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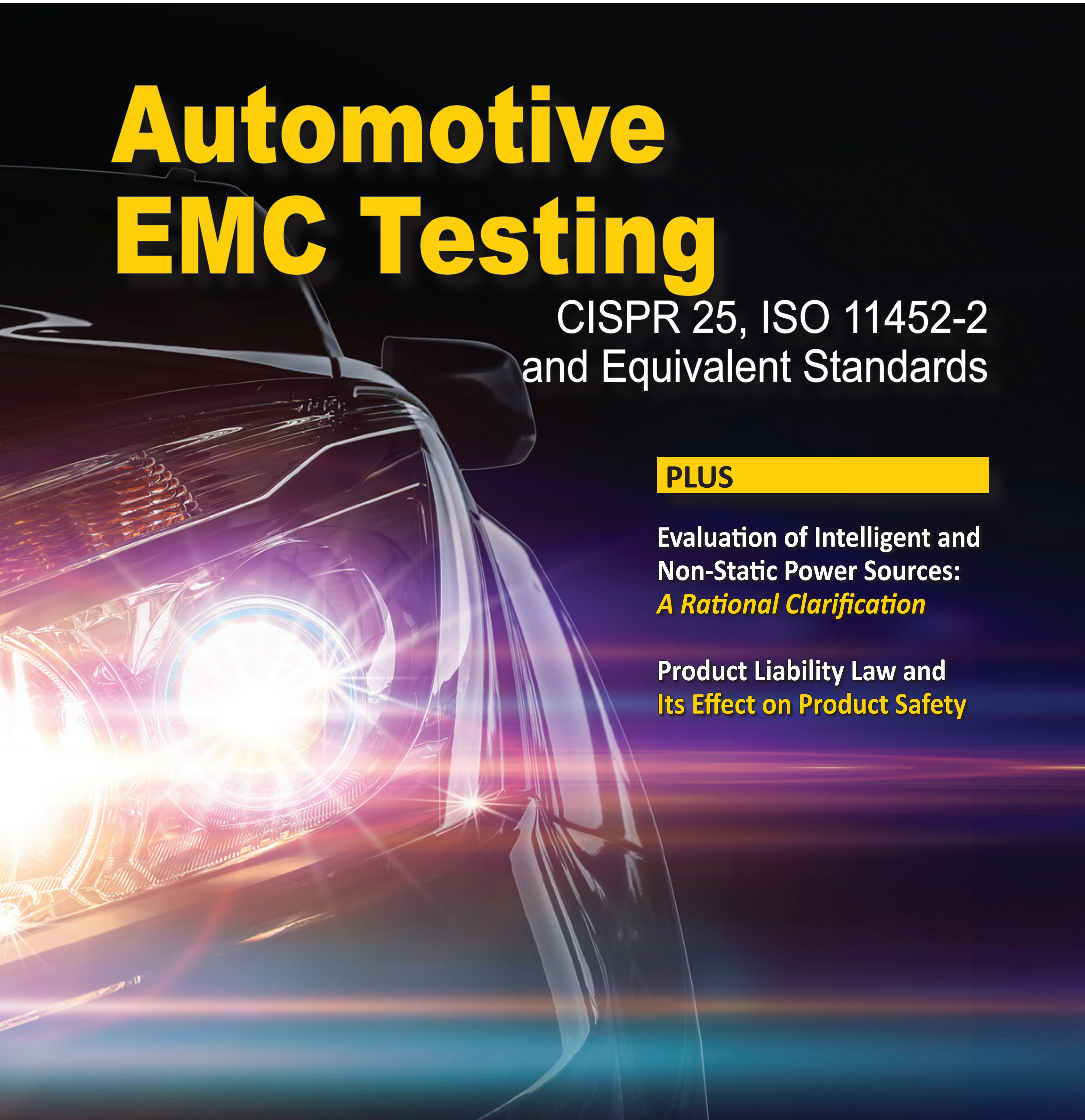

Automotive EMC Testing

CISPR 25, ISO 11452-2 and Equivalent Standards

PLUS

Evaluation of Intelligent and Non-Static Power Sources: ***A Rational Clarification***

Product Liability Law and Its Effect on Product Safety

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FCC Proposes Updated Data Breach Reporting Requirements

The U.S. Federal Communications Commission (FCC) has proposed updating its rules requiring telecommunications operators to notify customers and law enforcement of breaches of confidential consumer information.

The proposed rule changes were detailed in a Notice of Proposed Rulemaking issued by the Commission. In brief, the proposed changes would eliminate the current seven business day mandatory waiting period to issue notifications of a breach, and would also require notification of all reportable breaches to the FCC, the Federal Bureau of Investigation (FBI), and the U.S. Secret Service.

The Commission also seeks to expand the definition of "breach" to include any inadvertent access, use, or disclosure of customer information. This change would help to protect customers not just from malicious breaches by third parties but also from accidental access, use, or disclosures.

If adopted, the proposed changes would dramatically overhaul Commission rules first enacted in 2007. The Commission acknowledged in its Notice that the threat landscape facing telecommunications operators has changed dramatically over the past 15 years and that its proposed changes are necessary to keep pace with emerging challenges to data security.

FCC Adjusts Civil Monetary Penalties to Reflect Inflation

Just like ordinary businesses and consumers, agencies of the U.S. federal government are subject to increased costs directly linked to inflation. So it's no surprise that the U.S. Federal Communications Commission (FCC) has recently taken steps to align its forfeiture penalties to reflect the current economic reality.

In an Order issued in late 2022, the FCC approved across-the-board increases of approximately 7-8% for most forfeiture penalties for violations of FCC rules and requirements. Under the 2015 Inflation Adjustment Act, federal agencies are required to annually adjust civil monetary penalties for violations of their rules. The updated forfeiture amounts apply to penalties assessed on or after January 15, 2023.

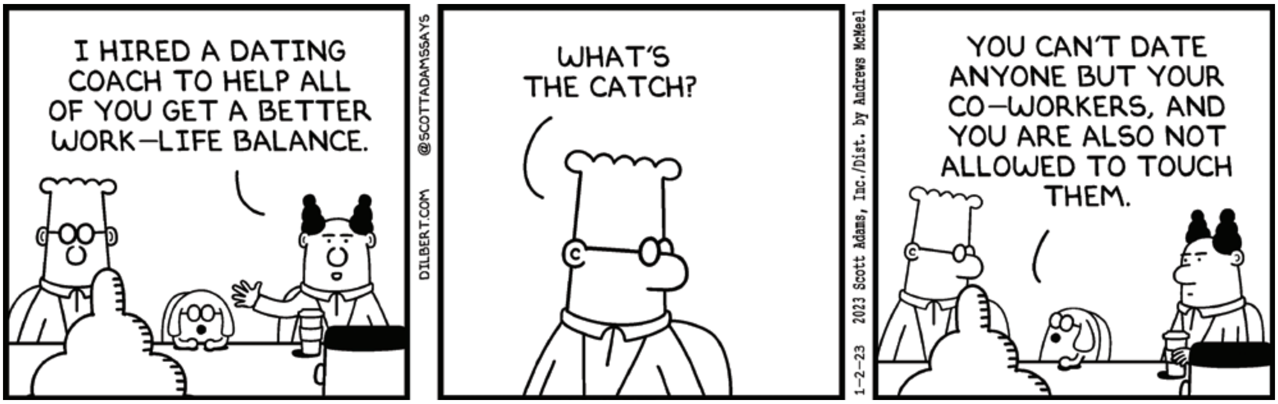
FCC Begins Rulemaking for Drones' Spectrum Allocation

The U.S. Federal Communications Commission (FCC) is proposing rules that would more effectively support wireless communications with drones and other unmanned aircraft systems (UAS).

In a Proposed Notice of Rulemaking, the FCC is seeking comment on service rules that would provide UAS operators with access to licensed spectrum in the 5030-5091 MHz band to support safety-critical UAS communications links.

At present, no spectrum is licensed in the U.S. exclusively for UAS communications use. Instead, operators have generally relied on unlicensed operations or experimental licenses. However, these options do not provide users with protection from harmful interference, potentially affecting the reliability of essential UAS communications.

As UAS operations expand to include activities with a higher risk profile, the Commission sees the increasing importance of access to interference-protected licensed spectrum for UAS wireless communications. Hence, the decision to issue the proposed service rules.



FCC Commissioner Calls for Mandatory Security Updates for Wireless Devices

As concerns increase about cybersecurity threats targeting all types of electrical and electronic equipment, a Commissioner for the U.S. Federal Communications Commission (FCC) is calling on the agency to require manufacturers to provide ongoing security updates for their wireless devices.

In a presentation at the Practicing Law Institute's 40th Annual Institute on Telecommunications Policy & Regulation, Commissioner Nathan Simington called on the FCC to modify its equipment authorization process to require device manufacturers to provide software security updates to their wireless devices for a defined period of time.

"It's time to turn our attention to the millions of wireless devices in our country that are insecure, not because they're made by unfriendly state-controlled entities or criminal hackers masquerading as legitimate manufacturers, but rather, because their makers have failed to put sufficient care into making and keeping them secure," said Simington.

According to Simington, "For software updates…all that's required is that the maker identify the flaw in the code, fix it, test it, and release it through their update channels…The burden of releasing a software update—a relatively small amount of labor inside a company's engineering offices—is vastly outweighed by the benefit to society—a dangerous vulnerability being closed on thousands or millions of devices in active use across American households and businesses."

As for the FCC's authority to act in this matter, Simington believes that "Title 3 of the Communications Act gives us expansive authority to regulate RF emitting devices to make sure they don't cause harmful interference." Accordingly, "I believe that our equipment authorization and spectrum licensing regime includes such a requirement already. It's just a matter of updating our assumptions about what's possible."

AUTOMOTIVE EMC TESTING:
CISPR 25, ISO 11452-2 AND EQUIVALENT STANDARDS PART 1

EMC Standards and Chamber Testing for Automotive Components

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Photo © Jerry Ramie

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

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

Automotive standards addressing electromagnetic compatibility (EMC) are developed mainly by CISPR, ISO, and SAE. CISPR and ISO are organizations that develop and maintain standards for use at the international level. SAE develops and maintains standards mainly for use in North America. In the past, SAE developed many EMC standards which were eventually submitted to CISPR and ISO for consideration as an international standard. As the SAE standards become international standards, the equivalent SAE standard is then withdrawn as a complete standard and reserved for use to document differences from the international standard.

Each vehicle manufacturer has internal corporate standards that specify the testing, severity, and sensitivity levels that components used in their vehicles, and the complete vehicle must meet. As with the government standards, these documents usually refer to the CISPR and ISO documents with differences in scope or test levels. In the past, a vehicle manufacturer based in the U.S. referenced SAE documents in their corporate standards, today most U.S.-based vehicle manufacturers market worldwide. Therefore, they reference CISPR and ISO standards in their internal corporate standard, and this is also true for other established and emerging manufacturers.

CISPR/D is responsible for developing and maintaining the standards used to measure the emissions produced by vehicles and their components. ISO/TC22/SC32/WG3 is responsible for developing and maintaining the standards used for immunity testing of vehicles and their components. ISO standards for the vehicle industry are mainly broken into two categories, vehicle (ISO 11451-xx) or component (ISO 11452-xx, ISO 7637-xx). Table 1 on page 10 provides an overview of the CISPR and ISO EMC standards for the automotive industry.

As with the ISO EMC standards, SAE EMC standards are mainly broken into two categories, vehicle (SAE J551-xx) and component (SAE J1113-xx). As can be seen in the notes of Table 1, many of the SAE standards are inactive because they have been withdrawn as complete standards and reserved for use to document differences from the international standards. Table 2 on page 12 does not show all the EMC standards related to automotive published by the SAE, but it gives an overview of the main standards and cross-references to the equivalent ISO or CISPR document. Table 2 shows the main SAE standards that are still active for both vehicle components and vehicles.

As with Table 1, Table 2 is not intended to show all the different parts of the standard, but to show the complexity of the standard documents and the many parts and methods that are covered under them. As mentioned above, government standards and directives in many cases refer to the CISPR or ISO methods. 2004/104/EC, which surpassed 95/54 EC, is a European directive for vehicle EMC. Its sections related to automotive components follow the directions given in the CISPR 25 document.

CISPR 12, CISPR 25, AND CISPR 36

CISPR 12 and CISPR 36 deal with "radio disturbance characteristics for the protection of off-board receivers" [1] [6]. CISPR 25 deals with "radio disturbance characteristics for the protection of receivers used on-board vehicles, boats and on devices" [2]. It is important to remember that CISPR 12 and CISPR 36

Document No.	Title	Type	Equivalent	Test Setup	Chamber Requirement
ISO-11451-1	Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology	N/A	SAE J551/1	Definitions	N/A
ISO-11451-2	Part 2: Off Vehicle Radiation Sources	RI	SAE J551-11 (Note 1)	Vehicle Radiated Immunity test in an anechoic chamber	Vehicle Absorber lined chamber
ISO-11451-3	Part 3: On-board transmitter simulation	RI	SAE J551-12 (Note 2)	Vehicle Absorber Lined Shielded Enclosure (ALSE) is required	Vehicle Absorber lined chamber
ISO-11451-4	Part 4: Bulk Current Injection (BCI)	RI	SAE J551/13 (Note 3)	Test was designed for machines and vehicles too large to fit in a standard vehicle EMC	Outdoor Test Site (OTS) or Vehicle Absorber lined chamber
ISO-11451-5	Part 5: Reverberation chamber	RI (DRAFT)	None	Vehicle Radiated Immunity test in a reverberation chamber	Reverberation chamber
ISO-11452-1	Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology	N/A	SAE J1113/1	Definitions	N/A
ISO-11452-2	Part 2: Absorber lined chamber	RI	SAE J1113/21 (Note 4)	An absorber lined chamber is required. Antennas and field generator to cover the range are required. No need to scan	Absorber lined chamber
ISO-11452-3	Part 3: Transverse electromagnetic (TEM) cell	RI	SAE J1113/24 (Note 5)	TEM cell	N/A
ISO-11452-4	Part 4: Bulk current injection	RI	SAE J1113/4	Radiated immunity using the BCI method	Shielded room
ISO-11452-5	Part 5: Stripline	RI	SAE J1113/23 (Note 6)	Radiated immunity using a stripline	Shielded room
ISO-11452-7	Part 7: Direct radio frequency (RF) power injection	RI	SAE J1113/3 (Note 7)	Conducted immunity test 250 kHz to 500 MHz	Bench or Shielded room
ISO-11452-8	Part 8: Immunity to magnetic fields	RI	SAE J1113/22 (Note 8)	Helmholtz coils are used	Bench test: no shielded room required
ISO-11452-9	Part 9: Portable transmitters	RI	None	Small antennas are used in conjunction with amplifiers and signal sources to simulate portable transmitters	Absorber lined chamber
ISO-11452-10	Part 10: Immunity to conducted disturbances in the extended audio frequency range	CI	SAE J1113/2 (Note 9)	Conducted immunity test 15 Hz to 500 MHz	Bench test: no shielded room required
ISO-11452-11	Part 11: Reverberation Chamber	RI	SAE J1113/28 (Note 10)	Reverberation chamber – Mode Tuned	Reverberation chamber
ISO 7637-1	Road vehicles — Electrical disturbances from conduction and coupling — Part 1: Definitions and general considerations	N/A	SAE J1113/1	Definitions	N/A
ISO-7637-2	Part 2: Electrical transient conduction along supply lines only	CI	SAE J1113/11	Conducted immunity to transients as they are applied directly to the power leads of the test item.	Bench test: no shielded room required

Document No.	Title	Type	Equivalent	Test Setup	Chamber Requirement
ISO-7637-3	Part 3: Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines	CI	SAE J1113/12	Conducted immunity to transients as they are applied directly to the I/O lines of the test item.	Bench test: no shielded room required
ISO-10605	Road vehicles — Test methods for electrical disturbances from electrostatic discharge	ESD	SAE J1113/13 J551/15	ESD testing performed on a module on a bench or a vehicle in a temperature and humidity-controlled environment	Bench test: no shielded room required
CISPR 12	Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers	RE	SAE J551/2 (Note 11)	Vehicle Radiated Emissions	OTS or Vehicle Absorber lined chamber
CISPR 25	Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers	RE	SAE J551/4 (Note 12)	Clause 5: Vehicle portion of the standard. This is to measure the amount of noise generated by the vehicle will be induced into the on-board receiver antenna port.	Vehicle Absorber lined chamber
CISPR 25	Vehicles, boats, and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers	CE & RE	SAE J1113/41 (Note 13)	Clause 6: Component (module) test section where conducted and radiated emissions are measured.	Absorber lined chamber
CISPR 36	Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers	RE	SAE J551/5 (Note 14)	Vehicle Radiated Emissions	OTS or Vehicle Absorber lined chamber

Note 1 SAE J551-11 Withdrawn as a complete standard and reserved for use to document differences from ISO 11451-2. At the present time J551-11 is not used.

Note 2 SAE J551-12 Withdrawn as a complete standard and reserved for use to document differences from ISO 11451-3. At the present time J551-12 is not used.

Note 3 SAE J551-13 Withdrawn as a complete standard and reserved for use to document differences from ISO 11451-4. At the present time J551-13 is not used.

Note 4 SAE J1113-21 Withdrawn as a complete standard and reserved for use to document differences from ISO 11452-2. At the present time J1113-21 is not used.

Note 5 SAE J1113-24 Withdrawn as a complete standard and reserved for use to document differences from ISO 11452-3. At the present time J1113-24 is not used.

Note 6 SAE J1113-23 This standard has been withdrawn.

Note 7 SAE J1113-3 Withdrawn as a complete standard and reserved for use to document differences from ISO 11452-7. At the present time J1113-3 is not used.

Note 8 SAE J1113-22 Withdrawn as a complete standard and reserved for use to document differences from ISO 11452-8. At the present time J1113-22 is not used.

Note 9 SAE J1113-2 Withdrawn as a complete standard and reserved for use to document differences from ISO 11452-10. At the present time J1113-2 is not used.

Note 10 SAE J1113-28 Withdrawn as a complete standard and reserved for use to document differences from ISO 11452-11. At the present time J1113-28 is not used.

Note 11 SAE J551-2 Withdrawn as a complete standard and reserved for use to document differences from CISPR 12. At the present time J551-2 is not used.

Note 12 SAE J551-4 Withdrawn as a complete standard and reserved for use to document differences from CISPR 25. At the present time J551-4 is not used.

Note 13 SAE J1113-41 Withdrawn as a complete standard and reserved for use to document differences from CISPR 25. At the present time J1113-41 is not used.

Note 14 SAE J551-5 Withdrawn as a complete standard and reserved for use to document differences from CISPR 36. At the present time J551-5 is not used.

Table 1: Some of the main CISPR and ISO EMC standards for the automotive industry

(the test methods and/or limits) are commonly used for regulatory purposes. The regulatory bodies want to make sure that an item with an internal combustion engine or electric propulsion system does not cause unwanted interference with TV and radio reception when it drives past (or is used nearby) a residence or business. These standards also cover electrically driven vehicles while stationary and in the charging mode of operation. CISPR 25 is not typically used for regulatory purposes, it is commonly used by vehicle manufacturers to assure good performance of receivers mounted on-board the vehicle. If the radio mounted in the vehicle, boat or other device does not perform reliably, then consumer satisfaction and ultimately product sales could suffer.

Both CISPR 12 and CISPR 25 deal with automobiles (vehicles that operate on land) powered by internal combustion engines or an electric propulsion system, boats (vehicles that operate on the surface of water) powered by internal combustion engines, and devices powered by internal combustion engines (but not necessarily for the transport of people). This last category includes compressors, chainsaws, garden equipment, etc.

SAE Doc No.	Title	Type	Equivalent	Test Setup	Chamber Requirement
SAE J551/1	Performance Levels and Methods of Measurement of Electromagnetic Compatibility of Vehicles, Boats (up to 15 m), and Machines (16.6 Hz to 18 GHz)				SAE J551/1
SAE J551/5	Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, 150 kHz to 30 MHz	RE	CISPR 36 Vehicles	Vehicle ALSE may be used	OTS or Vehicle Absorber lined chamber
SAE J551/15	Vehicle Electromagnetic Immunity – Electrostatic Discharge (ESD)	ESD	ISO-10605 Clause 10	ESD test at the vehicle level would not need a shielded enclosure.	No shielded room required
SAE J551/16	Electromagnetic Immunity - Off-Vehicle Source (Reverberation Chamber Method) - Part 16 - Immunity to Radiated Electromagnetic Fields	RI	None	Vehicle Sized Reverberation Chamber is needed for this test. Method allows for the reverberation test along with a "hybrid test which utilizes direct illumination and reverberation.	Vehicle Sized Reverberation Chamber
SAE J551/17	Vehicle Electromagnetic Immunity - Power Line Magnetic Fields	RI	None	Magnetic Field RI testing at the vehicle level would not need a shielded enclosure.	No shielded room required
SAE J1113/1	Electromagnetic Compatibility measurement procedures and limits for vehicle components (except aircraft), 60 Hz-18 GHz	N/A	ISO-11452-1	Definitions	N/A
SAE J1113/4	Immunity to radiated electromagnetic fields- bulk current injection (BCI) method	RI	ISO-11452-4	Radiated immunity using the BCI method	Shielded room
SAE J1113/11	Immunity to conducted transients on power leads	CI	ISO-7637-2	Conducted immunity to transients	Bench test: no shielded room required
SAE J1113/12	Electrical interference by conduction and coupling - coupling clamp	CI	ISO-7637-3	Conducted immunity to different coupling mechanisms	Bench test: no shielded room required
SAE J1113/13	Electromagnetic compatibility procedure for vehicle components-immunity to electrostatic discharge	ESD	ISO-10605	ESD testing performed on a bench in a temperature and humidity-controlled environment	Bench test: no shielded room required
SAE J1113/27	Immunity to radiated electromagnetic fields reverberation method	RI	None	Reverberation chamber – Continuous Stirred	Reverberation chamber

Table 2: Some additional active SAE automotive EMC standards

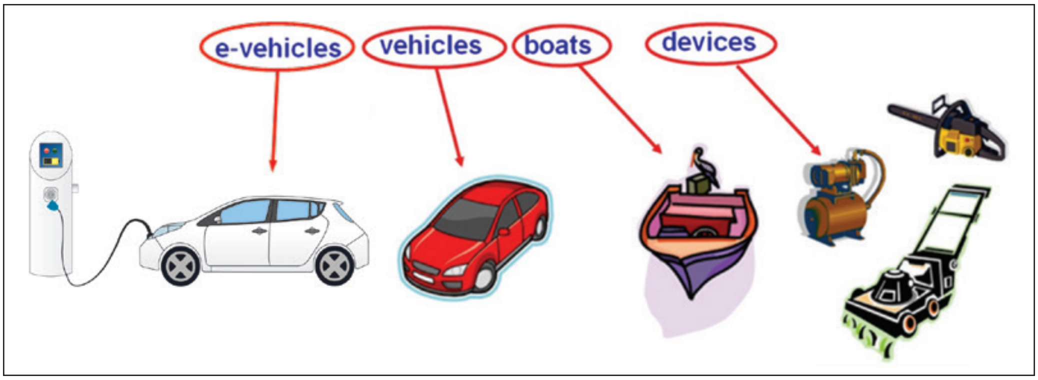

Figure 1: EUTs within the scope of CISPR 12 and CISPR 25

CISPR 12 would apply to all of these devices since they could affect the performance of nearby (off-board) receivers. CISPR 36 only applies to road vehicles driven by an electric propulsion system. It should be noted that CISPR 25 should only be considered for items that contain on-board receivers. As an example, a chainsaw with an internal combustion engine (but with no on-board receivers) would need to meet the requirements of CISPR 12, but CISPR 25 would not apply to this chainsaw since it does not utilize any on-board receivers.

CISPR 12 radiated emissions measurements are made at either 3-meter or 10-meter test distances (although the limits are for the protection of off-board receivers at a distance ≥ 10 meters). The measurements are normally done on an outdoor test site (OTS) or in an absorber-lined shielded enclosure (ALSE) if the ALSE can be correlated to an OTS. Measurements for boats can also be made on the water. The correlation of the ALSE to an OTS has been a point of discussion over the past few years within the group of experts who are responsible for the maintenance of CISPR 12. The specification currently does not provide a method to achieve this correlation. A working group has been tasked with developing a method to validate an ALSE, OATS, or OTS that could be used for vehicle measurements. The plan is to add a site validation annex to CISPR 12 7th Edition when it is published.

CISPR 36 radiated emissions measurements are made at 3-meter test distance with a loop antenna (although the limits are for the protection of off-board receivers at a distance ≥ 10 meters). The magnetic field emissions measurements are normally done on an OTS, open area test site (OATS), or in an ALSE. Site correlation/validation is currently not covered in CISPR 36. However, site validation is being considered as a work item for future editions.

CISPR 25 has two parts. One part deals with a full vehicle or system test in which the antennas mounted on the vehicle are used to sense the noise generated by the different electric and electronic systems mounted on the same vehicle. This test shows how much noise generated by the vehicle will be introduced into the radio antenna port (sort of a self-immunity test). The other section of the standard deals with conducted and radiated measurements of vehicle components and modules. In this article, we are going to concentrate on the module radiated emissions test section of CISPR 25, and only briefly highlight some of the additions needed to support electric vehicles. More specifically, this article will concentrate on the chamber requirements for the standard.

CISPR 25 states that the electromagnetic noise level in the test area has to be 6 dB lower than the lowest level being measured. Some of the radiated emissions limits found in CISPR 25 are as low as 18 dB (μV/m). This means that the ambient noise must be 12 dB (μV/m) maximum for a compliant environment. An RF-shielded room is typically used to keep RF signals from the external environment out of the test area so that the equipment under test (EUT) remains the dominant source of any radiated interference.

Although the shielded room is too small to support resonant modes at low frequencies, the number of modes increases with frequencies above the cut off of the chamber. When these resonant modes appear, they can add significant errors to the measurements. To reduce these errors, the shielded room covered with RF absorber material on its ceiling and interior walls greatly suppresses internal reflections so that the dominant coupling path is between the EUT and measurement antenna. By adding RF absorber to the walls and ceiling of the shielded room, the room becomes an absorber-lined shielded enclosure (ALSE). CISPR 25 in its current version (Ed 5:2021) covers a frequency range of 150 kHz to 5.95 GHz and to date absorber technology is unable to provide appreciable absorption at levels down in the 150 kHz range. One beneficial consequence of the low measurement frequency and the 1-meter measurement distance is the fact that the chamber sizes are electrically small at these low frequencies, so no significant resonant behavior appears. Therefore, the standard concentrates on absorber performance at 70 MHz and above. The standard requires that the absorber used must have

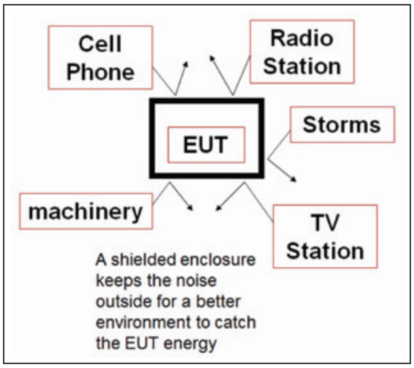

Figure 2: A shielded room blocks the noise from outdoor sources of EM interference

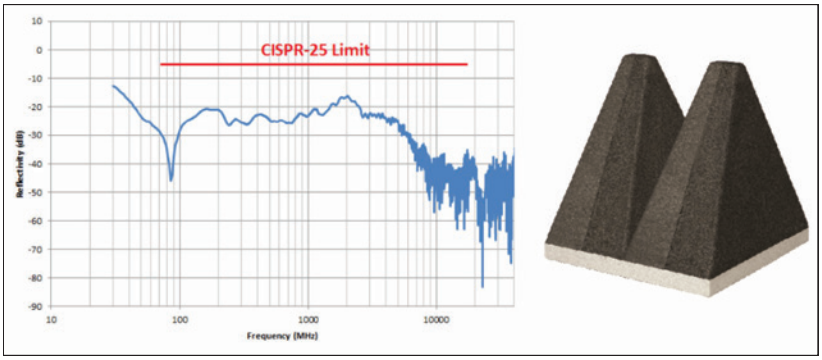

Figure 3: Typical performance of polystyrene absorber

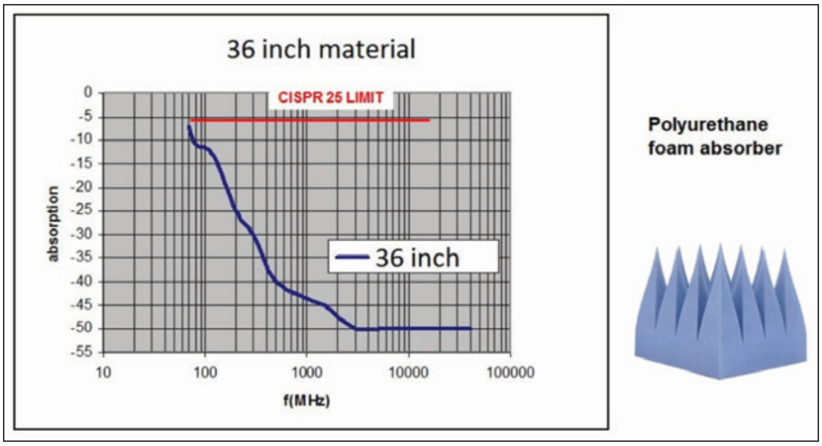

Figure 4: Typical performance of 36″ polyurethane absorber material

better than -6 dB absorption at normal incidence. To achieve these levels, there are several types of absorber technology on the market today.

One of the most efficient and cost-effective is a polystyrene-based absorber that combines a high-performance ferrite tile with a polystyrene EMC absorber, having a 60cm x 60cm base and 60cm height. The main absorber substrate is based on expanded polystyrene (EPS), which is volumetrically loaded with lossy materials, and environmentally friendly fire retardants. Advanced uniform loading in the manufacturing process results in superior RF performance and excellent absorption uniformity. The closed cell structure of this type of absorber makes it suitable for use even in high-humidity environments. These features all contribute to providing a better controlled and predictable chamber test environment. Figure 3 presents the performance of one type of hybrid polystyrene absorber.

An alternative polyurethane absorber typically 36 inches (1m) in depth, EHP 36, can be used with improved high frequency performance due largely to the increased material length. But, without the benefit of the matching ferrite material used in the hybrid, the polyurethane only absorber suffers from reduced low frequency performance. Figure 4 shows the typical performance of this material and its compliance with the CISPR 25 limit.

The layout and dimensions of the typical CISPR 25 ALSE is guided by the standard. Several guidelines must be followed when sizing the chamber and the starting point is the EUT, which determines the size of the test bench. Figure 5 shows a typical test bench used in a CISPR 25 and ISO 11452-2 type chamber.

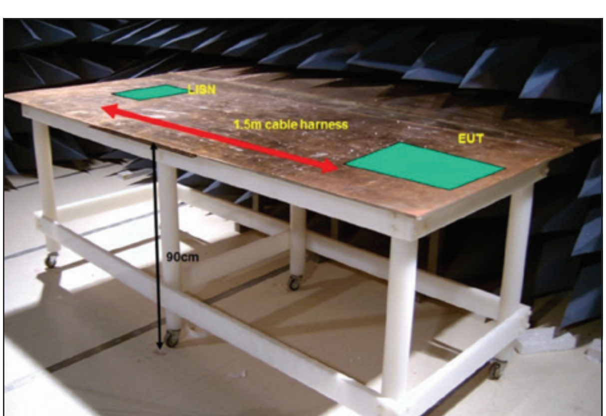

Figure 5: A typical conductive test bench

As Figure 5 shows, the bench must accommodate the largest EUT and all the cables that are needed to power and communicate with the device. The cables are routed in a cable harness that is positioned along the front edge of the bench. The cable harness itself is a significant component of the EUT and is the main component illuminated by the measurement antenna since at lower frequencies (frequencies for which the device under test is electrically small) the main coupling to radiated fields will occur through the cables feeding the device. This same procedure is used in MIL-STD 461 [3] and in ISO 11452 [4] and as shown in the illustration, a line impedance stabilization network is used to provide a defined impedance for the power to the device.

Figure 6 shows how the size of the bench is determined. The ground plane bench must extend all the way to the shield and in most cases, it is grounded to the wall of the shielded room. Grounding of the ground plane to the wall of the ALSE, especially if the chamber utilizes hybrid (ferrite/foam) absorbing material, has shown to reduce measurement system resonant conditions that may occur in the 10-70 MHz frequency range. The standard, however, does permit the bench to be grounded to the floor as an alternative.

As defined in CISPR 25, the minimum width of the reference ground plane (bench) for radiated emissions shall be 1000 mm, the minimum length of the ground plane for radiated emissions shall be 2000 mm, or the length needed to support the entire EUT plus 200 mm, whichever is larger.

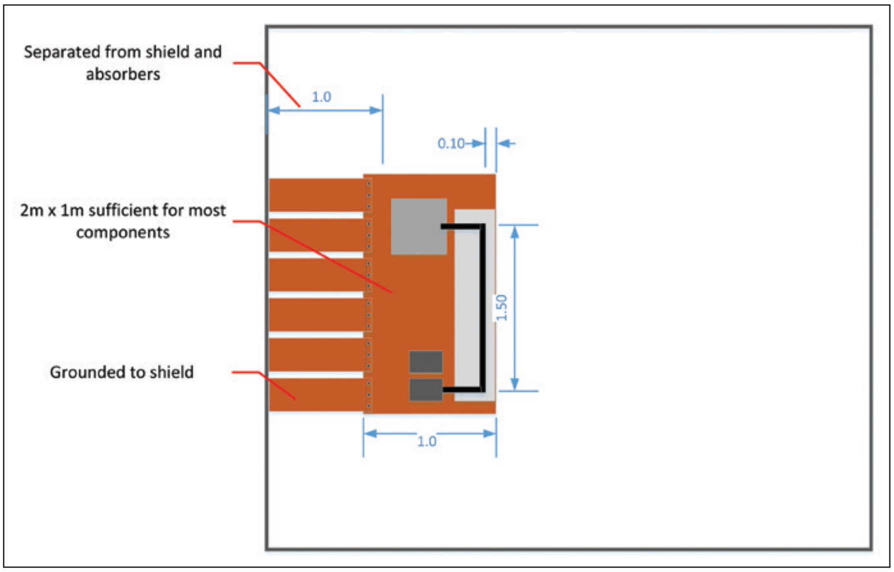

Figure 6: Sizing the bench

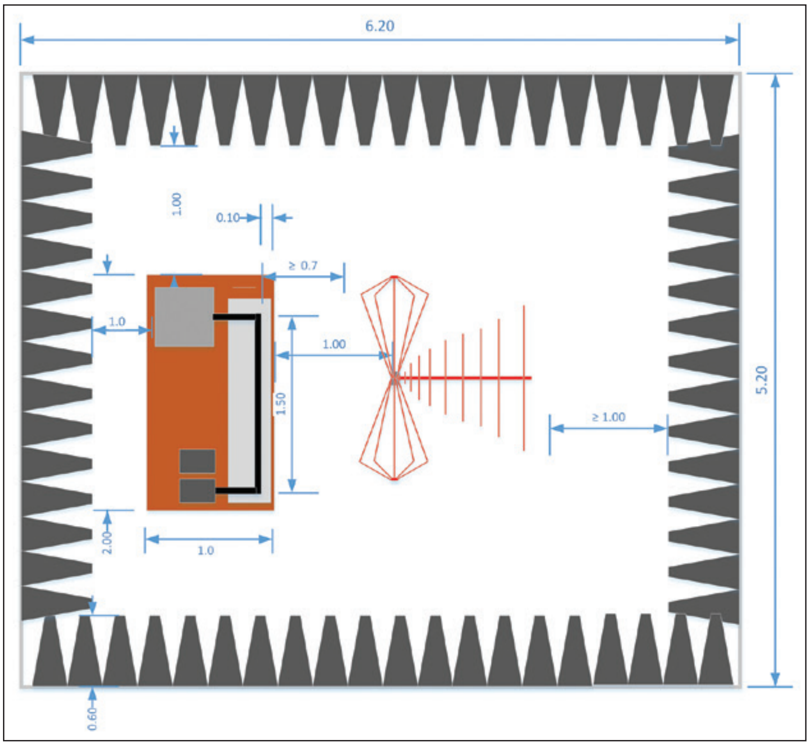

Figure 7: Width and length of the CISPR 25 chamber (multiple antenna types shown for reference)

The minimum overall dimensions of the compliant chamber are determined by a series of dimensional relationships based primarily on the size of the test bench. With the use of a hybrid absorber with a depth of 60 cm to line the walls and ceiling of the chamber, Figure 7 shows that the width and length of the chamber is determined by the length of the absorber material with a one-meter space left between the bench (actually the DUT) and the tips of the absorbing material. For chambers that will also be used for e-motor testing, the motor is also part of the EUT. In some cases, the motor is supported on a separate structure adjacent to the test bench for mechanical reasons as shown in Figure 8 on page 18. In this case, it still needs to be connected to the ground plane so in effect it will be an extension of the ground plane bench and subject to the minimum distances as defined in the standard.

For the height and the length of the chamber, CISPR 25 further defines the separation distances to be followed in determining the minimum space needed. The first and most critical is the test distance where emissions are to be measured at a minimum distance of 1 m from the cable harness to the antenna.

The other rule states that no part of the antenna can be closer than 1 m away from the tips of the absorbing material. These rules and recommended antennas define the length and height of the chamber. The 1 m distance to the cable harness is measured from the axis of the antenna elements for the monopole rod and the biconical antenna. For the log periodic dipole array (LPDA), the distance is measured from the tip of the antenna. Finally, for the horn antennas the distance is measured from the front face or aperture plane of the antenna. The longest antenna is usually the LPDA. A typical LPDA for the 200 MHz to 1 GHz range is about 1 m in overall length. In addition to the 1 m test distance and the 1 m for the antenna length, we have a 1 m clearance from the back of the antenna to the tips of the absorber. Figure 8 also shows the reference distances for an LPDA and bicon antennas in the chamber for the CISPR 25 setup.

The height of the chamber will be driven by the longest antenna. The longest vertical antenna is usually the active rod monopole. The monopole is used with an extremely electrically small ground plane. Per the standard, the monopole rod is about 80 cm in length and it is positioned such that the ground plane is at the same level as the bench which as Figure 5 suggests is nominally 90 cm in height. The 1 m rule for the separation between the antenna and the absorber tip will again determine the minimum height of the chamber as shown in Figure 9.

With the components discussed in the previous sections, a chamber lined with 0.6m long hybrid absorber with a size of 5.2 meters wide by 6.2 meters long and 3.6 meters high will meet the minimum size requirements for performing compliant CISPR 25 tests. And, as we will see in the next section of this article, this chamber will also meet the requirements of ISO 11452-2. Furthermore, since this is a shielded environment, most of the tests defined in standards requiring a shielded room can be performed inside the chamber described in the present section.

The CISPR 25 document prepared by the CISPR organization, and the requirements and guidelines on antennas and receivers, are already comprehensively defined in the CISPR 16-1-4 document [5]. The recommended antenna types used for the CISPR 25 measurements are therefore cross-referenced to the CISPR 16 document. For low frequencies, an active rod monopole antenna is preferred. At frequencies between 30 MHz and 200 MHz, a typical biconical antenna is the recommended antenna. From 200 MHz to 1 GHz, the antenna of choice is an LPDA and finally, from 1 to 5.95 GHz, the dual ridge horn (DRH) antenna can be a more compact and efficient antenna that easily meets the cross pole requirements of the standard, although lower gain LPDAs can still be used. It should be noted that bi-log antennas are not allowed for CISPR 25 measurements and all references to the bi-log antenna have been removed from CISPR 25 5th Edition.

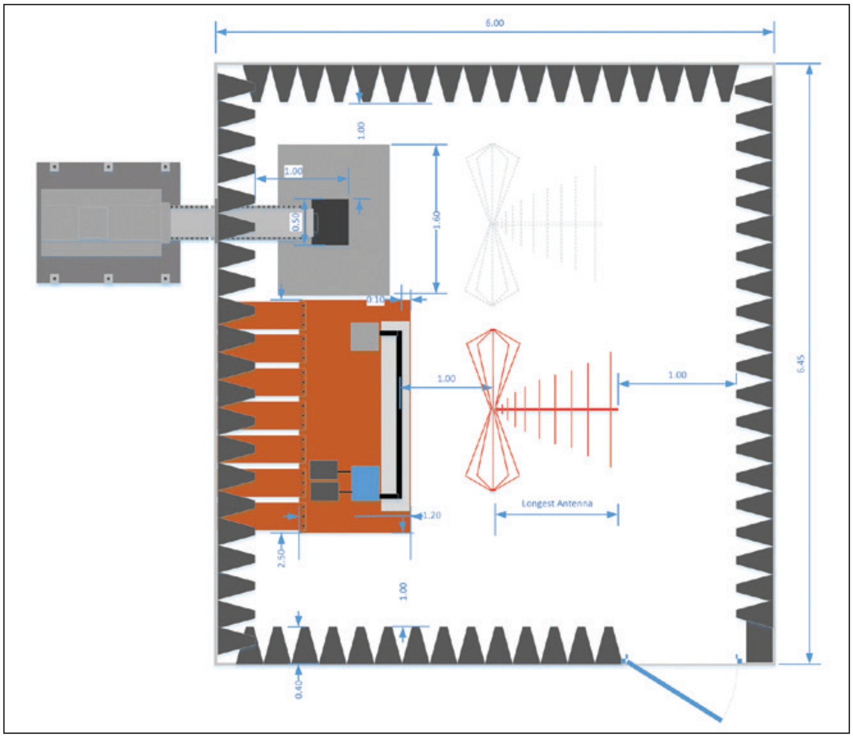

Figure 8: Increased width of CISPR 25 chamber for e-motor dyno (multiple antennas shown for reference)

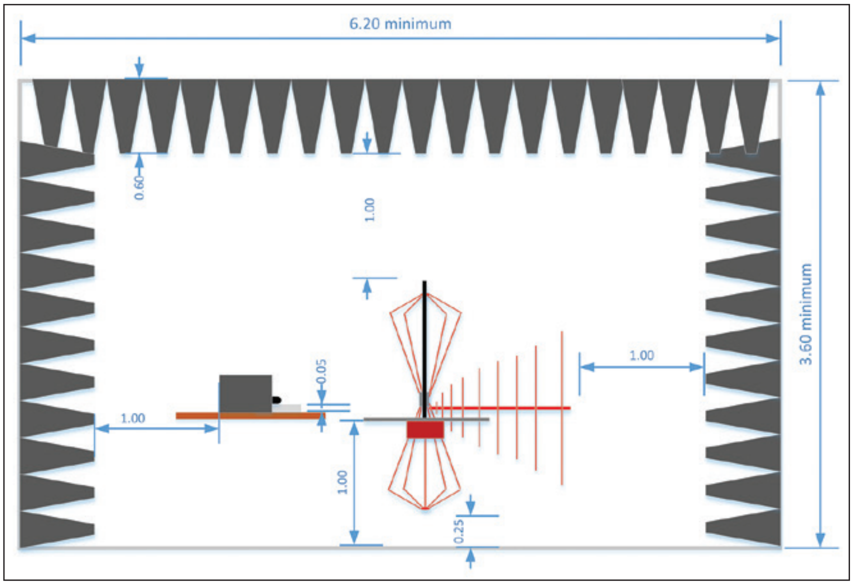

Figure 9: Height of the CISPR 25 chamber with multiple antennas shown for reference.

CISPR 25 5th Edition contains an annex (Annex I) that provides methods to validate the performance of an ALSE used for component-level radiated emission tests. The ALSE validation annex (Annex J) in CISPR 25 4th Edition contained two methods (one method based upon reference measurements and another method based upon modeling) for validating the ALSE. However, after the 4th Edition validation methods were used for several years, the experts responsible for CISPR 25 decided to include only the chamber validation method based upon modeling for CISPR 25 5th Edition. The ALSE validation method in CISPR 25 currently covers the frequency range of 150 kHz to 1 GHz. However, this remains an informative annex and experts are discussing ALSE validation methods >1GHz for future editions of CISPR 25.

As mentioned at the beginning of the article, CISPR 25 also covers the measurement of emissions received by a vehicle antenna for a full vehicle setup. CISPR 25 5th Edition contains special setups to be used for the testing of electric vehicles (EVs) and hybrid electric vehicles (HEVs) and the modules (inverters, batteries, etc.) to be used on EVs and HEVs. The committee found that special testing and limits are required for the testing of these electric-driven vehicles and their components.

These vehicles represent a special case since there are high currents and voltages involved not only in normal operation but also during charging cycles. There will be more detailed information on the measurement setups to be used for EV and HEV measurements under different connection and charging scenarios. The testing adds new conditions for when the vehicle is not being driven, but connected to the mains or a charging station. This is currently already required as part of the European directive ECE Regulation 10, which outlines the EMC requirements for wheeled vehicles marketed in the European Union. Although

ECE Reg 10 has its own limits for vehicle and ESA testing, it references both CISPR 25 and CISPR 12 for test setups and measurement techniques.

ISO 11452-2

ISO 11452-2 is a vehicle component immunity standard that applies to the 200 MHz to 18 GHz range. This standard, like many automotive, military, and aerospace standards, calls for moderately high fields to be generated. Table 3 shows the severity levels. At frequencies below 200 MHz, antennas get physically larger and also less efficient. For frequencies below 200 MHz, the standard recommends the methods stated in parts 4, 3, and 5 of the ISO 11452 standard. Those sections describe the bulk current injection, TEM, and stripline test methods. These other methods are far more efficient and economical to test for immunity to high fields.

Severity Level	Field
I	25 V/m
II	50 V/m
III	75 V/m
IV	100 V/m
V	(open to the users of the standard)

Table 3: ISO 11452-2 severity levels

The ISO 11452-2 standard also requires that the tests be performed in an ALSE. As is common with most immunity measurements, the intent of the test is to produce RF field levels that can be disruptive or damaging to the EUT; the shielded room removes the risk of unintended disruption to other sensitive devices or equipment outside of the test region. In the US, as in most other countries, there are limits on the radiation of energy without licenses, at frequencies that could affect licensed broadcasts.

These tests are conducted at frequencies above 200 MHz and as discussed previously, the chance of resonant modes being developed inside the shield room is increased, so to reduce measurement errors the use of an absorber is required. The chamber is treated such that the reflectivity in the area of the EUT is -10 dB. Figures 3 and 4 show that for the 200 MHz to 18 GHz range, the -10 dB level is higher than the typical reflectivity of the recommended materials. This means that the same absorber used in the CISPR 25 chamber can be used in the ISO 11452-2 chamber, with the relevant guidance on minimal separation distances between DUT, absorbers, and antennas. Antenna selection is in keeping with the need to generate the required field levels in the most effective and efficient manner given the cost of amplifiers. It is recommended that a dual ridge horn antenna be used for the 200 MHz to 2 GHz range. Above that, octave horns and standard gain horns with high gain are the preferred antenna choice.

CONCLUSION

In Part 1 of this article, the reader has been introduced to the two main standards for automotive vehicles and components with an overview of the revision status of these and several related standards produced by CISPR and ISO. In Part 2 of this article, we will concentrate on designing a chamber to meet the requirements of CISPR 25 and show how the same chamber can be used for ISO 11452-2.

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EVALUATION OF INTELLIGENT AND NON-STATIC POWER SOURCES: A RATIONAL CLARIFICATION

Editor's Note: *The paper on which this article is based was originally presented at the 2021 IEEE International Symposium on Product Compliance Engineering (ISPCE), conducted virtually in September 2021. It is reprinted here with the gracious permission of the IEEE. Copyright 2021, IEEE.*

INTRODUCTION

Power sources are becoming more complex as systems are devised to supply power over communication cables and other infrastructure cabling independent of the mains power supplied from the electrical grid. This document proposes to clarify how to properly test and measure the voltage, current and power with regard to these power supplies or sources that do not behave as a static mains source since the control system is embedded in the power source and includes feedback from the remote powered equipment or distribution cabling to the source to maintain proper operation, or even initiate a continuous power output.

Examples of these Intelligent or Non-Static Power Sources, include USB, Power over Ethernet (PoE), Reverse Power Feeding (RPF), and "intelligent fault managed" technologies. These technologies and Intelligent fault managed systems (sometimes called "Fault Managed Power Systems") may include sources that sense a specified connection to some remote equipment and then turn on power, and/or, disconnects/reduces the voltage level when a fault condition is sensed. A sensed fault condition could include an abnormal load impedance or circuit, and/or a simulated human bridging.

By Jim Wiese and Peter Perkins

Failure to be able to perform appropriate tests and make proper measurements based on just evaluating the source equipment can lead to unsafe equipment being placed into service and potentially create shock and fire hazards in the equipment or connected cabling.

EASE OF USE

There are many things that we do from our training and experience without thinking twice about it; we call these basic assumptions and they are part of every little piece of our life. When it comes to product safety testing there is always the assumption that the needed power to run the Equipment Under Test (EUT) is readily available and comes from either DC or AC mains supplies. As such, we only reference it on the product nameplate as required by the safety standard, which is generally adequate. But we now need to examine this in more detail to properly apply the evaluation of secondary outputs from the equipment under test, called Power Sourcing Equipment (PSE), or the power into a remote device called the Powered Device (PD). The process used is well-known and typically called provisioning or configuring, which we will use in this discussion. Provisioning (typically software/firmware) or configuring (typically hardware) includes specifically providing the firmware/software plus the load equipment which needs to be adjustable for the various Normal, Abnormal, and Fault tests required. It may also be necessary to use support equipment that communicates with the PSE to generate certain outputs or signals that need to be measured.

Examining the usual situation for many appliances, office and commercial single-phase equipment that receive power from the mains, the expectation is that the power source will be available in the test lab, provide the needed nameplate voltage & current and have the capacity to handle the Normal, Abnormal and Fault currents needed for proper operation during testing. Using the raw grid power certainly will be adequate for testing such equipment; having an intermediate, adjustable power supply (local generator or variable power supply) needs more scrutiny before testing begins. None of this is even mentioned in the safety standards we normally use; it is assumed.

When a PSE product also supplies power to downstream equipment there can be difficulty understanding it fully, without making assumptions about the characteristics. When evaluating a PD, the rated input (Voltage and Current or Power) must be understood. However, for the PSE which is sourcing the power to the PD, the safety standards generally do not require any labeling of these sources. So the test lab has to determine and understand the characteristics of the source to evaluate a PD, and maybe more importantly, must understand how to ensure that the PSE output source is placed into a situation that allows the tests to be performed in a manner that replicates the intent of the safety standard. And this can involve a considerable knowledge of the equipment and include support equipment, special software/firmware, and even connection of a representative PD. These concepts may be foreign to many product safety evaluations that often include only the specific equipment submitted for evaluation. When additional equipment is needed this is often called a system-level test, and many safety standards are written based on testing a single unique piece of equipment since the equipment connected in normal use is often unknown or may not even be manufactured by the same vendor. Since non-static or intelligent sources use additional control information (at one or both ends) this must be clearly disclosed and, in most cases, proper transmit and receive modules provided just to get the circuit to operate at all. Any necessary load equipment supplied is in addition to other provisioning/configuring software/firmware equipment that may be necessary.

It should be noted that IEC 62368-1 is specifically referred to as an equipment standard and as such many labs and manufacturers test PSE's and PD's independently as standalone unique entities. It is often argued that IEC 62368-1 is not a system standard and as such equipment at the remote end (whether PSE or PD) is outside the scope of the particular evaluation. This creates quite a conundrum, as it is expected that test and load the equipment is necessary to obtain the expected conditions, but without an actual opposite end of the system or a device that is representative of the worst-case device, (or maybe even cabling where IR losses can be a significant load), you cannot attain the desired condition for the various tests. In some cases, the manufacturer of a PSE or PD does not even manufacturer the far end equipment, making this much more difficult. One simple example is PoE where a PoE switch might be manufactured by a large switch manufacturer and it may have 4 to 96 ports, with some maximum amount of power it can source with PoE powering (for instance 800 watts total), and software controls how much wattage is distributed to cabling and PD's (such as an IP phone, security camera, or even LED lighting) based on what devices are connected and their needed power consumption. And more often than not PD manufacturers do not make the PSE's and visa versa.

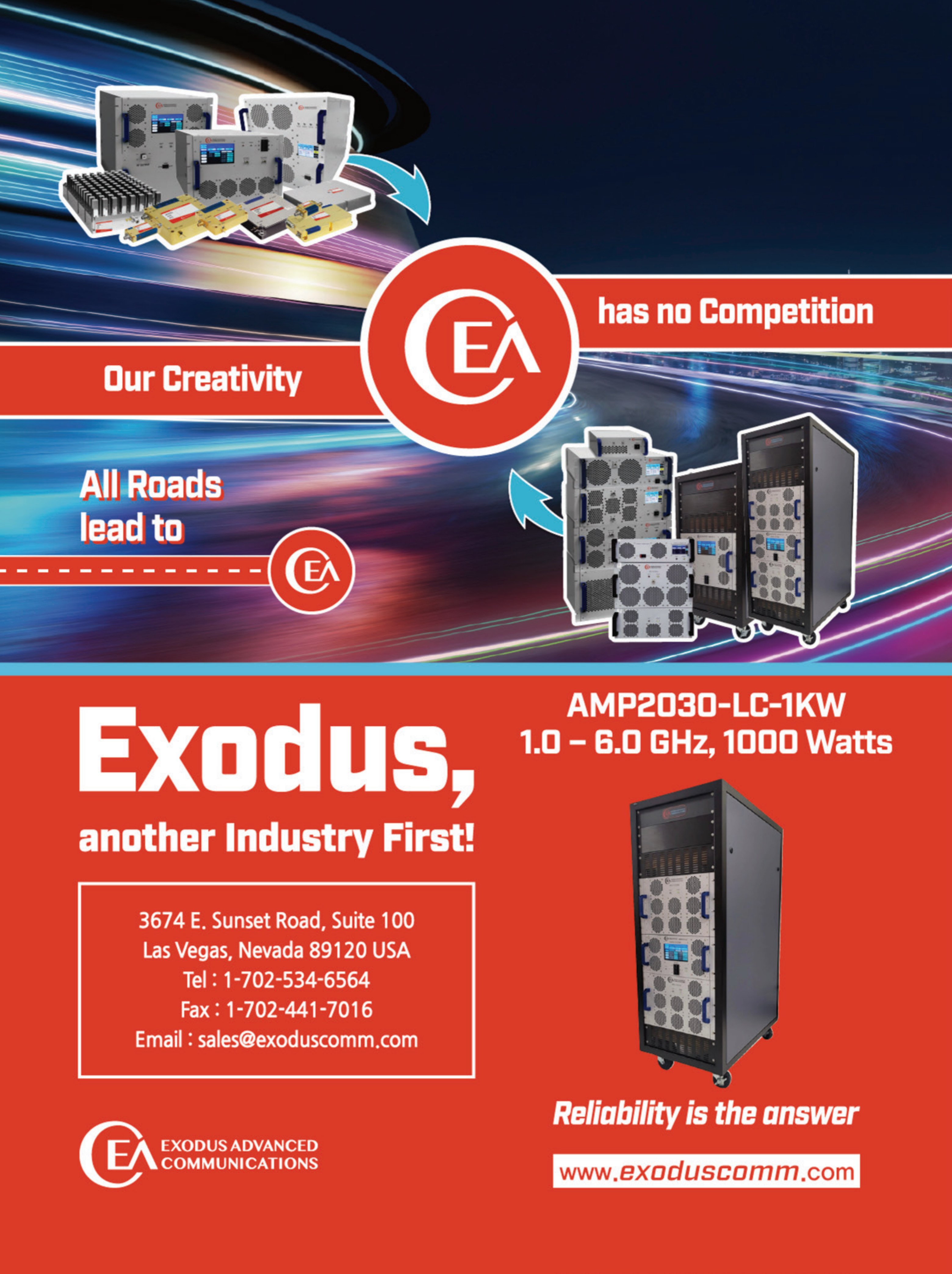
This conundrum requires rethinking of assumptions and requirements for IEC 62368-1; where provisioning/configuration for proper testing requires a system-level concept and setup for the purposes of evaluating a single entity within the system, and also a thorough understanding of the products operation characteristics by the test lab. Both the equipment manufacturer and the test lab must come to an agreement on the equipment provided for the test setup which will allow the full evaluation of the equipment being tested; additional modules, etc. either PSE or PDs as will be required for the evaluation.

IEC 62368-1 as well as IEC 60950-1 and IEC 62368-3, and most other standards assume that External Information and Communication Technology (ICT) circuits that have power sourced from the PSE to the PD are fed by circuits that output a maximum voltage into an open circuit without a load, the measurement is commonly called the open-circuit voltage. In general, under load the voltage might sag as resistance is lowered (the load on the PSE is increased), and current increases until fold-back occurs (typically with switching power sources) or maximum short circuit current is supplied (typically with linear sources). These sources might respond as expected to resistive loads at the resistance values such as 2000 ohms or 5000 ohms defined in a safety standard. These values simulate a typical human body resistance under a specific condition. To be considered safe, the source either must supply a safe touch current or an acceptably low touch voltage as defined in IEC 62368-1 Table 4, 'Electrical energy source limits…' to provide electric shock protection. These values are based on IEC 60479-1 using IEC 60990 measurement techniques.

However, many newer technologies and supplies have no output (or have a very small pre-turn-on or tickling output) into resistive loads. As such, it is becoming apparent that testing is not being performed as intended which includes into normal PD's. This includes but is not limited to determination of the source classification, which affects criteria such as insulation requirements. It also affects surface temperature measurements and others to thermal loading tests as the sources are not operating at anywhere near their maximum output.

For example, PoE outputs periodic or small output voltages looking for an impedance signature from a PD. Until it sees that handshaking signature, it will not supply normal voltage and currents to power to a PD. And into the open circuit or other conditions (such as non-capacitive loads) specified in IEC 62368-1 the PoE PSE will only send out these small signals indefinitely.

The vast majority of test reports reviewed from labs all over the world indicate no voltage or only small voltage reported for these types of PoE External circuits. This is not unexpected since IEC 62368-1 defines using non-capacitive loads and/or open circuits to measure or load equipment. Since these conditions do not cause proper handshaking, the source activation is not accomplished such that the circuit can be characterized or evaluated against the requirements in the safety standard. Testing of the equipment or circuit(s) under the defined load conditions cannot be performed as intended until this initial check on the circuit characteristics has been successfully completed which requires a load simulator or a representative worst-case PD and cabling.



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Another example is a technology that operates well beyond RFT-V and RFT-C normally (around 330-400VDC with several thousands of effective watts) but, as IEC 62368-1 is interpreted today, would have no output since it requires a PD that is somewhat capacitive and specially designed for that PSE. The output is just an occasional pulse into an open circuit or resistive non-capacitive load which IEC 62368-1 specifies for testing. Again, this is a failure of providing proper configuration guidance in the standard to get the circuit up and running then characterized before testing to specific load conditions.

The details and intent are anticipated to be clarified in IEC 62368-1 4th edition in Annex B and these same clarifications described in IEC 62368-2 Rationale to ensure these circuits are tested and reported suitably. This will be accomplished by using a proper system level method to simulate normal operation, including the conditions assumed in IEC 62368-1 with normally tested with open circuits and various loads, including non-capacitive loads, applied. However, a question may be asked how to do an open-circuit voltage measurement whether at the PSE source or the PD load when an added cable/load is required. The measurement may have to be made under a minimal load. Other required test cases may use specific resistances to load or measure circuits and these can trip or turn off the sources. The answers are not simple and require considerable thought during the testing process. Reasonableness must be used in performing the test to demonstrate conformity with the intent of the standard.

Outlined here is specific text proposed clause-by-clause for IEC 62368-1 to cover the issues as discussed.

The final specific text in the standard will be adjusted, of course, dependent upon which version of the standard is being updated.

LAYING OUT SPECIFIC CHANGES NEEDED IN IEC 62368-1

4.1.3 Equipment design and construction

Equipment shall be so designed and constructed that, under **normal operating conditions** as specified in Clause B.2, **abnormal operating conditions** as specified in Clause B.3, and **single fault conditions** as specified in Clause B.4, **safeguards** are provided to reduce the likelihood of injury or, in the case of fire, property damage.

Parts of equipment that could cause injury shall not be **accessible**, and **accessible** parts shall not cause an injury.

Where equipment is designed such that one or more of its power sources require a specific configuration technique, a load or protocol or software to turn on the supply output, keep the supply output active or obtain the intended output voltage, current or power under normal, abnormal and single fault conditions plus a method of achieving that output shall be provided for evaluation and testing and employed.

For example, connecting intended representative worst-case loads or external powered devices, and repeating with any needed load including under fault conditions in the distribution wiring and applied loads.

This is critical for determining characteristics such as output voltage and current for ES and PS classifications, use on building and other wiring, see IEC 62368-1, Annex Q, circuits intended for connection to building wiring, as well as proper loading for heating tests.

These examples are not necessarily all inclusive.

Compliance is checked by inspection and by the relevant tests.

5.6.4.2.3 Internal circuit as the source

Where the source is a circuit within the equipment, the **protective current rating** of the circuit is:

- The rating of the overcurrent protective device if the current is limited by an overcurrent protective device; or
- The maximum output current, if the current is limited by the source impedance of the supply. The output current is measured with any resistive load including a short-circuit measured after stabilization, usually 60 s or more after the application of the load if current is limited by impedance or the current limiting device is a fuse, a circuit breaker or a PTC device, or at longer times such as 5 s or more in other cases.

If the source is a type that does not output normal voltages/currents into a resistive load, the source needs to be connected to a terminating device/impedance that turns on the source voltage/current and creates the needed test conditions including the worst-case test conditions.

5.7 Prospective touch voltage, touch current and protective conductor current

5.7.1 General

Measurements of **prospective touch voltage**, **touch current**, and **protective conductor current** are made with the EUT supplied at the most unfavorable supply voltage (see B.2.3).

Activation: If a power source is of a type that requires handshaking/negotiating between a load or intelligently detects loads and as a result does not allow output of normally occurring voltages/currents into resistive loads, the source needs to be connected to a terminating device/impedance that turns on the source voltage/current and generates an output under the *rated* conditions specified.

6.2.2 Power source circuit classifications

6.2.2.1 General

An electric circuit is classified PS1, PS2, or PS3 based on the electrical power available to the circuit from the power source. The electrical power source classification shall be determined by measuring the maximum power under each of the following conditions:

- For load circuits: a power source under normal operating conditions as specified by the manufacturer into a worst-case fault (see 6.2.2.2);
- For power source circuits: a worst-case power source fault into the specified normal load circuit (see 6.2.2.3).

If the source or load circuit are of a type that does not allow output of normal occurring voltages/currents into resistive loads, the source needs to be connected to a activation terminating device/impedance that turns on the source voltage/current and generates the worst-case power delivery under normal and fault conditions. If measuring a load device of this type, the source is the maximum effective power that can be delivered during normal operating conditions as well as faults.

The power is measured at points X and Y in Figure 34, Power measurement for worst-case fault and Figure 35, Power measurement for worst-case power source fault.

6.5.2 Requirements for interconnection to building wiring

Equipment intended to provide power over the wiring system to remote equipment shall limit the output current to a value that does not cause damage to the wiring system, due to overheating, under any normal operating conditions or external load conditions. The maximum continuous current from the equipment shall not exceed a current limit that is suitable for the minimum wire gauge specified in the equipment installation instructions.

NOTE: This wiring is not usually controlled by the equipment installation instructions, since the wiring is often installed independent of the equipment installation.

PS2 circuits or PS3 circuits that provide power and that are intended to be compatible with LPS to **external circuits** (see Annex Q) shall have their output power limited to values that reduce the likelihood of ignition within building wiring during normal operating and external fault conditions.

External paired conductor cable circuits, such as those described in Table 13, 'External circuits transient voltages', ID numbers 1 and 2 having a minimum wire diameter of 0,4 mm, shall have the current limited to 1,3 Arms or d.c.

EXAMPLE: Time/current characteristics of type gD and type gN fuses specified in IEC 60269-2 comply with the above limit. Type gD or type gN fuses rated 1 A, would meet the 1,3 A current limit.

Compliance is checked by test, inspection and where necessary *by the requirements of Annex Q.*

ADDITIONAL CHANGES IN THE SUPPORTING ANNEXES

B.3.5 Maximum load at output terminals

Output terminals of equipment supplying power to other equipment, except socket-outlets and appliance outlets directly connected to the **mains**, are connected to the most unfavorable load impedance, including short-circuit.

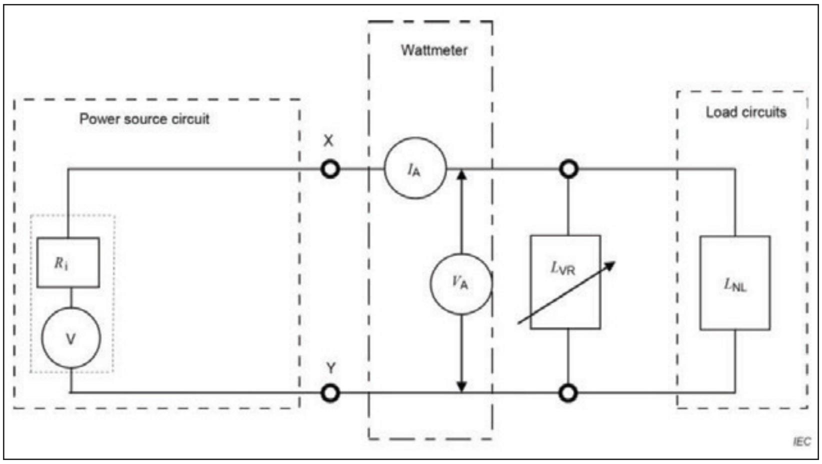

Figure 1: IEC 62368-1, Figure 34, Power measurement for worst-case fault

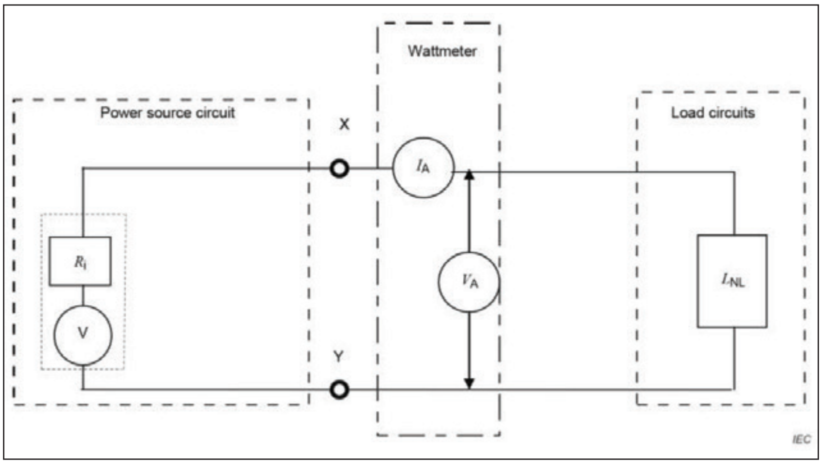

Figure 2: IEC 62368-1, Figure 35, Power measurement for worst-case power source fault

If the source is a type that does not output normal voltages/currents into a resistive load, the source needs to be connected to a terminating device/impedance that turns on the source voltage/current and creates the worst case normal and abnormal conditions.

E.1 Electrical energy source classification for audio signals When classifying audio signals as an electrical energy source (see Table E.1), the equipment shall be operated to deliver maximum **non-clipped output power** into its **rated load impedance**. The load is removed and the electrical energy source class is determined from the resulting open-circuit output voltage.

If the source is a type that does not output normal voltages/currents into a resistive load, the source needs to be connected to a terminating device/impedance that turns on the source voltage/current which creates the worst case normal and abnormal conditions.

Q1 Limited power source

Q.1.1 Requirements

A limited power source shall comply with one of the following:

a) The output is inherently limited in compliance with Table Q.1; or

b) Linear or non-linear impedance limits the output in compliance with Table Q.1.

If a PTC device is used, it shall:

a) Pass the tests specified in Clauses 15, 17, J.15 and J.17 of IEC 60730-1:2013; or

b) Meet the requirements of IEC 60730-1:2013 for a device providing Type 2.AL action;

c) A regulating network limits the output in compliance with Table Q.1, both with and without a simulated single fault (see Clause B.4), in the regulating network (open circuit or short-circuit); or

d) An overcurrent protective device is used and the output is limited in compliance with Table Q.2; or

e) An IC current limiter complying with Clause G.9.

Where an overcurrent protective device is used, it shall be a fuse or a non-adjustable, non-autoreset, electromechanical device.

If the power source is of type that requires handshaking/negotiating between a load or intelligently detects loads and as a result does not allow output of normally occurring voltages/currents into resistive loads, the source needs to be connected to a terminating device/impedance that turns on the source voltage/current and generates the power delivery under the conditions specified.

Q.1.2 Test method and compliance criteria

*Compliance is checked by inspection and measurement and, where appropriate, by examination of the manufacturer's data for **batteries**. **Batteries** shall be fully charged when conducting the measurements for U_{oc} and I_{sc} according to Table Q.1 and Table Q.2. The maximum power shall be considered, such as from a **battery** and from a **mains** circuit.*

*The load referenced in footnotes b and c of Table Q.1 and Table Q.2 and in Q1.1. is adjusted to develop maximum current and maximum power transfer in turn. **Single fault conditions** are applied in a regulating network according to Clause Q.1.1, item c) while under these maximum current and power conditions.*

Q.2 Test for external circuits – paired conductor cable

*Equipment supplying power to an **external circuit** paired conductor cable intended to be connected to the building wiring shall be checked as follows.*

If current limiting is due to the inherent impedance of the power source, the output current into any resistive load (see note e of Q.1 or f of Q.2), including a short-circuit, is measured. The current limit shall not be exceeded any time after 60 s of test. If current limiting is provided by an overcurrent protective device having a specified time/current characteristic:

- *The time/current characteristic shall show that a current equal to 110 % of the current limit will be interrupted within 60 min; and*
- *The output current into any resistive load, including a short- circuit, with the overcurrent protective device bypassed, measured any time after 60 s of test, shall not exceed 1 000/U where U is the output voltage measured in accordance with B.2.3 with all load circuits disconnected (see note e of Q.1 or f of Q.2).*

If current limiting is provided by an overcurrent protective device that does not have a specified time/ current characteristic:

- *The output current into any resistive load (see note e of Q.1 or f of Q.2), including a short-circuit, shall not exceed the current limit any time after 60 s of test; and*
- *The output current into any resistive load (see note e of Q.1 or f of Q.2), including a short-circuit, with the overcurrent protective device bypassed, measured any time after 60 s of test, shall not exceed 1 000/U, where U is the output voltage measured in accordance with B.2.3 with all load circuits disconnected (see note e of Q.1 or f of Q.2).*

Output voltage [a] U_{oc}		**Output current** [b d] I_{sc}	**Apparent power** [c d] S
V AC	V DC	A	VA
$U_{oc} \leq 30$	$U_{oc} \leq 30$	$\leq 8,0$	≤ 100
-	$30 < U_{oc} \leq 60$	$\leq 150/U_{oc}$	≤ 100

a. U_{oc}: Output voltage measured in accordance with B.2.3 with all load circuits disconnected. (see note e for exception) Voltages are for substantially sinusoidal AC and ripple free DC For non-sinusoidal AC and DC with ripple greater than 10 % of the peak, the peak voltage shall not exceed 42,4 V. b Isc: Maximum output current with any load, including a short-circuit.

b. *S* (VA): Maximum output VA with any load.

c. Measurement of Isc and S are made 5 s after application of the load if protection is by an electronic circuit and 60 s in case of a PTC device or in other cases. The limits are not just at 5 s and 60 s respectively, but also apply any time after that.

d. For all notes in Table Q.1,

- If the power source is of type that requires handshaking/negotiating between a load or intelligently detects loads and as a result does not allow output of normally occurring voltages/currents into resistive loads, the source needs to be connected to a terminating device/impedance that turns on the source voltage/current and generates the power delivery under the conditions specified.
- Voltage and current are maximum ACrms, or DC peak values, Power is the effective power, and all apply regardless of frequency, or if DC is continuous or pulsed.

Table Q.1: Limits for inherently limited power sources

CONCLUSIONS

Although conceptually straightforward, the implementation of adequate requirements to achieve the needed full evaluation of either a PSE or PD unit is complex when fitted into the overall requirements of a standard such as IEC 62368-1 in order to ensure that they each will operate independently in a safe manner.

The details presented here are based upon personal experience in dealing with the evaluation process for this type of equipment, a detailed understanding of the requirements as laid out in the standard plus the application of reasonableness, a Hazard Based Standard adaptation technique, to the process of evaluation for these units.

The detail here will provide the user with a comprehensive roadmap through IEC 62368-1 outlining the specific details that need to be considered in the evaluation.

Each party in the assessment process needs to apply reasonableness in adapting these evaluations, as is done in other situations (which are usually not as complex) to ensure a complete evaluation of the hazards by showing that the safeguards placed are adequate to protect the user and the local environment.

ACKNOWLEDGMENT

The authors thank IEC TC 108 HBSDT for feedback in dealing with this unresolved problem and to the IEC directly for base quotations from IEC 62368-1 shown with modifications here in detail in order to deal with this ongoing difficult issue.

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Output voltage [a] U_{oc}		Output current [b d] I_{sc}	Apparent power [c d] S	Current rating of overcurrent protective device [e]
V AC	V DC	A	VA	A
≤ 20	≤ 20			≤ 5,0
$20 < U_{oc} \leq 30$	$20 < U_{oc} \leq 30$	$\leq 1000/U_{oc}$	≤ 250	$\leq 100/U_{oc}$
-	$30 < U_{oc} \leq 60$			$\leq 100/U_{oc}$

a. U_{oc}: Output voltage measured in accordance with B.2.3 with all load circuits disconnected (see note f for exception). Voltages are for substantially sinusoidal AC and ripple free DC For non-sinusoidal AC and for DC with ripple greater than 10 % of the peak, the peak voltage shall not exceed 42,4 V.

b. Isc: Maximum output current with any load, including a short-circuit, measured 60 s after application of the load. The limits are not just at 60 s, but also apply any time after that.

c. S (VA): Maximum output VA with any load measured 60 s after application of the load. The limits are not just at 60 s, but also apply any time after that

d. Current limiting impedances in the equipment remain in the circuit during measurement, but overcurrent protective devices are bypassed.

- The reason for making measurements with overcurrent protective devices bypassed is to determine the amount of energy that is available to cause possible overheating during the operating time of the overcurrent protective devices.

e. The current ratings of overcurrent protective devices are based on fuses and circuit breakers that break the circuit within 120 s with a current equal to 210 % of the current rating specified in the table.

f. For all notes in Table Q.2,

- If the power source is of type that requires handshaking/negotiating between a load or intelligently detects loads and as a result does not allow output of normally occurring voltages/currents into resistive loads, the source needs to be connected to a terminating device/impedance that turns on the source voltage/current and generates the power delivery under the conditions specified.
- Voltage and current are maximum ACrms, or DC peak values, Power is the effective power, and all apply regardless of frequency, or if DC is continuous or pulsed.

Table Q.2: Limits for power sources not inherently limited (overcurrent protective device required)

PRODUCT LIABILITY LAW AND ITS EFFECT ON PRODUCT SAFETY

Does the Law Provide Useful Guidance?

Product liability is one of the most important U.S. legal developments in the last 100 years. It has directly impacted consumers, product users, manufacturers, and others who produce and sell products, government regulators, insurance companies who insure the defendants in these claims and lawsuits, and, of course, lawyers for the plaintiffs and defendants. Product liability cases have bankrupted manufacturers and insurance companies, caused manufacturers to stop making and selling certain products, and created an entire industry of those who seek compensation for injuries and loss, those who seek to make money prosecuting or defending the parties in these claims and lawsuits and, finally, those who seek to make products safer.

The goal of any manufacturer is to prevent or minimize the possibility of incidents, ensure compliance with all applicable legal, safety, and technical requirements, and do what they can to make themselves and their products defensible in the event incidents or alleged non-compliances occur. To do that and to minimize or prevent liability, manufacturers need to understand the legal requirements, standards, and best practices so they can design, manufacture, and sell reasonably safe and compliant products, adequately monitor their products after their sale, and comply with any resulting post-sale regulatory requirements.

NEGLIGENCE AND STRICT LIABILITY

Negligence, which has been in existence for hundreds of years, is the original theory used by product users against product sellers. A jury uses the following variables to decide whether the manufacturer or product seller was negligent: 1) the probability that injury would result from the manufacturer's conduct; 2) the gravity of the harm that could be expected to result should an injury occur; and 3) the burden of taking adequate precautions to avoid or minimize the injury.

In other words, if the probability of harm and the gravity of the harm are greater than the burden of taking precautions to reduce the risk, a manufacturer could be deemed negligent if they do not minimize the risk. Another way to state it is that the manufacturer

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By Kenneth Ross

failed to exercise reasonable care in designing and manufacturing its product and that this failure was the cause of the injury.

In negligence cases, the injured party had to prove that the product caused the plaintiff's harm, that the product was unsafe when it left the hands of the manufacturer or product seller, and that the lack of safety was brought about through the negligence of a specific person at the manufacturer.

In the 1960s, strict liability was adopted. What strict liability did was eliminate the need for the injured party to prove negligence and specifically who was negligent. All they had to prove was that there was a defect in the product, that the defect was in existence at the time the product left the manufacturer's or seller's control, and that the defect caused the injury. The jury was allowed to infer that someone was negligent because the product was defective, but it was unimportant to identify that person.

Under strict liability, the manufacturer was liable even if their quality control and manufacturing procedures were reasonable and not negligent. In other words, even if they did a good job of designing or manufacturing the product, the manufacturer could be held liable if the product turned out to be defective and dangerous and it injured a consumer.

The adoption of strict liability started an explosion of claims and lawsuits because consumers and lawyers believed that they could more easily recover against manufacturers. Even more important, strict liability resulted in more lawyers being willing to take product liability cases and sue.

DEFECTS

Over the years, the focus in any product liability case has evolved so that it now deals with any of three clearly separate defects. So, when we look at the law to help us understand whether the product is reasonably safe, we need to look at these three defects.

Manufacturing Defects

A manufacturing defect exists if the product "departs from its intended design even though all possible care was exercised in the preparation and marketing of the product." In other words, even if the manufacturer's quality control was the best in the world, the fact that the product departed from its intended design means that it has a manufacturing defect. The plaintiff need not prove that the manufacturer was negligent, just that the product was defective. The focus is on the final product, not on the conduct of the manufacturer.

Common examples of manufacturing defects are products that are physically flawed, damaged, incorrectly assembled, or do not comply with the manufacturer's design specifications. The product turned out differently from that intended by the manufacturer. If that difference caused injury, the manufacturer will be liable. There are very few defenses.

Of course, the best way to defend against this allegation is to have good documentation that the product complied with design and manufacturing specifications so that the manufacturer can argue that, if there was something wrong, it was caused by someone else in the chain of distribution or by the consumer.

Design Defects

Design defects are very different. With manufacturing flaws, there are typically only a handful of products that have the problem. And it usually is proven or can be inferred that someone made a mistake or was negligent.

With design defects, the manufacturer intended for the product to be designed and manufactured in a certain way, and the product was manufactured in the way in which it was designed. The problem was that there was something deficient with the design.

Under the law in many states, a product is deemed to be defective in design if a foreseeable risk of harm posed by the product "could have been reduced or avoided by the adoption of a reasonable alternative design," and the failure to use this alternative design makes the product not reasonably safe. Within the scope of this definition, the jury can hold the manufacturer liable if they believe that the product could have been or should have been made safer.

This test is much more subjective than the test for manufacturing defects and this subjectivity is the cause of most of the problems in product liability today. Manufacturers cannot easily determine how safe they need to make their products and cannot predict how a jury will judge their products based on this test. It is up to the jury to decide whether the manufacturer was reasonable or should have made a safer product.

To help determine whether a product was "reasonably safe," juries in many states are typically told that they can consider the following factors:

- Usefulness and desirability of the product;
- Safety of the product – the likelihood that it will cause injury and the probable seriousness of the injury;
- The availability of a substitute product that performed the same function and was safer;
- The ability of the manufacturer to eliminate the unsafe characteristic of the product without lessening its usefulness or making it too expensive;
- The user's ability to avoid harm by being careful when using the product;
- The user's awareness of the risk, either because it is obvious or because of suitable warnings and instructions;
- Feasibility by the manufacturer to spread the risk by way of price increases or purchasing insurance.

These factors provide a more comprehensive and understandable basis for a jury to make a decision, and provide more guidance to the litigants in evaluating their case. Equally important, these factors also provide a basis for a manufacturer to evaluate the safety of their product before its sale and definitely should be considered by a manufacturer when designing the product so that someone can testify as to why they believe the product is reasonably safe.

Foreseeability

There are several other legal concepts that need to be discussed that can help a manufacturer understand if the finished product or any of its components have a design defect. The manufacturer can only be held liable for design defects where the risk of harm relates to a foreseeable use of a product that could have been reduced by adopting a reasonable alternative design. Therefore, the risk of harm from unforeseeable product use should not create potential liability. Thus, a manufacturer is not liable if the product was misused, abused, or altered after it left the manufacturer's control and the misuse, abuse, or alteration that caused the harm was not foreseeable.

It is clear in the law that a manufacturer must design a product so that it is reasonably safe for reasonably foreseeable use and misuse. It is not a defense to say that the product was misused if the misuse was reasonably foreseeable. For example, automobile manufacturers must consider safety in crashes even though crashes are not intended uses and frequently constitute misuse of the product. However, thousands of crashes occur each year and therefore courts have deemed it "foreseeable misuse."

Likewise, if a manufacturer provides a safety guard that makes it difficult to use the product, they may not have a defense if the user removes the guard or disengages it. It is foreseeable that the user will do so, and the manufacturer should have foreseen the difficulty and designed a better guard.

Unforeseeable misuse has been defined to be a "use or handling so unusual that the average consumer could not reasonably expect the product to be designed and manufactured to withstand it – a use which the seller, therefore, need not anticipate or provide for."

Everything is foreseeable but not everything is reasonably foreseeable. The trouble is that there is very little guidance in the law about how to distinguish the two. And, in fact, sometimes different courts rule differently on the same misuse.

Compliance with Standards, Laws, and Regulations

Another complex area involves laws, standards, and regulations. As part of the initial risk assessment, a manufacturer must identify those laws, standards, and regulations that apply to the product. That is not always easy to determine, especially if there are numerous and different ones that must be considered and reconciled.

Laws and regulations enacted by a government that apply to the product's design must be complied with. If the product does not comply and this noncompliance caused the injury, then the manufacturer most likely would be liable. Unfortunately, compliance with all applicable laws and regulations is not, for most products, an absolute defense in a product liability case. Therefore, a jury could come back and say the laws and regulations are a minimum and that a manufacturer should have exceeded them. In other words, the manufacturer could have utilized a "reasonable alternative design" and made the product even safer.

Voluntary industry standards and even certifications like UL are considered minimum requirements. They are also not mandatory unless adopted by some government agency by reference. As a result, compliance with voluntary standards and certifications is not an absolute defense although it is pretty good evidence that the product was reasonably safe. Noncompliance is a problem if it caused or contributed to the injury since the standard creates the "state of the art" and establishes a reasonable alternative design.

Manufacturers should absolutely comply with all mandatory laws, regulations, and standards. They should also comply with all applicable voluntary standards and consider exceeding them, especially if their competitor's products exceed the standard. Where there are different safety standards in different states or different countries where a given product is being sold, manufacturers should consider selling the safest version of the product worldwide. If they try to sell products that are less safe in certain jurisdictions, they should think about how to justify not using the safest version of the product.

Optional Safety Devices

The focus of a product liability case is whether the product should have and could have been made safer. Was there a "reasonable alternative design" that was technologically and commercially feasible?

However, when it comes to optional safety devices, it gets even more complex. Some courts have said that there is no such thing as an optional safety device. The reason is that the manufacturer has developed and has in existence an alternative design. So, assuming this design makes the product safer, how could it be optional? The argument is that the less safe product is safe enough and not defective but that the consumer has the option to buy a safer product if they so choose. This can be done, but the manufacturer needs to be very careful and consider state law on this issue.

The manufacturer must also be careful in selling a product that is unassembled or lacks certain safety devices that are manufactured by them or by someone else. Some courts say that the manufacturer cannot delegate the obligation to install safety equipment to someone else, including the plaintiff's employer. As a result, it is important that there be a clear understanding by the ultimate user that it is their responsibility to purchase and install appropriate safety devices for the safe use of the product. If you

A manufacturer or product seller may have a duty to warn customers about hazards they learn about after the sale. This duty can arise even if the product was not defective or hazardous when sold.

don't have this understanding and the customer doesn't do it and their employee is hurt, the manufacturer may find it hard to defend themselves.

Component Parts

An original equipment manufacturer (OEM) buys components from a variety of sources. The law holds an OEM liable for defects in its components and raw materials and for their installation into a final product. An OEM is also responsible for the final selection of the components used in its product. The component part manufacturer may be fully or partially at fault, but the OEM has the ultimate potential liability.

The kinds of safety analyses that are available, such as risk assessment, need to be applied to the parts manufactured by both the OEM and by the component part supplier. But how far to go is not easily determined. Does the OEM have to go to the parts suppliers' location and do its own analysis? How much does the OEM have to do to ensure that the component parts it buys and incorporates into its products are designed safely?

First, OEMs need to identify "safety-critical" parts. For these parts, the OEM needs to do more to ensure that they are safe than they would for parts that are not critical for safety. Also, the OEM must make an initial decision whether to make or buy such parts and, if they buy them, whom to buy them from.

The OEM should at least confirm that the component part supplier did a risk assessment addressing the use of their component in the OEM's product. If they haven't done this, the OEM should consider doing so. And they may want to look at the supplier's risk assessment to confirm that they agree with the supplier's decision on design, warnings, and instructions. The OEM should not redo the risk assessment themselves for the component and if the supplier has not performed a risk assessment, they should consider whether it is a good idea to buy from that manufacturer.

Warnings and Instructions

The third kind of defect involves inadequacies in warnings and instructions. The definition is similar to that of design defect and says that there is a defect if the foreseeable risks of harm posed by the product "could have been reduced or avoided by …reasonable instructions or warnings" and this omission makes the product not reasonably safe.

Again, this is an extremely subjective test, making it difficult for a manufacturer to know how far to go to warn and instruct about safety hazards that remain in the product. It is up to the jury to decide whether a warning or a better warning would have made a difference and prevented the accident. It can be assumed that the jury would believe that the manufacturer could have easily provided a better warning.

This requirement applies to the finished product and all of its components. Therefore, the manufacturer should consider the adequacy of the warnings and instructions on the components that will be seen by the end user and possibly request the supplier to make improvements if appropriate.

POST-SALE DUTIES

One other theory of liability that could be very important in a product liability case involves post-sale duties. A manufacturer or product seller may have a duty to warn customers about hazards they learn about after the sale. This duty can arise even if the product was not defective or hazardous when sold. While this duty can involve any of the three kinds of defects described above, the legal theory that the jury can use is negligence. When accidents are occurring, this is fairly easy to prove.

Manufacturers need to establish a robust post-sale information gathering system that captures potential and real safety issues received from consumers through various channels such as phone calls, emails, blogs, and more.

In those states that have adopted this theory, the common law generally says that a product manufacturer or seller can be liable for failing to provide a warning after sale or distribution if a reasonable person in the seller's position would have provided such a warning. There are four factors that can be considered by the jury to determine if a post-sale warning should be required, as follows:

1. The seller knows or reasonably should know that the product poses a substantial risk of harm to persons or property;
2. Those to whom a warning might be provided can be identified and can reasonably be assumed to be unaware of the risk of harm;
3. A warning can be effectively communicated to and acted on by those to whom a warning might be provided;
4. The risk of harm is sufficiently great to justify the burden of providing the warning.

The common law is clear that allegations concerning negligence in performing post-sale duties are independent of an allegation that the product was defective when sold. Therefore, selling a defective product can result in a claim that the product was defective when it was sold and an additional claim can be made that the manufacturer either failed to issue a post-sale warning or that a post-sale recall was negligently performed.

In addition, the common law makes it clear that if the product was defective when sold, the manufacturer cannot avoid liability for selling a defective product merely by issuing a post-sale warning. Therefore, a manufacturer may be deemed to have complied with its post-sale duties but still held liable for selling a defective product. And the manufacturer could be held liable for post-sale negligence even if the product was not defective when sold.

Another part of the common law provides that the seller or distributor is not liable for a failure to recall the product unless the recall is required by statute or regulation. However, the law also says that if the seller or distributor voluntarily undertakes to recall the product and does so negligently, they can be held liable. So, recall adequacy can be a big issue if not done effectively.

The common law also makes it clear that the manufacturer has no duty to inform product customers of safety improvements. However, if the safety improvement was made because of some problem in the field, then arguably, the manufacturer is fixing a defective product and should have offered this "fix" to its prior customers.

Manufacturers need to establish a robust post-sale information gathering system that captures potential and real safety issues received from consumers through various channels such as phone calls, emails, blogs, and mail, and from entities such as distributors and retailers and service providers. The manufacturer should also have in place a good system for investigating, analyzing, and cataloging this information so that trends and real problems can be identified and taken care of. A failure to do all of this can result in missed opportunities to prevent accidents, resulting in a need to defend itself against the consequences.

CONCLUSION

Despite the fact that the jury ultimately gets to decide if the manufacturer should be held liable, the law does provide some important guidance on which a manufacturer can base their decisions during the design and manufacturing process and after sale. Having the opportunity to say that the company was very aware of the law and believes it complied could be extremely helpful in defending itself in a lawsuit.

SINUSOIDAL STEADY STATE ANALYSIS OF TRANSMISSION LINES

Part II: Voltage, Current, and Input Impedance Calculations – Circuit Model 1

By Bogdan Adamczyk

This is the second of the three tutorial articles devoted to the frequency-domain analysis of a lossless transmission line. In the previous article, [1], the general solution for the voltage and current in sinusoidal steady state was derived and the concept of the input impedance to the line was presented. This article shows numerous methods of calculating the voltage, current, and input impedance at various locations on the transmission line, using the Circuit Model 1, [1], described next.

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1. VOLTAGE AND CURRENT AT ANY LOCATION Z AWAY FROM THE SOURCE

Consider a lossless transmission line with the characteristic impedance Z_C, driven by the source located at $z = 0$ and terminated by the load located at $z = L$, as shown in Figure 1. (This circuit was referred to as *Circuit Model 1*, in [1]).

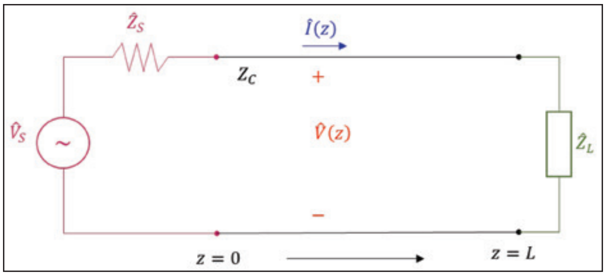

Figure 1: Transmission line circuit with the source located at $z = 0$ and the load at $z = L$

The voltage and current *at any location z* away from the source were derived in [1] as

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

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

where β is the phase constant of the sinusoidal voltage source and the $\hat{V}_z^+$ and $\hat{V}_z^-$ are yet to be determined constants.

Note: In [1] these constants were denoted as $\hat{V}^+$ and $\hat{V}^-$. Here, we use a different notation to distinguish between the constants for two different circuit models. Using Model 1, shown in Figure 1, we move from the source at $z = 0$ to the load at $z = L$, and use constants $\hat{V}_z^+$ and $\hat{V}_z^-$. In Model 2, discussed in the next article, we move from the load at $d = 0$ to the source at $d = L$, and use constants $\hat{V}_d^+$ and $\hat{V}_d^-$. These two sets of constants are different.

The solutions in Eqns. (1.1) consist of the forward- and backward-traveling waves. The forward-traveling voltage wave is described by

$$\hat{V}_f(z) = \hat{V}_z^+ e^{-j\beta z} \tag{1.2a}$$

while the backward-traveling voltage wave is given by

$$\hat{V}_b(z) = \hat{V}_z^- e^{j\beta z} \tag{1.2b}$$

Using these two waves, we define the voltage reflection coefficient *at any location z*, as the ratio of the backward-propagating wave to the forward-propagating wave

$$\hat{\Gamma}(z) = \frac{\hat{V}_b(z)}{\hat{V}_f(z)} = \frac{\hat{V}_z^- e^{j\beta z}}{\hat{V}_z^+ e^{-j\beta z}} = \frac{\hat{V}_z^-}{\hat{V}_z^+} e^{j2\beta z} \tag{1.3a}$$

Thus,

$$\hat{\Gamma}(z) = \frac{\hat{V}_z^-}{\hat{V}_z^+} e^{j2\beta z} \tag{1.3b}$$

From Eq. (1.3b) we obtain

$$\hat{V}_z^- = \hat{\Gamma}(z)\hat{V}_z^+ e^{-j2\beta z} \tag{1.4}$$

Utilizing Eq. (1.4) in Eq. (1.1a) gives

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z} + \hat{\Gamma}(z)\hat{V}_z^+ e^{-j2\beta z} e^{j\beta z} \tag{1.5a}$$

or

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z}\left[1 + \hat{\Gamma}(z)\right] \tag{1.5b}$$

Utilizing Eq. (1.4) in Eq. (1.1b) gives

$$\hat{I}(z) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta z} - \frac{\hat{\Gamma}(z)\hat{V}_z^+ e^{-j2\beta z}}{Z_C} e^{j\beta z} \tag{1.6a}$$

or

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

Equations (1.5b) and (1.6b) express voltage and current at any location z, away from the source, in terms of the unknown constant $\hat{V}_z^+$ and the voltage reflection coefficient $\hat{\Gamma}$ at any location z away from the source.

Let us return to this reflection coefficient, given by Eq. (1.3b). Letting $z = L$, we obtain the voltage reflection coefficient at *the load*

$$\hat{\Gamma}(L) = \hat{\Gamma}_L = \frac{\hat{V}_z^-}{\hat{V}_z^+} e^{j2\beta L} \tag{1.7a}$$

Note that the load reflection coefficient can always be obtained directly from the knowledge of the load and the characteristic impedance of the line as

$$\hat{\Gamma}_L = \frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} \tag{1.7b}$$

Let us return again to the reflection coefficient given by Eq. (1.3b).

$$\begin{aligned}\hat{\Gamma}(z) &= \frac{\hat{V}_z^-}{\hat{V}_z^+} e^{j2\beta z} = \frac{\hat{V}_z^-}{\hat{V}_z^+} e^{j2\beta(z+L-L)} \\ &= \frac{\hat{V}_z^-}{\hat{V}_z^+} e^{j2\beta L} e^{j2\beta(z-L)} = \hat{\Gamma}_L e^{j2\beta(z-L)}\end{aligned} \tag{1.8a}$$

Thus, the voltage reflection coefficient *at any location z*, away from the source, can be expressed in terms of the load reflection coefficient as

$$\hat{\Gamma}(z) = \hat{\Gamma}_L e^{j2\beta(z-L)} \tag{1.8b}$$

Equation (1.8b) can be used to determine the voltage reflection coefficient *at the input to the line*, i.e., at $z = 0$, (we will need it shortly),

$$\hat{\Gamma}(0) = \hat{\Gamma}_L e^{-j2\beta L} \tag{1.9}$$

Utilizing Eq. (1.8b) in Eqns. (1.5b) and (1.6b) gives

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z}\left[1 + \hat{\Gamma}_L e^{j2\beta(z-L)}\right] \tag{1.10a}$$

$$\hat{I}(z) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta z}\left[1 - \hat{\Gamma}_L e^{j2\beta(z-L)}\right] \tag{1.10b}$$

Equations (1.10) express voltage and current at any location z, away from the source, in terms of the unknown constant $\hat{V}_z^+$, and the load reflection coefficient.

In summary, the voltage and current at any location z, away from the source, can be obtained from

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z} + \hat{V}_z^- e^{j\beta z} \tag{1.11a}$$

$$\hat{I}(z) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta z} - \frac{\hat{V}_z^-}{Z_C} e^{j\beta z} \tag{1.11b}$$

or

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z}\left[1 + \hat{\Gamma}(z)\right] \tag{1.11c}$$

$$\hat{I}(z) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta z}\left[1 - \hat{\Gamma}(z)\right] \tag{1.11d}$$

or

$$\hat{V}(z) = \hat{V}_z^+ e^{-j\beta z}\left[1 + \hat{\Gamma}_L e^{j2\beta(z-L)}\right] \tag{1.11e}$$

$$\hat{I}(z) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta z}\left[1 - \hat{\Gamma}_L e^{j2\beta(z-L)}\right] \tag{1.11f}$$

The last set of equations is perhaps the most convenient since the load reflection coefficient, $\hat{\Gamma}_L$, can be obtained directly from Eq. (1.7b) and the only unknown in this set is the constant $\hat{V}_z^+$.

The three sets of equations (1.11) can be used to determine the voltage and current at the input to the line, and at the load.

Letting $z = 0$, in Eqns. (1.11) we obtain the *voltage and current at the input to the line* as

$$\hat{V}(0) = \hat{V}_z^+ + \hat{V}_z^- \tag{1.12a}$$

$$\hat{I}(0) = \frac{\hat{V}_z^+}{Z_C} - \frac{\hat{V}_z^-}{Z_C} \tag{1.12b}$$

or

$$\hat{V}(0) = \hat{V}_z^+[1 + \hat{\Gamma}(0)] \tag{1.12c}$$

$$\hat{I}(0) = \frac{\hat{V}_z^+}{Z_C}[1 - \hat{\Gamma}(0)] \tag{1.12d}$$

or

$$\hat{V}(0) = \hat{V}_z^+[1 + \hat{\Gamma}_L e^{-j2\beta L}] \tag{1.12e}$$

$$\hat{I}(0) = \frac{\hat{V}_z^+}{Z_C}[1 - \hat{\Gamma}_L e^{-j2\beta L}] \tag{1.12f}$$

Letting $z = L$, in Eqns. (1.11) we obtain the *voltage and current at the load* as

$$\hat{V}(L) = \hat{V}_z^+ e^{-j\beta L} + \hat{V}^- e^{j\beta L} \tag{1.13a}$$

$$\hat{I}(L) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta L} - \frac{\hat{V}^-}{Z_C} e^{j\beta L} \tag{1.13b}$$

or

$$\hat{V}(L) = \hat{V}_z^+ e^{-j\beta L}[1 + \hat{\Gamma}_L] \tag{1.13c}$$

$$\hat{I}(L) = \frac{\hat{V}_z^+}{Z_C} e^{-j\beta L}[1 - \hat{\Gamma}_L] \tag{1.13d}$$

Next, let us turn our attention to the undetermined constants $\hat{V}_z^+$ and $\hat{V}_z^-$. These constants can be determined from the knowledge of the voltage and current *at the input to the line*.

Eqns. (1.12a) and (1.12b) can be rewritten as

$$\hat{V}(0) = \hat{V}_z^+ + \hat{V}_z^- \tag{1.14a}$$

$$Z_C \hat{I}(0) = \hat{V}_z^+ - \hat{V}_z^- \tag{1.14b}$$

Adding Eqns. (1.14a) and (1.14b) gives

$$\hat{V}(0) + Z_C \hat{I}(0) = 2\hat{V}_z^+ \tag{1.15}$$

and thus

$$\hat{V}_z^+ = \frac{\hat{V}(0) + Z_C \hat{I}(0)}{2} \tag{1.16}$$

Subtracting Eq. (1.14b) from Eq. (1.14a) gives

$$\hat{V}(0) - Z_C \hat{I}(0) = 2\hat{V}_z^- \tag{1.17}$$

and thus

$$\hat{V}_z^- = \frac{\hat{V}(0) - Z_C \hat{I}(0)}{2} \tag{1.18}$$

These two undetermined constants, $\hat{V}_z^+$ and $\hat{V}_z^-$, can alternatively be obtained from the knowledge of the voltage and current *at the load*.

Eqns. (1.13a) and (1.13b) can be rewritten as

$$\hat{V}(L) = \hat{V}_z^+ e^{-j\beta L} + \hat{V}^- e^{j\beta L} \tag{1.19a}$$

$$Z_C \hat{I}(L) = \hat{V}_z^+ e^{-j\beta L} - \hat{V}^- e^{j\beta L} \tag{1.19b}$$

Adding Eqns. (1.19a) and (1.19b) gives

$$\hat{V}(L) + Z_C \hat{I}(L) = 2\hat{V}_z^+ e^{-j\beta L} \tag{1.20}$$

and thus

$$\hat{V}_z^+ = \frac{\hat{V}(L) + Z_C \hat{I}(L)}{2} e^{j\beta L} \tag{1.21}$$

Subtracting Eq. (1.19b) from Eq. (1.19a) gives

$$\hat{V}(L) - Z_C \hat{I}(L) = 2\hat{V}_z^- e^{j\beta L} \tag{1.22}$$

and thus

$$\hat{V}_z^- = \frac{\hat{V}(L) - Z_C \hat{I}(L)}{2} e^{-j\beta L} \tag{1.23}$$

Observation: To obtain the voltage or current at any location z, away from the source, we need the knowledge of the undetermined constants, $\hat{V}_z^+$ and $\hat{V}_z^-$, (or at least $\hat{V}_z^+$). To obtain the undetermined constant, $\hat{V}_z^+$ and $\hat{V}_z^-$, we need the knowledge of the voltage and current at the input to the line, or at the load. We resolve this stalemate by introducing the concept of the input impedance to the line.

2. INPUT IMPEDANCE TO THE LINE AT ANY LOCATION Z AWAY FROM THE SOURCE

At any location z, away from the source, the input impedance to the line, $\hat{Z}_{in}$, shown in Figure 2, is defined as the ratio of the total voltage to the total current at that point.

$$\hat{Z}_{in}(z) = \frac{\hat{V}(z)}{\hat{I}(z)} \tag{2.1}$$

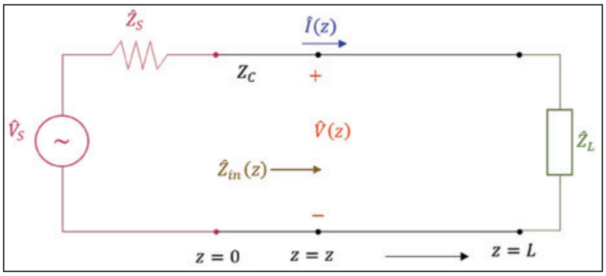

Figure 2: Input impedance to the line at any location *z* away from the source

Since the total voltage and current at any location z away from the source can be obtained from the three different sets of Eqns. (1.11), it follows that the input impedance to the line, *at any location z away from the source* can be obtained from

$$\hat{Z}_{in}(z) = Z_C \frac{\hat{V}_z^+ e^{-j\beta z} + \hat{V}_z^- e^{j\beta z}}{\hat{V}_z^+ e^{-j\beta z} - \hat{V}_z^- e^{j\beta z}} \tag{2.2a}$$

or

$$\hat{Z}_{in}(z) = Z_C \frac{1+\hat{\Gamma}(z)}{1-\hat{\Gamma}(z)} \tag{2.2b}$$

or

$$\hat{Z}_{in}(z) = Z_C \frac{1+\hat{\Gamma}_L e^{j2\beta(z-L)}}{1-\hat{\Gamma}_L e^{j2\beta(z-L)}} \tag{2.2c}$$

Letting $z = 0$, in Eqns. (2.2) we obtain the *input impedance to the line at the input to the line* as

$$\hat{Z}_{in}(0) = Z_C \frac{\hat{V}_z^+ + \hat{V}_z^-}{\hat{V}_z^+ - \hat{V}_z^-} \tag{2.3a}$$

or

$$\hat{Z}_{in}(0) = Z_C \frac{1+\hat{\Gamma}(0)}{1-\hat{\Gamma}(0)} \tag{2.3b}$$

or

$$\hat{Z}_{in}(0) = Z_C \frac{1+\hat{\Gamma}_L e^{-j2\beta L}}{1-\hat{\Gamma}_L e^{-j2\beta L}} \tag{2.3c}$$

Since the constants, $\hat{V}_z^+$ and $\hat{V}_z^-$, are still unknown, in the calculations of the input impedance to the line at the input to the line, we are left with the remaining two equations, (2.3b) and (2.3c).

Since,

$$\hat{\Gamma}(0) = \hat{\Gamma}_L e^{-j2\beta L} \tag{2.4}$$

at this point, we effectively have just one equation (2.3c) to determine the input impedance to the line at the input to the line. Towards this end, we first determine the load reflection coefficient from

$$\hat{\Gamma}_L = \frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} \tag{2.5}$$

and then use Eq. (2.3c) or Eq. (2.9b), derived next, to calculate the input impedance to the line *at the input to the line.*

There is one more useful set of formulas for obtaining the input impedance to the line at the input to the line. Using Eq. (2.5) in Eq. (2.3c) we get

$$\hat{Z}_{in}(0) = Z_C \frac{1+\frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} e^{-j2\beta L}}{1-\frac{\hat{Z}_L - Z_C}{\hat{Z}_L + Z_C} e^{-j2\beta L}} \tag{2.6a}$$

or

$$\hat{Z}_{in}(0) = Z_C \frac{\hat{Z}_L + \hat{Z}_L e^{-j2\beta L} + Z_C - Z_C e^{-j2\beta L}}{\hat{Z}_L - \hat{Z}_L e^{-j2\beta L} + Z_C + Z_C e^{-j2\beta L}} \tag{2.6b}$$

or

$$\hat{Z}_{in}(0) = Z_C \frac{\hat{Z}_L(1+e^{-j2\beta L})+Z_C(1-e^{-j2\beta L})}{\hat{Z}_L(1-e^{-j2\beta L})+Z_C(1+e^{-j2\beta L})} \tag{2.6c}$$

Now,

$$1 + e^{-j2\beta L} = e^{-j\beta L}\left(e^{j\beta L} + e^{-j\beta L}\right) \tag{2.7a}$$

$$1 - e^{-j2\beta L} = e^{-j\beta L}\left(e^{j\beta L} - e^{-j\beta L}\right) \tag{2.7b}$$

Utilizing Eqns. (2.7) in Eq. (2.6c) we get

$$\hat{Z}_{in}(0) = Z_C \frac{\hat{Z}_L(e^{j\beta L}+e^{-j\beta L})+Z_C(e^{j\beta L}-e^{-j\beta L})}{\hat{Z}_L(e^{j\beta L}-e^{-j\beta L})+Z_C(e^{j\beta L}+e^{-j\beta L})} \tag{2.8a}$$

or, using the Euler's formulas

$$\hat{Z}_{in}(0) = Z_C \frac{\hat{Z}_L 2\cos\beta L+Z_C j2\sin\beta L}{\hat{Z}_L j2\sin\beta L+Z_C 2\cos\beta L} \tag{2.8b}$$

leading to

$$\hat{Z}_{in}(0) = Z_C \frac{\hat{Z}_L \cos\beta L+jZ_C \sin\beta L}{Z_C \cos\beta L+j\hat{Z}_L \sin\beta L} \tag{2.9a}$$

or equivalently,

$$\hat{Z}_{in}(0) = Z_C \frac{\hat{Z}_L+jZ_C \tan\beta L}{Z_C+jZ_L \tan\beta L} \tag{2.9b}$$

3. VOLTAGE AND CURRENT AT THE INPUT TO THE LINE

At the input to the line, we have a situation depicted in Figure 3.

It is apparent the voltage and current *at the input to the line* can be now obtained from

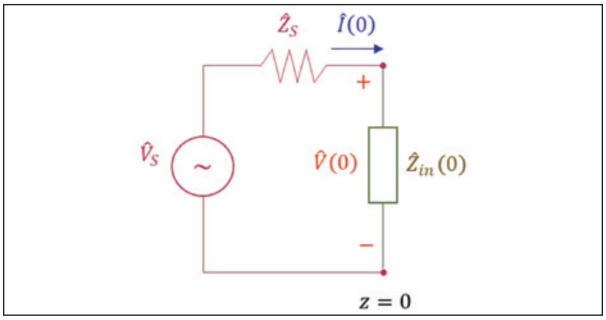

Figure 3: Equivalent circuit at the location *z = 0*

$$\hat{V}(0) = \frac{\hat{Z}_{in}(0)}{\hat{Z}_S+\hat{Z}_{in}(0)}\hat{V}_S \tag{3.1a}$$

$$\hat{I}(0) = \frac{\hat{V}(0)}{\hat{Z}_{in}(0)} \tag{3.1b}$$

Now, from the knowledge of $\hat{V}$ and $\hat{I}$ we can determine the constants $\hat{V}_z^+$ and $\hat{V}_z^-$ from

$$\hat{V}_z^+ = \frac{\hat{V}(0)+Z_C\hat{I}(0)}{2} \tag{3.2a}$$

$$\hat{V}_z^- = \frac{\hat{V}(0)-Z_C\hat{I}(0)}{2} \tag{3.2b}$$

or

$$\hat{V}_z^+ = \frac{\hat{V}(L)+Z_C\hat{I}(L)}{2}e^{j\beta L} \tag{3.2c}$$

$$\hat{V}_z^- = \frac{\hat{V}(L)-Z_C\hat{I}(L)}{2}e^{-j\beta L} \tag{3.2d}$$

At this point we can obtain the voltage, current, or impedance at any location *z* away from the source using the previously derived equations.

In the next article, we will analyze the circuit where we move from the load is located at *d = 0* towards the source located at *d = L* (Model 2). Such a circuit is shown in Figure 4.

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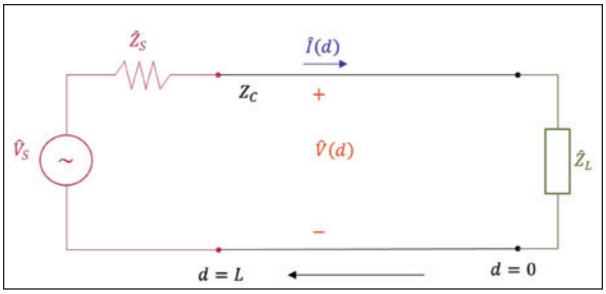

Figure 4: Transmission line circuit with the load located at *d = 0* and the source at *d = L*

A LOOK INTO GENERATOR WAVEFORMS: DO THEY MEET THE IEC 61000-4-2 WAVEFORM SPECIFICATION?

By Kathleen Muhonen for EOS/ESD Association, Inc.

This article explores the waveform specifications called out in the IEC 61000-4-2 standard [1]. Verifying that a generator meets this specification requires specific equipment and conversion equations. The setup, data collection, and calculations required to validate equipment are explained here. Waveforms have been captured using the target called out in the standard, often called a Pelligrini target, for three different generator manufacturers and one pulser. These waveforms are analyzed in the time domain to verify the generators were within the standard's specification. What comes as a surprise is the real waveforms. Waveforms from different generators look very different and it is surprising that they all pass the specification [2].

IEC SPECIFICATION

The IEC 61000-4-2 waveform is shown in Figure 1 for contact discharge mode. The parameters that are called out in the specification are rise time, peak current, 30 ns current, and 60 ns current.

The spec limits are shown in Table 1. Note that the spec limits are quite wide; for instance, at the 30 ns and 60 ns current, the waveforms can vary by ±30%. The peak current can even vary by ±15%.

TEST SET-UP

The test setup to capture the waveforms is shown in Figure 2 on page 44. It uses a target for the tip of the ESD Generator to contact and thus capture the waveform. This target is seated in a large ground plane; thus, radiated fields will not be captured and are not a part of this study. A faraday cage can also be used to house the oscilloscope.

On the other side of the target is a high frequency cable connecting to ample amounts of attenuation to protect the front end of a high-speed oscilloscope.

Kathleen Muhonen is currently a Principal Development Engineer at Qorvo in Greensboro, NC. She is responsible for developing ESD (electrostatic discharge) on-chip protection for mobile and millimeter wave applications. Kathleen has served as a member of the ESD Association and sits on all device testing standards committees

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.

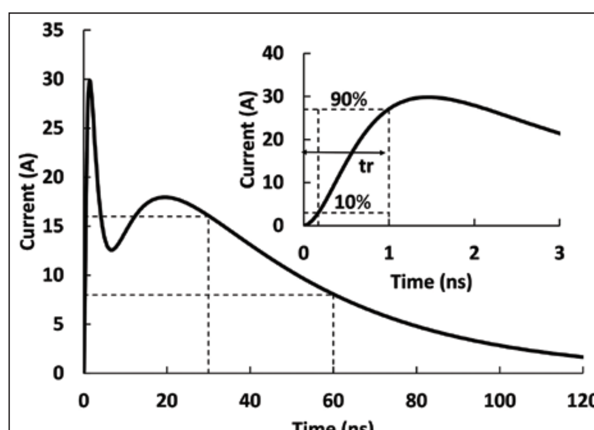

Figure 1: Time Domain Specs for IEC Waveform

Pulse Parameter	Value	Unit
10 to 90% Rise Time	0.8 +/- 25%	ns
First Peak Current (Ip)	3.75 +/- 15%	A / kV
Current at 30 ns from initial 10% point	2 +/- 30%	A / kV
Current at 60 ns from initial 10% point	1 +/- 30%	A / kV

Table 1: IEC Pulse Parameters and Spec Limits

> Despite the smooth waveform shown in the IEC standard, real generator waveforms are very erratic but nonetheless compliant. Pulsers, on the other hand, do provide an extremely repeatable and smooth waveform.

The attenuators in Figure 2 are 50-watt attenuators with a total attenuation of 29dB. This amount of attenuation ensures the peak voltage incident on the scope does not exceed the max voltage of 5V RMS on any precharge voltage setting. The oscilloscope should be at least 6 GHz of bandwidth in order to measure the rise time accurately. Adequate sampling is also needed to ensure enough points during the rise time for analysis. Typically, the scope is set to 20 nsec or 40 nsec per division. Adjustment of the vertical scale is needed to always capture the waveform using the entire vertical screen of the scope. This further ensures that the vertical resolution is at its maximum.

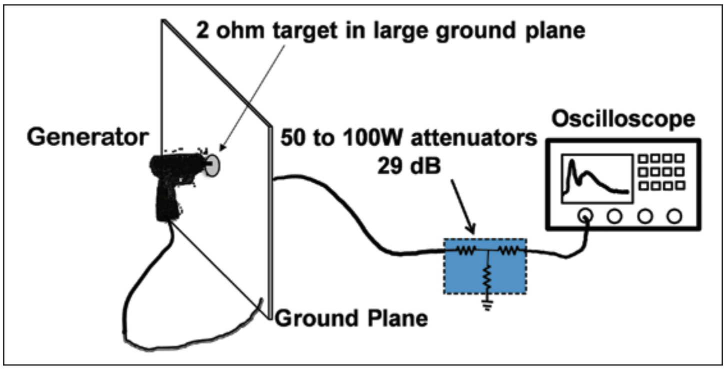

Figure 2: Test Set-up to Capture Generator Waveforms

Figure 3a shows a closeup view of an example target from the front and Figure 3b shows the back of the target with an N to SMA adapter for connection to a high frequency cable.

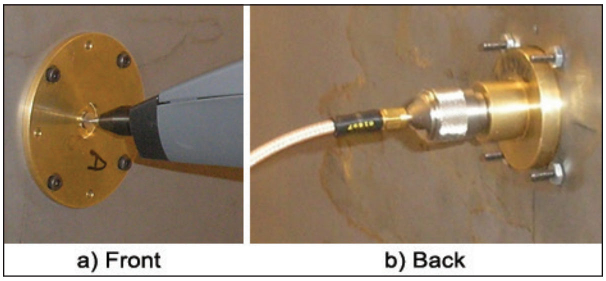

Figure 3: Example Target, a) Front b) Back

DATA COLLECTION AND CURRENT WAVEFORM CALCULATION

To capture a waveform the scope is set to single shot mode with the trigger on a positive rising edge. The waveform is stored for further processing. The data that the scope stores is represented in Figure 4 as the term V_{scope}. This data has to be converted to current in the generator. Figure 4 shows the circuit representation of the test set-up in Figure 2. The term V_{corr} is the voltage incident on the attenuator before the scope input. The equation in Figure 4 shows how to convert the scope data to this voltage V_{corr}.

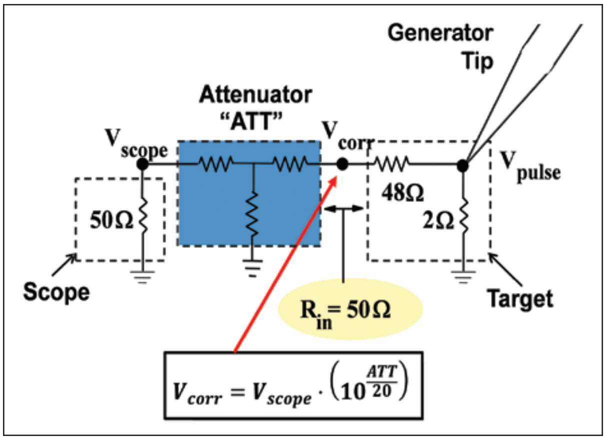

Figure 4: Detail of Circuit for Capturing Waveforms

Figure 5 shows the equivalent circuit of Figure 4 with the input to the attenuator as 50 ohms to ground. Below this equivalent circuit are the calculations to transform the corrected voltage from Figure 5 to pulse current. The target used in this study had 2 ohms to ground and a series 48 ohms connecting to output on the back of the target. Icorr, is effectively the current into the attenuator. This current can then be used to calculate the voltage the generator produces across the 2 ohms to ground which is V_{pulse} in the figure. This voltage is divided by the target impedance yielding the target current. The target current plus the current into the attenuator is the current in the generator. This is the current called out in the IEC specification. The final equation in Figure 5 shows conversion from the scope data, V_{scope}, to the generator current, I_{pulse}.

REAL CURRENT WAVEFORMS

Although Figure 1 looks well behaved, actual waveforms are not. Figure 6a shows three different generator waveforms at 8kV and even a waveform from a 50-ohm pulser. These waveforms were captured using a scope with a bandwidth of 7GHz and a sampling rate of 20 Gsamples/sec. The scope was set up so that the max record length was used while capturing 400 ns worth of data. All of these generators meet the IEC spec. Figure 6b shows that although all the waveforms comply with the rise time, peak current, 30 ns, and 60 ns current, they still vary considerably and can look quite different from each other [3].

SUMMARY

Verifying that a generator meets the IEC spec requires a target, attenuation, and a high-speed scope. Using the scope data to calculate the current a generator has in its waveform has been explained. Despite the smooth waveform shown in the IEC standard, real generator waveforms are very erratic but nonetheless compliant. Pulsers, on the other hand, do provide an extremely repeatable and smooth waveform.

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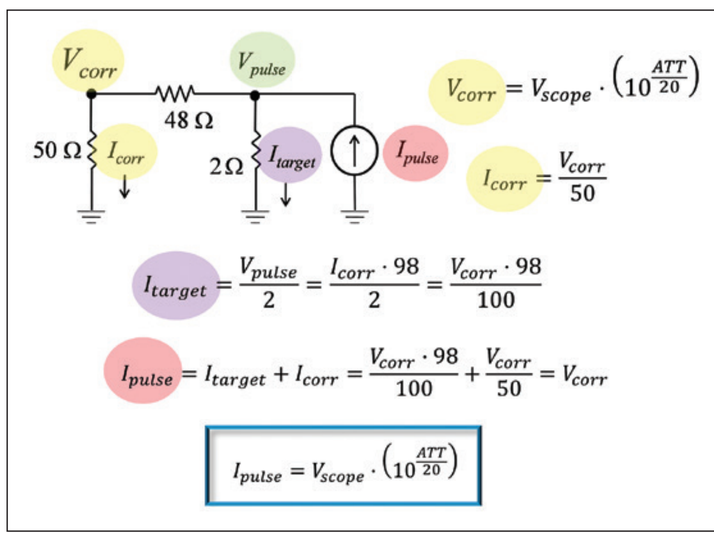

Figure 5: Equations to Calculate Current in the Target

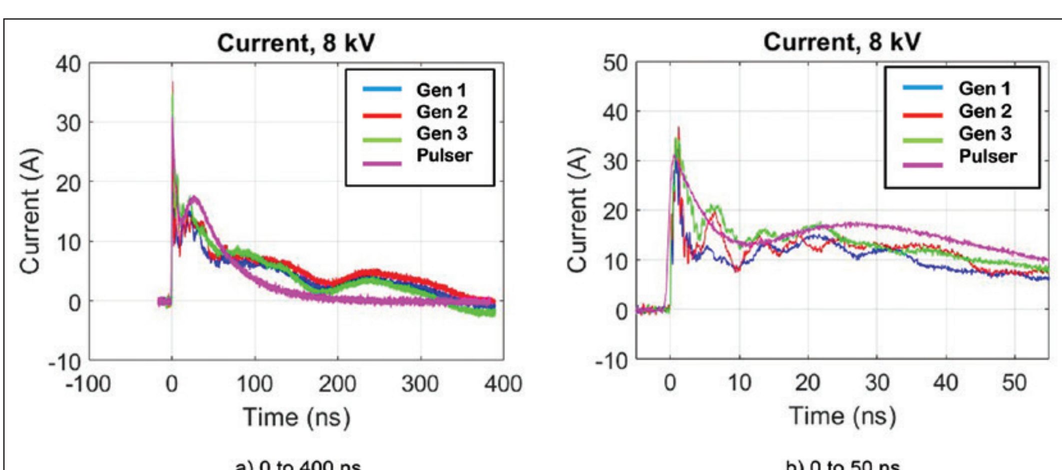

Figure 6: Current waveforms for 3 IEC Generators.

A CAPACITIVELY COUPLED PIN INJECTION METHOD FOR TROUBLESHOOTING IMMUNITY ISSUES

By Dr. Min Zhang

Bulk current injection (BCI) tests are widely used for automotive, military, and aerospace EMC immunity tests. The test setup requires a high-power amplifier (often at least 80-watt unsaturated output power) and a BCI injection probe to achieve a reasonably high interference level on the device under test (DUT).

Dr. Min Zhang is the founder and principal EMC consultant of Mach One Design Ltd, a UK-based engineering firm that specializes in EMC consulting, troubleshooting, and training. His in-depth knowledge in power electronics, digital electronics, electric machines, and product design has benefitted companies worldwide. Zhang can be reached at info@mach1desgin.co.uk.

In one recent example, an automotive remote controller unit experienced immunity issues during the BCI test in an accredited EMC testing laboratory. The module's local interconnect network (LIN) lost communication in the frequency range between 5 and 15 MHz.

The same failure mode must be reproduced in a pre-compliance EMC test setup to fix the issue. For pre-compliance EMC tests, producing the same failure mode often requires a different setup unless the specific BCI test equipment is available.

Some of the test setups often used in pre-compliance EMC immunity tests include:

1. A workbench BCI test using an RF monitor current probe as an injection probe is described in [1];
2. A homemade BCI probe method is described in [2];
3. A coupling and decoupling network (CDN) method;
4. A transverse electro-magnetic cell (TEM Cell) method.

A Fischer current monitor probe F-33-1 is often used as an injection probe for pre-compliance BCI testing [1]. The test setup was documented in detail in [3] and it was mentioned that, in order to achieve a higher level of RF interference, one would need to put some ferrite chokes on the other side of the probe to reflect more energy to the DUT.

While this method might work to some extent, it is generally not a good practice to use an RF monitor probe to inject noise unless you know the specified maximum RF power that you can feed into the probe.

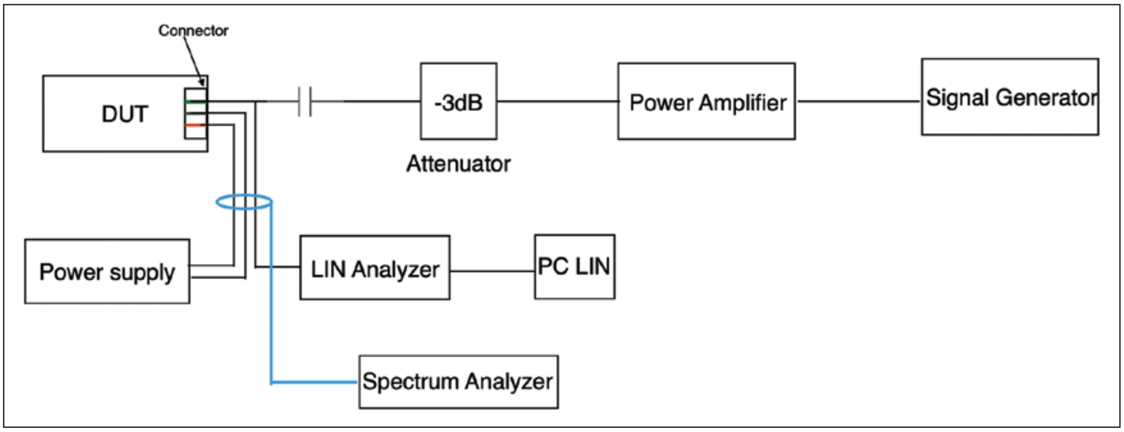

Figure 1: Diagram of the test setup

Besides, most of the RF monitor probes are designed to receive rather than emit RF signals. BCI injection probes typically have very large cross-section toroids to increase the saturation levels.

Today, using CDNs is the recommended choice for the immunity test, compared with the BCI test, CDN testing requires a much smaller power level to achieve a higher coupling factor. Using a TEM cell for an immunity test is also gaining popularity [4] since studies have shown that there's a strong correlation between the TEM cell and BCI test results [5].

In this column, we'll present a capacitively coupled pin injection method as an alternative testing method.

INTRODUCING THE CAPACITIVELY COUPLED PIN INJECTION METHOD

Test Setup

A diagram of the test setup is shown in Figure 1, and the test setup is shown in Figure 2. An RF current monitor probe is clamped to the cable to monitor the injected RF current level during the immunity test. Note that the current level depends on the output of the RF amplifier, the impedance of the capacitance value of the injection probe, and the circuit impedance of the DUT.

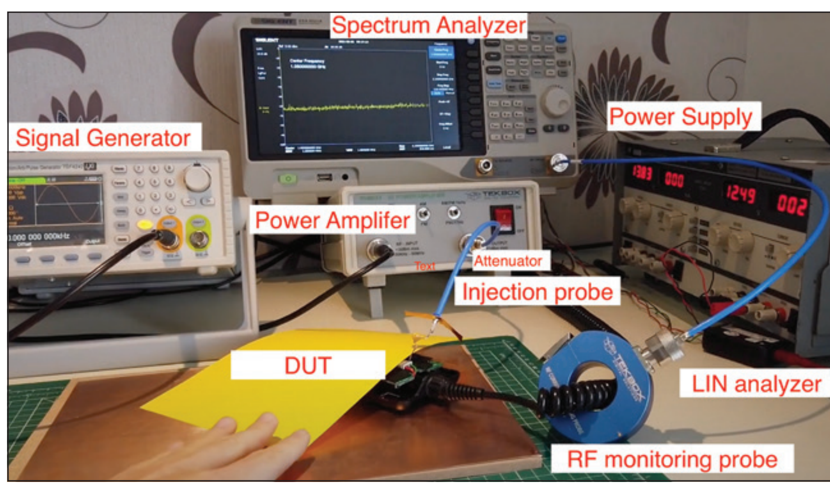

Figure 2: Picture of the test setup

Making a "Flying" Probe

The injection probe used in this test is also referred to as a "flying" probe because the capacitive probe often has a small ground plane to increase the coupling between the probe and the DUT's power/ground plane. The small ground plane looks like a wing, hence the name flying probe (or "wing" probe).

It is easy to make a homemade flying probe, as shown in Figure 3. Steps to make the probe include:

1. Cut a semi-rigid coaxial cable in half;
2. Drill a hole with the same diameter as the coaxial cable in a small piece of copper and solder the piece of copper to the shield of the coaxial cable. Using a small PCB with a solid continuous ground plane is also a good idea;

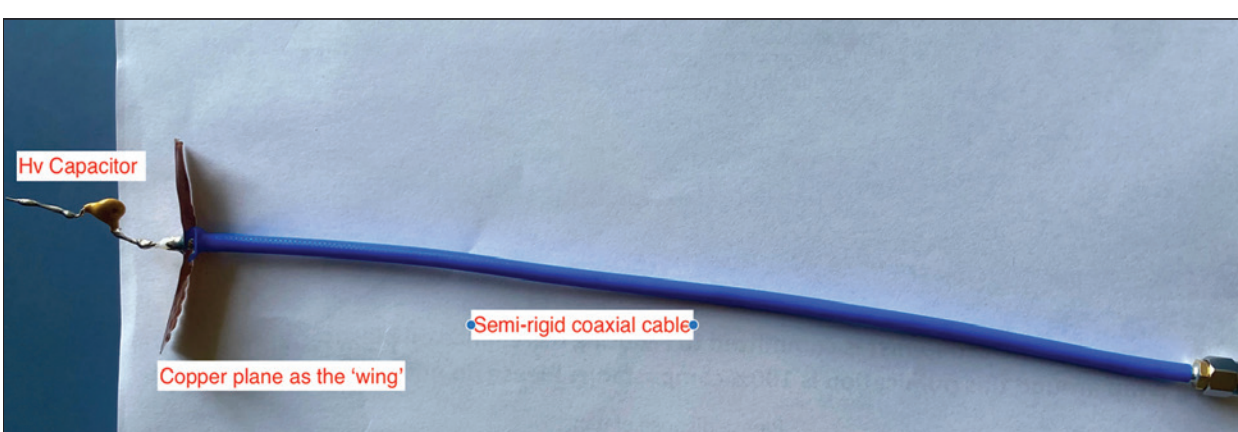

Figure 3: An example of a "flying" probe

Although most modern RF amplifiers have a high voltage device rating against impedance mismatch, special care is needed to prevent impedance mismatch. To avoid impedance mismatch of the power amplifier, often an attenuator is also recommended to be connected between the output of the power amplifier and the flying probe.

3. The tip of the coaxial cable signal line is then soldered to a 250V capacitor. The value of the capacitor depends on the level of interference current one would like to inject (see the next section).

Selecting the Right Size of a Coupling Capacitor

The injected RF current level depends on the amplifier's source impedance, the capacitance value, and the load impedance. Often the load impedance is unknown and frequency dependent. But the general rule is that, at the frequency range of interest, the capacitor's impedance should be more or less the same as 50 Ω (to match with the RF amplifier output impedance). For instance, if the DUT has an immunity issue at 68 MHz, then a 47 pF would be a good choice because the impedance of a 47 pF capacitor at 68 MHz is about 50 Ω. If the DUT has an immunity issue below 30 MHz, then a 100 pF capacitor would be a better choice.

Although most modern RF amplifiers have a high voltage device rating against impedance mismatch, special care is needed to prevent impedance mismatch. To avoid impedance mismatch of the power amplifier, often an attenuator (such as a 3 dB one) is also recommended to be connected between the output of the power amplifier and the flying probe.

Because the failure mode in this particular case occurred at the sub 20 MHz range, a 100 pF, 250V Y Class capacitor was selected. It is also important to note that a capacitor's equivalent series inductance (ESL) has little impact at this frequency range. However, as the frequency increases, the long lead of a capacitor begins dominating the impedance as parasitic inductance increases with frequency.

Therefore, if the injected noise level is in the hundreds of MHz range, the impedance vs. frequency curve of the selected capacitor needs to be checked to ensure the capacitor's impedance is not too high. The long leads of the capacitor will undoubtedly need to be shortened in the MHz frequency range.

Test Results

This test was simple to perform. The signal generator was configured to perform a fixed amplitude, variable frequency sweep between 5 and 15 MHz. It was noticed that the LED lights of the DUT started flashing during the sweep, and the PC monitor also recorded multiple LIN communication errors. This was the same behavior the DUT experienced in the BCI test. The RF current level which was monitored through the RF monitor probe served as another useful tool to identify the potential issue on the circuit.

With the failure mode visible in the pre-compliance test set-up, fixing the issue and validating the results are more easily achieved.

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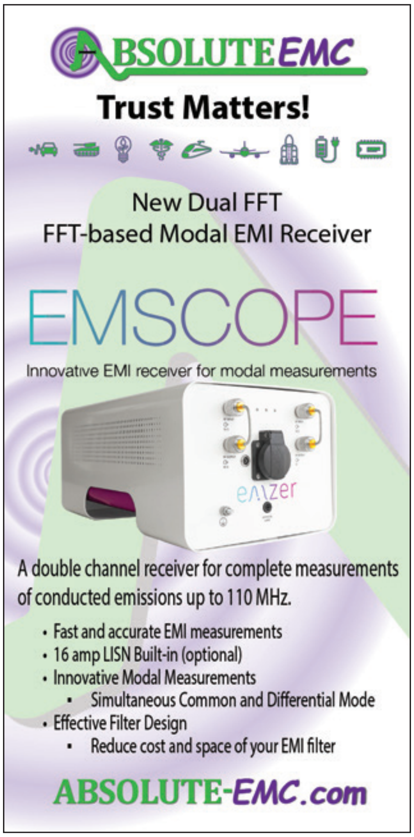
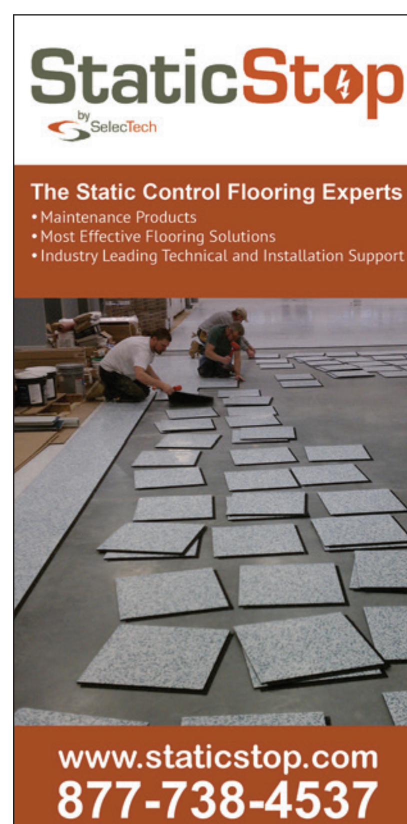
5. D. Trout, "Investigation of the Bulk Current Injection Technique by Comparison to Induced Current from Radiated Electromagnetic Fields," NASA, George C. Marshall Space Flight Center.

PRODUCT Showcase





Advertiser Index

Upcoming Events

Due to COVID-19 concerns, events may be postponed. Please check the event website for current information.

January 31 - February 2
DesignCon 2023

February 28 - March 2
Fundamentals of Random Vibration and Shock Testing Training

March 20 - 24
EMC Designing for Compliance

March 23 - 31
17th European Conference on Antennas and Propogation (EUCAP)

March 26 - 30
2023 International Applied Computational Electromagnetics Society (ACES) Symposium

March 27 - 30
Military Standards 810 (MIL-STD 810) Test Training

March 27 - 31
EMC Designing for Compliance

March 28 - 30
EMV 2023