most of the discussions will be sensitive and could become the basis of a product liability case and a governmental enforcement action. While it is not a good idea for legal counsel to try and make all of the writings of this committee legally privileged and confidential, counsel should provide some guidelines to committee members on what to write and what not to write and should review the minutes of the meetings and documents with recommendations.

Some manufacturers should consider running mock recalls. While these would not involve sending notices to consumers, they might include notices to the first tier of distribution or possibly even further. The purpose of sending notices like this is primarily to test the accuracy of the addresses – mail, e-mail, or social media – on file for each customer. You want to be able to immediately stop production, stop shipping, and stop sales of all products subject to the recall. Therefore, having the ability to quickly communicate to your immediate customers (i.e., distributors) and for your customers to be able to quickly communicate to their customers (i.e., retailers) is important.

While it is still important to be able to communicate with the end-use customer eventually, this should not be part of a mock recall. However, if end-use customers send registration cards to you, you might periodically send them a letter or an e-mail to test out the accuracy of their addresses. Then, when the time comes for you to communicate with them about a recall, most if not all of the addresses you have will be current and accurate.

Even if the company does not run mock recalls, training employees about all of these issues is very important. Product safety personnel cannot be everywhere. You want everyone involved in designing and making products and monitoring their performance in the field to understand what information they may receive that would be helpful in predicting potential safety issues and what to do about them. In addition, legal counsel should assist with the training so that employees understand what documents they need to create and keep that will help defend the adequacy of post-sale actions, including recalls.

One other task that should be undertaken is to develop templates for various types of communications that you will want to send out in the event of a recall. If you sell regulated products, you will want to look at the recall guides for those products to find the templates provided by the government agency. You can then use these as the basis for your template communications, recognizing that these are a minimum and you might want to exceed the requirements of that agency.

Also, you might want to consider testing the template communications with sample users or even personnel in the company. You want to know whether the communication makes it clear that this is a safety-

related matter, that it is important that they comply, and that it is clear what you want them to do. In addition, you might want to ask end-use consumers how they would like to receive such communications if any are necessary in the future.

The use of social media has significantly increased in the recent past. That is fine if the consumer is willing to receive information through these means and has signed up to do so. That is one reason why asking consumers how they would like to receive this information could be valuable. Some may be willing to receive it by letter, others prefer e-mail, and others prefer Facebook, Twitter, or text messages.

There are new companies being formed that are developing recall applications through social media that will help manufacturers get recall notices to those consumers who are interested in receiving this information. Manufacturers need to keep track of these developments and utilize those that make sense for their products. Ultimately, almost everyone will be willing to receive communications in some electronic form, thus making it quicker and less costly to send out recall notices or safety alerts.

Finally, in cases where a retailer has established a loyalty program for frequent customers, it makes it much easier to identify that customer and the products they purchased. One membership chain uses the data gathered through cards carried by its millions of members and calls them within 24 hours if they have purchased a recalled item. The company follows up with a letter. This results in the vast majority of recalled products (90% with some products) being returned to the store.

CONCLUSION

Compliance with the government's requirements and approval of your corrective action program may not be a defense in a product liability case brought in the U.S. or, most likely, anywhere else. Therefore, thinking about the defensibility of the program as it is being implemented will help a company anticipate challenges to the program's adequacy and help it respond to suggestions that it could have done more to prevent the accident that is the subject of the lawsuit.

There have been significant developments, procedurally and technologically, around the world that should help manufacturers do a better job in a more cost-effective way. But a manufacturer must plan for the possibility of a recall as soon as it begins designing a product. Doing so will reap huge benefits if the worst happens and a recall occurs. It will also help prevent the recall from turning into a corporate tragedy that hampers a company's activities or threatens to put it out of business.

ENDNOTES

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EVALUATION OF PCB DESIGN OPTIONS ON ANALOG SIGNAL RF IMMUNITY USING A MULTILAYER PCB

Part 3: Conducted Immunity Testing

By Bogdan Adamczyk, Scott Mee, and Bilguun Baatar

This month's column is the last of three parts devoted to designing, testing, and EMC immunity evaluation of multilayer PCBs containing analog circuitry. The first article presented a top-level block diagram description of the design problem under research [1,2]. The second article discussed the radiated immunity results [3]. This article is devoted to the conducted immunity testing according to the ISO11452-4 Bulk Current Injection from 1 MHz – 400 MHz up to severity level 4. As a reminder, two analog measurements are present on the PCB. The first analog measurement captures analog temperature values from an NTC thermocouple at the end of a short harness. The second analog measurement captures the analog voltage of 12 volts connected at the banana jack terminals of the PCB. Both sets of values are processed by the microcontroller and reported to the test engineer outside the chamber via UART and fiber optic communications for isolation. However, for the purposes of this article, only analog temperature measurements are presented and discussed.

Dr. Bogdan Adamczyk is professor and director of the EMC Center at Grand Valley State University (http://www.gvsu.edu/emccenter) where he regularly teaches EMC certificate courses for industry. He is an iNARTE certified EMC Master Design Engineer. Prof. Adamczyk is the author of the textbook "Foundations of Electromagnetic Compatibility with Practical Applications" (Wiley, 2017) and the upcoming textbook "Principles of Electromagnetic Compatibility with Laboratory Exercises" (Wiley 2022). He can be reached at adamczyb@gvsu.edu.

Scott Mee is a co-founder and owner at E3 Compliance which specializes in EMC & SIPI design, simulation, pre-compliance testing and diagnostics. He has published and presented numerous articles and papers on EMC. He is an iNARTE certified EMC Engineer and Master EMC Design Engineer. Scott participates in the industrial collaboration with GVSU at the EMC Center. He can be reached at scott@e3compliance.com.

Bilguun Baatar is an electrical engineer specializing in EMC design and testing. He graduated from Grand Valley State University with a BSE in Electrical Engineering and his focus is on EMC pre-compliance testing and expanding the understanding of EMC concepts/procedures. He can be reached at bilguun.baatar@e3compliance.com.

1. PCB VARIANTS AND TESTS CONFIGURATIONS

In this study, there are seven design variants that all contain a similar schematic but implement different PCB layout techniques (see [2] for the details). The design variants are described in Table 1.

Variant	Analog Trace Routing Style	Analog Trace Routing Layer	Grounding Method	Ground Split Geometry	Ground Split Layers
1	Differential	Microstrip on top layer	Single Ground Reference (GND)	N/A	N/A
2	Single Ended				
3	Differential	Embedded on layer 3			
4	Single Ended				
5	Single Ended	Microstrip on top layer	Split Ground Reference (AGND and GND)	AGND under analog circuitry, adjacent to GND*	All layers
6				AGND under analog traces, surrounded by GND*	Layer 2 only
7		1-3-1-3-1-3-1-3-1			

Table 1: Design variants

Table 2 shows the test configurations used during the testing of the selected variants.

The measurement setup for conducted immunity is shown in Figure 1 (see [4] for details).

2. IMMUNITY TESTING RESULTS – CONFIGURATION A

Variant 1 and Variant 2 test results are shown in Figure 2.

Configuration A	Configuration B	Configuration C
• Non-conductive enclosure • No filters on analog signal traces • All 7 variants	• Conductive enclosure • 4 non-conductive standoffs • Non-conductive ground ring gaskets (top & bottom) • No filters on analog signal traces • 3 worst performing variants, (1,5,6)	• Conductive enclosure • 4 conductive standoffs • Conductive ground ring gaskets (top & bottom) • Selective filtering on analog signal traces • Worst performing variant (1)

Table 2: Description of test configurations

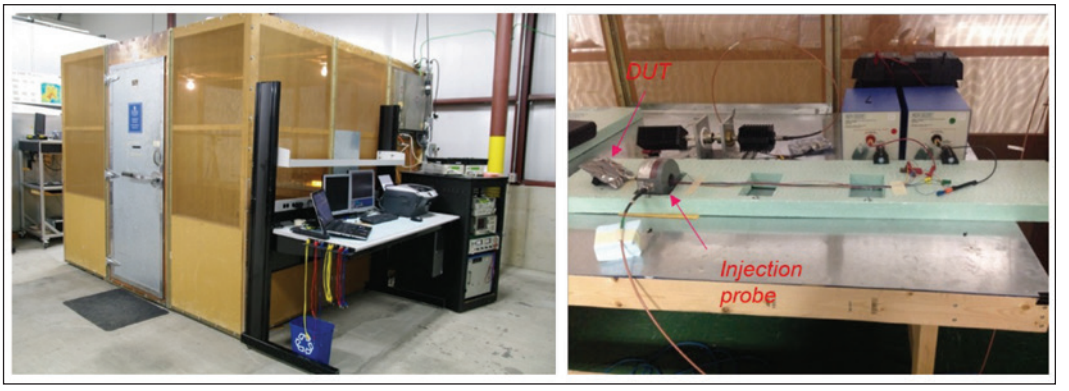

Figure 1: ISO11452-4 measurement setup

Observations: Variant 1 tested in Configuration A exhibited anomalies (with exception of 1 to 2 MHz and 5 to 9 MHz) with the analog temperature readings. Variant 2 tested in Configuration A exhibited anomalies (with exception of 1 to 4 MHz) with the analog temperature readings. Compared to Variant 1, Variant 2 performed worse, especially above 9Mhz. This demonstrates that differential routing provided some benefit.

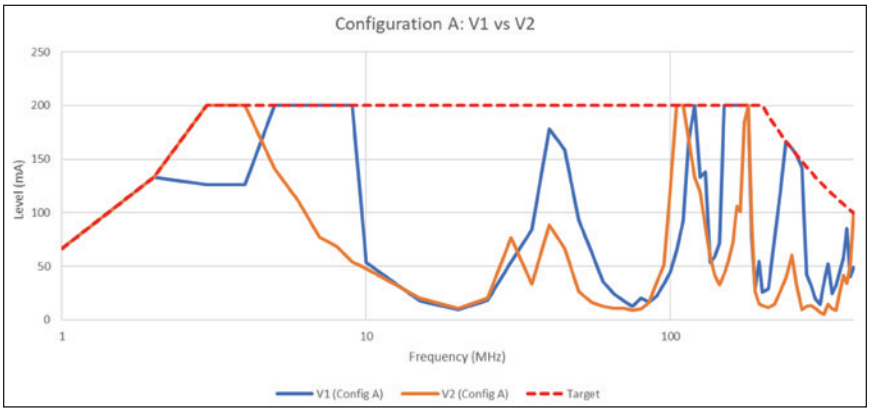

Figure 2: Configuration A: Variant 1 vs. Variant 2

Next, Variant 3 was tested and the results were compared to those of Variant 1. The comparison is shown in Figure 3 on page 44.

Observations: Variant 1 performed better than Variant 3 at lower frequencies (2 to 7 MHz) and

slightly better at higher frequencies. Beyond 10 MHz there aren't significant differences between the two variants. This demonstrates that burying differentially routed traces beneath the ground plane on layer 2 did not provide an overall benefit above 7 MHz.

Next, Variant 4 was tested and the results were compared to those of Variant 2. The comparison is shown in Figure 4.

Observations: Variant 4 performed better than Variant 2 from 1 MHz to 9 MHz and from 120 MHz to 200 MHz. This demonstrates that burying the single ended traces on layer 3 beneath the ground plane on layer 2 provides an improvement in immunity performance in the respective frequency ranges.

Next, Variant 5 was tested, and the results were compared to those of Variant 2. The comparison is shown in Figure 5.

Observations: Variant 5 performed similarly to Variant 2 across the entire spectrum. This demonstrates that splitting the grounds (GND and AGND) has a negligible impact on the conducted immunity performance. This is likely due to the fact that while there is a split between the two references, they both allow for a continuous reference return adjacent to the analog trace routes to provide a low inductance RF return path.

Next, Variant 6 was tested and the results were compared to those of Variant 5. The comparison is shown in Figure 6.

Observations: Variant 6 performed similarly to Variant 5. This demonstrates that splitting the grounds (GND and AGND) has a negligible impact on the conducted

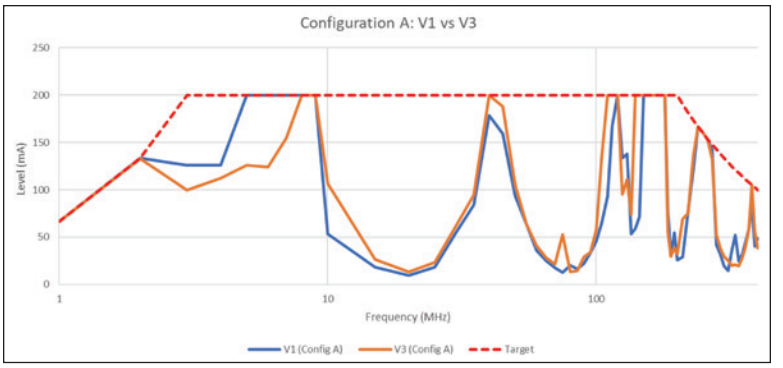

Figure 3: Configuration A: Variant 1 vs. Variant 3

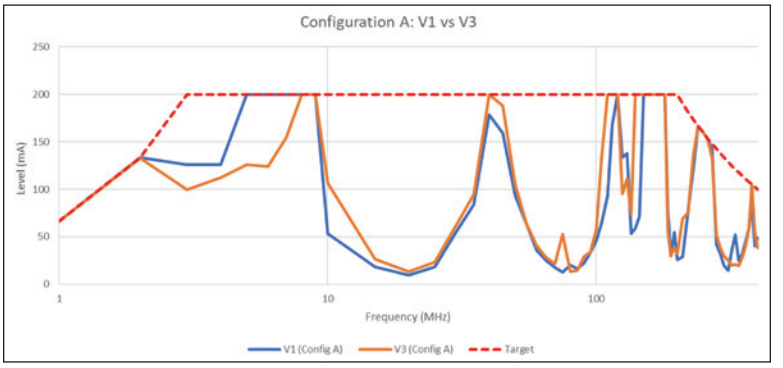

Figure 4: Configuration A: Variant 2 vs. Variant 4

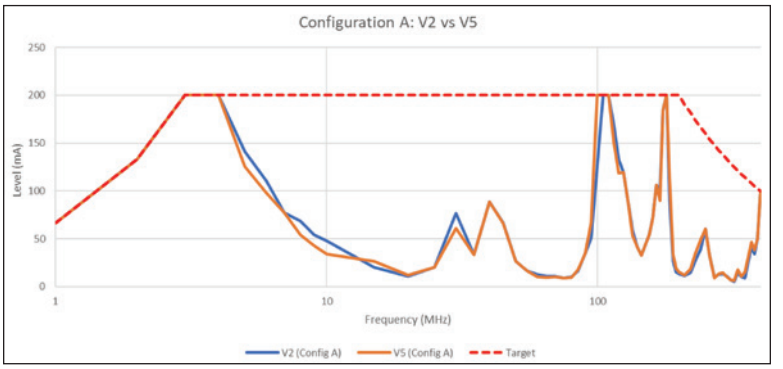

Figure 5: Configuration A: Variant 2 vs. Variant 5

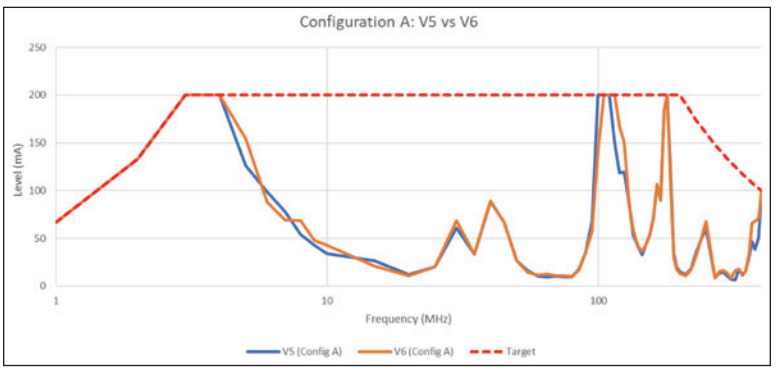

Figure 6: Configuration A: Variant 5 vs. Variant 6

immunity performance. This is likely due to the fact that while there is a split between the two references, they both allow for a continuous reference return adjacent to the analog trace routes to provide a low inductance RF return path.

Next, Variant 7 was tested and the results were compared to those of Variant 6. The comparison is shown in Figure 7.

Observations: Variant 7 performed almost the same as Variant 6. This came as a surprise since Variant 7 has the analog nets alternating between layers 1 and 3 multiple times. One would assume that by routing the analog traces this way they would become more vulnerable to conducted immunity disturbances, however the data shows very little impact (positive or negative).

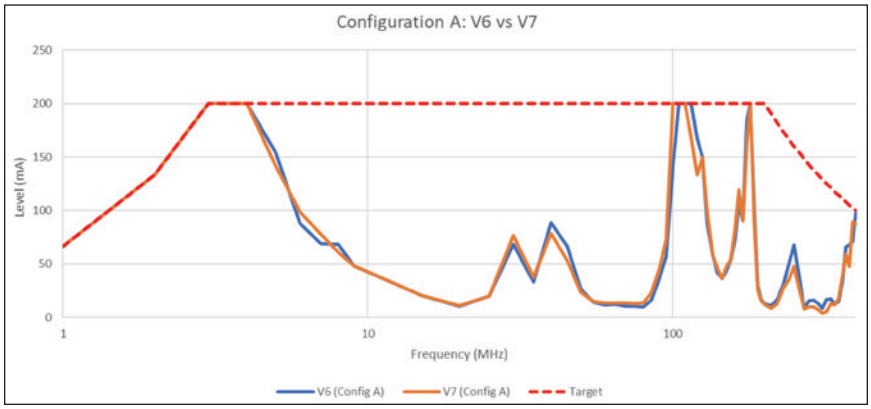

Figure 7: Configuration A: Variant 6 vs. Variant 7

3. IMMUNITY TESTING RESULTS – CONFIGURATION B

The three variants which exhibited the weakest RF immunity performance in Configuration A were re-tested in the same frequency range. For Configuration B, a conductive enclosure was added with non-conductive standoffs (ungrounded shielding). The weakest RF immunity was exhibited by the Variants 1, 5, and 6.

Figure 8 compares the test results for Variant 1, Configuration A vs. B.

Observations: Variant 1 in Configuration A generally outperforms Configuration B up to 9 MHz and beyond 90 MHz. Between 9 MHz and 90 MHz, Configuration B shows a benefit. Based on the data, an ungrounded shielded enclosure provides benefit in a limited frequency range when routing the analog trace differentially on the top side.

Figure 9 compares the test results for Variant 5, Configuration A vs. B.

Observations: Variant 5 in Configuration B performed similarly to Configuration A with the exception of 100 MHz – 130 MHz range and at 190 MHz where Configuration A did better than Configuration B. There are no benefits of Configuration B over Configuration A and Configuration B exhibited two areas of degradation at the frequencies mentioned. This is most likely due to the split ground strategy and lack of conductive standoffs that introduce a discontinuity in the shielding effectiveness from the enclosure and PCB reference plane areas.

Figure 10 compares the test results for Variant 6, Configuration A vs. B.

Observations: Variant 6 in Configuration A performed better than Configuration B with the exception of the frequency range 110 MHz – 180 MHz where the ungrounded shielding provides some benefit. However, there are inconsistent benefits overall of introducing an ungrounded conductive enclosure (Configuration B). In Variant 6, the analog traces are routed on the top layer with PCB GND

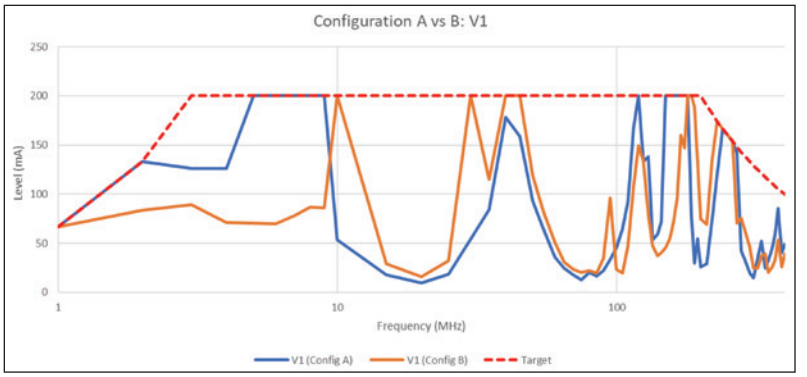

Figure 8: Variant 1 – Configuration A vs. B

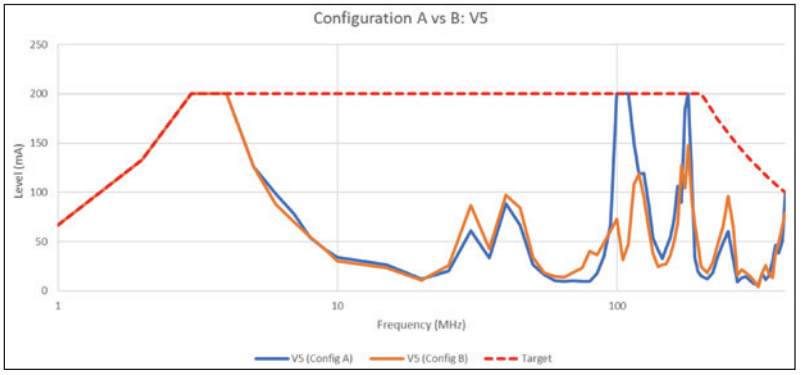

Figure 9: Variant 5 – Configuration A vs. B

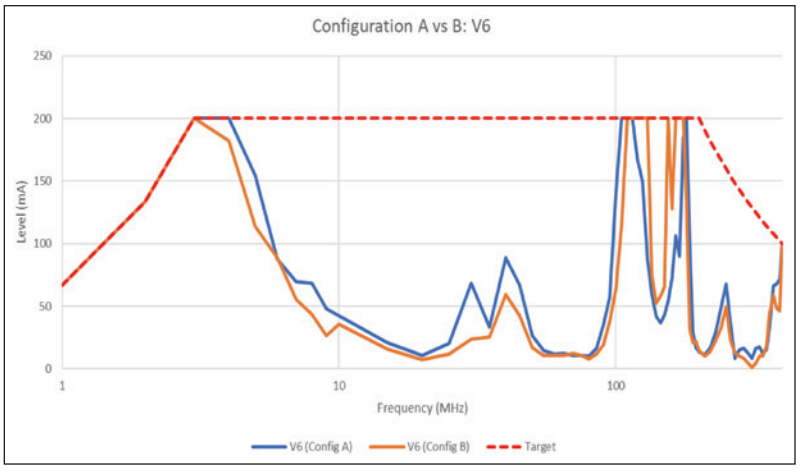

Figure 10: Variant 6 – Configuration A vs. B

surround and a separate Analog GND is beneath on Layer 2. All other layers are PCB GND. These layout design features minimize the ungrounded shielded enclosure's impact on the conducted immunity performance.

4. IMMUNITY TESTING RESULTS – CONFIGURATION C

Finally, the worst-performing variant from Configuration B (Variant 1) was re-tested in the same frequency range according to Configuration C (conductive standoffs, conductive gasket, selective filtering components on analog lines). Figure 11 compares the test results for Variant 1, Configuration A vs. C.

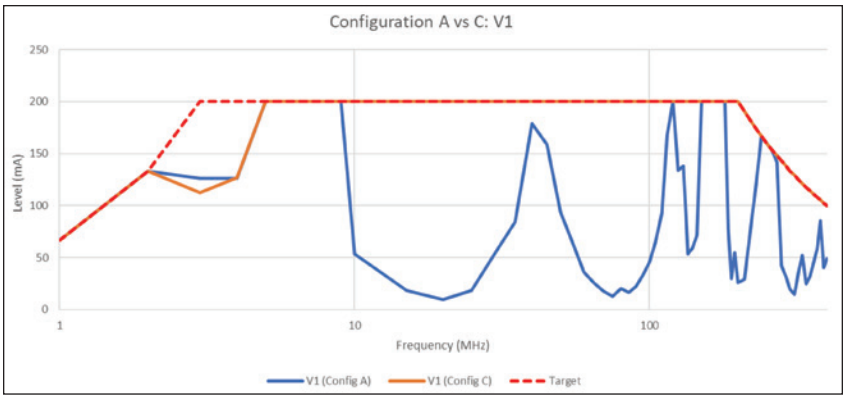

Figure 11: Variant 1 – Configuration A vs. C

Observations: Variant 1 in Configuration C performed dramatically better than Configuration A over a wide band of frequencies from 9 MHz to 400 MHz. Improvements were made due to the shielded enclosure, conductive standoffs, conductive gaskets, and selective filtering components on the analog lines. Since Configuration B (shielded enclosure, non-conductive standoffs) didn't provide as much benefit as Configuration C, the added conductive gaskets, conductive standoffs, and component filtering likely provided the most benefit.

SUMMARY

In summary, there are conducted immunity benefits to burying analog lines on internal layers and keeping a consistent reference alongside and/or beneath the analog traces. Additional benefits can be achieved by filtering the analog signals and adding a shielded enclosure with good conductive seals and bonding to PCB GND reference planes. Findings from this study show that some of the disturbance from the bulk current injection probe radiates directly to the PCB and the conducted disturbance on the harness lines.

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LATCH-UP ELECTRONIC DESIGN AUTOMATION CHECKS

By EDA Working Group 18 for EOS/ESD Association, Inc.

This article introduces typical latch-up verification techniques to detect and prevent latch-up. These techniques rely on electronic design automation (EDA) tools to deliver the coverage necessary to identify and eliminate latch-up risks.

INTRODUCTION

For semiconductor CMOS technologies, the phenomenon of latch-up has been extensively studied over the past 30 years, resulting in the development of different solutions to address latch-up risks [1]. These solutions depend on device operating voltages and process technology, including well isolation techniques. Modern integrated circuits pose additional latch-up challenges due to system on a chip (SoC) complexity: increased metal interconnect resistivity, high device density, and multiple power domains. Some of these challenges are addressed in the recently released new version of the latch-up JEDEC test standard [2] and the ESD Association Technical Report for Latch-up Electronic Design Automation (EDA) [3].

While there is a common understanding of the physical phenomena leading to latch-up across the industry, verification methods to identify these risks vary. The Latch-up EDA Technical Report [3] outlines several EDA verification flows and tools used throughout the industry to uncover latch-up risks. The report provides an overview of scenarios beyond conventional latch-up, including grounded and biased n-wells, transient latch-up, native devices, radiation-induced latch-up, and special high voltage (HV) and FinFET technology requirements. The technical report includes a description of power management and system-level latch-up challenges and consideration of triggering parasitic structures during unpowered ESD events. The report provides a reference for latch-up prevention design rules classified based on physical category and EDA implementations.

LATCH-UP ANALYSIS AND VERIFICATION FLOWS WITH EDA TOOLS

There are several approaches used to perform analysis and verification of latch-up robustness. Leveraging EDA tools, these approaches can be broadly described by the following categories:

- Dynamic
- Empirical
- Static

Dynamic analysis leverages EDA tools that simulate device and semiconductor material (including substrate) behavior, which may also include the underlying physical phenomena. The compute-intensive nature of these techniques limits scalability, relegating simulation-based techniques to specific areas of a design and/or simplified layouts. Dynamic analysis is often used to characterize and perform analysis in identifying latch-up conditions that may form the basis of design rules used in (predominantly static) EDA tools. EDA tools, such as those based on field solver technology, technology CAD (TCAD), and SPICE simulation, fall within this category.

Empirical analysis techniques use (portions of) actual silicon die to characterize the limits of latch-up robustness. Specific areas of these dice often contain test structures used to perform such characterization for a particular process node and metal stack. Automation of these tests may be done to ensure consistency and repeatability. Once characterized, these findings are used to develop design rules used in (predominantly static) EDA tools. As empirical methods are more closely aligned with physical device characterization.

Static verification flows generally check design rules (constraints) derived from dynamic and empirical measurements to evaluate the robustness of the design. This evaluation often focuses on the physical implementation (layout) and may utilize several

techniques to provide a holistic view of latch-up susceptibility. These techniques generally include design rule checks (DRC), often without connectivity considerations, current density (CD) and point-to-point (P2P) resistance, along with hybrid approaches that leverage connectivity and voltage information to perform topology/net aware DRC checking with limited connectivity, as well as advanced hybrid DRC and electrical rule check (ERC) with full connectivity. These hybrid verification approaches are often described as being "context-aware" due to considerations of topology and voltage. The context (the type of net or voltage considerations) influences the outcome of an otherwise static rule that may be overly conservative had the design context not been made available.

For this reason, context-aware verification techniques are desirable for their ability to mitigate the application of over-constrained design rules. Static approaches scale to full-chip levels of the design and can be used for design sign-off. Static approaches identify "at-risk" areas while providing a cohesive debugging environment from schematic and other EDA views.

A graphical representation of these verification flows is shown in Figure 1 on page 50.

Latch-up verification is a complex task requiring detailed knowledge of the impacts and interactions of the manufacturing process, design style, and mitigation techniques. EDA tools can significantly improve the quality of this verification, particularly when the context of electrical connectivity and consideration of the voltages applied to the design are also leveraged.

Finally, latch-up EDA tools are mature and sophisticated so they help guide the designers to prevent potential latch-up failures before the IC design tape out. However, it is good to note that the EDA checks are developed based on the best available

information and sometimes written conservatively. Therefore, there is always room for interpretation and flexibility in special cases where designs may constrict.

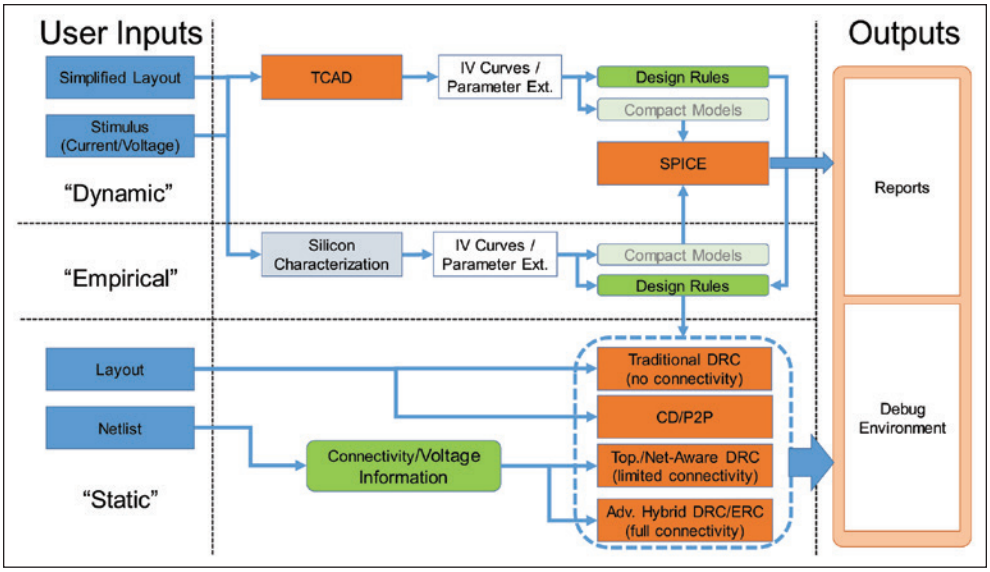

Figure 1: Latch-up Analysis and Verification Flows: Dynamic (Simulation-Based), Empirical Measurements, and Static Flows

The Latch-up EDA technical report [3] describes several latch-up prevention techniques and the corresponding verification methods used in the industry. The report presents various latch-up scenarios using case studies to explain where and how latch-up rules are leveraged by EDA tools and put to best use. In addition to discussing applications, a comprehensive reference for latch-up rules is provided for those wishing to implement them in EDA tools and internal flows of their choice.

With such diversity, the specific implementation of latch-up verification flows is expected to differ from company to company, with each foundry having its own best practices. Simultaneously, unique device variations, design margins, and design methodologies contribute to specific differences in effective implementation and verification strategies selected for latch-up prevention in different process nodes. However, the fundamental verification concepts described within this technical report should still hold true. As more latch-up EDA solutions become commercially available, along with increased foundry adoption, further opportunities for standardizing latch-up EDA verification approaches and specific latch-up checks will become available.

ESDA WG18 INFORMATION

At the time of publishing Technical Report for Latch-up Electronic Design Automation, the ESDA EDA Working Group 18 consists of the following members: Michael Khazhinsky (Silicon Labs, Inc.), Dolphin Abessolo-Bidzo (NXP Semiconductors), Muhammad Ali (Intel Corp.), Fabrice Blanc (ARM), Krzysztof Domanski (Intel Corp.), Frank Feng (Synopsys), Eleonora Gevinti (ST Microelectronics), Subhadeep Ghosh (Texas Instruments), Ulrich Glaser (Infineon Technologies AG), Akhil Gore (Synopsys), Harald Gossner (Intel Corp.), Fatjon (Toni) Gurga (Reliant ESD), Wolfgang Hartung (Infineon Technologies AG), Matthew Hogan (Siemens Digital Industries Software), David Klein (pSemi), Peter Koeppen (ESD Unlimited), Akhilesh Kumar (ANSYS), Wei Liang (GLOBALFOUNDRIES), Peter Michelson (Siemens Digital Industries Software), Steven Poon (TSMC), Guido Quax (NXP Semiconductors), Nicolas Richaud (Intel Corp.), Scott Ruth (AMD), Jens Schneider (Infineon Technology AG), Karthik Srinivasan (ANSYS), Nitesh Jagdishchandra Trivedi (Intel Corp.), Vladislav Vashchenko (Maxim Integrated), Paul Zhou (Analog Devices, Inc). If you have questions or comments, please contact the working group chair Michael Khazhinsky at michael.khazhinsky@silabs.com.

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ANSI Z535 IN FOCUS

By Erin Earley

What the Latest Updates to the Standards Mean for Your Warnings and Instructions

You're likely familiar with this critical set of accident prevention-related standards from the American National Standards Institute (ANSI) – those that manufacturers and workplaces across the U.S. use as a guide for safety colors, safety signs, safety symbols, product safety labels, safety tags, and how safety information is presented in product manuals. This year, 2022, is a revision cycle year for ANSI Z535, and it marks the first time many of the standards have changed in over a decade. This month's column explores the latest updates and what they mean for product safety.

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.

WHY ANSI Z535 MATTERS FOR MACHINERY SAFETY

While machine safety labeling and on-product warnings may seem straightforward, the processes behind the wording, design, and risk communication are often multi-layered and complex. It's a science, as well as an art. While standards exist to guide the decision-making process, there isn't one best format for every machine or company. Understanding the product, the audience, and the environment are key areas that need to be considered, interpreted, and documented to develop a clear, consistent safety label program.

"Although there are many gray areas, what I can say with certainty is that by striving to follow industry consensus standards that define today's best practices in visual safety communication – the (U.S.) ANSI Z535.4 and (international) ISO 3864-2 – equipment manufacturers can improve product safety and reduce their liability exposure," says Angela Lambert, head of standards compliance at Clarion Safety Systems, with a focus on product safety and liability. "The ANSI Z535.4 standards describe the content options for product safety signs and labels in the U.S., making them a perfect starting point for safety professionals producing and shipping products domestically to use as a guide for their efforts."

THE LATEST UPDATES TO THE STANDARDS

ANSI Z535 goes through a regular revision process where the standards are regularly updated for consistency and relevancy. 2022 is a revision cycle year for ANSI Z535 and, at the time of writing, the standards publication is expected for the second quarter of the year.

"This is a key year for ANSI Z535 as it marks the first time that many of the standards – including ANSI Z535.4 – have been reviewed and updated in more than 10 years. The committee as a whole, as well as each standard's subcommittee, has worked hard to come to a consensus on how to refine the best practices related to communicating safety in order to help protect people from harm," says Lambert, who is actively involved at the leadership level in the ANSI and ISO standards for product safety and visual safety communication, as chair of the ANSI Z535.1 subcommittee and delegate representative to ANSI for the ISO/TC 145 SC2 WG 1 committee – the group responsible for the library of ISO 7010 registered symbols and the ISO 3864 set of standards.

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KEYNOTE SPEAKERS

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Senior Staff Engineer Intertek (Plano, TX) North Texas IEEE Product Safety Engineering Society Co-Founder and Chair
*See Linkedin profile **here**.*

Ethics in Engineering, Making the Right Choices

Steve Reinecke
Chief Scientist and Regulatory Compliance Officer Proximity Systems
*See Linkedin profile **here**.*

UVC and Copper in Disinfection - The Good, the Bad and the Ugly

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An example of an ISO "wordless" format label (at left) and its ANSI-formatted counterpart (at right), including a combination of symbols and text.

The 2022 publication will replace the latest version of the standards – from 2017 – when the prior 2011 version was reaffirmed or republished without changes.

Change proposals for each ANSI Z535 standard have been balloted and determined, including global (encompassing all six of the standards) and standard-specific proposals. A few of the highlights from this process include:

- ANSI Z535.1 (Safety Colors), ANSI Z535.2 (Environmental and Facility Safety Signs), and ANSI Z535.5 (Safety Tags and Barricade Tapes) will undergo new clarifications revisions in how they relate to and can be combined with other applicable standards and regulations. Revisions will include modifications to be more consistent with other ANSI Z535 standards.
- ANSI Z535.3 (Criteria for Safety Symbols) will see updates regarding symbol comprehension testing to eliminate outdated methods and updates to several symbols found in its annex.
- ANSI Z535.4 (Product Safety Signs and Labels) will be updated with further clarification on its usage with other relevant standards. It will also see new text, definitions, and minor modifications to wording.
- ANSI Z535.6 (Product Manuals, Instructions, and Other Collateral Materials) is being revised to include minor clarifications and updates to German translations of select signal words.

In addition to these changes to the existing family of standards, another significant update is underway for ANSI Z535. A new ANSI Z535 standard – ANSI Z535.7 – focusing on safety information in electronic media has been approved for development after the idea was developed in 2021. Its scope is expected to include video materials, webpages, smartphones/tablets, and virtual reality.

CONSIDERATIONS FOR HARMONIZATION WITH ISO

A major topic of discussion in ANSI's revision has focused on whether or not to harmonize the standards in their differing opinions on ISO's symbol only or wordless formats and ANSI's text inclusive formats. "Even with the publication of the 2022 version of ANSI Z535, this will continue to be an area that those looking to follow both the ANSI and ISO standards may have questions around how best to navigate," Lambert says.

ISO 3864-2's latest (2016) standards update included significant changes to label format options, including symbol use. A new symbol-only or "wordless" format was introduced, using what ISO calls a "hazard severity panel" but no signal word. It communicates the level of risk through color-coding of the hazard severity panel. ANSI doesn't specifically include this option in its standards, but it does allow manufacturers to use ISO formats.

"Depending on whether you deem it more appropriate to follow the U.S.-based ANSI standards, the international ISO standards, or a combination of these, you have the option to use a word-message-only format, a symbol-only/wordless format, or a combination of symbols and text," Lambert says. "The standards aren't prescriptive in that regard, but they do provide options and considerations to consider for the application at hand."

PRODUCT Showcase

Banana Skins

385 Search and rescue transmitter interferes with car alarms, central locking, and garage door openers in Las Vegas

At first the motorists of Las Vegas and neighbouring Henderson suspected that machines had taken over the world: thousands of car alarms, central-locking systems and remote garage door openers simultaneously stopped working. Local car dealerships were overwhelmed by calls from angry customers. "We were getting a hundred calls a day," said Katie Baumann, a service operator at the Ford Country dealership in Henderson, told the Las Vegas Sun. "I tried every button everywhere. I couldn't get it to lock. I couldn't get it to unlock," said Bill Zawistowski, one frustrated motorist. "Nothing I could do would make it work."

After nearly six months, the riddle of the malfunctioning alarms and central locking systems has this week been solved by two engineers from Ford. The cause turned out to be a faulty "search and rescue" radio signal repeater located 4,000ft up nearby Frenchman Mountain, accessible only by four-wheel-drive vehicle. The radio tower had accidentally started broadcasting at 315MHz, the same frequency used by most remote keyfobs. "The repeater had been stuck on transmit probably since its last use during the winter," said Maurice Durand, of Ford. "The relatively strong nature of the signal produced interference with many remote entry keyfobs."

(Reported by Chris Ayres in Las Vegas, in The Times, Saturday August 24, 2004, page 19, https://www.the-times.co.uk. This conclusion followed months of fevered speculation that either UFOs or top-secret military experiments at nearby Nellis Air Base – which includes the famous 'Area 51'military research facility – were to blame, see Roger Franklin's article "Case of the mysterious lockout" in the "Weekend World" section of the New Zealand Weekend Herald, Saturday-Sunday March 6-7 2004, https://www.nzherald.co.nz.)

386 LED rear lamps interfere with car radio

For some time now, owners of some lightweight British sports cars with LED rear lights have been posting complaints of interference to their AM radio reception every time they apply the brakes.

While other owners posted helpful comments such as "do not apply the brakes, it slows you down", it was clear there was an EMC issue at the source of the problem. New cars fitted with LED rear light clusters as factory original equipment usually use some form of pulse width modulation (PWM) power control to adjust the brightness of the LEDs. For instance, where the distinction is necessary between night-time rearward illumination and full brightness braking illumination.

It seems to be this PWM control (and associated harmonics) causing the problem in the 100s of kHz region on these sportscars. Some of the manufacturers are now selling owners inductive jump connectors for the wiring loom controlling the rear lights, at £20 for a pair, to suppress this interference.

(Sent in by Alex McKay, by email, 31st July 2006. The editor supposes it is only natural for British sports car drivers to listen to AM radio.)

387 New UK advice on mobile phones in hospitals

Britain's Medicine and Healthcare products Regulatory Agency (MHRA) has issued a statement on the use of mobile phones in hospital settings. In a departure from long-held conventional wisdom, the Agency does not recommend a blanket ban on mobile phones in hospitals. The statement goes on to say, however, that "under certain circumstances, the electromagnetic interference from a mobile can affect the performance of some medical devices."

The MHRA recommends that hospitals and trusts develop local rules to minimize the risk of interference with critical care equipment, and the Agency has developed two posters that can be displayed for safe use of mobiles. The use of mobile phones is not recommended in critical care areas such as intensive therapy units and special baby care units, or where patients are attached to complex devices.

(From Interference Technology e-news, 28th July 2006.)

388 Solar flares can interfere with GPS, with serious consequences

Solar flares can drown out GPS signals, with potentially serious consequences for airlines, emergency services, and anyone relying on satellite navigation. It turns out that these bursts of charged particles, which produce auroras and geomagnetic storms, also generate radio waves in the 1.2 and 1.6GHz bands used by GPS.

How was such a clash missed? Because GPS receivers only became common during a period of low solar activity. By 2011 solar flares will reach the peak of their cycle and receivers will likely fail. Or so Alessandro Cerruti of Cornell University, New York, told a meeting of the Institute of Navigation in Fort Worth, Texas, last week. The only solution would be to redesign GPS

receivers or satellites, which may not be practical, says Cerruti.

(From 'Technology', New Scientist, 7th October 2006, page 27, https://www.newscientist.com. Cerruti's claims were also reported in 'News', Electronics Weekly, 11th October 2006, page 4, https://www.electronicsweekly.com. The editor keeps being surprised by how many organisations are using, or planning to use GPS for safety-critical functions, despite its well-known unreliability – reported in numerous previous Banana Skins.)

389 TV blackouts aren't Tetra's fault

I have been following recent correspondence in E&T about the Airwave Tetra System with interest. The interference with television signals that Alan Gordon described in the September issue is not, it seems to me, related to the standard of the installation of the Airwave equipment in police vehicles, nor to its use. Rather, the problem is one of poor immunity of much domestic equipment to out-of-band radio signals.

Lack of immunity is often most obvious where the radio transmissions have an element of amplitude modulation and so Tetra mobiles have the potential to show up this deficiency. The solution is for do domestic equipment to meet the relevant EMC standards. Currently some manufacturers simply ignore the need for proper EMC provisions.

(From 'Feedback', in the IET's Engineering and Technology magazine, October 2006, page 6, https://www.theiet.org. Also see Banana Skin No. 325.)

390 Microwave ovens interfere with Wi-Fi

Recently, indoor wireless communication systems in the 2.4GHz band, such as IEEE802.11b WLAN (Wireless LAN), are becoming widespread. However, this frequency band is allocated to ISM (Industrial, Scientific, and Medical) equipment. Hence, electromagnetic noises emitted from the ISM equipment may cause interference with WLAN systems. Since there are a tremendous number of microwave ovens for domestic use, oven noises often cause serious performance degradation in WLAN systems.

(Taken from the Abstract of the paper entitled: "Reduction of Microwave Oven Interference in DS-SS WLAN Systems using Adaptive Filters", by M. Nkatsuka et al, EMC-Europe 2004 Symposium, Eindhoven.)

391 Microwave cooker interferes with Wi-Fi

With reference to Banana Skin No.390, from my own personal experience: I have a wireless LAN at home (IEEE802.11b/g) and also a wireless video sender, to transmit composite video and audio (running in the 2.4GHz band), and also a DECT phone. All of which are happy to cohabit with no problems.

However when I use my microwave cooker, all systems are affected. The wireless LAN on my laptop loses the connection, although it continues to see the router at a good signal level, but is unable to connect. Interference on the video sender makes it completely un-watchable, and a faint crackle can be heard on the phone. This also happens around mealtimes occasionally even when the microwave is not in use, presumably due to neighbours' microwaves? (I live in a terraced house.) My microwave carries a CE mark and is about 7 years old. The microwave is situated about 10 metres away from all the wireless systems. When I come to replace my microwave I intend to complain if the new microwave causes the same interference.

(Sent in by Stuart Nottage of Lambda UK, on Dec 5th 2006, by email)

392 FCC Part 15 unlicensed devices and interference

The Federal Communications Commission's Part 15 rules on unlicensed RF devices and the ways in which possible interference from such wireless systems are addressed have generated an amazing amount of misinformation. Simply reading some of the comments filed by various services on how Part 15 radio devices—specifically WLANs (wireless local area networks)—interfere with their systems might seem to indicate a near-crisis situation.

In responses and conversations, various manufacturers of licensed equipment would have us believe that such Part 15 wireless systems are as beneficent as the Black Plague. However, a thorough examination of the problem indicates that the actual issues are far less troubling—in fact, even manageable.

Yes, interference issues do exist. For example, some of the telecom companies have banned or restricted WLAN devices from their switching stations because their equipment (Part 15 unintentional radiator devices) are subject to interference from WLAN devices. The problem is not the WLAN devices themselves but the fact that the industry immunity standard used in testing these devices does not use "real world" transmitter emissions from a WLAN.

In First Report and Order 01-278, the commission required that radar detectors be certified (they were exempt as a receiver operating over 960 MHz). This action was to avoid a serious field complaint from VSAT (satellite terminal) operators whose services were being disrupted by radar detectors. Occasionally, the FCC has requested that a WISP (wireless Internet service provider) operating Part 15 WLAN equipment cease operation until a specific interference problem has been fixed.

Is the situation perfect? No, far from it, but it is not as chaotic as some people think or, at least, state in their public filings. Apparently, a bit of fear and/or melodrama is being used to advance the case for some complainants.

(Some extracts taken from "A look at Part 15 interference problems", by David A Case, published in Interference Technology's EMC Directory & Design Guide 2005.)

393 Interference to broadband services

Response 19.4: A telecommunications company said that Regulation 17 has the effect of meaning that a suspension notice issued under Regulation 44 can only be issued in respect of apparatus placed on the market after 20 July 2009. They are aware of numerous cases of interference to broadband services from apparatus that is faulty or from installations that are poorly maintained. They would like to see suspension 11 notices issued in all cases of interference regardless of age of equipment since there is no other legislation that protects telecommunications networks from this type of interference.

DTI Comments: Regulation 17 has been modified to follow the placing on the market and putting into service provisions of the Directive.

(Taken from: "Implementing the new Electromagnetic Compatibility (EMC) Directive in the United Kingdom", DTI Response to the Public Consultation, December 2006, URN 06/2236.)

The regular "Banana Skins" column was published in the EMC Journal, starting in January 1998. Alan E. Hutley, a prominent member of the electronics community, distinguished publisher of the EMC Journal, founder of the EMCIA EMC Industry Association and the EMCUK Exhibition & Conference, has graciously given his permission for In Compliance to republish this reader-favorite column. The Banana Skin columns were compiled by Keith Armstrong, of Cherry Clough Consultants Ltd, from items he found in various publications, and anecdotes and links sent in by the many fans of the column. All of the EMC Journal columns are available at: https://www.emcstandards.co.uk/emi-stories, indexed both by application and type of EM disturbance, and new ones have recently begun being added. Keith has also given his permission for these stories to be shared through In Compliance as a service to the worldwide EMC community. We are proud to carry on the tradition of sharing Banana Skins for the purpose of promoting education for EMI/EMC engineers.

August 1 - August 5, 2022 **Spokane, Washington**

2022 IEEE International Symposium on Electromagnetic Compatibility, Signal Integrity and Power Integrity

Hosted by the IEEE Electromagnetic Compatibility Society, the world's largest organization dedicated to the development and distribution of information, tools and techniques for reducing electromagnetic interference

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Monday, August 1		
TIME	**SESSION NAME**	**FORMAT**
8:30 am - 12:00 pm	Automotive EMC Standards and Instrumentation Update	Workshops and Tutorials
8:30 am - 12:00 pm	Recent Advancements in HEMP, EMP, and IEMI Protection – A Global Perspective	Workshops and Tutorials
8:30 am - 12:00 pm	Low Frequency EMI and Modeling of Conducted Interference in Systems with Multiple Converters	Workshops and Tutorials
8:30 am - 12:00 pm	EMC Testing Basics	Workshops and Tutorials
8:30 am - 5:30 pm	Fundamentals of EMC	Workshops and Tutorials
1:30 pm - 5:30 pm	Automotive EMC – Advances in Design and Test Methodologies	Workshops and Tutorials
1:30 pm - 5:30 pm	Model Based System Engineering, Mode Filtering, Robotics: Modern Antenna Measurement Techniques for EMC and RF Applications	Workshops and Tutorials
1:30 pm - 5:30 pm	Introduction to Power Electronics Electromagnetic Interference Analysis and Suppression	Workshops and Tutorials
1:30 pm - 5:30 pm	Introduction to 5G and Related Health Effects Issues	Workshops and Tutorials

Tuesday, August 2		
TIME	**SESSION NAME**	**FORMAT**
8:00 am - 5:30 pm	Global University	
8:30 am - 10:00 am	Return-to-Flight Electromagnetic Measurements: The NASA Shuttle Ascent Debris Radar System	Keynote
10:30 am - 12:00 pm	Solving Complicated SIPI/EMI/Thermal Engineering Issues in Mobile Systems Using Multiphysics Simulations	Special Session
10:30 am - 5:30 pm	Technical Papers	
1:30 pm - 3:00 pm	Critical Challenges and Solutions in Spectrum Engineering	Special Session
1:30 pm - 5:30 pm	Introduction to EMI Modeling Techniques	Workshops and Tutorials
1:30 pm - 5:30 pm	Application of Reverb Chambers	Workshops and Tutorials
3:00 pm - 5:30 pm	Low-Frequency Conducted Emissions Issues in Complex Smart Power Grids under Close EMI Coexistence	Special Session

Wednesday, August 3		
TIME	**SESSION NAME**	**FORMAT**
8:00 am - 5:30 pm	Global University	
8:30 am - 12:00 pm	Site Validation Standards by the United States National Committee C63 on EMCS	Workshops and Tutorials

Wednesday, August 3 *continued*		
TIME	**SESSION NAME**	**FORMAT**
8:30 am - 12:00 pm	Lessons Learned Creating Reliable Computational Models for SI and EMC Applications	Workshops and Tutorials
8:30 am - 12:00 pm	Hardware Security for Smart Society	Special Session
8:30 am - 5:30 pm	Technical Papers	
1:30 pm - 5:30 pm	Smart Grid and EMC Issues	Workshops and Tutorials
1:30 pm - 5:30 pm	Full System EMC Simulation Using Encrypted 3D Components	Workshops and Tutorials

Thursday, August 4		
TIME	**SESSION NAME**	**FORMAT**
8:00 am - 12:30 pm	Global University	
8:30 am - 12:00 pm	Ham Radio Through History and Today	Workshops and Tutorials
8:30 am - 12:00 pm	Signal Integrity Methods for Card, Connector, and Baseboard: PCI Expres 64.0 GT/s Performance on a Budget	Workshops and Tutorials
8:30 am - 12:00 pm	E1 HEMP Coupling to Power Substation Cables	Special Session
8:30 am - 5:30 pm	Technical Papers	Special Session
4:00 pm - 5:30 pm	Noise and Interference in Modern Electrical Power Networks	Special Session

Friday, August 5		
TIME	**SESSION NAME**	**FORMAT**
8:30 am - 12:00 pm	Basic EMC Measurements	Workshops and Tutorials
8:30 am - 12:00 pm	Risk-Based EMC Initiatives in Europe	Workshops and Tutorials
8:30 am - 12:00 pm	Product Safety Compliance and Global Market Access	Workshops and Tutorials
8:30 am - 12:00 pm	EMC Test and Design for Cables and Connectors	Workshops and Tutorials
8:30 am - 12:00 pm	Innovative Wireless Test Methodologies for 5G New Radio and mmWave Applications	Workshops and Tutorials
8:30 am - 12:00 pm	Advancing Simulation Tools and Computational Methods with Packaging Benchmarks	Workshops and Tutorials
1:30 pm - 5:30 pm	About Electromagnetic Compatibility of Track Circuits with the Traction Supply System of Railway	Workshops and Tutorials
1:30 pm - 5:30 pm	EM Resilience: Managing Functional Safety and Other Risks with Regard to Electromagnetic Disturbances	Workshops and Tutorials
1:30 pm - 5:30 pm	EMC Overview of Tests Applicable to 5G and WLAN Devices in Brazil	Workshops and Tutorials
1:30 pm - 5:30 pm	Becoming a Succesful Book Author for the IEEE EMC Society	Workshops and Tutorials

www.emc2022.emcss.org

Sunday, July 31	
MEETING NAME	**TIME**
EMC Society Board of Directors Meeting	9:00 am – 5:00 pm

Monday, August 1	
MEETING NAME	**TIME**
Speaker Breakfast	7:00 am – 9:00 am
Technical Advisory Committee (TAC) Meeting #1	7:00 am – 9:00 am
Standards Advisory & Coordination Committee (SACCom)	8:00 am – 9:45 am
L-EMCPA Editorial Board Meeting	10:00 am – 12:00 pm
Standards Development and Education Committee (SDECom)	10:20 am – 12:00 pm
P1128 Working Group	10:45 am – 12:00 pm
Chapter Chair Training Session and Luncheon	12:00 pm – 1:30 pm
Standards Working Group Chair Training	1:55 pm – 3:10 pm
Standards Continuity Round Table	1:55 pm – 3:10 pm
The IEEE Standards Process Explained	1:55 pm – 3:10 pm
SC-1 Smart Grid and EMC Issues Committee Meeting	5:30 pm – 6:30 pm
Young Professionals Jeopardy & Social Event	5:30 pm – 8:00 pm

Monday, August 1 5:30 pm - 8:00 pm

Young Professionals EMC Jeopardy and Social @ The Onion

Tuesday, August 2 6:00 pm - 8:00 pm

Welcome Reception @ Riverside Terrace

Tuesday,August 2	
MEETING NAME	**TIME**
TC-2 EMC Measurements Committee Meeting	7:00 am – 8:30 am
Speaker Breakfast	7:00 am – 9:00 am
EMCS PerCom	8:00 am – 9:00 am
P2718 Working Group	10:20 am – 12:00 pm
IEEE EMC Standards Explained	10:20 am – 12:00 pm
SC-5 Power Electronics EMI/ EMC Committee Meeting	12:00 pm – 12:50 pm
TC-10 Signal and Power Integrity Committee Meeting	12:00 pm – 1:00 pm
TC-8 Aeronautics and Space EMC Committee Meeting	12:00 pm – 1:00 pm
Amateur Radio Luncheon	12:00 pm – 1:55 pm
P2718 Standard Meeting	1:30 pm – 3:30 pm
International SDOs and Standards Explained	1:55 pm – 5:20 pm
Computational EM & Validation Standards Continuity Group	3:35 pm – 5:20 pm
Welcome Reception	6:00 pm – 8:00 pm

Thursday, August 4
12:30 pm - 2:00 pm

Awards Luncheon @
Centennial Ballroom

Wednesday, August 3
7:00 pm - 10:00 pm

Evening Gala @
Centennial Ballroom

Wednesday, August 3

MEETING NAME	TIME
IEEE EMC Society Education Committee Meeting	7:00 am – 8:30 am
Speaker Breakfast	7:00 am – 9:00 am
TC-1 EMC Management Committee Meeting	7:30 am – 9:00 am
TC-11 Nanotechnology and Advanced Materials Committee Meeting	8:00 am – 9:00 am
T-EMC Committee Meeting	8:00 am – 10:00 am
P2715/P2716 Working Group	8:30 am – 9:45 am
P1897 Working Group	10:20 am – 12:00 pm
Shielding Standards Continuity Group	10:20 am – 12:00 pm
TC-9 Committee Meeting	12:00 pm – 1:00 pm
TC-7 Low Frequency EMC Committee Meeting	12:00 pm – 1:00 pm
TC-5 High Power Electromagnetics (HPEM) Committee Meeting	12:00 pm – 1:30 pm
Founders and Past Presidents Luncheon	12:00 pm – 1:30 pm
P2855 Working Group	12:00 pm – 1:55 pm
IEEE 473 Working Group	12:00 pm – 1:55 pm
TC-4 Electromagnetic Interference Control Committee Meeting	12:00 pm – 2:00 pm
Youth Technical Program	1:00 pm – 3:30 pm
Women In Engineering Event (WIE)	3:00 pm – 5:00 pm
Exhibitors Reception	5:00 pm – 6:00 pm
Evening Gala Event	7:00 pm – 10:00 pm
Young Professionals Evening Networking Event	10:00 pm

Thursday, August 4

MEETING NAME	TIME
Team EMC Bike Ride	6:50 am
TC 6 Spectrum Engineering Committee Meeting	7:00 am – 8:30 am
Speaker Breakfast	7:00 am – 9:00 am
TC-12 EMC for Emerging Wireless Technologies Executive	8:00 am – 9:00 am
Functional Safety Standards Continuity Group	8:00 am – 9:45 am
Awards Luncheon	12:30 pm – 2:00 pm
Standards Development & Education Committee (SDECom)	1:55 pm – 3:10 pm
TC-3 Electromagnetic Environment Committee Meeting	2:00 pm – 3:00 pm
EMC Society Board of Directors Meeting	6:00 pm – 9:00 pm

Friday, August 5

MEETING NAME	TIME
Speaker Breakfast	7:00 am – 9:00 am
Technical Advisory Committee (TAC) Meeting #2	7:00 am – 9:30 am
IBIS Summit	8:00 am – 12:00 pm

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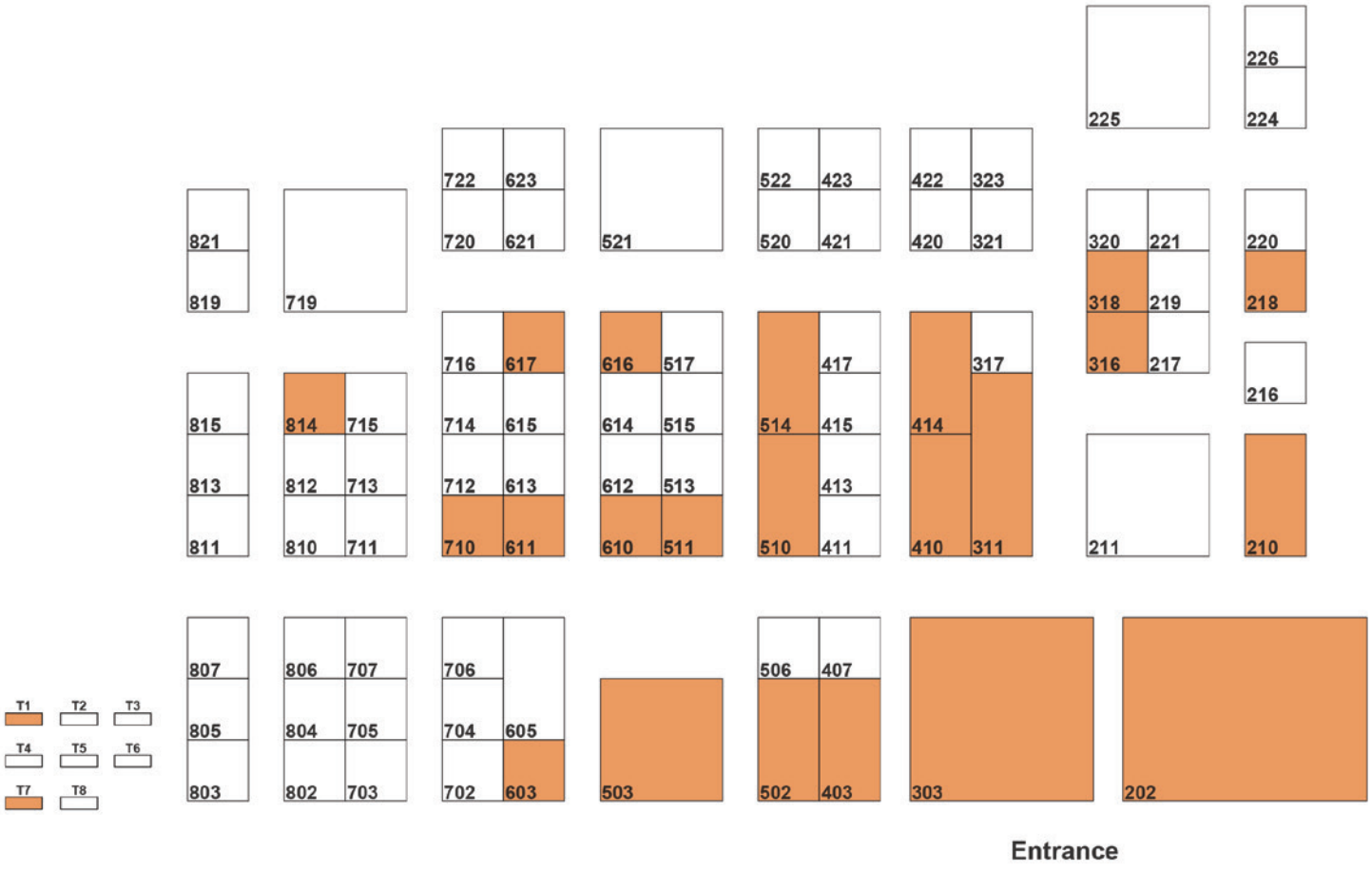
Explore the Exhibit Hall and learn about new technologies, instrumentation, and solutions that service the industry.

Tuesday, August 2	Wednesday, August 3	Thursday, August 4
10:00 am - 5:00 pm	9:00 am - 5:00 pm	9:00 am - 12:00 pm



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July 12-14
EMV 2022

August 1-5
IEEE EMC+SIPI 2022

September 5-8
EMC Europe 2022

September 13-15
The Battery Show

September 13-15
Fundamentals of Random Vibration and Shock Testing Training

September 13-16
Lab Techniques, Robust Design, and Troubleshooting

September 18-23
44th Annual EOS/ESD Symposium

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September 29
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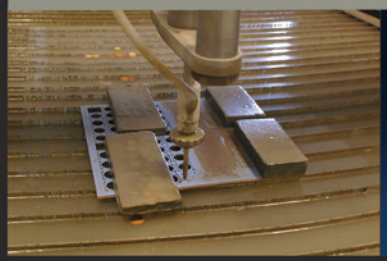

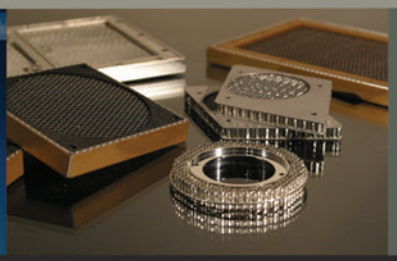

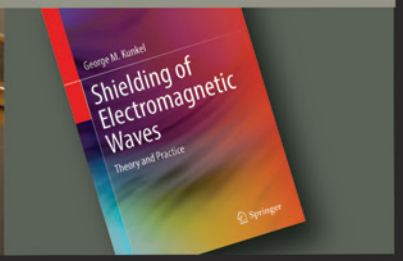

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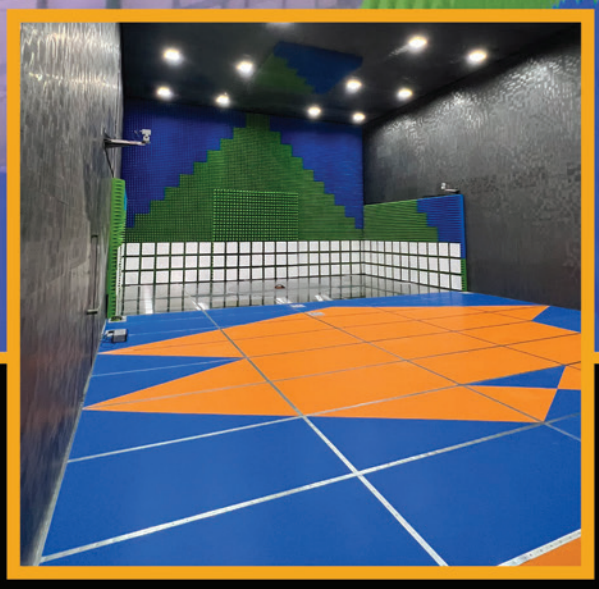

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