APRIL 2023

IN COMPLIANCE™

THE COMPLIANCE INFORMATION RESOURCE FOR ELECTRICAL ENGINEERS

Troubleshooting Intra-System EMI

PLUS


All you
need in one
small package
Antennas | Probes | Accessories | Preamplifiers | Low-Loss Cables | Recalibration Services
Travel Made Easy
with Next-Day,
On-Time
Delivery
Don't Leave home without it. A.H. Systems provides many models of Portable Antenna Kits, each containing all the necessary Antennas, Current Probes, and Cables to satisfy numerous customer requirements. Excellent performance, portability (compact size and lightweight), along with ease of setup make all of the Antenna Kits your choice for indoor or field testing. Loss and breakage are virtually eliminated as each component has a specific storage compartment within the case. All Antenna Kits are accompanied with a Tripod and Azimuth & Elevation Head, both contained in a Tripod Carrying Case**...and dont forget your keys!**
ANTENNAS...
and KITS TOO...
Innovation
Quality
Performance
Phone: (818)998-0223 ♦ Fax (818)998-6892
http://www.AHSystems.com
A.H. Systems

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

IN COMPLIANCE

Same Page Publishing Inc.
451 King Street, #458
Littleton, MA 01460
tel: (978) 486-4684
fax: (978) 486-4691

advertising
For information about advertising contact Sharon Smith at sharon.smith@incompliancemag.com.

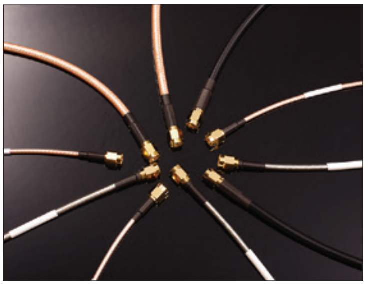
subscriptions
In Compliance Magazine subscriptions are free to qualified subscribers in North America. Subscriptions outside North America are $129 for 12 issues. The digital edition is free. Please contact our circulation department at circulation@incompliancemag.com

PRINTED WITH SOY INK

APRIL 2023

Volume 15 | Number 4

CONTENTS



Apple Files Patent for EMC Testing Chamber

One of the world's most prolific developers of innovative technology products for consumers and businesses appears to be expanding its innovation efforts into the EMC testing space.

According to a recent article posted to the website "Patently Apple," a patent application, titled "Electromagnetic Shielding Testing Chamber with Ventilation," was published earlier this month by the U.S. Patent & Trademark Office. The patent application details a testing apparatus for electromagnetically sensitive equipment that includes housing designed to block the transmission of external electromagnetic waves while also reducing the reflection of electromagnetic waves within the testing chamber.

The testing apparatus design also includes tubing to provide airflow between the interior of the testing chamber and the external environment that is configured to block external electromagnetic waves from entering the chamber.

In addition to the EMC testing chamber application, Apple has also reportedly filed several additional patents related to various aspects of the graphics processors used in its devices.

EU Commission Proposes to Extend MDR/IVDR Deadlines

The Commission of the European Union (EU) has proposed extending the transition period for existing medical devices under its Medical Device Regulation (EU 2017/745, also known as the MDR) and the In Vitro Diagnostic Regulation (EU 2017/746, also known as the IVDR).

The Commission is seeking to extend the validity of certificates issued between May 2017 and May 2021 under Directive 93/42/EEC for medical devices, Directive 90/385/EEC for active implantable medical devices, and Directive 98/79/EC for in vitro medical devices. According to the formal proposal issued in January, the Commission is proposing extending certificate validity for devices that have been placed on the market until the end of December 2027 for Class III and certain Class IIb implantable devices, and December 2028 for other Class IIb devices and for Class IIa and Class I devices.

The current transition deadline under the MDR is the end of May 2024, while the IVDR's transition deadlines range from May 2025 to May 2027, depending on the class of the device.

The Commission's proposed transition deadline extension is an effort to address the shortage of Notified Bodies authorized to qualify devices under the MDR and IVDR, leading to longer-than-anticipated wait times. According to the Commission, other factors, including the Covid Pandemic and the war in Ukraine, have constrained efforts to certify new devices and recertify legacy devices.

You Can't Make This Stuff Up

Scientists Detect Radio Signal from 9 Billion Light Years Away

Between wars, political conflict, and the economy, you may feel some mornings like just staying in bed and pulling a blanket over your head. So here's a bright spot to help you start your day.

Scientists working at the Giant Metrewave Radio Telescope (GMRT) in India have detected a radio signal emanating by one of the universe's earliest atoms nearly 9 billion light years from earth! According to a recent posting to the *LiveScience* website, the radio signal was generated from neutral hydrogen atoms, one of the universe's most primitive elements formed from the debris generated by the Big Bang 400,000 years after the birth of the universe.

According to the posting, a neutral hydrogen atom emits electromagnetic radiation at a wavelength of 21 centimeters, placing it in the category of radio waves. Prior to the GMRT discovery, the furthest such signal to be detected was from about 4.4 million light-years away, less than half the distance of the most recently detected signal.

The GMRT scientists were reportedly able to leverage an effect based on Einstein's theory of relativity called "gravitational lensing," in which a signal coming from a distant object is magnified. In this case, gravitational lensing magnified the signal by a factor of 30, allowing the GMRT telescopes to detect it.

5G RF Receiver Performance White Paper Released

The widespread adoption of the 5G spectrum for advanced wireless communications ultimately depends on the quality and the performance of the equipment required to support it. Toward that end, industry trade organization 5G Americas has just published its assessment of the factors essential to ensuring radio frequency receiver performance.

The white paper, titled "Radio Frequency Receiver Performance," provides a comprehensive review of current receiver standards and other applicable studies and analyses on key receiver performance requirements. The paper also offers a deep dive into the specific technical aspects of RF receivers that must be addressed to fully support 5G wireless communications while also making the most efficient use of the available spectrum.

The paper concludes with a series of recommendations for regulators on how to formulate regulatory policy that upholds minimum performance standards without constraining industry innovation and independence.

AI Risk Management Framework Released by NIST

As artificial intelligence (AI)-based technology and systems are more widely deployed, the U.S. National Institute of Standards and Technology (NIST) is taking steps to help organizations leverage the benefits of AI while minimizing the potential risks.

According to a press release, NIST has released "Artificial Intelligence Risk Management Framework (AI RMF 1.0)," a guidance document that maps out a flexible but structured and measurable framework to assess AI-related risks. The framework includes four specific processes (govern, map, measure, and manage) to address the practical risks associated with the use of AI systems.

The AI RMF is the product of 18 months of work by NIST in conjunction with partners from both the public and private sectors. The final guidance reflects nearly 400 contributions from more than 240 different organizations.

TROUBLESHOOTING INTRA-SYSTEM EMI

Some Case Studies That Demonstrate Good Techniques for Grounding, Shielding, and Cabling

(About the Author) Dr. Min Zhang is the founder and principal EMC consultant of Mach One Design Ltd, a UK-based engineering firm that specializes in EMC consulting, troubleshooting, and training. His in-depth knowledge of power electronics, digital electronics, electric machines, and product design has benefitted companies worldwide. Zhang can be reached at info@mach1design.co.uk.

By Dr. Min Zhang

The concepts of intra-system and inter-system electromagnetic compatibility (EMC) are defined in [1]. Inter-system EMC focuses on the compatibility of a system with its environment and with other systems and apparatus in that environment. Intra-system EMC, on the other hand, deals with the compatibility with each of the various other items within the system.

Experience has shown that most intra-system EMI issues are related to inadequate grounding structure, as the power and signal integrity of devices in a system are tied to the return path. This article will review three case studies to illustrate how to achieve a proper grounding structure.

CASE STUDY 1 – INTRODUCING A CLASSIC INTRA-SYSTEM ISSUE

This is a typical intra-system EMI issue. Both the electric vehicle and the radar module pass EMC tests. However, in one of the vehicle safety tests, the radar module does not function as expected; the objects in front of the vehicle are not detected by the radar system, posing a safety risk. The component manufacturer performs a comparison investigation, and the results show that vehicles produced by different manufacturers using the same radar module have no functional issues.

Figure 1 shows the radar module as the device under test (DUT). The DUT has a metal housing and shares the same ground as the 24 V power return path (0 V, or KL31). The wire bundle of the DUT consists of power lines and CAN bus as the communication line. The following tests are performed to further investigate the issue:

1. Using a low-frequency current clamp, we measure the DC current on the return wire when the DUT is mounted on and taken off the chassis bracket, as shown in Figure 1 (a); and
2. Using an RF current probe, we measure the common mode current on the wire bundle when the DUT is mounted on and taken off the chassis bracket, as shown in Figure 1 (b).

The results are shown in Figure 2 and Figure 3 respectively, seen on page 10. In Figure 2, the current clamp has an output ratio of 100 mV/A; the result indicates about 170 mA DC current in the 0 V wire when the DUT is disconnected from the chassis. When the DUT is mounted on the chassis, the DC current drops to almost zero, and an increased high-frequency noise is observed on the power return wire.

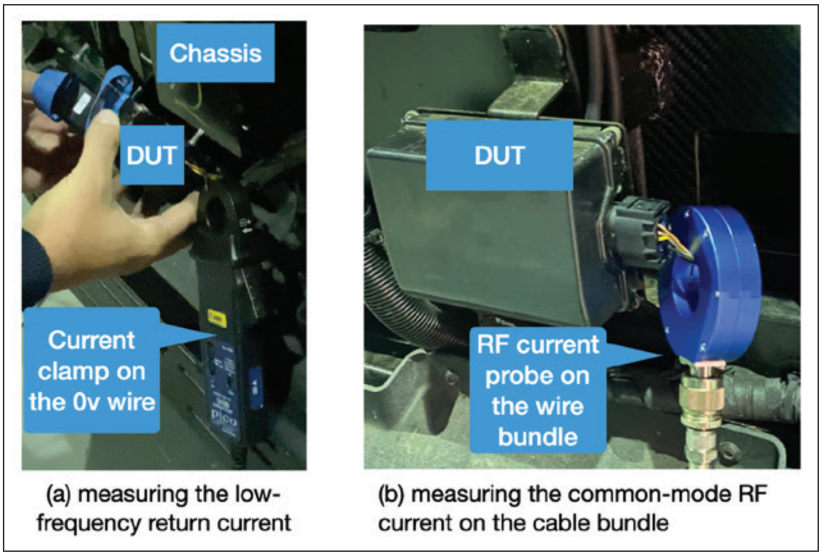
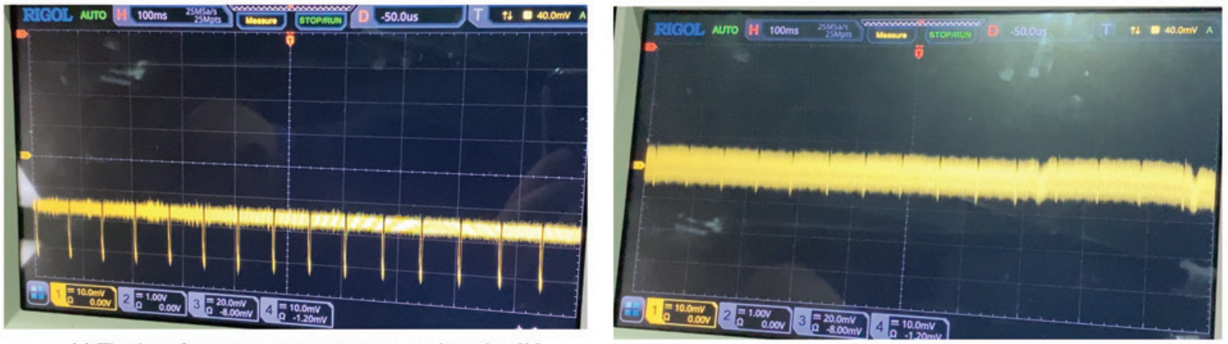


Figure 1 (a) and (b): Using two types of current probes to measure the DUT

Figure 3 shows the common-mode current on the cable bundle, both in the time and frequency domain. Between the two configurations, the common-mode current is about 40 dB (or 100 times) higher across a wide frequency range when the DUT is mounted on the chassis.

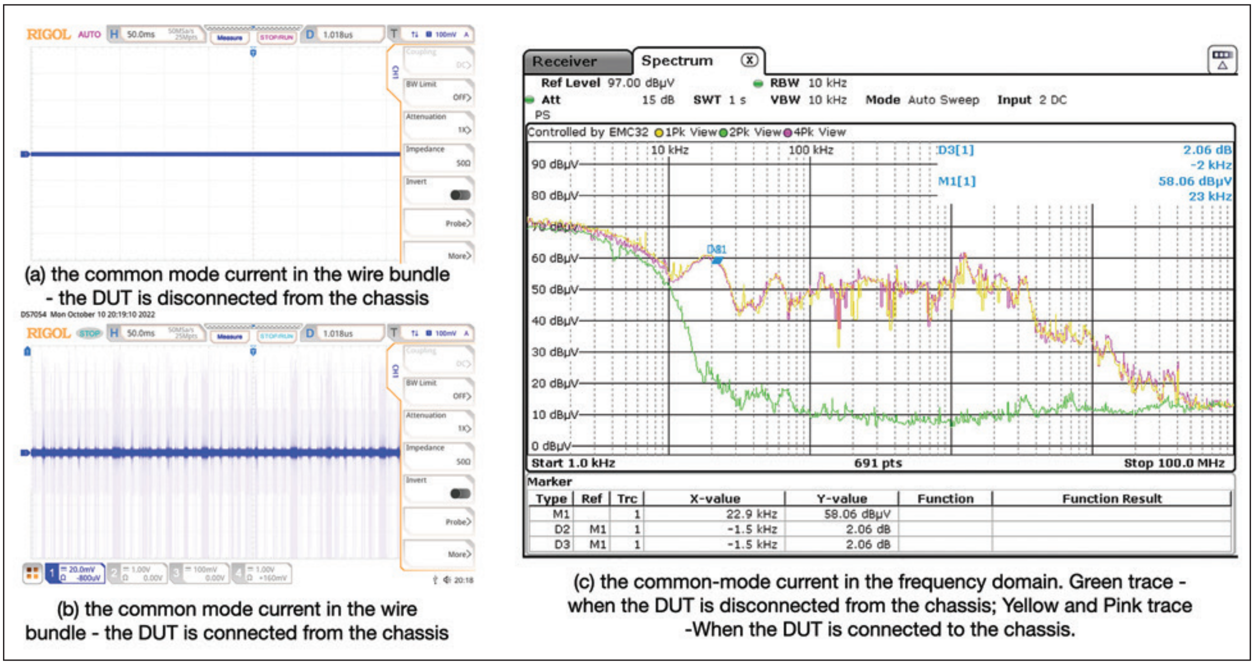
The results enable us to clearly understand the power and signal paths in such systems. The DC (or the low-frequency) current spreads out because it takes the return path of the least resistance. In this case, the chassis structure is a lower resistance path than the 0V return wire. The CAN bus communication line, a differential signal pair, normally has relatively good immunity to ground potential change. However, CAN bus lines can suffer noise issues when a large ground loop or noisy electronic control units (ECUs) share the same chassis [2]. The high common mode noise measured on the cable bundle suggests a ground bounce.



(a) The low-frequency current measured on the 0V wire - when the DUT is isolated from the chassis

(b) The low-frequency current measured on the 0V wire - when the DUT is mounted on the chassis

Figure 2 (a) and (b): The low-frequency current measured in the 0V wire (a) when the DUT is disconnected from the chassis; and (b) when the DUT is mounted on the chassis



(a) the common mode current in the wire bundle - the DUT is disconnected from the chassis

(b) the common mode current in the wire bundle - the DUT is connected from the chassis

(c) the common-mode current in the frequency domain. Green trace - when the DUT is disconnected from the chassis; Yellow and Pink trace -When the DUT is connected to the chassis.

Figure 3: The common-mode current is measured in two configurations

There are three ways to solve this intra-system EMI issue, as follows:

1. We can isolate the housing of the DUT electrically by applying paint on the chassis bracket;
2. We can trace back to the 0 V wire connection to the vehicle chassis and look at the other ECUs that share the same CAN bus lines; or
3. If the noise is due to other noisy ECUs that share the same chassis, apply EMC fix on the noisy ECUs.

Since EMC engineering should always apply the most cost-effective solutions to a problem, here we applied the electrical isolation of the DUT as a temporary solution while we redesigned the grounding scheme of the wiring and harnessing for the next design.

CASE STUDY 2 – PROVIDING A BETTER SIGNAL RETURN PATH

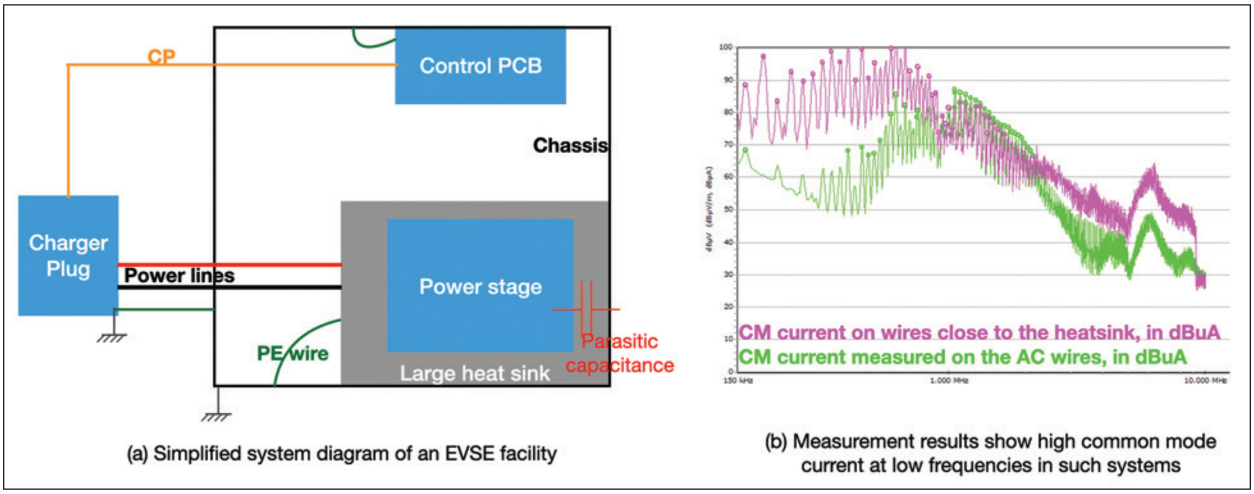
In this case, the control pilot (CP) signal line of a 500 kW charging station fails to work properly. Electric vehicle service equipment (EVSE) facilitates the safe delivery of power to electric vehicles from the grid. Many EV manufacturers have adopted the SAE J1772 standard, in which the vehicle and charging facility communication relies on two-way communication over a single wire called the CP wire [3].

The CP wire is required to travel down several meters of cable and carries a 1 kHz PWM signal. Because of the high amplitude (>10 V) and low-frequency characteristics, many charging facilities do not require special signal protection on the CP line. However, in this case, the high-power application means that significantly high RF currents can be induced into the system even though the IGBT modules were switched at a relatively low frequency.

Figure 4 (a) demonstrates the intra-system noise issue. The power module often consists of high voltage, high current power electronics devices mounted on a large-size heatsink. Depending on the power level, forced air or liquid can be used for cooling. But, regardless of the cooling methods, the heatsink is always big and heavy.

This introduces problems because there is only a very thin layer of thermal paste between the power electronics switches and the heatsink, which means that there is a very large parasitic capacitance between the power switches and the heatsink. Between the transistors and the heat sink, the parasitic capacitance of a few nF is not unusual. At 200 kHz (a low frequency for most EMC engineers), the impedance is only around 100 ohms[4].

Design engineers use fast switching devices (shorter rise/fall time) to increase system efficiency for high-power applications, making EMI worse. For example, at 800 V DC, assuming 1 nF parasitic capacitance, a switching event with 100 ns rise time gives 8 Amps current (based on CdV/dt). This current is directly injected into the heatsink. The heatsink is often physically connected to the cabinet chassis and the protective earth wire. The control circuitry is often bonded to the cabinet chassis, which is subject to interference such as ground bounce.



(a) Simplified system diagram of an EVSE facility

(b) Measurement results show high common mode current at low frequencies in such systems

Figure 4 (a) and (b): The simplified system diagram of an EVSE facility (a), and the common mode current measured in wires inside the system (b)

It should be noted that the "ground" in such systems is often the protective earth wire, which effectively is the cabinet chassis. The low-frequency nature of the noise also means it can affect a large area in the system. The EMC challenge in such systems often involves the high low-frequency common mode current, as shown in Figure 4 (b).

The sharp edges of the common mode current can easily couple to the CP wire and degrade the signal quality. We have a few options to protect the signal integrity of the CP wire, which include:

1. On the noise source side, slowing the power electronics devices reduces the system efficiency. But this approach will probably lead to further changes in thermal design and is, therefore, not encouraged;
2. On the coupling path, we can reduce the parasitic capacitance from the heatsink to the protective earth/chamber chassis by floating the heatsink. This can be done on an air-cooled system. Another way is to insert a shield between the transistor and the heatsink. The heatsink needs to be bonded to the 0 V of the system, but this makes the thermal path worse; or
3. On the impacted side, it is much easier to apply cost-effective solutions. Using a braided shield to protect the wire worked. The shield works because the inner shield provides a continuous return path for the signal. Without the shield, the return path is the chassis, which could be 10s of centimeters away from the signal line. The shield needs to be terminated on the 0 V of the control circuitry. The other end of the shield can be left unterminated in this case, as the noise we're attempting to deal with is in the low-frequency range.

A guarded 0 V wire might also work in the Option 3 scenario. If the CP wire "flies" over the power stage, we need to re-arrange the wiring layout so that it avoids the noisy circuitry inside the system.

CASE STUDY 3 – WHEN THE INTRA-SYSTEM EMI MEETS THE INTER-SYSTEM EMI

In [1], Williams states:

> *"Difficulty arises when these two approaches (the intra-system and the inter-system) are confused one with the other, or at the interface where they meet. This can happen when commercial equipment is used in other environments, for instance, on vehicles or in aircraft… Military projects might require commercial-off-the-shelf (COTS) products to be procured, but their EMC performance requirements are substantially mismatched to military needs. Grounding and bonding techniques which are necessary and appropriate for intra-system requirements can be misapplied to attempt to meet the EMC Directive."*

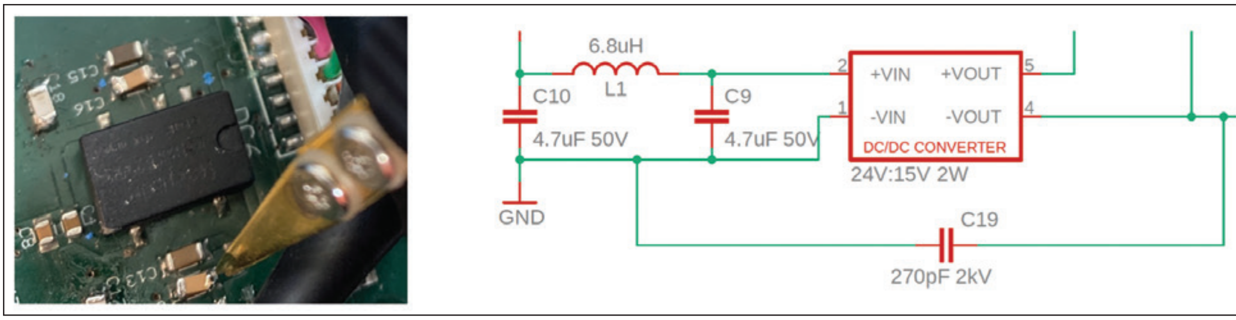


Figure 5: The COTS DC-DC converter and its configuration on the gate driver board

Case Study 3 perfectly demonstrates this point. When troubleshooting the conducted emissions of a power converter used for EV applications, we find a COTS DC-DC converter on the gate driver board, as shown in Figure 5. After reviewing the datasheet, we notice that the product, when designed with the filter configuration shown in Figure 5, only complies with EN55032 Class B conducted emissions. Obviously, the conducted emission standard in the automotive world is much more stringent than those applicable to systems intended for commercial use.

The recommended filter configuration for the DC-DC converter is inadequate in achieving a low noise performance. Therefore, the filter needs to be modified.

Note that the π filter is mainly designed to suppress the differential mode noise, while the conducted emissions caused by this circuitry are predominantly a common mode noise. Since the converter is an isolated type, the capacitor (C19) between the primary and secondary sides greatly impacts the common mode noise.

So the first thing we try is to increase the capacitance value. Because the noise issues we're trying to deal with are around 1 MHz, we replace the 27 0pF capacitor with a 10 nF capacitor. The 10 nF capacitor reduces the low-frequency common mode noise of the system. However, an unexpected peak around 7 MHz appears, as shown in Figure 6. The resonance peak shifts as we change the capacitance value. This is the classical

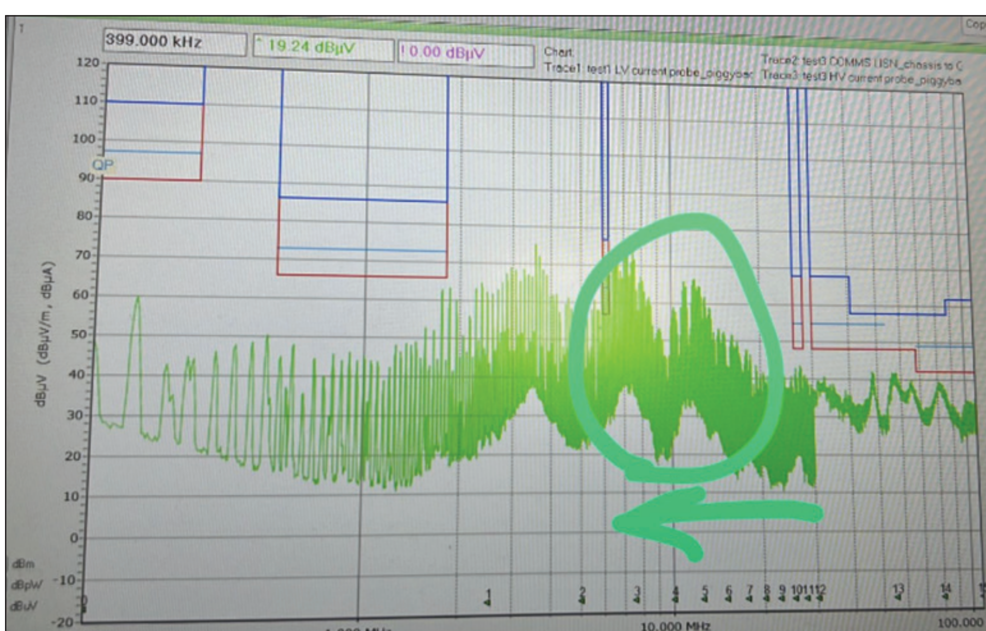


Figure 6: The conducted emission results of the power converter

"balloon effect", where squeezing one end of a balloon makes it expand at the other end [5]. In this case, it might be due to the board resonances with the system.

We manually "tune" the resonance frequency when introducing a new capacitance value. It could also be the case that, when providing a larger value capacitance across the transformer of the small DC-DC converter, the noise generated from the switches finds a lower impedance path to conduct through, which is then reflected in the conducted emission results.

There are a few approaches to dealing with the resonance phenomenon. Using a lossy component is not easy in this application. Redesigning the system and targeting better grounding (there are four PCBs in this power converter) is simply not an option. We end up selecting a 4.7 nF capacitor as a trade-off. The lesson here is that, when selecting a COTS product for different applications, we need to do an EMC risk assessment in the design stage and ensure that a mitigation plan is included.

SUMMARY

In this article, we detail three case studies for troubleshooting intra-system EMI issues. Most of the intra-system issues are function related. Sometimes, it takes days and weeks for the designers to realize the seemingly functional issue is EMI related. Good grounding, shielding, and cabling techniques are often the most effective way of solving these issues.

REFERENCES

1. T. Williams, *EMC for Product Designers*, Fifth Edition, Newnes, 2017.
2. Analog Devices, *AN-770 Application Note, iCoupler Isolation in CAN Bus Applications*, 2005.
3. Texas Instruments, *TIDA-010071, SAE J1772-compliant electric vehicle service equipment reference design for level 1 and 2 EV charger.*
4. M. Zhang, "Troubleshooting Low-Frequency Common Mode Emissions," *Signal Integrity Journal*. https://www.signalintegrityjournal.com/articles/2965-troubleshooting-low-frequency-common-mode-emissions
5. K. Wyatt, *Workbench Troubleshooting EMC Emissions (Volume 2)*, Wyatt Technical Services LLC, Colorado, 2021.

TOP 10 ISO/IEC 17025:2017 DEFICIENCIES FOUND IN ELECTRONICS TESTING LABORATORIES

Consider These Clauses When Conducting Your Laboratory's Internal Audit

Rob Miller is a General Manager of Accreditation Services at A2LA. He oversees the day-to-day operations and program growth for the accreditation schemes related to materials testing (mechanical, chemical, acoustics and vibration, thermal, non-destructive, electrical, and construction materials), product certification, and inspection. He can be reached at rmiller@A2LA.org.

By Rob Miller

Achieving ISO/IEC 17025:2017 accreditation for your electronics testing laboratory can be an exhaustive and time-consuming process. But an outside evaluation based on internationally recognized standards can improve your organization's overall competitive advantage. Accreditation not only showcases your organization's commitment to quality work but also demonstrates the integrity of your personnel and supports the validity of your test results.

Whether your organization is seeking ISO/IEC 17025 accreditation for the first time or renewing your current accreditation, there are a few frequently overlooked or misunderstood sections of the ISO/IEC 17025 standard to pay close attention to. If you and your team members are aware of the common deficiencies most often experienced in connection with these sections, you're better positioned to identify them through internal audits and address them before seeking accreditation from an outside accreditation body.

Testing laboratories should always conduct an internal audit to identify gaps or weaknesses in their systems and procedures to determine if additional resources are needed to ensure compliance. Sufficient records must be kept of the internal audit results and any follow-up actions taken. The outcome of the internal audit may help determine if your laboratory is, in fact, ready for an external assessment or if additional work is needed before applying for accreditation.

THE MOST IMPORTANT ISO/IEC 17025 CLAUSES TO CONSIDER

Here is a brief summary of the ten clauses in ISO/IEC 17025 to consider when seeking testing laboratory accreditation.

7.2.1: Validation of Methods

This clause has multiple parts, all of which cover the selection, verification, and validation of methods. Laboratories not only have to select methods appropriate for their customer's needs but must also have the appropriate documentation and records to show verification and validation of those methods.

Additionally, 7.2.1.5 requires that laboratories verify that they are capable of performing a method before introducing it to their scope. Furthermore, when a method is revised by the issuing body, this verification must be repeated. The depth of this verification is to be determined by the laboratory. However, records must be maintained. This is commonly missed by laboratories adding new methods to their scope or updating existing methods consistent with standard revisions.

8.8: Internal Auditing

An internal audit needs to confirm that a testing laboratory's management system and activities are in compliance with ISO/IEC 17025. The language in this section is broad so as to allow laboratories to determine the frequency and depth of the audits, depending on the laboratory's needs and risk tolerance. Once the internal audit plan is decided, records of implementation are required.

While ISO/IEC 17025 ultimately leaves it up to the laboratory to determine the frequency and depth of internal audits, it is important that laboratories adhere to their own internal procedures and plans. When it comes to internal audits, deficiencies are often cited against the laboratory's own procedures rather than those described in ISO/IEC 17025.

7.8: Reporting of Results

This section details the requirements for reporting lab results. There are many variables regarding these reports, depending on the customer contract, the type of laboratory activities performed, and the methods used. Organizations must take an attentive and individualized approach to applying the requirements of this section.

Regardless of the monitoring activities chosen by the laboratory, it is important that pre-defined criteria are determined, and that results are recorded in a way to easily detect and evaluate trends.

One area commonly missed in this section is 7.8.2.2, which requires the laboratory to identify within the report any data that was supplied by the customer. Additionally, a disclaimer must be made on the report when data provided by the customer can impact the validity of results.

7.7: Ensuring the Validity of Results

This section specifies that the laboratory must document procedures intended to continuously monitor the validity of test results and the required elements of the procedures that must be included. The laboratory must collect and analyze data from monitoring activities to evaluate and potentially improve their activities. This section also states that laboratories must compare their actual performance and results against that of other laboratories, referred to as proficiency testing. This section frequently uses phrases such as "where appropriate" and "where available." For some laboratories, specific elements of these requirements will not be applicable, but the laboratory should be prepared to account for why that is the case.

Regardless of the monitoring activities chosen by the laboratory, it is important that pre-defined criteria are determined, and that results are recorded in a way to easily detect and evaluate trends. Oftentimes, laboratories overlook these requirements, resulting in a deficiency. These steps are crucial in maintaining confidence and quality in a laboratory's results.

7.5: Technical Records

The focus of this section is the traceability and reproducibility of results. All laboratory activities must have technical records that are detailed enough to reproduce the exact process that initially produced them. This means that many factors will need to be consistently and diligently recorded, and that both original records and their amendments must be retained. Commonly cited deficiencies in this area include failing to record relevant environmental conditions such as temperature and humidity, or simply omitting data on when the test was performed and who performed it.

6.6: Externally Provided Products and Services

It is impossible to completely control what goes on outside your testing laboratory, but the quality of externally provided products and services is still within your control. This section requires that laboratories determine the suitability of externally provided products and services in a way that supports compliance. It requires that the testing laboratory create, document, and maintain procedures, evaluation criteria, and communication methods.

Oftentimes, deficiencies are cited because a laboratory does not document or record the appropriate processes and criteria required by 6.6.2, parts a) through d). Furthermore, it is common for a laboratory to define its requirements for evaluating a supplier but then fail to include how the supplier will be re-evaluated and what actions will be taken based on this evaluation.

6.2.5: Personnel Procedures and Records

This clause requires that laboratories have procedures for various activities related to the competence, training, and monitoring of personnel, as well as for retaining records of those activities. There is a list of specific topics that need to be addressed, either in one procedure or individual procedures. All relevant personnel must adhere to these procedures and records of implementation must be maintained in all cases as objective evidence the procedures are being followed.

Similar to section 6.6 discussed previously, laboratories oftentimes fail to define the various processes and criteria required by this section. Clause 6.2.5 a) through f) requires that the laboratory maintain procedures and records for determining competence requirements as well as selection, training, supervision, authorization, and monitoring of personnel. It is common for a laboratory to miss one or more of these items in their personnel procedures or records.

6.2.2: Documented Competencies and Supporting Records

The standard states that that several elements of competencies must be documented, including education, training, and experience. Each position category that has an influence on laboratory results must have a documented level of competency. Additionally, it is important to keep in mind that 6.2.5 a), discussed previously, requires that the laboratory maintain a procedure for determining competence requirements, an area commonly missed.

8.9.2: Management Review Inputs

This clause contains a list of 15 items that must be recorded as part of a management review, all of which the laboratory must take care to cover and record. This section may be removed from the list in the next year or so as laboratories undergoing certification renewal must work in advance to get their management review process in order and conduct these reviews with records showing each input.

Often cited deficiencies in this area include all 15 items required by 8.9.2 a) through o). Similar to internal audits discussed above, it is up to the laboratory to determine the frequency of their management reviews. However, the intervals shall be planned. It is important for the laboratory to follow its own internal procedures here as deficiencies are often cited for not adhering to planned schedules or processes.

6.4.: Equipment

Based on our data, this section of the standard is the one that has most frequently proven to challenge

Once accredited, your lab may advertise its accreditation, giving you a competitive advantage and instilling confidence in your test results and product quality.

electronics testing laboratories. In the most recent version of the standard, the term "equipment" is used to refer to all types of laboratory resources, including measuring equipment, reference standards, reference materials, reagents, consumables, and more. This section requires procedures for all equipment, including, but not limited to, accessibility, maintenance, storage, calibration, and record-keeping. It lists the specific equipment records that laboratories must maintain for all the equipment in their facility which can influence the activities listed on their scope of accreditation.

The most commonly cited deficiencies in this area are related to equipment calibrations. When sending equipment out for calibration, it is imperative for the laboratory to be aware of specific calibration requirements (procedures, frequency ranges, etc.) outlined in a given test method. Other commonly cited deficiencies in this area include failing to record software and firmware versions in equipment records (6.4.13a), not labeling, coding, or otherwise identifying the calibration status of laboratory equipment so that it is clear to all personnel (6.4.8), and failing to maintain a maintenance plan and maintenance records for relevant equipment (6.4.13g).

TAKING CORRECTIVE ACTION AND AVOIDING DEFICIENCIES

All deficiencies found during an assessment must be addressed by conducting a root cause analysis, taking corrective action, and providing objective evidence that the deficiency has been corrected. By going back to the problem, asking the right questions, and thoroughly investigating it, you can determine what caused the issue and potentially eliminate the risk of non-conformity recurrence.

In addition, implementing and maintaining a Quality Management System (QMS) can greatly reduce your risk of deficiencies. A QMS is where documented processes and procedures are kept and maintained so that personnel can reference them at any time, ensuring consistency and efficiency. It serves as a framework for all laboratory activities, reducing the likelihood of deficiencies, and offering a competitive advantage.

Another option to consider when seeking accreditation is training for you and your laboratory staff. Although it is not mandatory, training can be done early in the accreditation process to help personnel gain an understanding of the standard, the overall importance of accreditation, and the need for continuous competency improvement. Training can be done in-house or through a public venue, and a variety of options may be found through a simple internet search. There are also virtual course options that allow you to receive the training you and your team need while keeping costs low.

When in doubt, always refer to your copy of the ISO/IEC 17025:2017 standard. The accreditation process is thorough so it's critical to pay close attention to each clause and perform corrective actions when deficiencies are found.

CONCLUSION

Once accredited, your lab may advertise its accreditation, giving you a competitive advantage and instilling confidence in your test results and product quality—not only with customers but also with shareholders and other industry professionals. Frequently promote your accreditation to acknowledge the hard work put into achieving accredited status. If you have any questions about the process, you can always contact your accreditation body to discuss any references to your accreditation that you wish to publish.

IEEE
ISPCE 2023
IEEE International Symposium on Product Compliance Engineering
MAY 1-3, 2023 | DALLAS, TEXAS

IEEE Advancing Technology for Humanity

PSES Product Safety Engineering Society

REGISTRATION INFORMATION

Full Conference Registration Rates

CONFERENCE REGISTRATION	ADVANCED (THROUGH FEB 12, 2023)	REGULAR / ON-SITE (AFTER FEB 12, 2023)
PSES Members	$900	$1,000
IEEE Members	$1,000	$1,100
Non-Members	$1,100	$1,200
IEEE Life Members	$300	$325
Students	$100	$100

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

Exploring Product Compliance Careers Event Registration

Date: May 2, 2023
Time: 1:30 pm – 6:00 pm

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

***FREE**
LIMITED AVALIBILITY (50 MAX)

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

Daily Registration Rates

CONFERENCE REGISTRATION	ADVANCED (THROUGH FEB 12, 2023)	REGULAR / ON-SITE (AFTER FEB 12, 2023)
PSES Members	$400	$425
IEEE Members	$425	$450
Non-Members	$475	$450
Students	$40	$40

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

Katie Mack, Conference Catalysts, LLC
kmack@conferencecatalysts.com

AUTOMOTIVE EMC TESTING:
CISPR 25, ISO 11452-2, AND EQUIVALENT STANDARDS, PART 2

Antennas, Patterns, and Ground Benches for Testing for Automotive Components and Full Vehicles

This two-part article is an update of the original article authored by Dr. Vince Rodriguez, then with ETS-Lindgren. An earlier update was published in the February 2016 issue of In Compliance Magazine.

In Part 2 of this article, we shall talk a bit about the antennas used for automotive EMC testing. Specifically, we are going to concentrate on the typical biconical, LPDA, and DRH antennas recommended for CISPR 25, and the DRH antenna recommended for ISO 11452-2.

Recently it has become important to understand the radiation characteristics of these antennas. The typical biconical antenna as shown in Figure 1 is an omnidirectional

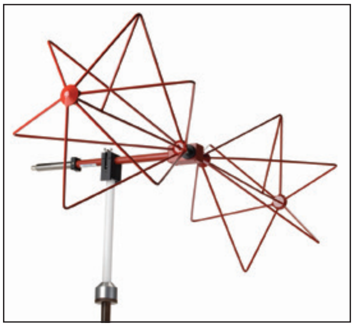


Figure 1: Typical biconical antenna

Garth D'Abreu is the Director, Automotive Solutions at ETS-Lindgren.
He can be reached at garth.dabreu@ets-lindgren.com.

Craig Fanning is the EMC Lab Manager at Elite Electronic Engineering.
He can be reached at cfanning@elitetest.com.

Ammar Sarwar is the Regional Sales Manager, EMEA North, for ETS-Lindgren in Europe. He can be reached at ammar.sarwar@ets-lindgren.com.

By Garth D'Abreu, Craig Fanning, and Ammar Sarwar

radiator. Its pattern shown in Figure 2 at 100 MHz is typical of the radiation pattern across the entire range. From these patterns, we can extract the half power beam width (HPBW). For the H plane, it is clear that the HPBW is larger than 180 degrees, and there is no main beam. For the E plane, the beamwidth ranges between 40 and 90 degrees. On the measured data, we can see the effects of the stem and balun holder on the pattern. The stem is oriented to the 180-degree mark. We can see how on the H plane the balun holder reduces the intensity of the radiation by 2 to 3 dB. The beamwidth of the measured data and the computed data track each other nicely.

Figure 3 shows a picture of an LPDA antenna and the numerical model created with specialized software. This is the other typical antenna type recommended by CISPR.

In Figures 4 and 5 on page 24, we see the measured and modeled performance of the LPDA antenna. There are clearly some differences between the measured data and the computed results. Close examination reveals that the error is under 3 dB. There are several sources of error in the measurement. Using the measured values for the HPBW, the EMC engineer will err on the side of safety.

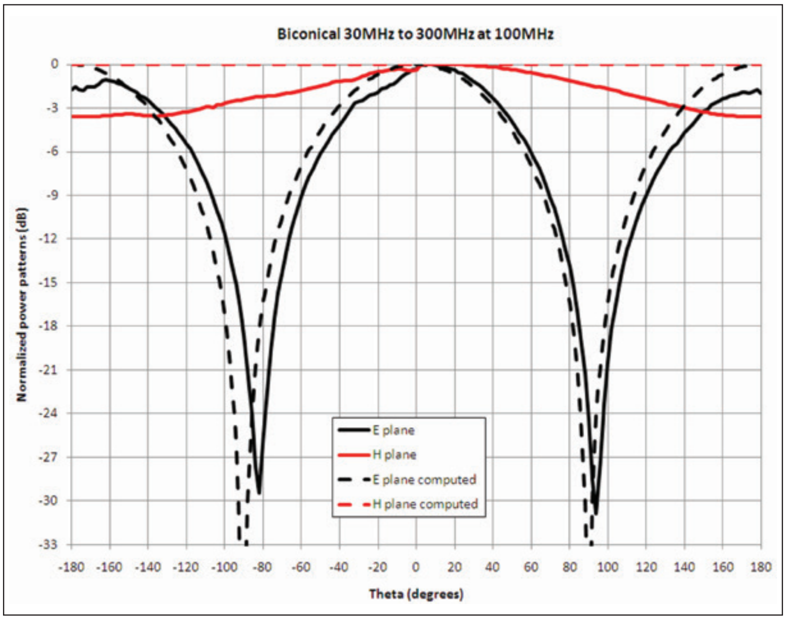


Figure 2: Measured and computed patterns at 100 MHz

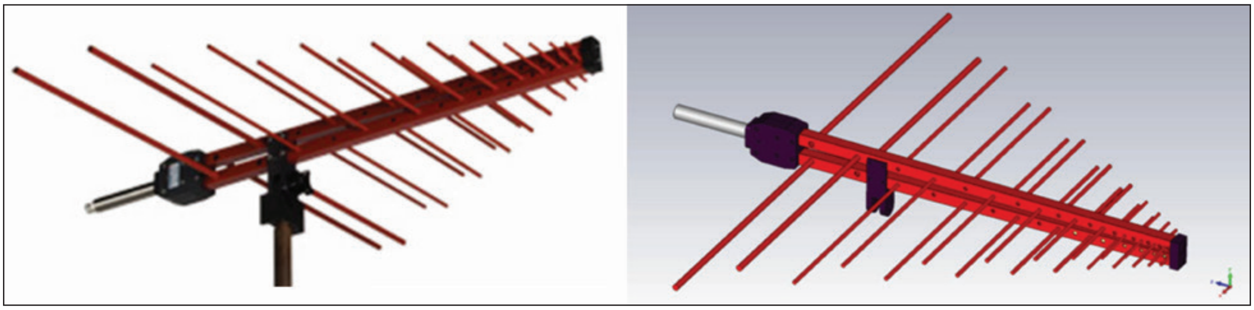


Figure 3: A picture of the measured LPDA antenna and the numerical model geometry.

Figure 4 shows the data at 400 MHz, in which there is very good agreement between the measured and the computed results. The data for 1 GHz (shown in Figure 5) shows good agreement between measured and computed data for the main beam.

The HPBW of the LPDA antenna is usually fairly flat. This is especially the case for the center of the frequency band covered by the antenna. From about 200 to 1000 MHz, the antenna being measured exhibits an HPBW ranging from 100 to about 60 degrees for both planes.

DRH antennas are the antenna of choice for higher frequencies. This family of antennas has been described numerous times in the literature. Their radiation pattern has been widely described. Reference [6] describes issues with the radiation pattern of these antennas at frequencies above 12 GHz for models operating in the 1 to 18 GHz range. References [7] and [8] introduce a new design for the 1 to 18 GHz range that has a better-behaved pattern where the main beam does not split into multiple beams. Figure 6 shows the measured radiation patterns for the horn analyzed in [6] and the one introduced in [7] and [8]. The data on the left shows a better-behaved pattern than the antenna on the right without the narrow beams and the split main lobe of the pattern.

In References [8, 9] several improvements were made to the radiation patterns of DRH antennas operating in the 200 MHz to 2 GHz range. These are the horns we recommend for ISO 11452-2 since the modifications correct the nulls in the middle of the main beam.

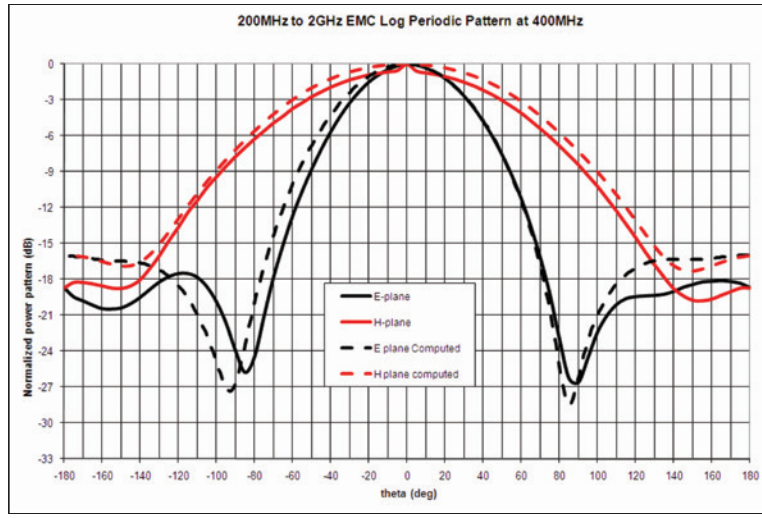


Figure 4: LPDA measured and computed pattern at 400 MHz

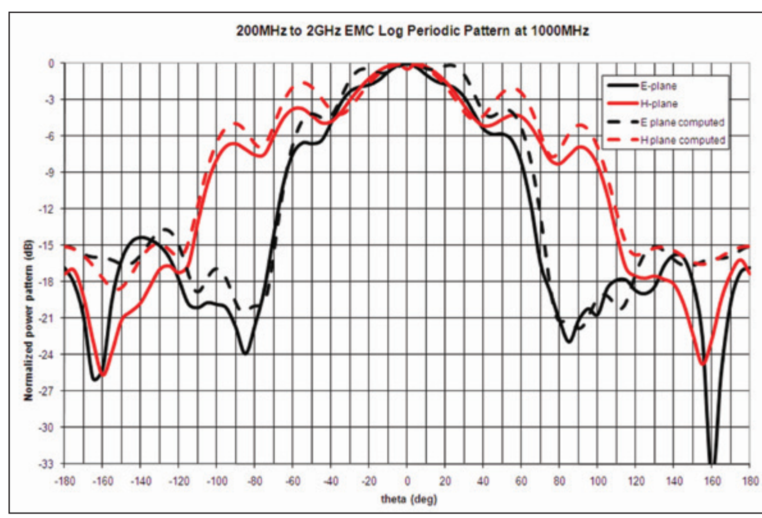


Figure 5: LPDA measured and computed pattern at 1 GHz

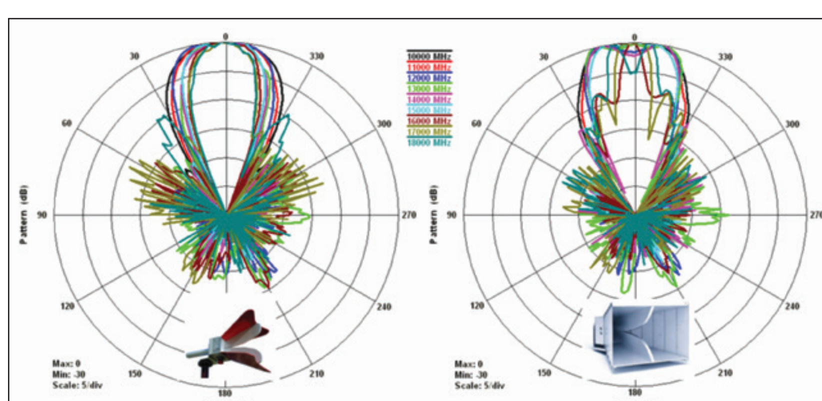


Figure 6: H plane radiation patterns from 10 to 18 GHz. The new (left) and traditional (right) DRH antenna for the 1 to 18 GHz range are shown.

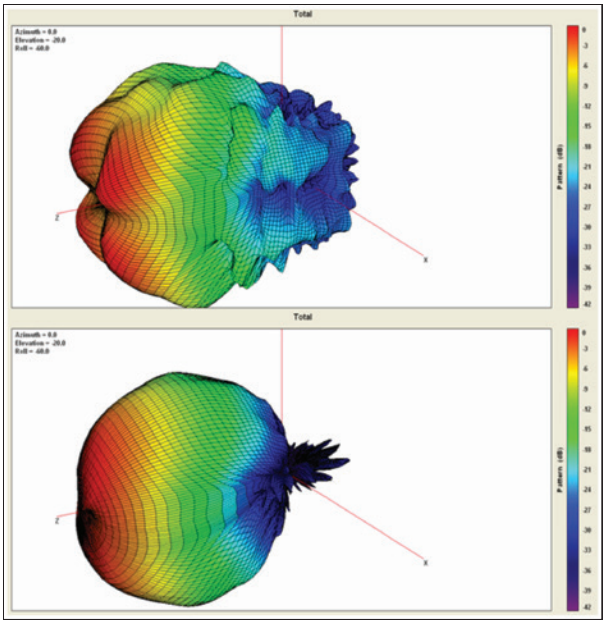


Figure 7: Comparison of a pattern at 2 GHz for the traditional and improved 200 MHz to 2 GHz DRHA

It is important to keep in mind that the data shown for the patterns is free space and far-field data. While it is true that it provides an idea of the antenna coverage, it can be misleading once we are in the presence of conductive benches. Figure 8 shows a typical setup for either CISPR 25 or ISO 11452-2. An antenna is placed 1 m away from the bench that is grounded. For the horizontal polarization case, Figure 9 shows the dramatic effect that the bench has on the fields. While the cable harness will be covered by the antenna, the EUT will barely be in the illumination. This happens at all frequencies and it is related to the boundary conditions that are part of the electromagnetic phenomena.

The LPDA, DRH, and SGH antennas have been a stable and long-standing part of immunity measurements for many years. Within this period we have witnessed the development of model variants with higher gain, customized bandwidths (for radar pulse testing, for example), extended bandwidths, and higher power handling, all in an effort to improve the efficiency of the measurement setup with reduced antenna changes and reduced amplifier power.

This trend is continuing, and we have already started seeing the emergence of the next generation of immunity antennas.

The DRH antenna remains an attractive antenna for automotive EMC testing largely due to its wide operating bandwidth, stable radiating characteristics, and small size. However, the lower gain at its lower frequency end drives the need for high amplifier input power, making it impractical to achieve the required high field strength as required by ISO 11542-2 in some instances. In addition to achieving higher field levels for many immunity tests, it is also critical that the field uniformity (FU) requirements are

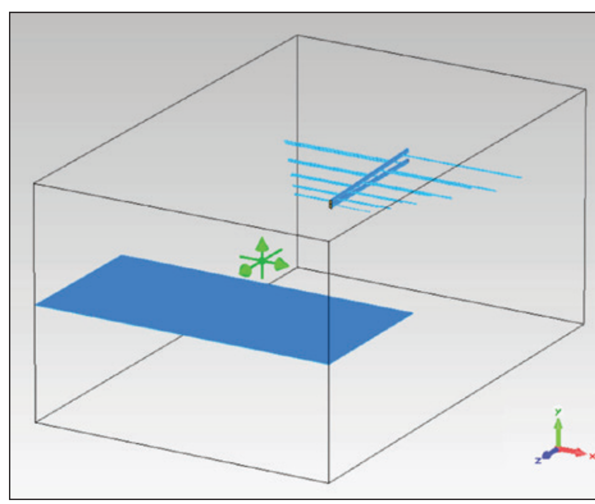


Figure 8: A horizontally polarized LPDA antenna placed in front of a conductive bench

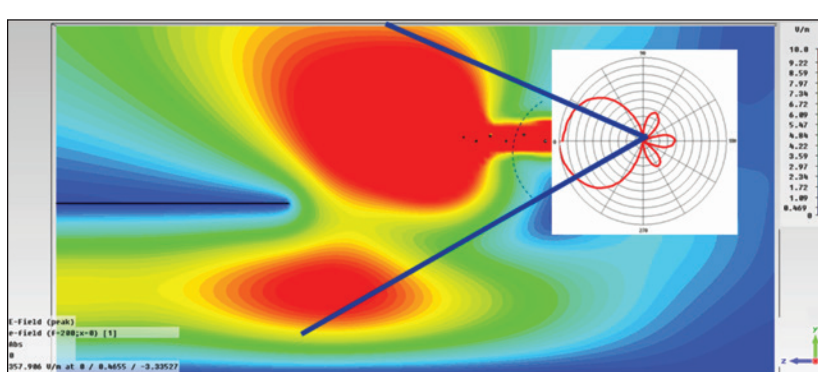


Figure 9: Field distribution from the LPDA shown in Figure 8. The cable harness which rests 5 cm above the bench is covered, but most of the EUT will not be covered.

satisfied (also required by ISO 11451-2). It is accepted that higher antenna gain is typically associated with narrower beam width which may lead to FU deterioration, so finding the correct compromise of size, gain, bandwidth, and beamwidth remains one of the antenna designer's goals.

To solve this problem, horn antennas with lenses have become increasingly popular for automotive EMC testing applications. With dielectric lenses having properties such as low loss and wide operational frequency range, ridged horn antennas have been able to meet both field strength and FU requirements for automotive EMC testing in the 1 - 5 GHz frequency range. Figure 10 shows how adding a lens to a ridged horn antenna can drastically improve the gain vs bandwidth balance.

A ridged horn antenna with a lens (1-3.1GHz), mounted over a stand, is shown in Figure 11. Its lightweight meta-material lens increases the gain of the horn at a 1 m distance by 9 dBi. This characteristic makes the antenna ideal for automotive component

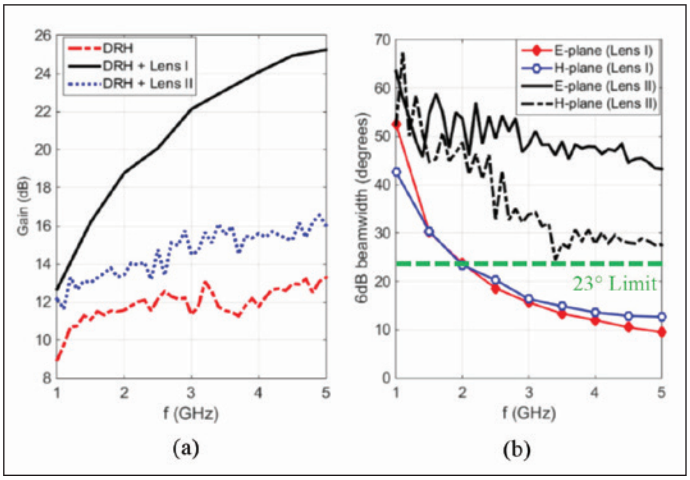


Figure 10: Simulated results of a typical DRH with lenses, (a) gain, (b) 6 dB beamwidth

Figure 11: A ridged horn lens antenna

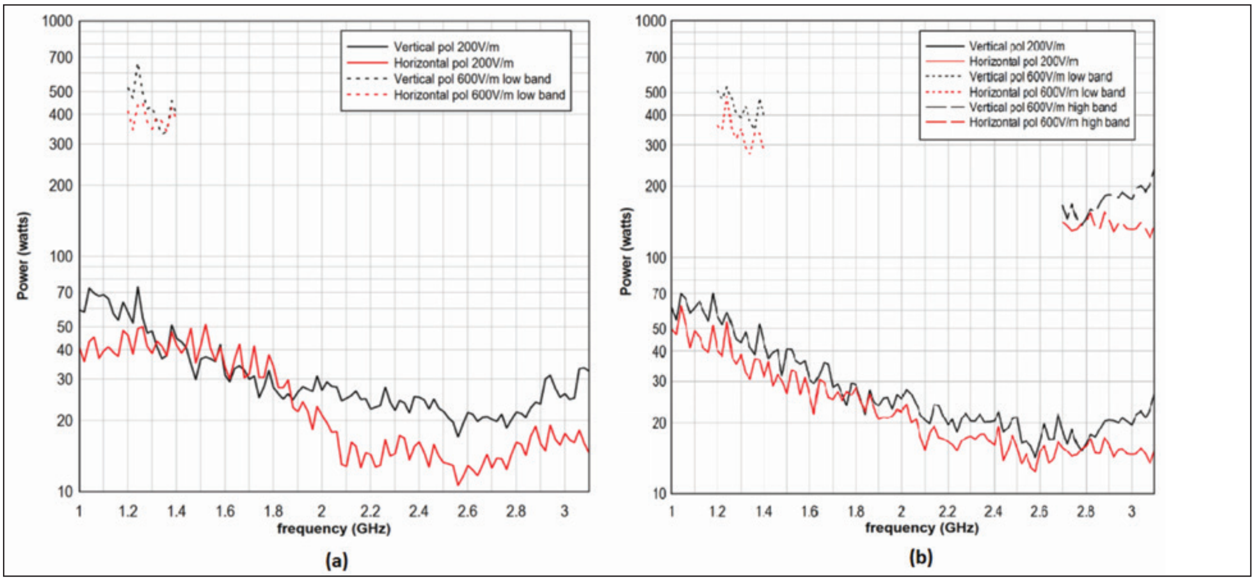


Figure 12: Typical power of ridged horn antenna with lens, (a) for conductive bench, (b) for non-conductive bench

immunity testing. Such high-gain antennas help to meet the narrow band high field strength requirement with less input power for automotive immunity testing. Figure 12 shows the power vs frequency plots required for this antenna to achieve 200V/m and 600V/m.

As described previously, a compliant CISPR 25 chamber with a 2m long ground plane bench for component testing can be as small as 6.2m x 5.3m x 3.6m. For full vehicle testing, however, a larger chamber is needed depending on vehicle size, test range length, and testing scope. The EMC chamber facility shown in Figure 13 is an example of a full vehicle chamber where the hybrid polystyrene absorbers previously mentioned in Part 1 of this article have been used to achieve the desired test volume reflectivity performance.

Figure 13: Automotive test chamber using polystyrene absorber (image courtesy of ETS-Lindgren)

The chamber shown below is fully lined with the polystyrene absorber material providing optimum performance for EMC measurements with satisfactory performance for the low and intermediate frequency antenna pattern measurements.

The interior dimensions of this 10-meter chamber are approximately 20.8m x 12m x 8m with a 5m diameter quiet zone and 10m range according to CISPR 16-1-4. Absorber coverage was provided on all wall and ceiling surfaces (see Figure 13). This newly retrofit chamber has been designed for automotive and commercial EMC testing in accordance with international standards CISPR 12, CISPR 25, ISO 11451, ISO 11452, and IEC 61000-4-3, as well as military standard MIL-STD-461E/F.

More recent chambers with a hybrid layout as the example shown in Figure 14 have been designed to also support antenna pattern measurements. In this example, the chamber has overall dimensions of 54m x 15m x 14m height including the 18m x 15m rectangular section. This chamber is also fully lined with the polystyrene absorber material providing optimum performance for EMC measurements with satisfactory performance for the low and intermediate frequency antenna pattern measurements. This chamber was designed to meet the CISPR 12/16/25, ISO 11451/11452, R10, SAE, and ANSI C63.4 standards.

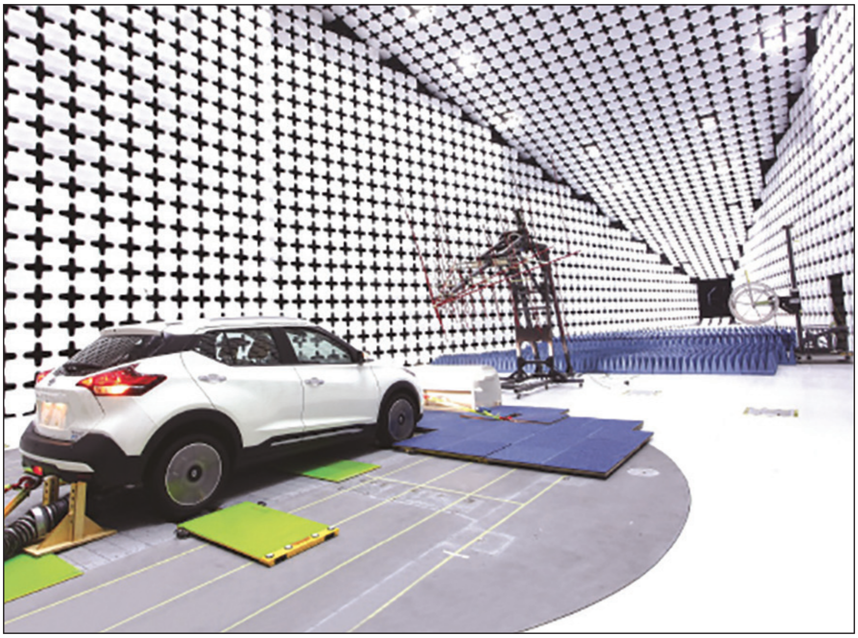


Figure 14: Chamber designed with a hybrid layout

Nr.	Test type	Standard	Freq. range	Performance
1.	NSA at 10m for 4m dia. QZ	CISPR-16-1-4	30 - 1000 MHz	<4 dB
2.	sVSWR	CISPR-16-1-4	1 - 18 GHz	compliant
3.	Absorber reflectivity	CISPR 25 Ed 5	70 M - 2500 MHz	Better than 6 dB
4.	Site Performance	CISPR 25 Ed 5	150 k - 1 GHz	Long wire compliant
5.	Field Uniformity	IEC-61000-4-3	60 M - 6 GHz	Less than 6 dB
6.	Absorber reflectivity	MIL-STD-461E		Better than 6 dB from 80 M-250 MHz Better than 10 dB above 250 MHz
7.	Shielding effectiveness	EN 50147-1		Compliant

Table 1: Chamber verification methods and performance results for the chamber in Figure 13

The chamber installation example we've presented here highlights the notion that, wherever possible, new installations should take advantage of the best available technology and the latest revisions of the relevant standards.

CONCLUSION

In this two-part article, we have introduced the two main standards for automotive vehicles and components with an overview of the revision status of these and several related standards produced by CISPR and ISO. We have concentrated on designing a chamber to meet the requirements of CISPR 25 and showed that the same chamber is usable for ISO 11452-2. Finally, we have shown some radiation patterns of the typical antennas recommended by the standards, the performance improvements for a ridged horn fitted with a lens, and the benefits of reducing the power demand. The various patterns will give the user an idea of the illumination area that the antennas cover when used, and how the presence of the bench can have a dramatic effect on the radiation pattern and the coverage of the antennas. This is clearly an aberration caused by the setup used for these standards and not by the antennas being used. So, as with most measurements, caution is recommended in the selection of antennas, set up, and validation steps taken to verify that the intended fields are present over the entire area of the EUT to account for any distortions or resonances that may be present.

In closing, the chamber installation example we've presented here highlights the notion that, wherever possible, new installations should take advantage of the best available technology and the latest revisions of the relevant standards, as is shown with the use of the proposed CISPR 25 5th Edition chamber validation method and, as in the case of a hybrid design, other tests and standards can be accommodated with careful absorber selection and treatment.

ACKNOWLEDGMENT

The authors would like to thank Mr. Stéphane Blanc of UTAC CERAM Group for providing the measurement data of their automotive EMC 10-meter chamber, and the engineers at NISSAN for the opportunity to collaborate on a novel chamber design to support EMC as well as antenna pattern measurements.

REFERENCES

1. CISPR 12, *Vehicles, boats and internal combustion engines - Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers,* Sixth Edition, IEC Geneva, Switzerland, 2007.
2. CISPR 25, *Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices- Limits and methods of measurement,* Fifth Edition, 2021.

A Most Memorable Meeting
of the ISO/CISPR D Automotive EMC Committee

by Janet O'Neil

The most recent meeting of the ISO and CISPR D Automotive EMC Committees was held in October 2022 at ETS-Lindgren in Cedar Park, Texas. Over a nearly two-week period, more than 60 global automotive experts gathered to address the latest automotive EMC measurement techniques in the CISPR 12, CISPR 25, CISPR 36, ISO 11451-x, and ISO 11452-x standards.

Behind the scenes, committee members were also planning to honor Ariel Lecca and Mike Bettlestone, who had previously announced their plan to retire from their respective Committee leadership positions at the end of our meetings. Together, Ariel, the leader of the ISO Standards Committee, and Mike, the leader of the CISPR D Standards Committee, contributed nearly 50 years of active participation to the work of these committees, and a special celebration was in order.

Ariel Lecca

Mike Bettlestone

During a convivial celebratory meal on the last day of our meetings, we shared humorous stories about Ariel's and Mike's involvement over the years, took several photos, exchanged warm handshakes and hugs, and shed a few tears in the process.

The celebration was our small way to recognize and honor the dedicated leadership of Ariel and Mike. Their intelligence and tenacity, combined with their diplomacy and sense of humor, helped guide our work on these important automotive EMC standards, allowing us to continuously adapt these standards to the latest technologies while also maintaining the utmost integrity in EMC measurements.

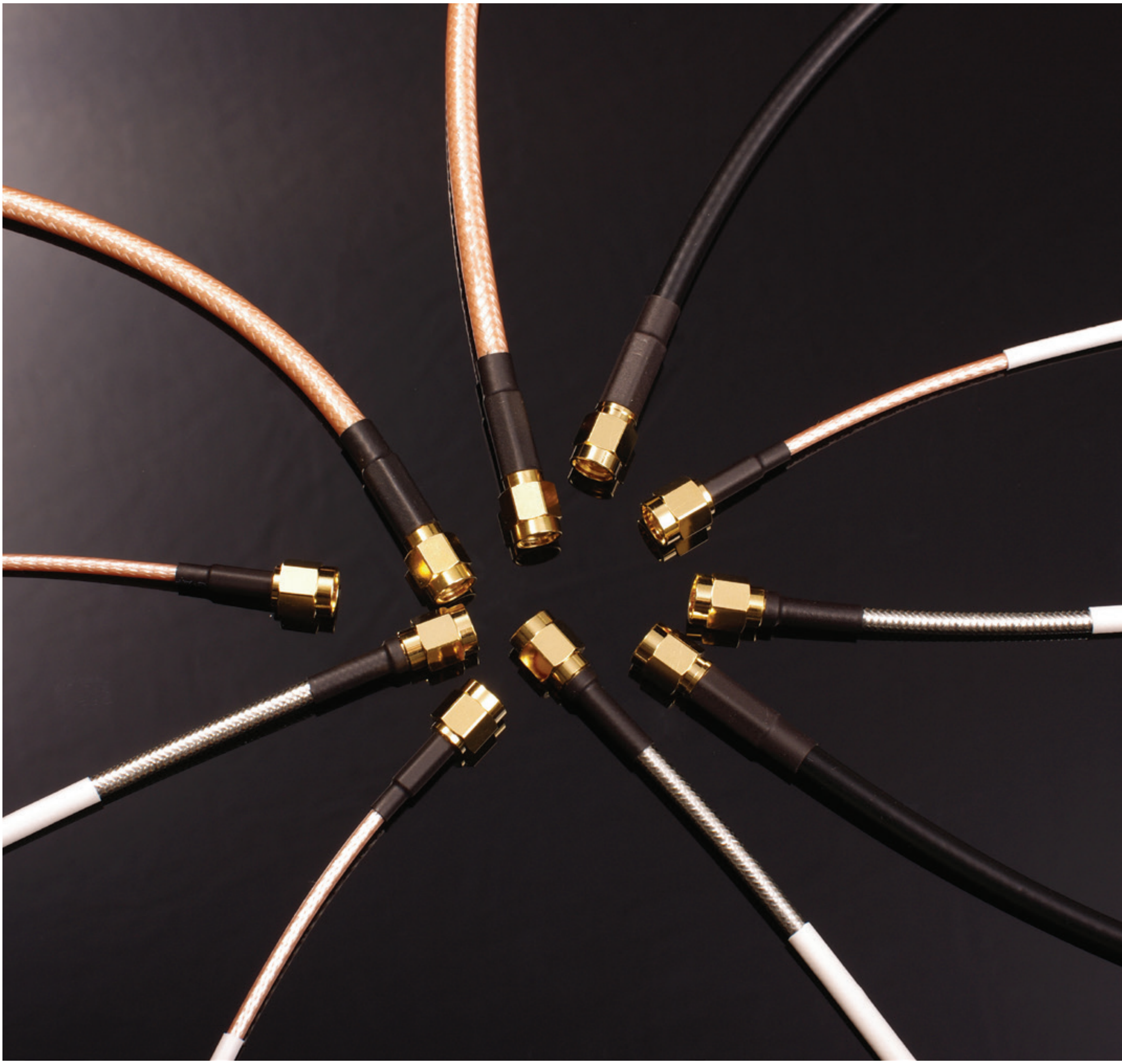
And so, to Ariel and Mike, thank you for expertly guiding the ISO and CISPR D Automotive EMC Standards Committees for many years! Your legacy will not be forgotten!

3. MIL-STD 461, *Requirements for the control of Electromagnetic Interference Characteristics of Subsystems and Equipment,* Department of Defense Interface Standard 10, December 2007.
4. ISO 11452, *Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 2: Absorber-lined shielded enclosure,* Second Edition.
5. CISPR 16-1-4, *Specification for radio disturbance and immunity measurement apparatus and methods, Part 1-4: Radio disturbance and immunity measuring apparatus – Antennas and test sites for radiated disturbance measurements,* Third Edition, IEC Geneva, Switzerland, 2010.
6. C. Bruns, P. Leuchtmann, and R. Vahldieck "Analysis of a 1-18 GHz Broadband Double-Ridge Antenna," *IEEE Transactions of Electromagnetic Compatibility*, Vol 45, No. 1, pp.55-60, February 2003.
7. V. Rodriguez "New Broadband EMC Double-ridge Guide Horn Antenna," *RF Design,* May 2004, pp. 44-50.
8. V. Rodriguez, "A New Broadband Double Ridge Guide Horn with Improved Radiation Pattern for Electromagnetic Compatibility Testing," *16th International Zurich Symposium on Electromagnetic Compatibility*, Zurich, Switzerland, February 2005.
9. V. Rodriguez, "Improvements to Broadband Dual Ridge Waveguide Horn Antennas," *2009 IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting,* Charleston, SC, June 1-5, 2009.
10. V. Rodriguez, "Recent Improvements to Dual Ridge Horn Antennas: The 200 MHz to 2 GHz and 18 GHz to 40 GHz Models," *2009 IEEE International Symposium on EMC,* Austin, TX, Aug 17-21, 2009.
11. CISPR 36, *Electric and Hybrid Electric Road Vehicles – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers below 30 MHz*, First Edition, IEC Geneva, Switzerland 2020.


SAN DIEGO 2023
See Yourself At IMS2023
IMS
Register Now!
IEEE MTT-S International Microwave Symposium
11-16 June 2023
San Diego California
The Coolest Ideas Under the Sun
SAN DIEGO 2023
IEEE
ims-ieee.org
MTT-S
IEEE MICROWAVE THEORY & TECHNOLOGY SOCIETY

9 STEPS TO SELECT A TEST CABLE FOR MILLIMETER WAVE APPLICATIONS

Coaxial Cable Characteristics to Consider



John Muzzio is applications engineer and test and measurement product line manager at Times Microwave. His previous background included optical, mechanical, and electrical applications engineering and design, focusing on the semiconductor and aerospace markets.

By John Muzzio

Radio signal frequencies rise to the millimeter-wave (mmWave) range as applications such as 5G networks, automotive radar systems, and RF semiconductor probing demand more bandwidth at higher frequencies. Testing is an integral aspect of developing quality new products that will operate in these mmWave frequencies, and coaxial cable assemblies play a vital role in the process.

However, given the complexity of mmWave applications, not just any coaxial cable will do. Critical parameters such as impedance match and insertion loss must be considered to obtain repeatable, reliable test results at higher frequencies. As a result, RF testing for mmWave applications requires unique coaxial cable and connector solutions.

FACTORS TO EVALUATE IN SELECTING THE OPTIMAL COAXIAL CABLE TEST ASSEMBLY

Typically, the RF testing process incorporates a device under-test (DUT) connected to a vector network analyzer (VNA), spectrum analyzer, or oscilloscope. The signal path to the circuit board is critical, and the test setup must not introduce unwanted variables or errors, VSWR spikes, or excessive insertion loss. This includes the test cable and connectors.

Test cable assemblies must be robust enough to withstand extensive handling and continuous movement from frequent connecting and disconnecting while also maintaining precise repeatability of measurement and reliable electrical performance. There are numerous characteristics to evaluate before selecting the optimal coaxial cable assembly for a specific application, including frequency range and cable diameter, test equipment type, connectors, measurement type/application, flexibility, phase stability, power, impedance, and allowable loss budget.

Frequency Range and Cable Diameter

When selecting a test cable, one of the first things to consider is the frequency range required to test the application. This will help to determine other factors, such as the cable type and mechanical structures needed. For example, as frequency rises, the cable's diameter becomes smaller. It's an inverse situation, and all of the ratios must work correctly at the different frequency levels.

Test Equipment

Next, evaluate the type of test to be performed and what kind of equipment will be used. For example, the test could be a standard S-curve type of measurement looking at the loss of a device under test or evaluating how it performs at specific frequencies. All variables must be considered up front when selecting a test cable assembly that will perform well for each unique testing scenario.

Connectors

Once the frequency, type of test equipment, and cable size are determined, the connector type comes next. This is a critical consideration in mmWave applications because any inconstancy in connectors can introduce errors in the measurement that will be amplified as the test frequency range increases.

The test equipment will have a specific connector type on it, usually determined by the highest frequency that the test equipment can achieve. For example, if testing at 110 GHz, there will be a 1-millimeter connector on the test equipment; therefore, a mating connector of the same size will be required on the test cable assembly.

It is critical to understand what power levels the test cable can withstand. For example, a standard test cable is likely unable to handle a high-power application.

Some common mmWave connector sizes include:

- 2.92 mm - 40 GHz
- 2.4 mm - 50 GHz
- 1.85 mm - 67 and 70 GHz
- 1.0 mm - 110 GHz

For applications where high signal density is needed, push-on connectors such as SMP, SMPM, and SMPS connectors are also ideal.

Measurement Type/Application

Each application being tested will have specific environmental factors to consider, including, among others:

- Temperature
- Humidity
- Elevation
- Pressure

Most coaxial cable manufacturers provide guides to help assess these further considerations. For example, an ultra-high frequency application will require a cable that not only meets the frequency requirements but is also phase stable. By going with a high-frequency, phase stable cable, the type of connector available for use becomes limited. As the user moves through the process, options that match these additional considerations will be provided.

Flexibility

In testing, many users are further interested in a cable's flexibility and bend radius. Due to the nature of test environments, it is often essential to use a very flexible cable material that can be moved around on a test bench, either in a production or R&D environment.

Testing also often moves from module to module. High frequencies could require recalibration when a module or cable is moved. Using a coaxial cable that can bend and flex will significantly reduce the need for recalibration while maintaining stability.

Phase Stability

Another key aspect related to the need to constantly move the cables around is phase stability. Movement introduces phase change, and the test assembly needs to maintain a very low rate of change to get accurate measurements. A robust cable is therefore critical to keep phase as stable as possible.

Additionally, when testing mmWave technologies such as 5G, the source and receiver might be running at two different frequencies at the same time. A phase stable assembly will further ensure that harmonics are not introduced back into the system. A phase-stable cable assembly utilizing a TF4, or microporous PTFE dielectric, coupled with a helically wound metalized interlayer, will help maintain a flexible, phase, and amplitude stable test assembly.

Everything related to radiofrequency (RF) characteristics involves trade-offs. Higher frequency equals smaller cable diameter, which also often results in higher losses on the cable.

Power

It is also critical to understand what power levels the test cable can withstand. For example, a standard test cable is likely unable to handle a high-power application. In terms of mmWave applications, higher frequencies will push through less power because the cable diameter inversely shrinks, as previously mentioned.

Impedance

The standard impedance seen in test environments is 50 ohms. However, there are also 75-ohm impedances used in a video type of environment and also some lower frequency measurements. At any rate, impedance differences are essential to keep in mind when going through a test cable selection checklist.

Loss Budget

Everything related to radiofrequency (RF) characteristics involves trade-offs. Higher frequency equals smaller cable diameter, which also often results in higher losses on the cable. However, the loss can be negated using the VNA in a typical RF measurement

It is critical to understand what power levels the test cable can withstand. For example, a standard test cable is likely unable to handle a high-power application.

application. A network analyzer has the ability to "null out" loss in the cable assembly, so when the device is hooked up to it, the cable's loss will not reflect the measurements taken on the device itself.

On the other hand, when a signal transitions from the circuit board to the connector, it is imperative to minimize reflections. At higher frequencies, these imperfections in the transition from a coaxial connector to a circuit board structure become more evident and may cause undesirable effects such as parasitic and spurious signal responses that result in return loss or insertion loss, VSWR spikes, and magnitude increases. In this case, if the signal integrity is not quite right and there is noise in the measurement, the test will not produce a correct reading. Therefore, a repeatable, low insertion loss cable that functions throughout the desired frequency range should be used to ensure high-fidelity measurement.

SOME EXAMPLES OF mmWAVE TESTING APPLICATIONS

5G

The increased speed of 5G is partially achieved using higher-frequency radio waves with a much more extensive potential frequency range. This has introduced challenges for 5G testing, including repeatability, reliability, and reproducibility.

For example, 50 GHz cables have been used in production environments for 5G modules. The stability and repeatability of this type of cable are paramount in producing reproducible results in the test.

Automotive Testing

RF electronics technologies incorporating automotive radar have created safer, more efficient connected vehicles. Automotive radar sensors that use RF are increasingly used to detect the speed, range, and angle of objects in the automobile's vicinity in complex and safety-critical applications such as advanced driver-assistance systems and autonomous driving.

Unfortunately, they have also created new challenges for RF testing. Many new applications are moving away from the previous standard of 24GHz to 77 GHz plus mmWave ranges due to the wide bandwidth available in those bands. Wider bandwidth increases range resolution and accuracy by up to 20x in some applications and produces shorter wavelengths that enable smaller form factors.

This increases the complexity of test setups, requiring more test leads and connection points than ever before, along with new RF testing requirements. As a result, it's necessary to revisit the way connection points and test leads are built and review the different types of connectors available, ensuring that the latest test assemblies work in concert with changes made by test equipment manufacturers.

A 70 or 90 GHz cable will have the ability to test at both the fundamental and harmonic frequencies required.

RF Semiconductor Probing

As the semiconductor industry continues to experience rapidly increasing demand with aggressive time-to-market goals, the ability to perform high-precision testing with the expedience of automation is critical. Highly sensitive RF testing processes are required to measure RF performance on the surface of a semiconductor wafer, requiring coaxial cable assemblies that can support the smooth, robotic movement of a probe and automatically and precisely touch down on the surface to measure performance and functionality. Because of the specific type of measurement required, the test assembly must also be able to pick up and move to repeat the process at a different location on the device surface.

A test cable that provides a low loss, stable connection for up to 70 GHz testing is often optimal for use in probing measurement of RF circuits in wafer and semiconductor manufacturing. They can be specially designed for firm attachment to a manipulator device to enable the highly stable placement of a probe for making individual measurements at multiple points, automatically or semi-automatically, utilizing a solid tube at the attachment point. A low-profile design allows the probe heads (manipulators) to traverse their full range of motion without optical scope interference.

High-Frequency Testing

There is a new class of test cables designed specifically to accommodate the challenges addressed above for the higher frequencies needed for 5G, automotive systems, semiconductor probing, and other advanced mmWave application testing. These test leads offer very repeatable, low insertion loss cable options that function throughout the desired frequency range to ensure a high-fidelity measurement, with specific options available that cover 70 GHz to 90 GHz and up to 110 GHz if required. For precision and stability, phase-stable cable assemblies that utilize a microporous PTFE dielectric coupled with a helically wound metalized interlayer can also help maintain a flexible, phase- and amplitude-stable test assembly.

CONCLUSION

When selecting any type of test cable assembly, designers should partner with a manufacturer with fully integrated design, production, assembly, and testing capabilities for customized solutions to meet the most demanding mmWave testing requirements.

SMITH CHART AND INPUT IMPEDANCE TO TRANSMISSION LINE

Part 1: Basic Concepts

By Bogdan Adamczyk

This is the first of the three articles devoted to the Smith Chart and the calculations of the input impedance to a lossless transmission line. This article begins with the load reflection coefficient and shows the details of the calculations leading to the resistance and reactance circles that are the basis of the Smith Chart. A sample Smith Chart is shown in Figure 1, [1].

Quite a daunting picture at first, isn't it? It isn't! To gain an insight into it let's start with some basics of the transmission line model and the load reflection coefficient. It is the load reflection coefficient that is the foundation of the Smith Chart.

1. TRANSMISSION LINE MODEL AND LOAD REFLECTION COEFFICIENT

A typical model of a transmission line is shown in Figure 2.

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 2023). He can be reached at adamczyb@gvsu.edu.

In this model, the source is located at $z = 0$, and the load is located at $z = d$, [2]. In some applications it is convenient to use an alternative model, shown in Figure 3.

In this model, the load is located at $d = 0$, and the source is located at $d = L$, [3]. Note that, in either

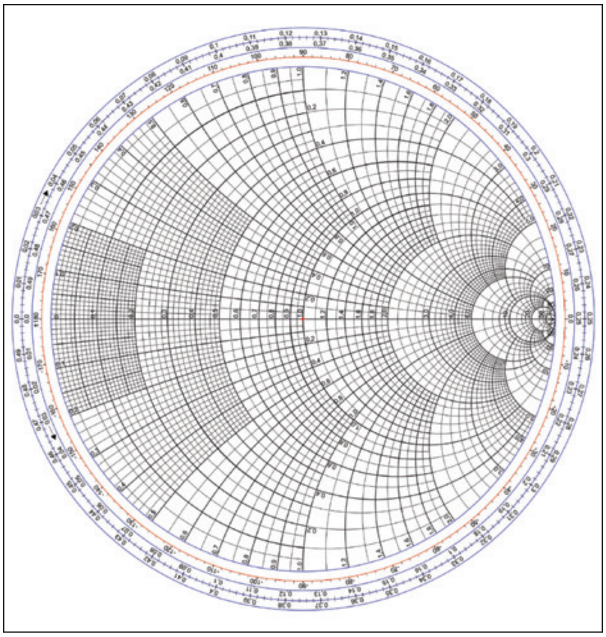


Figure 1: Sample Smith Chart

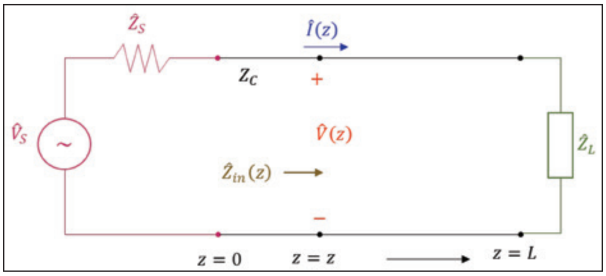


Figure 2: Model 1 - the source located at $z = 0$ and the load at $z = L$

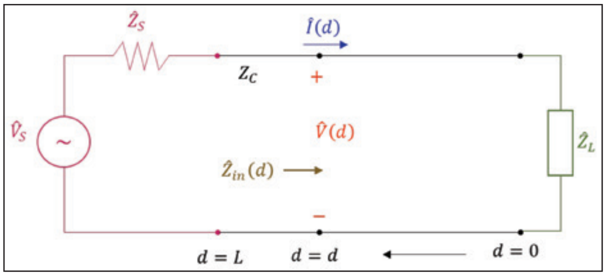


Figure 3: Model 2 - the load located at $d = 0$ and the source at $d = L$

model, the input impedance to the line at any location is always calculated looking towards the load [4].

The load reflection coefficient, in either model, can be obtained directly from the knowledge of the load and the characteristic impedance of the line as

$$\hat{\Gamma}_L = \frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} \tag{1.1}$$

There are three special cases of the load reflection coefficient

Short-Circuited Line, $\hat{Z}_L = 0$

$$\hat{\Gamma}_L = \frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} = \frac{0 - Z_C}{0 + Z_C} = -1 \tag{1.2}$$

Open-Circuited Line, $\hat{Z}_L = \infty$

$$\hat{\Gamma}_L = \frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} = \left.\frac{1 - \frac{Z_C}{\hat{Z}_L}}{1 + \frac{Z_C}{\hat{Z}_L}}\right|_{\hat{Z}_L \to \infty} = 1 \tag{1.3}$$

Matched Line, $\hat{Z}_L = Z_C$

$$\hat{\Gamma}_L = \frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} = \frac{Z_C - Z_C}{Z_C + Z_C} = 0 \tag{1.4}$$

2. LOAD REFLECTION COEFFICIENT AND Γ PLANE

Being a complex quantity, the load reflection coefficient be expressed either in polar or rectangular form as

$$\hat{\Gamma} = \Gamma e^{j\theta} = \Gamma_r + j\Gamma_i \tag{2.1}$$

If we create a complex plane with a horizontal axis Γ_r and a vertical axis Γ_i, then the load reflection coefficient will correspond to a unique point on that plane, as shown in Figure 4.

The magnitude of the load reflection coefficient is plotted as a directed line segment from the center of the plane. The angle is measured counterclockwise from the right-hand side of the horizontal Γ_r axis.

For passive loads, the magnitude of the load reflection coefficient is always

$$0 \le \Gamma \le 1 \tag{2.2}$$

The magnitude of 0 (center of the complex plane) corresponds to a matched load, the magnitude of 1 with the angle of 0° represents an open circuit, while the magnitude of 1 with the angle of 180° represents

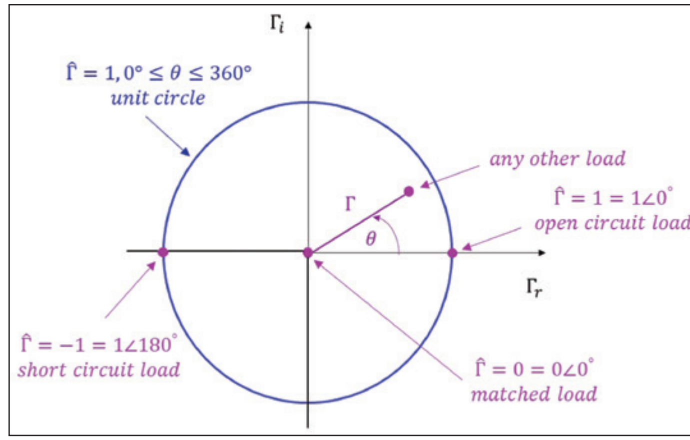


Figure 4: Load reflection coefficient and the complex Γ plane

a short circuit. Shown in Figure 4 is also a unit circle, which sets the boundary for all the points representing a passive load reflection coefficient.

Let's return to the load reflection coefficient given by Eq. (1.1) and divide the numerator and denominator by the characteristic impedance of the line, Z_C.

$$\hat{\Gamma}_L = \frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} = \frac{\hat{Z}_L/Z_C - Z_C/Z_C}{\hat{Z}_L/Z_C + Z_C/Z_C} = \frac{\hat{Z}_L/Z_C - 1}{\hat{Z}_L/Z_C + 1} \tag{2.3}$$

or

$$\hat{\Gamma}_L = \frac{\hat{z}_L - 1}{\hat{z}_L + 1} \tag{2.4}$$

where the small letter $\hat{z}_L$ denotes the *normalized* load impedance, i.e., $\hat{z}_L = \hat{Z}_L/Z_C$. Smith Chart is based on the plot of the load reflection coefficient utilizing this normalized load impedance, as explained next.

3. LOAD REFLECTION COEFFICIENT AND NORMALIZED LOAD IMPEDANCE

Equation (2.4) expresses the load reflection coefficient in term of the normalized load impedance. This equation can be solved for the normalized load impedance in terms of the load reflection coefficient as follows.

Multiplying both sides by the denominator of the right-hand side, we obtain

$$\hat{\Gamma}_L(\hat{z}_L + 1) = \hat{z}_L - 1 \tag{3.1}$$

or

$$\hat{z}_L\hat{\Gamma}_L + \hat{\Gamma}_L = \hat{z}_L - 1 \tag{3.2}$$

and thus

$$\hat{\Gamma}_L + 1 = \hat{z}_L - \hat{z}_L\hat{\Gamma}_L \tag{3.3}$$

leading to

$$\hat{\Gamma}_L + 1 = \hat{z}_L(1 - \hat{\Gamma}_L) \tag{3.4}$$

and finally,

$$\hat{z}_L = \frac{1 + \hat{\Gamma}_L}{1 - \hat{\Gamma}_L} \tag{3.5}$$

Both the normalized load impedance and the load reflection coefficient are complex quantities and as such they can be expressed in terms of their real and imaginary parts. That is,

$$\hat{\Gamma} = \Gamma_r + j\Gamma_i \tag{3.6}$$

$$\hat{z}_L = r_L + jx_L \tag{3.7}$$

where r_L is the normalized load resistance and x_L is the normalized load reactance.

Utilizing Eqns. (3.6) and (3.7) in Eq. (3.5) we obtain

$$r_L + jx_L = \frac{(1+\Gamma_r) + j\Gamma_i}{(1-\Gamma_r) - j\Gamma_i} \tag{3.8}$$

For now, let's focus on the right-hand side (RHS) of Eq. (3.8). Multiplying numerator and denominator by the complex conjugate of the denominator we get

$$RHS = \frac{(1+\Gamma_r)+j\Gamma_i}{(1-\Gamma_r)-j\Gamma_i} \times \frac{(1-\Gamma_r)+j\Gamma_i}{(1-\Gamma_r)+j\Gamma_i} = \frac{[(1+\Gamma_r)+j\Gamma_i][(1-\Gamma_r)+j\Gamma_i]}{(1-\Gamma_r)^2+\Gamma_i^2} \tag{3.9}$$

Multiplying out the terms in the numerator and grouping the real and imaginary part gives

$$RHS = \frac{1-\Gamma_r^2-\Gamma_i^2+j(\Gamma_i+\Gamma_r\Gamma_i+\Gamma_i-\Gamma_i\Gamma_r)}{(1-\Gamma_r)^2+\Gamma_i^2} \tag{3.10}$$

or

$$RHS = \frac{1-\Gamma_r^2-\Gamma_i^2}{(1-\Gamma_r)^2+\Gamma_i^2} + j\frac{2\Gamma_i}{(1-\Gamma_r)^2+\Gamma_i^2} \tag{3.11}$$

This result can be substituted for the right-hand side of Eq. (3.8) resulting in

$$r_L + jx_L = \frac{1-\Gamma_r^2-\Gamma_i^2}{(1-\Gamma_r)^2+\Gamma_i^2} + j\frac{2\Gamma_i}{(1-\Gamma_r)^2+\Gamma_i^2} \tag{3.12}$$

Equating the real and imaginary parts we get

$$r_L = \frac{1-\Gamma_r^2-\Gamma_i^2}{(1-\Gamma_r)^2+\Gamma_i^2} \tag{3.13}$$

$$x_L = \frac{2\Gamma_i}{(1-\Gamma_r)^2+\Gamma_i^2} \tag{3.14}$$

For now, let's focus on Eq. (3.13). Multiplying both sides by the denominator of the right-hand side, we obtain

$$r_L[(1-\Gamma_r)^2+\Gamma_i^2] = 1-\Gamma_r^2-\Gamma_i^2 \tag{3.15}$$

or

$$r_L(1-2\Gamma_r+\Gamma_r^2+\Gamma_i^2) = 1-\Gamma_r^2-\Gamma_i^2 \tag{3.16}$$

Multiplying out and rearranging we get

$$r_L\Gamma_r^2+\Gamma_r^2-2r_L\Gamma_r+r_L\Gamma_i^2+\Gamma_i^2 = 1-r_L \tag{3.17}$$

or

$$\Gamma_r^2(r_L+1)-2r_L\Gamma_r+\Gamma_i^2(r_L+1) = 1-r_L \tag{3.18}$$

Dividing both sides by $(1 + r_L)$ we have

$$\Gamma_r^2-\frac{2r_L\Gamma_r}{1+r_L}+\Gamma_i^2 = \frac{1-r_L}{1+r_L} \tag{3.19}$$

Adding $\left(\frac{r_L}{1+r_L}\right)^2$ to both sides results in

$$\Gamma_r^2-\frac{2r_L\Gamma_r}{1+r_L}+\left(\frac{r_L}{1+r_L}\right)^2+\Gamma_i^2 = \frac{1-r_L}{1+r_L}+\left(\frac{r_L}{1+r_L}\right)^2 \tag{3.20}$$

leading to

$$\left(\Gamma_r-\frac{r_L}{1+r_L}\right)^2+\Gamma_i^2 = \frac{(1-r_L)(1+r_L)+r_L^2}{(1+r_L)^2} \tag{3.21}$$

or

$$\left(\Gamma_r - \frac{r_L}{1+r_L}\right)^2 + \Gamma_i^2 = \frac{1+r_L-r_L-r_L^2+r_L^2}{(1+r_L)^2} \quad (3.22)$$

and finally,

$$\left(\Gamma_r - \frac{r_L}{1+r_L}\right)^2 + \Gamma_i^2 = \left(\frac{1}{1+r_L}\right)^2 \quad (3.23)$$

Now, let's look at Eq. (3.14). Multiplying both sides by the denominator of the right-hand side, we obtain

$$x_L[(1-\Gamma_r)^2 + \Gamma_i^2] = 2\Gamma_i \quad (3.24)$$

or

$$x_L(1 - 2\Gamma_r + \Gamma_r^2 + \Gamma_i^2) = 2\Gamma_i \quad (3.25)$$

Multiplying out and rearranging we get

$$x_L\Gamma_r^2 - x_L 2\Gamma_r + x_L\Gamma_i^2 - 2\Gamma_i = -x_L \quad (3.26)$$

Dividing both sides by x_L we have

$$\Gamma_r^2 - 2\Gamma_r + \Gamma_i^2 - \frac{2\Gamma_i}{x_L} = -1 \quad (3.27)$$

Adding $(1 + 1/x^2_L)$ to both sides results in

$$\Gamma_r^2 - 2\Gamma_r + 1 + \Gamma_i^2 - \frac{2\Gamma_i}{x_L} + \frac{1}{x_L^2} = -1 + 1 + \frac{1}{x_L^2} \quad (3.28)$$

leading to

$$(\Gamma_r - 1)^2 + \left(\Gamma_i - \frac{1}{x_L}\right)^2 = \left(\frac{1}{x_L}\right)^2 \quad (3.29)$$

Equations (3.23) and (3.29) have the form of

$$(x-h)^2 + (y-k)^2 = b^2 \quad (3.30)$$

which is an equation describing a circle in the *xy* plane. This circle has a radius *b* and is centered at $(x, y) = (h, k)$.

Thus, Eq. (3.23), repeated here

$$\left(\Gamma_r - \frac{r_L}{1+r_L}\right)^2 + \Gamma_i^2 = \left(\frac{1}{1+r_L}\right)^2 \quad (3.31)$$

describes a circle in the $\Gamma_r\Gamma_i$ plane. This circle has a radius

$$radius = \frac{1}{1+r_L} \quad (3.32)$$

and is centered at

$$(\Gamma_r, \Gamma_i) = \left(\frac{r_L}{1+r_L}, 0\right) \quad (3.33)$$

We refer to this circle as the *resistance circle*.

Similarly, Eq. (3.29), repeated here

$$(\Gamma_r - 1)^2 + \left(\Gamma_i - \frac{1}{x_L}\right)^2 = \left(\frac{1}{x_L}\right)^2 \quad (3.34)$$

describes a circle of

$$radius = \frac{1}{x_L} \quad (3.35)$$

centered at

$$(\Gamma_r, \Gamma_i) = \left(1, \frac{1}{x_L}\right) \quad (3.36)$$

We refer to this circle as the *reactance circle*.

The next article will focus on the resistance and reactance circles, and their relation to the location of normalized load impedance on the Smith Chart.

REFERENCES

1. https://upload.wikimedia.org/wikipedia/commons/7/7a/Smith_chart_gen.svg
2. Adamczyk, B., "Sinusoidal Steady State Analysis of Transmission Lines – Part II: Voltage, Current, and Input Impedance Calculations – Circuit Model 1," *In Compliance Magazine*, February 2023.
3. Adamczyk, B., "Sinusoidal Steady State Analysis of Transmission Lines – Part III: Voltage, Current, and Input Impedance Calculations – Circuit Model 2," *In Compliance Magazine*, March 2023.
4. Adamczyk, B., "Sinusoidal Steady State Analysis of Transmission Lines – Part I: Transmission Line Model, Equations and Their Solutions, and the Concept of the Input Impedance to the Line," *In Compliance Magazine*, January 2023.

CHALLENGES OF DESIGNING SYSTEM-LEVEL ESD PROTECTION AT THE IC LEVEL, PART 2

Conducting System-level ESD Current

By Hans Kunz for EOS/ESD Association, Inc.

A previous article (*Challenges of Designing System-Level ESD Protection at the IC Level: Misconceptions Regarding Current Flow to the IC* [1]) highlighted the challenges an IC designer faces when trying to determine the actual current that will flow into the IC during system-level ESD exposure. Once the current magnitude, duration, and wave shape reaching the IC are established, the next challenge can be addressed—properly designing for the current to flow through the IC, without impacting the system performance. As shown in Figure 1, this requires allowing the system-level current to flow through the board and the IC (both the IC package and die).

Hans Kunz joined Texas Instruments as an ESD Specialist in 2003. He was elected Senior Member of Technical Staff at Texas Instruments in 2012. Hans is co-author of multiple publications related to ESD and received the Best Presentation Award for the 2006 EOS/ESD Symposium. He holds six patents in the area of ESD protection, with an additional eight pending.

It is a common misconception that designing an IC for system-level ESD requirements simply requires an increase in the capability of the ESD cells, which are already present for safe handling ESD requirements, like Human Body Model (HBM). While creating an ESD cell that can conduct system-level ESD current is certainly not a trivial task, there are other significant challenges that must also be addressed. This article will discuss three of those challenges. First, the system-level ESD currents and current rise times are significantly more severe than those for safe-handling ESD requirements— as a result voltage drops across the circuit interconnects are much more difficult to manage. Second, the IC is connected to a full system during the stress; other components are attached to the IC, and these components can affect how the current returns to the system ground reference during the ESD event. Finally, system-level ESD is typically applied to a system that is powered up and operating, with more stringent failure criteria than those for safe-handling ESD requirements. While each of these challenges is significant by itself, this article will show how these challenges impact one another, further compounding the difficulty of meeting the system-level ESD design requirements.

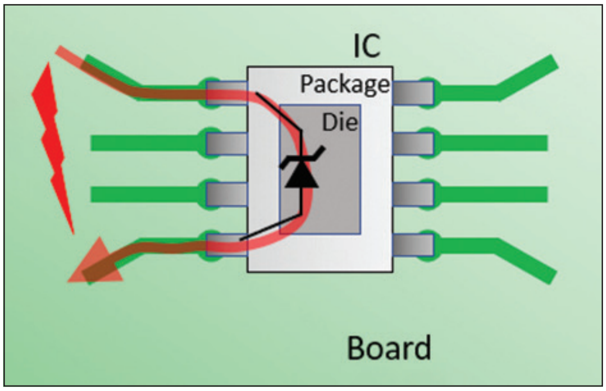


Figure 1: System-level ESD current flowing through the board and the IC (package and die)

As ESD current flows through a circuit path, additional voltage drops occur because of the impedance of the conductors which connect the circuit elements together. Typically, these impedances are small enough to be easily managed or even ignored. But consider a case where an IC is expected to conduct an entire system-level ESD event, produced with a 150 pF, 330 Ohm RC network [2].

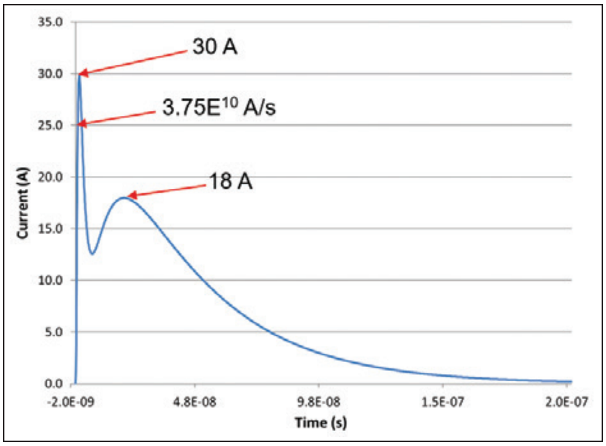


Figure 2: Current waveform for an 8-kV system-level contact ESD event (150 pF, 330 Ohm network)

When discharged at a typical 8 kV requirement, in contact mode, this event produces the current waveform shown in Figure 2. This current waveform has an initial peak current of 30 Amps, followed by a second peak current of 18 Amps. The initial rise-time and peak-current combine to produce a dI/dt of 3.75 E^{10} Amps per second. These values are much higher than typically experienced in normal operation, and even in safe-handling ESD conditions, requiring much lower impedances. The entire impedance in the system-level ESD current path must be considered—this includes the IC interconnect (both the metal routing on the die and the package interconnect and bond wires) and the board-level routing. Voltage excursions of tens of volts can arise from resistances as low as one-half of an Ohm and inductances as low as a few hundred pico-Henries. If system-level ESD protection is part of the IC, the designer must carefully consider where these protection elements will be placed on the die and optimize both the resistance and the inductance of the interconnect. The impedance requirements can be so low that extracting and predicting them (based on the geometry of the interconnects) can be as significant a challenge as actually achieving them.

In a safe-handling ESD test, like HBM, a single pin is stressed with respect to another pin (or group of pins) while the other pins are left floating. This allows the IC designer to clearly identify where current will enter and exit the IC. For system-level ESD testing, the IC is exposed while connected to the entire system—and, while the point where current enters the IC may be clearly identified, the exit point for the current is not clear. Circuitry on the die can connect to external circuitry in the full system in such a way that unexpected (and non-trivial) current paths are completed. This creates an added challenge for the IC designer, who must now consider how the IC interacts with the system, during system-level stress.

Here is a simple example of how unintended paths can be created. A common scenario is for an IC pin to have a diode on the die between an output pin and the power supply, connected in such a way that the diode is forward-biased when the output voltage exceeds the power supply. This diode may be part of the ESD protection strategy or may be part of the IC circuitry. Figure 3 shows an example of a case where the IC designer intended for the system-level ESD current to be conducted by an ESD cell directly between the output pin and ground, but a diode also exists between the output pin and power supply. When positive system-level ESD current is injected into the output pin, some of that current can flow onto the power supply net, and from there it can flow back to ground, either through the power

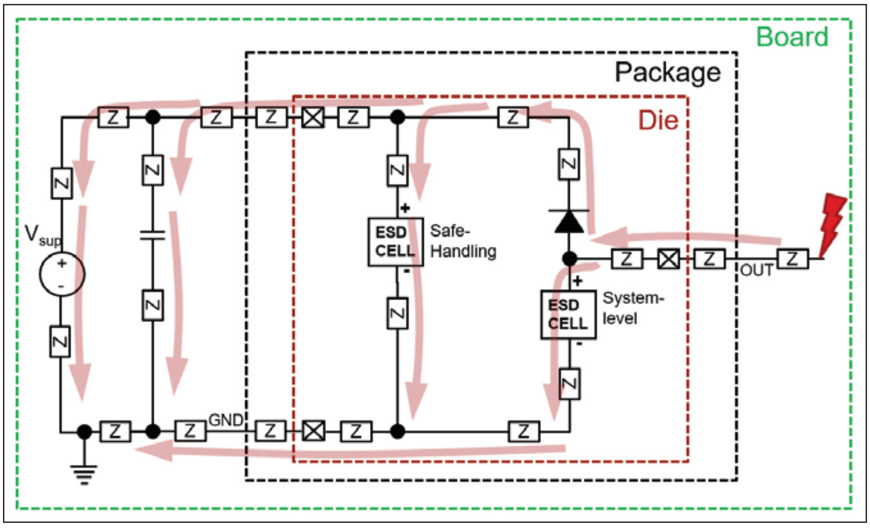


Figure 3: Example of multiple current paths resulting from interactions between the IC and the system

supply's ESD cell or out of the power supply pin and flow through decoupling capacitance or power supply in the actual system. Each of these paths must be considered and optimized to ensure they can carry the necessary current. But how current is shared among parallel paths is dependent on the impedance; this second challenge is thus exacerbated by the first challenge—parallel current paths exist, and determining their relative current requires careful consideration of the interconnect impedances.

The third challenge the IC designer faces is the fact that system-level ESD is often performed with the system powered-up and operating. Because the IC is powered, there is risk of a latch-up event being triggered by the ESD event—a risk which is not present in safe-handling testing. In addition to this risk, there is added consequence of a powered, operating system—if changes in how the system operates occur during or after the application of the ESD event occurs, this may be deemed a failure. Each system has its own requirements for determining pass or fail, and the IC designer must understand these requirements and design for them. Designing the IC to avoid disruptions can be a significant challenge. Imagine a signal that is driven to 3 V relative to a 0 V ground reference, an input circuit sensing that signal, whose ground reference is at 3 V, will not interpret that signal correctly. Thus, if the ground bus of the IC (or the system bus between two components) encounters voltage drops during the ESD stress, unwanted logic changes can occur, causing disruptions to the normal operation. For example, a logic change in a power-on-reset circuit could initiate a reset of the IC, significantly disrupting the operation of the full system. Managing the interconnect impedances and the relative current flow in parallel paths are significant challenges, just from the perspective of conducting the ESD event without physical damage. The added constraint of avoiding disruptions to normal operation adds significant complexity to the design.

This article has discussed three significant design challenges that result when system-level ESD protection is integrated into and existing IC. While the marketing advantages of such integration are well established, the engineering challenges are real, and must be carefully considered by the IC designer, within the full context of the overall system design. The challenges are more significant than simply sizing an existing IC-level safe-handling ESD solution to conduct the higher system-level ESD currents.

REFERENCES

1. H. Kunz, "Challenges of Designing System-level ESD Protection at the IC-level: Misconceptions Regarding Current Flow to the IC," *In Compliance Magazine*, August 2022.
2. *Electromagnetic Compatibility; Part 4-2: Testing and measurement techniques—Electrostatic discharge*, IEC 61000-4-2, Edition 2; 2008

DECIPHERING SAFETY SYMBOL COMPLEXITIES

By Erin Earley

For those that follow the "On Your Mark" column, you know that ANSI Z535 and ISO 3864 – the voluntary, consensus standards in the U.S. and internationally – provide critical guidance for developing today's most effective on-product labels and warnings. That's why, in our last article, we focused in on understanding the latest safety label formatting options available to you, per the most recent updates to these best practice standards. Now, we're going to cover specifics on symbol use – one of the fundamental elements of your labels – and options for handling complexities you may be facing.

WHAT IS A SAFETY SYMBOL?

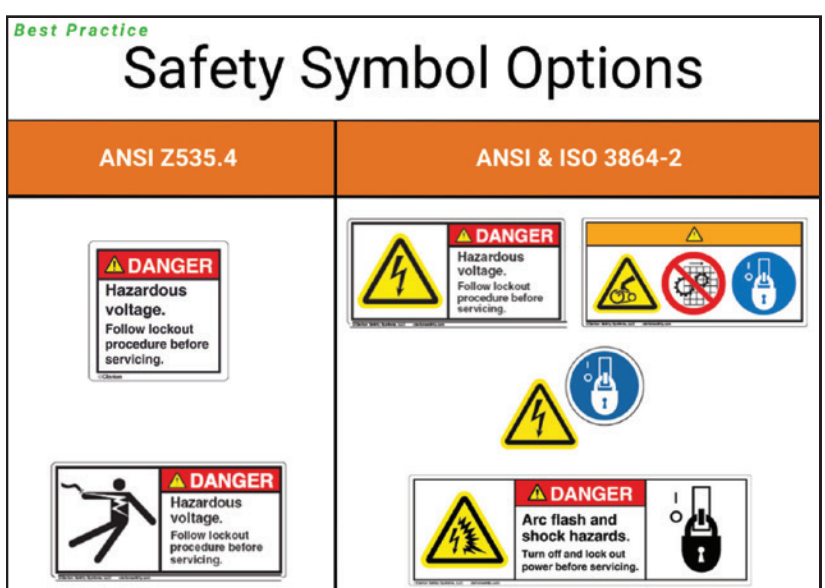
Also known as pictograms, pictorials, or glyphs, safety symbols can help to communicate a particular safety message – which is a key part of accident prevention and keeping people safe from harm – without the use of words. ANSI Z535.3 Criteria for Safety Symbols defines a safety symbol as a configuration that includes an image, with or without a surround shape, that communicates a message – usually a hazard or precaution to avoid a hazard – without words.

SYMBOL BASICS

"Depending on how you choose to implement the ANSI and/or ISO standards, you have the option to use labels without symbols, with only symbols and no text, or a combination of symbols and text," says Angela Lambert, head of standards compliance at Clarion Safety Systems. "However, the use of symbols is essential to the ISO standards and is encouraged by ANSI. That's because symbols can make labels more noticeable, communicate across language barriers, and can also help to convey and reinforce hazard-related information to a product's user."

ANSI VERSUS ISO

Using symbols in your safety labels. It sounds simple enough. Yet, how to apply the best practices from the latest ANSI and ISO standards for symbols to your products in today's global marketplace can be challenging.



Various Symbol Use Options for Safety Labels According to ANSI Z535.4 and ISO 3864-2

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.

Consider these differences in the current ANSI and ISO standards:

- According to ISO 3864-2, product safety labels must use at least one ISO-formatted safety symbol, where the symbol is placed in the colored surround shape. In ANSI, except for the safety alert symbol in the label's signal word panel, symbols are optional – not a requirement.
- Per ISO 3864-2, "wordless" formats that use only symbols and no text may be used. ANSI does not currently include this wordless format option, but allows its use by way of its section 3.1.1 which allows the use of ISO formats.
- ANSI Z535.3 states that there are four types of safety symbols: hazard alerting, mandatory action, prohibition, and information (this last type, however, is typically used in general safety or fire safety signs). ISO 3864-2 details five total categories of symbols, yet three of these effect product safety labels: warning, mandatory action, and prohibition. While the three main categories of symbols generally align, how they're implemented per ANSI and ISO contrasts; see the next point on surround shapes.
- ANSI Z535.3 states that a safety symbol may or may not use a surround shape – a geometric configuration around the image that conveys additional safety information. This contrasts with ISO. ISO safety symbols, the category of symbols used on your product safety labels, use a colored surround shape (a triangle, circle, or square) to define their overall safety function and to make these symbols more easily noticed and recognized.

SYMBOL COMPLEXITIES

And, there's more in terms of challenges. "Many manufacturers are at a point where they recognize the benefits of a symbol only or wordless approach for labels used on their products or product lines, and would like to move in that direction. But, because of factors like the sheer number of symbols involved in the warning, or the complexity of the message at hand, they're struggling," Lambert says. Here, Lambert stresses, there's not one easy solution; it's about working through the right options for your product and for your audience. "That may mean that it's not possible to go completely the symbol-only route to communicate the intended hazard and safety information; it may be finding a middle ground in the symbol and text use, as well as leaning on product manuals and safety training, as you continue down that path towards symbol-only formats."

Another point of confusion is around when and when not to use ISO 7010 safety symbols. "ISO 7010 is a technical standard for graphical symbols. It's an ISO collection document – essentially a library – of the symbols standardized by ISO for product safety labels (in addition to signage like exit path markings, water safety signs, and escape plans)," says Lambert.

"Product manufacturers may find themselves in a situation where an ISO 7010 symbol isn't available. And that's okay. When choosing symbols, look for the most appropriate fit or meaning for the application of use or message you're trying to convey. Yes, you should start with reviewing ISO 7010 in order to use a standardized, registered symbol – but another option is to select one based on the principles of the standard. That way, you'll still have visual consistency, allowing the symbols to build upon each other for one language of visual safety communication."

SYMBOL USE IN PRACTICE

While there are challenges to face in how you use symbols, it's not a bleak situation by any means. Looking back in the history of safety, a century ago, there was little in the way of safety regulations – and no safety sign, label, or symbol standards. Today, when it comes to labeling, we're fortunate to have the ANSI and ISO standards in this area, to continue to assess and document new and improved methods for visually communicating safety information. While the standards might not provide a black and white answer on the decisions you need to make in using safety labels and symbols, they provide a guideline – both for your unique situation and to keep all of us on the path towards consistency and improved comprehension.

"As someone who's been involved in the ANSI and ISO standards for over a decade, it's rewarding and encouraging to see trends moving towards more widespread symbol use and to standardization. Ultimately, these are steps in the right direction for improved safety and better protecting people from harm," Lambert says.

Banana Skins

422 ECG susceptibility to Gameboy™, iPod Nano™, cellphones, etc.

This experiment investigates the susceptibility of an ECG machine to emissions from unintentional emitters such as Gameboy™, iPod Nano™, and intentional emitters such as a Cell Phone, Portable 2.4GHz Phone, Portable 5.8GHz Phone, and walkie-talkie. Experiments were conducted both in a "lab" and hospital environments. The authors demonstrate that all of the above popular electronic devices can interfere with an electrocardiogram (ECG) and corrupt the readings.

Heartbeat changes ranging from 14 to 28 beats per minute were recorded due to EMI from these devices. Although doctors and Medical Technicians have been alerted to the possibility of interference from intentional emitters, they are generally unaware that popular unintentional emitters can corrupt their equipment. These results clearly illustrate the need for including both intentional and unintentional emitters in the EMI control of hospitals, medical offices and home care environments.

Home care is becoming more and more common, and people are relying on medical equipment for either monitoring, medicating or relieving medical conditions. Generally people are not aware of the possibility that popular electronic devices can interfere with their medical equipment. Patients are generally not warned which home equipment should, or should not, be used in proximity of the medical device. In the home setting EMI from many intentional and unintentional emitters can result in faulty operation of the medical device and possibly lead to grave consequences for the home care patient.

According to the signage in the hospitals we have visited, iPods™, Gameboys™ and even the Gameboy™ Advance DS (with wireless) are not banned. Especially in a Childrens' Hospital kids will play with these games or listen to their iPod™ to pass the time while undergoing lengthy tests and procedures. Airlines know that these devices should not be used during critical operations. Now we are proving that the same applies to Hospitals, Home Care and Doctor's Offices.

(Extracted from "Electrocardiogram (ECG) Susceptibility to Interference from Popular Electronic Devices", Matthew Pinchuk Meland and Anthony Dedes, IEEE EMC Society Newsletter, Winter 2007 (they mean Winter 2006!), Issue 212, pages 64-66, https://www.emcs.org.)

423 Interference causes poisoning of patient

European medical device regulations state mandatory limits at a distance of 10m, these measurements are performed in far field conditions. However, in many medical scenarios it is difficult to avoid the presence of EMI sources too close to sensitive equipment, and this situation is not covered by the standards.

Regarding the EMI that are not coming from medical devices, a typical situation is the use of a mobile phone inside medical facilities. There are several reports about medical problems attributed to the use of a mobile phone near a medical device: Hann in [4] reports the poisoning of a patient by an overdose of epinephrine prompted by the malfunction of an infusion pump due to a cellular phone call received by a family member.

[4] In-Hei Hahn, David Schnadower, Richard J Dakin and Lewis S. Nelson "Cellular phone interference as a cause of acute epinephrine poisoning" Annals of Emergency Medicine, Volume 46, no. 3: September 2005. pp 298-299.

(Extracts from "Medical Equipment Immunity Assessment by Time Domain Analysis", Mireya Fernández-Chimeno, Miguel Ángel García-González and Ferran Silva, 2007 IEEE International Symposium on Electromagnetic Compatibility, 8-13 July 2007, Honolulu, Hawaii, ISBN: 1-4244-1350-8, IEEE EMC Society, https://www.emcs.org.)

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.

PRODUCT Showcase

Advertiser Index

Upcoming Events

April 5

Smart Grid EMC Standards

April 11-12

AMTA and Seattle IEEE EMC Chapter Regional Event

April 11-14

Applying Practical EMI Design & Troubleshooting Techniques

Advanced Printed Circuit Board Design for EMC + SI

Mechanical Design for EMC

April 13-14

Principles of EMC

April 15-16

Applied Measurement Uncertainty for Testing Laboratories

April 16-19

A2LA Annual Conference

May 1 -3

2023 IEEE International Symposium on Product Compliance Engineering

May 16-19

Applying Practical EMI Design & Troubleshooting Techniques

Advanced Printed Circuit Board Design for EMC + SI

Mechanical Design for EMC

May 16-17

EMC and Compliance Internationa Exhibition and Training

May 22-25

2023 Joint Asia-Pacific Symposium on EMC (APEMC) and International Conference on EMI & C (INCEMIC)

May 22-25

2023 International Instrumentation and Measurement Technology Conference (I2MTC)

May 23

Annual Chicago IEEE EMC MiniSymposium

May 25

EMC Fest 2023

June 11-16

IEEE International Microwave Symposium (IMS)

June 20-22

Sensors Expo & Conference

Always check the event website for current information.

PUSHING THE BOUNDARIES OF EMC COMPLIANCE

With the ever-growing demand for compliance with EMC standards, manufacturers are continuously seeking ways to push the boundaries of what is possible. To stay up to date on the latest compliance requirements, ETS-Lindgren's experts are active technical contributors to the industry standards committees. From chambers to test cells, absorbers, positioners, antennas, and software, our customers can rest assured that ETS-Lindgren's EMC Solutions will comply with the latest requirements in place today, and those expected tomorrow.

ETS-Lindgren is constantly innovating to create new solutions that meet the ever-changing standards. Our ability to create turnkey real-world test scenarios, troubleshoot potential failures, and maximize the chance of passing standards within the allotted time and budget helps our customers bring life-changing products to market – faster.

We understand that the compliance process can be daunting. Visit our website at www.ets-lindgren.com or contact your ETS-Lindgren representative to learn how we can help you stay *Committed to a Smarter, More Connected Future.*

Connect with us at:

COMMITTED TO A SMARTER, MORE CONNECTED FUTURE

ETS·LINDGREN®
An **ESCO Technologies** Company

Offices Worldwide | **ets-lindgren.com**