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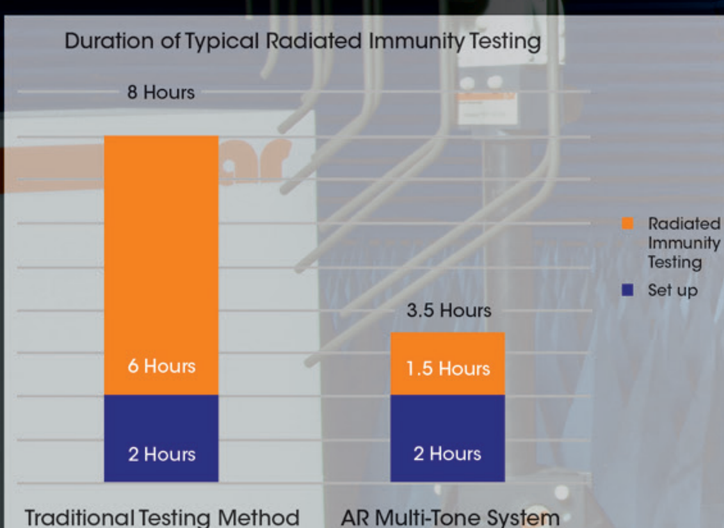

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CELEBRATING 15 YEARS OF INNOVATION AND EMPOWERMENT

Dear Readers,

Fifteen years ago, when we launched *In Compliance Magazine*, we could never have imagined the incredible journey awaiting us. Born out of a dream shared by three determined women, *In Compliance* has grown from a fledgling publication to a respected and influential voice in the world of electronics compliance engineering.

As we celebrate this milestone anniversary and the publication of our 16th August issue, I reflect on the challenges we've faced and the triumphs we've achieved along the way. When *Conformity* closed its doors in March 2009, it felt like a tragic loss. But that setback turned out to be the fertile ground in which we sowed the seeds of our dream.

In this issue, as we highlight Pioneers in Compliance Engineering, we realized that we ourselves are pioneers. We are the first women to step into the role of supporting the electronics compliance engineering profession through periodical publishing. We share our story among the stories of other pioneers in this issue's special section: Pioneers in Compliance Engineering.

Over the past 15 years, we've had the privilege of covering the latest updates on global standards to evolving practices in electronics design for compliance. We've delved into the benefits of becoming a certified engineer and pondered the development of standards and certification in today's society. And, of course, we've always made sure to sprinkle in a dash of joy and magic along the way because we believe that being an engineer should be as fun as it is rewarding.

As for the future, we remain committed to being at the forefront of sharing the vast body of knowledge built by exceptional engineers who have dedicated their careers to the pursuit of excellence in the field of electronics compliance engineering.

To our valued readers, advertisers, authors, and supporters: Thank you for being an integral part of our journey. Your contributions, encouragement, feedback, and support spur us forward, and we are profoundly grateful.

Here's to the next 15 years of *In Compliance Magazine* – may they be filled with even more growth, discovery, and inspiration!

In gratitude,

Lorie Nichols
Editor-in-Chief & Publisher

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publisher/ editor-in-chief Lorie Nichols
lorie.nichols@incompliancemag.com
(978) 873-7777

business development director Sharon Smith
sharon.smith@incompliancemag.com
(978) 873-7722

production director Erin C. Feeney
erin.feeney@incompliancemag.com
(978) 873-7756

marketing director Ashleigh O'Connor
ashleigh.oconnor@incompliancemag.com
(978) 873-7788

circulation director Alexis Evangelous
alexis.evangelous@incompliancemag.com
(978) 486-4684

features editor William von Achen
bill.vonachen@incompliancemag.com
(978) 486-4684

senior contributors Bruce Archambeault
Keith Armstrong
Ken Javor
Kenneth Ross
Min Zhang

columns contributors Bogdan Adamczyk
Erin Earley
Min Zhang
EOS/ESD Association, Inc.

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

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FEATURE ARTICLES

SPECIAL COVERAGE

COLUMNS

DEPARTMENTS

Facility Openings

Element Opens New Connected Technologies Center of Excellence

Element Materials Technology has opened its new Connected Technologies Center of Excellence in Guildford, Surrey (UK). The new 25,000 sq. ft. facility provides the company with increased capacity for electromagnetic compatibility (EMC), radio, and wireless testing, and adds specific absorption rate (SAR) testing to the company's portfolio of services in Europe. Element says that its new Connected Technologies Center and the expanded testing capabilities will help support the latest advancements in consumer electronics, medical devices, and wireless communications technologies.

TÜV Rheinland Unveils Cutting-Edge Facility in Massachusetts

TÜV Rheinland celebrated the grand opening of its Northeast Technology and Innovation Center in Boxborough, MA. The 65,000-square-foot facility boasts cutting-edge amenities, including a top-tier 10-meter Semi-anechoic Chamber. It offers advanced testing for electrical safety, wireless technology, EMC, environmental assessments, and medical devices. The center supports TÜV Rheinland's growth in North America. It provides comprehensive solutions throughout the product lifecycle, benefiting customers across various industries. The event featured a ribbon-cutting ceremony, tree planting, workshops, and an award presentation to Procter & Gamble.

Community Updates

Head Engineer at EMC Partner AG Receives Prestigious IEC Award

Michael Sacchi, the Head of Engineering at EMC Partner AG, has received the prestigious 1906 Award from the International Technical Commission (IEC). The award recognizes contributions to furthering standardization efforts in the field of electrotechnology. In addition to his role at EMC Partner AG, Sacchi is actively involved in the work of IEC TC 77, the IEC's Technical Committee on Electromagnetic Compatibility (EMC).

NCSES Releases Data on Science & Engineering Doctorate Recipients

Data from the U.S. National Center for Science and Engineering Statistics (NCSES) shows that over 90% of the nearly 31,000 science and engineering (S&E) doctoral recipients in 2022 with post-graduate commitments remained in the U.S., with more than 60% taking jobs in industry or business. Industries attracting the greatest number of post-grad doctoral recipients include physical sciences, engineering, computer and information sciences, and biological and biomedical sciences.

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Upcoming Events

August 5-9
★ 2024 IEEE 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

October 10
Cyber-Security Webinar

October 15
★ 2024 San Diego Test Equipment Symposium

October 24-November 1
★ 46th Annual Meeting and Symposium of the Antenna Measurement Techniques Association

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

★ Visit In Compliance's booth at these events!

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LNA1006	10 MHz - 18.0 GHz	20	23
MPA1118	10 MHz - 30.0 GHz	27	27
LNA1009	50 MHz - 6.0 GHz	25	25
0.2 GHz to 26.5 GHz LNA's & MPA's			
MPA1005	0.2 - 20.0 GHz	33	33
MPA1004	0.5 - 26.5 GHz	30	30
MPA1081	1.0 - 18.0 GHz	30	30
MPA1020-1	2.0 - 4.0 GHz	32	32
MPA1003	2.0 - 8.0 GHz	33	33
LNA1019A-3	2.0 - 18.0 GHz	20	20
LNA1019A-2	2.0 - 18.0 GHz	24	50
MPA1003-1	4.0 - 8.0 GHz	33	40
MPA1091-1M	6.0 - 18.0 GHz	27	27
LNA1017-2	10.0 - 15.0 GHz	10	20
18 GHz to 71 GHz LNA's & MPA's			
MPA3012	18.0 - 26.5 GHz	30	36
LNA3007-1	18.0 - 40.0 GHz	10	20
MPA1116	18.0 - 54.0 GHz	30	30
MPA3013	26.5 - 40.0 GHz	30	36
LNA3003	33.0 - 50.0 GHz	0	25
LNA3004	33.0 - 50.0 GHz	20	25
LNA1022	35.0 - 71.0 GHz	21	20
MPA3021	41.0 - 47.0 GHz	33	33
10 MHz to 47 GHz LNA's & MPA's			
MPA2006	10 MHz - 6.0 GHz	33	33
MPA2002	0.7 - 6.0 GHz	32	32
MPA2001	1.0 - 40.0 GHz	20	40
MPA2003	2.0 - 18.0 GHz	30	30
MPA4003	18.0 - 40.0 GHz	27	30
MPA4005	26.5 - 40.0 GHz	34	36
MPA4021	41.0 - 47.0 GHz	33	33

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FCC Proposes Fine for Violation of Equipment Marketing Rules

The U.S. Federal Communications Commission (FCC) has proposed a monetary penalty against one of the largest providers of computers and computer-related products for marketing devices that operated outside of their FCC-authorized power limits.

According to a Notice of Apparent Liability for Forfeiture, Taiwan-based ASUSTek Computer faces a fine of $367,436 for modifying one of its WiFi adapter models and a separate WiFi router model that had been previously authorized by the Commission. In both cases, the company reportedly modified the devices after receiving FCC approval so that they could operate above the power limits defined in their respective authorizations. In the case of the WiFi router model, testing by an independent certified test laboratory showed that the units were operating at nearly eight times their authorized output power level.

This is not the first time that ASUSTek has been charged with marketing devices that exceeded their authorized power limits. In 2014, the company entered into a consent decree with the Commission's Enforcement Bureau to resolve an FCC investigation into similar violations. Under the terms of that consent decree, ASUSTek agreed to adopt a 38-month compliance plan to ensure future compliance with FCC rules and to report any non-compliance issues to the Commission within five calendar days of discovering them.

FCC Plans Reporting Requirements for Router Security

The U.S. Federal Communications Commission (FCC) has proposed new rules intended to improve internet router security against cyberattacks.

In a Notice of Proposed Rulemaking (NPRM), the FCC mapped out plans to require broadband providers to submit confidential filings with the Commission, detailing their plans to mitigate potential vulnerabilities in their use of the border gateway protocol (BGP), the technical protocol critical to the routing of information across the internet. Specifically, the plans would include the implementation of BGP security measures that utilize the resource public key infrastructure (RPKI), a critical component of BGP security.

In addition, the nation's nine largest broadband providers would be required to make quarterly submissions to the Commission updating their progress in addressing BGP risk mitigation issues.

According to the NPRM, the goal of these proposed rules is to provide the Commission and other national security partners with current and up-to-date information on their efforts to promote more secure internet routing activities.

FCC Moves Forward with Ban on Certain TCB Certifications

The U.S. Federal Communications Commission (FCC) is moving forward with plans to ban the certification of testing laboratories that pose a potential threat to U.S. national security.

The Commission set forth its plan to prohibit entities identified on the Commission's "Covered List" from being authorized as telecommunications certification bodies (TCBs) under the FCC's equipment authorization program in a Notice of Proposed Rulemaking (NPRM). Specifically, the NPRM would ban any testing lab with direct or indirect ownership of 10% or more by an entity on the Covered List.

The FCC's Covered List includes major wireless equipment manufacturers that, in the Commission's view, "pose an unacceptable risk to the national security of the United States or the security and safety of United States persons." The Covered List includes major global wireless manufacturers, including Huawei and ZTE, which reportedly have ties to the government of the People's Republic of China and Chinese state-owned enterprises.

EU Council Approves Ecodesign Regulation

The Council of the European Union (EU) has given its final approval to a new regulation addressing ecodesign requirements for sustainable products.

The regulation, known as the Ecodesign for Sustainable Products Regulation (ESPR), was originally proposed in March 2022 to replace the EU's Ecodesign Directive (2009/125/EC). The ESPR includes more in-depth ecodesign requirements, including new rules on product durability, reusability, upgradability, and repairability, and will be more broadly applicable to a significantly larger number of product groups.

The overall goal of the ESPR is to reduce the EU's dependence on energy from countries outside of the EU, including Russia.

Following the Council's action, the ESPR is expected to be published in the *Official Journal of the European Union* and will enter into force 20 days following its publication. The specific requirements will be applied from 24 months after the regulation enters into force.

FCC Proposes Major Fine for Caller ID Authentication Failure

The U.S. Federal Communications Commission (FCC) has proposed a major enforcement action against one of the companies that transmitted illegal robocalls in advance of New Hampshire's 2024 Democratic Presidential Primary in January.

The company, Lingo Telecom, reportedly transmitted nearly 4000 of 9500 generative AI Deepfake voice messages that imitated the voice of President Joseph Biden two days ahead of the Primary. According to a Notice of Apparent Liability for Forfeiture issued by the Commission in late May, Lingo failed to verify the accuracy of the caller ID information and then mislabeled the calls with the highest level of caller IT attestation, leading other transmitters to believe that the calls were legitimate.

The FCC has proposed that Lingo pay a fine of $2 million for the company's apparent violation of the Commission's caller ID authentication rules, a first-of-its-kind enforcement action by the FCC.

IT'S ALL ABOUT THE PEOPLE: THE PIONEERS OF TODAY'S EMC SOCIETY

The Contributions and the Legacy of the Society's Founding Members

Daniel D. Hoolihan is the Founder and Principal of Hoolihan EMC Consulting. He is a Past President of the EMC Society of the IEEE and is presently the Chair of the EMCS History Committee. Hoolihan can be reached at danhoolihanemc@aol.com.

By Daniel D. Hoolihan

In the mid-1950s, a group of professionals in the electrical engineering specialty of radio frequency interference (RFI) began to formulate the idea of creating an organization devoted to their specific technical area of expertise. These informal discussions reached a new level at a luncheon on February 27, 1957, during the Third Conference on Radio Interference Reduction, sponsored by the United States Army Signal Engineering Laboratories and conducted by the Armour Research Foundation of the Illinois Institute of Technology in Chicago.

In his luncheon speech, Fred Nichols, Vice-Chairman of the Radio Interference Technical Committee of the Los Angeles area, proposed starting a National Professional Group on RFI. Six other individuals at the luncheon, including Anthony Zimbalatti, Milton Kant, Harold Schwenk, John Lucyk, Albert Ruzgis, and S. Nellis, enthusiastically endorsed the idea and volunteered to make it happen.

This core group, along with Vince Mancino and other United States engineers, eventually gathered 325 signatures on a petition that was delivered to the New York Office of the Institute of Radio Engineers (IRE) in July 1957. The petition to form a group devoted to RFI was approved by the IRE on October 10, 1957, and the first organizational meeting of the Professional Group on RFI (PGRFI) was held on November 20, 1957 in Asbury Park, NJ.

(A side note. In 1957, the Institute of Radio Engineers (IRE) had 57,000 members and was larger than its rival association, the American Institute of Electrical Engineers (AIEE). When the IRE and the AIEE merged in 1963 to form the Institute of Electrical and Electronics Engineers (IEEE), the IRE had 96,500 members versus the AIEE's 57,000 members! And the PGRFI was the predecessor of the Electromagnetic Compatibility (EMC) Society of the Institute of Electrical and Electronics Engineers (IEEE)).

This article addresses the pioneering work of Harald Schwenk, Fred Nichols, James McNaul, Milton Kant, Dr. Ralph Showers, Anthony Zimbalatti, Vince Mancino, and Sam Burruano. When we celebrated the 50th Anniversary of the EMC Society in 2007 in Hawaii (the 50th state in the United States), we had six very active Founders join us for the festivities. Each of those six founding members, McNaul, Kant, Showers, Mancino, Burruano, and Zimbalatti, are highlighted in this article. Sadly, Schwenk and Nichols passed away prior to the 50th Anniversary festivities, and all of the founding members of the EMC Society have passed away since then, with Milton Kant the last to pass away in May 2023 at the age of 97.

A BRIEF HISTORY OF THE FOUNDERS OF THE EMC SOCIETY

Harold R. Schwenk

The first chairman of the Professional Group on RFI (PGRFI) was Harold Raymond Schwenk, one of the engineers who attended the 1957 Chicago Luncheon. Schwenk was known for his teaching capability, especially with his fellow engineers. He joined the Sperry Gyroscope Company in NY, where he was involved with analyzing, designing, testing, and reworking electronics equipment to assure compliance with RFI and electromagnetic interference (EMI) requirements. In addition to founding the PGRFI, he also founded the Metropolitan New York IEEE EMC Society Chapter and served as chairman of that Chapter several times.

In 1967, he took his EMC expertise to Grumman Corporation in Bethpage, NY. There, Mr. Schwenk used his education and experience to help design the EMC capabilities of the A-6B, EA-6B, E-2B/C, F-14, and EF-11 aircraft. Harold also performed EMC engineering experiments that led to advancements in the design of shielded structures, including protecting electronics in all-composite aircraft from lightning effects.

Fred Nichols

Fred Nichols was the speaker at the Third Conference on Radio Frequency Interference Reduction sponsored by the Armour Research Foundation and held in Chicago in 1957, where he suggested starting a National Professional Group on RFI. At the time, he was Vice-Chair of the Radio Interference Technical Committee, an engineering group in the Los Angeles area that met on an irregular basis to discuss radio frequency interference issues. His talk at the Chicago Conference inspired U.S. RFI engineers to start a petition that resulted in the formation of the Professional Group on RFI as part of the Institute of Radio Engineers.

Fred Nichols in the testing laboratory

Over the years, Nichols served the EMC Society in many roles, including serving as President of the EMC Society in 1969. For over 20 years, Nichols was also the "official" photographer for the EMC Society. He gave away pictures to anyone and everyone he captured on film at Symposiums and local IEEE Meetings.

Early in his career, Nichols was president of Genistron, Inc. and was instrumental in evaluating security standards that required the use of shielded rooms. He then left Genistron and started his own company, LectroMagnetic Incorporated (LMI), where he worked on the B-1 bomber as well as many other military programs involving EMC. But perhaps Fred's greatest living contribution to today's EMC Society is his daughter, Janet Nichols O'Neil, who has served as the Secretary of the IEEE Society Board of Directors for more than 25 years and is currently serving as the Society's Vice-President of Member Services and as the Editor of the EMCS magazine.

James McNaul

McNaul was the first treasurer (1957-1959) and the second chairman (1959-1960) of the Administrative Committee of the PGRFI and was instrumental in drafting a constitution for the PGRFI. McNaul was a lieutenant in the Army Signal Corps R&D Labs at Fort Monmouth, NJ, from 1956-1958. While at Fort Monmouth, he served as an Assistant Project Officer for Project MONMOUTH, a three-year-long, large-scale investigation of communication systems in a future European war, with particular focus on the potential future impact of RFI on new communication technologies which were then being introduced into the Army's operational infrastructure.

James McNaul

In 1961, McNaul joined the Army Satellite Communications Agency, becoming Assistant Technical Director. In 1964, he returned to school at Stanford University and earned his Ph.D. in business, and then pursued a career in academia and business until his retirement in 1999. McNaul was one of the founding members who attended the celebration of the 50th Anniversary of the EMC Society in Hawaii in 2007.

Milton Kant

Milton Kant was an original member of the Administrative Committee of the PGRFI and helped prepare a draft Constitution for the PGRFI. He was also the first editor of the PGRFI Newsletter and published the first issue in January 1958. He then served on the Newsletter Committee of the PGRFI. In 1961, Milton served as secretary of the Administrative Committee of the PGRFI and then served as chairman of the Information Retrieval Committee (which led to the publication of EMCABS) before chairing the 1965 IEEE EMC Symposium Committee.

Initially, Kant worked for the Civil Aeronautics Administration and then the U.S. Air Force at the Rome Air Development Center. He became more involved with RFI when he moved to the Sperry Gyroscope Company in New York and then switched to RCA/GE to work on the Aegis destroyer radar system. Kant retired after working on the Aegis system for 22 years and was one of the founding members who attended the celebration of the 50th Anniversary of the EMC Society in 2007.

Ralph Showers

Ralph Showers was a Professor at the Moore School of Electrical Engineering at the University of Pennsylvania in Philadelphia, He was a member of the original Administrative Committee of the PGRFI and served as the third chairman of the PGRFI from 1960 to 1961. Dr. Showers also chaired the Technical Papers Committee, initiating the Transactions of the PGRFI.

In addition to his contribution in the formation of what is today's EMC Society, Dr. Showers also chaired the United States Committee on EMC (ANSI C63), for 33 years from 1973 to 2005, and also served as chair of the International Special Committee on EMC, CISPR. He remained active in CISPR Technical Advisory Groups on Emission and IEC Technical Committee 77 Technical Advisory Groups on immunity until his death in 2013.

Dr. Showers won numerous awards for his EMC standards activities, including the prestigious International Electrotechnical Commission's Charles Proteus Steinmetz Award in 1982 "for leadership in the development of standards for measurement of radio frequency interference." And Dr. Showers was one of the founding members of the EMC Society who attended the 2007 50^{th} Anniversary celebration in Hawaii.

The entrance of the Moore School of Electrical Engineering at the University of Pennsylvania

Vince Mancino at work at his electronic bench using a Stoddart RFI Receiver

Anthony Zimbalatti

Anthony Zimbalatti was one of the six "drivers" of the organizational founding of the PGRFI and was present at the February 1957 luncheon where it all began. Zimbalatti was a member of the Newsletter Committee of the PGRFI in 1958 and, for many years, wrote a thought-provoking column for the newsletter "Point and Counter Point." He enjoyed a very successful career as an EMC engineer at the Grumman Aircraft Company and was one of the founding members of the EMC Society who attended the 50^{th} anniversary celebration in 2007.

Vince Mancino

Vince Mancino was an early signer of the petition to form the Professional Group on Radio Frequency Interference (PGRFI) and he remained an active group member throughout the 1960s. He graduated from Rutgers University in 1951 with a BSEE degree and joined RCA as an Engineering Trainee. In 1960, Mancino transferred to Cornell-Dubilier Electronics in Massachusetts and became their Chief Engineer of the Filter Division. But he returned to RCA after several years at Cornell-Dubilier to work on their development of state-of-the-art weather satellites at a time when weather satellites only took pictures of cloud coverage during daylight hours. Mancino was one of the founding members of today's EMC Society who attended the 50^{th} Anniversary celebration in 2007.

Sam Burruano

Sam was an original member of the Administrative Committee of the PGRFI and was chair and co-organizer of the first IRE RFI Symposium in 1959. In June 1961, Burruano formed Burruano Associates to provide military and civilian agencies with practical and theoretical consultation in the fields of interference analysis and control. He was one of the six founding members of the EMC Society present at the 50^{th} Anniversary celebration in 2007.

SOME EMC PROBLEM-SOLVING STORIES FROM OUR FOUNDERS

What follows are edited version of "War Stories" shared by some of our founding members at the 50^{th} Anniversary celebration of the EMC Society in 2007.

A Story from Tony Zimbalatti

We did early-flight development testing of the Grumman-built E2A U.S. Naval Aircraft. The range of the low-frequency automatic directional finding (LFADF) system was limited because it was an early development aircraft. Because it had no other low frequency receiver to use for navigation, the range was restricted to less than five miles. This hampered the developmental flights for many months.

It was standard practice to have, for each aircraft, an avionics flight test engineer who reported his observations; one particular flight test engineer reported the failure of the aircraft radio to attain maximum range or sensitivity and claimed it was due to electromagnetic interference (EMI). He claimed, furthermore, that the EMI people didn't know how to solve the problem. In short, and for whatever reason, he didn't like EMI engineers; they had done something to him.

Several months after hiring onto Grumman in the late 1960s, I was asked to evaluate the problem and to develop a solution. The flight was scheduled on Christmas (bonus) Day because, in general, it was less than a half a day at work. I appeared at the flight-ready room, met the avionics engineer and the flight test engineer, and asked, "What now?"

He said, "Harness Up." I said, "Well, show me how. And what do I do, if we have to use the parachute?" (which is part of the harness, for those who are not familiar). He continued, "You mean you haven't been to school and been certified to fly?" I replied, "I just started at Grumman a couple months ago, what do I know?"

I noticed that he had a wry smile on his face, like, "It's an EMI guy, I'm going to get him." So, he harnessed me up, and we walked to the taxi strip where the plane was waiting with the pilot and the co-pilot.

He said, "This is how you use this. If we have to ditch (that's the technical term for getting out of the aircraft), stand on a seat, push out the plug, jump, count to ten, and you'll clear everything. Also, we'll be over water, so you're going to have to get rid of that harness." I started to feel queasy.

The way the set-up is on an E2 aircraft is that you have a pilot and co-pilot, you have a left and a right engine, and then in the aft compartment you have

Figure 5: The founding members of today's EMC Society in attendance at the 2007 IEEE International Symposium on EMC in Hawaii. From left to right, James McNaul, Vince Mancino, Milton Kant (in the "Hawaiian" shirt), Dr. Ralph Showers, Sam Burruano, and Tony Zimbalatti.

three operators with three scopes. The capacity was such that they could monitor the whole East Coast corridor and control all the traffic at Philadelphia, New York, and Washington. We actually ran an experiment with that aircraft to show that we could do that in case the three terminals were down. That is the capability of that aircraft; the equivalent of the Boeing aircraft that did the same thing for the Air Force. The Boeing did it with maybe ten or twelve people, while the Navy did it with three.

We took off successfully. I performed my test and was satisfied with the results that I got. Then, the pilot announced that, since we had time, he wanted to do a so-called "fish-tail experiment." As in "fishtailing" with a car, the aircraft swings from side to side. He wanted me to observe and report. I was in the rearmost seat of this 60-foot long airplane, feeling most uncomfortable. He was going to measure fishtailing!!

Stopping the engine on the right side, or stopping the propeller and feathering it (which turns it so it doesn't offer resistance), then replicating the procedure on the left side causes the plane to swing from side to side. I was watching the engine and starting to feel queasy. I don't like flying in the first place, and, with my inner-ear problems, balance is a big problem for me.

Fortunately, we didn't have to ditch. To this day, I still don't know if I would have gone down with the plane because I don't think I would have jumped. We came back and went into the debriefing room. I debriefed and said that my test proved it wasn't an EMI problem; it was an antenna problem. The flight test engineer grabbed the microphone, and he said that the test proved that it was an EMC problem. We were back to zero again!

The controversy persisted until a special flight test was made. I got a call from the chief test pilot for the E2 program. He said, "You still have the controversy?"

I said, "Yes, but Tommy, there is really no controversy. If you fly that aircraft with a dummy rigged antenna, we can prove it."

Now, Tommy was known for a secret. And what was his secret? In one of his maneuvers of the airplane, he dived, fired his gun, came back up into the gun, and riddled his own airplane with bullets. That was the kind of guy Tommy was!

He said, "Tony, if you tell me you want me to fly a dummy-rigged antenna, what are you going to do?" I said, "I am going to move the antenna out of the fuselage (outside of the aircraft) and drop it about six inches. Then we are going to fly."

He said, "It will be done in two days. The flight will happen Saturday. Want to come in and watch it?" I said, "Of course!"

So, Saturday comes, and Tommy took off. We were watching him. He went out five miles. He went out ten miles. He continued flying and, finally, we got a message.

He says, "I am at a hundred and ten miles." I'm going, "Tommy, we've got the flight restriction."

He said, "Don't tell me, that's my business to fly." I said, "Sorry."

So he went out one hundred and ten miles, which was well beyond the range that we needed to do our developmental flight testing. He came back and landed. You have to understand that at the Grumman Company at this time, the founders were there. The original aircraft people, including Leroy Grumman, were still alive. It was an engineering company. It was a company that had more engineers per worker than any other company in the US. In fact, its name was the Grumman Aircraft Engineering Company.

So Tommy says, "If anybody tries to take that antenna off, I will exercise my prerogative."

Everybody knew what that meant. He had a direct line to call the CEO. So, the flight test continued with a jury-rigged antenna.

Meanwhile, the antenna group and the avionics engineers were still arguing that it was not an antenna problem. Their basis was that I had moved the antenna away from the interference source by bringing it outside the airplane. I said, "Yes."

Meanwhile, I developed a test plan for the E2 for the EMC engineers that were assigned to the E2 because I was hired to work on another airplane. My section chief told me to write the plan.

I said, "I want you to collect the data to prove that it is an antenna problem."

They performed their test, basically dropping the antenna one inch at a time. I had math models to predict what would happen on the back of an envelope. You have an aperture, a small aperture, and a large surface. Rensselaer published some aperture results, and I used their quasi-static equations because we were dealing with 95KC to 1 MC (95 kHz to 1 MHz) – not a big deal. They came back with the results, and still, they insisted that it was the antenna. In the hierarchy, the antenna group, for some reason, is considered in high esteem. The reason, I think, is because everyone looks at it as a mysterious device. But it's nothing but a hunk of wire that gets tuned!

Meanwhile, nobody wanted to do anything. So, I grabbed the antenna installation manual that Collins had written. It said that the average aperture (I can't remember the exact dimension) was two feet square; the actual aperture was less than that, maybe one-foot square. I looked to the antenna engineer, and I said, "How did this happen?"

He said, "You know … structures. We are always concerned about cutting a big wall at that location on the aircraft." I said, "Yeah. I can understand that. So, what did you do?"

He said, "I called Collins and told him about the problem." Collins said: "Oh yeah, you could reduce the size of the aperture."

I said, "You have this documented, of course. And did you ask him for the mathematics to justify this decision?" I knew the answer by his reaction. I said, "You've done a very poor thing." I showed him the results because my boss had seen them.

He said, "I certainly endorse it. I don't want to be in an argument with this section chief."

I said, "He doesn't have to know."

So, to this day, that antenna sits two inches below the fuselage, forty or fifty years later.

A Story from Vince Mancino

When directly overhead, the satellite transmitted the data directly to a ground station in the local area. But, when the satellite was beyond the horizon, it would record the data on a tape recorder and then transmit it to Earth from the tape recorder with a more powerful data transmitter.

RCA Astro-Electronics Division had built a weather satellite for the U. S. Air Force and it was undergoing final simulation tests. This required the recording of weather data on the tape recorder and then playing it back to the transmitter, which would simulate transmission to an earth ground station.

Well, each time the data transmitter was turned on, the tape recorder output was turned to unintelligible gibberish. RCA had a high-powered managerial team frantically trying to solve the problem because there were schedule constraints and they were not making any progress.

And then, someone remembered that I had previous EMC expertise. With the help of a mechanical design engineer assigned to me at my insistence, we designed an add-on external box with compartments that could be attached to the tape recorder. This was feasible because the tape recorder was located within a sealed housing. All wiring entering or exiting the tape recorder had to pass through this "add-on external box." This permitted (and required) signal lines to be isolated from the command and control lines, and then both groups to be isolated from the power lines.

It also required miniature radio frequency (RF) suppression feed-through capacitors to be mounted inside the box on the outside wall away from the wall mating with the tape recorder. All tape recorder external wiring had to pass through the filtering devices inside this add-on box. This approach worked, and the successful test of the "RF-fix" was both dramatic and emotional.

The rules and principles that I laid down on this weather satellite became standard operating procedures for many years on all RCA-built weather satellites, as well as other satellites. In February 1967, I received an RCA Engineering Excellence Achievement Award for the satellite design "RF-fix."

A Story from Sam Burruano

What I want to do is tell you a little bit about the early days, some of my war stories. The technical stuff is great, but there are a lot of work stories to show you that EMC can be a fun job.

My first run-in with Air Force One was in the 1950s. Eisenhower was president, and Vice-President Nixon was on his way to Russia for the infamous Kitchen Debate. As Air Force One was flying over Poland, the navigation was via triangulation, and something was jamming the entire navigation system. They couldn't hear any of the transmissions from the radio stations and required special help from the Russians to get into Russia.

When the plane came back from Russia, they called and said: "We want to borrow Sam for three nights." They thought it was going to take that long to find out what the problem was. So, I went over to Wright-Patterson Air Force Base. They must have had about 15 or 20 guys out there making microscopic measurements on the body of the airplane.

I went up to the Colonel who was running the thing and said, "Look, send these guys home. I'll solve the problem for you." You pray a lot when you do this because that's gutsy. So, I sat down and started to do the logical things. What could be causing this? Is it on the airplane? What could it be? Could it be broadband or narrowband continuous wave?

Could it be the electronic system or the electrical system? I listed all the parts of the electric system. There was no sense in listing all the electronics sub-systems; I turned all of those on at once and it didn't do a thing to the navigational system. So, I started to go through the electrical sub-systems one by one. All of a sudden, BZZZZ!! Boy, I had found it. I looked down to see what it was, and it was the fluorescent lights.

So, it was a very simple solution. I got some non-fluorescent lamps and installed one interference filter, and the interference was gone. They thought I was a real hero. (I know, I know… a hero is really an Italian sandwich!)

CONCLUSION

The 50th Anniversary of the EMC Society provided a unique opportunity for young EMC engineers to meet with the six founders who were present at the 2007 IEEE International EMC Symposium. Many of the EMCS members took advantage of that opportunity throughout that year's Symposium, which ended with a special Awards ceremony during which each founder was awarded an IEEE Electromagnetic Compatibility Hall of Fame Award. It was an honor and a privilege to associate with the six honorees in Hawaii and in the years that followed before the last pioneer, Milton Kant, passed away in 2023. Each of our founders left an important legacy, as well as some fascinating EMC stories!!!

Pioneers in Compliance Engineering

A celebration of the industry leaders, founders, innovators, and influencers in the world of electronics engineering.

The Electromagnetic Wall of Fame

Celebrating Great Minds in EMC History

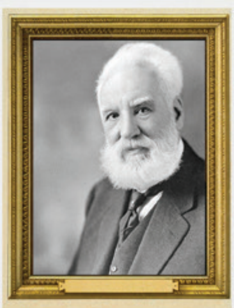
These pioneering spirits have significantly influenced electronic compliance engineering. Their work has not only advanced our understanding of electromagnetism but also set the stage for ongoing and future technological progress.

André-Marie Ampère

Founded electrodynamics, laying the groundwork for the science of electromagnetism, with the unit of electric current named in his honor.

Edwin Howard Armstrong

Invented FM radio, which dramatically improved the quality and reliability of radio transmissions and reduced electromagnetic interference.

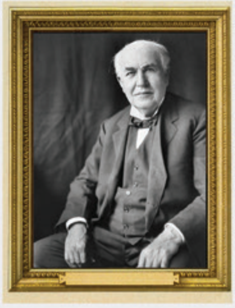


Alexander Graham Bell

Invented the telephone, revolutionizing global communication and laying the foundation for modern telecommunications systems.

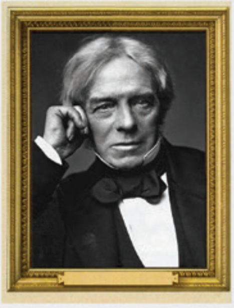
Edith Clarke

Developed the Clarke calculator and made major contributions to electrical power system analysis, becoming the first female professor of electrical engineering.



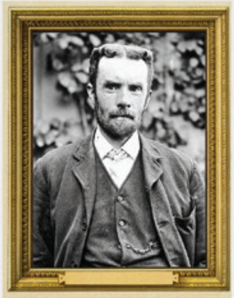
Thomas Edison

Invented numerous devices, including the phonograph and the electric light bulb, dramatically advancing electric power distribution and usage.



Michael Faraday

Discovered electromagnetic induction, which is the principle behind the electric transformer and generator.

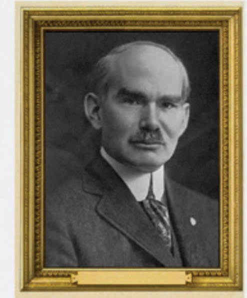


Oliver Heaviside

Reformulated Maxwell's equations into the simplified vector calculus form used today and developed the Heaviside layer theory.

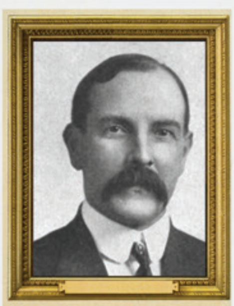
Heinrich Hertz

Demonstrated the existence of electromagnetic waves, thereby proving Maxwell's theories and paving the way for radio and wireless communication.



Lee de Forest

Invented the Audion, an early triode vacuum tube that could amplify electrical signals, leading to the development of radio, television, and other electronics.



Arthur Kennelly

Worked on the mathematical theory of electromagnetism and co-developed the Kennelly-Heaviside layer concept, crucial for understanding radio wave propagation.

Hedy Lamarr

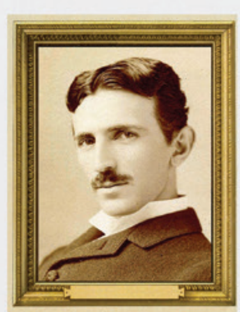
Co-invented spread spectrum technology, a precursor to modern wireless communications like Wi-Fi and Bluetooth.

Guglielmo Marconi

Pioneered long-distance radio transmission, leading to the development of modern wireless communication.

James Clerk Maxwell

Formulated Maxwell's equations, which describe the behavior of electric and magnetic fields and laid the foundation for modern electromagnetic theory.



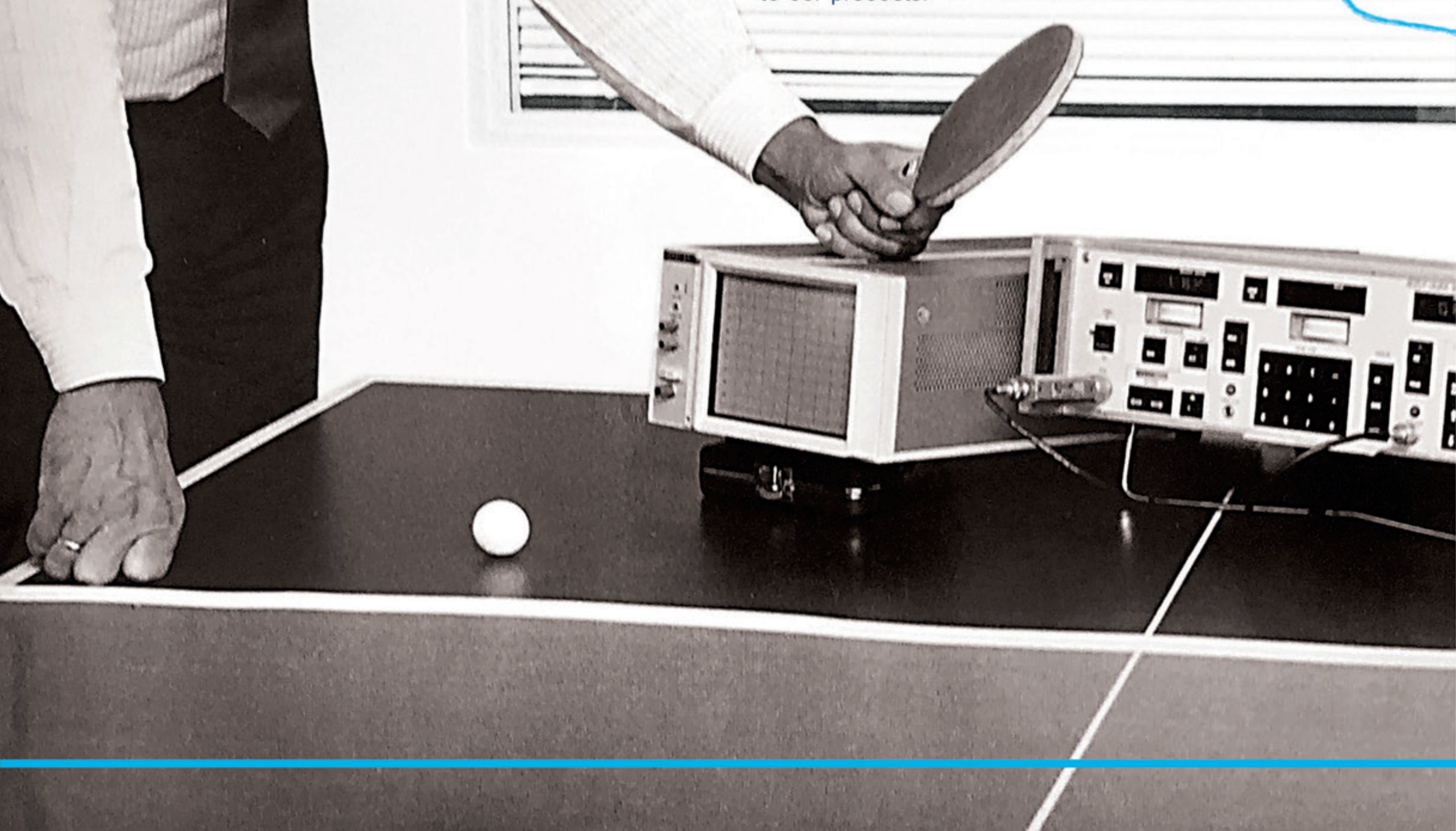
Nikola Tesla

Innovated in alternating current (AC) electrical systems, wireless communication, and numerous other areas, making substantial contributions to modern electrical engineering.

John Bardeen, William Shockely, and Walter Brattain

Co-invented the transistor, enabling the development of smaller and more efficient electronic devices.

From the left page to the right took us 44 years.



We are Bas and Rik de Groot, and the man on the left is our father, Hein, the founder of Comtest Engineering. Since 1980, Hein has been selling RF measuring equipment for Eaton Corporation's AILtech division, but the sales volume has been too small to support the operation. His first challenge was finding complementary product lines interesting to the same customer base: ESD test equipment, power amplifiers, and T&M equipment. This journey has been guided by his unwavering commitment to technical expertise.

In 1988, Comtest built one of the first semi-anechoic chambers in Europe using ferrite tiles and hybrid absorbers. Just before the turn of the millennium, we started manufacturing shielding, and that's when Bas joined the company, followed by Rik in 2017. Like our father, we learned by getting involved hands-on. The advantage is that we know every detail of our products, how they are built, and what they do. The LUF1000 on the other page is a recent testament to this commitment to our products.

CELEBRATING A CULTURE OF INNOVATION AND EXCELLENCE

element

Element Materials Technology has consistently stood at the forefront of telecommunications testing. With a history of technological leadership and innovation, we have helped shape the industry and set new standards. From the early days of mobile communication to modern 5G technologies, Element has pushed the technological boundaries of testing, investing in cutting-edge equipment, and leveraging the knowledge of our experts.

Our passionate team has helped bring transformative technologies to market, earning us a reputation as an industry leader and solidifying our partnerships with regulators and manufacturers. Advancements in telecommunications present both endless opportunities and new challenges, and we are committed to further strengthening our role as an industry leader.

Element's Legacy of Firsts

First mmWave Handset Approval

In April 2019, Element secured the first-ever approval for a mmWave handset, paving the way for the future of high-speed mobile communication. Our ability to navigate the complexities of mmWave technology has set us apart as innovators.

First mmWave Industrial Booster Approval

In late 2019, we were also the first to receive approval for a mmWave industrial booster. This enabled better connectivity and performance in industrial settings, improving productivity and revolutionizing the way businesses operate in high-demand environments.

Early Leader in 5G Testing and Approval

Starting in the late 2010s, Element was among the first to support end-user device testing for 5G handsets. Our expert team contributed significantly to the development and deployment of 5G technology in its earliest days, ensuring devices were robust and reliable.

Pioneering mmWave Base Station Approval

In February 2018, Element labs were among the first to approve a mmWave base station, a crucial step in establishing the infrastructure for widespread 5G adoption. Our work in this area has enabled faster, more reliable network connections, benefiting users worldwide.

Breakthroughs in Mobile Communication

First LTE Handset Certification

In the mid-2010s, Element granted the first LTE handset certification. This provided faster, more efficient communication capabilities and laid the groundwork for modern mobile networks. Element's expertise in LTE technology has led to smoother and more reliable mobile experiences.

Leadership in VoIP Technologies

Element was also at the forefront of Voice over LTE (VoLTE), Voice over Wi-Fi (Vo WIFI), and Voice over IP (VoIP) technologies in the 2010s, securing the first HAC (Hearing Aid Compatibility) grants for mobile handsets in these categories. These advancements have helped ensure that everyone, regardless of their hearing abilities, can benefit from the latest communication technologies.

Innovative Patents and Standards

Essential VoIP Test Procedure Patent

In 2016, Element obtained our essential VoIP test procedure patent, referenced in the ANSI C63.19-2019 standard. This patent exemplifies our commitment to establishing high-quality communication standards, which help maintain the integrity and reliability of telecommunications technologies.

Utility Patent for Unique OTA Holder Design

We also focus on practical solutions that enhance testing and deployment. In 2018, we obtained a utility patent for a unique OTA (Over-The-Air) holder design has streamlined testing, contributing to more accurate and efficient evaluations of mobile devices. This invention highlights our ability to identify and solve practical challenges in telecommunications testing.

Carrier Approvals and More

Element holds carrier approvals from major cellular providers around the world, reflecting our comprehensive approach to mobile technology development. These approvals have facilitated the integration of new devices into existing networks, ensuring compatibility and performance for devices entering the market.

Looking to the Future

Element's history is defined by bold but thoughtful innovation and a steadfast pursuit of excellence, both for ourselves and for the telecommunications industry. From the first mmWave handset approval to pioneering VoIP technologies, we have consistently led the way in telecommunications. As we celebrate our past, we remain dedicated to shaping the future and driving the industry forward.


element

IN COMPLIANCE Magazine

Turning Pages, Leading the Way:

Celebrating 15 Years of Pioneering Publishing

In 2006, the IEEE EMC Symposium was held in Portland, Oregon. *Conformity Magazine* attended that Symposium. It was a very important moment in time. Little did we know, it was also the beginning of a new adventure for the founders of *In Compliance Magazine*. At a lunch between friends, the question arose, "Why can't we do this ourselves?" This question planted the seeds of what would become our lives work.

A Phoenix Rising...

You see, as the U.S. was hit by a The Great Recession (2007 to 2009), more than 170,000 small businesses were closed. *Conformity*, the magazine that had served our industry for 13 years, fell casualty to that fateful period of decline. The staff of *Conformity* faced a tough decision - now what do we do? The plan began to reveal itself. We would do this ourselves. From the ashes left in the wake of *Conformity's* closure, the phoenix that was to become *In Compliance Magazine* arose.

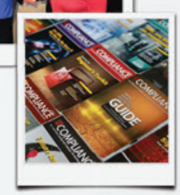
We would carry the torch lit by the predecessor of our predecessor, *Compliance Engineering* (many of you will remember this publication). There truly was no place to go from the final issue of *Conformity* but up. Things could only get better. We grabbed the torch and ran with it, publishing the premiere issue of *In Compliance Magazine* in August 2009. *In Compliance* debuted at the IEEE EMC Symposium in Austin, TX. And in January 2010, we mailed our first monthly issue.

We didn't realize it at the time, but it was then that we became true pioneers. We, the visionary group of three women, dared to shatter the status quo and pave the way for a new era of leadership and innovation. We have not only defied the odds, we, along with our contributors and our advertisers, have set a new standard for excellence in the industry of electronics compliance engineering.

Building a Village...

Along the way, there are some very special people who have supported the pillars of this publication. The saying "it takes a village" rings true for *In Compliance Magazine* for without your support, In Compliance Magazine would not exist.

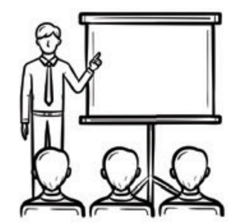
From the very beginning, a talented roster of authors and editorial contributors have contributed and supported our mission. These industry experts have consistently provided the insightful articles, technical papers, and thought leadership pieces that have made *In Compliance Magazine* the most relevant and useful resource for compliance professionals. Their dedication and expertise have been instrumental in ensuring the magazine remains at the forefront of industry developments.



With unwavering support from our advertisers, *In Compliance* delivers expert editorial on design, troubleshooting, problem solving, compliance and careers to readers worldwide. Some of our advertisers have been with us since the very beginning, some have stepped into the fold along the way. To all of our advertisers, with deep gratitude, thank you.

And the final pillar of this remarkable equation, you, our readers. You tie the pieces all together. You are the reason we picked up that torch back in 2009 and have continued to run this marathon publishing venture that is *In Compliance Magazine*!

Educating and Inspiring



Our commitment to education extends beyond the pages of *In Compliance Magazine*. We've partnered with educators to provide in-person training at both beginner and advanced levels. These training sessions have empowered professionals with the knowledge and skills they need to excel in their careers, reinforcing the magazine's role as a cornerstone of the compliance engineering community.

We've built a comprehensive website that stores 15 years of compliance content, an extensive vendor directory, a rotating resource library, and a weekly newsletter. The website features the latest industry news, in-depth articles, and a wealth of resources designed to support compliance professionals. The vendor directory connects readers with leading suppliers and service providers, while the resource library offers a curated collection of white papers, technical documents, and industry standards. The newsletter keeps subscribers informed with timely updates and exclusive content.

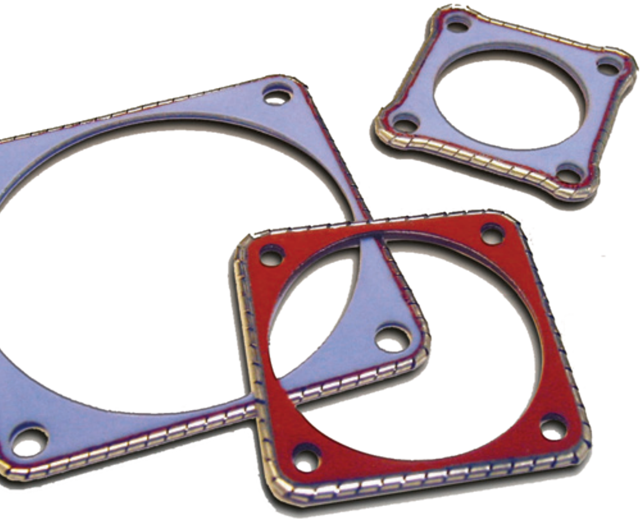
Now, as we celebrate the 15th anniversary of *In Compliance Magazine*, we take a moment to reflect on the extraordinary journey that brought us here. Our story is a testament to the power of perseverance, innovative leadership, and the incredible impact that a shared vision can have on an entire industry.

DESIGNED BY AN ENGINEER
FOR ENGINEERS

Imagine a world where electronic devices work flawlessly, free from interference. That's the world Spira EMI Gaskets & Shielding Products has been building for 45 years. Founded in 1978 by George M. Kunkel, a visionary design engineer, Spira emerged from a simple yet powerful idea: to meet an unmet need in the marketplace.

George, armed with his engineering expertise and an innovative spirit, invented the Spira EMI Gasket. This groundbreaking product quickly became known for its high shielding, long life, and unparalleled reliability. But George and his team didn't stop there. As new challenges arose in the ever-evolving world of electronics, Spira's creative engineers continued to innovate, developing new products to meet increasingly stringent EMI requirements across global industries.

Today, Spira stands as a beacon of excellence in the EMI/RFI shielding world. Their product line has expanded far beyond the original EMI gasket, now including environmental shielding solutions, custom configurations, and products for both military and commercial applications.



What sets Spira apart? It's their unwavering commitment to quality, demonstrated through ISO-9001 and AS9100 certifications and compliance with numerous industry standards.

But Spira isn't just about products; it's about people. Before retiring, George, with over 50 years of experience as an EMC design engineer, was at the helm, driving innovation and sharing knowledge. His ground breaking book, *Shielding of Electromagnetic Waves–Theory and Practice*, is a testament to his expertise. Today, a talented new team carries Spira's passion to advancing the field, and George's dream, forward.

What truly makes Spira special is their dedication to their customers. They understand that when EMI failure is not an option, you need a partner you can trust. That's why top manufacturers choose Spira for the best, most reliable EMI/RFI Shielding Gaskets and Honeycomb Filters. It's not just about exceptional products; it's about on-time delivery, superior customer service, and expert technical support.

As we look to the future, Spira continues to push boundaries. In a world increasingly reliant on electronic control systems, their role becomes ever more critical. They're not just keeping pace with change; they're driving it, constantly innovating to meet the evolving needs of industries across the globe.

From its humble beginnings as one engineer's solution to a problem to its current status as an industry leader, Spira's journey is a testament to the power of innovation, dedication, and expertise. As they celebrate 45 years, Spira EMI Gaskets & Shielding Products stands ready to face the challenges of tomorrow, continuing to design and manufacture products that keep our electronic world running smoothly and interference-free.

Advanced Test Equipment Corp.

Rentals • Sales • Calibration • Service

Over 40 Years of Growth

Through Challenges

Jim Berg, the founder and CEO of Advanced Test Equipment Corporation (ATEC), started the company in 1981 from his garage in San Diego, California. His vision was to create a test equipment rental company that excelled in customer service, technical expertise, and the availability of unique and unusual equipment.

In 1986, a major setback occurred when a fire destroyed their first facility, taking with it all their physical assets. The devastation was immense, erasing everything that they had worked for. However, amidst the rubble, a resilient determination emerged. They resolved to rebuild stronger and more resilient than ever.

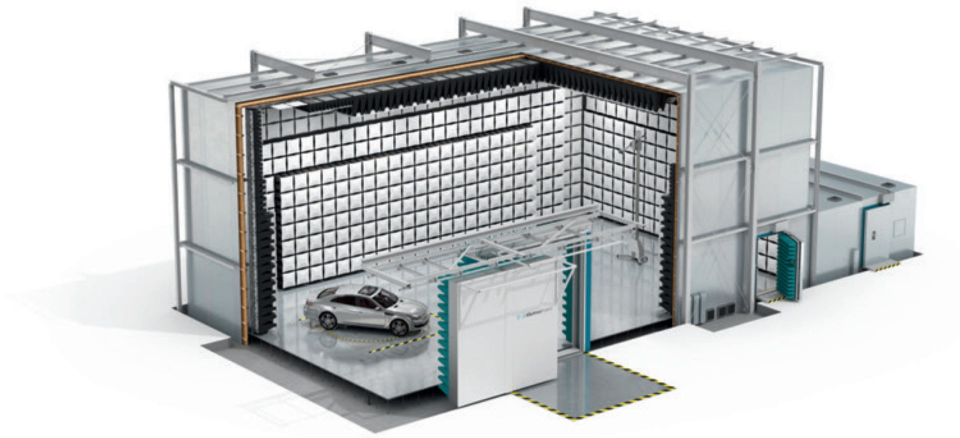
Since that fateful day, ATEC has not only rebuilt its physical structures but also strengthened its resolve. Adversity has taught them valuable lessons, turning setbacks into opportunities for growth and innovation. Challenges like embezzlement, theft, and flooding have been met with perseverance and dedication, each trial contributing to the company's journey from devastation to triumph.

Today, ATEC, also known as Advanced Test Equipment Rental, stands as a prominent leader in the industry, having grown with honor and integrity.

Under Jamison Berg's leadership since 2020, ATEC has continued to evolve, offering comprehensive test and measurement services. The company is constantly expanding its lab capabilities, inventory, and partnerships to offer our customers solutions with rentals, sales, calibration, and service.

Looking ahead, ATEC is confident that no challenge is insurmountable. Here is to the past, present, and future—to the indomitable spirit of our company!

AP Americas



Facility Chamber Solutions for EMC Testing

Commercial, Automotive, Medical, Aerospace, Military

AP Americas full product line offers superior chamber design and performance for accurate and repeatable test environments. We believe that test, analysis, and protective environments must be uncompromisingly dependable - 100%.

Albatross Projects Group Worldwide

SIEMENS

S+M COMPONENTS

History

- **1999** Foundation Albatross Projects GmbH and Albatross Projects Singapore
- **2001** China Representative Office Shanghai
- **2006** Albatross Projects Hong Kong
- **2007** Albatross Projects Shanghai, China
- **2010** E&C Anechoic Chambers N.V. Belgium & Hong Kong
- **2011** EMshield Munich, Germany
- **2012** Albatross Projects Americas (AP Americas), Dallas, Texas, USA
- **2015** Albatross Projects India, **Ghandinagar, India**
- **2024** Albatross Projects Americas GPS, New Jersey, USA

Milestones

- **2001** Built the largest Automotive EMC Test Centre in Asia for Hyundai Motors, Korea
  Building the worldwide first neuro-surgical MRI room for BrainSUITE
- **2007** Development of the worldwide first "full glass" MRI door
- **2008** World wide first 10m chamber at Siemens Erlangen with sVSWR test volume of 5.0m diameter at a 10m test distance
- **2011** 1st state-of-the-art European operating room project to incorporate an intraoperative MRI unit with a movable 1.5T magnet in Tübingen, Germany
- **2017** Highest multipurpose Chamber in the world. L x W x H 40 x 25 x 36,1 Meter Location: China

What sets us apart...

- Original Equipment Manufacturer (OEM)
  - Shielding Materials (Shielding/Doors)
  - Anechoic absorbers (Emerson & Cuming)
  - Highest quality materials and components
- Superior RF Shielding Performance
  - Modular Pan Type System
  - Doors and Large Gates
  - 100 dB isolation up to 40GHz
- Committed to excellent Service
  - Apply most accurate Installation practices
  - Performance, chamber longevity, convenience
  - Experienced, reliable & responsive Customer Service
  - Key partner(s) collaboration
  - Stand behind our product
- Certified
  - ISO 9001 and ISO 14001

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start with trust.

evolution Through Core Values

From the company's inception in 2006, the StaticWorx team has focused on education, believing an educated client is their own best advocate and the best advocate for their clientele. Out of this core value, we developed a program called GroundSafe ESD Flooring. A closed-loop system, the GroundSafe ESD flooring program ensures compliance at the specification stage and intercepts a non-compliant solution before implementation.

Industry protocols require pre-installation testing to be sure ESD flooring adheres to ASTM F150 and ANSI/ESD S20.20 standards. Electrical standards differ significantly by industry and application. Requirements for ANSI 20.20 electronics manufacturing programs, for example, often conflict with requirements for server rooms, FAA, telecommunications, DOD applications, and explosives handling.

Pre-installation testing through our GroundSafe ESD flooring program confirms that the ESD flooring system under consideration meets buyer expectations and adheres to best practices, including for:

- **Grounding methods**
- **Type of subfloor and its resistance to ground**
- **Installation method**
- **Adhesive usage & dry times**
- **Relative humidity and dew point**
- **Vapor in concrete**
- **Durability requirements**
- **Placement of grounded items, such as consoles and servers**

ASTM and ANSI standards also require post installation (verification) testing. Post-install testing verifies that the floor meets the buyer's specifications.

When you partner with StaticWorx, we work closely with you from your initial vision through post-installation to ensure that you specify the right ESD floor for your application and that you get exactly the floor you specified.

Pre-installation test patch: Durability Test
Benchmark Electronics

staticWorx®
GroundSafe® ESD Flooring

GroundSafe® ESD Flooring Program

Ensures compliance at the specification stage and intercepts a non-compliant solution before implementation.

Our StaticWorx GroundSafe ESD flooring program ensures that you get the *right* floor for your application. And verifies that your ESD floor meets your objectives and specifications.

Installed floor: AmeriWorx ESD vinyl

Post-installation testing: Electrical resistance

staticworx.com

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IN COMPLIANCE Magazine
15
Years of Publication
178
Issues Published
17,000
Subscribers
40,000
Monthly Website Visitors
221 Million
Pages Distributed
We are honored to be your choice as a primary source of electrical/electronic compliance engineering information.

Thank you for your support!

The In Compliance Team

HARDENING THE POWER SYSTEM FROM HEMP AND IEMI

A Cost-Effective Plan to Harden Existing Facilities

Dr. William A. Radasky, Ph.D., P.E., has worked in the field of high-power transient phenomena for more than 56 years and has published over 590 reports, papers, and articles during his career dealing with transient electromagnetic environments, effects, and protection. He was awarded the Lord Kelvin Medal by the IEC in 2004 and the Carl E. Baum Medal in 2017. He is an IEEE Life Fellow. He was also elected to the U.S. National Academy of Engineering in 2021. He founded Metatech Corporation in 1984 and is the President and Managing Engineer. He can be reached at williamradasky@metatechcorp.com.

Dr. William A. Radasky, Ph.D, P.E.

This article provides an extension of my article in the June 2021 issue of *In Compliance Magazine*, describing the different ways to protect power system electronics in high-voltage power control houses found in HV substations [1]. The intention here is to provide a specific plan to start to harden power grids against the fields produced by high-altitude electromagnetic pulse (HEMP) and intentional electromagnetic interference (IEMI). In addition, we will discuss the differences in protecting power company substation control houses and control centers and even power generation stations against these threats. Finally, there will be a discussion of the approach to protect the high voltage transformers (V ≥ 100 kV) against the late-time portion (E3) of the HEMP, which also will provide protection against an extreme geomagnetic storm if it were to occur.

While the worst-case levels of the early-time (E1) HEMP environment have not changed, this is not the case for the late-time (E3) HEMP environment, due to the work of the U.S. EMP Commission [2]. The worst-case level of E3 HEMP has doubled, and the IEC is in the process of increasing the worst-case level in IEC 61000-2-9 Ed.2 draft [3]. While this increase is significant, the same new draft version of IEC 61000-2-9 also discusses the fact that the worst-case E1 HEMP field occupies a very limited portion of the ground exposure. And, when considering that there are over 9000 high voltage substations in the U.S., they all cannot be illuminated at the worst-case E1 peak HEMP level with a single high-altitude burst. Also given the costs of hardening a large number of buildings, there have been discussions in the IEC and in other standards organizations considering resilience aspects to reduce the cost burden of protection [4].

Figure 1 presents the draft versions of the worst-case HEMP time waveforms, including the new version of E3 HEMP. In the standard, the actual "incident" E3 magnetic field is provided, along with the method to compute the electric field depending on the earth's deep conductivity. This accounts for the substantial variation of ground conductivities in many places of the world including the U.S. In the new standard, it is not assumed that the E3 HEMP electric field is the same everywhere and, in many places, could be more than a factor of 10 lower.

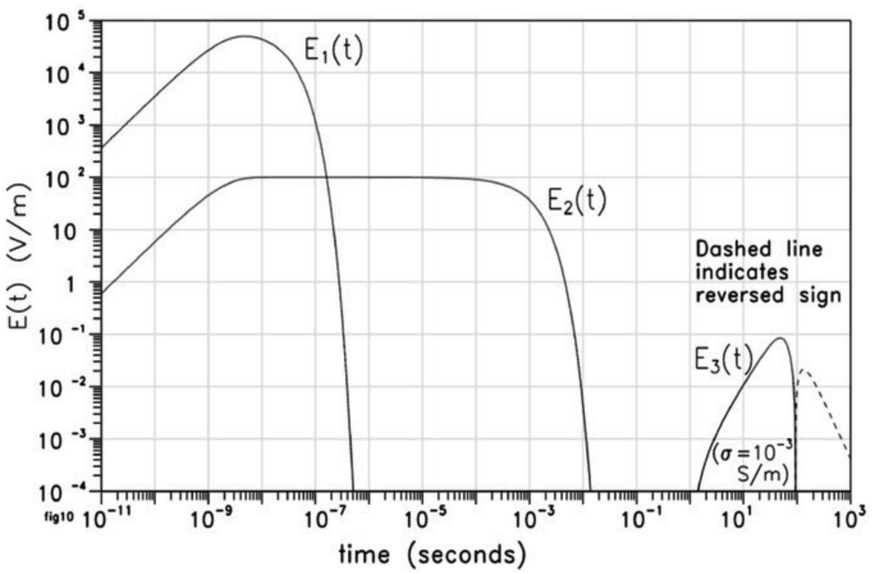

Figure 1: Worst-case HEMP waveforms in IEC 61000-2-9 CDV [3]

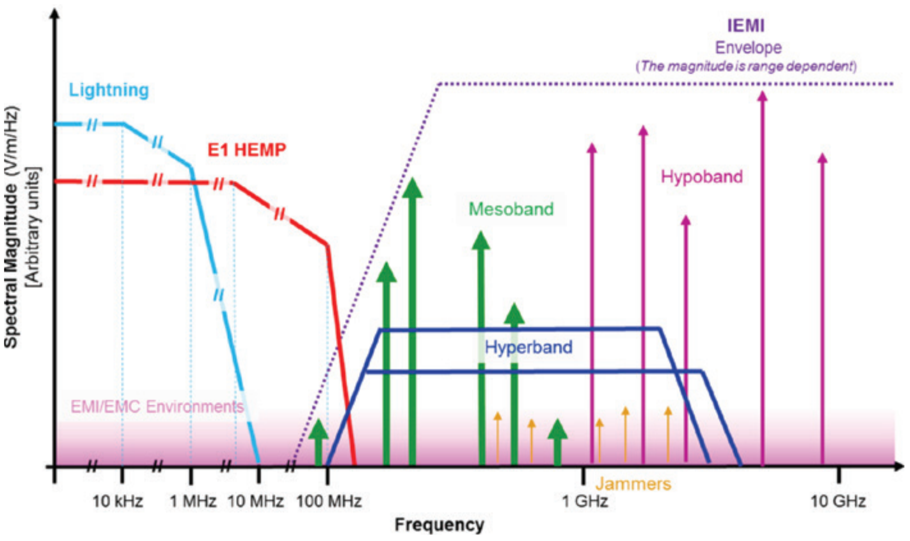

Figure 2: Comparison of the fields producing IEMI with the worst-case E1 HEMP, the nearby fields of a cloud-to-ground lightning strike, and the radiated environments considered in studies of EMC [1]

As this article will also discuss the additional protection needed for IEMI, Figure 2 describes the most recent presentation of the relationship of the electromagnetic fields in the frequency domain that can cause IEMI relative to E1 HEMP, lightning electromagnetic pulse and also standard levels of EM fields associated with EMC [1].

This article first discusses (in Section 2) the basic problem of hardening a large number of critical buildings to protect their electronics and then looks at the various options for protection. The issue of replacing existing buildings is also discussed. The role for high-level EM protection, such as recommended in MIL-STD-188-125-1, is also mentioned.

Section 3 of this article discusses the method to determine the level of hardening of buildings depending on the EMC requirements that are necessary to operate normally. Also, the variability of the incident environments is discussed along with the idea of considering resiliency.

Section 4 presents the best hardening approach for existing buildings for E1 HEMP and IEMI, while Section 5 discusses the best approach for protecting the large transformers that can be affected by E3 HEMP. Section 6 describes the rationale for developing a hardening program over time. Section 7 provides a summary and recommendations.

It should be noted that due to the extremely large amount of material to be covered here, this article will rely strongly on references to provide the details, as we cannot cover all of the hardening techniques in a single article. Most of the references are IEC standards or peer-reviewed publications from the IEEE EMC Society.

DEALING WITH IMPROVING EM HARDNESS OF EXISTING BUILDINGS

As mentioned in the introduction, most large power companies in the U.S. and worldwide have several hundred (or more) high-voltage substations connected to a control center. They also have an even larger number of distribution substations, although each of them controls much less power than a single high-voltage substation. The problem in terms of protecting substation control houses is that the threats of HEMP and IEMI are high impact, low probability (HILP) threats (HEMP has not occurred anywhere in the world since the 1962 tests by the U.S. and the Soviet Union – although the capability to detonate a high altitude burst clearly exists today).

As is clear to consumers over the past 5 years, it seems that the rates one pays for electricity are increasing, and power companies are not in a position to spend even more money on their existing infrastructure, when they are planning for increases in their overall grids due to shifts toward electrical cars and renewable power sources.

The best solution is to improve the hardness of the existing buildings by upgrading the protection of the best existing buildings, and to use this design for new substation control buildings, if needed. In addition, due to the criticality of particular substations

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(depending on their location and their service area), some of the existing buildings can be upgraded over time. For substation control houses, what should be the approach to evaluate methods to upgrade the hardening to HEMP and IEMI? Let us examine Figure 3, which describes the basic substation control house and the ways that EM fields and conducted transients can penetrate the building.

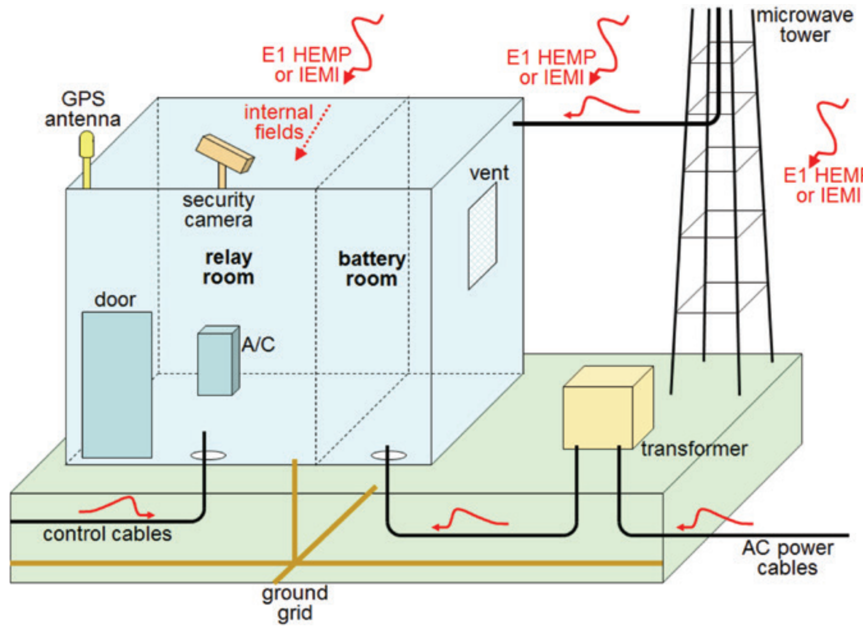

Figure 3: A general example of a typical metal control house showing the ways that E1 HEMP and IEMI environments could penetrate the building (note that internal wiring is not shown)

Beginning with a metal substation building, one can see in Figure 3 that there are many ways that EM fields and currents can penetrate the building and then reach the electronics inside (not shown). The best approach is to evaluate the control houses by testing their shielding effectiveness with emphasis on those recently built. The reason for considering recently built buildings is that one would like to emphasize those using current construction techniques from local vendors. The best test method is to use the signals from radio stations in the AM, FM, Digital TV, and cellular bands to measure the fields outside and inside the building. This allows the electronics to continue operating, as there is no new field being transmitted. This method is fully described in IEC 61000-4-23 [5] and is very quick to apply.

Once one finds the best building for a power company, then the next step is to evaluate the many possible EM leaking points, as are clearly observed in Figure 3. Using normal EMC protection techniques, one can improve the grounding and shielding of cable entries, shield windows with wire grids, provide gaskets for the doors, provide filters for the power entry, etc. [6]. The goal is not to protect all penetrations, but rather to determine which penetrations should be improved on a cost-effective basis. Once the best set of protection is installed, then testing should be performed again to ensure that the building achieves its recommended level of protection. While this approach will consider different types of building designs in the U.S., as there are over 150 major power companies in the U.S., there may be fewer or even one company operating a national power grid in European or Asian countries, which will make this process more efficient. Also, in the U.S. there are companies that make control house buildings in a factory that are transported for installation. In this case, there could be efficiency in the building evaluation process.

FACTORS THAT CAN REDUCE THE REQUIRED SHIELDING EFFECTIVENESS FOR SOME BUILDINGS

One of the special characteristics of a high-voltage control house with modern solid-state electronics inside is that the electronics must survive the daily electromagnetic disturbances typical from the switching transients in the high-voltage yard. Because of this, the IEC has published a special set of EMC immunity requirements for electronic equipment in high-voltage substations and power stations [7].

While there are requirements for radiated and conducted environments in this standard, those that are most severe are those of the conducted environments, which include the electric fast transient (EFT) test as described in IEC 61000-4-4 [8]. This voltage pulse has a 5 ns rise time and a 50 ns pulse width. The typical coupled E1 HEMP voltage for an above-ground conductor, such as a microwave cable, GPS, or camera cable, has a 10/100 ns pulse shape. The typical common mode requirement for the EFT is a peak of 4 kV for the electronics in a control house, while the expected transient for a buried yard cable is ~20 kV. So only a modest level of E1 HEMP protection is needed for the incoming yard cables. For a building shield of 30 dB, the worst-case internal E1 HEMP field would be ~1.7 kV/m. The coupled levels of conducted transients to internal cables will be lower than the 4 kV EMC immunity level. Unfortunately, some existing concrete substation buildings have been tested to shielding levels as low as 6 dB, which would allow fields that are too high into the building.

While the 30 dB level of shielding (along with POE protection) appears adequate for high-voltage power control houses, the situation is different for control centers. Each power company typically has 1 main control center for their high voltage substations, and a backup control center in case there is a failure at their main control center. The control center typically has communications and computer rooms, and digital displays to connect to all of their substation buildings to provide real-time information to ~4 operators.

While most of the power system operates with computer control, there are times when a particular substation loses communications, or there is a natural event such as a fire, lightning, or a fault that impacts the operation of the grid. These control centers are important to ensure that each grid operates efficiently and to prevent a blackout. The significant aspect of the control centers is that the electronics are not designed to tolerate high levels of EM noise as are those in a substation control house. Typical electronics are usually required only to have a "residential" level of immunity from EM disturbances, which could be as low as 0.5 kV for the EFT immunity test or up to a factor of 8 below the 4 kV requirement for substation electronics. This means that a control center needs approximately 50 dB of shielding effectiveness to protect its electronics.

In the recent past within the U.S., 3 separate new control centers have been built to protect against HEMP. Due to the relatively high level of shielding required, a decision was made in all 3 cases to use the military standard, MIL-STD-188-125-1 [9], with some modifications to correct for aspects of the standard that are not cost-effective [10]. During the construction of the first new HEMP control center in Houston in 2013, the A&E firm developing the construction plans evaluated the additional cost of an 80 dB HEMP shielded building vs. "normal" construction to be approximately 4%. This is consistent with cost studies performed in the past for the U.S. military for highly shielded buildings. It should be noted, however, that the cost of building a highly shielded building when the levels of required shielding are not high, is not cost-effective.

A third category to be considered are the power plants generating electricity. Of course, there are many different types of power plants from thermal (including nuclear), to solar panels, to wind turbines, to turbines at dams. In most cases, the large power plants need to convert turbine medium voltages to high voltages for transmission to population centers, and thus require a power substation; renewable plants also need a substation to coordinate the final AC power flow to the correct voltages and the proper phasing with the existing AC network. Therefore, the protection levels and approach required are the same as the high voltage substation control houses.

Clearly, those power plants that produce a significant amount of power for a particular company should be considered as a protection priority from the threats of HEMP and IEMI. It is also noted that power plants are often not owned by the power company operating the power network, introducing another difficulty in the hardening process.

One factor mentioned at the beginning of this article is the fact that the HEMP standards generally specify the worst-case HEMP environments for two reasons. This provides a reasonable upper bound of the fields that could be produced, but it also avoids the variability of the fields that could be produced based on the height of the burst, the location of the burst, the yield of the weapon, the weapon design, and for E3 HEMP the deep ground conductivity under the burst.

One presumes that if an attack is planned, the attacker would try to maximize the field levels. Of course, even if this is done, one cannot maximize the fields over the entire footprint of the exposure. For E1 HEMP the fields toward the edge of the exposure region can be lower than the worst case by factors of 2 to 10, and the maximum field exposure area is typically less than 10% of the total area exposed. For the E3 HEMP the fields typically fall to 10% or less at the edge of the exposure, and if the deep ground conductivity is high, all of the fields will be smaller than the worst case. This means that only a few substations will see the maximum fields.

There are other factors to consider, including the orientation of power lines, which affect the coupling of E1 HEMP. Based on the polarization of the E1 HEMP fields for the center of the U.S., E-W oriented cables will pick up more than 10 times the peak current and voltage than will N-S cables (in the air or buried) [11]. These are important aspects of the HEMP variability, and one should consider the advantage of using lower levels of fields based on these variations.

The last point of consideration is that all of the discussion thus far has been to evaluate the best way of adding protection to a "partially" shielded building. It is possible that in some cases, if an outage can be accepted for some limited time, then a plan to accept electronic upsets, and limited damage to electronics might be acceptable. This could be achieved by having replacement electronics available in the building that are not connected to power or data and which are placed in a modestly shield cabinet inside the building.

This approach could be used for buildings that are not as critical to the overall operation of the power grid, although a criticality study would need to be performed. In the U.S., power companies have been asked by the North American Electric Reliability Corporation (NERC) to determine their 9 most important assets, and to consider them to develop protection plans against different threats (but not necessarily HEMP and IEMI).

RECOMMENDED APPROACH FOR PROTECTING BUILDINGS – HEMP AND IEMI

As mentioned earlier in this article, the best approach for substation control houses is to evaluate the construction techniques of recently built houses with a preference for metal buildings. A shielding effectiveness measurement campaign should be developed to identify the best existing buildings in the network. As indicated earlier, the use of radio communications signals is a very efficient way of testing an operating control house, as the radio signals are already occurring, and they are usually far enough away to be considered to create a plane wave incident field. This method has been evaluated in peer-reviewed journal articles and is presented as a testing option in IEC 61000-4-23 [5].

Once this process is accomplished, then the best building (or two) should have between 20 and 30 dB of shielding effectiveness across the E1 HEMP spectrum (1 – 100 MHz). From past experience, the priority for improving the protection of the building is usually first determined by any above-ground penetrations of the shield without complete bonding and grounding. These are usually cable entries for GPS antennas, microwave cables, camera cables, A/C mounting, windows without EM mesh, and door gaskets. If the yard cables penetrate the building walls and not the floor, this is a major leakage path to be considered for improvement.

The best way to minimize the repairs and their cost is to perform the improvements while making measurements, usually with temporary copper tape, to determine the most important leakage points. In any event, after the repairs are made, it is important to remeasure the shielding effectiveness of the building with the EMC repairs completed. For buildings manufactured in a factory and then shipped, the measurements should be made before and after shipping to determine the impact of the shipping process.

As mentioned earlier, this process works well when the target protection level is 30 dB but does not work well (on a cost-benefit basis) for a control center building for the reasons mentioned earlier, which needs on the order of 50 dB. It is very difficult (and costly) to raise the shielding effectiveness of a 20 dB building to 50 dB by making repairs. Therefore, it is recommended that the MIL-STD-188-125-1 approach be used, which is also presented in IEC 61000-6-6 [12], with consideration of reducing some of the unnecessary costs and correcting the errors in the standard [10]. It is also recommended that the newest version of the MIL-STD-188-125-1A [13} not be used because it is not published for public use and has not been peer-reviewed by commercial technical organizations (IEEE, CIGRE). It is recommended only for certain military projects.

If particular power system buildings are to be considered for HEMP and IEMI protection, then the power substation at the power plant can apply the control house procedure mentioned above. If there is a local control center building for the plant, then it should also be considered for protection, but at the higher level of 50 dB. Typically, a control center room for a power plant is much smaller than a control center room for a power company's entire grid, so it may be possible to build a shielded room for this purpose at a lower cost than for an entire building.

While the emphasis in this section has been on the E1 HEMP, the IEMI has some differences to consider, although they are not usually very costly. First, the IEMI threat in the frequency domain is typically found between 100 MHz and 10 GHz. It is noted that in IEC 61000-2-13 [14], there are narrowband threats that are defined but also wider bandwidth threats (even single fast pulses, like JOLT [15]. The main difference with IEMI is that the threat comes from a local antenna outside the fence. The fields fall off rapidly from the antenna, and a solid metallic fence can cause the attacker to move further away to "fire" their threat over the fence. While normally substation electronics are in a building that is not close to the outside fence, there have been cases where they are close to the fence. These cases are clearly those where a new building needs to be built away from the fence to prevent very high IEMI fields from exposing the equipment.

When IEMI is considered in addition to the E1 HEMP, one factor to consider immediately is that the window meshes must be designed for higher frequency fields. E1 HEMP requires about a 4-inch mesh, while IEMI requires a mesh of a few cm [16]. Fortunately, there are commercially made meshes for a frequency of 18 GHz, which can be used for the IEMI threat. Of course, if the windows are not needed, they should be replaced with metal, eliminating the need for meshes.

Another point, in general, is that the cable penetration grounding is not as critical for IEMI, as the IEMI fields do not couple or propagate as well on external metallic cables as from E1 HEMP fields due to their frequency range. On the other hand, significant cracks in the shield allow more penetration of fields at higher frequencies. If the IEMI is important to a particular building due to close public access, then it is important that the building be tested at higher frequencies using cellular radio signals to ensure that important apertures are well sealed.

Finally, there are IEMI field detectors that are being made today [4], and these could be used to determine if an attack is underway. The placement of these detectors is important to ensure that the main attack scenarios are covered and that any alerts for an attack are evaluated against the possibility of false alarms.

RECOMMENDED APPROACH FOR PROTECTING LARGE TRANSFORMERS

While this article has dealt mainly with the high-frequency threats of E1 HEMP and IEMI on electronics that control the power grids, the late-time E3 HEMP is a serious threat to the large transformers that are the key part of the power transmission network. While high voltage (HV) transformers are defined to operate at V > 100 kV, most modern transmission systems operate at 400 kV (Europe) or 500 kV (U.S.). In China and India, new HV transformers are being built to operate at 1 MV to efficiently move power.

The process of coupling E3 HEMP fields and also geomagnetic storm fields into the power network is complex; there is an IEEE paper [17] that explains the entire process and a recent CIGRE Technical Brochure that reviews the worldwide measured geomagnetic fields from 1989 to 2018 [18]. It is noted that the E3 HEMP threat and the typical CME geomagnetic storm are very similar disturbances and couple to power grids and cause transformer difficulties in similar ways. Fortunately, there are modeling techniques that can evaluate power grids, which are essentially very large antennas, to determine where (which transformers) the largest currents will occur given an E3 HEMP or a large geomagnetic storm. This modeling process is not difficult and will identify those transformers at the highest level of risk.

Of course, it is prudent to validate the modeling technique used, and even a small geomagnetic storm from the recent past can be used for that purpose. It is useful to add geomagnetically induced current (GIC) monitors on transformer neutral cables to perform the validation. It is noted that the CIGRE TB 780 does provide information on how to install GIC sensors on transformers [18].

If the modeling process indicates a significant number of important transformers are at risk, the next step is to add additional GIC monitors on these transformers to observe the response of these particular transformers relative to others in the network. Over time, one should be able to confirm that these transformers will carry a significant portion of the GIC current. It is noted that transformers at the edge of the grid and transformers in regions of the earth where the deep ground conductivity is low are most at risk.

Once the utility is concerned that a particular transformer is at risk, and it supplies a significant amount of power to the overall network, then protection needs to be considered. The main cost-effective treatment is to add a neutral resistor [19]. One of our customers did this, and it reduced the induced current in the transformer by about a factor of 2, as indicated by a GIC measurement made during a significant geomagnetic storm in the early 2000s. The second treatment is a neutral capacitor, but it must be protected against power faults and lightning surges with a bypass arrester. Otherwise, the capacitor will be damaged. The problem with the capacitor is that, with bypass protection, they are expensive, so on a cost-effective basis, the neutral resistor seems to be the better approach.

In terms of resilience, another approach is to have backup transformers at the critical substations where high levels of GIC may occur. While it is typical for power companies to purchase a few large transformers in advance, the selected transformers are based normally on the age of the transformers. In this case, the placement of the transformers should be based on the probability of a high GIC and the importance of the substation to the overall operation of the grid. As noted by the EMP Commission in 2008 [20], if one waits for large transformers to be damaged during an E3 HEMP event, the delivery time could be many years, especially if a large number of transformers were damaged during one event.

PERFORM PROTECTION OVER TIME, NOT ALL AT ONCE

One of the questions that always occurs when the subject of HEMP and the power grid is discussed is why do we not protect the grid immediately? It is true that, as indicated in this article, we do know how to do the job. The problem is the cost will be very high due to the large number of high voltage substation control houses in the U.S. (~9000) and many more worldwide, and the number of experts available to perform the work is not large.

This is why the idea of evaluating buildings, which already exist, and hardening them on a cost-effective basis to achieve a sufficient level of protection is the best way to develop a prototype approach that can be used in the future, as power grids expand. This can be done separately by each power company. If these projects, including cost information, could be openly published as the work is completed, this would be a significant help to smaller power companies. It is possible that some national prototypes could be developed.

In the same way, the protection of power control centers requires higher levels of shielding, but it would be beneficial if those adapting the MIL-STD-188-125 approach to commercial applications as described by the IEC could publish their results so cost savings could also be shared across the industry.

Finally, the development of a group of backup power transformers at substations where the transformers are at significant risk from E3 HEMP is something that can be done over time and would only modify the procedures that are already embraced by the power industry. The main feature would be to determine the transformers at significant risk, along with other factors already considered by power companies.

SUMMARY AND RECOMMENDATIONS

The main recommendation of this article is to start the process of upgrading high voltage substation control houses to E1 HEMP and IEMI to protect the electronics inside by evaluating their best metal buildings for their shielding effectiveness and using the typical EMC hardening techniques to improve the shielding levels to at least 30 dB. Testing is needed to ensure the work is done on a cost-effective basis, and rapid test methods are recommended.

In a similar fashion, control center buildings need to be protected to ~50 dB due to the susceptibility of the type of electronics found inside, and this level is not amenable to reaching from a starting point of ~20 dB. This means the basic high shielded building approach should be used, but the MIL-STD-188-125-1 needs to be adapted and those adaptations published so it can be used on a commercial basis. The IEC has started that process by indicating areas where the military standard is not cost-effective, but more work is needed.

The consideration of the IEMI threat in addition to E1 HEMP is important, and while the threat does not cover a large area at one time (unless there is a coordinated attack), the IEMI threat is much more probable than a HEMP attack. The features of an IEMI attack are well understood, and many of those features are discussed in this article. The main factors are to ensure that an IEMI attacker cannot get close to the electronics, and to consider upgrading the substation fences to reduce the fields incident on the electronics. In terms of EM protection, the most important add-on for IEMI is to ensure that a fine metal mesh is used to cover windows.

The final aspect of this article is that the method of protecting the large power transformers that are very expensive and take many years to replace is straightforward. Validated analysis methods exist and can be used to determine which transformers are most at risk. Adding GIC sensors to those transformers and evaluating their measurements during future geomagnetic storms can confirm the potential vulnerability of particular transformers. In terms of protection, the neutral resistor appears to be the most cost-effective in that it can substantially reduce the currents that will flow in a particular transformer. A resilience approach includes providing backup transformers at the substations where transformers that are at risk are located.

As one who has worked directly for more than 20 power companies worldwide on this problem for over 20 years, I am trying to develop an industry-wide approach to cost-effectively protect power grids throughout the world. In addition, I have worked directly with IEC SC77C as the Chair for 25 years in the past and as an expert in writing and updating existing standards to be more accurate and cost-effective. This is too big of a job for a small group of experts to perform, and we need to develop techniques that can be used and replicated easily.

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3-D MODELING AND CHARACTERIZATION OF FERRITE AND NANOCRYSTALLINE MAGNETIC CORES FOR EMI APPLICATIONS

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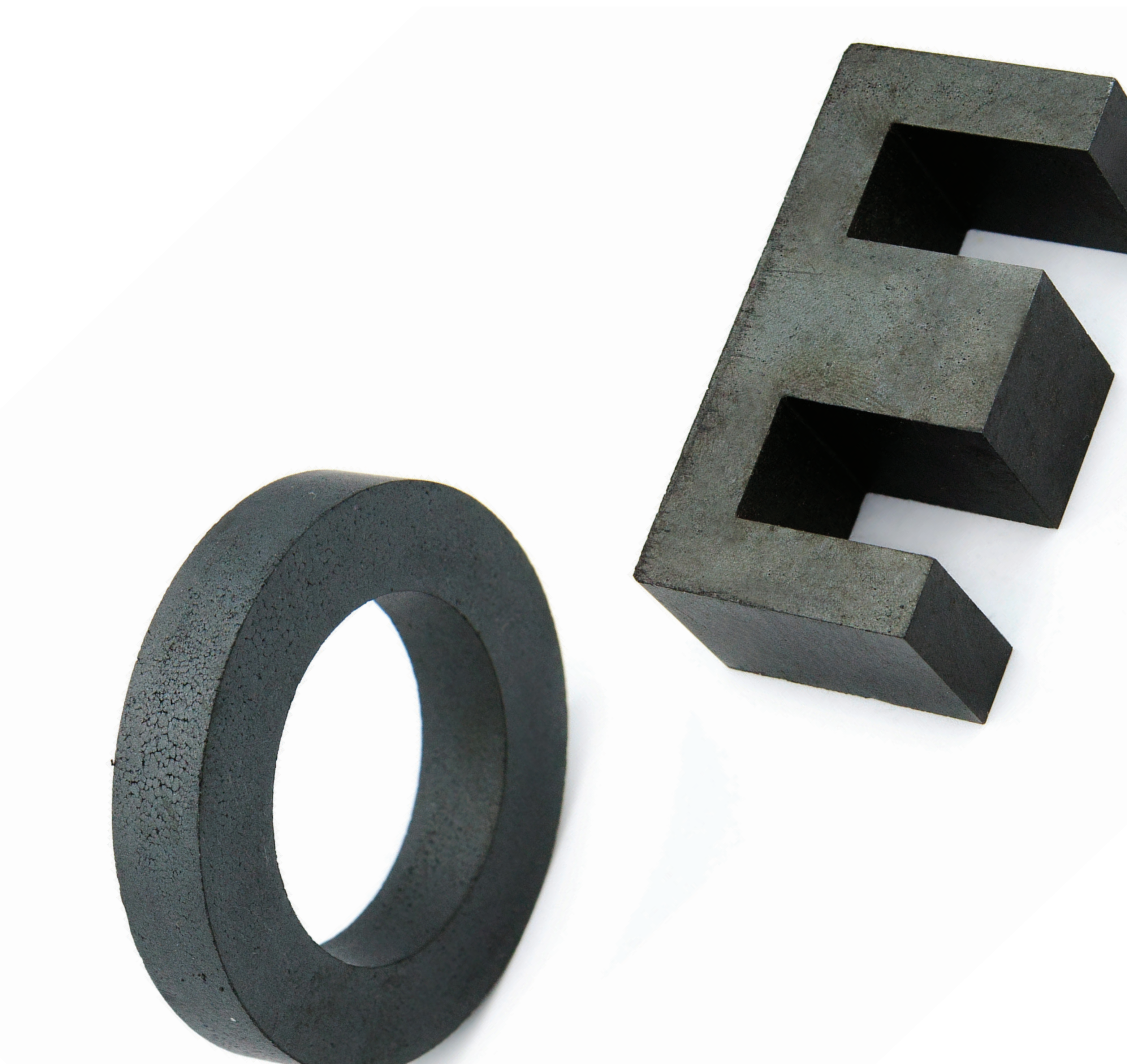

Rafael Suárez is a Ph.D. student on EMC engineering at Ikerlan and can be reached at resuarez@ikerlan.com.

Maria Tijero is an investigator at Ikerlan and can be reached at mtijero@ikerlan.es.

Roberto Moreno is the Manager of EMC at Ikerlan and can be reached at rmoreno@ikerlan.es.

Aitor Arriola is the team leader of Smart Connectivity at Ikerlan and can be reached at aarriola@ikerlan.es.

Jose Manuel González is an Adjunct Professor with the Department of Electronic Technology at the University of the Basque Country (Spain) and can be reached at josemanuel.gonzalezp@ehu.eus.

By Rafael Suárez, Maria Tijero, Roberto Moreno, Aitor Arriola, and Jose Manuel González

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I. INTRODUCTION

Ferrite and nanocrystalline magnetic toroids are commonly utilized in interference suppression part of electromagnetic compatibility (EMC), but their implementation is often based on a trial-and-error approach under the guidance of experienced senior engineers. Several studies have been conducted for modeling the behavior of magnetic toroids using equivalent circuits [1]–[3]. However, these studies do not account for certain surrounding environmental effects, and they are limited to tens of MHz. Consequently, 3-D electromagnetic simulation is currently being investigated to consider these effects [4]–[6]. 3-D electromagnetic simulations have gained widespread use in high-frequency design, such as for RF antennas or filters [7], [8]. Nevertheless, research in the field of magnetic toroids is more recent, and new difficulties related to accurately modeling magnetic materials appear.

This article focuses on the 3-D modeling and practical application of magnetic cores. Three toroidal magnetic cores used in the EMC field will be studied. The characterization of material properties is crucial for accurate 3-D simulation. In particular, correct extraction of complex magnetic permeability (CMP) is essential in magnetic materials simulation [9], [10].

The issue of CMP characterization has been a subject of great interest for a long time [11]–[13]. Due to the complexity of its extraction, it is often mentioned that the permeability value is conditioned by the geometry and dimensions of the core. However, this statement is not consistent when considering permeability as an intrinsic property of the material. Several methods have been developed to obtain the CMP of a toroidal magnetic core. The two most frequently employed methods use the approximate formula of the coil inductance to calculate its CMP.

One of these methods consists of inserting the core into a short-circuited coaxial holder. Then, the approximate formula for the inductance of a coil is applied to calculate the CMP. It is considered that the holder forms one turn around the core [11], [12], [14], [15]. The main advantage of this CMP extraction method is that it allows to reach GHz frequencies due to the stability of the measurement setup. Nonetheless, a different holder is needed for each core dimension. The other CMP extraction method used in this paper consists of winding a conducting wire around the core to extract the CMP value by measuring the impedance. This is a widely used method even though its frequency of use is limited to tens of MHz [4], [13], [16]–[18].

It is a very common practice to extract the CMP using the number of turns of the model that will be simulated [6], [19]. However, the CMP value changes depending on the number of turns used for its extraction. To the authors' knowledge, it has not been investigated how the characterization with different turn numbers influence the 3-D simulation of a magnetic core. This paper tries to find the proper way to extract the CMP for 3-D modeling any magnetic core regardless of the material. Hence, measurements were performed with different turn numbers (N_i) on various cores to compare the differences between their extracted CMP values. Then, an analysis to determine how they influence core simulation models with different turn numbers (N_j) up to 100 MHz is performed.

The paper is organized as follows. In Section II the influence of the number of turns on the extracted permeability is studied. An investigation of the extracted CMP effect on 3-D simulation follows in Section III. Finally, Section IV presents conclusions and future research lines.

II. TURN NUMBER INFLUENCE ON EXTRACTED COMPLEX MAGNETIC PERMEABILITY

A. Measurement Setup and Extracting Method

The method used in this paper for extracting the CMP of a magnetic toroidal core is based on winding the core with a conducting wire, measure its complex impedance, and calculate the CMP. CMP in series form can be expressed as

$$\bar{\mu} = \mu' - j\mu'' \qquad \text{Eq. 1}$$

where μ' and μ'' represent real and imaginary part of CMP respectively that are calculated through equations (2) and (3) [16].

$$\mu'(f) = \frac{2\pi X_{meas}(f)}{\omega N^2 \mu_0 H \ln\left(\frac{D_E}{D_I}\right)} \qquad \text{Eq. 2}$$

$$\mu''(f) = \frac{2\pi R_{meas}(f)}{\omega N^2 \mu_0 H \ln\left(\frac{D_E}{D_I}\right)} \qquad \text{Eq. 3}$$

where H represents the core height and Di and De represent its internal and external diameters, respectively. N is the number of turns. Keysight's E5080A vector network analyzer was used to measure the impedance with a 0 dBm input signal avoiding any significant skin effect. Measurement setup is shown in Figure 1a.

B. Results and Errors for Different Cores

Figure 1b shows the three cores that have been analyzed. The first, named C1 corresponds to the ferrite MnZn core of a common-mode choke (744831010205 from Würth Elektronik); the second, named C2 is a ferrite NiZn core (74270097 TOF core from Würth Elektronik) and the last one, named C3, is a nanocristalline one from Vitroperm (W624). The main properties of the cores are shown in Table 1. Physical dimensions were measured, and the rest of the properties were obtained from datasheets. Each of the cores has been characterized with 1, 3, 6, 8, 12 and 18 turns windings.

Figure 2 (a to f) represents the CMP values extracted with different numbers of turns for the 3 chosen cores. Resonance frequency is evident in the magnetic loss tangent ($\tan \delta_m$) curves. $\tan \delta_m$ is calculated from the following equation.

$$\tan \delta_m = \frac{\mu''(f)}{\mu'(f)} \qquad \text{Eq. 4}$$

The resonance frequency of any measurement occurs where the value of $\tan \delta_m$ changes from positive to negative. Sometimes fake resonances arise due to the use of S parameters, which only give phases in the [0, 2π] range [20]. The S parameters phase was checked around resonance frequency to ensure there were no phase jumps causing fake resonances. The negative loss tangent values seen in Figure 2 (d to f) have their origin in the negative values of the real part of the CMP. The negative real part of measured permeability is justified by a change in the material behavior causing a phase shift. For C1 core, the resonance frequency remains stable at around 1 MHz for every measurement due to the fact that the first resonance is caused by the magnetic capacity of the material [17]. On the other hand, for cores C2 and C3 the resonance frequency varies depending on the number of turns. The resonance of the CMP may be caused by a parasitic capacitance related to the measurement

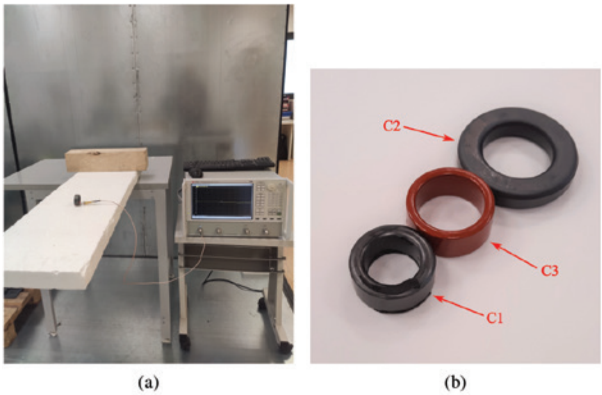

Figure 1: (a) Measurement setup and (b) analyzed cores

Core	Dimensions (mm)	μ_i	Material
C1	36.7 x 23 x 15.2	5000	Ferrite MnZn
C2	59.4 x 34.6 x 12.7	620	Ferrite NiZn
C3	40.2 x 30.62 x 16.8	15.000-90.000	Nanocristalline

Table 1: General information of measured cores.

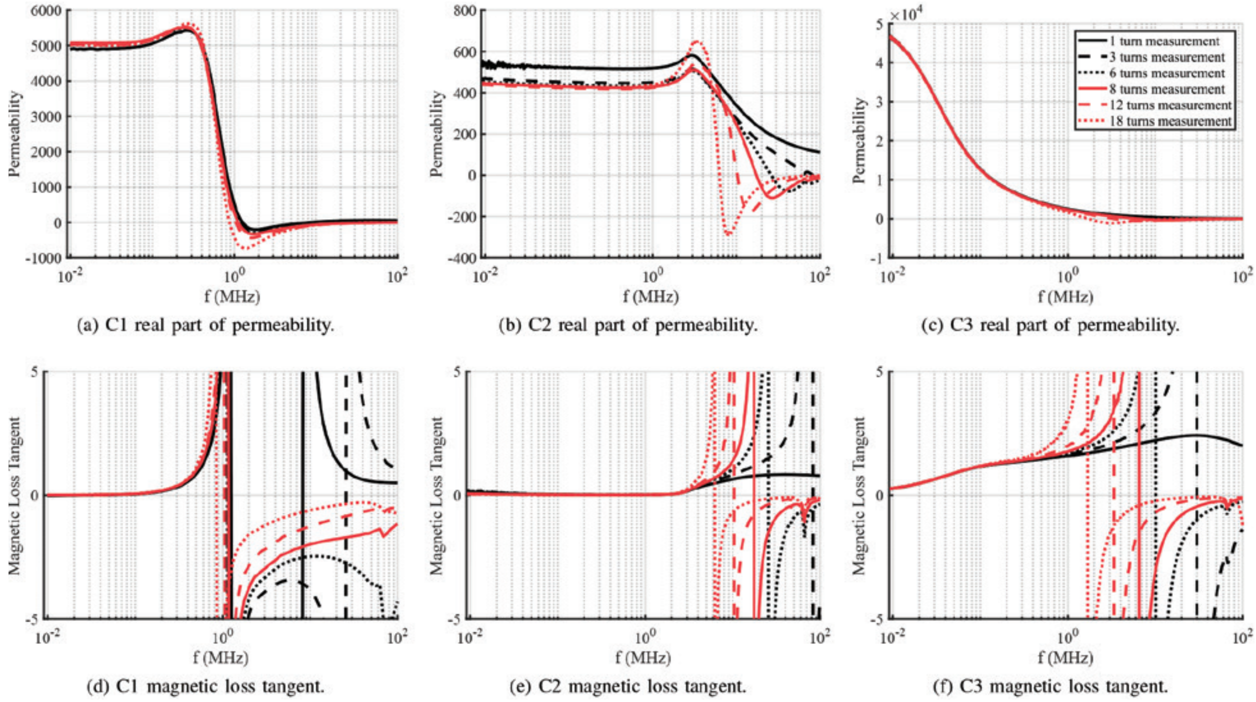

Figure 2: CMP obtained for the different cores

setup (winding capacitance) or by core-related effects such as displacement current or skin effect. However, the turns on the cores are not sufficient to generate a large enough winding capacitance that causes the resonance [17]. Thus, the resonance frequency shift should be caused by other core-related effects such as displacement current or skin effect.

With regard to the real part of the CMP, two regions divided by the resonance frequency are distinguished. Below resonance frequency, the real part of the permeability is large, whereas above the resonance frequency, the real part of the permeability is close to zero.

Figure 3 represents the mean relative error of the real part of the CMP values extracted from the three core measurements. The relative error is calculated with respect to the mean of the measurements using eq. (5). The mean value does not reflect the intrinsic permeability, but it is used as a comparative metric. Therefore, the error in Figure 3 must not be interpreted as the true error. Nonetheless, it does offer an idea of the measurements' dispersion. Only a few representative frequency points of the CMP behavior have been plotted. Figure 3 shows how the relative error remains below 10% at low frequencies. However, when the resonance frequency is exceeded, the error increases due to the close to zero values of the real part of the CMP. The effect of this error in simulations will be discussed in detail in Section III.

$$\mu'_{RelativeError}(f) = \left| \frac{\mu'(f) - mean(\mu'(f))}{mean(\mu'(f))} \right| \qquad \text{Eq. 5}$$

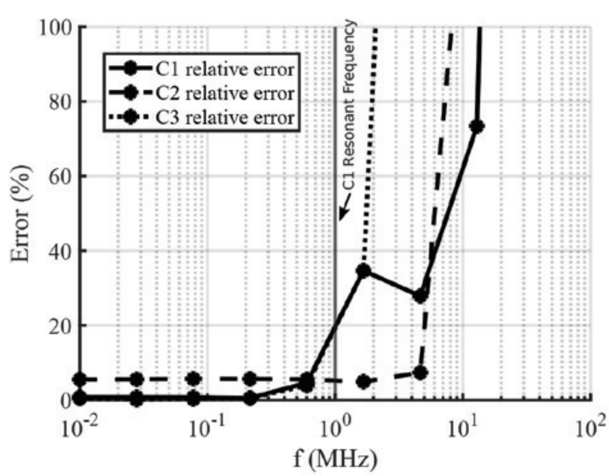

Figure 3: Comparison of mean relative error of the real part of the extracted CMP for the three cores

III. 3-D SIMULATION OF TOROIDAL MAGNETIC CORES

This section studies the influence of the CMP on the simulation of 3 magnetic toroidal cores. Analysis is detailed below, and results are discussed.

A. Analysis of the CMP Influence on 3-D Simulation

In order to perform an accurate simulation, it is important to provide a well-designed 3-D model, as well as to define the electromagnetic properties of the materials used correctly. Figure 4a shows a photograph of the 8-turn C3 core and Figure 4b shows its simulated 3-D model.

A full-wave finite-element method (FEM) 3-D simulation was performed using ANSYS HFSS 2022.R2 software with a driven modal solution type. The simulation included a defined radiation boundary surrounding the device under test (DUT) and a wave port, as illustrated in Figure 4b. Mesh refinement based on a maximum of 10 mm length was implemented over all the volume of interest. Finally, a multifrequency setup was established with a convergence condition of a 0.02 maximum ΔS for two different frequencies (1 and 100 MHz).

Regarding core parameters, the CMP property has typically been considered the most important for its simulation and it was the only property applied in this paper's simulations.

An analysis to determine the effect of the CMP in simulation was performed. Firstly, measurements with various numbers of turns (N = 1, 3, 6, 8, 12, and 18) were carried out with each of the studied cores. Secondly, the CMP value of each measurement

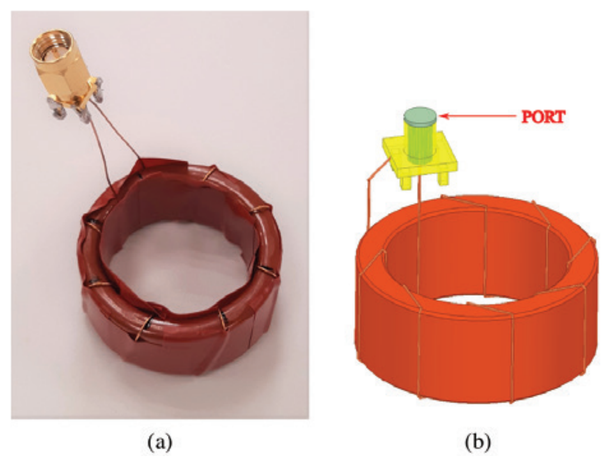

Figure 4: (a) Photograph and (b) simulation 3-D model of 8-turn C3 core

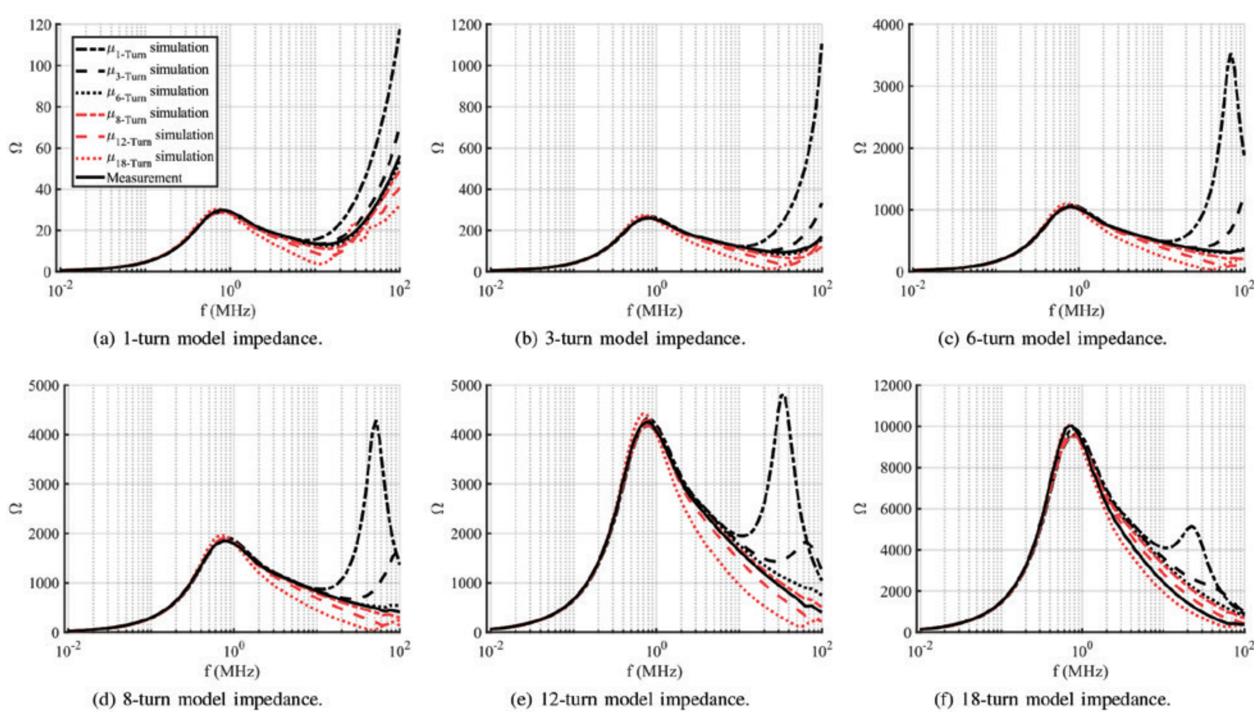

Figure 5: Measured and simulated impedance for C1 core

was calculated as shown in Section II. Finally, 3-D models representing each of the measurements were generated and simulated. A total of 6 simulations were performed with each core model, one with each extracted CMP.

Figure 5 (a to f) shows the results for the different simulations performed with C1 core. Simulations of the C2 and C3 cores were also performed, although only the 8-turn case of the C2 core was represented in Figure 6a and of the C3 core in Figure 6b. The inclusion of the rest of the cases was not considered relevant for the study since the conclusions obtained from them were similar to the ones obtained from the one shown. Figure 6 will be studied in Section III-B.

Figure 7 shows the process followed in the analysis. In this flowchart, the border line of the box represents the 3-D model simulated, while the fill style of the box represents which CMP is used in simulation.

Given the results of Figure 5, the influence of the extracted permeability in simulation is clear. For every core, an accurate simulation result is obtained using the CMP extracted with any number of turns up to the resonance frequency. Moreover, simulations are right taking into account only the CMP up to that frequency. However, above the resonance frequency, modeling is not valid for any extracted CMP, regardless of the number of turns used for extraction. In this frequency range, the real part of the CMP approaches zero and its dispersion increases. Therefore, simulations do not match each other or measurements.

For instance, in Figure 5c the simulation with the $\mu_{6\text{-}turn}$ perfectly matches the measurement but in Figure 5f simulation with that permeability does not.

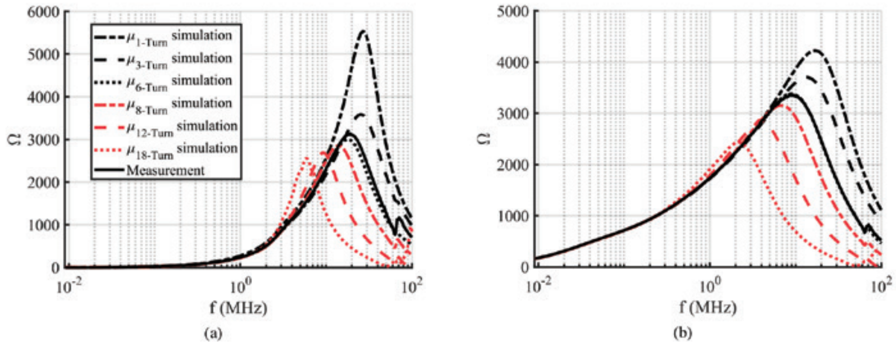

Figure 6: Impedance comparison for (a) C2 core and for (b) C3 core with 8 turns

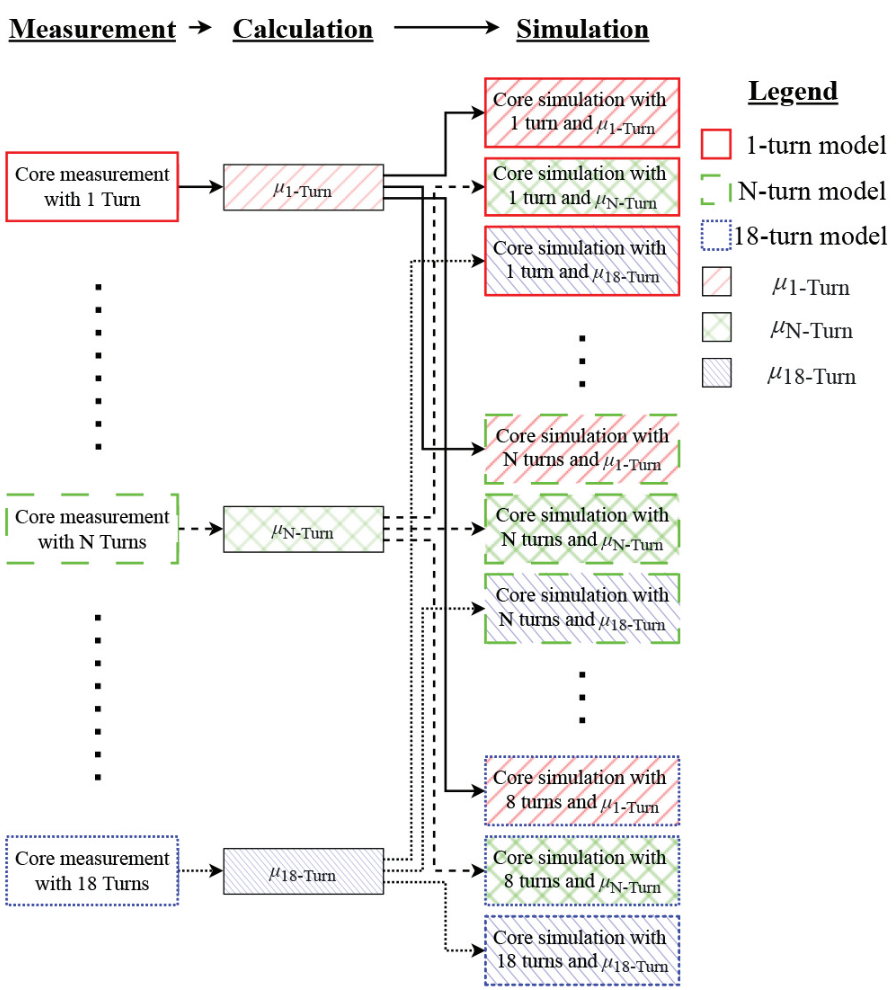

Figure 7: Flowchart of the developed analysis

In addition, it does not make physical sense for the CMP value to be changed for each model when the core is the same. Using a single CMP value for all models would be ideal, so only one characterization must be performed.

B. Relevance of CMP at High-Frequency

On one hand, as it can be observed in Figure 2d, the resonance frequency is constant for C1. On the other hand, the resonance frequency varies a few megahertz in the C2 and C3 cores as shown in Figures 2e and 2f. In these cases, as explained in Section II, the resonance frequency shift of the measurement is caused neither by the winding capacitance nor by the magnetic capacitance of the material, it should be caused by other core-related effects. These effects are not taken into account in the CMP extraction or in simulation so sometimes simulations can be inaccurate even below the resonance frequency (Figure 6a).

It can also be noticed that the resonance frequencies of the C2 core simulations shown in Figure 6a match the resonance frequencies of the CMP values used in each simulation (Figure 2e). The same is valid for the C3 core when comparing Figures 6b and 2f. This indicates that the CMP remains crucial and needs to be accurately characterized at high frequency. Nonetheless, the CMP resonance that causes the simulation resonance seems to be caused by core-related effects that were not taken into account in the CMP extraction.

In other words, the CMP is still highly relevant at high-frequency since its resonance causes the simulation resonance. However, CMP resonance seems to be caused by core-related effects such as skin effect or displacement currents, not by winding capacitance. These effects are considered neither in the CMP extraction nor in the simulation.

Thus, above the resonance frequency, simulation results cannot be trusted until other core properties in addition to CMP are taken into account. This idea will be discussed from another point of view in the next section.

C. Relevance of Other Properties at High-Frequency

Even by applying a correct value of the CMP to the simulation, it is evident that, above the resonance frequency, it is not enough to characterize only the CMP value of the core material to conduct simulations. To see this more clearly, it is necessary to look at the C1 core which has a stable resonance frequency. Figure 5c shows that the simulation performed with the CMP extracted from the 6-turn measurement matches the measurement of the real model. However, when this extracted value is applied to the 18-turn simulation (Figure 5f), simulations do not match the measurement.

A procedure with the C1 core has been carried out to understand the influence of the CMP on simulation. First, it was found a CMP value ($\mu_{adjusted}$) that fits the simulation with the 18-turn measurement. Then, $\mu_{adjusted}$ value was used for simulating the 6-turn model and it was compared with its measurement as well. Results are shown in Figure 8 representing the comparison of the simulations with their respective measurements.

Below resonance frequency, the value of the real part of the permeability is high, and this masks the effect of other material properties. In all cases, error in simulation is under 10% for C1 and C3 cores and under 20% for C2 core up to resonance frequency. Nevertheless, above resonance frequency dispersion of the real part of the CMP increases and its value is very close to zero. Therefore, simulations are not valid above resonance frequency, and other core properties could be needed for proper modeling.

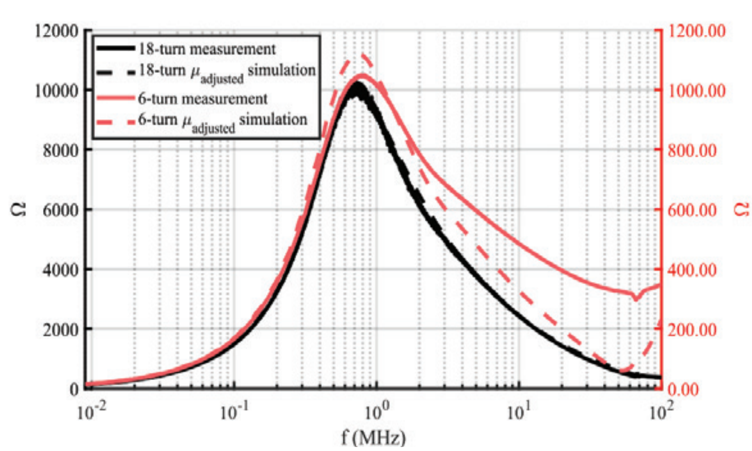

Figure 8: Comparison of results with an adjusted CMP

IV. CONCLUSIONS

In this paper, the CMP of three different ferrite and nanocrystalline magnetic cores used in the EMC field was analyzed. First, a CMP extraction method based on winding the cores was detailed. Next, measurements of CMP for different number of turns and their errors were investigated. The CMP spectrum was split into two regions: one below resonance frequency where the value of CMP is high and close to the initial permeability, and the other one above the resonance frequency where the CMP is close to zero.

In the case of the MnZn core the resonance frequency is stable due to the material magnetic capacitance. On the other hand, C2 and C3 resonance frequencies are not stable, and they present changes of a few MHz between different measurements. These changes seem to be caused by other core-related effects such as the skin effect or displacement currents that are not considered in the CMP calculation.

The influence of the extracted CMP on simulation was then investigated. First, 3-D models for all the measurements were generated and then every extracted CMP was applied to each model. The results showed a major relevance of CMP property in 3-D simulation over the entire studied frequency range.

On one hand, at low frequency only CMP is needed in simulation since its value is high enough to mask other properties of the core. In addition, at these frequencies, CMP can be extracted with any number of turns as the relative error is low for any measurement. Up to resonance frequency, simulation error remains below 10% for MnZn and nanocrystalline cores and below 20% for NiZn core in all cases. On the other hand, the CMP is still a crucial property for the core simulation in high-frequency region. However, in this zone the CMP is close to zero and dispersion between real parts of the extracted CMP values increases. In addition, other core properties could affect both CMP extraction and simulation at high frequency. Above the resonance frequency, simulations considering only CMP are not valid and other core properties, such as electric permittivity or conductivity, are not masked and could be influencing simulations.

Future research will be related to improved high-frequency simulation and also CMP extraction method. Permittivity for each core will be measured in order to take them into consideration and other parasitics and effects such as skin one will be also considered.

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PRODUCT Showcase

COMMON-IMPEDANCE COUPLING

Impact of the Return Path Impedance and the Return Current Levels

By Bogdan Adamczyk and Nick Koeller

This month we explore the impact of the return path impedance and the return current level on common-impedance coupling between circuits. The measurements presented here were performed on a custom PCB containing audio, video, and high-current circuitry, where the return paths for each circuit were selectively shared with other circuits. This topic had been previously discussed in [1], where the measurements were taken with a first-generation PCB. The PCB has since been redesigned to lend itself to future modifications and to contain off-the-shelf, readily available components.

Dr. Bogdan Adamczyk is professor and director of the EMC Center at Grand Valley State University (http://www.gvsu.edu/emccenter) where he performs EMC educational research and regularly teaches EM/EMC courses and EMC certificate courses for industry. He is an iNARTE-certified EMC Master Design Engineer. He is the author of two textbooks, "Foundations of Electromagnetic Compatibility with Practical Applications" (Wiley, 2017) and "Principles of Electromagnetic Compatibility: Laboratory Exercises and Lectures" (Wiley, 2024). He has been writing "EMC Concepts Explained" monthly since January 2017. He can be reached at adamczyb@gvsu.edu.

Nick Koeller is an EMC Engineer at E3 Compliance which specializes in EMC & SIPI design, simulation, pre-compliance testing and diagnostics. He received his B.S.E in Electrical Engineering from Grand Valley State University, and is currently pursuing his M.S.E in Electrical and Computer Engineering at GVSU. Nick participates in the industrial collaboration with GVSU at the EMC Center. He can be reached at nick@e3compliance.com.

1. COMMON-IMPEDANCE CIRCUIT MODEL

Consider the situation shown in Figure 1, where two circuits share the return path with a non-zero impedance.

The voltages at the loads are

$$\hat{V}_{L1} = R_{L1}\hat{I}_1 + \hat{Z}_G\left(\hat{I}_1 + \hat{I}_2\right) \quad (1a)$$

$$\hat{V}_{L2} = R_{L2}\hat{I}_2 + \hat{Z}_G\left(\hat{I}_1 + \hat{I}_2\right) \quad (1b)$$

Note that the load voltage of circuit *1*, $\hat{V}_{L1}$, is affected by the return current of circuit *2*, $\hat{I}_{L2}$; similarly, the load voltage of circuit *2*, $\hat{V}_{L2}$, is affected by the return current of circuit *1*, $\hat{I}_{L1}$. This type of coupling is called the *common-impedance coupling*. Common-impedance coupling becomes an EMC problem when two or more circuits share a common return path (common ground) and one or more of the following conditions exist:

- a high-impedance ground (at high frequency: too much inductance; at low frequency: too much resistance),

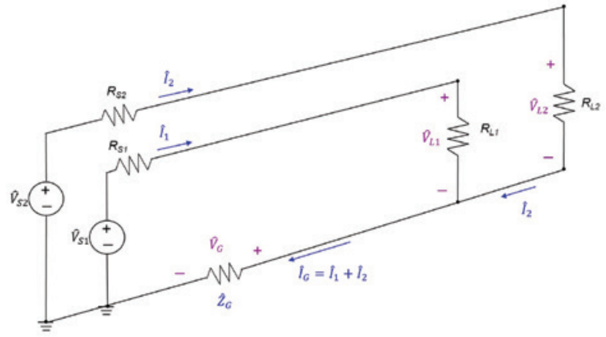

Figure 1: Common-impedance coupling circuit

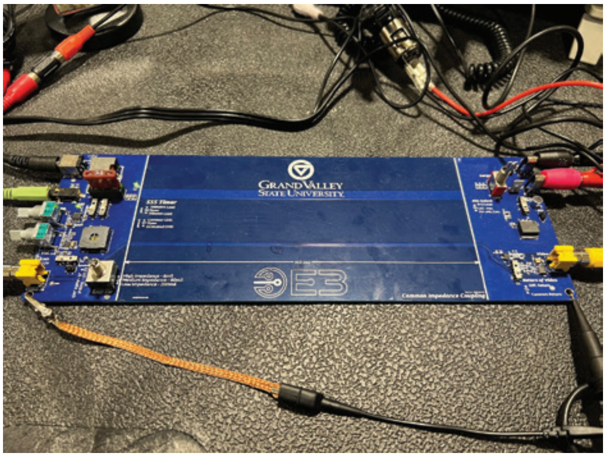

Figure 2: PCB board used in the experiment

- a large ground current,
- a very sensitive, low-noise margin circuit, sharing the ground with other circuits.

(Note: a similar situation occurs when the circuits share a common forward path).

2. MEASUREMENT SETUP AND PCB CIRCUITRY

Figure 2 shows the board used in the experiment, while Figure 3 shows the setup for the common-impedance measurements. The corresponding circuit diagram is shown in Figure 4. Figure 4 shows four different circuits and several switches controlling the return path for each circuit.

3. MEASUREMENT RESULTS

First, we investigated the impact of the return path impedance on the audio circuitry with no other circuit sharing that path. This configuration is shown in Figure 5.

Common-impedance coupling does not occur here, since there are no other circuits that could couple to the audio circuit. The measurement result is shown in Figure 6 on page 60.

In all measurements, cursor *a* shows the voltage levels for the low-impedance path, while cursor *b* shows the results for the high-impedance return path. There is an 18 mV voltage shift when changing from low to high impedance, with an audible increase in the speaker noise and slight video degradation.

Next, the video circuitry and the 555 timer currents were added to the common return path, shown in Figure 7 on page 60.

There was no discernible impact on the audio and video circuitry. Subsequently, the current level from the 555 timer was increased by a factor of 1000 by changing the resistance value from 100 kΩ to 100 Ω in the return path, shown in Figure 8 on page 60.

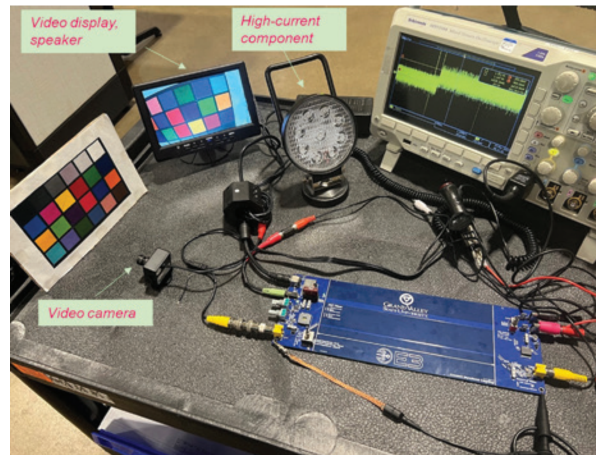

Figure 3: Measurement set up for common-impedance coupling

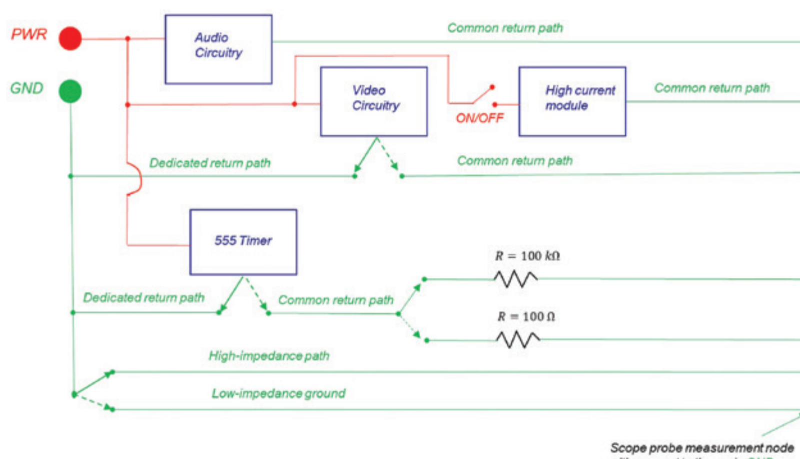

Figure 4: Circuit diagram

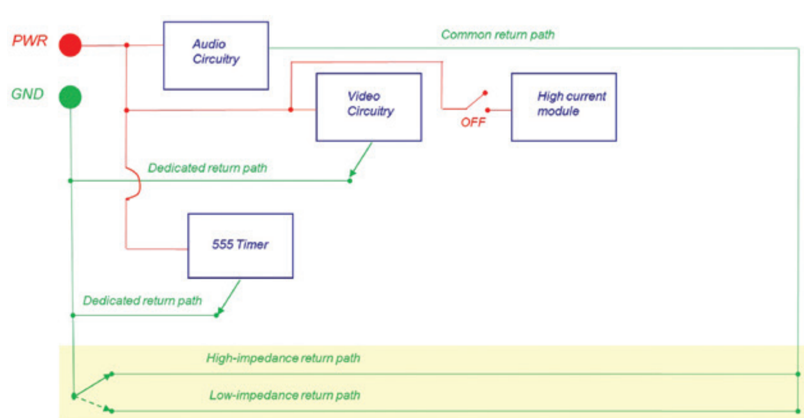

Figure 5: Audio circuitry: low- vs. high-impedance return path

The voltage shift between the low- and high-impedance paths was 78 mV, shown in Figure 9. The audible speaker noise increased with additional video degradation.

Figure 10 shows the final system configuration, where a high current was injected into the common return path. The measurement result is shown in Figure 11.

Note the significant increase in the voltage levels (610 mV) compared to the previous cases. Both the audible speaker noise and the video degradation increased considerably. The measurements and observations support the conclusions presented at the end of Section 1.

REFERENCES

1. Adamczyk, B. and Teune, J., "Common-Impedance Coupling between Circuits," *In Compliance Magazine*, January 2018.

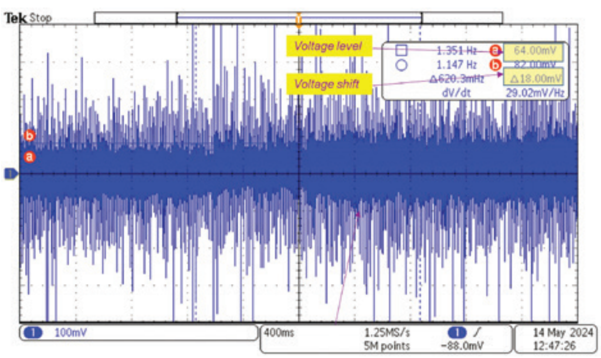

Figure 6: Audio circuitry measurement results: low- vs. high-impedance return path

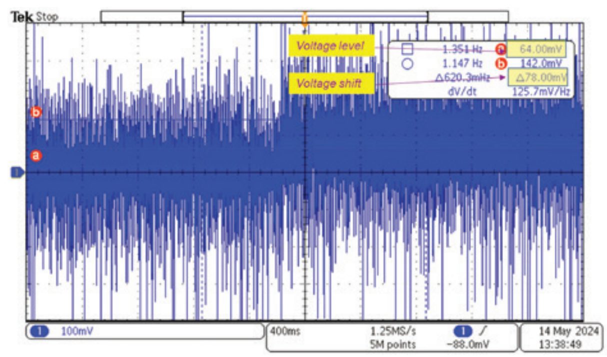

Figure 9: Audio, video, and 555 circuitry (R = 100 kΩ): low- vs. high-impedance return path

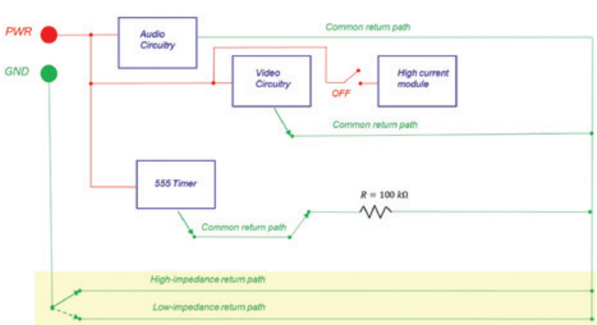

Figure 7: Audio, video, and 555 circuitry (R = 100 kΩ): low- vs. high-impedance return path

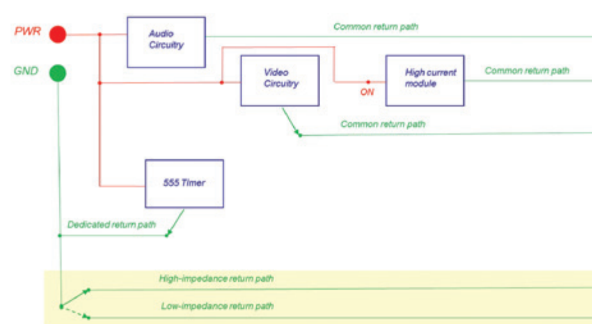

Figure 10: System configuration with the high current addition

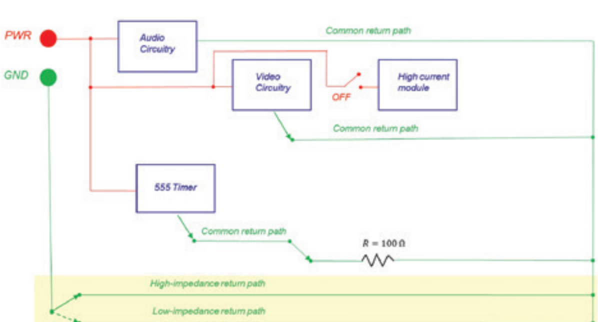

Figure 8: Audio, video, and 555 circuitry (R = 100 Ω): low- vs. high-impedance return path

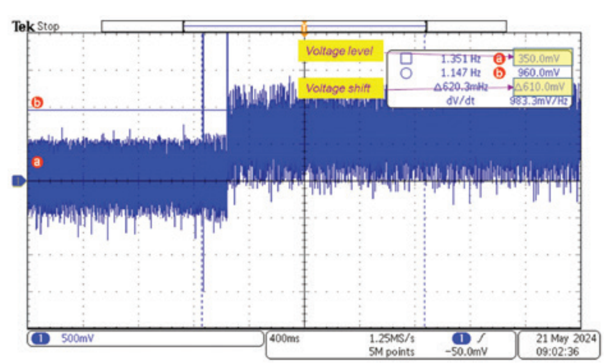

Figure 11: Measurement results with the high current addition

DOES AN ESD CONTROL PROGRAM REQUIRE HUMIDITY CONTROLS?

By Matt Jane and Andy Nold, on behalf of EOS/ESD Association, Inc.

ANSI/ESD S20.20 HUMIDITY REQUIREMENTS

Humidity control in relation to an ESD control program continues to be misunderstood across the industry. Humidity does help in the reduction of charge accumulation, but it does not control charge accumulation to reduce the risk to sensitive items. The differences in electrostatic charge accumulation on insulators from 20% to 30% RH at room temperature are minor. As a result, the EOS/ESD Association, Inc. does not rely on humidity as part of a control program in ANSI/ESD S20.20.

If a company meets the requirements of ANSI/ESD S20.20 or IEC 61340-5-1, the ESD control items used to mitigate risks of ESD shall be qualified prior to their initial use within the ESD control program. Most of the ESD control items require environmental conditioning during the product qualification testing process. This is typically conducted at 12% ± 3% RH and 23°C ± 3°C. If the ESD control item being qualified meets the requirements of ANSI/ESD S20.20 or IEC 61340-5-1, then humidity controls are not required as the item has been shown to function in a worst-case environment.

In the most recent revisions of ANSI/ESD S20.20 (-2021) and IEC 61340-5-1 (edition 3, to be published soon), organizations are allowed to complete product qualification at the lowest annual humidity the facility experiences. This lowest annual humidity may be due to ambient conditions where the facility is located or may be due to other factors, such as the environmental conditioning of the facility. For example, if the lowest humidity level in the facility is 30% RH, then any ESD control items that are used within the facility may be qualified at or below 30% RH. ESD control items that leave the facility, for example, packaging, must still be qualified per the standard test method as the environment the ESD control item may be exposed to is unknown.

Matt Jane leads Tesla's Global ESD Control Program, safeguarding sensitive electronics throughout the high-tech EV and energy manufacturing processes. He is a member of multiple EOS/ESD Association, Inc.'s standards working groups, technical committees, and is the Certification Business Unit Manager. Matt is a member of the United States National Committee/IEC Technical Committee 101, where he represents the United States.

Andy Nold is a Quality Engineer and Commodity Engineer at Teradyne. He is the Factory ESD subject matter expert and performs the company's internal ESD audits. Andy graduated from the University of Wisconsin with a bachelor's degree in Applied Math, Engineering, and Physics and a master's degree in Engineering Mechanics. During his career, Andy has worked for the FAA, a small aerospace company and the United States Navy.

PRODUCT QUALIFICATION DURING HIGHER HUMIDITY SEASONS

Product qualification must be completed per the requirements of ANSI/ESD S20.20. This allows for two approaches, either you qualify per the standard test method, or you qualify at the facility's lowest annual humidity. If you plan to qualify per the facility's lowest annual humidity during the summer when the relative humidity is high and in the winter the relative humidity drops to a much lower level, an acceptable approach would be the creation of a testing plan where product qualification measurements are completed over a period of time until the data is captured at the lowest annual humidity.

DEPARTURES FROM A FACILITY'S LOWEST ANNUAL HUMIDITY

If a facility experiences a humidity level that is below the product qualification level, the amount of change in relative humidity and the length of time are crucial factors in determining risk. In general, a low risk would be determined by a small change in humidity and a short time period.

Product qualification test methods typically have a ±3% RH tolerance to the environmental conditioning requirements, this tolerance could be applied to the facility's minimum humidity limit.

When humidity changes, it can take time for the materials in the environment to acclimate to the new environment. If, for example, the humidity dropped below the organization's limit by 3% RH or more for only a few minutes, this would be low risk. However, if this occurred for multiple hours, it may be considered non-conformance.

In either situation, the organization should gather additional objective evidence to determine whether it is deemed safe to handle ESDS items, including increased compliance verification of ESD control items or process assessment during this period. If it is determined that the program limits are being exceeded, the handling of ESDS items shall be stopped. If the objective evidence indicates handling of ESDS items is acceptable (for example, ESD control items meet program requirements), this information shall be captured and stored as a record.

HUMIDITY LEVELS BELOW THE ENVIRONMENTAL CONDITIONING REQUIREMENTS OF 12% ± 3% RH

All ESD control materials and items used in your facility must work at the lowest humidity level experienced at the facility or at least 9% to 15% relative humidity. If your facility experiences humidity levels lower than 9%, it is recommended to verify that the ESD control items still function properly at the lowest level experienced at the facility. Materials such as flooring, worksurfaces, garments, wrist straps, packaging, etc., that meet EOS/ESD Association, Inc. and IEC standard test methods should work at even lower humidity levels, but it is best to verify. This can be done with random resistance to ground testing on workstation items during extremely dry days.

USING RECIPROCITY THEOREM TO TROUBLESHOOT IMMUNITY ISSUES

By Dr. Min Zhang

When I first started working as an independent EMC consultant, I didn't have nearly half of the equipment I do now. The first piece of equipment I owned was a Siglent swept-type spectrum analyzer, and I made my own near-field probes and RF current probes following Ken Wyatt's book [1].

I remember a case in which I needed to troubleshoot an immunity issue, but I didn't have any equipment to inject noise into the system. At the time, I called my mentor, Keith Armstrong, and asked him if there was any way to solve the problem, given the limited kit I had. He said to me, "Have you heard about the reciprocity theorem?"

Here, I quote Henry Ott's explanation in his book [2]:

> *"Reciprocity means that if a structure (antenna) radiates well, then it will also pick up energy well, and vice versa. What prevents an antenna from radiating will also prevent an antenna from picking up energy. Therefore, the same techniques can be used to solve both emission and susceptibility problems."*

In this article, I will present a recent case study to demonstrate how useful this concept is in troubleshooting immunity issues.

A SENSITIVE SMART METER

A client of mine develops smart meters used in industrial kitchen environments. As one can imagine, variable speed drives and relays are widely seen in such environments. As a result, continuous RF interference and intermittent transient events are common. One of the most recent cases saw the emergency stop error showing on their product's display, even though the button was never pressed. This nuisance obviously needed to be fixed.

I sat down and analyzed the noise sources in the environment. Having never been to the site where the issue was reported, my options were quite limited. I could only guess the spectrum the noise predominantly occupied, but the client also mentioned that the issue was only found recently.

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

For the past few years, the unit had been functioning well and without problems. They also mentioned that the most recent change in the environment was the addition of a LoRa communication link. A quick search on Google showed that LoRa operates at 863-870/873 MHz in Europe.

TESTING THE SMART METER

So, my first attempt was to use my Tekbox TBDA3B, connect a near-field probe to the output of the amplifier, and inject 800-900 MHz RF power into the printed circuit board. I could also inject noise into the ribbon cable connection between the two boards. The TBDA3B has an output power of 40 dBmW (equivalent to 10 Watts). The field intensity of the near-field probe can be very high. To inject current into the ribbon cable, I used a BCI probe. The current injected into the ribbon cable via magnetic field coupling can reach tens of mA. However, I could not reproduce the same failure mode as the manufacturer saw in that particular location.

Here's the question: How confident are we that it is 800-900 MHz causing the issue? Could it be some other frequency band?

To find out, I recalled the reciprocity theorem and wondered if performing an emission measurement by placing an RF current probe on the ribbon cable would provide some good indication. Figure 1 shows an RF current probe clamped on the ribbon cable and the measurement results.

It is not surprising to see a broad-band noise spectrum caused by the switched-mode power supply (between a few MHz and 200 MHz). However, I did notice something unusual, as shown in Figure 1. Notice that, between 400 and 500 MHz, the noise level on the ribbon cable is pretty high.

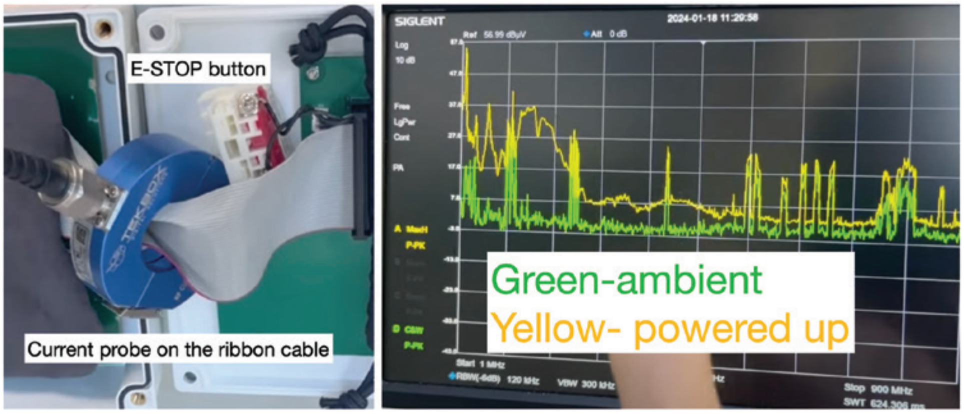

Figure 1: Measuring the RF common mode current on the ribbon cable

A WALKIE-TALKIE SOLUTION?

So, what noise source works in that frequency band and could potentially trigger the emergency stop? The first thing that came to mind was a two-way walkie-talkie (UK Business UHF Radios use frequencies from 400-470 MHz). Could it be the walkie-talkie then?

A quick injection using my walkie-talkie triggered the emergency stop, and the coupling path was identified as either the ribbon cable or the wire link between the emergency stop button and the PCB. Once this was identified, a flat ferrite core on the ribbon cable solved the problem.

Most walkie-talkies have an RF power rating of 1W, although some can operate at up to 4W or higher. This makes a walkie-talkie an excellent tool for injecting noise. By simply pressing the send button and moving the antenna around a PCB, you can introduce exposed RF noise into the circuit under test[1]. If the antenna runs parallel to a cable in close proximity, strong near-field coupling can occur, inducing RF current in the cable and affecting the unit.

Another valuable application is placing the walkie-talkie antenna in parallel with the seams or apertures of a metal enclosure. If the enclosure's shielding is not properly done, the field generated from the walkie-talkie may upset the unit.

THE LIMITS OF WALKIE-TALKIE TESTING

The major disadvantages of walkie-talkie testing include:

a. The actual field strength that is being developed at the EUT is unknown; depending on the output power of the walkie-talkie, this could be very high,

b. Repeatable results are difficult to achieve, and

c. Spot frequency tests may well miss resonances in susceptibility that will appear in the compliance test.

This is not to say that a walkie-talkie test that does, in fact, create a susceptibility is useless, as it will prompt the designer to harden the design. But it can't be relied on to predict compliance results. The same considerations apply to "testing" with a mobile phone.

REFERENCES

1. Ken Wyatt, *Create Your Own EMC Troubleshooting Kit (Volume 1) 2nd Edition: Essential Tools for EMC Troubleshooting (EMC Troubleshooting Trilogy).*
2. Henry W. Ott, *Electromagnetic Compatibility Engineering*, Wiley.

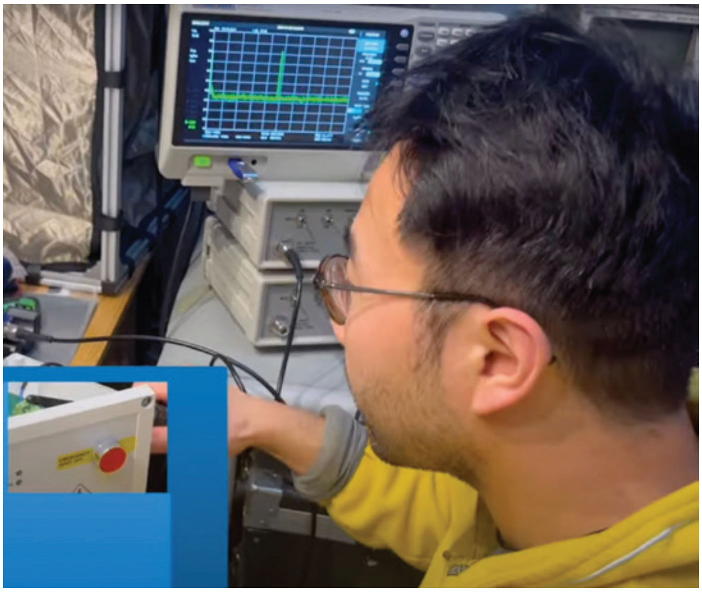

Figure 2: Using a walkie-talkie to inject interference to the DUT, you can observe the narrow band noise picked up by the spectrum analyzer.

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