JULY 2024

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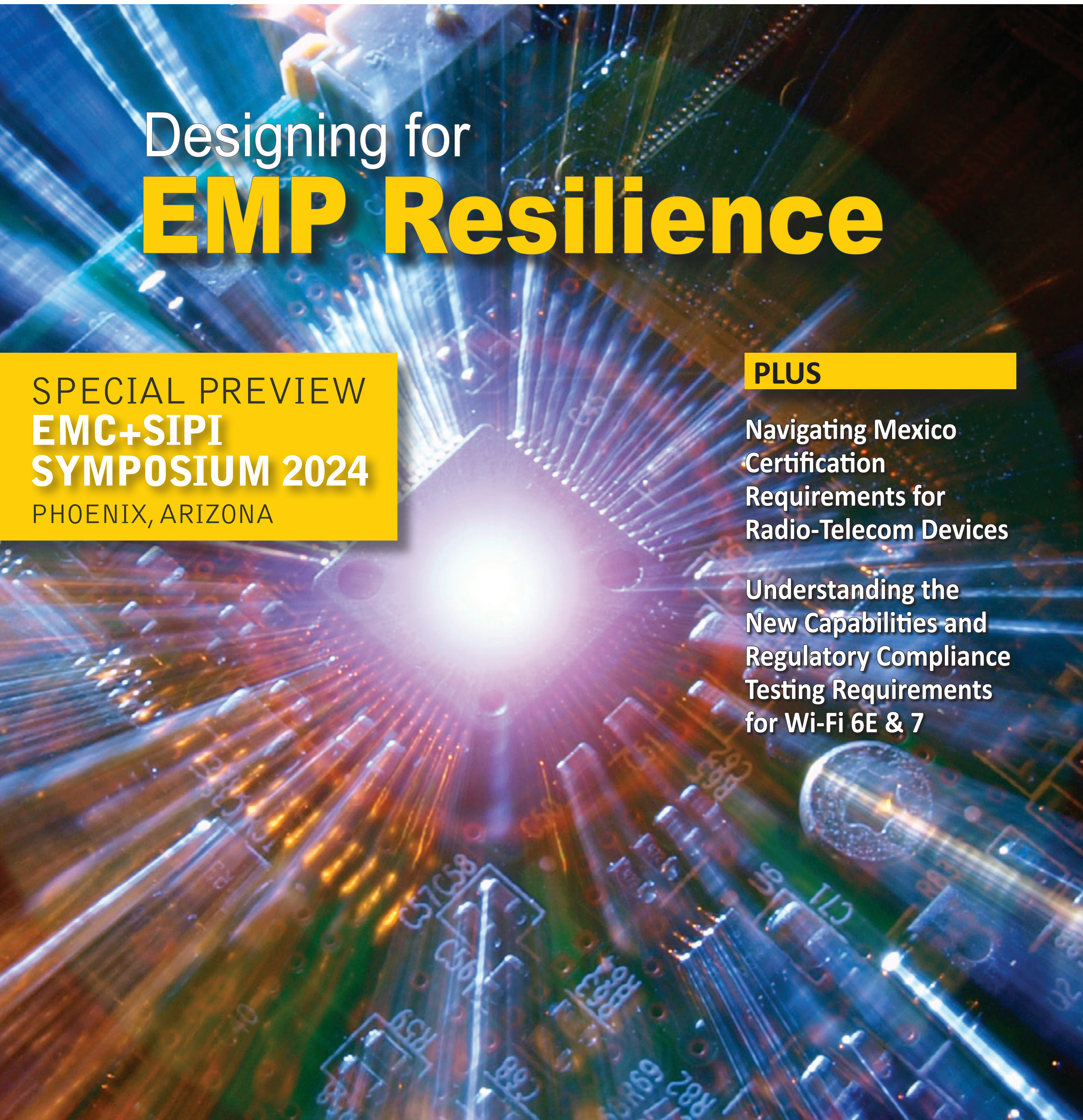

Designing for EMP Resilience

SPECIAL PREVIEW
EMC+SIPI SYMPOSIUM 2024
PHOENIX, ARIZONA

PLUS

Navigating Mexico Certification Requirements for Radio-Telecom Devices

Understanding the New Capabilities and Regulatory Compliance Testing Requirements for Wi-Fi 6E & 7

BEYOND COMPLIANCE: ENGINEERING SUCCESS

As compliance engineering professionals, we play a vital role in ensuring electronic products and systems meet regulatory requirements and safety standards. To excel in this field, it's essential to focus on key principles that guide our work and help us navigate the complex world of compliance. This month, we've compiled a list of best practices that we believe embody the very essence of a thriving compliance engineering career:

1. Continuous Learning: Stay current with industry standards, regulations, and technological advancements. Attend workshops, conferences, and training sessions to expand your knowledge and skills.
2. Attention to Detail: Meticulously review product designs, specifications, and test results. A keen eye for detail can help identify potential compliance issues early in development.
3. Proactive Approach: Engage with product development teams from the initial design stages. By providing guidance and recommendations up front, you can prevent costly rework and delays later.
4. Strong Communication: Effectively convey complex technical information to technical and non-technical stakeholders. Collaborate with cross-functional teams to ensure compliance requirements are understood and met.
5. Problem-Solving Mindset: Approach compliance challenges with creativity and a solution-oriented attitude. Develop practical strategies to mitigate risks and find compliant solutions that align with business goals.
6. Ethical Conduct: Maintain the highest standards of integrity and professionalism. Ensure that compliance decisions are based on objective evidence and not influenced by external pressures or biases.
7. Documentation Excellence: Maintain accurate and comprehensive documentation, including test reports, compliance certificates, and technical files. Well-organized documentation is crucial for audits and regulatory submissions.
8. Continuous Improvement: Embrace a mindset of continuous improvement. Regularly review and assess compliance processes, identify areas for optimization, and implement enhancements to streamline workflows and boost efficiency.
9. Professional Network: Build a strong network of compliance professionals, industry experts, and regulatory bodies. Engage in knowledge sharing, seek mentorship opportunities, and contribute to advancing the compliance engineering field.
10. Adaptability: Be prepared to adapt to the ever-changing landscape of regulations, technologies, and market demands. Embrace change as an opportunity to learn, grow, and innovate in your compliance engineering role.

In August, the IEEE EMC Society will host its annual symposium. This event offers development opportunities aligned with our best practices list, all in one place! You'll find a preview on page 52.

Lorie Nichols
Editor-in-Chief & Publisher

IN COMPLIANCE

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FEATURE ARTICLES

COLUMNS

DEPARTMENTS

SPECIAL COVERAGE

Community Updates

Engineer Robert Kado Honored for EMC Contributions

Robert Kado, a Senior Manager and Senior Technical Fellow at Stellantis EMC Engineering & Laboratories, was recently recognized in the June 2024 edition of the North American Engineering Academy & Technical Training Skills Team's Newsletter. With over 19 years of experience at Stellantis, Rob has been extensively involved in Electromagnetic Compatibility (EMC), Radio Frequency (RF), and EMC Homologation. He has had the opportunity to teach various classes that delve into corporate processes, specifications, and test methodologies related to these specialized subjects.

Singapore to Invest Millions in National Quantum Strategy

Singapore's government has announced its plans to invest approximately S$300 million ($219 million U.S.) in the implementation of the country's National Quantum Strategy (NOS). The funding, issued under the scope of Singapore's Research, Innovation, and Enterprise 2025 (RIE 2025) plan, is part of the government's effort to position Singapore as an international hub for quantum technology over the next five years.

University of Toronto Engineers Celebrated

Six members of the University of Toronto (U of T) Engineering community are recipients of the 2024 Ontario Professional Engineers Awards. Jointly awarded by the Ontario Society of Professional Engineers (OSPE) and Professional Engineers Ontario, the annual Professional Engineers Awards recognize engineering professionals in Ontario (Canada) who have made exceptional contributions to the profession and to society. The U of T recipients include Professor Giovanni Grasselli and alumni Paul Acchione, Michael Kropp, Inga Hipsz, David Poirier, and Serena Mandla.

Amateur Radio Mock Drill for Disaster Communication

Authorities in the India state of Nagaland are working with local amateur radio operators to reinforce disaster communications capabilities in the state. Working with Open Source Classes for Amateur Radio India (OSCAR India), the Nagaland State Disaster Management Authority (NSDMA) recently conducted a comprehensive mock drill exercise leveraging amateur radio technology. The NSDMA says that the mock drill is a first-of-its-kind effort to enhance alternative communication methods during emergencies in the region.

TÜV Rheinland Tech & Innovation Center Receives CAB Recognition for Korea Regulatory Requirements

TÜV Rheinland's new Northeast Technology and Innovation Center has been recognized by the National Radio Research Agency (RRA) as a Conformity Assessment Body (CAB) for the verification of equipment to Korea's KS C, KN, and KS X regulatory requirements. The Technology Center has also received accreditation from the American Association for Laboratory Accreditation (A2LA), and well as Energy Star certification from the U.S. Environmental Protection Agency (EPA) for a range of products, including computers, displays, and uninterruptable power supplies.

Governor Proclaims UL Solutions Day in Illinois

Illinois Governor J.B. Pritzker has proclaimed June 3rd UL Solutions Day in Illinois, honoring the organization's contributions to product safety and safety science over the past 130 years. The proclamation, which coincides with National Safety Month in the U.S., also recognizes UL's ongoing role "as a trusted, science-based safety, security and sustainability partner," to customers and clients worldwide.

Send news and updates about your company to editorial@incompliancemag.com

Upcoming Events

July 11
MIL-STD 461/810 Webinar

July 14-19
2024 IEEE International Symposium on Antennas and Propagation

July 14-19
GlobalEM

July 15-18
Military Standards 810 (MIL-STD-810) Test Training

August 5-9
★ 2024 IEEE International Symposium on Electromagnetic Compatibility, Signal Power Integrity (EMC+SIPI)

August 15
Integrating Modules

September 2-5
EMC Europe Symposium

September 11-13
Fundamentals of Product Safety

September 12
Space Applications, EMC, ENV

September 15-19
★ 46th Annual EOS/ESD Symposium & Exhibits

September 19
★ 2024 Minnesota EMC Event

September 22-27
European Microwave Week 2024

September 24-27
Applying Practical EMI Design & Troubleshooting Techniques

October 2-4
Battery Japan

October 7-9
EMC COMPO 2024

October 7-10
★ The Battery Show

★ Visit In Compliance's booth at these events!

Ask the Expert

When it comes to choosing a partner who is a well-versed expert in meeting global standards requirements, you want to know who you're dealing with.

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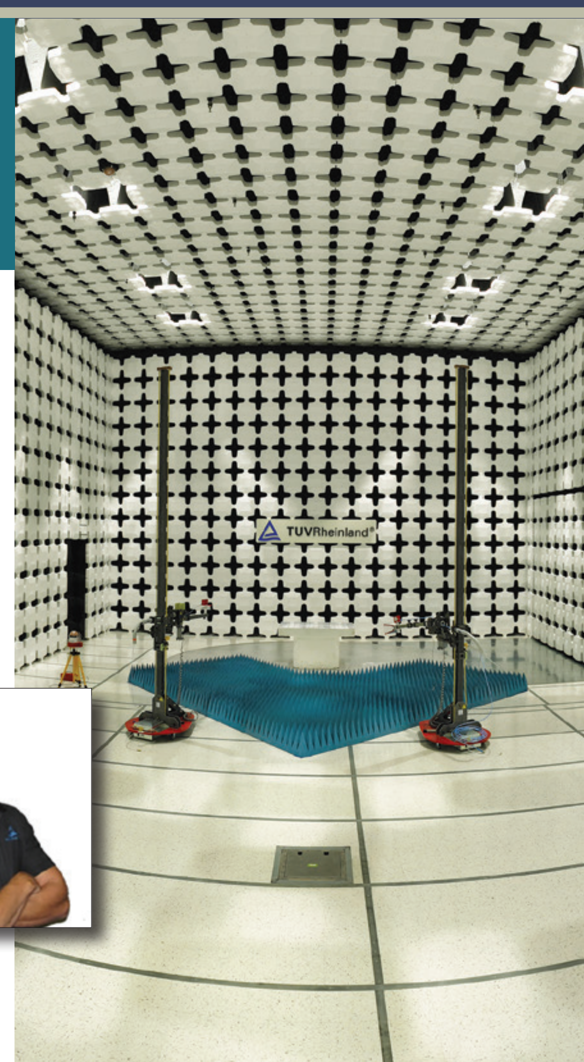

Crafting Quality Solutions

TÜV Rheinland elevates crafting quality solutions to an art form. Through rigorous analysis and comprehensive testing, we uphold the highest standards of quality, reliability, and safety. Our team of experts works tirelessly to deliver solutions that exceed expectations, meet industry demands, and are masterpieces of precision, functionality, and durability.

Evolution Over the Years

TÜV Rheinland has emerged as a global frontrunner, expanding capabilities, diversifying portfolios, and embracing cutting-edge technologies. We actively drive innovation, sustainability, and social responsibility. As a trusted partner, we guide clients through complexities, anticipate trends, and provide advanced services. TÜV Rheinland is poised to continue driving positive change and making a lasting impact.

Unveiling Our Technology

Our state-of-the-art facility in Boxborough offers a wide range of testing services, including safety, EMC, medical, environmental, and wireless testing, all under one roof. By integrating advanced technology, we streamline the testing process, ensuring both efficiency and accuracy. Our commitment to providing a single point of contact saves customers time and resources, while our advanced capabilities ensure the highest quality service and support. We aim to be a one-stop shop for all testing needs, facilitating a seamless testing process and significantly reducing time to market.

Ryan Braman
Director of Commercial and Solar Products
and General Manager – Boxborough Laboratory

FCC Issues Declaratory Ruling Reinstating Net Neutrality

As expected, the U.S. Federal Communications Commission (FCC) has moved forward to restore its rules intended to provide a national standard for broadband reliability, security, and consumer protection.

The Declaratory Ruling, titled "In the Matter of Safeguarding and Securing the Open Internet Restoring Internet Freedom," restores the Net Neutrality rules originally approved by the Commission in 2005. During the ensuing years, the FCC's authority to implement such rules was repeatedly challenged in the federal courts, ultimately leading the FCC to withdraw the rules in 2018.

The 700-plus page Declaratory Ruling classifies broadband internet access service (BIAS) as a telecommunications service, thereby placing the regulation of such services under the purview of the FCC, as specified in Title II of the Communications Act of 1934, as amended. Further, a companion Report and Order issued by the Commission details specific rules for the "Open Internet" and a process for enforcing those rules.

Illegal Robocaller Faces $6 Million Fine for Election Spoofing Campaign

Telemarketer Used AI to Impersonate President Biden, Spoofed Caller IDs in NH Primary

The U.S. Federal Communications Commission (FCC) has proposed a $6 million fine in connection with an AI-generated robocall campaign targeting New Hampshire voters just ahead of that state's Democratic Presidential Primary Election in January.

According to a Notice of Apparent Liability for Forfeiture issued by the Commission, Steve Kramer was responsible for generating thousands of illegal prerecorded voice robocalls using misleading and inaccurate caller ID information, in violation of the Truth in Caller ID Act. The caller ID transmitted with the calls actually belonged to the spouse of a prominent New Hampshire Democratic political operative who had no knowledge of the calls and had not consented to its use.

Further, Kramer's illegal robocall campaign relied on so-called deep fake generative artificial intelligence (AI) to create voice messages that imitated the voice of President Joseph Biden. Contrary to the Democratic Party's efforts to encourage voters to write in President Biden's name on the Primary Election ballot, the robocall message encouraged people not to vote at all in the Primary.

U.S. Congress Mandates More Strict Lithium-Ion Battery Safety Standards

The U.S. House of Representatives has passed legislation that would strengthen safety standards applicable to rechargeable lithium-ion batteries.

CBS News reports that the legislation passed by the House, titled "Setting Consumer Standards for Lithium-Ion Batteries Act," will require the U.S. Consumer Product Safety Commission (CPSC) to establish a safety standard applicable to rechargeable lithium-ion batteries. The legislation was originally introduced in 2023 by Congressman Ritchie Torres (D-NY) as H.R. 1797 and passed with an overwhelming bi-partisan vote of 378-34.

The legislation now goes to the U.S. Senate where it will be reviewed by the Senate's Committee on Commerce, Science, and Transportation.

The legislation arises from the surge in fires stemming from poor-quality rechargeable batteries used in e-bikes and electric scooters. As evidence of the scope of the problem, CBS cites statistics from the New York City Fire Department, which reported more than 400 fires, 300 injuries, and 12 deaths from fires caused by defective lithium-ion batteries in New York City between 2019 and 2023.

Largest Observatory Camera Ever Built Now Being Installed

An overnight success, two decades in the making!

The U.S. National Science Foundation (NSF) reports that the largest space camera ever built is now being installed at an international space observatory site in a remote area of Chile. The 3200-megapixel Legacy Survey of Space and Time (LSST) Camera was built over a period of 20 years at the U.S. Department of Energy's (DoE's) National Accelerator Laboratory in Menlo Park, California, and is being installed at the Rubin Observatory located on Cerro Pachon in Chile.

According to the NSF, the LSST Camera will produce detailed images of space with a field of view seven times wider than the full moon. The NSF says that the camera will further advance the exploration of the nature of dark matter and dark energy, as well as aid future efforts to map the solar system and the Milky Way.

FDA Issues Final Guidance on Remanufacturing of Medical Devices

The U.S. Food and Drug Administration (FDA) has published a Final Guidance to clarify the meaning of "remanufacturing" of reusable medical devices that need either maintenance or repair.

According to the FDA, the Final Guidance, titled "Remanufacturing of Medical Devices: Guidance for Industry, Entities that Perform Services or Remanufacturing," clarifies the specific types of activities that it classifies as "remanufacturing," as well as its current requirements applicable to remanufacturers. The Guidance also includes recommendations for information to be included in device labeling to help ensure the quality, safety, and effectiveness of remanufactured devices over their anticipated useful life.

Medical devices intended for reuse play an integral part of healthcare, and include ventilators, endoscopes, and defibrillators. Proper servicing of such devices is essential in protecting the health and safety of patients and healthcare providers.

DESIGNING FOR EMP RESILIENCE

High-Altitude Electromagnetic Pulse Protection for Critical Electronic Systems

Jeffrey Viel is the Chief Engineer, EMI/E³ for Element U.S. Space & Defense and has been with the organization for 26 years. He has over 30 years of equipment and system level EMI/E³ test and analysis experience in the defense and aerospace industries. Viel can be reached at jeffrey.viel@elementdefense.com.

By Jeffrey Viel

The modern world as we know it is ruled by technology. Every aspect of life today is encompassed by some sort of microprocessor-based electronic device intended to simplify tasks, reduce processing times, increase efficiency, and improve accuracy. Electronics are used to communicate with loved ones, manage finances, fly aircraft, autonomously drive us to work, and even save lives. As we achieve further advances in technology, electronics will continue to lead the way in adapting these technologies into new critical systems and processes.

The benefits that electronics have provided us are undeniable. However, there is a significant drawback as the implementation of sensitive electronic circuitry continues to increase our vulnerability to the effects of electromagnetic threats such as an EMP attack. An electromagnetic pulse (EMP) is defined as a high amplitude, short duration, broadband pulse of electromagnetic energy that can have devastating effects on unprotected electronic equipment and systems. EMPs are historically known as the electromagnetic effects following a nuclear blast occurring at high altitudes.

THE SCIENCE BEHIND EMP

Initial research of the electromagnetic effects was documented by the U.S. in 1958 during a series of high-altitude atmospheric tests. The most noted was during the detonation of the nuclear payload named "Starfish Prime" over the Pacific Ocean over 800 miles away from Hawaii. It produced a severe electromagnetic pulse that traveled distances much further than the shock wave and blast effects that were reported to have disrupted radio stations, damaged electrical equipment, and even blew out streetlights along the shoreline of Hawaii.

A high-altitude nuclear electromagnetic pulse (HNEMP) develops from the detonation of a nuclear bomb at very high altitudes above the surface of Earth. The blast releases a burst of gamma rays that travel at the speed of light in all directions from the detonation. When these gamma rays enter Earth's atmosphere, they collide with oxygen atoms, causing a scientific phenomenon known as "Compton scattering" to occur. When a high energy light photon collides at a molecular level with one of the atom's electrons, it transfers some of its energy and changes its trajectory. This collision also sends the negatively charged electron on an accelerating trajectory away from its positively charged nucleus.

Commonly known as a "Compton electron," this electron spirals along the Earth's magnetic field lines, resulting in rapidly varying electric and magnetic fields, which produces a large, fast-rising asymmetric

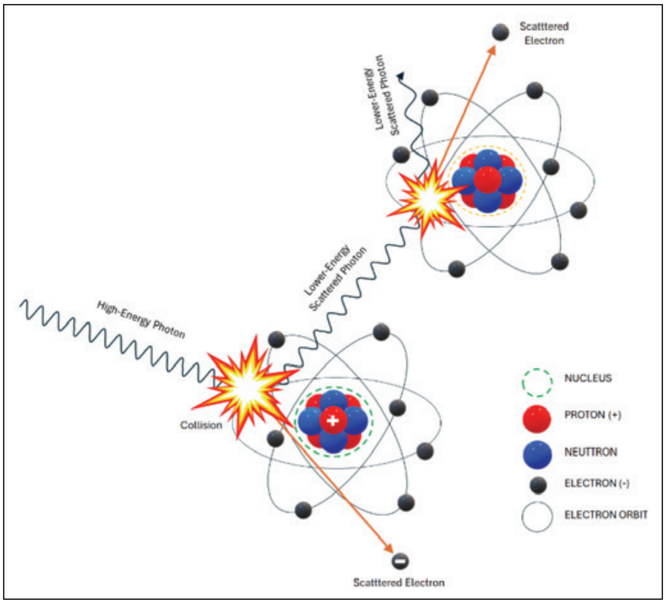

Figure 1: Illustration of the Compton effect

electric field pulse. Additionally, the photon will continue to collide with other nearby air molecules in its trajectory path until it is depleted of energy. Secondary electromagnetic pulses caused by the interaction of the initial pulse with the Earth's surface and the ionosphere may occur as well.

The exposure radius of a high-altitude EMP, commonly known as the "disposition region," is determined by three main elements:

1. The height of the blast;
2. The size of the blast; and
3. The type of explosion.

In general terms, the disposition region increases with the altitude of the detonation. Altitude also plays a role in the asymmetry of the pulse waveform as well. The size and type of blast will determine the magnitude of the EMP. Theoretically, the size of the EMP disposition region is only limited by the curvature (horizon) of the planet.

It has been theorized that a 100-megaton nuclear payload detonated at a height of approximately 300 miles over the state of Kansas (central United States) would result in an EMP disposition region large enough to envelope the entire country. A HNEMP from this height would extend to the visual horizon of the planet as seen from the burst point perspective (see Figures 2 and 3).

ABOUT HNEMP

A HNEMP is a complex multi-pulse waveform containing a broad spectrum of electromagnetic radiation spanning a range from a few Hz to several GHz.

The pulse is defined in terms of three components:

- *E1 Early Time Pulse:* Also defined as the prompt gamma signal, E1 early time pulse is characterized by its fast rise time (2-10 nsec) and peak values between 50 kV/m - 100 kV/m. The E1 early time component is used as an EMP evaluation tool as its fast rise time exceeds the reaction time for commonly integrated lightning protection devices. The E1 pulse magnitude can temporarily disrupt or permanently damage the operation of electronic devices due to high induced voltages and currents.

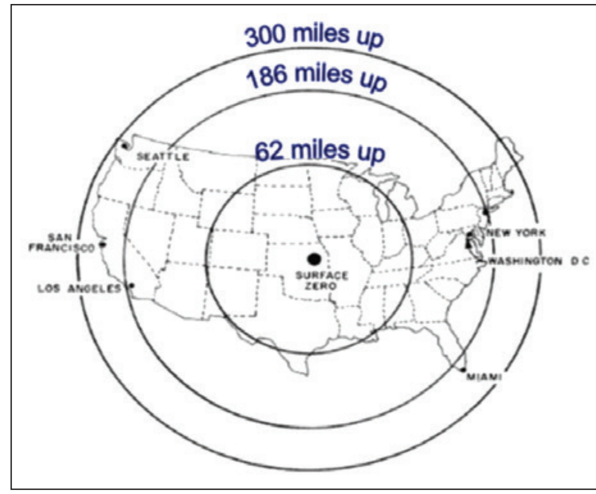

Figure 2: HNEMP disposition range based on height over the United States

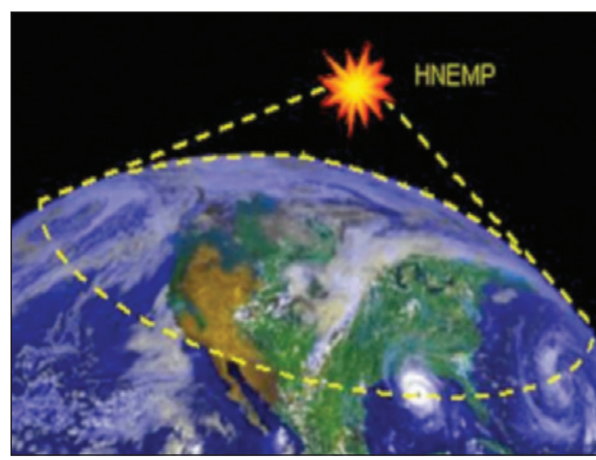

Figure 3: HNEMP disposition extended to the visual horizon

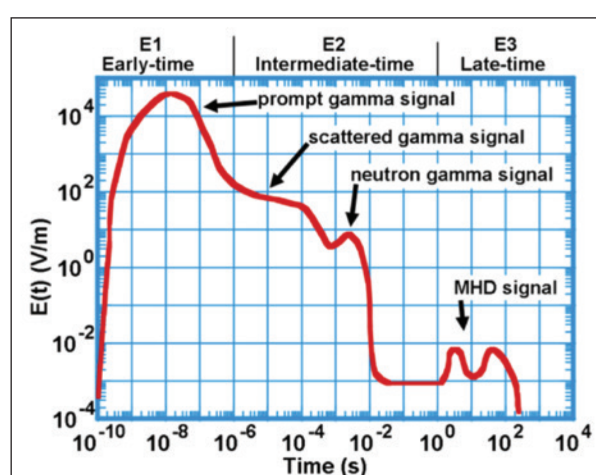

Figure 4: The unclassified nominal high altitude electromagnetic pulse composite environment (E1, E2, and E3)

The E1 pulse frequency spectrum couples to RF antennas and receiver ports, equipment enclosures (through apertures), and short and long cabling and power lines.

- *E2a Intermediate Time Pulse:* Related to the scattered gamma signaling effects, E2 pulse operates around 1/1000 μsec, with peak values in 100 V/m range. Characteristics are similar to low-level indirect lightning strikes, and common lightning surge protectors will help mitigate E2 EMP pulses coupled to power lines and antenna ports, including long power lines, vertical antenna towers, and aircraft with trailing wire antennas.
- *E2b Intermediate Pulse:* Also referred to as the neutron gamma signal, E2b pulse durations are long and slow, around 1 second, with peak values in the 10 V/m range. Effective coupling to long overhead and buried power lines and to extended VLF and LF antennas can mitigate the effect. However, dominant frequencies overlap AC power and audio spectrums, making filtering difficult.
- *E3 Late Time*: Referred to as the Magnetohydrodynamic (MHD) signal, the E3 signal has a very long duration, ranging from 50 minutes to several hours. E3 signal amplitude is quite low, around 100 mV/m. The E3 signal characteristics are similar to geomagnetic solar storms and flares.
- Due to the long duration of the E3 signal, disruptive geomagnetically induced currents (GIC) can occur in power transmission lines that can affect the normal operation of long electrical conductor systems such as electric transmission grids, buried pipelines, oil and gas pipelines, non-fiber optic undersea communication cables, non-fiber optic telephone and telegraph networks, and railways. The associated electric field (measured in V/km) acts as a voltage source across conducting networks. GIC are often described as being quasi-direct current (DC), although the variation frequency of GIC is governed by the time variation of the electric field.

WEAPONS LEVERAGING EMP TECHNOLOGIES

While a high-altitude nuclear electromagnetic pulse attack may seem unlikely, at least in the near term, non-nuclear weaponized EMP technologies have been progressively developed worldwide for decades. These technologies are classified as direct energy weapons (DEW) and are currently being used today by our U.S. armed forces and government agencies worldwide.

DEWs are designed to emulate the HNEMP E1 pulse characteristics and direct this at the target, much like that of a conventional EMP, at close range. Some DEWs have been shown to be capable of specialized tuning fork graduated effects on specific electronics types ranging from operational disruption, permanent hardware damage, and complete destruction of systems.

A prime example of this technology is the "anti-drone rifle" or "anti-drone gun," a battery-powered electromagnetic pulse weapon that is shoulder-fired and intended for disabling flying drone targets (see Figure 5). The device emits separate electromagnetic pulses to suppress navigation and transmission channels used to operate the drone and terminate the drone's contact with its operator, ultimately resulting in the out-of-control drone crashing.

A similar example of this is the Russian "Stupor," a shoulder-fired EMP gun reported to have a range of two kilometers, covering a 20-degree sector. This device also suppresses the drone's cameras. The Stupor is reported to have been used by Russian forces during the Russian military intervention in the Syrian civil war in 2011.

Yet another example of non-nuclear EMP technology is the flux compression generator (FCG). The FCG was first demonstrated by Clarence Fowler at

Figure 5: Anti-drone EMP rifle

Los Alamos National Laboratories (LANL) in the late fifties. This technology injects a high-energy pulse into a large conductive coil. At the point of peak pulse current, a small explosive charge is deployed, which rapidly compresses the coil to one end of the generator, developing a massive amount of electromagnetic energy (see Figure 6). The first designs were several feet in length but, through technological advances, they are now reported to be roughly the size of a beer can.

The U.S. Navy used an FCG pulse weapon (see Figure 7 on page 16) during the opening hours of the Persian Gulf War to effectively destroy vast amounts of Iraqi electronics, power, and telecommunications system infrastructure quickly and efficiently. The deployment of EMP weaponry instantly caused what is known as the "Fog of War" (a complete loss of communications between troops and command posts), which devastated the Iraqi forces, essentially ending the war before it began.

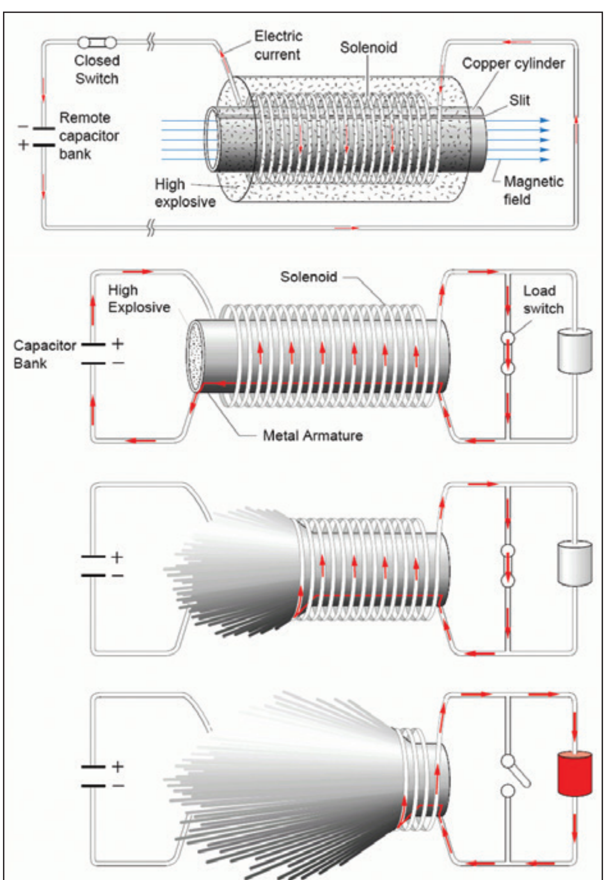

Figure 6: Operational stages of an FCG

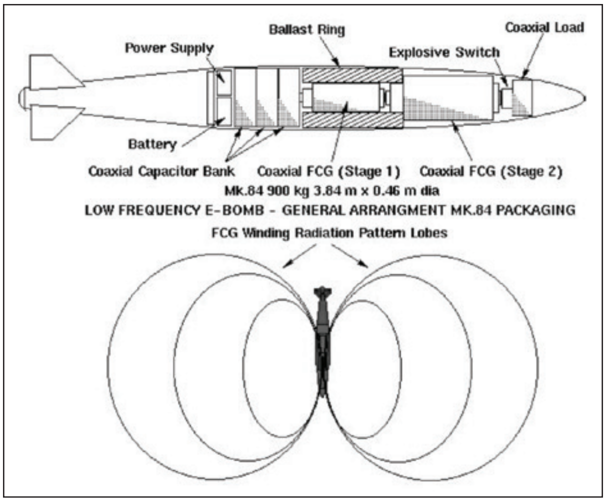

Figure 7: Illustration of an FCG instrumented missile

TESTING FOR EMP RESILIENCE: MIL-STD-461G, RS105 TEST METHOD

With the creation of non-nuclear direct energy weapons and the increased use of devices on the battlefield and in civilian non-combat environments, the need to protect electronic equipment is at an all-time high. There are a number of well-established standards and design guidelines available for hardening equipment and systems against the effects of a weaponized electromagnetic pulse attack.

MIL-STD-461G provides test methodology and screening levels for determining a device's immunity to EMP from a radiated and conducted standpoint. The coupling modes onto the equipment enclosure and its interconnecting cabling can be complex and, therefore, are evaluated separately.

The RS105 test method specified in MIL-STD-461G addresses the risk of radiated exposure to an EMP event.

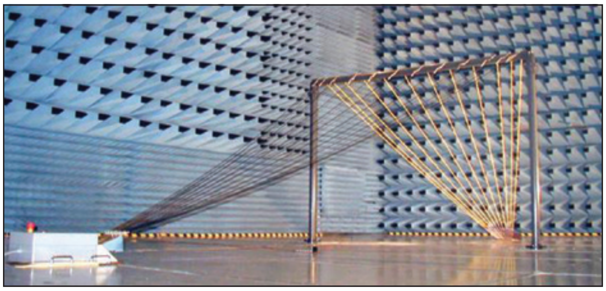

Figure 8: Typical RS105 EMP equipment level test setup

RS105 testing is generally applicable for equipment installed in exposed and partially exposed environments. The U.S. Department of Defense (DoD) requires an electromagnetic environmental effects (E3) assessment for nearly every platform, from surface ships, submarines, and aircraft to space systems and ground applications, including fixed and mobile mission-critical C4i facilities.

The RS105 electromagnetic pulse characteristics consist of a fast rise time, short pulse duration, and high amplitude, which resemble the E1 early-time characteristics of an HNEMP. Peak field strengths of 50 kV/m -0 + 6dB are specified for equipment that may be exposed or partially exposed to an EMP once deployed. However, tailoring the peak field levels is often required for partially exposed installations due to the attenuated effects provided by enclosures, such as the deckhouse structure or hangar doors.

For example, equipment installed on a ship near a deckhouse aperture is required to meet the full EMP threat environment reduced by the aperture's partial electromagnetic shielding effectiveness or 40 dB of shielding provided by the deckhouse structure, whichever is less. In other cases, the EMP field levels may be increased to determine the resiliency threshold of a particular device or to assess the linear effectiveness of its EM shield.

Equipment-level EMP exposure testing to RS105 testing is performed with a transmission line connected to a transient pulse generator (see Figure 8). The EMP generator, which basically consists of a high voltage DC source, high voltage capacitor bank, and a switch, is connected to one end of the transmission line and referenced to ground. The far end of the transmission line is then securely bonded to the ground plane. This ground connection provides a return path, allowing current flow and the generation of electromagnetic fields to develop within the transmission loop.

The field developed between the transmission line and the ground plane consists of a large differential voltage and current field. MIL-STD-461G also requires that the EMP field is uniformly distributed over the test article (see Figure 9). Therefore, the field is verified at five points vertically based on the maximum dimensions of the equipment under test (EUT).

The results taken at each point must be within -0 to 6dB tolerance. In terms of voltage, the uniform field level between all measured points shall be between 50,000 and 100,000 V/m.

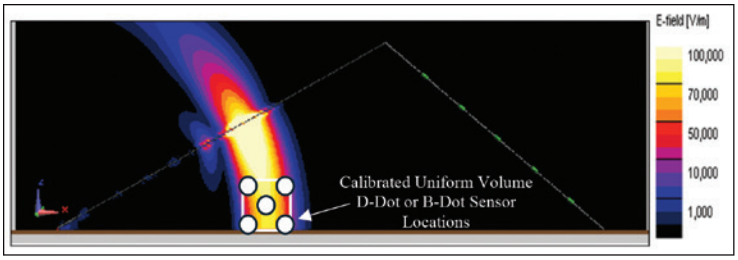

Figure 9: Predicted uniform field region under the RS105 EMP transmission line

The purpose of RS105 testing is not to damage the equipment but to determine its operational threshold level to the electromagnetic pulse. Here, testing is performed at a very low pulse level (500 V/m or 10% of the maximum peak field level), then gradually increased until either susceptibility is observed or the specified peak field level is reached.

It is important to note that RS105 testing is intended to evaluate the effects of a radiated EMP only. Therefore, the test setup requires that all metallic interconnecting cabling, including power input lines, are routed in shielded conduit and/or underneath the ground plane and filtered as necessary to minimize EMP coupling effects.

TESTING FOR EMP RESILIENCE: MIL-STD-461G, CS 116 TEST METHOD

The MIL-STD-461G CS116 test method is then used to evaluate the coupling effects of EMP on metallic interconnecting lines. The intent of this test is to ensure the equipment's ability to withstand conducted damped sinusoidal transients excited by platform switching operations, indirect effects of lightning, and EMP. The minimum set of test frequencies includes 10 kHz, 100 kHz, 1 MHz, 10 MHz, 30 MHz, and 100 MHz, which broadly covers the EMP critical frequency spectrum. In accordance with MIL-STD-461G, CS116 testing is applicable for all installation platforms and procurement agencies, with limited applicability for submarines.

Similar to RS105, CS116 testing is used not to damage the equipment but to determine its operational threshold to the coupling effects of an electromagnetic transient pulse. This is performed by starting at 10% of the peak field level and gradually increasing the field until susceptibility is determined or the specified peak field level is reached.

One important aspect to note about this testing method is that the transient signals are inductively coupled to each line separately. In an actual fielded exposure scenario, all interconnecting lines are likely to be exposed simultaneously. Additionally, the amount of voltage and current induced onto each line is dependent on its common mode impedance. Higher impedance lines will allow for greater voltages to be achieved at lower currents, whereas low impedance lines, such as shielded cabling, will achieve greater currents at lower voltages.

To avoid excessive over-testing, pre-calibration of the injected currents into a 100-ohm loop impedance is performed, and the currents induced onto each line are monitored. As mentioned, test levels are gradually increased until equipment susceptibility is detected and the current limit is achieved, or the generator setting determined during the 100-ohm calibration is reached.

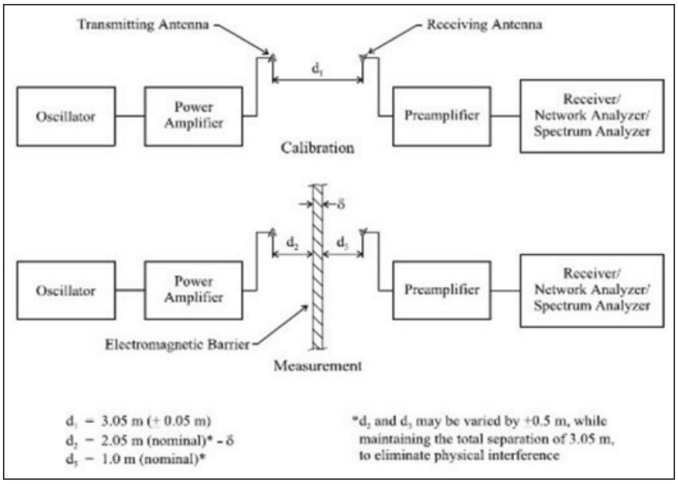

Figure 10: MIL-STD-188-125 SE baseline measurement setup

TESTING FOR EMP RESILIENCE: MIL-STD-188-125

MIL-STD-188-125-1 & -2 outline the unclassified high altitude electromagnetic pulse (HEMP) protection control requirements for fixed and mobile ground-based command, control, communications, computer, and intelligence (C^4I) systems and facilities. EMP protection performance in accordance with this standard is assessed in multiple phases:

- Shielding effectiveness (SE) testing
- Pulsed current injection (PCI) testing
- Continuous wave (CW) immersion testing
- Threat level illumination EMP testing

Shielding Effectiveness Testing

Shielding effectiveness (SE) testing has long been used to evaluate the performance of an electromagnetic shielded boundary used to suppress radiated electromagnetic signals entering or leaving the shield's inner boundary. There are numerous industry standards and SE test methods, such as those found in IEEE-STD-299 that can be used to assess the performance of a large, shielded equipment enclosure intended specifically for protection from an external EMP event.

From a basic sense, transmitting and receiving antennas are first centered on each other at a set distance. The antenna type and frequency band being tested are normally matched. The instrumentation is then stepped through the measurement frequencies while forward power data and transmitted signal emissions readings are recorded. This establishes a baseline to determine the SE value (see Figure 10).

Depending on the location where testing is being performed, the baseline measurement may need to be performed outdoors or in an uncontrolled electromagnetic environment. In these cases, it becomes critical to account for sufficient dynamic range when establishing the baseline reading, as it is likely that the ambient electromagnetic environment will interfere with these readings.

A general rule of thumb is to ensure that the dynamic range is at least 6 dB greater than the anticipated SE value over the test frequency range. It is common to level the baseline value across the test frequency spectrum by adjusting the transmitter's forward power level. This approach may simplify the SE calculation process when in the presence of a noisy ambient background environment.

Once the baseline is established, the antennas are positioned on either side of the shielded boundary. The shielding effectiveness measurement axis (the imaginary line between the transmitting antenna and receiving antenna locations) for each test area shall be normal to the shield surface and shall pass through the geometric center of the area. Additionally, the same spacing between the two antennas used during the baseline measurement must be observed during the SE measurement, as this will impact the measured results.

Once completed, the baseline power level is replayed, and the attenuated signal level is received. The SE value is then calculated by simply subtracting the attenuated signal measurement data from the baseline data (see Figure 11).

This process is repeated multiple times along the enclosure's entire surface area (including the floor when both sides of the shield are accessible).

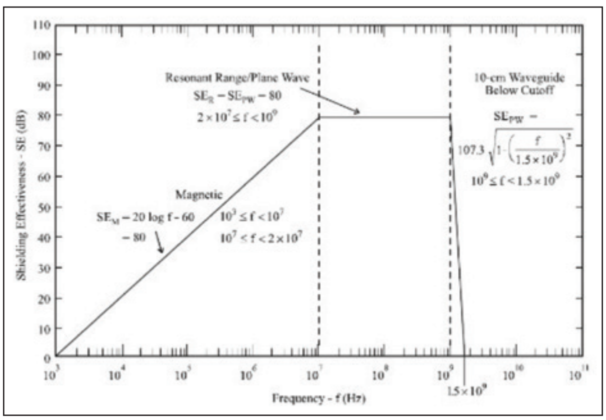

Figure 11: MIL-STD-188-125 SE limit

MIL-STD-188-125 requires that the minimum number of positions should be divided into numbered plane areas no greater than 3.05 m × 3.05 m (10 ft × 10 ft). However, specific mechanical design elements, including seams and aperture features that could constitute a weakness of the electromagnetic boundary, must be tested.

It should be noted that, unlike a radiated emissions control specification, SE performance should either meet or exceed the limit requirements versus having some margin below the limit specification. The higher the shield's SE performance, the greater its suppression of an external EMP field.

SE data is also incredibly useful during EMI/E[3] system risk assessments during the early stages of development. Assuming SE data can be applied linearly to an external field response, the internal environment of the shielded boundary can be determined based on an external electromagnetic environment of any level within the measurement frequency range.

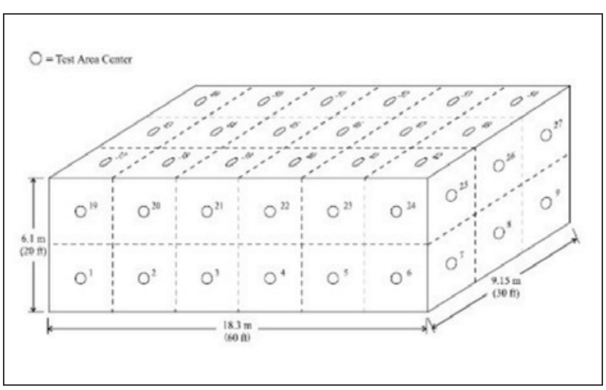

Figure 12: MIL-STD-188-125 SE limi

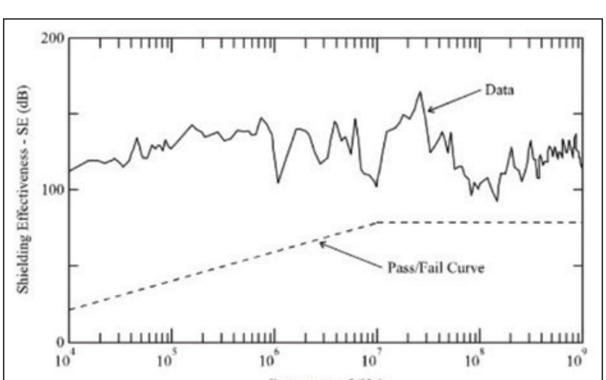

Figure 13: SE Limit comparison

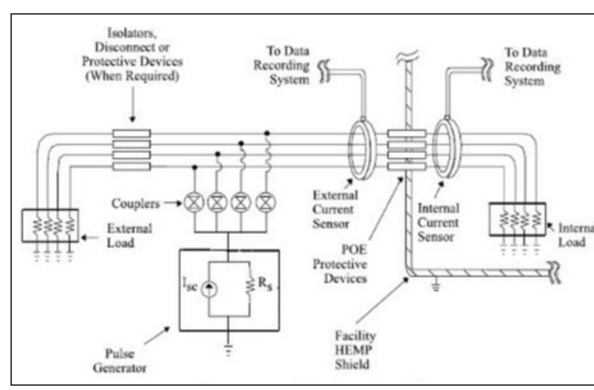

Figure 14: Common mode PCI setup

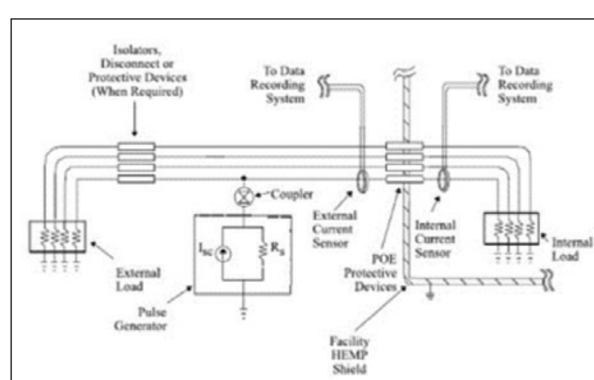

Figure 15: Differential mode PCI setup

Pulsed Current Injection (PCI) Testing

Pulsed current injection (PCI) testing assesses all electrical point-of-entry (POE) protective devices installed on cabling interfacing with low-risk HEMP ground-based facilities. It is used to demonstrate that electrical point of entry (POE) protective devices provide adequate transient suppression/ attenuation of externally coupled EMP currents in accordance with MIL-STD-188-125. Much like test method CS116 for equipment-level testing, compliance with this test demonstrates that mission-critical systems (MCS) are not damaged or upset by residual internal transient stresses caused by an external EMP event.

The PCI tests are conducted by injecting threat-relatable transients to conductors at injection points outside the electromagnetic barrier. This is performed on each penetrating conductor and cable, radio frequency (RF) antenna shield, and conduit shield. Unlike test method CS116 testing, simultaneous injection of all electrical POE protective devices is preferred when practical, as this best represents the effects of an actual external EMP event. Injections are also performed in both common mode (all penetrating conductors of a cable simultaneously driven with respect to ground), and individual wire-to-ground configurations are required. Residual internal responses are then measured, and the operation of the system is monitored during the test for indications of mission-aborting damage or upsets.

CONCLUSION

The development of electromagnetic pulses is very complex, and the effects it can have on electronic equipment and systems can be devastating. This poses an operational threat to mission-critical processes and infrastructures worldwide. It is incredibly important to establish and implement EMP-hardened design features to increase system-level resiliency against potential EMP attacks now.

To successfully navigate the design, assessment, and validation processes to ensure EMP resilience, we strongly recommend working with an experienced third-party testing organization with knowledgeable subject matter professionals expert in EMP-specific issues. Doing so will help to ensure the resilience of your technology against EMP threats and enable you to bring high-quality technologies to market more efficiently and cost-effectively.

NAVIGATING MEXICO CERTIFICATION REQUIREMENTS FOR RADIO-TELECOM DEVICES

A Guide to the Ever-Changing World of Mexico Regulatory Compliance

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By Claudia Cordon and John Grinager

Mexico's regulatory compliance process is challenging and changes regularly. Companies who export their products to Mexico can face difficulties because most products entering the country must prove compliance with different Official Mexican Standards (Norma Oficial Mexicana) (NOM) mark/certification requirements to pass customs. All NOM requirements are defined and issued by the Secretary of Economy (Secretaría de Economia) and published in the country's Official Gazette of the Federation (Diario Oficial[1]) and may apply to products ranging from food such as chocolate to electronics.

The local laws and product regulations are set up to provide assurance that the products and services are 1) of good quality and 2) fit for consumer needs.

Proving compliance with NOMs and other regulations applicable to Electronics and Electrical Equipment is more rigorous than other products and involves several processes and players, as described below. Once a product is found to be compliant with the applicable NOM requirements, a Certificate of Conformity (CoC) is issued in the name of a Mexican company, and the product can be marked with the NOM Mark, as shown in Figure 1. Most Certification Bodies (CBs) in Mexico require a modified version of this mark that includes their logo.

Figure 1: The Norma Oficial Mexicana (NOM) Mark

The following are two of the most common Mexican Radio/Telecom NOMs:

- *NOM-208-SCFI-2016:* Radiocommunication systems that use the spread spectrum technique-Frequency hopping and digital modulation radiocommunication equipment to operate in the bands 902 MHz-928 MHz, 2400 MHz-2483.5 MHz and 5725 MHz-5850 MHz-Specifications and test methods.[2]
- *NOM-221/2-SCFI-2018:* Technical specifications of mobile terminal equipment that can make use of the radio spectrum or be connected to telecommunications networks. Part 2. Mobile terminal equipment operating in the 700 MHz, 800 MHz, 850 MHz, 1900 MHz, 1700 MHz/2100 MHz and/ or 2500 MHz bands.[3]

NOM VS. TECHNICAL DISPOSITION

It is important to understand the difference between distinct types of standards that affect compliance for radio-telecom products in Mexico. NOMs, which are official mandatory standards, are issued by the Secretary of Economy. However, The Federal Institute of Telecommunications[4] (IFETEL) issues mandatory Technical Dispositions (Disposición técnica) (TD) on which radio/telecom equipment NOMs are based. TDs describe the frequencies, power levels, test procedures, and other details associated with specific NOMs that are subsequently considered for the issuance of CoCs. Some examples of equivalent NOMs and TDs are:

- NOM-208-SCFI-2016 = IFT-008-2015
- NOM-221-SCFI-2017 = IFT-011-2017 part 1
- NOM-221/2-SCFI-2018 = IFT-011-2017 part 2
- IFT-012-2019 is a specific absorption rate (SAR) requirement that has a Technical Disposition but does not have a particular NOM equivalent yet.

IFETEL is working on two new TDs that will lead to the creation of new radio NOMs. The first would apply to devices that use frequency bands of the radio spectrum from 30 MHz to 3 GHz. The second would apply to the following bands: 5150-5250 MHz, 5250-5350 MHz, 5470-5600 MHz, 5650-5725 MHz, 5725-5850 MHz, and 5925-6425 MHz.[5]

HOW TO DETERMINE NOM REQUIREMENTS

The Mexican Customs Service (Agencia Nacional de Aduanas de Mexico, ANAM) takes a lead role in the compliance process because of its role in surveilling products entering the country. Therefore, assessing NOM requirements for a product begins with this agency:

1. Consult guidance documents associated with the Mexican tariff code assigned by Customs (see next section). In general, the Customs Broker facilitating the import of the product to Mexico will provide a recommendation of the appropriate code that applies to the product.
2. If the applicable standards are not obvious from customs information, then one may consult with a CB to match product specifications with standards. These are subsequently summarized by the CB in an Official Opinion (Dictamen Técnico, or Dictamen).

USE OF TARIFF CODES TO DETERMINE APPLICABLE NOMS

The Government of Mexico has its own harmonized system of goods classification, commonly referred to as Harmonized System (HS) codes or tariff codes (Fracción Arancelaria).

To determine which NOMs apply to a product, the Customs Service has a website where it lists possible NOMs to be applied to a product based on its HS Code. Customs Brokers normally review these requirements and, based on their analysis, provide the requirements to the prospective approval holder. Unfortunately, there is no updated information source where the public can check the NOM requirements in the current HS code system.

Using incorrect HS codes can complicate the importation process and cross-border sales and incur lengthy delays and/or high fees. The Harmonized System in Mexico historically has been slightly different from other systems around the world. In January 2021, the Customs Service incorporated the "Trade Identification Numbers/TIN – (Número de Identificación Comercial/NICO)," and the creation of 10-digit tariff classification was implemented in the 2020 amendment to the General Import and Export Tax Law (Ley de los Impuestos Generales de Importación y Exportación, or LIGIE).[6]

The purpose of the change to the Harmonized System was to identify goods more accurately and improve the statistics gathering for Mexico's Foreign Trade. A benefit of this change is that it is now more aligned with the World Customs Organization's (WCO) modern Harmonized Tariff Schedule (HTS) structure and is similar to the systems of the US, Canada, and China. Although all 10 digits in the code may be used to determine the applicable NOMs, currently, CoCs, which list the HS Codes, only show the first 8 digits. The complete 10-digit-code, including the NICO allocation, is used for the basic Mexican import document, which is the Import Request (Pedimento de Importación).[7]

KEY PLAYERS IN THE COMPLIANCE PROCESS

Because Mexico has chosen an enforcement regime for compliance that begins at the border but also includes rules regarding the commercialization of regulated products once products have passed customs, there are many key players involved in the certification process, including the following:

- *Manufacturers*: These provide product documentation and samples (if required);
- *Importers*: They are the official holders of certificates and are responsible for importation;
- *Customs brokers*: Customs brokers assist in identifying the proper Mexican HS code and, when ready, get shipments through customs;
- *Accredited test laboratories*: Test labs must be accredited according to Mexican regulations. They perform tests to prove compliance to specific NOMs;[8/9]
- *Peritos*: These are engineers located in Mexico who have been certified as Telecommunications experts by IFETEL; [10]
- *Certification bodies*: These are accredited entities that review and determine if a product's test reports and other required documents associated with regulated products comply with the applicable NOM(s). They issue CoCs and conduct any subsequent surveillance;[11] and
- *IFETEL*: The Instituto Federal de Telecomunicaciones is the federal authority in charge of Telecommunications in Mexico. It is responsible for issuing Certificates of Homologation (CoH) and performs a surveillance role. [2]

THE IMPORTANCE OF THE LOCAL IMPORTER

Under Mexican laws, the NOM certificate holder is responsible for warranty, maintenance, and product liability. NOM certificates are non-transferable. However, a local company that is a NOM holder may request a CB to add an importer or distributor to the CoC. If this is done, the same request must subsequently be updated on the CoH. For a local company to obtain certificates in its name and import products, it must first register with the following organizations:

- Ministry of Finance and Public Credit (Secretaría de Hacienda y Crédito Público), which will issue a Mexican TAX ID (RFC).
- One or more CBs.
- Certification Authorities, such as IFETEL.
- Mexican Customs in its "Importers Database" (Padrón de Importadores).

KEY DOCUMENTS TO CLEAR CUSTOMS AND LEGALLY MARKET PRODUCTS IN MEXICO

Various documents may be necessary to demonstrate compliance to NOMs or to meet other requirements to pass customs and subsequently commercialize products in Mexico. Customs Letters, CoCs, Constancies, and Dictamens are used to pass customs. Subsequently, a CoH is necessary to commercialize a product once it has passed customs. The following explains the role of each document:

- *Customs Letter:* This document is used to clear samples that are coming in for testing purposes.
- *Certificate of Conformity (CoC):* These documents are issued by a CB to prove that a product complies with a specific NOM standard. Radio and telecom certificates are subject to potential annual audits. Official holders of certificates must present CoCs during the importation process.
- *Constancies:* These documents are issued by a CB to prove that a product complies with some NOMs, the most important of which is NOM-024-SCFI-2013, which defines commercial marking, user manual, and warranty policy requirements.
- *Official Opinion (Dictamen Técnico, or Dictamen):* These documents are written opinions from CBs to determine which specific NOM, if any, applies to a product. If none apply, Dictamens may be used to

facilitate importation acting as official documents to exempt a product from the scope of a NOM.

- *Certificate of Homologation (CoH):* This is a document issued by IFETEL to prove that a product meets all Mexican telecommunications standards. CoHs are not officially required for Customs clearance, but sometimes a Customs Agent might ask for proof that a CoH is in process or in place.

PEC VS. TRADITIONAL RADIO-TELECOM HOMOLOGATIONS

In Mexico, the process of complying with a radio or telecom standard, as opposed to complying with a safety standard, is known as homologation. Up until 2005, radio and telecom devices were approved without testing by certified radio/telecom experts (Peritos). However, beginning in 2005, Mexico began to establish official radio and telecom standards, including one used for WIFI/Bluetooth, one for wired-analog devices (analog phones and fax machines), and one for digital-multi-line devices (E1). Testing to these new standards became required for approval. Since 2005, the two regulatory systems have existed side-by-side. Over the years, the Federal Commission of Telecommunications (Comisión Federal de Telecomunicaciones, COFETEL) and its replacement agency, IFETEL, have continually reformed the approval processes. The current processes have been in effect since June 27, 2022. A summary of these regulatory systems follows:[12]

- *Type A Conformity Process (PEC):* A product that is in the scope of "Procedimiento de evaluación de la conformidad en materia de telecomunicaciones y radiodifusión" or PEC, is subject to a particular Mexican NOM standard (most common is NOM-208-SCFI-2016) and requires testing in a laboratory accredited by IFETEL. After testing, one must obtain a CoC issued by a local CB (such as NYCE, ANCE, etc.) and a CoH issued by IFETEL. This process is outlined in the PEC and follows the four (4) Schemes of Type Approval explained in more detail below. Under the current process, a single CoC is issued, mentioning all applicable NOMs or Technical Dispositions. Then this is submitted to IFT to get a Single CoH listing all applicable Standards.
- *Type B: Expert (Perito/Traditional)*: This is a process for telecommunications and radio products that are not subject to a specific Mexican NOM. In lieu of testing to Mexican NOMs, the Traditional process uses the "Perito" process mentioned above, in which a certified radio/telecom expert creates a written analysis of a product to show that it is consistent with a Mexican and/or an international standard. This document is called a Technical Report or Technical Dictamen (Memoria Técnica). After an application for homologation, accompanied by the Technical Report and other required documents, is submitted to IFETEL, it issues a CoH with a validity of 2 years.
- *Type C: Combination PEC and Traditional:* Considering the specifications of a product, it may be subject to both the "Perito" (Type B) and the PEC (Type A) process. One example of a product subject to both systems is a WIFI device that operates in the 2.4/5.7 GHz bands (subject to PEC) and operates in the lower 5 GHz bands (subject to the "Perito" process.) Although subject to both processes, under the current practice, a single IFETEL CoH is issued that covers both regulatory systems with a validity of 2 years.

CURRENT HOMOLOGATION PROCESSES UNDER THE PEC SYSTEMS (TYPES A & C HOMOLOGATIONS)

Currently, IFETEL has defined four PEC Schemes of Homologation based on how the product/group of products are classified. The exact scheme applicable to a product is determined by the CB used by the manufacturer. When choosing a CB, one should confirm that it has accreditation that includes all the radio/telecom interfaces included on the product because the single CoC must include all applicable NOMS. The four schemes available for PEC homologation are the following:

- *Scheme I (Single Batch):* By model for one shipment.
- *Scheme II (Multiple Batch):* By model for more than one shipment/batch. Subject to surveillance.
- *Scheme III (Family)*: By family of products with the same brand and technical design. Subject to surveillance.
- *Scheme IV (Device):* Approval of similar models using the same radio device (module). This is only applicable to Internet of Things (IoT) products. Subject to surveillance.

No matter which PEC scheme is chosen, the subsequent approval process is the same. Before starting the process every local company that wishes to hold a radio/telecom approval must register at IFETEL and at a CB. Following the registrations, one must complete the following steps with the following entities:

1. *Importer:* An Importer, or an authorized third party acting on its behalf, submits application forms and samples and other required documents to a CB.
2. *Certification Body:* The CB analyzes the product and determines which NOMs, and certification schemes apply. It then delivers samples and required documents to an accredited Mexican lab for testing.
3. *Laboratory:* An accredited laboratory tests the product and issues one or more Test Reports for submission to the CB.
4. *Certification Body:* The CB then issues a CoC listing all applicable NOMs / TDs and notifies IFETEL of the process.
5. *Importer:* The Importer, or an authorized third party acting on its behalf, submits application forms for a CoH, along with the test report, CoC, and other required documents including a Spanish language user guide to IFETEL.
6. *IFETEL:* After a positive review of the documentation, IFETEL issues a CoH and may subsequently alert the CB of project completion to enable the CB to begin the process to maintain the validity of the CoC. Currently, CBs are not always obtaining IFETEL notifications but are instead reaching out to applicants to provide proof of CoH submission and, subsequently, of the final certification.
7. *Certification Body:* Each year, CBs randomly select a percentage of CoCs that they have issued for audit. For audited certificates, it is necessary to re-test the associated products with new samples from current production.

CONFORMITY PROCESS (PEC), RECENT REFORMS

Since the beginning of the PEC system in 2005, there have been several changes to the rules affecting radio and telecom product certification in Mexico. The following summarizes major changes from the system as it appeared in 2020 (PEC 2020) to the reforms instituted on June 27, 2022 (PEC 2022).[12]

Approval Holder

PEC 2020 stated that every importer needed its own CoC and, if testing applied to the product, every CoC would need an independent test report. This had a major impact on companies that have many distributors/importers. Under PEC 2022, The main holder may request the CB to include or eliminate importers who may make use of a CoC issued after the new rule implementation date. Importers added to the CoC will have all the responsibilities of the CoC holder. For this purpose, the Interested Party must comply with the requirements of Annex A and the presentation of these together with the request of Annex B of this ordinance, in accordance with the provisions of Article 11, sections V and IX.) (see above). After receiving the updated CoC, a request must be made to IFETEL to update the CoH with all affected approval holders.

Sample Requirements

SCHEME I, II, IV
The two-sample requirement per model under PEC 2020 was reduced to one.

SCHEME III
The two samples from-two-different-models requirement (total of 4 samples) was reduced to one sample from two-different-models (total of two samples).

Test Reports

The validity of test reports increased from 60 to 120 days. In addition, test reports, which previously were automatically shared by the CB with IFETEL, are now only shared upon request. This was done to increase the confidentiality of the products to be certified.

Scope of the PEC

The scope of the PEC was extended to include both new and used equipment.

Validity for PEC and Traditional CoH Certificates

Under previous regulatory processes, IFETEL issued separate CoHs for PEC and Traditional Certificates. Therefore, products that had radio interfaces subject to both processes had two certificates. Further, traditional certificates had a validity of only one year. Currently, traditional certificates (Type B) and combination certificates (Type C) have a validity of two years but then may be made permanent with new "Perito" filings. Type A certificates, although they have no expiration dates, continue to be subject to the audits for the underlying CoC.

Validity for CoC Certificates

Under PEC 2020, many importers obtained CoCs but subsequently failed to obtain CoHs. This is because the CoCs enabled them to import the products successfully, and by failing to obtain CoHs, they saved on further compliance expenses. Under PEC 2022, if the homologation process with IFETEL is not completed, the CoCs are canceled after five business days.

IFETEL Label Requirements

- Currently, each Approved Product must have a physical or electronic marking or label that contains the number of the current CoH, following the format "IFT XXXXXXXX-XXXXXX."
- Physical markings or labels must be permanently fixed (engraved, stamped, printed, or affixed) and easily visible to future users.
- In the event the product is too small for physical labeling or marking, the label or mark may be displayed electronically in the product's operating system, included in the product's user manual, and/or included on the product packaging.
- Some TDs may include additional labeling and/or warning statement requirements.
- If the product is a "device" (module) approved under Scheme IV of the PEC, the mark or label must be applied only to the end products.
- If a product is subject to a Safety or Radio/Telecom NOM, it must also bear the NOM mark. Products subject only to the Traditional regulatory process, and which are not subject to safety NOMs may not require the NOM mark.

- On December 26, 2023, IFETEL Issued "The Guidelines for the use of the IFT Seal" (Lineamientos para el uso del Sello IFT) on approved products, equipment, devices, or devices intended for telecommunications or broadcasting. Examples of vertical and horizontal versions appear in Figure 2. More details can be found in the Federal Government's Official Gazette. This will be mandatory after October 2024.[13]

ift
IFT ABCDEF23-123456

ift IFT ABCDEF23-123456

Figure 2: Vertical (top) and horizontal (bottom) versions of the IFT seal

CONCLUSION

Every country presents challenges in complying with national radio and telecom regulations. In Mexico, the technical challenges are not especially difficult as it has harmonized its standards with the ITU and, in the case of radio standards, has mostly harmonized with the requirements of the U.S. Federal Communications Commission (FCC). The greater challenge for manufacturers is to keep up with customs requirements, understand the scopes of particular standards, and classify products under an evolving dual regulatory system (PEC vs Perito). In order to successfully navigate these issues, one must develop a team that includes importers, customs house brokers, test labs, certification bodies, and a third-party expert when warranted.

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PRODUCT COMPLIANCE CHALLENGES FOR WIRELESS RADIO DEVICES IN VEHICLES

By Steve Hayes, Technical Director – Connected Technologies, Element

Because the regulations for radio devices in vehicles are different from the normal Federal Communications Commission (FCC) or European Commission (EC) marking requirements, designers and manufacturers of vehicle wireless devices often struggle to understand what requirements apply to their product and how to ensure compliance. This article gives an overview of common regulatory markings for vehicles and how safety and performance requirements differ for radio devices in vehicles, especially regarding electromagnetic compatibility.

Steve Hayes is the Technical Director for the Connected Technologies business unit at Element. His decades of experience and unique technical insight help Element stay at the forefront of testing highly complex and evolving products against regulatory, industry, and carrier-specific global requirements. Steve sits on many national and international committees and regulatory forums, where he lends his expertise to the creation of regulatory standards. To see more of Steve's articles and recorded webinars or to learn more about Element, visit https://element.com.

REGULATORY & MANUFACTURER REQUIREMENTS

Most vehicles on the market today display at least one of these four regulatory marks:

- **E-Mark:** This proves that a vehicle or vehicle component complies with safety regulations, laws, and directives in the European Union. All vehicles sold in Europe must bear an E-Mark, but different countries may have different requirements, so the mark also has a number to indicate which national authority issued it.
- **CCC Mark:** This is a product safety mark that is compulsory for a wide variety of products sold or used in China, including vehicles.
- **CE mark:** A European product safety mark that applies to a wide array of products sold on the European market, including vehicles.
- **FCC Mark or SDOC (suppliers declaration of conformity):** This mark indicates that the product complies with the requirements of the Federal Communication Commission of the United States.

All these are examples of regulatory marks, indicating compliance with rules enforced by a government body, but non-government entities also impose requirements on radio devices in vehicles.

The US, notably, does not have a regulatory mark for radio devices used in vehicles. It is the responsibility of vehicle original equipment manufacturers (OEMs) to ensure the safety of every component they use, so OEMs create their own safety standards. Most US OEM standards include the same regulatory tests required by the E-Mark or FCC Mark, plus additional requirements unique to the manufacturer. These additional requirements are partly to protect their brand integrity, so prestigious brands usually have stricter requirements.

DEVICE COMPATIBILITY CHALLENGES

Modern vehicles often incorporate dozens of radio devices, from GPS navigation to tire pressure monitors to proximity sensors. These safety and convenience features are in demand, so manufacturers will only continue to add more. However, the more radio devices you have in a small area, the greater the risk that they will interfere with one another. These built-in devices must operate correctly together, but they must also be compatible with devices in or near the vehicle, like phones, and the radios in other, nearby vehicles.

Interference between radio devices is not just annoying, it can be dangerous, especially in a moving vehicle. Some types of device interference may unintentionally amplify radio frequencies to a level that may be harmful to humans, while other types of interference may cause essential vehicle components to malfunction.

ELECTROMAGNETIC COMPATIBILITY AND VEHICLE ELECTRONICS

Many regulations throughout the world address electromagnetic compatibility (EMC), but depending on the context, the term EMC may refer to compatibility in terms of either safety or functionality. Radio devices in a typical usage environment have fewer safety concerns than those in vehicles. If a set of headphones malfunctions due to electromagnetic interference, this does not cause a safety risk for the user. If, however, an object sensor on a vehicle stops working unexpectedly, this could cause a collision. It is helpful to think of electromagnetic testing for safety reasons as separate from electromagnetic compatibility testing.

For this reason, many EMC regulations don't apply to vehicles or have separate vehicle-specific requirements. In Europe, for example, the EMC Directive applies to most electronics, but not anything used in a vehicle that is "non-immunity related." The term non-immunity related means that if the product was to malfunction, it doesn't compromise the safety of the vehicle. The UNECE R10 standard, required for E-Marking in Europe, specifically addresses vehicle electromagnetic safety testing for people inside and outside the vehicle. Table 1 separates the concepts of electromagnetic safety and electromagnetic compatibility, and illustrates how common testing standards apply in each case.

To make matters more confusing, vehicle OEM standards and vehicle regulations generally base their test requirements on ISO or SAE standards, which focus on electromagnetic safety, while cellular products typically use FCC, ETSI, or IEC test methods, which focus on electromagnetic compatibility. If a manufacturer produces two mechanically identical radio devices but intends that one be built into a vehicle and one be used in a home, they will likely find that the requirements for testing the vehicle-specific device are much more stringent.

In Europe, the standardization body European Telecom Standards Institute (ETSI) offers a guide that is critical to radio equipment manufacturers and vehicle OEMs, explaining what assessments apply based on the device application. In the US, the FCC provides some instructions on their website for how to gain certification through a certification body.

NAVIGATING REQUIREMENTS AS A RADIO DEVICE SUPPLIER

Regulatory and contractual responsibilities need to be negotiated and agreed upon between the equipment supplier and the purchaser to clarify which party is responsible for testing and certification. Radio equipment manufacturers designing for an aftermarket product are responsible for providing accurate and sufficient information to the buyer, so the buyer can ensure they aren't creating a safety risk by integrating the equipment into a vehicle.

The vehicle manufacturer or integrator also has some responsibility to ensure that the final product is compliant. The vehicle manufacturer should understand if the radio equipment is providing an immunity-related function, which dictates what EMC requirements would apply and if the device has the potential to affect the safe operation of the vehicle.

Essentially, both radio equipment suppliers and vehicle manufacturers share responsibility for understanding how regulations apply to radio devices in vehicles. Although radio devices are now a common feature, this remains a complex area of testing with significant safety ramifications, and compliance is essential. ◻

	UNECE Reg 10.5/6	EMCD (2024/30/EU)	RED (2024/53/EU)		FCC	OEM
			Article 3.1(a)	Article 3.1(b)	CFR 47	
EM Compatibility	✗	✓	✗	✓	✓	✓
EM Safety	✓	✗	✓	✗	✗	✓

Table 1: Concepts of electromagnetic safety and electromagnetic compatibility and how common testing standards apply in each case.

UNDERSTANDING THE NEW CAPABILITIES AND REGULATORY COMPLIANCE TESTING REQUIREMENTS FOR WI-FI 6E & 7

Reduce Time To Market and Visits to Testing Labs for New Wi-Fi Products

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By William Koerner

Wireless connectivity has had such an impact on how we conduct our daily lives. With the wires removed, we are suddenly able to be connected to almost anyone, anywhere and anytime. According to a report released by IDC Research, 3.8 billion Wi-Fi devices were shipped in 2023.

Over the last few years, the number and complexity of Wi-Fi standards has grown. The United States (U.S.) opened up the 6 GHz band, while the European Union (EU) opened up about half of the 6 GHz bands for Wi-Fi 6E and now Wi-Fi 7. Although the Wi-Fi 7 standard has yet to be formally adopted, manufacturers have already released Wi-Fi 7 products. Each new standard offers more: more bandwidth, more data transfer options, and more capability.

However, one of the final steps to introducing new wireless products to the market is regulatory approval. And with each wireless standard, the regulatory requirements get more challenging. Focusing primarily on the U.S. and EU, this article will review the changes introduced by each wireless standard and discuss the measurement challenges in achieving regulatory approval.

OVERVIEW OF SUBSTANTIAL CHANGES TO WI-FI STANDARDS

Wi-Fi 6E

The Institute of Electrical and Electronics Engineers (IEEE) formally released the 802.11ax standard in 2021. This version of the standard focused on establishing a higher efficiency (HE) physical layer. Thus, it is also referred to as the HE standard and commercially known as Wi-Fi 6. Wi-Fi 6E is also the 802.11ax standard but extended (E) for use in the 6 GHz band, where allowed.

Table 1 shows the significant changes introduced with the 802.11ax standard and their impact on the radio interface.

160 MHz Bandwidth

Perhaps the first thing most will notice is the wider bandwidth. This allows for the use of 160 MHz, or 80+80 MHz noncontiguous channel bandwidths in the 5 or 6 GHz frequency bands. This allows for more data to be transmitted compared to the previous 80 MHz. This is optional but most likely standard for these devices.

Feature	Description	Impact
160 Max Channel Bandwidth	Ability to transmit in a 160 MHz Channel Bandwidth	Allows for more devices to transmit at the same time, and higher data rates
OFDMA	Modulation format that allows for assigning Resource Units (RUs) to associated stations	Lower contention overhead, increase the efficiency of spectrum usage
MU-MIMO	Multi-user MIMO, allows the AP to simultaneously receive and transmit to multiple stations	Simultaneous transmit/receive allows for even more efficient use of spectrum and lower latency
1024 QAM	10 bits per symbol	Higher data rate, up to 1201 Mb/sec theoretically
Preamble Puncturing	Multiple RUs allow for the ability to control each RU transmission, turn certain RUs off to address interference	Efficient use of spectrum, no need to switch operating channels to address interference

Table 1: New features introduced in 802.11ax

Orthogonal Frequency Division Multiple Access (OFMDA)

An extension to the OFDM that was already available, this system allows for sharing of the channel with multiple clients simultaneously. This is a mandatory feature for both the down link (DL) and up link (UL) and allows for a more efficient use of the spectrum.

Multiple User – Multiple Input Multiple Output

This feature, along with OFDMA, allows for up to eight spatial streams and simultaneous transmissions to each client. This feature potentially allows for continuous transmission and reception to multiple clients at the same time. The Down Link MU-MIMO is mandatory, and Up Link MU-MIMO is optional.

1024 Quadrature Amplitude Modulation (QAM)

1024 QAM is an extension of the modulation technique used for the previous standard, 802.11ac. This means that the I/Q constellation has 1024 points in its constellation and allows for transmitting 10 bits per symbol, allowing for higher data rates over previous standards.

Preamble Puncturing

This is an optional feature for Wi-Fi 6, and I am not aware of any commercial products that have enabled this feature. This feature is used with OFDMA to allow transmissions to be stopped in certain subcarriers, mostly as a way to avoid interference from other signals (noise, or other transmitters). This allows the devices to continue transmitting in the same channel, but avoiding parts of the channel while the interference is present.

Wi-Fi 7

Wi-Fi 7 is the commercial name given to the IEEE Standard of 802.11be. Its main design goal is to achieve extremely high throughput (EHT). This standard has not been formalized by the IEEE, but Wi-Fi 7 products have been available, at least in the U.S., for at least six months. However, those early products will not have all of the new features defined for this standard.

Table 2 shows the significant features added for 802.11be and its impact on the radio interface.

320 MHz Bandwidth

This is optional for both the 5 and 6 GHz band, but typically the first feature to be implemented due to the increase in potential data rates. It is even possible to implement a 240 MHz bandwidth as well. I know of one commercial AP that is using a 240 MHz channel in the 5 GHz band.

4096 QAM

4096 QAM allows for 4,096 points in the constellation, as compared to 1,024 for Wi-Fi 6. This equates to 12 bits per symbol, compared to 10 for Wi-Fi 6. Thus, again, higher data rates, theoretically up to 2882 Mbits/sec.

Feature	Description	Impact
320 Max Channel Bandwidth	Ability to transmit in a 320 MHz Channel Bandwidth	Allows for more devices to transmit at the same time, and higher data rates
4096 QAM	12 bits per symbol	Higher data rate, up to 2882 Mb/sec theoretically
Multi-Link Operation (MLO)	Ability to simultaneously send and receive to associated stations and to APs using different frequency bands and operating channels	Simultaneous transmit/receive allows for even more efficient use of spectrum and lower latency
Bandwidth Reduction	Multiple RUs allow for the ability to transmit and receive in non-standard bandwidths; contiguous and non-contiguous 320/160 + 160 MHz and 240/160+80 MHz bandwidths	Can be used for Low Power indoor devices to mitigate contention-based protocol/incumbent interference Allows for 240 MHz bandwidth channel in the 5 GHz band
Preamble Puncturing	Multiple RUs allow for the ability to control each RU transmission and turn certain RUs off to address interference. Mandatory to be considered a Wi-Fi 7 Certified device	Efficient use of spectrum, no need to switch operating channels to address interference

Table 2: New features added for 802.11be

Multi-Link Operation (MLO)

MLO allows sending/receiving packets concurrently on multiple channels which can be either in the same band or different bands. It is designed to provide:

- High spectrum efficiency
- Low latency
- Load balancing
- High reliability

Bandwidth Reduction

With the adaptive connections possible with Wi-Fi 7, it is possible to reduce the bandwidth of the current operating channel. This could be for either avoiding interference in part of the channel, or a way to optimize the use of the network when only part of a nominal channel is available. This allows the devices to stay on the same channel instead of either stopping transmissions or having to find a free channel. This is not the same as preamble puncturing.

Preamble Puncturing

While optional for Wi-Fi 6, it is mandatory for Wi-Fi 7 certified devices. This allows the devices to notch out, or puncture, part of the original channel to avoid interference and keep transmitting on the current channel. While the overall data rate may reduce, it prevents the devices from having to vacate the whole channel and move to another channel.

6 GHZ BAND – WIDE OPEN SPACES… WITH RULES…

On April 23, 2020, the U.S. Federal Communications Commission (FCC):

> *"…adopted the rules that make the 1,200 MHz of spectrum in the 6 GHz band (5.925 – 7.125 GHz) available for unlicensed use…*
>
> *"The 6 GHz band is currently populated by, among others, microwave services that are used to support utilities, public safety, and wireless backhaul. Unlicensed devices will share this spectrum with incumbent licensed services under rules crafted to protect those licensed services and enable both unlicensed and licensed operations to thrive throughout the band…"*

On June 17, 2021, the European Commission:

> *"…adopted a Decision harmonising the use of the 6 GHz band for wireless networks across the EU, which will support a growing number of devices, online applications and innovative services that require larger bandwidth and faster speeds…*

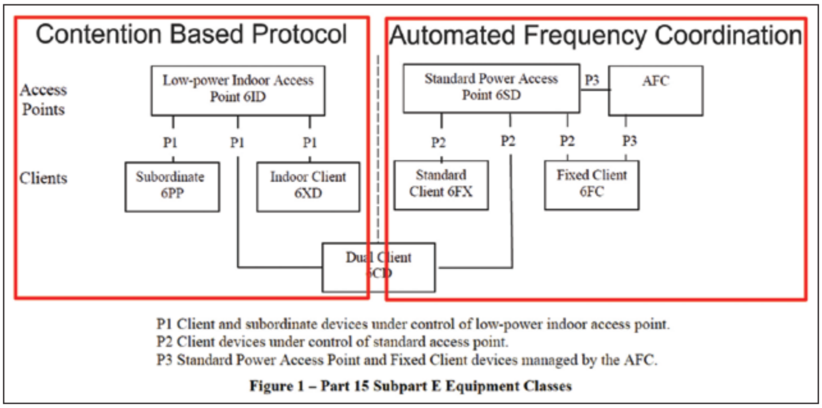

Figure 1: Current FCC Subpart E equipment classes with test requirements

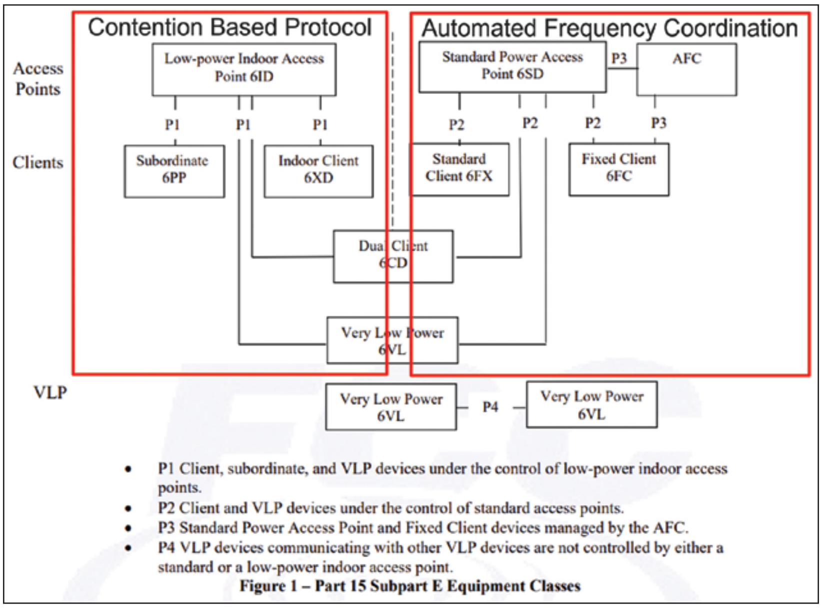

Figure 2: Draft FCC Subpart E equipment classes, including VLP devices, with test requirements

"…The harmonisation decision will make 480 MHz of additional spectrum available in the 6 GHz band. It will almost double the amount of available spectrum, adding to the 538.5 MHz available in the 2.4 GHz and the 5 GHz bands…

"…Member States shall make this frequency band available for the implementation of Wi-Fi by 1 December 2021…"

So, while devices will be able to use the new spectrum for free, there are still regulations with which to comply to avoid interfering with those who have paid to use the spectrum.

Applicable Regulations

FCC

The FCC is responsible for setting the rules and specifications for devices that use the spectrum in the U.S. Those specifications are found in the Code of Federal Regulations (CFR). The following sections contain the rules and specifications for the different frequency bands in the U.S.:

1. Part 15 Subpart C Intentional Radiators - 15.247 Operation with the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz – for the 2.4 GHz band; and
2. Part 15 Subpart E Unlicensed National Information Infrastructure (U-NII) Devices - 15.407 General technical requirements – for the 5 and 6 GHz bands.

The test requirements, or guidance documents, are part of the FCC's Knowledge DataBase (KDB) and describe how to make the required measurements or refer to other standards for complete measurement procedures, typically ANSI 63.10. The following KDB documents apply for the 2.4, 5, and 6 GHz bands:

1. KDB 558074 D01 Meas Guidance v05r02 – Measurement Guidance for the 2.4 GHz band;
2. KDB 905462 D02 UNII DFS Compliance Procedures New Rules v02 – Dynamic Frequency Selection for the 5 GHz band;
3. KDB 789033 D02 General UNII Test Procedures New Rules v02r01 – Measurement Guidance for the 5 GHz band;
4. KDB 987594 D02 U-NII 6 GHz EMC Measurement v02r01 – Measurement Guidance for the 6 GHz band; and
5. KDB 987594 D05 AFC DUT Test Harness Testing v01r01

The FCC regulates the use of the 6 GHz band for unlicensed devices through the use of equipment classes and has different specifications and rules for each class. Figures 1 and 2 show the current and just released draft equipment classes for use in the 6 GHz Band (found in KDB 987594 D01 U-NII 6GHz General Requirements v02r02.)

The devices on the left side are part of the low power indoor (LPI) devices and are managed by a contention-based protocol (CBP). This protocol requires devices to monitor the operating channel, and, if an incumbent signal is detected anywhere in the channel, it must stop transmitting in that channel until the incumbent stops transmitting.

The devices on the right side were recently authorized for use by the FCC (August 2023). These devices must be associated with a standard power (SP) access point (AP) and are managed by an automated frequency coordination (AFC) system. These devices are typically designed for outdoor use, and thus must ensure they are not transmitting on frequencies that are known to be used by incumbents in the immediate area.

Figure 2 shows the recently released draft (April 2024) equipment classes that now includes very low power

(VLP) devices. These devices may be connected to an access point or operate in a peer-peer association (think augmented reality (AR), etc.). Note that VLP devices that are in a peer-peer association are not required to be managed by an AFC system, unless they are also connected to an SP AP.

EU

The European Commission determines the directives for radio devices (known as the Radio Equipment Directive, or RED). Article 3(2) of the RED states that:

> *"2. Radio equipment shall be so constructed that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference."*

The specifications to meet those requirements are defined by the European Telecommunications Standards Institute (ETSI). The following ETSI documents are applicable for the 2.4, 5, and 6 GHz bands in the EU:

1. EN 300 328 V2.2.2 – covers the harmonized standards for the 2.4 GHz band;
2. EN 301 893 V2.1.1 – covers the harmonized standards for the 5 GHz band, including DFS; and
3. EN 303 687 V1.0.0 – covers the harmonized standards for the 6 GHz band.

The EU manages the use of the 6 GHz through the harmonized standard EN 303 687. Developed by ETSI, this standard manages the interaction of the unlicensed and incumbent signals through the following methods:

1. Restricted equipment classes – Similar to the FCC approach, ETSI only allows two types of equipment classes for use in the 6 GHz band:
    a. Low power indoor (LPI): Similar concept as the FCC, limited power and for indoor use only; and
    b. Very low power (VLP): Right now, this is for narrowband-restricted devices. Currently, no AFC system is in use in the EU.
2. No channels above 6425 MHz – Rather than worry about interference in the upper half of the spectrum, the use of unlicensed devices is not allowed.
3. Adaptivity interference testing – This method has been in use for many years, and for all frequency bands. ETSI has a more restrictive approach to devices managing incumbents and is similar to CBP in that devices must stop transmitting while incumbents are transmitting.
4. Punctured channel masks – For those devices employing channel or preamble puncturing, there are very well-defined emission masks for the punctured sub-channels as part of the harmonized standard.

REGULATORY TESTING IMPACT

Wi-Fi 6E

Table 3 lists the regulatory testing impact of the changes introduced with the Wi-Fi 6E standards.

160 MHz Bandwidth

1. Adding a new bandwidth will require additional transmitter tests for both the FCC and ETSI. These tests are required for each operating mode of a device, which includes the channel bandwidth, and for each frequency band with the new bandwidth.
2. The additional bandwidth will add DFS tests for the FCC. The FCC requires that several of the tests be conducted for each channel bandwidth (KDB 905462). For ETSI, the focus is on testing, potentially, the lowest and highest bandwidth, so this is not adding any additional testing.

Changes	Regulatory Test Impact	FCC	ETSI
160 MHz Channel Bandwidth	Additional Transmitter Tests	Y	Y
	Additional DFS Tests	Y	N
Open up 6 GHz Band for use	All of 6 GHz Band?	Y	N
	New Receiver Test	Y	N
	Device Classifications	YY	Y
	Automated Frequency Coordination (AFC)	Y	N
Channel Puncturing	Additional DFS Tests	Y	N
	Tx Masks for Punctured Channel	Y/N	Y
New Modulation Format	Additional Tests?	Y	Y

Table 3: Regulatory testing impacts for Wi-Fi 6E

6 GHz Band

1. As mentioned earlier, the FCC opened up the whole 6 GHz band, allowing for 60-20 MHz channels and seven (7) 160 MHz channels. More channels mean more testing, as tests are typically on the low, mid, and high channels of the band. For the EU, there are only three (3) 160 MHz channels available.
2. The FCC added a new receiver test for LPI devices, contention-based protocol. Any device that is associated with an LPI AP must employ a CBP system. ETSI has always had a receiver-based detection system, so this does not add any new receiver tests.
3. As discussed above, both the FCC and ETSI manage the 6 GHz band by defined classes of equipment. Each device will have specific maximum output power limits and interference management techniques.
4. The FCC has added the AFC requirement for standard power devices, those that would typically be used outside. This relies on a requirement for the AP to request frequency and power limits based on its geolocation. All devices connected to that AP must also adhere to the frequency and power limits dictated by the AP. ETSI currently does not employ an AFC system.

Preamble (Channel) Puncturing

1. If the feature is employed in Wi-Fi 6E, it can be used in the 5 GHz band to avoid interference with detected radar signals (DFS Requirement). This will require additional tests for the punctured channel. It is unclear if ETSI requires additional tests for DFS for punctured channels in the 5 GHz band.
2. No new Tx masks are required for the FCC for the 6 GHz band. There are Tx mask requirements for the 5 GHz band. ETSI currently has Tx masks specified for punctured channels in both the 5 and 6 GHz bands.

New Modulation Format

It is currently unclear if this will add new testing, but both the FCC and ETSI require that the devices be tested under the worst-case conditions. It is also unclear if the higher-density QAM modulation will represent a worst-case condition, but it will have to be investigated as part of pre-compliance testing to determine its impact.

Wi-Fi 7

Table 4 lists the regulatory testing impact of the changes introduced with the Wi-Fi 7 standards.

320/240 MHz Bandwidth

1. Similar to the requirement for Wi-Fi 6E, adding a new bandwidth will require additional testing for the FCC for all operating modes for transmitter tests. ETSI does not currently support bandwidths greater than 160 MHz.
2. The possibility of using a 240 MHz bandwidth in the 5 GHz bandwidth will add additional DFS testing for the FCC only. ETSI currently does not support bandwidths wider than 160 MHz.
3. Similar to the requirement for Wi-Fi 6E, the FCC added CBP tests for LPI devices in the 6 GHz band. ETSI already has receiver tests, so there are no additional tests required.

Multi-Link Operations (MLO)

This feature allows a Wi-Fi 7 device to transmit on more than one channel or frequency band at one time. This change may or should require additional testing. The FCC states that it is recommended to verify that a device, when transmitting in different bands, does not exceed the spurious emission requirements, or if transmitting in the same band, that the total power spectral density (PSD) does not exceed the limits. I have seen several test reports where the test lab indicates that they have looked at the MLO operation and saw nothing of concern. It is unclear if there is a similar requirement from ETSI on this topic as well.

Changes	Regulatory Test Impact	FCC	ETSI
320/240 MHz Bandwidth	TX Tests	Y	N
	Additional DFS Tests	Y	N
	Additional Receiver Tests	Y	N
Adds Preamble Puncturing	Additional DFS Tests	Y	?
	Additional AFC Tests	Y	N
	Tx Masks for Punctured Channel	N	Y
Adds Multi-Link Operation (MLO)	Additional Spurious Emission/PSD Tests	?	?
Adds New Modulation Format	Additional Tests?	Y	Y

Table 4: Wi-Fi 7 regulatory testing impacts for Wi-Fi 7

Preamble Puncturing

1. Similar to the requirement for Wi-Fi 6E, the use of preamble, or channel, puncturing in the 5 GHz band will require additional DFS tests for the FCC only. ETSI supports preamble puncturing, but it is unclear if additional tests would be required to satisfy DFS requirements.
2. The FCC will have new tests for the AFC functionality for punctured channels for devices that are either an SP AP or connected through an SP AP. ETSI currently does not support an AFC system.
3. The FCC does require a spectral emission mask for the 6 GHz band but does not require different masks due to preamble puncturing. It does, however, require a Tx emissions mask for punctured channels in the 5 GHz band. ETSI has already defined spectral emission masks for punctured channels in the 5 and 6 GHz bands.

New Modulation Format

It is currently unclear whether this will add new testing, but both the FCC and ETSI require that the devices be tested under the worst-case conditions. It is also unclear if the higher-density QAM modulation will represent a worst-case condition, but it will have to be investigated as part of pre-compliance testing to determine its impact.

REGULATORY MEASUREMENT CHALLENGES

FCC

Contention Based Protocol (CBP)

CBP was implemented as part of the requirements for LPI devices that are operating in the 6 GHz bands. The overall requirement is that, if there is an incumbent signal detected by a device at a level of -62 dBm or lower anywhere in the channel, the device must stop transmitting completely in that channel until the incumbent is no longer detected.

For Wi-Fi 7, it is possible for paired devices to use bandwidth reduction, that is, reduce the bandwidth of the operating channel to avoid the incumbent signal. If your devices support that, you would be required to perform the CBP test in this scenario. This will require a tuned measurement on the sub-channel where the incumbent was detected.

The FCC has not provided any guidance for addressing this issue, so we advise consulting with an FCC-authorized Telecommunications Service Body (TCB) for final review and approval. However, a suggested measurement procedure would likely include the following steps:

1. Set the center frequency of the spectrum analyzer to the center of the sub-channel where the incumbent was detected.
2. Set frequency span to zero span.
3. Ensure that the resolution bandwidth (RBW) is not too wide to detect the signal from the remaining channel.
4. Use the existing CBP measurement procedure for 90% detection probability.

It is important to note that preamble puncturing cannot be used to circumvent CBP requirements.

Preamble Puncturing – Emission Masks

6 GHz Band

At the October 2023 TCB Workshop, the FCC summarized the results of discussions between industry and the FCC on the subject of emission mask requirements for punctured channels in the 6 GHz band. After lengthy discussions and review, the FCC stated (and included in KDB 987594) that if channel puncturing is used in the 6 GHz Band:

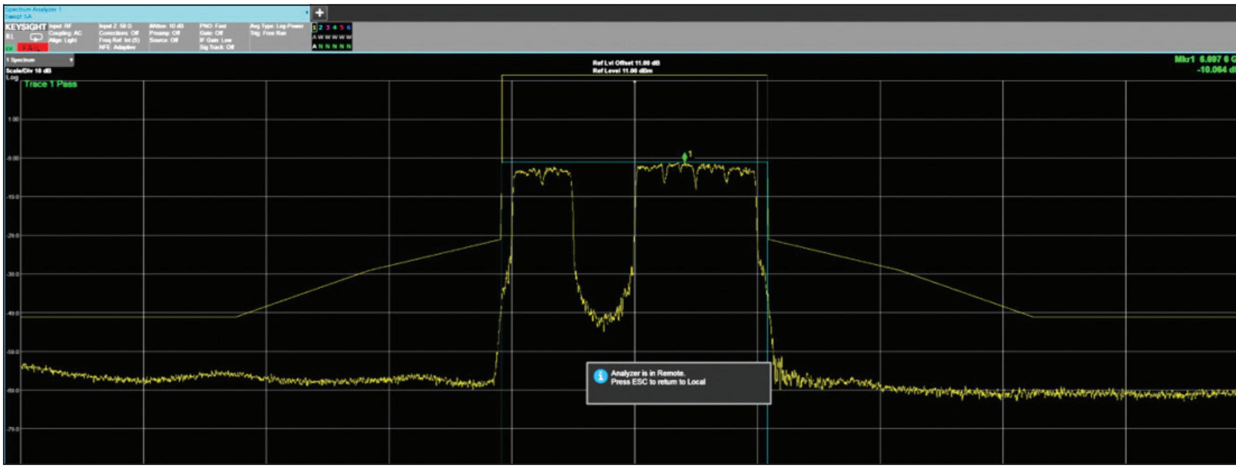

Figure 3: Example of FCC punctured channel emission mask result generated from testing software[1]

1. For standard power devices, the emission mask of a channel that has employed channel puncturing and the emission mask requirements are the same as those for the whole operating channel. The device, however, must comply with all AFC requirements; that is, the power level within the punctured sub-channel must be at or below the power that the AFC systems would permit across the whole sub-channel.
2. For low power indoor devices, channel puncturing is not permitted, as CBP must be used if incumbents are detected anywhere inside the operating channel.

Figure 3 shows an example of using industry-available testing software to make such a measurement.

Note that the emissions mask is the mask for the whole 160 MHz channel, and no changes for the punctured sub-channel.

5 GHz Band

The 5 GHz band represents a different challenge for emission masks for the 5 GHz band. Currently, there are no in-band emission mask requirements for the 5 GHz band. But the FCC made a change to address when channel puncturing is used to avoid an incumbent/radar signal in the 5 GHz band. From KDB 789033 D02:

> *"When a 20 MHz portion is punctured the remaining emissions do not bleed into the notched channel, i.e., 26 dB or 99% bandwidth is contained outside of the notched band."*

Currently, there is no defined measurement procedure for this. So, once again, we recommend consulting with a TCB for review and approval. However, from the wording, it appears that the following could be a reasonable engineering best guess for a procedure:

1. Measure emissions or 99% bandwidth of both sides of puncture;
2. Verify that the bandwidth upper frequency of left sub-channel is not greater than the center frequency of sub-channel – 10 MHz; and
3. Verify that the bandwidth lower frequency of the right sub-channel is not greater than the center frequency of sub-channel + 10 MHz.

Figure 4 shows an example of this type of measurement procedure where the fifth-20 MHz sub-channel of a 160 MHz channel was punctured, and just the lower remaining channels are shown.

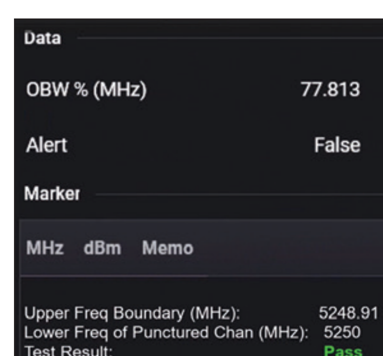

Figure 4: Example of a 5 GHz punctured channel FCC emission mask measurement[2]

Preamble Puncturing – DFS Requirements

Another other requirement added by the FCC for channel puncturing and DFS Testing is:

> *"For purposes of DFS testing, verify channel closing and move times are met when one and two 20 MHz channels are punctured."*

In this scenario, you will be required to test for puncturing in at least 2-20 MHz sub-channels with an injected radar signal. Currently, it only requires a measurement of the channel close and moving time and be within the specifications of the existing DFS test. This will require a tuned measurement on the punctured sub-channels instead of monitoring the whole operating channel.

Once again, there is no current measurement guidance on how to do this, so the following is a reasonable engineering best guess for a procedure:

1. Set the center frequency of the spectrum analyzer to center of channel ("sub-channel") where radar was detected;
2. Set frequency span to zero span;
3. Ensure RBW is not too wide to detect signal from remaining transmission; and
4. Use the existing channel move and close time measurement procedure.

Figure 5 shows an example of what that punctured signal might look like.

AFC – 6 GHz LPI

In KDB 987594, the FCC indicates that the Wi-Fi Alliance (WFA) AFC Test Harness is to be used to verify the requirements for SP APs and devices controlled by an SP AP. The test harness emulates an AFC system to request information from the equipment under test (EUT) and return the requested frequency/channel and power (PSD) limits. RF test equipment is required to monitor the frequency and power of the EUT to then verify it does not exceed the defined limits.

The test harness is only available through the Wi-Fi Alliance. It does have the ability to incorporate RF test equipment but is limited to whatever drivers have been developed by test equipment vendors. Many companies (including mine) have yet to develop drivers for incorporation into the test harness and are reviewing the requirements for integrating its drivers into the test harness. But keep in mind that a test report generated by the test harness is required in order to be accepted by the FCC.

ETSI

Preamble Puncturing – Emission Masks

ETSI has much more stringent emission mask requirements for any 6 GHz channel that employs preamble puncturing to notch out part of the channel. Figure 6 shows an example (taken from Annex D of EN 303 687) of the mask where the third 20 MHz channel of an 80 MHz channel is punctured.

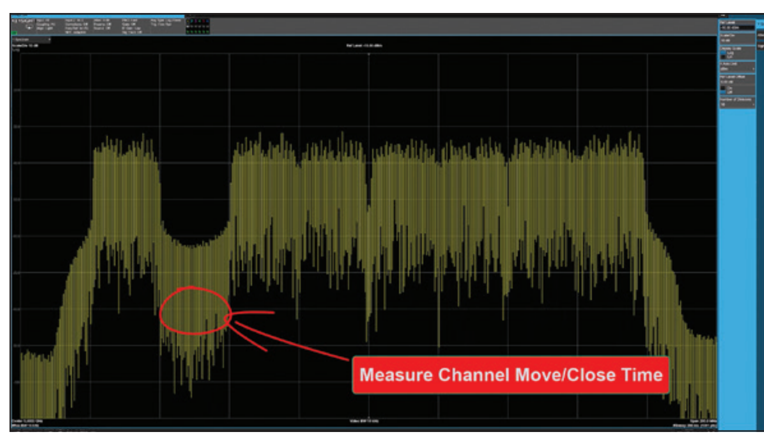

Figure 5: DFS channel move and close time FCC requirements for punctured 5 GHz channel

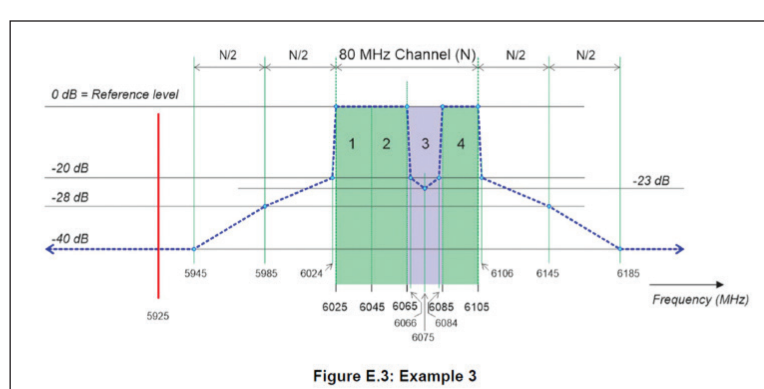

Figure 6: ETSI punctured channel emission mask - 6 GHz

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Education Symposium

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Figure 7 shows an example of using testing software to make a measurement on a punctured channel where two-20 MHz channels are punctured, and the applicable emission mask taken from EN 303 687.

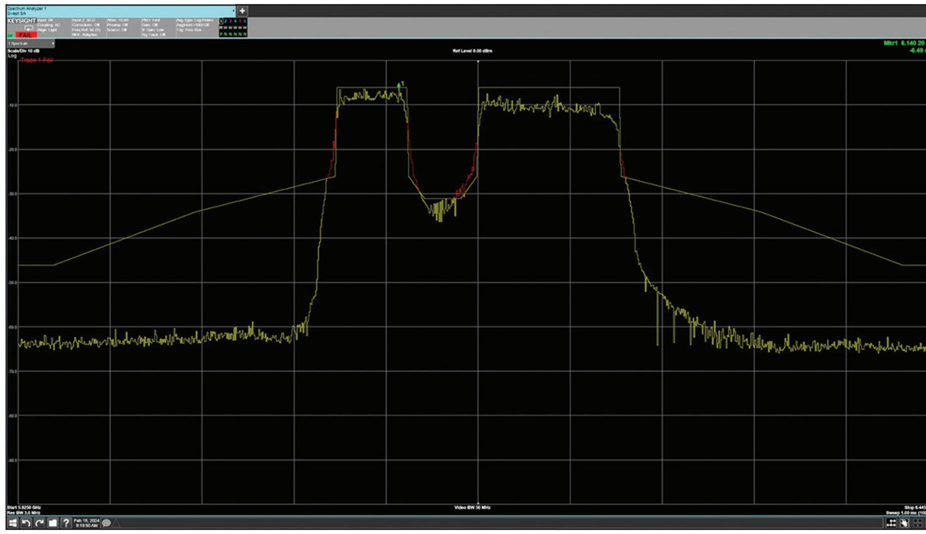

Figure 7: ETSI punctured channel emission mask measurement[3]

SUMMARY

Here is a summary of the additional requirements applicable to the implementation of Wi-Fi 6E and Wi-Fi 7:

FCC

1. No preamble puncture allowed for indoor devices using the 6 GHz band to avoid CBP; however, bandwidth reduction is allowed.
2. Preamble puncturing is allowed in the 5 GHz band to avoid interfering with local radars.
3. Unknown emission mask requirements for the punctured channel in the 5 GHz band, other than comparing the 26 dB or 99% bandwidth to the punctured sub-channel.
4. Outdoor devices under the control of a standard power AP must also meet the requirements of an AFC system.

ETSI

1. It is unclear if there are additional requirements or if preamble puncturing is allowed for DFS capabilities in the 5 GHz band. It is possible to use a Notified Body to review and approve measurement techniques.
2. Preamble puncturing is available in the 6 GHz band and uses procedures in EN 303 687.
3. ETSI currently does not support bandwidths greater than 160 MHz. The next version of EN 303 687 addresses this but is not expected to be formalized anytime soon.
4. Finally, it is possible to submit measurement procedures and results to Notified Bodies for approval of the capabilities described above. Several commercial products have been approved for Wi-Fi 7 use in the EU.

With each new wireless standard, the regulatory requirements tend to get a bit more complicated, as do the measurement requirements. Because of this, many larger device manufacturers have taken to performing exhaustive pre-compliance testing before sending the device to the test lab for final testing. This can result in increasing time to market as multiple trips to the test lab can be quite time-consuming. It is also an excellent way to quickly verify if changes to firmware/hardware cause an unexpected change in the regulatory testing results.

ENDNOTES

1. Test results were generated using Keysight XA5002A FCC Regulatory Testing Software
2. Test results were generated using Keysight XA5002A FCC Regulatory Testing Software
3. Test results were generated using Keysight XA5001A ETSI Regulatory Testing Software

CROSSTALK BETWEEN PCB TRACES – TIME AND FREQUENCY DOMAIN MEASUREMENTS

Part 2: Impact of a Guard Trace

By Bogdan Adamczyk, Mathew Yerian-French, and Ryan Aldridge

This is the second article of a two-article series devoted to the topic of crosstalk between PCB traces. In the first article [1], we varied the circuit topology (the distance between traces and the distance to the ground plane) and investigated its impact on crosstalk, both in time and frequency domains. In this article, we investigate the impact of a guard trace on crosstalk reduction. This topic was previously discussed in [2], where we used an earlier-generation PCB and concentrated on signal integrity or the time domain measurements. This article presents measurements taken with the latest-generation PCB, both in time and frequency domains. Frequency domain measurements are taken with a near-field scanner using an *H*-field probe.

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Ryan Aldridge is the Operations Manager for Grand Valley State University's Innovation Design Center. He works closely with Prof. Adamczyk, developing EMC educational material, and assists him with GVSU's EMC Center. He attended Grand Valley State University for his bachelor's and master's degrees in electrical and computer engineering.

PCB TOPOLOGY WITH A GUARD TRACE

In this study, the PCB traces were 30 mils from each other and 52 mils from the ground plane. The traces were separated by a guard trace selectively connected to ground at either or both ends or left floating. This arrangement is depicted in Figure 1.

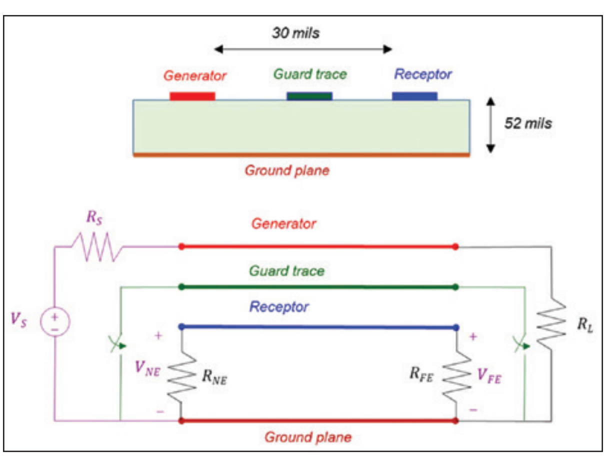


Figure 1: PCB topology and guard trace connections

Figure 2 shows the details of PCB topology.

Figure 2: PCB topology

TIME DOMAIN MEASUREMENT SETUP AND RESULTS

The setup for time domain crosstalk measurements is shown in Figure 3.

Figures 4 and 5 show the generator signal, V_S, as well as the resulting near-end voltage, V_{NE}, and far-end voltage, V_{FE}, induced in the receptor circuit. The source signal is an open-circuit voltage 0-5 V_{pp}, 1 MHz trapezoidal pulse train having 100 ns rise time, 200 ns fall time, and a 50% duty cycle. Figure 4 shows the results with no shield, while Figure 5 shows the results with the shield floating (not connected to ground). It is apparent that a floating shield has virtually no effect on the crosstalk-induced voltages.

Figure 6 shows the results when the shield is grounded at the near end while the far end is open.

Figure 7 shows the results when the shield is grounded at the far end while the near end is open.

The results show that grounding the shield only at one end decreases the near-end voltage while *increasing (in the absolute sense) the far-end voltage*. How can this happen? We will answer this question shortly.

Figure 8 shows the results when the shield is grounded at both ends. Grounding the shield at both ends reduces both the near-end and far-end induced voltages. Table 1 summarizes the results.

As noted earlier, when the shield was grounded at either end, the near-end voltage *decreased* while the far-end voltage *increased*. To explain this phenomenon, we need to look at the formulas governing these voltages [3].

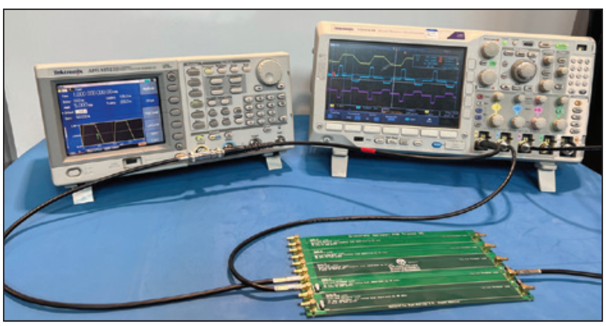


Figure 3: Experimental setup for time domain measurements

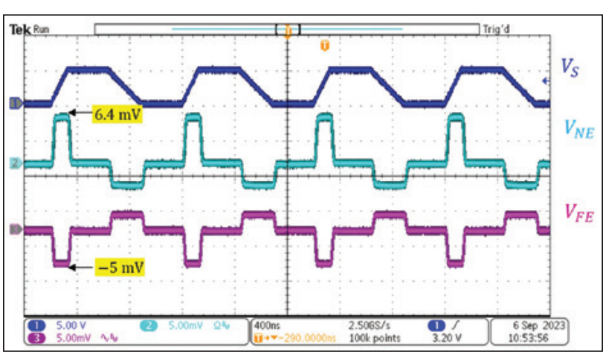


Figure 4: Crosstalk induced voltages with no shield

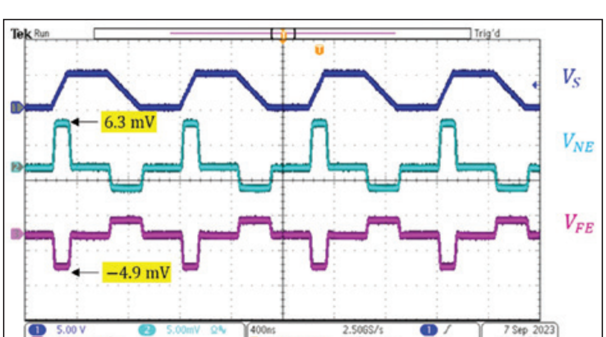


Figure 5: Crosstalk induced voltages with shield floating

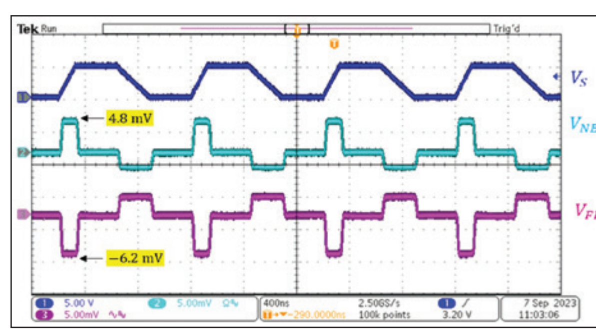


Figure 6: Induced voltages with shield grounded at near end, far end open

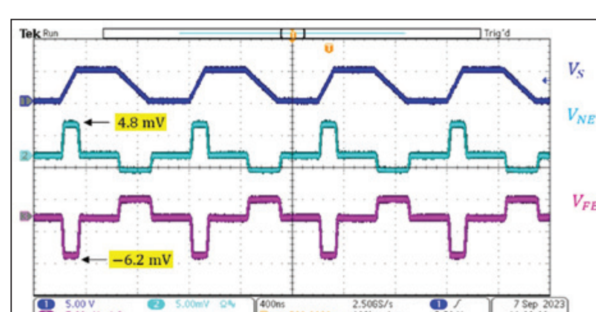


Figure 7: Induced voltages with shield grounded at far end, near end open

$$v_{NE}(t) = \left[\underbrace{\frac{R_{NE}}{R_{NE}+R_{FE}} L_{GR} \frac{1}{R_S+R_L}}_{Inductive\ Coupling} + \underbrace{\frac{R_{NE}R_{FE}}{R_{NE}+R_{FE}} C_{GR} \frac{R_L}{R_S+R_L}}_{Capacitive\ Coupling}\right] \frac{dv_S(t)}{dt} \quad (1)$$

$$v_{FE}(t) = \left[\underbrace{-\frac{R_{FE}}{R_{NE}+R_{FE}} L_{GR} \frac{1}{R_S+R_L}}_{Inductive\ Coupling} + \underbrace{\frac{R_{NE}R_{FE}}{R_{NE}+R_{FE}} C_{GR} \frac{R_L}{R_S+R_L}}_{Capacitive\ Coupling}\right] \frac{dv_S(t)}{dt} \quad (2)$$

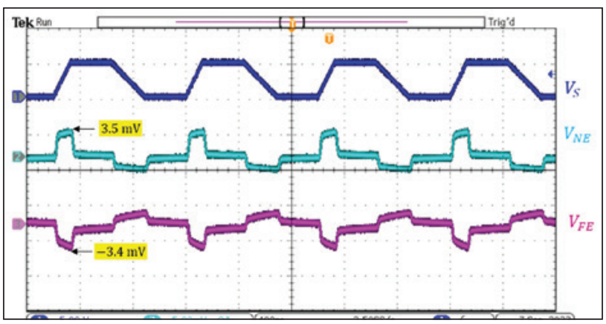


Figure 8: Induced voltages with shield grounded at both ends

Note that both terms in the expression for the near-end voltage are positive. When the shield is grounded at one end, inductive coupling does not change, while the capacitive coupling is reduced. Thus, the sum of the inductive and capacitive coupling is reduced.

At the far end, the expression for inductive coupling is negative, while the expression for the capacitive coupling is positive. When the shield is grounded at one end, inductive coupling does not change (from the ungrounded case), while the capacitive coupling

Shield Connection	V_{NE} [mV]	V_{FE} [mV]
floating	6.3	-4.9
NE grounded, FE open	4.8	-6.2
FE grounded, NE open	4.8	-6.2
grounded at both ends	3.5	-3.4

Table 1: Summary of the time domain results

is reduced. On a microstrip PCB, the inductive coupling usually dominates the capacitive coupling [4]. Effectively, the sum of the inductive and capacitive couplings (crosstalk) at the far end may increase (in the absolute sense) when the shield is grounded only at one end.

FREQUENCY DOMAIN MEASUREMENT SETUP

The setup for the near-field *H*-probe measurements is shown in Figure 9.

Figure 9: Experimental setup for frequency domain measurements

The source signal had the same parameters as in the time domain setup, except for the rise and fall times, which were set to 10 ns. The *H*-field probe in the near-field scanner took measurements at 9 MHz and 49 MHz.

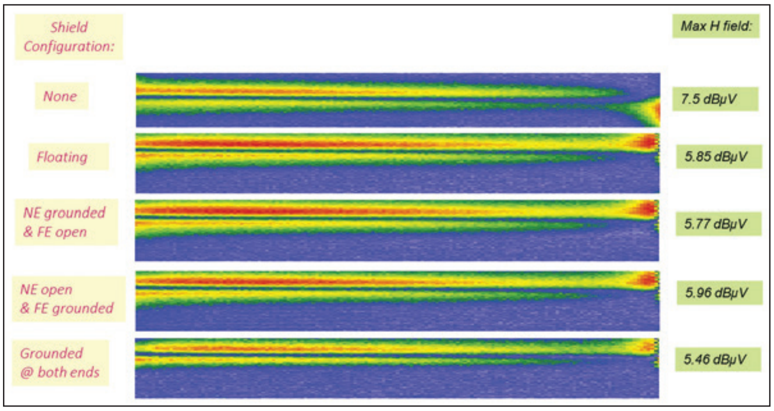


Figure 10: H-field measurement results at 9 MHz

Figure 10 shows the measurement results at 9 MHz, while Figure 11 shows the results at 49 MHz. Table 2 summarizes these measurements.

The results show that the shield has a small to no effect on the measurement, regardless of its termination.

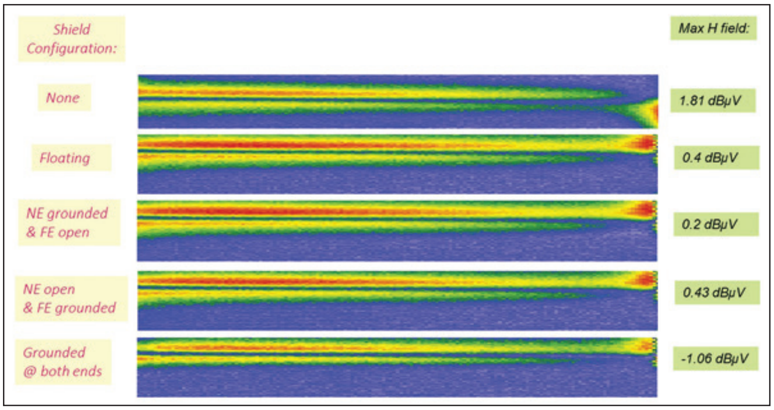


Figure 11: H-field measurement results at 49 MHz

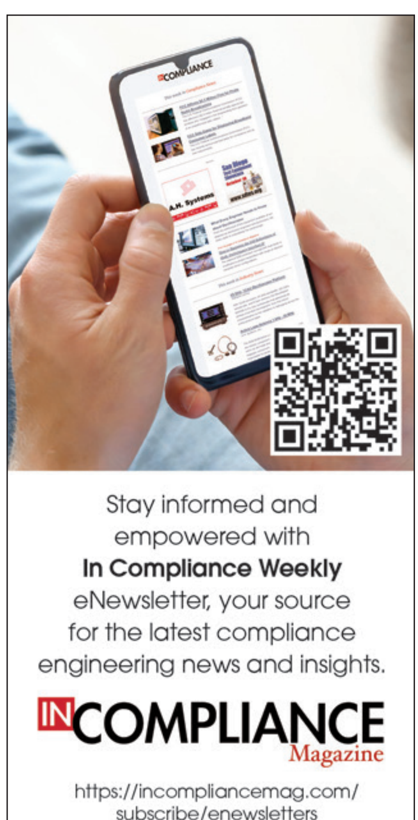
Shield Configuration	H_{max} @ 9 MHz [dBμV]	H_{max} @ 49 MHz [dBμV]
none	7.5	1.81
floating	5.85	0.4
NE grounded, FE open	5.77	0.2
FE grounded, NE open	5.96	0.43
grounded at both ends	5.46	-1.06

Table 2: Near field measurement summary

REFERENCES

1. Bogdan Adamczyk, Mathew Yerian-French, and Ryan Aldridge, "Crosstalk Between PCB Traces – Time and Frequency Domain Measurements, Part 1: Impact of the Circuit Topology," *In Compliance Magazine*, June 2024.
2. Bogdan Adamczyk and Ryan Aldridge, "Guard Trace Impact on Crosstalk Reduction Between PCB Traces," *In Compliance Magazine*, February 2018.
3. Bogdan Adamczyk, *Principles of Electromagnetic Compatibility: Laboratory Exercises and Lectures*, Wiley, 2024.
4. Howard Johnson and Martin Graham, *High-Speed Digital Design – A Handbook of Black Magic*, Prentice Hall, 1993.

PRODUCT Showcase



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Each year, it brings us great joy to see and meet with many of our readers, authors, and advertisers as they visit our booth to pick up the latest issue of the magazine and collect their annual In Compliance t-shirt. This in person opportunity allows us to connect with so many engineering professionals to discuss the latest challenges and learn valuable tips, solutions, and updates.

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