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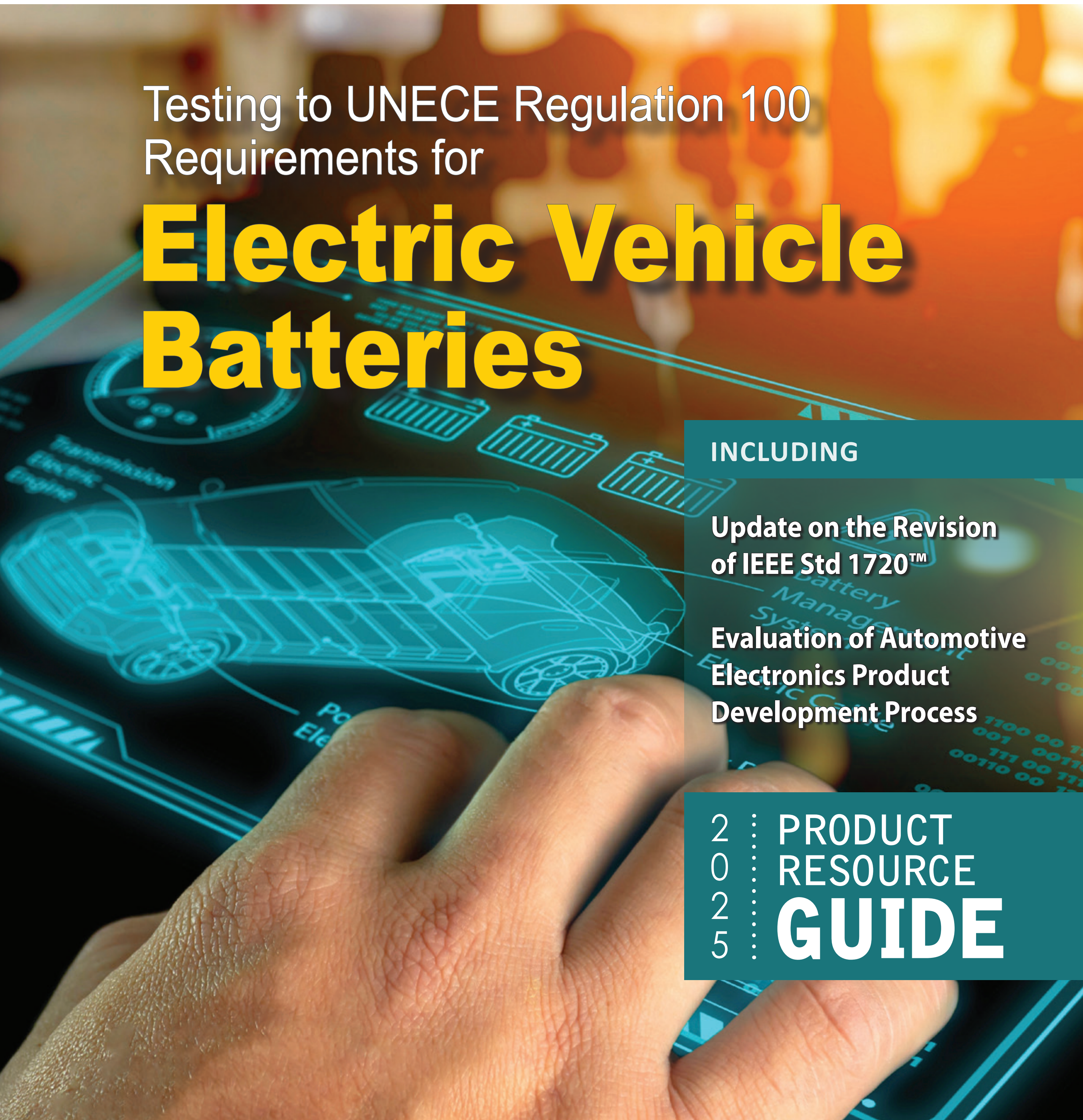

Testing to UNECE Regulation 100 Requirements for Electric Vehicle Batteries

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Update on the Revision of IEEE Std 1720™

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Don MacArthur
"The Practical Engineer"
Contributing Author

IN COMPLIANCE

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FEATURE ARTICLES

COLUMNS

DEPARTMENTS

Mobile Phones Not Linked to Brain Cancer, Researchers Find

For decades, numerous reports have raised concerns about potential links between mobile phone use and brain cancer. But now, a comprehensive review conducted by the World Health Organization (WHO) has determined that there is no increased risk of brain cancer associated with mobile phones.

The WHO's report, "The effect of exposure to radiofrequency fields on cancer risk in the general and working population," is a meta-analysis of the findings of 63 different studies published in 22 countries around the world between 1994 and 2022. Each of the studies reviewed by WHO investigated the health effects of exposure to radio frequency-electromagnetic fields (RF-EMF) generated by mobile phones.

The report found "RF-EMF exposure from mobile phones (ever or regular use vs. no or non-regular use) was not associated with an increased risk of glioma, meningioma, acoustic neuroma, pituitary tumors, salivary gland tumors, or pediatric brain tumors..."

FCC Sets Initial Rules for Drone Operations in the 5 GHz Band

To help facilitate the safe operation of uncrewed aircraft systems (UAS, otherwise known as drones), the U.S. Federal Communications Commission (FCC) has published new rules applicable to the operation of UAS in the 5 GHz spectrum band.

A Report and Order issued by the Commission establishes initial service rules applicable to wireless communications technologies that support UAS control and operations. Specifically, the rules allow UAS operators to obtain frequency assignments in a portion of the 5 GHz band intended for use by non-networked operations.

The FCC says the new rules are based on the use of dynamic frequency management systems that can manage and coordinate access to the spectrum and provide temporary frequency assignments to support UAS communications in controlled airspace and other safety-critical situations.

The use of drones and other types of UAS is growing rapidly and has become increasingly essential in search and rescue missions. The FCC predicts that UAS operations will triple during the current decade in terms of the number of devices in use. Hence the need to provide safe access to expanded portions of the wireless spectrum.

$2.3 Million Fine for Pirate Radio Broadcaster

The Federal Communications Commission (FCC) has issued a Forfeiture Order in connection with its investigation of a Bronx, NY, pirate radio station operator.

Issued in early August, the Forfeiture Order confirms the agency's proposed fine of $2.3 million against Johnny Peralta, the alleged operator of an unauthorized radio station on 105.7 MHz, known as "La Mia Radio." Peralta must pay the Forfeiture Penalty by early September or face further prosecution by the U.S. Department of Justice.

The station, which the FCC says has operated since at least 2018, was first identified by agents from the New York Field Office of the FCC's Enforcement Bureau in September of that year by tracing the source of the radio transmissions to an FM transmitter antenna located at an apartment building in the Bronx. After a warning was posted on the building's front door, the transmitter antenna was, according to the Commission, temporarily moved to another location in the Bronx but later relocated to the original site, where it continued to operate through at least mid-2023.

The Commission finally issued a Notice of Apparent Liability for Forfeiture (NAL) against Peralta in November 2023, proposing a financial penalty of $2,316.034 for his willful violations of FCC regulations. However, since then, Peralta has failed to file a response to the NAL, prompting the FCC's decision to issue the Forfeiture Order affirming the fine.

List of Medical Devices Incorporating Virtual Reality Technology Updated

The U.S. Food and Drug Administration (FDA) has updated its list of authorized medical devices that incorporate augmented reality (AR) and virtual reality (VR) technologies.

The FDA's list now includes 69 different AR- or VR-augmented devices that have been authorized by the agency through its 510(k), De Novo, or Premarket Approval processes. The authorized devices include a variety of technologies applicable for used in many different fields of medicine, including orthopedics, radiology, ophthalmology, cardiology, and others.

The FDA says that AR and VR "have the potential to transform healthcare, delivering new types of treatments and diagnostics and changing how and where care is delivered." Examples of AR include the ability to mix digital imagery with the real world (mixed or merged reality), while examples of VR include devices that project medical images onto a patient during an operating procedure to help guide the surgeon.

FDA Releases Paper on Health Equity for Medical Devices

As part of a broader effort to expand health outcomes across diverse populations in the U.S., the U.S. Food and Drug Administration (FDA) has published a Discussion Paper to facilitate a public discussion on how to advance health equity in connection with medical devices.

Published by the FDA's Center for Devices and Radiological Health (CDRH), the Discussion Paper, titled "Health Equity for Medical Devices," outlines various factors and considerations that may be important for device manufacturers to consider in clinical studies intended to support the development of advanced and innovative medical devices.

Specifically, the paper discusses three considerations (disease burden or condition; physiology, anatomy, and pathophysiology; and technology) that may need to be considered in the design of clinical studies to adequately reflect the intended use population for a given device. The paper also addresses other aspects to consider in evaluating whether data derived from clinical studies is representative of the intended use population for a given device.

NY High School Helps Train Next-Gen Amateur Radio Operators

On a bright note, a teacher at a high school in Staten Island, NY is helping to train the next generation of America's amateur radio operators!

According to a recent news brief posted on the website of the National Association for Amateur Radio (ARRL), Everton Henriques, a teacher at the Staten Island Technical High School and a licensed amateur radio operator, has developed a program intended to teach his students about radio technologies. Henriques has reportedly taught his students about high-frequency technologies, local repeater use, foxhunting, and space communications and plans to incorporate training on mesh networking in the coming academic year.

Equally important, Henriques has helped more than 100 of his students take and pass the licensing exam, with many of them successfully passing the tests necessary to upgrade their licenses from General to Extra.

FCC Reaches Settlement with Transmitter of Spoofed Election Calls

The Enforcement Bureau of the U.S. Federal Communications Commission (FCC) has reached a settlement with a telecommunications provider in connection with charges that the company transmitted illegal, AI-generated robocalls in advance of New Hampshire's 2024 Democratic Presidential Primary in January.

According to an Order issued by the FCC's Enforcement Bureau in late August, Lingo Telecom has agreed to pay a $1 million civil penalty to resolve the Bureau's investigation into claims that the company transmitted nearly 4000 generative AI Deepfake voice messages that imitated the voice of President Joseph Biden two days ahead of the Democratic Primary.

Lingo also reportedly failed to verify the accuracy of the caller ID information it used and then mislabeled the calls with the highest level of caller ID attestation, leading other transmitters to believe that the calls were legitimate.

The settlement between Lingo and the FCC follows a Notice of Apparent Liability for Forfeiture issued by the Commission in May, in which the FCC proposed a fine of $2 million for Lingo's alleged violation of the Commission's caller ID authentication rules, a first-of-its-kind enforcement action by the FCC. In addition to paying the $1 million penalty, Lingo has also agreed as part of its settlement with the FCC to implement a robust compliance plan to prevent future such violations of FCC's rules.

Upcoming Events

October 2-4
Battery Japan

October 3
EU Regulatory Update for Electronics Producers 2024 Webinar

October 7-9
EMC COMPO 2024

October 7-10
★ The Battery Show

October 8- 9
2024 IEEE Symposium on Product Compliance Engineering

October 10
Cyber-Security Webinar

October 15
★ 2024 San Diego Test Equipment Symposium

October 22-25
Applying Practical EMI Design and Troubleshooting Techniques

October 27-November 1
★ 46th Annual Meeting and Symposium of the Antenna Measurement Techniques Association

October 28-October 31
Military Standard 810 (MIL-STD-810) Test Training

November 5-7
XIV Electromagnetic Compatibility Course

November 15
IoT Applications

November 20-22
Battery Japan

December 3-5
Fundamentals of Random Vibration and Shock Testing Training

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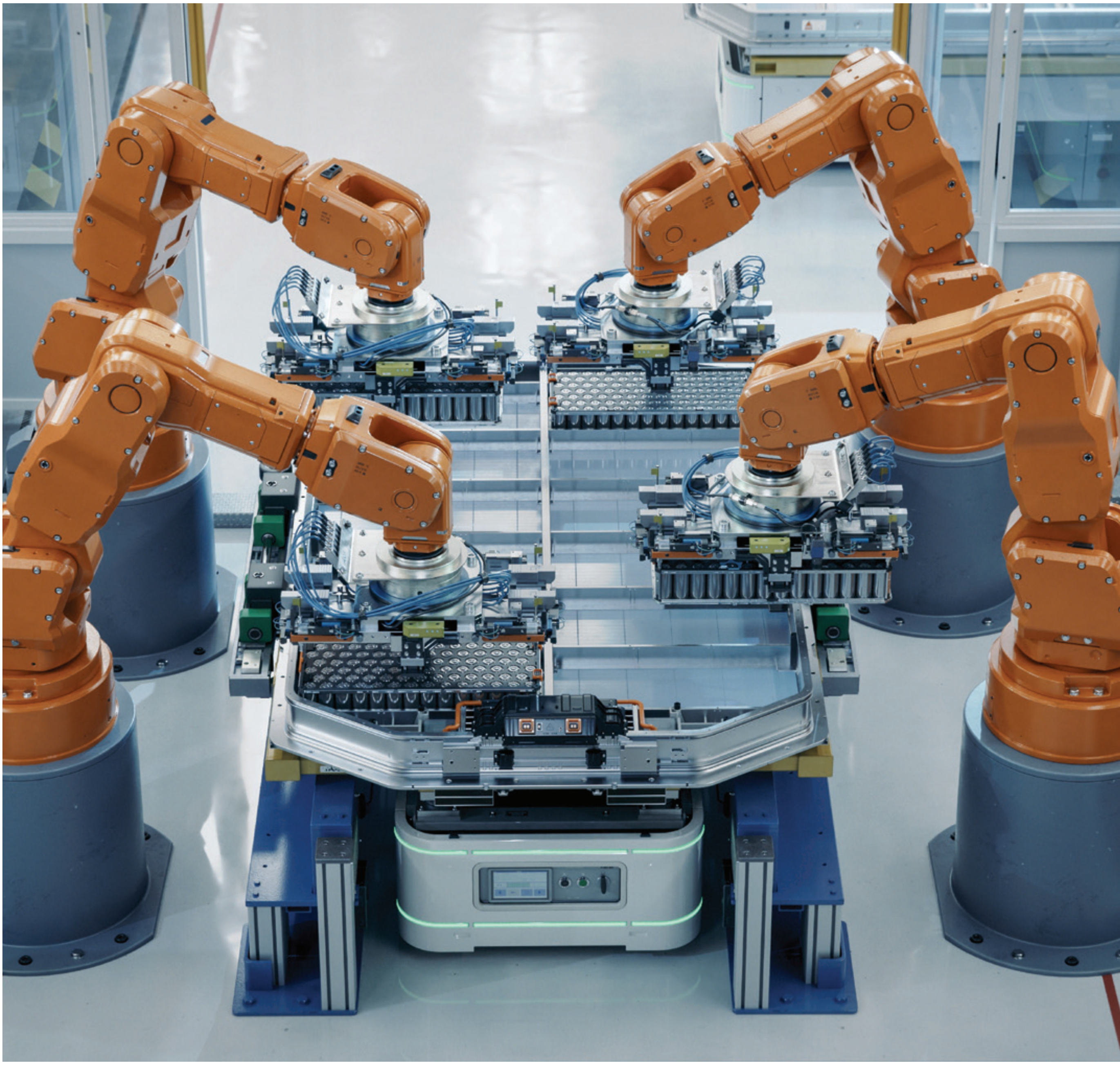
In the words of our team

As Mike Pendleton, Technical Director for Battery, emphasizes, "Battery testing is not just about meeting standards; it's about exceeding them to deliver products that perform reliably, safely, and efficiently in every situation." Element remains a forward-thinking leader, pushing the boundaries of battery testing to support the future of technology.

Mike Pendleton
Technical Director, Battery

TESTING TO UNECE REGULATION 100 REQUIREMENTS FOR ELECTRIC VEHICLE BATTERIES

Help Ensure the Integrity and Safety of EV Battery Systems



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By Sebastian Cerne and Michael Winter

Revision 3 of UNECE Regulation No. 100 (R100) imposes a number of new and updated requirements on manufacturers of rechargeable electrical energy storage systems (REESS) designed for use in motor vehicles manufactured, sold, or operated in the European Union and other countries.

R100 now includes a new overcurrent test and adjusted requirements on the system-on-chip (SOC) level, as well as new requirements relating to thermal propagation. All of these are intended to ensure the integrity and safe operation of such systems under anticipated operating conditions, as well as to provide a higher level of safety for vehicle drivers and passengers.

Although these updated requirements will increase the compliance burden for battery manufacturers, they will also ease the acceptance and use of battery packs with type approval, thereby broadening the market for manufacturers. In this article, we'll provide a summary of the requirements and the benefits likely to accrue to battery manufacturers.

WORLD FORUM FOR THE HARMONIZATION OF VEHICLES

The creation of global standards for motor vehicles, including electric vehicles and REESS, falls under the purview of the World Forum for the Harmonization of Vehicles. Originally formed in 1952, the Forum is today a permanent working party (WP 29) operating under the auspices of the Transport Division of the United Nations Economic Commission for Europe (UNECE). The primary objective of the Forum is to establish globally harmonized regulations for motor vehicles in order to remove barriers to international trade, promote road safety, and protect the environment.

The work of the Forum has its legal basis in the so-called 1958 Agreement, formally known as the "Agreement concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions." Under the terms of the Agreement, signatory countries agree to a mutual recognition of type approvals. This means that they comply with a common set of technical specifications and requirements in connection with motor vehicles produced within their respective countries and allow for the importation, sale, and use of motor vehicles from other countries that meet these specifications.

Initially, the agreement was only open to ECE member countries. But, in 1995, the agreement was revised to allow the participation of non-ECE members. At present, 64 countries worldwide are signatories to the 1958 Agreement, but two major vehicle markets, the U.S. and China, have not signed the agreement.

Specific technical requirements for motor vehicles are documented in approximately 130 separate UN Regulations (formerly known as "UNECE Regulations" or "ECE Regulations"). Individual regulations address topics as diverse as vehicle components like lighting and instrumentation, and operational characteristics including crashworthiness and environmental compatibility.

To demonstrate compliance with UN Regulations, manufacturers must submit vehicle products and components to an authorized third party ("Technical Service") for type approval evaluation.

Applications for type approval under R100 have been limited exclusively to entire motor vehicle assemblies. Evaluations of the safety and performance of vehicle components were conducted as part of a total vehicle assessment, and limited in scope and depth.

Reports of these evaluations are then submitted by the Technical Service to the type-approval authority in the signatory country, which then issues the actual type approval certificates and authorizes manufacturers to apply the E-mark to their products. Type approvals issued in one signatory country are deemed legally equivalent to those issued in other signatory countries. Accordingly, vehicles and components that have received type approval in one signatory country must be accepted for importation, sale or use in all other signatory countries.

As the U.S. is not a signatory to the Forum's 1958 Agreement and does not recognize UN Regulation-type approvals, manufacturers seeking to sell motor vehicles in the U.S. must meet that country's Federal Motor Vehicle Safety Standards (FMVSSs) that address the design, construction, performance, and durability of motor vehicles and motor vehicle components. However, unlike type approval requirements in Forum signatory countries, compliance with U.S. motor vehicle safety standards is demonstrated by a manufacturer's self-certification, and independent verification is not required prior to vehicle sale, importation, or use.

The CCC Mark (China Compulsory Certificate) is a mandatory requirement for both domestically manufactured products and products imported into China. Automotive products that require the CCC Mark include many whole, completed, or incomplete vehicles that fall in the L, M, and N categories, as well as motorcycles in the O category and vehicle parts (e.g., seat belts, tires, safety glass products, and headlamps). The CCC certification procedure involves the testing of the product itself, as well as a factory inspection and the creation of documentation.

UNECE REGULATION NO. 100

UNECE Regulation No. 100 is officially titled "Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train." Also referred to as R100, the Regulation addresses the safety requirements specific to the electric power train of road vehicles, as well as those high-voltage components and systems that are "galvanically connected" to the high-voltage bus of the electric power train.

R100 was originally published in 1996 under the terms of the Forum's 1958 Agreement. Revision 1 of the Regulation was issued in March 2011 to ensure that the Regulation kept pace with new automotive technologies, with minor amendments issued in 2012 and 2013. However, since its inception, applications for type approval under R100 have been limited exclusively to entire motor vehicle assemblies. Evaluations of the safety and performance of vehicle components, such as drive trains and battery packs, were conducted as part of a total vehicle assessment, and limited in scope and depth.

Because R100 type approvals covered an entire vehicle, vehicle manufacturers seeking type approval were subject to a complex and time-consuming testing and evaluation process. More problematic, the "whole vehicle" approach to type approval meant that vehicle manufacturers were unable to change individual systems or components or to substitute components from one sub-manufacturer with those from another since any changes to the originally approved design would require a new type approval application for the complete high voltage electrical powertrain.

The publication of the second revision of R100 in 2013 introduced significant changes in the overall type approval process applicable to REESS, including electric vehicle batteries, and became mandatory in July 2016. For the first time, the Regulation provided a separate approval path for REESS and rechargeable battery packs, along with an expanded set of specific tests exclusively applicable to these systems.


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COMTEST

R100 contains two parts. Part I covers safety requirements of a vehicle for the electric power train, such as protections against electrical shock. Part II covers requirements of the rechargeable electrical energy storage systems with regards to its safety.

Revision 3 came into force in June 2021 and is thus applicable to type approval. The transition period between Revision 2 and 3 is currently in effect, with the application of Revision 3 being obligatory from September 2023 for new type approvals and from September 2025 for all type approvals. Annex 9 of Revision 3 defines the specific test standards for type approval of traction batteries for all types of electric vehicles (EVs), including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs).

SAFETY REQUIREMENTS

R100 contains two parts. Part I covers safety requirements of a vehicle for the electric power train, such as protections against electrical shock. This includes protection against electrical shock, requirements applicable to the REESS, and preventing unintended vehicle movement. Protection against electrical shock includes protection against direct contact, protection against indirect contact, and requirements on insulation resistance.

Additional requirements regarding protection against water effects have been introduced in Revision 3. The Revision states that the vehicle shall maintain isolation resistance after exposure to water. The vehicle needs to comply with requirements regarding an insolation resistance warning system. Otherwise, compliance of isolation resistance of the electrical design of the vehicle after water exposure or protection against water effects must be proven. Requirements applicable to the REESS include accumulation of gas, warning in the event of failure, warning in the event of low energy content, and compliance with Part II of this Regulation.

Part II covers requirements of the REESS with regards to its safety. This includes proof of design and the requirements for component testing before installation in the vehicle. Revision 3 introduces a new mandatory battery test procedure addressing overcurrent protection, which increases the number of mandatory tests from nine to ten. All mandatory test procedures are described in Annex 9 of this Regulation (9A Vibration Test, 9B Thermal shock and cycling, 9C Mechanical shock, 9D Mechanical integrity, 9E Fire resistance, 9F External short circuit protection, 9G Overcharge protection, 9H Over-discharge protection, 9I Over-temperature protection and 9J Over-current protection).

Additional requirements regarding low-temperature protection, warning in the event of operational failure, and warning in the case of thermal event and thermal propagation have also been introduced in Revision 3.

REESS

The essential requirements regarding the REESS in Revision 3 of R100 can be found in Section 6 of the Regulation. Annex 9 provides detailed information on the specific testing procedures applicable to the REESS identified in Section 6 of the Regulation. As specified in this Annex, R100-required assessments for the REESS include the following tests:

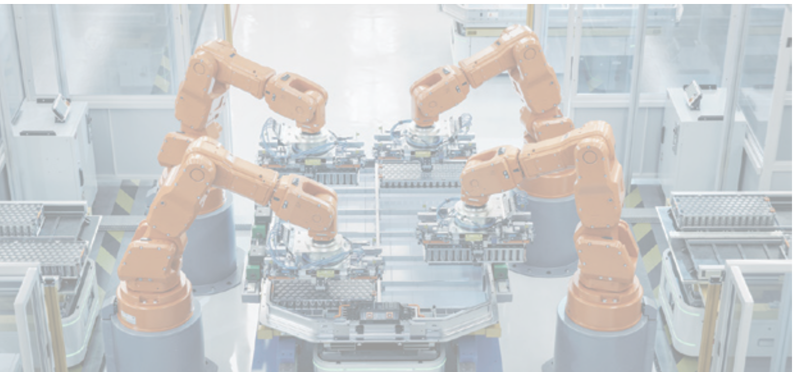
- ***Vibration***—The vibration test is intended to verify the safety performance of the REESS under vibration conditions similar to those likely to be experienced during normal vehicle operations. The REESS under test is subject to a vibration having a sinusoidal waveform with a logarithmic sweep between 7 Hz and 50 Hz and back to 7 Hz in the span of 15 minutes. This sweep is repeated 12 times for a total test period of three hours. At the completion of the vibration testing, the REESS is subject to a standard discharge followed by a standard charge and then observed for one hour. New requirements in Revision 3 include a fully charged battery before the start of testing and the added acceptance criteria “no venting.”
- ***Thermal Shock and Cycling***—The thermal shock and cycling test is intended to verify the

resistance of the REESS to sudden changes in temperature likely to be experienced during its life. The REESS is first stored for at least six hours at a test temperature of 60°C, followed by six hours of storage at -40°C. The maximum time interval between test temperature extremes shall be 30 minutes. This cycle is repeated five times, followed by a storage period at ambient temperatures for 24 hours. At the completion of the thermal shock and cycling test, the REESS is subject to a standard discharge followed by a standard charge and then observed for one hour. New requirements in Revision 3 are a fully charged battery before the start of testing and the added acceptance criterion of "no venting."

- ***Mechanical Shock***—The purpose of the mechanical test is to verify the safety performance of the REESS under inertial loads that may occur in vehicle crash conditions. The REESS is accelerated or decelerated at speeds specified in the tables accompanying the Regulation, and the actual gravitational force is compared with the values specified in the tables. Upon the completion of the mechanical shock test, the REESS is observed for one hour. A new requirement in Revision 3 is a fully charged battery before the start of testing.
- ***Mechanical Integrity***—The mechanical integrity test is intended to verify the safety performance of the REESS under the kinds of contact loads that might be experienced in vehicle crash conditions. The REESS is crushed between a resistance plate and a crush plate with a force of at least 100 kN with an onset time of less than three minutes and a hold time of between 100 milliseconds and 10 seconds. At the completion of the mechanical integrity test, the REESS is observed for one hour. A new requirement in Revision 3 is a fully charged battery before the start of testing.
- ***Fire Resistance***—The purpose of the fire resistance test is to verify the resistance of the REESS to exposure from a fire originating outside of a vehicle in order to provide a driver and passengers with sufficient escape time. The REESS is subject to both direct and indirect exposure to a flame that has been produced by burning commercial fuel or LPG gas. At the completion of the fire resistance test, the REESS is observed for a period of three hours, or until it

has cooled to ambient temperature, whichever is less. Revision 3 introduces the LPG burner test for the first time. It is now possible to choose between the test methods with gasoline or LPG as a fire source. The new LPG method requires additional measurement of the flame temperature and does not include an indirect exposure period to the flames. Instead, the direct exposure time is increased to two minutes.

- ***External Short Circuit Protection***—The external short circuit protection test is intended to verify the performance of the short circuit protection system that limits the consequences associated with short circuits. The REESS is subject to an intentional short circuit by connecting the positive and negative terminals, using a connection with resistance of not more than 5 mΩ. The short circuit condition is continued until the function of the short circuit protection can be confirmed or for at least one hour after the temperature measured on the REESS casing has stabilized. At the completion of the external short circuit protection test, the REESS is subject to a standard discharge followed by a standard charge, if not inhibited, and then observed for one hour. New requirements in Revision 3 are a fully charged battery before the start of testing and the added acceptance criterion of "no venting."
- ***Overcharge Protection***—The purpose of the overcharge protection test is to verify the performance of the overcharge protection system. When conducting the overcharge protection test, the REESS is charged until it automatically interrupts or limits the charging or until it is charged to twice its rated capacity. At the completion of the overcharge protection test, the REESS is subject to a standard discharge followed by a standard charge, if not inhibited, and then observed for one hour. The new requirement in Revision 3 is the added acceptance criterion of "no venting."



- ***Over-Discharge Protection***—The over-discharge protection test is intended to verify the performance of the over-discharge protection system. During the over-discharge protection test, the REESS is discharged until it interrupts or limits the discharge or when it is discharged to 25% of its nominal voltage level. At the completion of the over-discharge protection test, the REESS is subject to a standard discharge followed by a standard charge, if not inhibited, and then observed for one hour. The new requirement in Revision 3 is the added acceptance criterion of "no venting."
- ***Over-Temperature Protection***—The purpose of the over-temperature protection test is to verify the resistance of the REESS against internal overheating during operation, even when the REESS's cooling function fails. When conducting the over-temperature protection test, the REESS is first repeatedly charged and discharged with a steady current so as to increase the temperature of cells as rapidly as possible. The REESS is then placed in a convection oven or climatic chamber, and the temperature of the oven or chamber is gradually increased to a pre-determined level. The test is concluded when the REESS inhibits and/or limits the charge and or discharge to prevent the temperature increase or when the temperature is stabilized. The new requirement in Revision 3 is the added acceptance criterion of "no venting."
- ***Over Current Protection***—This is an entirely new test procedure introduced by Revision 3. Its purpose is to verify the performance of the overcurrent protection system during external charging of REESS. During the test, the battery is charged with the maximum charging current, with the charging current increased over five seconds from the highest normal charge current to the overcurrent level. Charging is then continued at this overcurrent level. Charging is terminated when the overcurrent protection of the battery terminates the charging current, or the battery temperature is stabilized over two hours. Immediately after the termination of charging, the REESS is subject to a standard discharge followed by a standard charge, if not inhibited, and then observed for one hour.

It is important to note that testing values that differ from those presented in Annex 9 of the Regulation may be applied in coordination with the Technical Service, depending on the requirements or preferences of the manufacturer of an REESS or the vehicle.

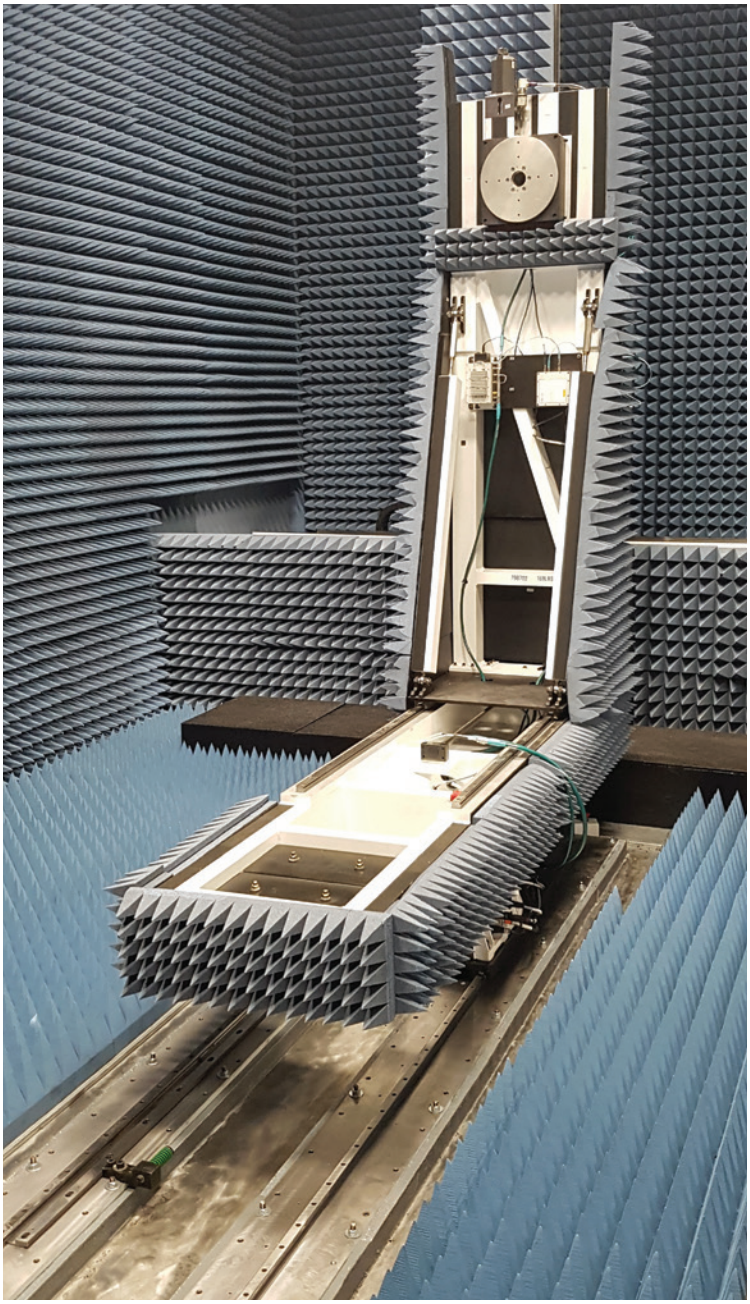
Revision 3 of R100 also includes a new requirement regarding thermal propagation. This refers to the sequential occurrence of thermal runaway within a REESS, triggered by thermal runaway of a cell in that REESS. This means that either 1) vehicle occupants shall not be exposed to any hazardous environment caused by thermal propagation triggered by an internal REESS, or 2) the vehicle system is required to provide a signal to activate the advance warning system five minutes prior to the presence of a hazardous situation inside the vehicle to provide sufficient time for passengers to escape. Furthermore, the REESS or vehicle system shall have functions or characteristics in the cell or REESS that are intended to protect vehicle occupants.

While this requirement doesn't come with a mandatory test, real-case scenarios have shown that proving compliance without additional practical testing is very difficult. Consent between technical services, manufacturers, and official authorities to conduct additional thermal propagation testing will ensure compliance with this important new requirement.

CONCLUSION

Revision 3 of R100 introduces some important new and modified requirements for manufacturers of REESS and rechargeable batteries for electric vehicles. It also maintains the type approval scheme introduced by Revision 2, a change that is likely to continue increasing competition in the REESS marketplace.

UPDATE ON THE REVISION OF IEEE STD 1720™



Near-field measurements are widely recognized as a highly accurate and versatile technique for testing antennas. The theory behind these measurements has been known for many decades. Indeed, in the 1960s, the company Scientific Atlanta marketed planar near-field systems where the Fourier transform operation was performed via operational amplifier circuits [1]. In the 1980s, spherical near-field measurements were introduced [2]. Since those days, especially in the past 25 years, these measurement techniques have become one of the preferred approaches for testing a broad range of antennas. Today, there are hundreds of near-field antenna test facilities installed across the globe, attesting to the method's proven effectiveness and significance.

The acceptance of these methods and techniques was the driver behind the creation of the IEEE Standard 1720™, "Recommended Practice for Near-Field Antenna Measurements" (IEEE Std 1720, see Figure 1.)

When it was initially approved in 2012, IEEE Std 1720 was a completely new standard developed by the IEEE Standards Association Standards Board (SASB). But advancements in technology and emerging developments over the past decade have made a revision necessary to ensure the document remains current. Further, the IEEE Standards Association (SA) mandates that all currently-active standards must be revised every ten years.

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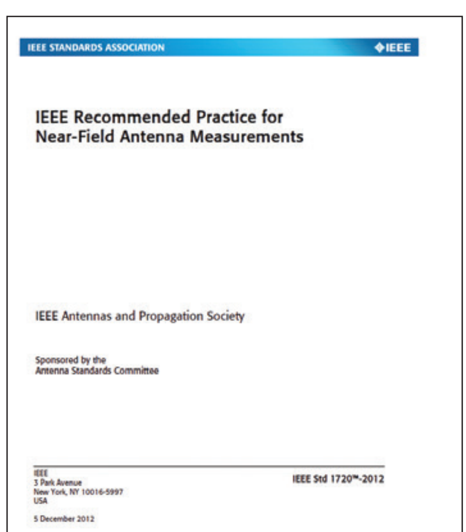
By Lars Jacob Foged, Justin Dobbins, Jeff Fordham, Vince Rodriguez, and Vikass Monebhurrun

For these reasons, the IEEE-SASB approved project authorization request (PAR) P1720 in 2019 for an SASB working group to undertake a revision of the original standard. To accomplish this task, a Working Group (WG) was formed under the Antennas and Propagation Society Standards Committee (APS/SC).

Currently comprised of approximately fifty committed volunteer members from industry, academia, and government, the WG is representative of the near-field measurement community, with both users and experts in the field. WG members hail from almost every continent, thus their work across numerous time zones has not been easy to manage. Nonetheless, the WG has been actively engaging in regular virtual meetings, with occasional face-to-face gatherings when possible. The primary focus of the WG has been on revising the existing material and identifying pertinent new NF measurement topics to be included in the updated standard.

To facilitate smooth collaboration, the IEEE-SASB has provided a dedicated workspace with an accessible database for all WG members. This comprehensive platform houses up-to-date documents and a complete history of developments [5]. Additionally, the workspace enables group decision-making through online discussions and electronic voting on various topics. The efficiency of this approach has significantly contributed to the progress of the WG's efforts.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IEEE
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New York, NY 10016-5997
USA

5 December 2012

IEEE Std 1720™-2012

Figure 1: IEEE Std 1720-2012, "Recommended Practice for Near-Field Antenna Measurements [3]

During the Antenna Measurements Techniques Association (AMTA) Symposium in 2023, a comprehensive report of progress on special topics was presented [6], which provided details on the proposed contents of the special topics section. In this article, we provide an update on the WG's progress and highlight a few of the newer additions to the standard.

CONTENT OF THE REVISED IEEE STD 1720

As the current revision of IEEE Std 1720 is considered "minor," the outline of the new document closely follows the original standard [3]. The main NF scanning geometries (planar, cylindrical, and spherical) are covered in detail. This original material is being reviewed and updated or rewritten depending on the level of review performed. The changes are intended to renew, update, and reflect widely accepted changes in technology and post-processing techniques. Here is the current draft outline of the revised Standard:

1. Overview
2. Normative reference
3. Background
4. Measurement systems
5. Planar near-field scanning measurements
6. Cylindrical near-field scanning measurements
7. Spherical near-field scanning
8. Non-regular scanning techniques
9. Probes
10. Determination of antenna gain
11. Uncertainty analysis
12. Special topics

CHANGES TO THE MAIN CLAUSES OF IEEE STD 1720

The IEEE standard time convention for time-harmonic electromagnetic fields is of the form exp(+jωt), where "j" is the imaginary unit, "ω" is the the angular frequency, and "t" is time. Using this convention, the corresponding propagation phase factor is exp(-jkr), where "k" is the wave number and "r" is the propagation distance. This notation is sometimes referred to as the "engineering" time notation. This differs from the "physics" notation in which the "+" and "-" signs are interchanged in the above expressions. Throughout the standard, both time conventions are used without much distinction.

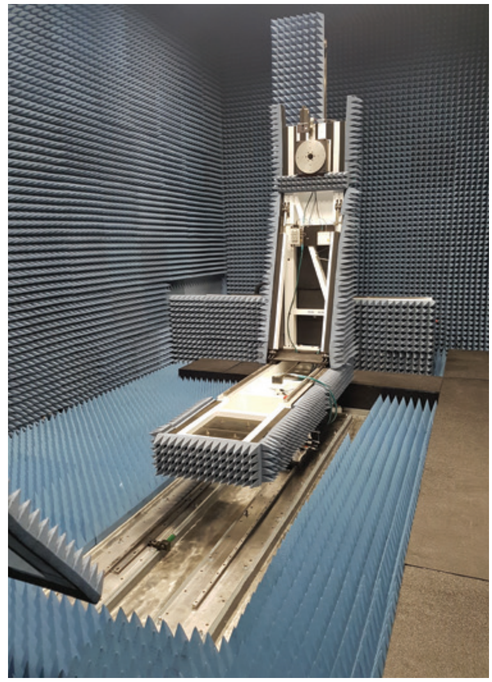

Figure 2: A planar near-field system (the scanner is shown in the back) with an AUT positioner to allow for spherical near-field measurements

As the choice of convention does not matter as long as consistency is maintained, the WG decided to preserve the mix of engineering and physics time conventions in the Standard as foundational references exist using both conventions. Any new material based on commonly accepted practices will be in the engineering time convention. It is important that the convention used in the text is clear to the user of the standard.

In Clause 3 of the Standard, titled "Background," the physics time convention is used predominantly. The rest of the document mainly uses the engineering convention. Mixed time conventions are commonly encountered in antenna measurements. It is particularly important that the system hardware/software implementations have the same convention to avoid erroneous results during near-field to far-field (NFFF) transformation.

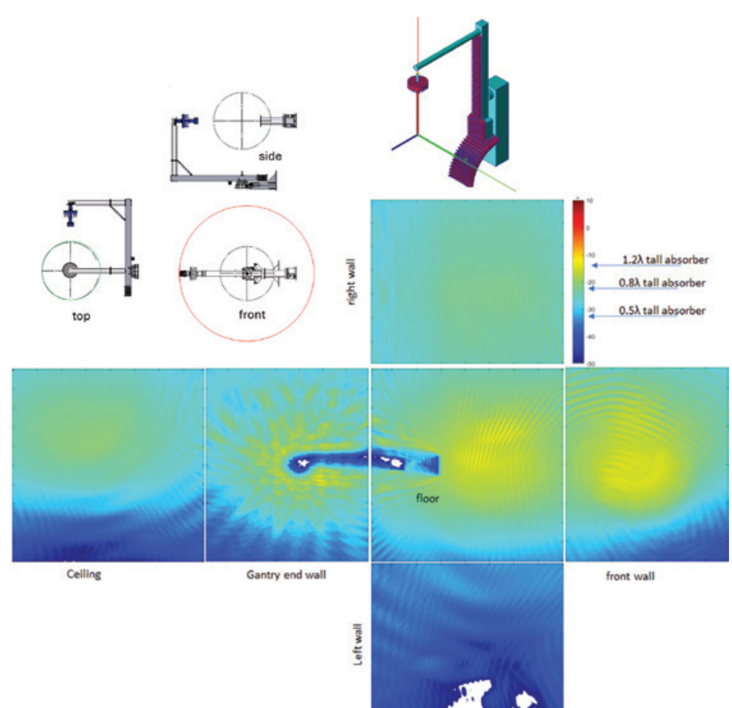

Figure 3: Recommendations for range absorber coverage are now presented in Clause 4 of IEEE 1128. In this figure from the Standard, the illumination of the end wall of the SNF range with moveable gantry is shown.

Clause 4 of the Standard is dedicated to the discussion of measurement systems used in near-field scanning. These systems require a combination of essential components, including a radio-frequency (RF) transmit and receive system, computerized scanning capabilities, data acquisition tools, and analysis software. The practical implementation of mechanical and electrical systems in these measurement setups can vary based on specific requirements, suitability, and the relative importance of various factors. The initial focus is on the acquisition of data on specific geometries, such as planes, cylinders, or spheres (see Figure 2). This provides practitioners with valuable insights into the selection of appropriate scanning systems that align with their specific measurement needs.

An important new addition to Clause 4 is a comprehensive discussion on modern anechoic chamber design, along with corresponding recommendations. This inclusion addresses the significance of optimizing the chamber environment for accurate and reliable near-field scanning measurements.

In the original 2012 version of the Standard [3], there was only a short paragraph on the RF absorber placement. Clause 5.3.1.8 of that version dealt with the absorber placement, but there were no specific recommendations for coverage except for planar near-field (PNF) scanning. Indeed, Clause 5 dealt with PNF scanning measurements. Hence, the only recommendation in Clause 5.3.1.8 of the original version of the standard was to treat the range surface in front of the antenna such that the main beam was maximally absorbed, thus reducing the possibility of a standing wave between the antenna and the end wall that could have cause errors on the measurement.

Much like was done with the IEEE STD 149-2021 [4], the work presented in [7] on the updated version of IEEE Std 1720 is used to provide recommendations for the size and positioning of the RF absorber, not only for the PNF case but for the spherical and cylindrical scanning cases as well.

The recommendations presented aim to reduce the range multi-path to levels that are at least -40 dB lower than the direct path between the probe and antenna under test (AUT). In addition to these recommendations, the Standard points to references in the bibliography where optimizations of the absorber layout can be performed, as demonstrated in [8]. Figure 3 shows the possibility of using numerical methods to evaluate the illumination of the range walls to optimize the RF absorber coverage.

Clause 5 of the standard provides an overview of planar near-field theory along with practical implementation considerations. This method is particularly suitable for measuring antennas with moderate to high directivity. During planar near-field measurements, a probe is scanned over a planar surface located in front of the AUT. To transform the near-field measurements into the far-field domain, a fast Fourier transformer is commonly employed. Planar near-field scanning is commonly employed for high directivity antennas due to the truncation of the scan area. The planar near-field scanning method was the first geometry for which probe correction theory was developed. The probe correction process is performed direction by direction, ensuring accurate and reliable results.

Clause 6 of the standard focuses on NFFF transformation techniques using cylindrical scanning. While this approach introduces a moderate increase in analytical and computational complexity compared to planar scanning, it offers the advantage of reconstructing the complete radiation pattern of the antenna, excluding the regions near the positive and negative cylindrical axes. In cylindrical scanning, the near-field data is acquired along a cylindrical grid and is thus particularly well-suited for fan-beam type antennas. By accounting for the effects of the probe, it becomes possible to accurately determine the far-field pattern of the AUT. Also included in Clause 5 is a brief introduction to advanced scanning techniques aimed at reducing the number of measurement points (and thus measurement time) and the associated processing.

Clause 7 of the standard addresses spherical scanning techniques. It starts by providing a fundamental explanation of the theory behind spherical scanning, highlighting the use of probes with special symmetry properties, specifically the $\mu = \pm 1$ probes. The benefits and advantages of employing these probes are thoroughly explained, emphasizing their significance in achieving accurate measurements. The clause has been further enhanced by an expanded discussion on higher-order probe compensation strategies. By incorporating probe compensation techniques of any order, practitioners can effectively minimize

Figure 4: A planar near-field scanner showing the tower for the vertical scan resting on the horizontal stage for the horizontal motion of the probe

Figure 5: A robot arm-based near-field system that allows for non-canonical arbitrary surfaces to be measured

the impact of probe characteristics and enhance the accuracy of the measured results for a wider variety of probes. This comprehensive coverage of probe compensation techniques ensures that practitioners have the necessary tools and knowledge to perform precise spherical near-field scanning measurements.

Clause 8, titled "Non-regular scanning techniques," encompasses the implementation of non-redundant sampling representations in different canonical scanning geometries such as planar, cylindrical, and spherical configurations. The primary objective of these techniques is to minimize measurement time. Furthermore, this clause also provides guidance on techniques applicable to the growing trend of sampling over non-canonical surfaces, highlighting the increased use of airborne drones and robotic systems for this purpose (see Figure 5).

In Clause 9 of the standard, the selection and calibration of probes for near-field measurement applications are thoroughly discussed. The choice of suitable probes for near-field measurements is crucial as it directly affects the accuracy of the calculated far-field characteristics of the AUT. To ensure precise determination of the far field of an AUT using near-field data, it is essential to account for the probe's influence during the measurement process. This necessitates knowledge of the probe's on-axis gain and polarization characteristics, as well as its co-polarization and cross-polarization patterns.

Clause 9 provides detailed instructions on measuring and determining these probe properties, enabling practitioners to accurately characterize the probe's behavior. The clause offers guidance on selecting an appropriate probe for specific measurement scenarios. Factors such as the scan surface geometry and the desired measurement accuracy are taken into consideration to aid practitioners in making informed decisions regarding probe selection.

Clause 10 of the standard is dedicated to the analysis of gain in near-field measurement systems. Accurate gain determination techniques for near-field measurements are a fundamental challenge. The pursuit for precise gain measurements still revolves around selecting the most suitable gain measurement techniques for a given antenna and measurements scenario. Each technique inherently possesses its own limits in terms of accuracy, influenced by factors such as the measurement setup, environmental conditions, and the necessary equipment.

Additionally, the choice of technique can impact the efficiency and throughput of the measurement setup. Striking a balance between the financial investment required to obtain accurate gain measurements and the desired level of precision remains an ongoing challenge. This clause provides guidance on best practices to help choose the best methodology.

Clause 11 of the standard addresses the analysis of uncertainty in near-field antenna measurements. It serves as a resource for practitioners to understand and address the sources of uncertainty that can arise during the measurement process. The clause has been updated and revised to reflect recent changes and follows standardized procedures in line with widely recognized guidelines.

Clause 12 is dedicated to "special topics," where various themes of relevance to near-field antenna measurements and post-processing techniques are described. Among these are several new techniques that are now widely accepted by near-field antenna measurement practitioners. [4]

Subclause 12.1 covers antenna system testing. This subclause has undergone some significant changes in the recent update. The term "antenna system" describes a device-under-test that consists of one or more passive radiating (or receiving) antennas that are connected to one or more active electronic devices and typically remain connected for the duration of the test. The testing of such systems typically aims at determining the receive and/or transmit power performance parameters of the electronic devices connected to the antenna.

To illustrate what is addressed in this subclause, three example antenna systems are shown in Figure 6.

In configurations where it is difficult or undesirable to separate the active electronics from the passive antenna aperture(s), it is not possible to directly measure some component-level quantities of interest (e.g., aperture gain, transmitted power, receiver noise figure). However, it is possible to characterize combinations of these parameters that can be used to assess system-level performance.

This subclause of the standard describes methods for the measurement of common antenna system parameters of interest when the measurement probe is in the near field of the device under test. Subclause 12.1 provides recommendations on common methods of testing parameters such as equivalent isotropically radiated power (EIRP), saturating flux density (SFD), gain over noise temperature (G/T), effective isotropic sensitivity (EIS), and digital error rates.

CONCLUSION AND NEXT STEPS

The original 2012 version of IEEE Std 1720 expired in 2022 and is currently inactive. A Working Group of the APS/SC was formed to update the Standard, and this article provides an overview of the update and discusses the planned changes.

As of the time this article was prepared, the draft standard is on version P1720/D4. This draft has been reviewed by a small group of knowledgeable

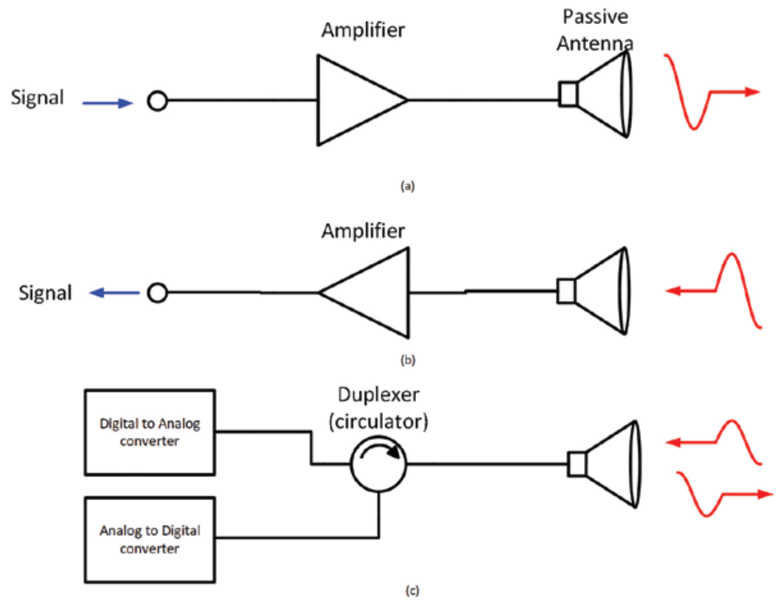

Figure 6: Three antenna systems: a) a transmitting antenna system; b) a receiving antenna system; and c) an antenna system capable of transmitting and receiving simultaneously

practitioners of the art of near-field measurements that have provided valuable comments for incorporation. In order to have time to complete these changes, the chairs of the WG have decided to file a one-year extension and go to balloting near the end of 2024, with the complete updated version of the standard slates for publication in early 2025.

ACKNOWLEDGMENT

The authors would like to recognize the hard work of the entire P1720 WG [5] for their continued dedication to the development of the standard.

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EVALUATION OF AUTOMOTIVE ELECTRONICS PRODUCT DEVELOPMENT PROCESS AND IMPLEMENTATION OF IN-HOUSE EMC DEVELOPMENT TESTING FACILITY

Implementing an Effective Product Development Process

Arnold Nielsen has over 50 years of experience in the automotive electronics industry. He has worked as an instrumentation engineer, powertrain (engine, transmission) hardware/software design engineer and as a Senior Technical Specialist in Reliability, Product Assurance, and EMC. After retiring in 2005, he has consulted on a wide variety of products (Arnie Nielsen Consulting LLC). He is an iNARTE certified Master EMC design engineer and can be reached at arnienielsen@gmail.com.

By Arnold Nielsen

I have spent most of my engineering career (50 years) at an automotive original equipment manufacturer (OEM), a Tier 1 electronics supplier, and as a consultant who has worked with over 40 different companies. I have observed that the quality of the product development process (PDP) and the experience of the design and test staff vary widely among different OEMs and suppliers.

There are a number of factors that impact the efficiency and effectiveness of the development process. Some examples are short design cycles, increasing complexity, staff reductions (including the most experienced people) and cost-cutting. However, there are also a number of things that are holding progress back including "we've always done it this way."

There is such a large test infrastructure (equipment manufacturers, test labs, large OEM/vendor departments) that it is extremely difficult to change the PDP. OEMs all have similar testing specs which must be contractually met - these are minimum requirements. However, there are things that can be done to improve the process.

Many specs were written when automotive electronics represented an emerging technology. Further, environmental and EMC specs have evolved over many years, but these test methods have many limitations that are not appreciated by contemporary practitioners. To cite just one example, simple pass-fail criteria can result in test results that do not reflect real-world concerns and provide only a false sense of security.

No single designer can be expected to have the scope of experience necessary to consider all aspects of a PDP. Instead, such experience is often spread throughout an organization and not concentrated on any one project. Therefore, a holistic approach is required to achieve the best results in an efficient manner.

Although EMC is a very important part of the PDP, it is important for all involved to be aware of all parts of the process. By being informed of the overall process, more insightful, effective, and efficient designs and test plans can be developed. The main goal should be customer satisfaction and avoidance of very costly warranty repairs and recalls.

This article addresses the overall PDP and condenses the lessons that I've learned over many years. The goal is to make the development process more efficient and effective, especially by focusing on the development stage. This includes implementing in-house EMC development testing capability.

PDP OBSERVATIONS

To start, here are some personal observations on the trajectory of the product development process during the course of my career and where we stand today:

1. Originally, reliability for automotive electronics was poor so a lot of tests were "invented." There were minimal design practices for automotive EMC.
2. As product complexity and technology evolve, the traditional "cookbook" approach is not effective at finding and addressing many real-world concerns.
3. Testing methods have many limitations and compromises that may not be appreciated by contemporary practitioners.
4. Much time and money are spent on low-value exercises due to limited knowledge of specification history (practitioners don't know when to "hold or fold").
5. Much testing addresses old issues with limited added value, especially for modules that follow known basic design rules and use mature technology.

6. Different people looking at the same data can come up with quite different conclusions, depending on their background, insight, and flexibility.
7. Test specs/plans mainly "test for success." You cannot maximize information by maximizing success rate. Instead, it is testing failures that serve to maximize information in the development stage.
8. Typical testing is often based on repeatability. However, some testing requires randomness to identify real-world issues.
9. Requirements validation (e.g., hardware, software, EMC, etc.) conducted under ideal conditions does not sufficiently address system interactions. Many tests are idealized simulations of the real world.
10. Testing of production-representative modules frequently occurs late in the design cycle. However, simple testing early in the PDP will help identify issues when they can be addressed efficiently and economically.
11. The test process currently employed by many OEMs is so complex, long, and expensive that it diverts from "play" time to identify bugs early.
12. Meeting specifications alone is not sufficient to mitigate field issues. The main goal is to minimize potential field issues, not just to meet the specifications. (See Figure 1.)

SAE J1938, SAE J2628

The recently published 32-page SAE information report, SAE J1938_202211, "Product Development Process and Checklist for Vehicle Electronic Systems" [1] addresses the many aspects of overall design-process issues for automotive electronic modules. The report (which I co-authored with the SAE's Committee on Automotive Electronic Systems Reliability Standards) serves as a companion document to SAE J2628_201806, "Characterization, Conducted Immunity" [2]. Since it is impossible to be all-inclusive and cover every aspect of the design/validation process, J1938 can be used as a basis for preparation of a more comprehensive and detailed plan that reflects the accumulated "lessons learned" at a particular company.

The following is a condensed Table of Contents for J1938:

1. Scope
2. References
3. Contemporary design-validation perspective
   a. Test-related issues
   b. Test effectiveness example
   c. Cost reduction (CR)
   d. Trouble not indicated (TNI)
   e. Sample sizes
   f. Reliability prediction
4. Robustness validation process (RV)
   a. Preliminary assessment.
   b. Development stage
   c. Design validation (DV) readiness evaluation
   d. Design validation (DV)
   e. Product validation (PV)
   f. Conformity, TNI
   g. Example of RV process results
5. Design checklist for modules
   a. Component selection - 10 sections
   b. Circuit design checklist - 6 sections
   c. Software
   d. Diagnostics
   e. Reparability
   f. Environmental (non-EMC) - 5 sections
   g. Electromagnetic compatibility (EMC)
      - Component (module) level, test requirements
      - PCB layout rules for EMC
   h. Miscellaneous manufacturing process checklist

Figure 1: "But it met specifications!"


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TYPICAL DESIGN AND TEST PROCESS

Some of the major parts of such a process are as follows:

1. Design of the product to meet customer requirements (e.g., analysis, design reviews, etc.)
2. Development testing, usually based on variations of OEM specs*
3. Design verification (DV) testing following OEM specs*
4. Product validation (PV) testing following OEM specs* (can be modified depending on changes to the device under test (DUT) from DV level)

(* Environmental tests typically are hi-lo temp operation, thermal cycle, thermal shock, humidity, vibration, etc. Most OEM environmental-EMC specs are very similar and based on international standards.)

Design reviews are very important, but in practice there is wide variation in the quality of the event. It is difficult to conduct such reviews in today's environment where experienced staff are limited. Detailed reviews (e.g., schematics) between the OEM and vendor are not always conducted since vendors may not want to share what they consider confidential information with those outside their company.

Of all the stages in such a process, development testing is one area in which OEMs can differentiate themselves from competitors. Factors include:

- Providing the maximum flexibility to experiment
- Allowing for sufficient reaction time
- Providing opportunity for early staging where failures maximize information
- Ability to push products beyond specification limits to determine design margins

Development testing may not be a large part of the typical test plan. Typical plans usually focus on verifying that a product functions in a known way within a given set of input conditions (i.e., meets requirements). What is often missed are those other unwanted outcomes that result from complex

Item	Name	Comments
	Characterization	
1	Design Margins	See Figure 2. Reference SAE J2628 (1)
2	Current, normal	Monitor true RMS current during power on-off, T-hi,T-lo,T-ambient. Reference SAE J2628 (1)
3	Current, overvoltage	Monitor true RMS current at 19 V, 24 V, T-hi,T-lo,T-ambient. Reference SAE J2628 (1)
4	Current, reverse battery	Monitor true RMS current at -14 V. good indicator of sneak paths. Reference SAE J2628 (1)
5	Switch Input Noise	Random noise created by chattering relay. Reference SAE J2628
6	Oscillator Function	Momentary short oscillator, verify automatic recovery, T-hi,T-lo,T-ambient
	Failure Modes	
7	Shorts to power and ground	0.3 Ω short (may trick some sensing circuits), monitor current during shorts.
8	Load Faults	Opens, partial shorts in certain loads.
9	Leakage Resistance	Pins tolerant to 50K Ω to power or ground.
10	Sneak Paths, Opens	In system configuration, open power-ground to DUT (at DUT)
	EMC	
11	Conducted Immunity (CI), transients	Use RCB 200N1 transient immunity test generator, more realistic than ISO 7637 transients.
12	RF Immunity	Hand-held transmitters (e.g. cell phone)
13	RF Emissions	Use DSP radio, scan bands and compare results with DUT off then on. Some DSP radios have signal strength and signal/noise indicator.
	Environmental	
14	Moisture Immunity	For non-conformal coated PCB, apply Windex (wetting agent) directly to PCB. Verify no combustion.
15	Mechanical Disturbance	Powered, continuous monitor for intermittent operation: Tap with plastic hammer Drop (15cm) Flex of PCB Wiggle test - wire harness, connectors
16	High Temp Exposure	Monitor suspect hot points (temp probe), hot box if DUT fully enclosed.

Table 1: Development tests, Level 1

(1) Also useful for detecting changes in DUT response (degradation) after subjected to other environmental stresses.

dynamic interactions of hardware/software, timing, throughput, electrical excursions, extreme operation, system interactions, and interfaces.

To be effective, the DUT should be tested in a sub-system configuration using realistic loads and interfaces. This is difficult to do since each module is typically tested independently using simulated loads/interfaces.

Both J1938 and J2628 provide details regarding the type of tests that should be part of the development evaluation, many of which are not included in typical OEM specs. These tests were developed by analyzing actual field issues and devising methods to identify them. There are two levels of such tests:

- *Level 1*: Level 1 tests (see Table 1) are not typically called out in OEM specifications but can provide an early indication of DUT robustness. These tests are best done by the design engineer since results are often not pass-fail and must be interpreted by those intimately familiar with details of the design.
- *Level 2*: Level 2 tests are more complex and are listed under the section "In-House EMC Testing" (see Table 2). Some Level 2 tests are modified versions of those that are typically called out in the OEM spec.

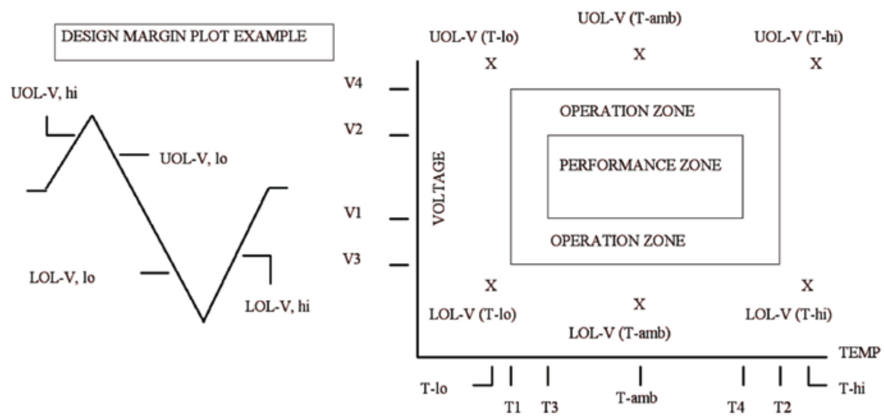

Figure 2: Design margin plot from SAE J2628

Test	Typical OEM Test Method	Development Equipment Examples	Approximate Cost
		Shielded room, Lindgren series 71	Used = 20k
Miscellaneous, used in various tests		Spectrum analyzer, oscilloscope, LISN's, Power supply, battery.	5k
Primary Tests			
1. RE (Radiated Emissions)	CISPR 25, Edition 5, 0.15 MHz-5.925 GHz, dBuv/m (1)	RF signal amplifier, spectrum analyzer, software. (2)	3.5k
2. Conducted Emissions (CE), Voltage	CISPR 25, Edition 5, 0.15-108 MHz, dBuv	LISN, Spectrum analyzer	
3. CE Current	CISPR 25, Edition 5, 0.15-108 MHz, dBua	Current monitoring probe	500
4. Radiated Immunity (RI), BCI	ISO 11452-4, 1-400 MHz	BCI injection probe, calibration fixture, NSG-4070C-45	45k
5. RI, ALSE	ISO 11452-2 80 MHz-18 GHz (1)	NSG-4070C-45. (2)	
6. RI, Coupling	ISO 7637- 3	Teseq CDN-500, RCB 200N1	
Primary Total Cost			70k
Secondary			
7. Conducted Immunity (CI): Sine, transients, interruptions, power dips	ISO 16750-2	Sig gen, arb gen, DC power amplifier	150k
8. ESD	ISO 10605	ESD simulator	20k
Secondary Total Cost			>170k

Table 2: Summary of pre-compliance implementation; many OEMs use variations of these tests

(1) Development lab may not be able to cover an entire frequency range.

(2) OEM method not practical for development (requires anechoic chamber), use open sided TEM cell, parallel plate or antenna. Useful up to about 1 GHz which covers most issues.

The EMC design and testing process can be time-consuming, inefficient, and costly. EMC issues are often identified during qualification testing in an accredited EMC testing lab late in the design cycle.

EMC PART OF THE PROCESS

EMC specification limits are all idealized simulations of the real world. Many specification setups and limits create a situation much worse than what would typically be experienced in a vehicle (could be considered as over-testing to maintain a safety margin). Reference 3 gives the history of an EMC specification for one major OEM. It addresses the quality of the event, the chance of success, and a summary of the many tests (origins, setups, limitations, etc.).

A few examples of EMC testing considerations that may result in undetected issues include:

- Not preconditioning the DUT before majority of EMC testing (i.e., DUT not subjected to other environmental stresses such as thermal cycling/shock, high temp exposure, ESD). These other stresses can "weaken" the DUT (e.g., electrolytic capacitor degradation), and is logistically difficult to assess.
- Not testing subsystem configurations. Each component of a subsystem may be tested separately (separate vendors) and may not represent the interactions that occur when tested as a realistic subsystem. This is difficult to implement since each DUT supplier usually does not want to share details of their design.
- Due to high testing costs and time restraints, it is often not possible to test the DUT in all possible operating modes and supply voltages, and the evaluation must rely on a thorough analysis.

The EMC design and testing process can be time-consuming, inefficient, and costly. EMC issues are often identified during qualification testing in an accredited EMC testing lab late in the design cycle. To develop a cost-effective solution may take a lot of time. However, many accredited EMC labs may be fully booked, have long lead times, and are expensive (typically > $2k per day). To run a full qualification test on a product with multiple operating modes can easily exceed $100k.

IN-HOUSE EMC DEVELOPMENT TESTING

Major suppliers to automotive OEMs typically have extensive in-house capability, but smaller suppliers may not. Setting up an in-house pre-compliance test

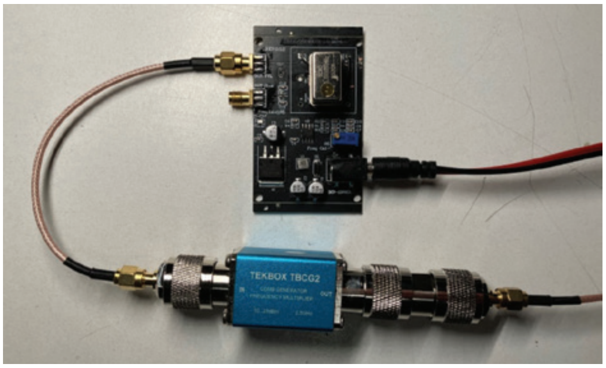

Figure 3: Comb generator components

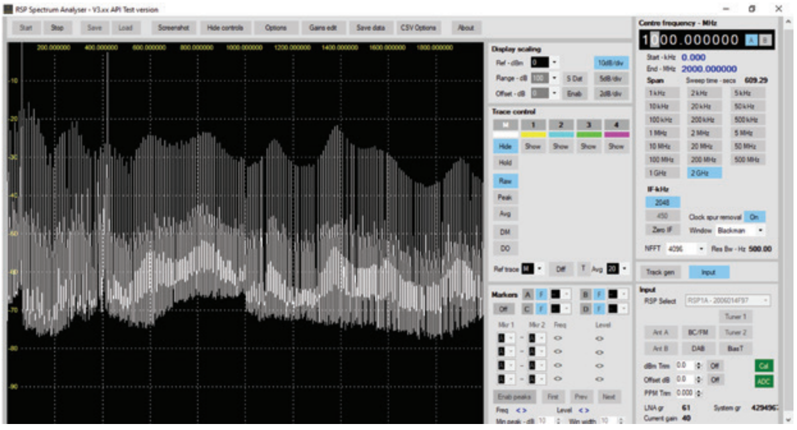

Figure 4: Comb generator output up to 2 GHz

facility can improve first-pass qualification success and can be used early in the design cycle to identify potential issues before formal lab testing. Identifying issues early allows maximum flexibility to experiment and sufficient reaction time before a design is frozen and difficult to change.

This article includes specific details regarding the cost of setting up such a facility at an automotive OEM whose main products are headlight and taillight assemblies. Implementation can be separated into two parts:

1. Primary test characteristics:
2. High frequency
3. Many issues occur in these tests
4. Resolving can be lengthy so need in-house facility

Secondary test characteristics:

1. Low frequency (except ESD)
2. Equipment expensive
3. Minimal test time
4. Does not require a shielded enclosure
5. If an issue is discovered, a fix is often easy to identify (e.g., using an oscilloscope to troubleshoot)
6. Can be performed without resorting to an outside EMC lab

RADIATED EMISSIONS AND IMMUNITY TESTING

Comb Generator

For evaluating radiated emissions (RE), a comb generator is useful to determine test cell response. Figure 3 shows one inexpensive way to implement a comb generator. It consists of a TTL 10 MHz oscillator driving a Tekbox TBCG2. The rise times of the TTL oscillator are not fast enough to produce a broad spectrum, but the TBCG2 contains step recovery diodes which create a much broader spectrum. Figure 4 shows spectrum analyzer results for the TBCG2 output.

Open-Sided TEM Cell

This is one option that can be bought for about $1k (Tekbox TBTC3). However, it has limited test volume, and a plate separation of about 15cm, which may be an issue for larger DUTs. This was the case for some products such as headlight assemblies (see Figure 5).

Figure 5: Headlamp assembly, rear view

Parallel Plate

This was implemented by removing the center plate from the aforementioned open-sided TEM cell and modifying the end terminations (see Figures 6 and 7). Reference 4 addresses this issue. Although that paper only covers up to 150 MHz (per EN 55020, EN 61000-4-20), it is useful up to 1 GHz for development. However, doing so provides a challenge since the impedance theoretically becomes 100 ohms instead of 50 ohms (Reference 5). Although RF high power for radiated immunity (RI) terminations are readily available for 50 ohms, 100 ohm high power ones are not.

For better matching terminations, Figure 8 shows an L-pad and 100 ohm implemented by 100 ohm high power RF resistors. 100 ohm was used as compromise and is more readily available. Even without terminations to better match both ends, it is useful with standard 50 ohm. Figure 9 shows results of RE for the comb generator.

It is important to position the parallel plate (PP) on a non-conductive table (not on a ground plane). Reference 6 shows how the area surrounding a TEM can affect the results. But for development testing purposes, such limitations can be tolerated since we are only looking for differences. The use of a screen room is not critical for RE. The setup consists of a 50-ohm termination on one end and a direct feed to a spectrum analyzer on the other end.

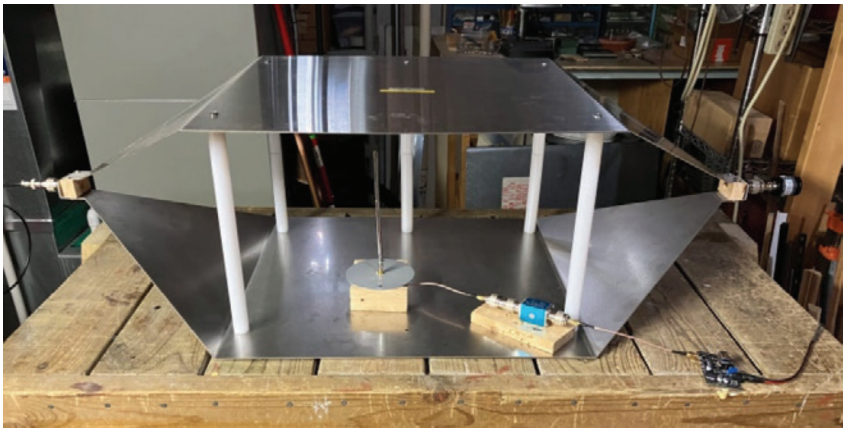

Figure 6: Parallel plate with comb generator setup

Figure 7: Parallel plate termination modification detail

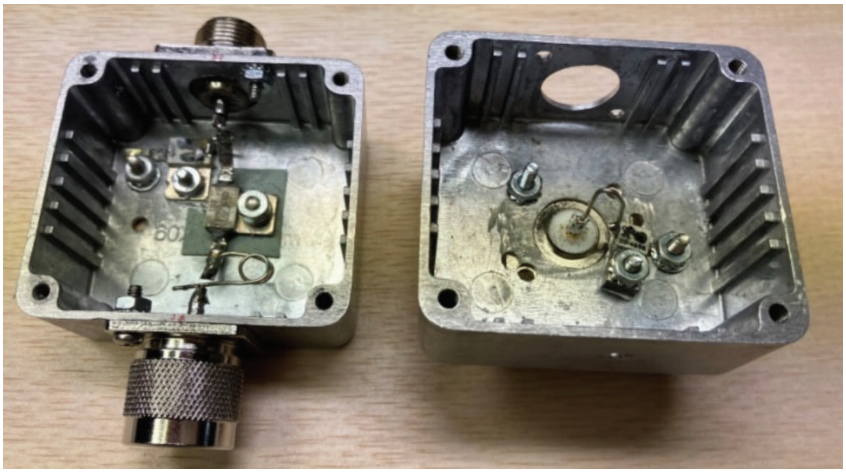

Figure 8: PP terminations; left = L-pad, right = 100 ohm

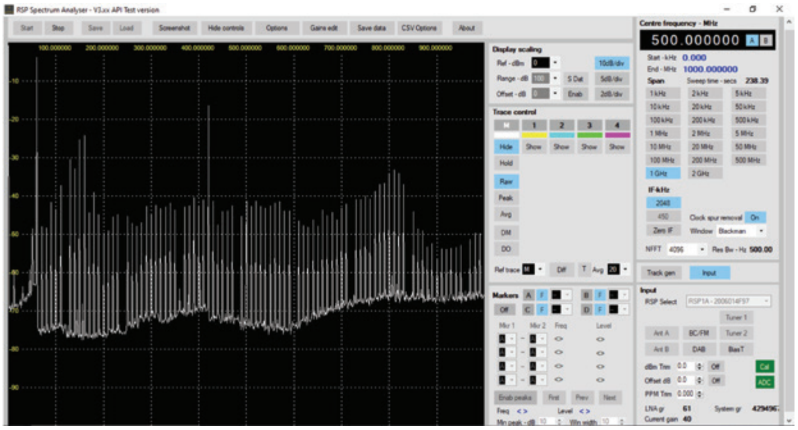

Figure 9: PP comb generator RE results

For RI, field strengths approaching 100v/m can be achieved with a 40-watt amplifier such as a NSG C4070-45 signal generator and power amplifier. Use of a shielded enclosure is required to prevent interference with surrounding communications.

PCB Log Periodic

This is based on Reference 7 by Ken Wyatt. Figure 10 shows the RE comb generator setup and Figure 11 on page 36 shows the results are good in the antenna specified range of 400-1000 MHz. The antenna can also be used for RI. Reference 8 states that the antenna can easily take 100 watts at 400 MHz. In the antenna data sheet, a table of frequency vs. antenna factor is given, and using online calculators (e.g. A.H. Systems), field strengths exceeding 50 v/m at 0.75 meters require only about 20 watts.

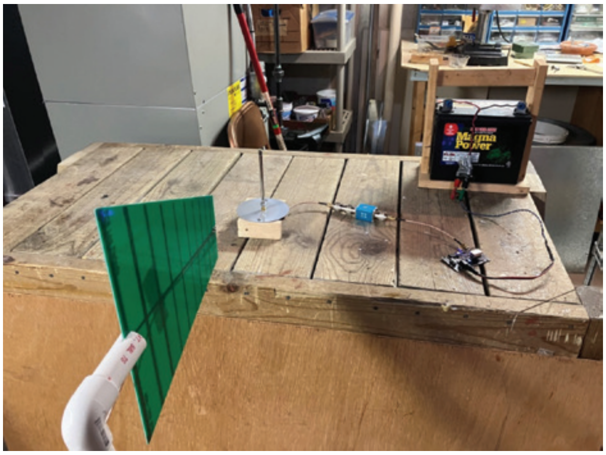

Figure 10: PCB log periodic setup; rod = 5 inches, distance = 10 inches

ACKNOWLEDGMENTS

Much of the information regarding implementation of a development EMC test lab was done at Flex N Gate in Allen Park, Michigan with the help of Monesh Hazari.

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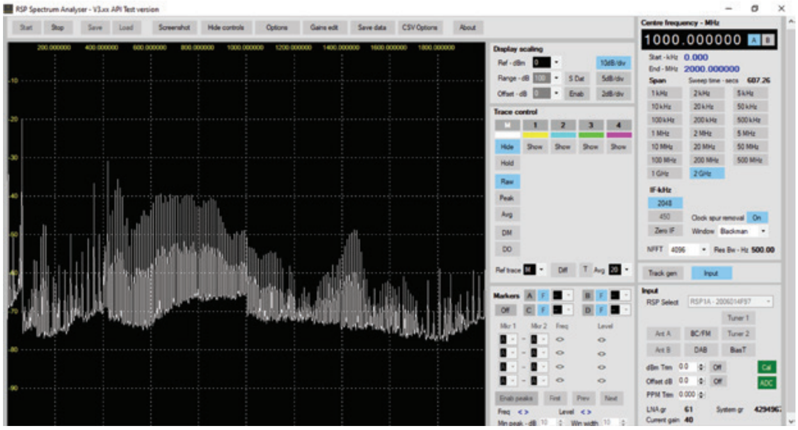
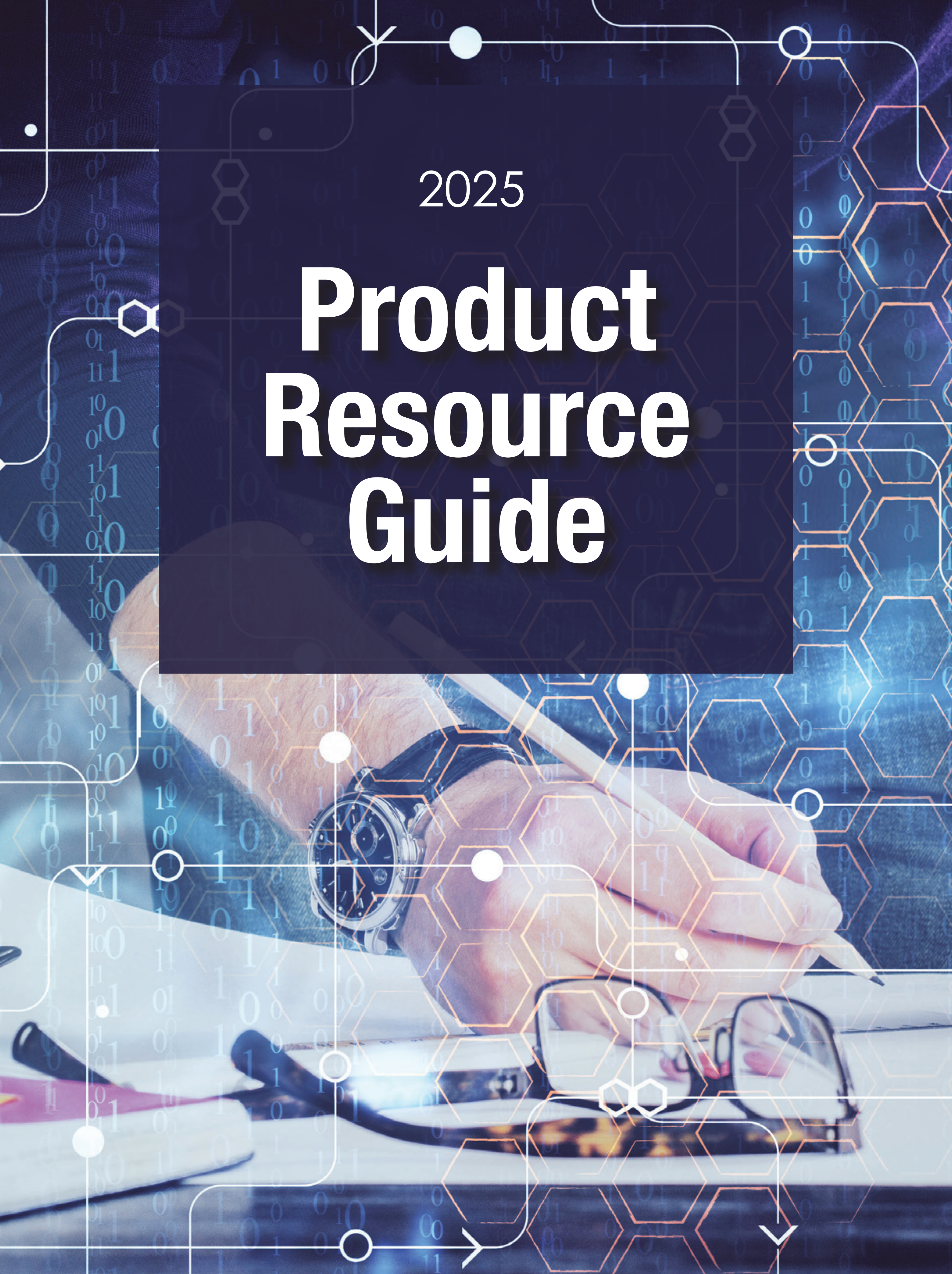


Figure 11: Comb generator RE results up to 2 GHz

2025

Product Resource Guide



ABSORBING MATERIALS

Enhancing EMC with Informed Ferrite Application

BY DON MACARTHUR

During critical moments, like when you're racing against a tight deadline and your product fails an EMC emissions test, have you ever turned to ferrite beads or other RF-absorbing materials to suppress unwanted RF emissions? Sometimes, despite our hopes, these ferrite beads don't seem to work as expected. In those moments, we playfully dub them 'prayer beads,' hoping for a miraculous solution. However, perhaps the issue lies not with the ferrite itself but with our understanding of how and when they are most effective.

Background Information

Before delving into the intricacies of why ferrites often fall short of our expectations, let's start with a brief review of what ferrites are and how they function.

A ferrite bead, also called a ferrite choke or ferrite core, serves as a passive electronic component used for noise suppression and filtering in circuits. It achieves this by dissipating high-frequency currents within a ferrite ceramic. When installed on power pins of digital circuits, ferrite beads effectively suppress high-frequency signals.

Ferrites consist of alloys containing iron/magnesium or iron/nickel. These materials are selected for their high permeability at high frequencies and high impedance. At low frequencies, ferrites primarily exhibit inductive behavior; at high frequencies, they behave predominantly as reactive components. Conceptually, they can be considered a parallel combination of a resistor and an inductor, dissipating high-frequency energy in the form of heat.

Ferrite beads find applications in three main areas:

- External Cabling: Large ferrite beads are commonly used on external cables.
- Internal Circuits: Smaller ferrite beads are employed internally around pins of components such as transistors, connectors, and integrated circuits.
- DC Conductors: Beads can block low-level unintended radio frequency energy on wires intended for DC signals.

Reasons Why They May Not Work When We Need Them To

Ferrite beads may not always meet expectations due to several factors:

- When attempting to suppress noise using a ferrite bead, we often find ourselves in a situation where we don't fully understand the source of the noise. In such cases, we're essentially guessing its location.

  In a recent personal experience, I encountered two different end-products that incorporated similar TFT liquid crystal displays. Both devices exhibited excessive RF emissions in the 30 to 50 MHz range. Attempts were made to suppress these emissions by placing a properly selected ferrite sleeve around the display's I/O cable. Interestingly, the outcomes differed significantly:

  1. First Case: The ferrite effectively did its job, reducing emissions below Class B levels.
  2. Second Case: Surprisingly, nothing changed. The ferrite appeared ineffective.

Upon investigation, it became clear that the source of emissions in the second case was not the display itself, nor did they radiate from the display's cable. Instead, they originated from another source entirely. Consequently, the ferrite's lack of effectiveness was justified.

Side Note: In the first scenario, high-frequency probing techniques were employed to successfully pinpoint the problematic display I/O cable. However, in the second case, no efforts were made to identify the precise source of emissions.

- Circuit impedance is too high.

  A ferrite bead or choke behaves like a lossy inductor. Consequently, it is effective primarily between low-impedance circuits. If placed in a high-impedance circuit or transmission line, it provides minimal attenuation.

- An application note or other outdated advice may contain errors.

  Perhaps you've followed conventional wisdom and added a few ferrites to your design as a precaution. However, the current advice suggests refraining from adding ferrites unless you're specifically addressing a problem. When attempting to create proper filtering in the power delivery network (PDN) on a printed circuit board (PCB), adding ferrites can inadvertently disrupt the network's impedance. The ferrite's impedance may resonate with the network's capacitance, leading to significant voltage spikes. By adding the ferrite, you prevent digital circuits on the PCB from drawing power at high frequencies. Interestingly, this wasn't a concern a decade ago where the ferrite's gain at resonance wasn't a problem.

Pro Tip: If you need filtering in a PDN, there are better options available:

1. Use a π-filter with inductors and capacitors.
2. Use an RC filter with resistors and capacitors.
3. Use an inductor instead of a ferrite.

- The incorrect ferrite was used.

  Typically, when we use ferrites to address a problem, it's for a specific frequency range. Various materials are employed to make ferrites, each offering attenuation over specific frequencies. Haphazardly grabbing any available ferrite from the test lab and hoping for the best can lead to errors. It's crucial to invest extra time in researching and selecting the right ferrite material tailored to your specific situation.

Summary

The era of casually slapping a ferrite onto a circuit and expecting miracles is behind us. Ferrites are intricate components that require thoughtful consideration to achieve the desired performance. Interestingly, there are cases where adding ferrites can exacerbate noise issues. However, when used appropriately, ferrites remain valuable tools that will perform as we expect.

Resources

1. Montrose, M.I., *EMC and the Printed Circuit Board: Design, Theory, and Layout Made Simple*, IEEE, 1999.
2. Altium Academy, "Ferrites in PCB Design: What the Experts Say."
3. Altium Academy, "Ferrites as a Filtering Element - Are They Effective?"
4. Altium Academy, "Ferrites in Power Delivery Networks - Part One."
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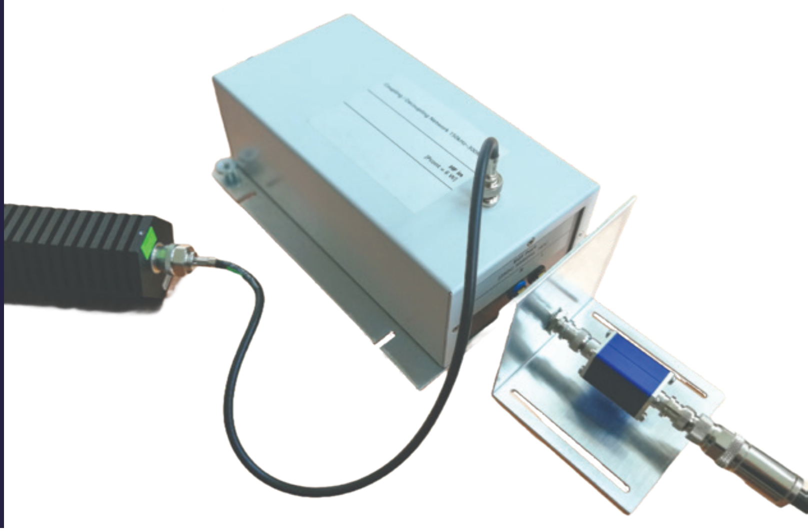
AMPLIFIERS

Amplifier Operational Classes and Important RF Amplifier Specifications

BY DON M^AC^ARTHUR



Because the typical RF amplifier costs a considerable amount of money, it is important to gain at least a rudimentary understanding of amplifier operational classes and other important specifications before selecting one for a specific application. Not performing some type of "due diligence" could cost dearly. As such, the following provides rudimentary knowledge and additional references should one decide to dig deeper into this very important subject.

Pro Tip: No matter what – always carefully read the datasheet/specifications before deciding to purchase any amplifier!

Amplifier Operational Class Types

Some of us with education or backgrounds in electrical/electronics may recall studying transistor bias modes or the percentage of the time during which the amplifier is "amplifying" or conducting power and different operational classes of amplifiers. The idea is the same here:

- Class A: Conducts over the entire (360°) of the input power cycle.
- Class B: Conducts (with large nonlinearities) over half (180°) of the input power cycle. Not suitable for RF applications.
- Class C: Conducts over less than half (< 180°) of the input power cycle. Primarily used for pulse applications and not addressed in this article.
- Class A/B: Compromise between Class A and Class B where the conduction angle is intermediate; each of the two active elements conducts more than half the time.

From the above list of amplifier operational class types, the two most widely used in RF applications are Class A and Class A/B.

Class A and Class A/B Amplifier Types, Pros and Cons

Class A amplifiers provide the most accurate reproduction of the input signal, have lower harmonics, have no cross-over distortion, and are robust to any impedance mismatches between their outputs and the load (VSWR). However, Class A amplifiers are less efficient, requiring greater power requirements and producing more heat than their Class A/B counterparts.

Specification	Class A	Class A/B
Linearity	Excellent	Poor
Harmonics	Low	High
Cross-over distortion	None	Present
VSWR Capabilities (High reflected power conditions can damage the amplifier)	Excellent (Implemented with hardware)	Poor (Software controlled VSWR foldback protection required)
AC Power Requirements	High	Low
Efficiency	Low	High
Junction temperatures	High	Low
Size	Medium to Large	Small

On the other hand, Class A/B amplifiers are more efficient, produce lower junction temperatures, and are physically smaller than their Class A counterparts. However, Class A/B amplifiers do have some drawbacks. These drawbacks include less-than-ideal linear performance, susceptibility to damage from mismatches between their outputs and the load (VSWR), and can suffer from cross-over distortion.

Other Important Amplifier Specifications

Other important specifications to consider include gain (dB), gain flatness (+/- dB), harmonics (dBc), saturated power (dBm), linear power (dBm), and load Voltage Standing Wave Ratio (VSWR).

Linear Power (P1dB)

Although it is very important to pay attention to all of these specifications in relation to your application, one of the most important to understand is linear power, also known as P1dB. This specification is described as the output power at which the gain has varied by +/- 1dB from its small signal level. If the gain varies by more than +/- 1dB, then the amplifier is not able to reproduce the input signal faithfully, and the signal integrity of the output waveform is suspect and cannot be relied upon. In some instances, this may be okay, but it is not in other areas, such as fully compliant EMC testing to RF immunity standards like IEC 61000-4-3.

Voltage Standing Wave Ratio (VSWR)

Another important specification when researching RF amplifiers is Voltage Standing Wave Ratio or VSWR. When connecting an amplifier's output to a load, the ideal condition is when the impedance of the output matches the input. When both impedances match, the load absorbs all the power generated by the amplifier, and none is reflected into the amplifier. The problem is that this ideal condition does not exist in real life. The load to the amplifier is typically an antenna, and the input impedance changes depending on frequency. If the VSWR is severe enough (load is completely open or short), then the amount of power reflected into the amplifier is extreme and damages it, rendering it inoperable until repaired. Even when used with extreme care, preventing connection to high VSWR loads is nearly impossible. It is, therefore, important that amplifier manufacturers design their amplifiers to handle (continue to operate without damage) situations where VSWR is severe.

Summary

In summary, this article has covered why amplifier class is important depending on the application and reviewed the pros and cons of Class A versus Class A/B amplifiers. It further described the meaning and usefulness of P1dB and Voltage Standing Wave Ratio capabilities when choosing an RF amplifier.

References

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2. Amplifier Research, *Orange Book of Knowledge*, 9th Edition.

Tips for Selecting AMPLIFIERS

Determine the frequency range of operation needed, sometimes more than one amplifier is required.

Determine if you need a Pulse or CW type of amplifier. Example: HIRF EMC applications require high power pulse amplifiers.

Determine the minimum acceptable linear or saturated power needed from the amplifier. Harmonics should be considered based on the frequency range. Example: As you go up in frequency antenna gain improves so a lower power amplifier may be acceptable but the higher gain of the antenna may affect the Harmonic Level.

Assess the system losses between the amplifier and the antenna/DUT. Example: If the test setup has 6dB of losses then the Amplifier power needs to be 6dBm higher.

Some modulations if required for the test application, would require a higher power amplifier. Example: When performing an 80% AM modulation test the amplifier needs to have 5.1dBm of margin to accommodate the peak.

Antennas, cables, DUTs, and rooms have cumulative VSWR, it is best to allocate for some power margin. Example: working into a 2:1 requires 12% more forward power.

Consider the application, is this a single test or will it be used repetitively?

Consider your desired RF connection types and locations to be optimal for your application.

Consider if automation will be used so the appropriate remote capability is included.

Courtesy of

EXODUS ADVANCED COMMUNICATIONS

ANTENNAS

Antenna Factor

BY DON M[AC]ARTHUR

There are many properties of antennas used to describe their performance. These include gain, directivity, beamwidth, radiation resistance, polarization, input power, VSWR, antenna factor, etc., to name a few. Out of all these properties, antenna factor (AF) is most useful to those performing electric (E) field radiated emissions measurements. The following describes why.

Definition

Before going much further, let us define what AF is, assuming a 50 Ω measurement system (a valid assumption since 50 Ω is standardized worldwide throughout the EMC measurement community). According to reference 1, AF is the ratio of the magnitude of the E-field incident upon a receive antenna divided by the voltage developed at the antenna's coaxial connector.

To calculate AF, two pieces of information are required: 1) λ, which is wavelength in meters, and 2) antenna gain (G) as a power ratio. Once this information is known, then AF is calculated using this basic formula:

$$AF = \frac{9.734}{\lambda\sqrt{G}}$$

Why is Knowing the Antenna Factor Helpful?

Since AF is a voltage ratio, it is more convenient to use it instead of gain when calculating E-field emissions received by the measurement system during a radiated emissions test.

Recall that the purpose of the antenna in a radiated emission test is to couple the E-field emanating from the equipment under test (EUT) to the measuring device (measuring receiver or spectrum analyzer). Since E-field strength limits are provided in terms of volts per meter (at a specific distance from the EUT), and the measuring device is calibrated in volts, then the antenna must be calibrated in terms of volts output for a given E-field strength at each test frequency. Makes perfect sense, right?

> **Pro Tip:** Think of AF simply as a loss that the antenna introduces into the measurement that must be added back into the calculation that provides the correct E-field value emanating from the EUT.

AF, specified in dB/m (decibel per meter), is the antenna calibration mentioned in the previous paragraph. The antenna manufacturer provides it as a table of dB/m versus frequency, so it is convenient to plug its value into the calculation that obtains the E-field strength from the measured voltage. It is a necessary element of conducting a valid radiated emissions test. AF is simply a way to convert measured voltage in dBμV to measured E-field strength in dBμV/m. The value obtained is then easy to compare with the E-field limits specified in FCC, CISPR, IEC, MIL, and other standards.

Converting Measured Voltage to E-field Strength

To obtain the desired E-field strength at a particular frequency, three pieces of information are required: 1) the voltage in dBμV obtained from the measuring device; 2) the AF provided in dB/m (provided by the antenna manufacturer); and 3) the cable loss (CL) in dB of the coaxial cable connecting the output of the antenna to the input of the measuring device (self-explanatory).

Given a value in dBmV obtained from the measuring device, an AF in dB/m from the antenna calibration report, and cable loss in dB, then the E-field (E) in dBμV/m emanating from the EUT is easily calculated as follows:

$$E\ (dB\mu V/m) = V\ (dB\mu V) + AF\ (dB/m) + CL\ (dB)$$

E (dBμV/m) is then compared with the specified limits to determine if the EUT complies with the requirements or not. Due to uncertainties in the measurement from test facility to test facility, adding some margin to E (dB(V/m) result obtained is highly recommended to help ensure all products tested in different facilities and at different times pass emissions testing. The amount of margin is an internal management decision.

> **Pro Tip:** Apply 6 dB for Class A limits and 3 dB for Class B.

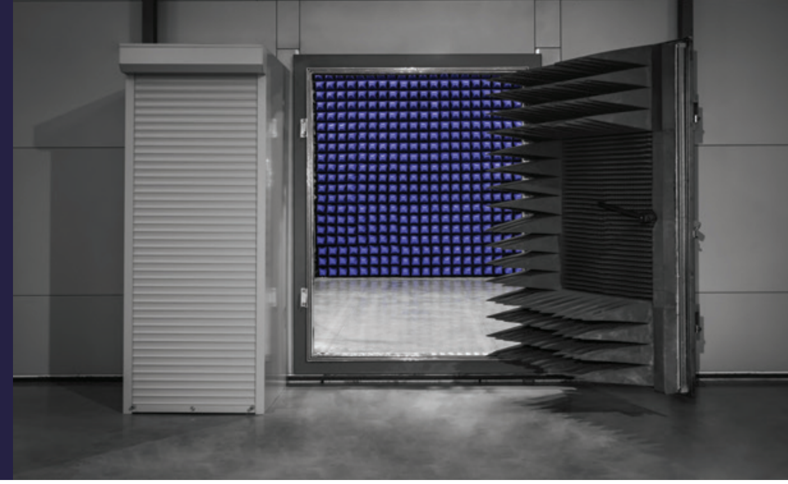
Summary

Antenna factor is one of the most important properties of antennas used for radiated emissions measurements. It is a calibration provided by suppliers of antennas used in EMC measurements. It provides a convenient way of calculating the E-field strength obtained from a voltage measurement, making it easy to determine whether a product complies with the limits.

CHAMBERS

The Sources of Uncertainty in Radiated Emissions Tests

BY DON MACARTHUR



Radiated emissions tests are crucial for ensuring that electronic devices comply with electromagnetic compatibility (EMC) standards. However, several sources of uncertainty can affect the accuracy and reliability of these tests. These sources of uncertainty are described briefly in this article.

Measurement Equipment

Variations in the performance of antennas, receivers, and other test equipment can introduce uncertainty. Calibration and maintenance of these instruments are essential to minimize this uncertainty.

Test Environment

The physical environment where the test is conducted, such as an anechoic chamber or open area test site, can impact results. Factors like reflections from nearby objects, ambient electromagnetic noise, and temperature fluctuations contribute to uncertainty.

Test Setup

The positioning and orientation of the device under test (DUT) and the test equipment can affect measurements. Consistency in setup is crucial to reduce variability.

Operator Skill

The experience and skill of the test operator can influence the outcome. Proper training and adherence to standardized procedures help mitigate this source of uncertainty.

Device Variability

Differences in the equipment under test (EUT or DUT) itself, such as manufacturing tolerances and component variations, can lead to inconsistent emissions.

External Interference

Uncontrolled external electromagnetic interference from other devices or sources can affect the test results.

Uncertainty Versus Error

Uncertainty is not the same as error. Uncertainty is the upper limit for expected measurement error (error < uncertainty), as shown in Figure 1.

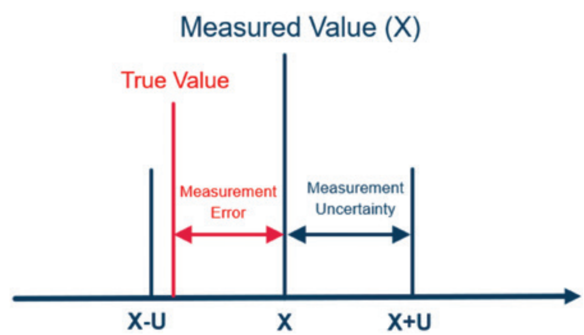


Figure 1

Measurement Uncertainty Budget

Professional test laboratories document the sources of uncertainty in their radiated emissions test setups in what is called an uncertainty budget. The data is usually input into a spreadsheet or other similar program which not only helps keep things organized but also allows for easy computation of values. The measurement uncertainty budget includes a list of contributors or sources of uncertainty (as described above), measurement system repeatability, the value of uncertainty, the probability distribution (rectangular, normal, triangular, U-shaped, etc.), the divisor associated with the probability distribution, the result of dividing the value by the divisor (μ_i) – this is called the "standard uncertainty" and it is uncertainty of an individual measurement result, expressed as a standard deviation, and the result of the division squared (μi^2).

All the μ_i's are root-sum-squared to obtain a "combined standard uncertainty" (μ_c). This is the uncertainty that results from combining all individual uncertainties (μ_i's).

$$u_c = \sqrt{(u_1{}^2 + u_2{}^2 + u_3{}^2 + ux^2 + \ \dots)}$$

Tips for Selecting CHAMBERS

Since chamber selection is primarily driven by testing requirements, clearly define applicable test standards, operating frequency range, and whether the chamber will be multi-function.

Consider the shape, size, weight, type, and heat generation of devices intended to be tested. Ensure that the chamber dimensions can comfortably accommodate the devices under test.

If the chamber will be installed in an existing facility, choose a layout that conforms to space limitations and constraints imposed by the parent room.

A chamber manufacturer can help navigate local permitting requirements, fire suppression systems, seismic approvals, structural supports, emergency features, safety systems, and design for extreme environmental conditions.

The type, size, placement, and number of RF shielding doors should be decided based on frequency of personnel access and the expected movement of devices under test.

Explore options for chamber accessories and test equipment including turntables, antenna masts, test tables, crane or hoisting systems, shielded cameras, ramps, and more.

Assess connections to the parent building for electrical, HVAC, and fire suppression systems.

Determine if a control room, raised floor, or other custom configuration is required for cable management.

A modular chamber design that allows for customization, expansion, upgrades, or potential relocation, can help expand test capabilities and adapt to future needs.

To extend the usable lifetime of the chamber and to ensure performance, regular preventative maintenance and chamber validation testing are essential.

Courtesy of

RAYMONDEMC

An "expanded uncertainty" (U) is then calculated using a coverage factor (k), which is typically set equal to 2. The result of the uncertainty calculation is reported in terms of a confidence interval.

If you're already familiar with the normal distribution and standard deviations, then the coverage factor (k) is the same as the Z-score. A Z-score of 2 means there is a 95.45% probability that the true value obtained lies within the limits. In the metrology world, since calculating measurement uncertainty is just an estimate anyway, we just round down to 95% when we specify k = 2. $U = k * \mu_c$.

Here are some other values for k:

- k = 2 results in a 95% (or more precisely 95.45%) confidence interval
- k = 2.6 results in a 99% confidence interval
- k = 3 results in a 99.7 % confidence interval

From personal experience, the two distributions shown in Figure 2 are the most widely used in measurement uncertainty analysis.

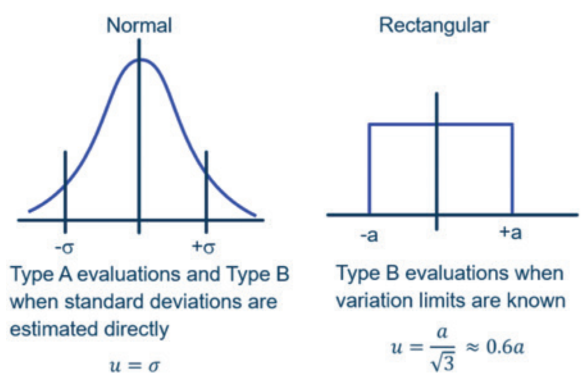


Figure 2

Note: Probability density refers to the shape of the distribution or more precisely the change in probability as we move away from the mean value. With a normal distribution, the probability decreases with deviation from the mean, while with the uniform distribution the probability remains constant up to the limit where it sharply falls to zero.

Expanded Uncertainty (U) Visualized

Figure 3 is what the expanded uncertainty (U) looks like with the coverage factor k included:

Expanded uncertainty (U): Often written with ± sign in front so it takes the same form as a tolerance or specification. Use divisor k to yield a quantity expressed as equal to one standard deviation ($\mu_c = U / k$).

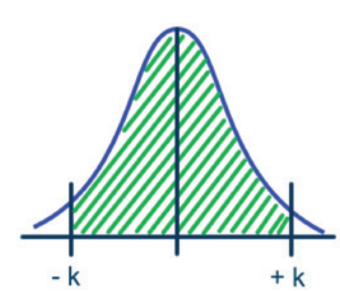


Figure 3

Measurement Uncertainty Notes Section

Some say that the most important part of the uncertainty budget is the notes section. This is where you document your thought process and how you made the decision to include or exclude certain sources of uncertainty. If you're going through an audit, the assessor will likely ask you about how you developed your uncertainty budget and the notes section is a good way to remind yourself why you decided to do certain things the way that you did.

Measurement Uncertainty Training

Figuring out all the sources of uncertainty and then calculating the total measurement uncertainty for any type of measurement is a complex topic, too deep to fully cover in this brief article. If you're interested in learning more, the following entities provide some excellent in-depth training:

- Rick Hogan (highly recommended)
  https://www.isobudgets.com
- HN Metrology Consulting, Inc.
  https://www.hn-metrology.com
- A2LA Workplace Training
  https://a2lawpt.org/training?gad_source=1
- QuametecTM Institute of Measurement Technology
  https://www.qimtonline.com

See also the references and further reading for more information.

Summary

Understanding and controlling sources of uncertainty is vital for obtaining reliable and repeatable results in radiated emissions testing. Calculating measurement uncertainty is an important skill that most compliance professionals should carefully consider adding to your 'bag-of-tricks."

Resources

1. Williams, T., *EMC for Product Designers*, 5th Edition, Newnes, 2017.
2. Fluke Corporation, *Calibration: Philosophy in Practice*.
3. Certified Calibration Technician Primer by Quality Council of Indiana.
4. Measurement Uncertainty Analysis Fundamentals by James D. Jenkins.
5. The Metrology Handbook, 2nd or 3rd Editions.

COMPONENTS

Non-Ideal Behavior of Passive Components

BY DON MACARTHUR

Parasitics refers to undesirable characteristics and unwanted effects that deviate from ideal behavior in electronic components and circuits. These characteristics are often modeled using equivalent lumped elements, which include Resistance, Capacitance, and Inductance.

It is crucial to account for their non-ideal, parasitic characteristics when using passive components to mitigate electromagnetic interference (EMI). You might encounter situations where you initially attempt to employ a component to suppress an unwanted signal, only to discover that it does not yield the expected results. This discrepancy often arises due to the component's non-ideal behavior.

For instance:

- Beyond their self-resonant frequency, capacitors cease to function purely as capacitors and start behaving more like inductors.
- Conversely, inductors may exhibit capacitive behavior above their self-resonant frequency.

In your exploration of system components for EMI management, understanding how each behaves beyond its self-resonant frequencies is essential. This knowledge ensures that you recognize when a component no longer adheres strictly to its ideal characteristics as a capacitor, inductor, or resistor.

The following outlines the parasitic behavior exhibited by a select few passive components:

Wires

Wires, often underestimated, wield substantial influence over circuit performance. The internal impedance of a long cylindrical conductor—such as a wire—hinges on factors like radius, permittivity, permeability, and conductivity. When scrutinizing these conductors, we observe deviations from ideal models due to material properties and construction techniques. These natural deviations occur beyond the scope of commonly accepted approximations.

At radio frequency (RF) levels, the skin effect becomes significant. High-frequency AC currents predominantly flow on the outer layer (skin) of wires, increasing AC resistance. Remember that this phenomenon also manifests in other components constructed with wires, including inductors, transformers, and common mode chokes.

Transformers

While ideal transformers are a theoretical concept, real-world transformers exhibit parasitic resistances, inductances, and capacitances.

These parasitic elements arise due to the physical construction of transformers and their materials.

Here are some key aspects of the non-ideal behavior of transformers:

- **Resistance (Rp and Rs):** The winding resistance in both primary (Rp) and secondary (Rs) coils contributes to power loss and affects efficiency.
- **Leakage Inductance (Llk):** Some magnetic flux does not link both windings directly, leading to energy losses.
- **Magnetizing Inductance (Lm):** This inductance is essential for energy transfer but can also introduce non-ideal effects.
- **Core Loss (Rc):** The magnetic core material experiences hysteresis and eddy current losses.
- **Self-Capacitance (Cp and Cs):** Capacitance between windings and within each winding affects high-frequency performance.
- **Primary-to-Secondary Capacitance (Cm):** Inter-winding capacitance influences frequency response.
- **Core Materials:** The choice of magnetic core material greatly impacts transformer performance. Materials like powdered metals, ferrite ceramics, and air allow optimization for various applications but introduce non-ideal effects

Due to their non-ideal characteristics, transformers operate within a restricted bandwidth, exhibit insertion loss, adhere to a maximum power rating, and manifest other frequency-, temperature-, and power-dependent behaviors.

Capacitors

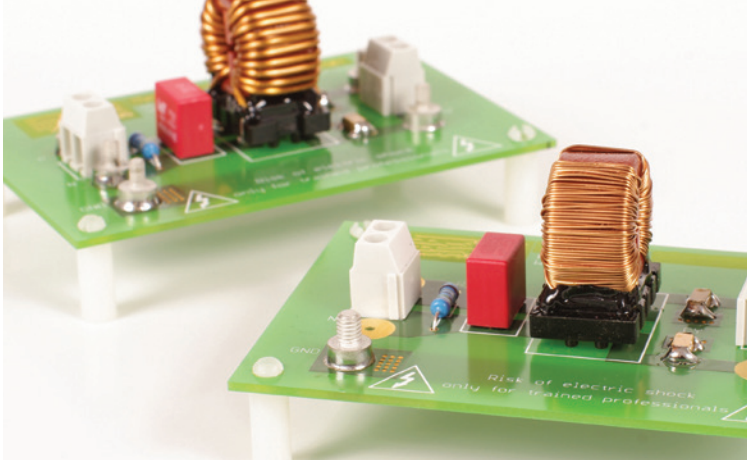
No discussion of the non-ideal parasitic behavior of passive components would be comprehensive without acknowledging capacitors. These components play a pivotal role in low-pass filters, the most widely employed filter type for electromagnetic interference (EMI) mitigation.

- **Resistance (ESR):** Real-world capacitors possess a small amount of equivalent series resistance (ESR). This resistance emerges from imperfections within the capacitor's material, leading to energy dissipation. Essentially, ESR impacts the capacitor's overall performance.
- **Inductance (ESL):** Equivalent Series Inductance (ESL) arises from the physical construction of capacitors, encompassing factors like leads and internal connections. As frequencies escalate, ESL becomes increasingly significant, impacting the overall performance of the capacitor.
- **Self-Resonance:** Capacitors possess a self-resonant frequency where their inductive and capacitive behaviors reach equilibrium. Beyond this frequency, capacitors cease to function purely as capacitors and instead exhibit inductive characteristics.
- **Lead Inductance**: Lead inductance, arising from the connections between traces, can profoundly affect the frequency response of capacitors in real-world circuits.

Common Mode (CM) Chokes

Another powerful player in EMI suppression is the Common Mode (CM) choke. These chokes find application in mitigating electromagnetic interference (EMI) from switched-mode power supplies (SMPS) and other circuits where CM noise suppression is essential. By incorporating CM chokes, designers ensure compliance with electromagnetic compatibility standards.

However, there is a caveat: parasitic capacitances associated with CM chokes can detract from their high-frequency filtering performance. If this limitation



goes unnoticed, it can lead to extended design cycles and escalated filter costs. To address this, modeling their non-ideal behavior involves considering parameters like equivalent series inductor (ESL) and equivalent series resistor (ESR), both stemming from parasitic effects. Understanding these nuances is critical for effective EMI management and optimal system performance.

Other Components Impacted by Parasitic Effects

Resistors

- Real-world resistors have a small amount of inductance due to their physical construction. At high frequencies, this inductance becomes significant, affecting impedance.
- 1/f Noise: Resistor noise increases with frequency, impacting performance.

Inductors

- Inductors have inherent (parasitic) capacitance due to winding geometry. This affects their high-frequency response.
- At high currents or frequencies, inductors may saturate, altering their behavior.

Summary

This article provides a succinct overview of the non-ideal behavior exhibited by passive components. However, I recommend delving into specialized articles and book chapters that go much deeper into this captivating subject for a more in-depth exploration.

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EMI/RFI SHIELDING

Shielding at the PCB Level

BY DON M[AC]ARTHUR

This article provides insight into how shielding is used in product development, in particular the effectiveness of shielding when it is applied at the PCB level.

A Proper Approach to Shielding

In product development it is usually most beneficial from a cost, schedule, quality and performance standpoint to carefully consider and implement proper design as early as possible in the project development cycle. Add-ons and other "quick" fixes implemented later in the project are more often than not non-ideal solutions functionally, are of inferior quality and reliability, and are more costly than if they had been implemented sooner in the process. A lack of forethought in the early design stages of the project usually results in late shipments and potentially unhappy customers (both internal and external). This problem applies to any design, whether it be analog, digital, electrical, or mechanical, etc.

The cost of the shielding increases the further away it is applied from individual ICs or small areas on a PCB. Compared with shielding of individual ICs and small areas of a PCB, it costs roughly 10x to shield an entire PCB, 100x to shield a complete product, and 1000x to shield and entire assembly or compartment. The cost is really astronomical if shielding of an entire room or building is required because improper shielding (or no shielding) was implemented at lower levels.

A "nested" shielding approach is a possible solution. A nested approach is one where shielding is applied at each of the lowest possible levels of a product design. For example, shielding is first applied to:

- individual ICs/small area of the PCB, followed by
- entire PCBs, then
- sub-assemblies, and finally
- to complete products.

A nested shielding approach is one that results in the lowest overall cost to manufacture a quality product, on time, and within performance specifications.

Shielding at the Lowest Possible Levels

Shielding at the lowest possible levels (individual ICs, small areas of the PCB, and the PCB level), makes a lot of sense for several reasons:

- Enclosure shielding does not help attenuate interference between individual ICs located on a PCB whereas, PCB level shielding does help attenuate interference between individual ICs.
- From a practical/cost-efficiency level, typical enclosure shielding technology is incapable of providing significant attenuation performance at higher (GHz) frequencies, whereas PCB level shielding does provide this performance.
- Cost and weight of shielding at higher levels is minimized through effective use of shielding at the PCB level.
- From a susceptibility stand-point, modern ICs with their ever-shrinking silicon features, faster rise-times, and lower noise margins, can be made to function

dependably in the noisy atmosphere that they are often required to operate in, simply by employing shielding at the PCB level.

- Integration of intentionally noisy wireless communication modules within products can cause harmful inference to other sensitive analog and digital components located in close proximity. This noise can also be mitigated through use of PCB level shielding.
- Enclosure shielding is often compromised to a point of total ineffectiveness due to the need to have holes and slots added for the penetration of input / output cables, displays, ventilation, access to removal media, etc. This situation becomes less of a problem when PCB level shielding is utilized.
- Effective enclosure shielding usually requires substantial filtering of all cables which pass in and out of the product, right at the point where they penetrate the enclosure shield. It's possible to lessen the need for this extra filtering when PCB level shielding is utilized.

Whether you design a cell phone, tablet, portable computer, or some other form of electronic product, good PCB layout in addition to PCB level shielding is critical to keeping EMI to a minimum. Ground (return) and power planes can be utilized as EMI shields of high-threat noisy signals and this technique is a good first step towards minimizing noise from these high-threat signals. One problem with this approach is that RF energy can still radiate off component leads and packages and a more complete solution is required. This is where a PCB level shield (a.k.a. "a shielding can") can be utilized to attenuate the noise emanating from these noisy devices.

In order to provide the most benefit, a PCB level shield must form a complete six-sided metallic enclosure. This is accomplished by soldering the shield to a solid ground plane which lies underneath all the components that require shielding. To be most effective, the ground plane must not have any substantial slots or openings in it. The real-world performance of all shielding and ground planes is always compromised by apertures such as holes for adjustments, indicators, wires, construction seams and the gaps between a shielding can's ground plane connections, so whenever possible these items should be avoided.

The goal of an EMI shield is to create a Faraday cage around the enclosed RF noisy components using the six sides of a metallic box. The top five sides are created using a shielding cover or metal can, while the bottom side is achieved by using the ground plane within the PCB. In an ideal enclosure, no emissions would enter or exit the box. Unwanted emissions from these shields does occur, such as from holes perforated into soldered cans that allow thermal heat transfer during solder reflow. These leaks can also occur from imperfections along an EMI gasket or solder attachments. Noise can also escape from the spaces between ground via-holes used to electrically connect the shielding cover to the ground plane.

PCB shields are traditionally attached to the PCB using through-hole solder tails, manually soldered after the main assembly process. This is a time-consuming and costly process. If maintenance is required during setup and servicing, access to circuitry and components under the shields requires de-soldering. In densely populated PCB areas containing highly sensitive components, there is a high risk of expensive damage. There are manufacturers of shield cans that provide solutions which mitigate these problems.

Typical Attributes of PCB Level Shield Cans

- Small footprints;
- Low-profile configurations;
- Two-piece design (fence and cover);
- Through-hole or surface mount;
- Multi-cavity patterns (isolate multiple components using the same shield);

- Virtually limitless design flexibility;
- Ventilation holes;
- Removable covers for quick access to components;
- I/O holes;
- Connector cutouts;
- Enhanced shielding with RF absorbers;
- ESD protection with insulator padding;
- Reliable protection from shock and vibration using secure locking features between the frame and cover.

Typical Shielding Materials

A wide range of materials are generally available for shielding, including brass, nickel silver and stainless steel. The most common types are:

- Tin plated cold rolled steel (cheapest option)
- Tin plated copper
- Nickel silver
- Stainless steel
- Tin plated phosphorous bronze

In general, tin plated steel is the best choice for shielding below 100 MHz while tin plated copper is best above 200 MHz. Tin plating allows for the best soldering efficiency possible. Because aluminum on its own is not easily soldered to a ground plane with its heat-sinking properties, it is not generally used for PCB level shielding.

Depending on the regulatory burden of the end-product, all materials used for shielding may need to be RoHs compliant. In addition, if a product is intended for hot and humid environments, galvanic corrosion and oxidation may be of concern. If in doubt, check suitability of the shielding material with the supplier.

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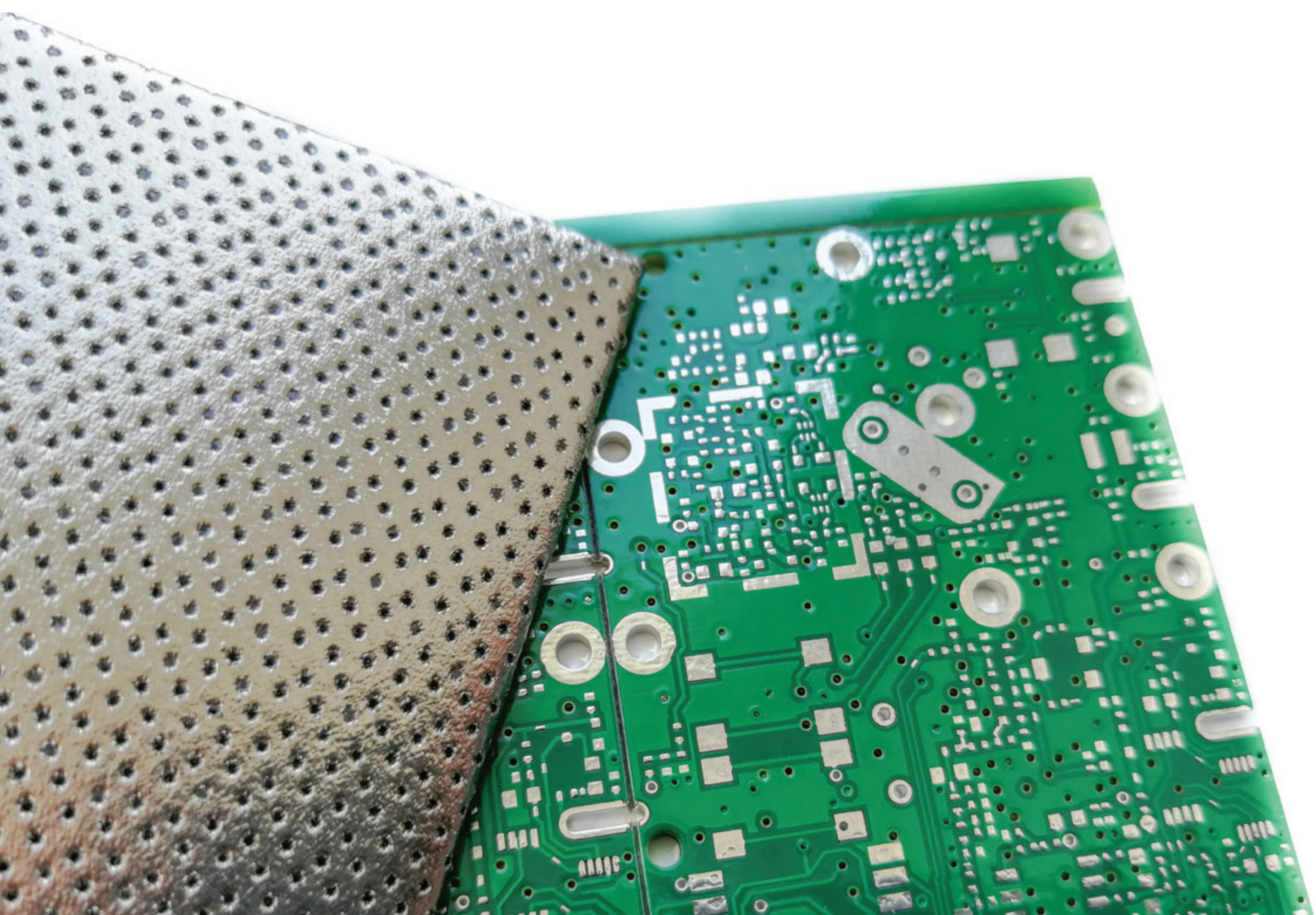

Understanding Capacitor Frequency Characteristics

BY DON MACARTHUR

When dealing with noise problems, having a solid grasp of capacitor characteristics is crucial. Let's break it down:

Capacitor Impedance and Frequency

- The relationship between capacitor impedance (Z) and frequency (f) is fundamental. Impedance refers to the opposition a capacitor offers to the flow of alternating current (AC).
- As frequency changes, so does the impedance of a capacitor. This behavior is depicted in Figure 1.
- Keep in mind that impedance is not just about the electrostatic capacitance (denoted as C). Other factors or components come into play.

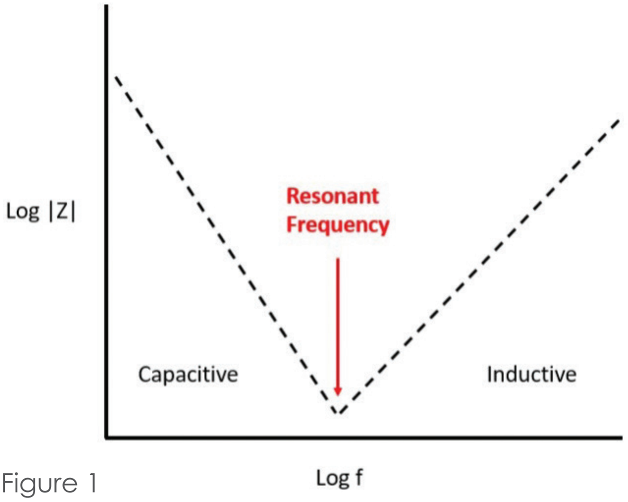

Figure 1

Additional Components

Beyond the basic electrostatic capacitance, there are three key components:

- ESR (Equivalent Series Resistance): This is the resistive component that exists in series with the electrostatic capacitance. ESR accounts for energy losses due to internal resistance within the capacitor.
- ESL (Equivalent Series Inductance): ESL represents the inductive component also in series with the capacitance. It arises from the physical layout of the capacitor and the leads.
- EPR (Equivalent Parallel Resistance): EPR is a parallel resistance that exists alongside the electrostatic capacitance. It's related to insulating resistance (IR) between the capacitor's electrodes or any leakage current.

Series Resonance Circuit

- When you combine the capacitance (C) and the inductance (ESL), you get a series resonance circuit.
- Up to the resonance frequency, the capacitor behaves primarily as a capacitive element, and its impedance decreases.
- The exact impedance at resonance depends on the ESR.
- However, beyond the resonance frequency, the impedance characteristic shifts to an inductive behavior. As frequency increases further, impedance rises due to the inductance effect.

Pro Tip: Choosing capacitors with lower ESR and ESL values results in lower noise reduction.

Filtering Unwanted Frequencies

Capacitors can act as filters to attenuate specific frequency components. For example:

Low-Pass Filters: Use capacitors in conjunction with resistors to create low-pass filters. These filters allow low-frequency signals (such as DC or slow-changing signals) to pass while attenuating high-frequency noise.

Other Filter Types: Although not often used in EMC work, capacitors are also used as high-pass filters (allow high-frequency signals to pass while blocking low-frequency noise) and band-pass filters (allow a specific range of frequencies to pass through).

Choose the Right Capacitor Type

Different types of capacitors have varying characteristics. Here are a few considerations: Ceramic Capacitors, Tantalum Capacitors, Electrolytic Capacitors, and Film Capacitors. See reference 2 for more information on capacitor types.

Placement and Layout

Proper placement of capacitors matters when trying to suppress unwanted noise. If proper placement is not carefully utilized, the filtering ability of the capacitive filter is compromised. Remember that noise mitigation is a holistic effort. It involves not only capacitor selection but also proper grounding, shielding, and overall circuit design. See references 3 and 4 for more information on proper placement and layout of filters.

Summary

In summary, understanding a capacitor's frequency-dependent characteristics helps engineers design effective circuits and manage noise issues. It's like knowing the dance moves of a capacitor—when to waltz (capacitive behavior) and when to tango (inductive behavior)!

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PRODUCT
MARKETPLACE

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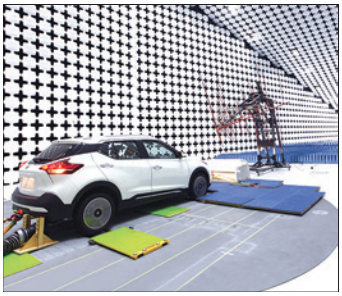

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ANALYSIS OF TRANSMISSION LINES IN SINUSOIDAL STEADY STATE

Different Circuit Models and Their Applications: Part 1

By Bogdan Adamczyk

This is the first of three articles discussing four different circuit models of transmission lines in sinusoidal steady state. All four models, while equivalent, serve a different purpose. Model 1 is used to present the solution of the transmission line equations. It serves as the basis for the remaining three models. Model 2 is best suited for the introduction of the standing waves. Evaluation of the minima and maxima of the standing waves is mathematically most expedient using Model 3. The location of the minima and maxima of the standing waves is determined using Model 4. This article discusses Model 1 and Model 2 and their usefulness.

1. TRANSMISSION LINE MODEL 1

Model 1 is best suited for the straightforward derivation of the transmission line equations and their solutions. These solutions are obtained in the most natural and mathematically least complicated way. The solutions reveal that voltages and currents travel as waves on transmission lines. It is also the easiest model to obtain the expressions for the magnitudes of the voltages and currents at any location away from the source. These expressions, shown at the end of this section, provide a starting point for subsequently discussing Model 2.

Model 1, shown in Figure 1, was discussed in [1, 2] and is briefly reviewed here.

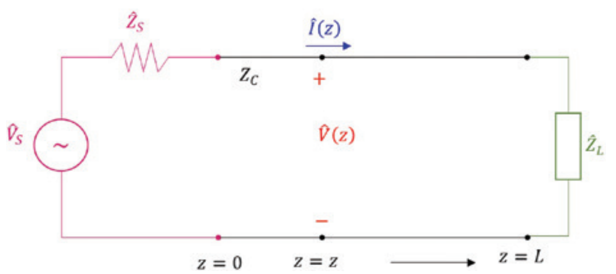

Figure 1: Transmission line circuit – Model 1


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A sinusoidal voltage source $\hat{V}_S$ with its source impedance $\hat{Z}_S$ drives a lossless transmission line with characteristic impedance Z_C terminated in an arbitrary load $\hat{Z}_L$. In this model, we are moving away from the source located at $z = 0$ towards the load located at $z = L$. The voltage and current at any location z, away from the source, are given by:

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z} + \hat{V}_z^- e^{j\beta z} \tag{1.1a}$$

$$\hat{I}(z) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta z} - \frac{\hat{V}_z^-}{Z_C} e^{j\beta z} \tag{1.1b}$$

where the $\hat{V}_z^+$ and $\hat{V}_z^-$ are constants [2] and β is the phase constant of the sinusoidal voltage source, related to the wavelength by:

$$\beta = \frac{2\pi}{\lambda} \tag{1.2}$$

The solutions in Eqns. (1.1) consist of the forward- and backward-traveling waves [3].

$$\hat{V}(z) = \hat{V}_f(z) + \hat{V}_b(z) \tag{1.3a}$$

$$\hat{I}(z) = \hat{I}_f(z) + \hat{I}_b(z) \tag{1.3b}$$

The forward-traveling waves are described by:

$$\hat{V}_f(z) = \hat{V}^+ e^{-j\beta z} \tag{1.4a}$$

$$\hat{I}_f(z) = \frac{\hat{V}^+}{Z_C} e^{-j\beta z} \tag{1.4b}$$

while the backward-traveling waves are given by:

$$\hat{V}_b(z) = \hat{V}^- e^{j\beta z} \tag{1.5a}$$

$$\hat{I}_b(z) = -\frac{\hat{V}^-}{Z_C} e^{j\beta z} \tag{1.5b}$$

The voltage and current at any location *z*, away from the source, given by Eqns. (1.1), can alternatively be expressed by [2]:

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z}\left[1 + \hat{\Gamma}_L e^{j2\beta(z-L)}\right] \tag{1.6a}$$

$$\hat{I}(z) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta z}\left[1 - \hat{\Gamma}_L e^{j2\beta(z-L)}\right] \tag{1.6b}$$

where $\hat{\Gamma}_L$ is the load reflection coefficient. The magnitudes of the voltage and current at a distance *z* away from the source are:

$$\left|\hat{V}(z)\right| = \left|\hat{V}_z^+\right| \left|\left[1 + \hat{\Gamma}_L e^{j2\beta(z-L)}\right]\right| \tag{1.7a}$$

$$\left|\hat{I}(z)\right| = \left|\frac{\hat{V}_z^+}{Z_C}\right| \left|\left[1 - \hat{\Gamma}_L e^{j2\beta(z-L)}\right]\right| \tag{1.7b}$$

2. TRANSMISSION LINE MODEL 2

Circuit Model 2, shown in Figure 2, is best suited for introducing the concept of standing waves.

In this model, the load is located at *d = 0*, and the source is located at *d = L*. The voltage and current are now a function of the distance variable *d* when moving from the load towards the source. The two distance variables are related by:

$$d = L - z \tag{2.1a}$$

$$\left|\hat{I}(d)\right| = \left|\frac{\hat{V}_d^+}{Z_C}\right| \left|\left[1 - \hat{\Gamma}_L e^{-j2\beta d}\right]\right| \tag{2.1b}$$

Utilizing Eq. (2.1b) in Eqns. (1.3) gives the magnitudes of the voltage and current at a distance *d* away from the load as:

$$\left|\hat{V}(d)\right| = \left|\hat{V}_d^+\right| \left|\left[1 + \hat{\Gamma}_L e^{-j2\beta d}\right]\right| \tag{2.2a}$$

$$\left|\hat{I}(d)\right| = \left|\frac{\hat{V}_d^+}{Z_C}\right| \left|\left[1 - \hat{\Gamma}_L e^{-j2\beta d}\right]\right| \tag{2.2b}$$

where [3]:

$$\hat{V}_d^+ = \hat{V}_z^+ e^{-j\beta L} \tag{2.3a}$$

$$\left[\hat{V}_d^+\right] = \left|\hat{V}_z^+ e^{-j\beta L}\right| = \left|\hat{V}_z^+\right| \tag{2.3b}$$

When the load is short circuited, the magnitudes of the voltage and current in Eqns. (2.2) become [1]:

$$\left|\hat{V}(d)\right| = 2\left|\hat{V}_d^+\right| \left|\sin\left(2\pi\frac{d}{\lambda}\right)\right| \tag{2.4a}$$

$$\left|\hat{I}(d)\right| = 2\frac{\left|\hat{V}_d^+\right|}{Z_C} \left|\cos\left(2\pi\frac{d}{\lambda}\right)\right| \tag{2.4b}$$

and are shown in Figure 3.

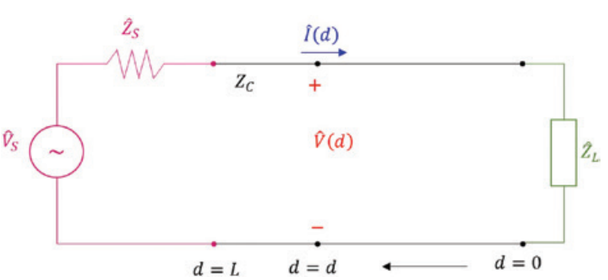

Figure 2: Transmission line circuit – Model 2

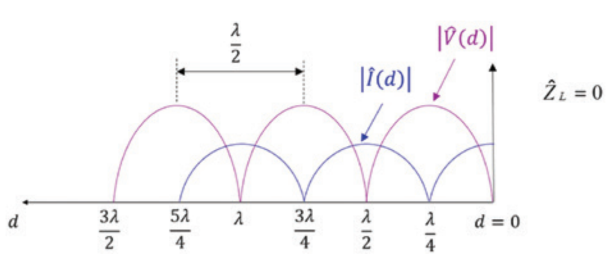

Figure 3: Magnitudes of the voltage and current for a short-circuited load

When the load is open circuited, the magnitudes of the voltage and current in Eqns. (1.2) become

$$\left|\hat{V}(d)\right| = 2\left|\hat{V}_d^+\right| \left|\sin\left(2\pi\frac{d}{\lambda}\right)\right| \tag{2.5a}$$

$$\left|\hat{I}(d)\right| = 2\frac{\left|\hat{V}_d^+\right|}{Z_C}\left|\cos\left(2\pi\frac{d}{\lambda}\right)\right| \tag{2.5b}$$

and are shown in Figure 4.

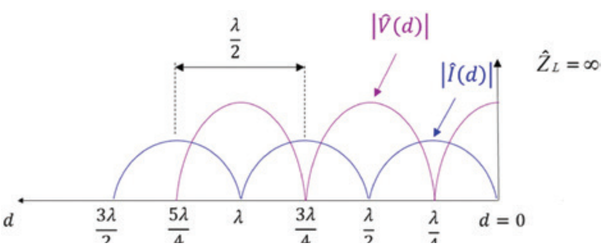

Figure 4: Magnitudes of the voltage and current for an open-circuited load

When the load is matched, the magnitudes of the voltage and current in Eqns. (1.2) are constant

$$\left|\hat{V}(d)\right| = \left|\hat{V}_d^+\right| \tag{2.6a}$$

$$\left|\hat{I}(d)\right| = \left|\frac{\hat{V}_d^+}{Z_C}\right| \tag{2.6b}$$

and are shown in Figure 5.

For an arbitrary load (other than short, open, or matched), the magnitudes of the voltage and current at a distance *d* away from the load are obtained from equations (2.2). Figure 6 shows a sample plot of these magnitudes.

The locations (distance from the load) of the voltage maxima and minima are determined by the actual load impedance. In all cases (other than the matched load), the distance between two adjacent voltage maxima or minima is one-half wavelength (same for the current), while the distance between a voltage maximum and its closest minimum is one-quarter wavelength (same for the current).

We also observe that the voltage and current do not travel as the time advances, but stay where they are, only oscillating in time. In other words, they do not represent a traveling wave in either direction.

The resulting wave, which is a superposition of two traveling waves with opposite direction of travel is a *standing wave*.

In the next article, we will introduce two remaining circuit models of transmission lines in sinusoidal steady state. These models will be used to determine the locations and values of the standing waves voltage/current maxima and minima.

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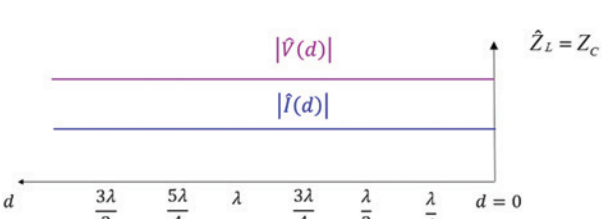


Figure 5: Magnitudes of the voltage and current for a matched load

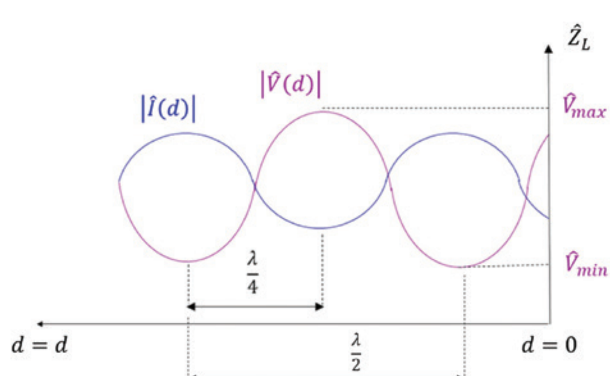
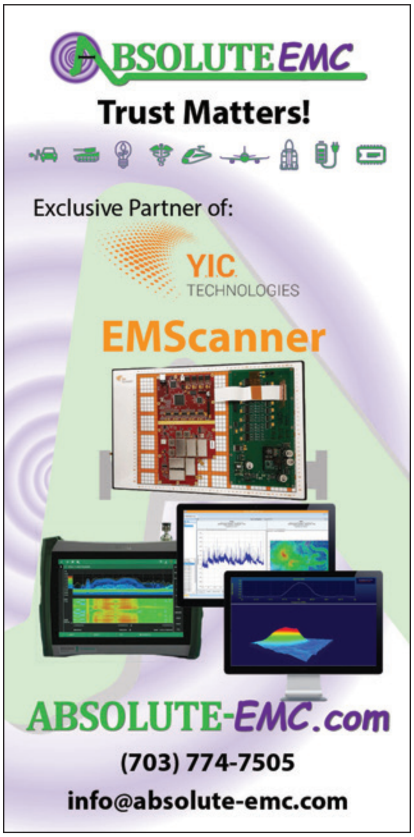
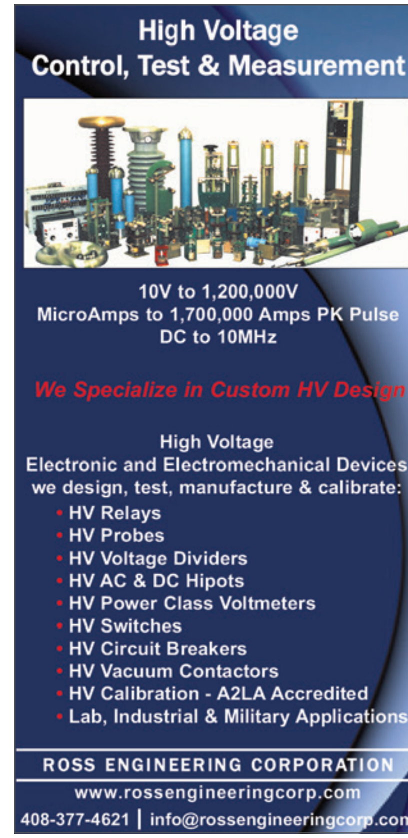
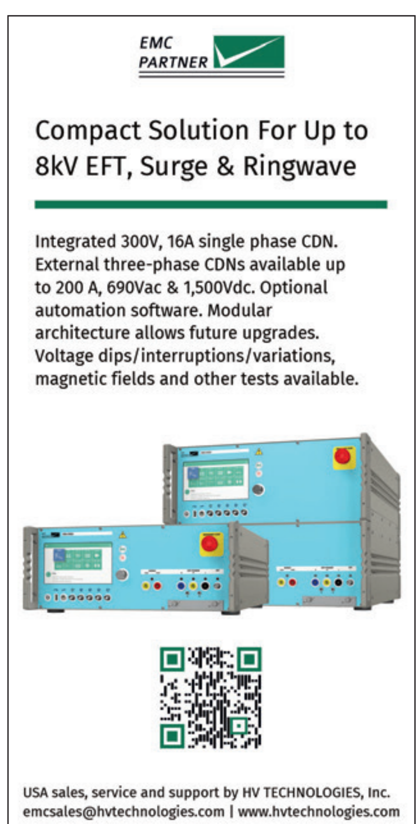


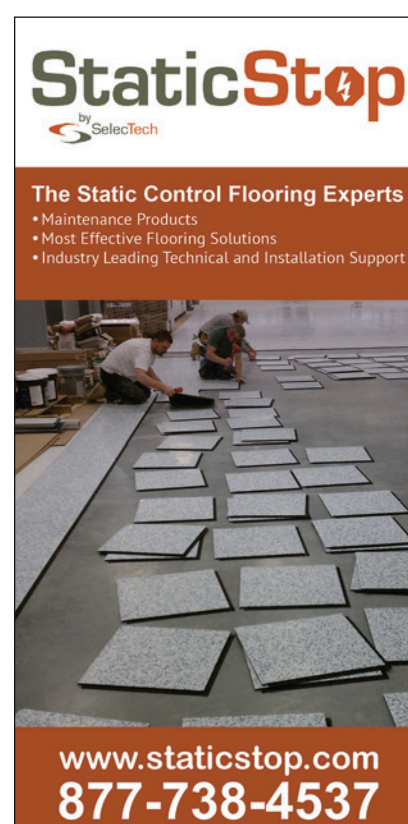
Figure 6: Magnitudes of the voltage and current for an arbitrary load

PRODUCT Showcase









ARE ESD & ESA CONTROLS IN PLACE IN SEMICONDUCTOR WAFER FABS?

By EOS/ESD Association, Inc.

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

Is your semiconductor fab certified to S20.20? If yours is like most fabs, the answer is likely no. This is because the ESD controls needed in the front-end fabs are different from the back-end processes for which S20.20 was primarily written.

Several semiconductor fab representatives have stated that their customers have requested that they provide proof and/or certification that their established ESD/ESA control program is sufficient for their respective semiconductor manufacturing processes. Wafers, as they are being built, are typically more susceptible to electrostatic attraction (ESA) of particles than to damaging electrostatic discharge (ESD). However, they can still be damaged by ESD events, particularly those with the extreme energy seen when no static control principles are applied. In some cases, electrostatic fields in excess of 20,000 volts can be found in wafer fabrication facilities when no static control principles are used. Attenuation of these fields can reduce not only the risk of damaging ESD events but also a reduction of ESA onto critical surfaces.

As the wafers near final processing and move to back-end assembly operations, the focus on static control becomes more important for ESD than for ESA, although controls for both may still be needed. Many of these controls reduce the risk of ESD damage. The primary method to remove charge from conductive materials is by grounding them. While sounding simple initially, this can be more complicated as one digs into the details.

Examples of common conductors that should be grounded are tool surfaces and stainless steel tables. What may be less obvious is conductive wafer-handling robots that move and may be more difficult to ground. Other less obvious items are static dissipative materials used as part of tool surfaces, wafer carriers, FOUP's, etc. Static dissipative items such as these must be grounded similarly to conductive materials to bleed off any accumulated charge.

Another conductive item is personnel. In wafer fabrication facilities, unless personnel are directly involved in handling product, grounding may not be as critical, but many other considerations need to be evaluated. When it is needed, the grounding of personnel can be best accomplished through the floor/footwear system. In addition, the floor must be conductive or static dissipative and designed to work with the footwear chosen to ground personnel.

One of the largest problems seen in wafer fabrication facilities is the prevalent use of charge-generating and charge-accumulating insulative materials. Materials inert to the many chemicals used in wafer processing are needed in many processing locations. Many of these materials are insulative and will accumulate significant charge when moved or handled. The best solution, if possible, is to re-engineer the items with materials that are static dissipative. If they are made from static dissipative materials, the grounding of the items will need to be considered. Windows in tools and Equipment Front End Modules (EFEMs) have traditionally been made from acrylic and similar materials and charge significantly when touched.

Static dissipative versions of these materials are available and becoming more prevalent in these applications. However, many static dissipative materials may not be clean enough for ultra-clean wafer processing. In addition, the wafers themselves will have insulative features that can attract contaminants through ESA. The best solution for these situations is to provide sufficient air ionization to neutralize the charge on insulative materials and the wafers being processed.

Many different forms of ionization are used in wafer fabrication facilities for ESA and ESD control. EFEMs typically will have ionization bars installed in the air stream above the wafer-handling robots. Room system ionization is utilized in many wafer fabrication facilities in the manufacturing areas to control the charge on wafers and other insulative materials. In addition, room system ionization is sometimes used in the gowning rooms to reduce the charge on garments and airborne particles to prevent dragging contaminants into the cleanroom on personnel. Likewise, equipment transfer rooms may have ionization present (room and/or local blow-off ionization) to assist in ensuring that the material coming in through these rooms is as clean as possible before entering the cleanroom.

One of the current requirements in ANSI/ESD S20.20 is that the offset voltage of all ionization must be less than ±35V. This requirement stems from the need to control voltage on ungrounded conductive items. It should be noted that in most cases, this requirement is not needed in front-end semiconductor wafer manufacturing, and the benefit of using room and in-tool ionization that may not meet the ±35V requirement far exceeds not using ionization.

The EOS/ESD Association is currently working on a document about the challenges to ESD/ESA controls in a semiconductor fab. Besides the ESD/ESA controls listed above, it will also address topics in the fab such as contamination control, reticle handling, open cassette vs SMIFF/FOUP carriers, wafer backside power processing, and 2.5D/3D bonding.

IMPLEMENTING "WORDLESS" SAFETY LABELS

By Erin Earley

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.

In our most recent "On Your Mark" columns, we've focused on ANSI Z535 – the U.S. standards that create a guide for the design, application, and use of signs, colors, and symbols intended to identify and warn against hazards and for other accident prevention purposes. These standards, along with their international counterpart, ISO 3864-2, can be effective starting points in helping you to develop adequate warnings. The standards are intended to be guidelines, not prescriptive instructions for the right symbol or content choices for your product or situation. And, that's why implementation can be tricky; you need to understand the standards and best practices and then apply them in a way that works best for your product and its audience. In this column, we'll look at the practical implications of implementing a "wordless" approach to your safety labels or safety label program.

WHAT ARE "WORDLESS" SAFETY LABELS?

In recent years, safety label formats have progressed to include a more graphic-based approach. When we think about safety labels that use symbols alone, without words, to communicate safety messages, there are two main standards-based options: a "symbol only" approach (a style of label that uses only ISO-formatted symbols without a word message or an ANSI/ISO signal word panel) and a "wordless" approach (a style of label that uses an ISO wordless format, meaning ISO-formatted symbols with a hazard severity panel). In this article, we're focusing primarily on the latter, the wordless format approach.

WHEN TO CONSIDER THIS FORMAT

Your goal is to make your product as safe as possible and to communicate to the user how to safely use the product. To adequately warn, reduce risk, and protect people, as well as follow the applicable best practice standards, you need to consider your product itself (including the types of risk and the physical space on the product for warnings) and your audience (including their skill level, language requirements, and location – whether domestic or international).

"Wordless label formats are able to be used domestically in the U.S. and internationally; they meet both the ANSI Z535.4 and ISO 3864-2 standards. The ANSI Z535.4 standard doesn't specifically include this label format, but ANSI allows manufacturers to use it through its section 3.1.1, which allows for the use of ISO formats," says Angela Lambert, ANSI Z535 committee member and head of standards compliance at Clarion Safety Systems.

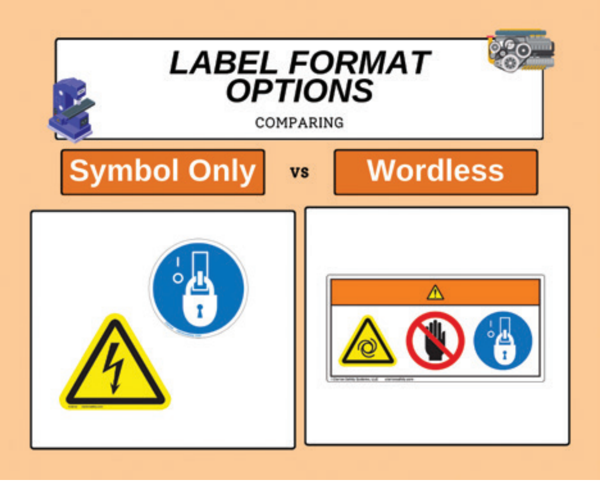


Figure 1: At left, examples of a symbol only approach to labeling and at right, an example of a wordless format label.

The benefits of this type of format are that it can communicate across language barriers without translations, and that these symbols typically use less space than other types of formats. The limitations are that more than one symbol-only label may be needed to communicate the safety message, the severity of the hazard isn't defined, and that symbol comprehension testing or training may be needed.

A CASE IN POINT ON MOVING TOWARDS WORDLESS SAFETY LABELS

It can be challenging to find a balance between providing your product's user with complete safety and hazard information, so that they can make wise decisions, while also being brief and impactful.

"While warnings do need to have complete information so product users can be fully informed, they also have to clearly communicate," Lambert says. "That can be the first hurdle that those responsible for product safety face. The existing labels being used may show a long list of information or too much text, potentially without the use of symbols. That can lead to the warning being illegible or even ignored."

A case in point is shown in Figure 2, in the example at left. The content in the label shown is text-heavy, not well-organized, redundant, and isn't complemented with symbols to call attention and reinforce meaning.

"To optimize the label shown, I'd recommend that either an ANSI-style symbol and text approach or a wordless approach be considered," Lambert says. Examples of these approaches are shown in the middle and right labels of Figure 2. In the ANSI-style symbol and text label, the word message has been simplified to present the information in a more organized and direct way, and standardized symbols have been added. In the wordless approach, a hazard severity panel has been added to color-code and reinforce the level of risk and standardized symbols alone are used to provide details on the hazard.

Lambert continues that when choosing to implement a wordless approach rather than an ANSI-style symbol and text approach, it's important to weigh the pros and cons related to the product and its anticipated audience.

"The wordless approach is acceptable for use domestically in the U.S. and internationally – and certainly has benefits when it comes to communicating across language barriers, without translations. If the aim is to have one format of label that can be used for a variety of markets, wordless format labels may be especially appealing," Lambert says.

"Those striving to implement this format will want to look closely at comprehension concerns. Consider items like use of standardized symbols and comprehension of the symbols used as well as the characteristics of the audience and if warnings are supported by a well-structured, clear and accessible manual that provides further context and instructions."

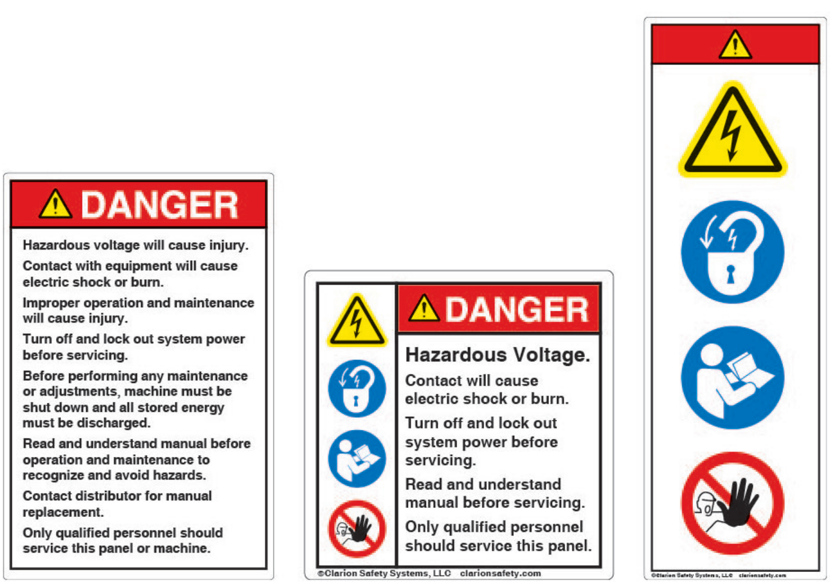


Figure 2: Examples of safety labels that use a word heavy approach (left), an ANSI-style symbol and text approach (middle), and a wordless approach (right).

While there's not one perfect or failsafe solution to labeling or implementing a wordless approach, reviewing the standards and spending time to interpret how best to implement them can help in the journey to create effective, best practice labels, as part of a comprehensive product safety strategy.

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