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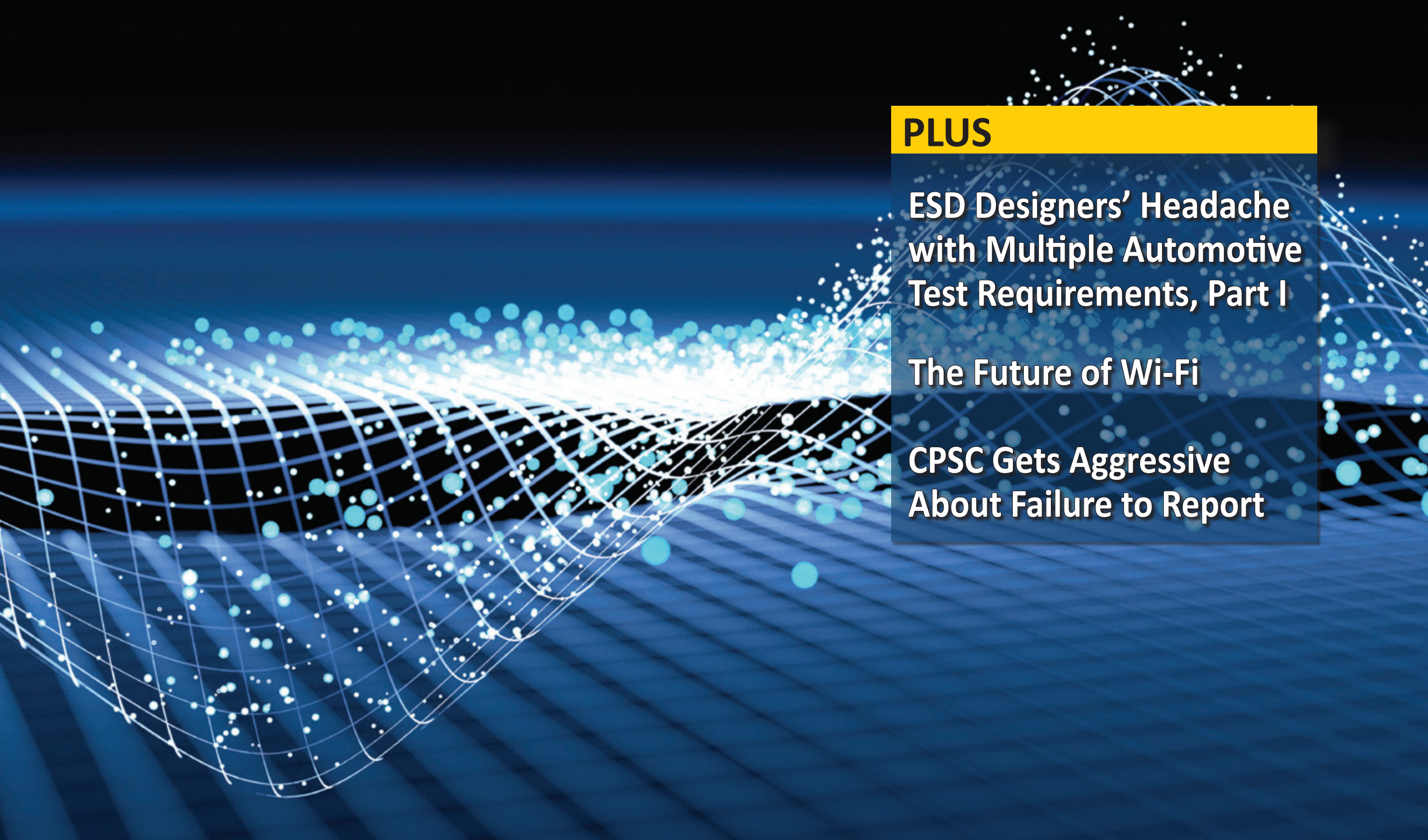

PLUS

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The Future of Wi-Fi

CPSC Gets Aggressive About Failure to Report

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MAY 2023 CONTENTS

Volume 15 | Number 5

FCC Updates References to Equipment Authorization Standards

As part of its ongoing effort to ensure that its regulations align with technical issues covered in new and updated standards, the U.S. Federal Communications Commission (FCC) has updated its rules to incorporate four new standards under its equipment authorization program.

In a Report and Order, the Commission has listed four new standards that can be used by FCC-recognized accredited laboratories to evaluate equipment for conformity with FCC requirements.

The FCC's Report and Order also includes a number of changes to currently referenced standards, mostly addressing obsolete references. The complete list of the additions and changes is in Appendix A of the Report and Order.

FDA Posts Updated FAQs on Medical Device Cybersecurity

The U.S. Food and Drug Administration (FDA) has released an updated list of frequently asked questions (FAQs) on the agency's requirements regarding cybersecurity provisions applicable to medical devices.

Published on the FDA's website, the FAQs address a range of issues critical to achieving compliance with FDA requirements regarding cybersecurity that apply to medical device premarket submissions filed on or after March 29, 2023. Among other issues, the FAQs clarify the definition of a cyber device, identifies the parties and the types of premarket submissions which are subject to the new requirements, and details resources available to device manufacturers to aid in their efforts to achieve compliance.

Although cybersecurity requirements are now applicable to medical device premarket submissions, the FDA says that it will provide a six-month grace period for manufacturers, and will not issue "refuse to accept" (RTA) decisions for premarket submissions filed before October 1, 2023. Instead, until that date, the agency will work collaboratively with those making premarket submissions as part of its deficiency review process.

EU Commission Updates MDR/IVDR Transitional Provisions

The Commission of the European Union (EU) has modified the transitional provisions of its regulations under the EU's Medical Device Regulation (2017/745, or MDR) and the In Vitro Diagnostic Regulation (2017/746, or IVDR) to reflect the current capacity constraints of currently designated notified bodies.

Regulation (EU) 2023/607 extends the validity date of certificates issued between May 25, 2017 and May 26, 2021 under the EU's original directives on medical devices (90/385/EEC) and in vitro diagnostic medical devices (98/79/EC). For class III and certain class IIb devices, the new transition date by which a device manufacturer must demonstrate compliance with the MDR or IVDR is now December 31, 2027. The new transition date for all other class IIb devices and class IIa and class I devices is now December 31, 2028.

In addition, medical devices brought to market under the legacy directives during the original transition period based on a declaration of conformity but that now require notified body review under the MDR or IVDR may remain on the market until December 31, 2028.

Robert Metcalfe Wins Turing Award

The so-called "father of the Ethernet" has now received the "Nobel Prize of computing."

Robert Metcalfe, who along with the late David Boggs developed a groundbreaking standard for connecting computers, was named the recipient of the 2022 Association for Computing Machinery (ACM) A.M. Turing Award. Metcalfe now joins other tech luminaries, including Sir Tim Berners-Lee (the World Wide Web) and Edwin Catmull (3D computer graphics) who have made lasting and technically important contributions in the computer science field.

Working at Xerox's Palo Alto Research Center (PARC) in the early 1970s, Metcalfe was tasked with designing a network to connect the company's newly developed personal computer that would allow connected computers to share information with each other. His work was detailed in an article, "Ethernet: Distributed Packet Switching for Local Computer Networks," co-written with Boggs and published in 1976 in the ACM publication *Communications of the ACM*.

The Turing Award is named after Alan Turing who was instrumental in the development of modern theoretical computer science in the early 1900s. The award comes with a $1 million prize funded by Google.

FCC Adopts Rules on Scam Texting

Text messaging scams have increased more than 500%

The U.S. Federal Communications Commission (FCC) has adopted regulations that specifically target so-called scam text messages being sent to consumers.

Detailed in a Report and Order and Further Notice of Proposed Rulemaking, the new regulations will require mobile service providers to block certain robotext messages that originate from phone numbers that are unlikely to transmit text messages. Such numbers would include invalid, unallocated, or unused numbers, as well as numbers for which the designated subscriber has self-identified as never sending text messages. The Report and Order also requires mobile wireless services providers to establish a point of contact for text senders that they can use to enquire about blocked texts.

The FCC estimates that text messaging scams have increased more than 500% during recent years, rising from around 3300 in 2015 to nearly 19,000 in 2022. The growing risk to consumers from text messaging scams is reportedly the basis for the Commission's decision to implement text-specific regulations.

FCC Proposes $2.3 Million Fine for Pirate Radio Broadcasting

Continuing its efforts to curtail illegal pirate radio broadcasting, the Enforcement Bureau of the U.S. Federal Communications Commission (FCC) has issued a new round of proposed financial penalties.

In its most recent actions, the Bureau has proposed a penalty of over $2.3 million against a couple for operating a longstanding, unauthorized radio station, in Queens, NY. According to a Notice of Apparent Liability for Forfeiture, the couple's pirate radio station, Radio Impacto 2, started operations as far back as 2008, generating complaints to the FCC as early as 2013.

Separately, the Enforcement Bureau has proposed an $80,000 penalty against a man who allegedly has been operating a pirate radio station in La Grande, Oregon since at least 2018.

SEVENTY YEARS OF ELECTROMAGNETIC INTERFERENCE CONTROL

IN PLANES, TRAINS, AND AUTOMOBILES (AND SHIPS AND SPACESHIPS, AS WELL)

Understanding Today's EMI Limits and Test Methods Begins With Knowing How We Got Here

Ken Javor is a Senior Contributor to *In Compliance Magazine* and has worked in the EMC industry for over 40 years. Javor is an industry representative to the Tri-Service Working Groups that maintain MIL-STD-464 and MIL-STD-461. He can be reached at ken.javor@emccompliance.com.

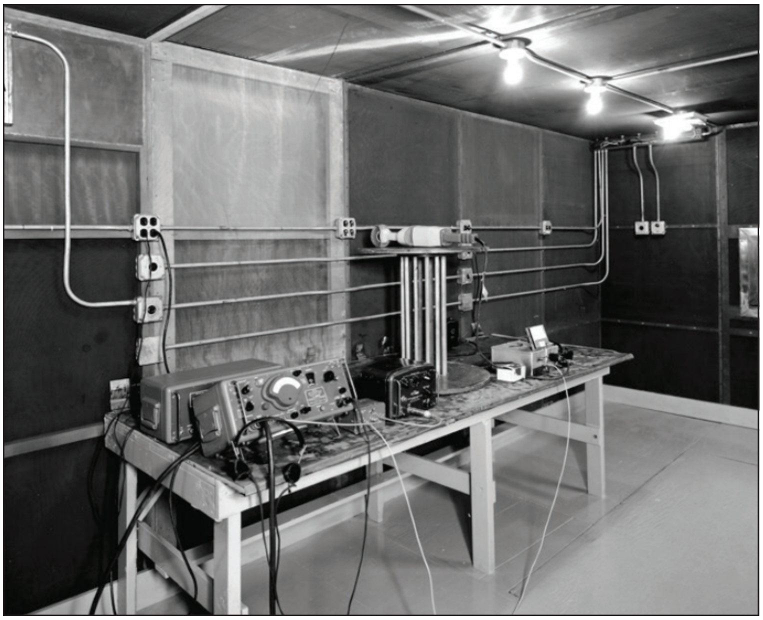
By Ken Javor

EXPLANATORY NOTE[1]

This is the first in a multi-part series of articles exploring the background of modern electromagnetic interference (EMI) requirements and test methods. In this first part, we'll cover general topics. Part 2 will address the line impedance stabilization network (LISN) and test methods based on it. Subsequent parts will be devoted to radiated emission control and will address the important topic of "(Re)Discovering the Lost Science of Near Field Measurements."

In each of these articles, there is a preponderance of references to various military electromagnetic interference specifications.[2] This should not be interpreted as limiting the subject matter discussed to the military sector. Both aerospace and automotive EMI specifications/standards bear a strong resemblance to military EMI standards, and that resemblance has been tracked over decades as these specifications/standards evolved. That is, commercial aerospace specifications from the 1960s and 1970s look like contemporaneous military specifications, and when the automotive industry later instituted EMI qualifications, those qualifications were similar to contemporaneous military practices.

This is not to say that these industry sectors simply copied military practices. At any particular point in time, radios,[3] culprit noise sources, and their installations tend to be similar, causing similar EMI issues and consequently similar EMI controls (limits and test procedures).



1950s EMI test set-up. (Photo courtesy of Ed Price.)

21st century EMI test chamber. (Photo courtesy of Rohde & Schwarz.)

Prior to the end of World War II, there were no EMI specifications at all.[8] Instead, there were specifications describing how to verify that integrated vehicles had sufficient EMI suppression to ensure the vehicle's suite of radios would operate free from interference.

It is commonplace to contrast military vs. commercial EMI test practices, but that is not a fundamental distinction. Commercial aerospace and automotive EMI test practices have much more in common with military practices than they do with the qualification of consumer items on open area test sites (OATS) or in fully or semi-anechoic chambers (FAC/SAC). The fundamental difference is in installation in a vehicle (usually metal) vs. equipment slated for use in homes, offices, and industrial plants. EMI testing of equipment installed in vehicles requires acknowledgment of the immediate proximity of electrical ground (vehicle structure) and the possibility that vehicle antennas will be placed in close proximity to culprit electrical noise generators.

Vehicles of all kinds – even large ships – must countenance culprit-victim separations in the very near field. Not all antenna-culprit separations will be precisely one meter, and while one-meter measurements are not scalable as are far-field measurements, the vehicle EMC verification process takes that into account.

The subject matter in this multi-part series of articles has been limited to a length and level of detail appropriate for magazine publication. An expanded discussion of these topics will be posted on the author's website in the near future.[4] Sections with significantly expanded coverage in the website version are flagged with an asterisk (*).

INTRODUCTION

This year marks the seventieth anniversary of several developments that culminated in the birth of the modern EMC discipline. EMI specifications released in late 1952 and throughout 1953 incorporated technical improvements in test equipment and measurement procedures that previously didn't exist, or existed in a more primitive state.

We shall take as an example MIL-I-6181B, whose seventieth anniversary is this month.[5] While the improvements in MIL-I-6181B showed up in multiple contemporaneous specifications, MIL-I-6181B has two very important aspects that the other specifications don't. The MIL-I-6181 series (1950 – 1967) ran right up until MIL-STD-461 superseded all Service-specific EMI specifications, whereas most of the other specifications dead-ended prior to that. MIL-I-6181B changes stood the test of time.

Secondly, we have a rationale or white paper report detailing the engineering behind the radiated emissions portions of MIL-I-6181B. NADC-EL-5515 precisely documents the problem and the solutions developed, and the process between problem and solution.[6] This report, authored in 1955 by William Jarva of the Naval Air Development Center, serves as a Rosetta Stone, unlocking the mystery behind the limits and test methods used to control unintentional radiated emissions. It should be required reading for anyone involved in vehicle EMC.

THE WAY THINGS WERE (PRE-1967)

Some brief background is in order for those readers unfamiliar with anything before the Tri-Service MIL-STD-461 (1967 forward).[7]

Prior to the end of World War II, there were no EMI specifications at all.[8] Instead, there were specifications describing how to verify that integrated vehicles (planes, trains, automobiles, ships, and submarines) had sufficient EMI suppression to ensure the vehicle's suite of radios would operate free from interference. Such EMC specifications were accompanied by quite sophisticated handbooks and suppression specifications showing proper installations of both radio and non-radio electrical equipment so as to minimize the probability of radio frequency interference. Eventually, it was determined

Two big technology changes appeared between 1950 and 1953. These were the widespread adoption of the 5 uH LISN, still in use in aerospace and automotive EMI practice to the present day, and the commercial availability of the AN/PRM-1 EMI receiver.

that designing a certain amount of suppression and immunity into electrical and electronic equipment was more efficient overall than trying to solve everything during vehicle integration, and this gave birth to JAN-I-225, the first EMI specification.[9]

From 1945 to 1967, there were individual Service-unique EMI specifications. During that period, there were multiple standards that were similar to but slightly different from each other. So test engineers had to have intimate familiarity with each of as many as a dozen specifications and their various nuances, and also access to and knowledge of different fully manual EMI receivers required in various specifications. Any reader who works for a living in the business of EMI testing should be grateful for a single Tri-Service specification![10]

While MIL-I-6181B evolved from a predecessor specification, it was revolutionary in many aspects.[11,12]

TECHNOLOGICAL CHANGES

Two big technology changes appeared between 1950 and 1953. These were the widespread adoption of the 5 uH LISN, still in use in aerospace and automotive EMI practice to the present day, and the commercial availability of the AN/PRM-1 EMI receiver. Developed by the Stoddart Aircraft Radio Company circa 1950, this was the first EMI receiver operating below 30 MHz (conducted emission and rod antenna frequency range) with a peak detector.

Both of the EMI receivers shown in Figure 1 were designed for direct attachment of a 41" rod. Only the AN/PRM-1 has a (slide-back) peak-detecting capability.[13] The Ferris meter was much older, dating from 1932. According to Al Parker, the AN/PRM-1 was developed between the end of WWII and 1950.[14]

The advent of an EMI receiver with a peak detector operating in the conducted emission measurement frequency range meant it was no longer necessary to count the repetition rate of broadband impulses in order to apply correction factors based on the rep rate. This resulted in a less complex measurement set-up, and much less time analyzing EMI signatures.

(The 5 uH LISN was such an important development that it gets its own separate discussion in Part 2 of this article series.)

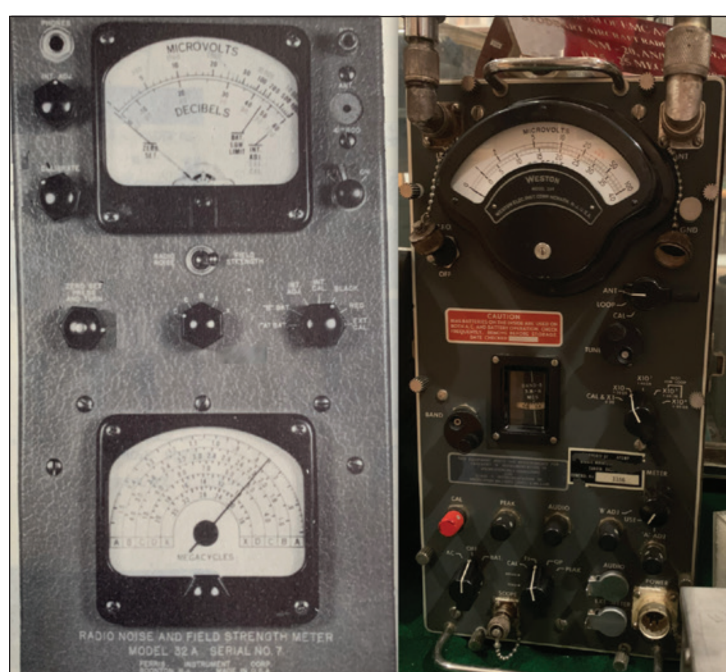


Figure 1: Ferris 32-A and Stoddart's AN/PRM-1 EMI receivers. (Photo courtesy of the Museum of EMC Antiquities.)

BANDWIDTH MATTERS

Discrimination between narrow and broadband interference sources is dealt with in detail in MIL-I-6181B, whereas the issue had been largely ignored before that. That is, where multiple EMI receivers are available, utilizing different measurement bandwidths, some with and some without peak detection, the measurement of broadband signals must be normalized on a per-unit bandwidth basis. Not only that, but the BC-348Q radio, which was the actual victim used to determine the limit, had a bandwidth of about 2 kHz, whereas the Ferris meter had a 10 kHz bandwidth.[15,16] Further, if a peak detector is not available, the response of the EMI receiver is dependent on the repetition rate of the impulses, so that a repetition rate correction factor curve is provided in MIL-I-6181B.

This was the inception of narrowband-broadband discrimination and separate limits. While that is largely obsolete today, it is not without merit. The demise of separate limits in MIL-STD-461D in 1993 was largely based on the perception that not enough people were doing it correctly, and the procedure had to be simplified to the point where people were all doing it the same way.[17] Hence, single-bandwidth measurements are ubiquitous today. These rely on CISPR 16-1 specifying these bandwidths for all EMI receivers, and also on these bandwidths being representative of those used by the actual radios protected by emission limits.

But the failure of such simplifications is evident in cases where multiple bandwidths are in use by various radio services. For instance, dithered clocks spread clock harmonics across several measurement bandwidths, decreasing the signal measured in any one bandwidth. This is a fine design technique as long as the radio protected from such interference has a bandwidth similar to that mandated by CISPR 16-1. But when the victim radio has a much larger bandwidth, such as broadcast television, then even the dithered clock energy falls within a single channel. So even though the dithered clock amplitude is under the limit measured with a 120 kHz bandwidth, such signals can cause TVI. If a separate bandwidth such as 1 MHz or better yet 6 MHz were used, that would tell the tale for the TV receiver.

Nowadays this is easily achieved with FFT or time-domain type receivers, which can look at a very large spectrum and then digitally simulate what would be measured using various smaller bandwidths and detectors, all from a single high-speed sweep. It may be time to take a look at this 1953 innovation once again.

THE ANSWER TO AN OFT-POSED QUERY

Sometimes a complex subsystem has a great number of attached cables. MIL-STD-462D (and subsequent versions of MIL-STD-461 that rolled MIL-STD-462D into MIL-STD-461) requires that the cable closest to the front edge of the ground plane be 10 cm back from the edge, and then 2 cm between each succeeding cable and the last.[18] With enough attached cables, the ground plane may not provide enough depth. It is often asked if the first cable may be pushed closer to the edge to free up some room. Or is it better to bunch cables closer than 2 cm separation?

Another question less often posed is if the installation is known to hold cables much closer to the structure than 5 cm, can the test set-up simulate that?

The closer that first cable is to the ground plane edge, the more efficiently it radiates (RE102), and the more efficiently a radiated field can couple to it (RS103) – hence the need for standardization. As illustrated in Figures 2 and 3, the separation of cables on standoffs holding them 2" (now 5 cm) above a ground plane is

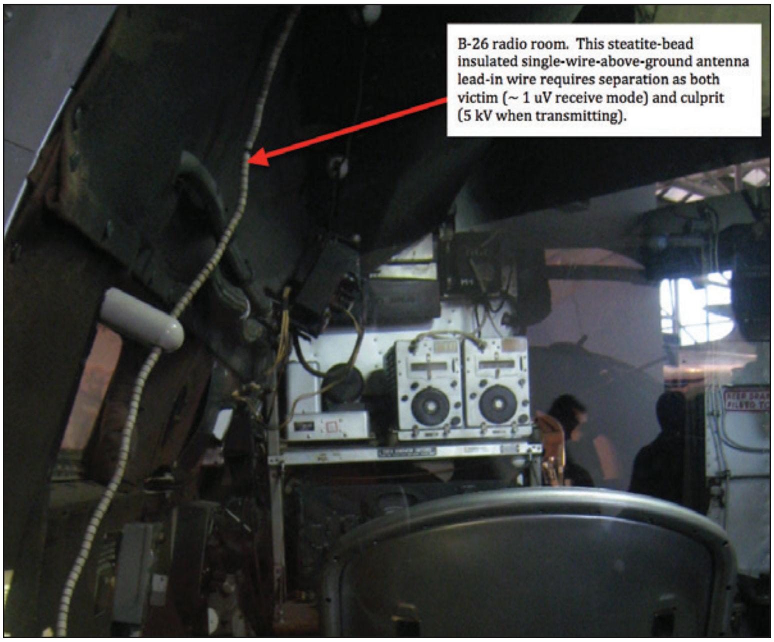


Figure 2: Unshielded antenna lead-in WWII-era B-26 bomber radio room. The BC-348 radio to which it connects is forward of the seat back and below silver-colored radio equipment in the rack. BC-348 is shown to better effect in Figure 4. (Photo taken by the author at Smithsonian National Air & Space Museum.)

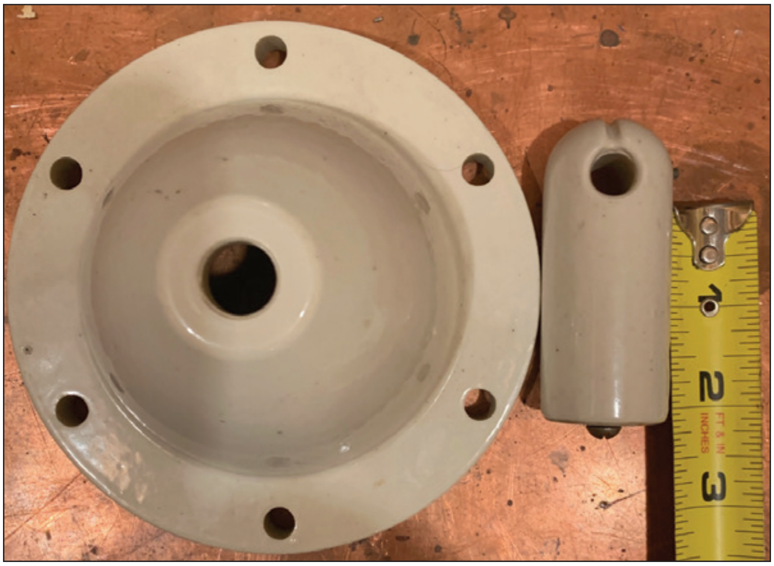


Figure 3: The circular ceramic is the fuselage penetration treatment for the unshielded antenna lead-in. It wasn't just the 5 kV transmit voltage driving the treatment, but also the high frequency requiring control of shunt capacity. Control of shunt capacity was provided within the aircraft by ceramic standoffs. The 2" distance between the base and the hole is the basis for the 2" (5 cm) standoff requirement in all subsequent EMI specifications and standards. (Photo courtesy of the Museum of EMC Antiquities.)

first found in MIL-I-6181B. Previously in JAN-I-225 (and thus MIL-I-6181 which relied on JAN-I-225 for test procedures) it was a quarter-inch over the ground plane. Separation between cables was also 2", but that has decreased to 2 cm in MIL-STD-461. For a "seeing is believing" demonstration of the reason behind the cable-to-cable separation requirement, see https://youtu.be/uiyLQ_psOqX8. Armed with this information, the reader may now make informed decisions.

Figure 4: The author's unaltered BC-348Q radio, the specific radio model whose performance characteristics drove the emissions and susceptibility requirements in MIL-I-6181B below 20 MHz. The photo shows a noisy but audible response to a 1 kHz modulated radio frequency signal at a level of – 3 dBuV. (Photo courtesy of the Museum of EMC Antiquities.)

EVOLUTION OF CONDUCTED EMISSION LIMITS*

As evidenced in the above-cited YouTube video, the BC-348 radio had very little EMI filtering on its 28 Vdc power input and was susceptible to very low levels of RF noise on its power input. MIL-I-6181B conducted emission limits protecting the BC-348 radio are portrayed in Figure 5, with the superseding CE03 limits superimposed. MIL-I-6181B imposed a value of 1 mV for conducted susceptibility. This level increased to 100 mV in subsequent releases of MIL-I-6181, and then up to 1 volt in MIL-STD-461.

These measures were taken to gradually force improvement in power-line EMI filtering. At the same time, the very stringent conducted emission limits found in MIL-I-6181B had to be levied to protect the existing inventory of installed radios with little or no power-line filtering. As time went by, these stringent conducted emission limits were relaxed as the inventory of obsolete susceptible receivers declined, being replaced by receivers that met the higher level conducted susceptibility limits.

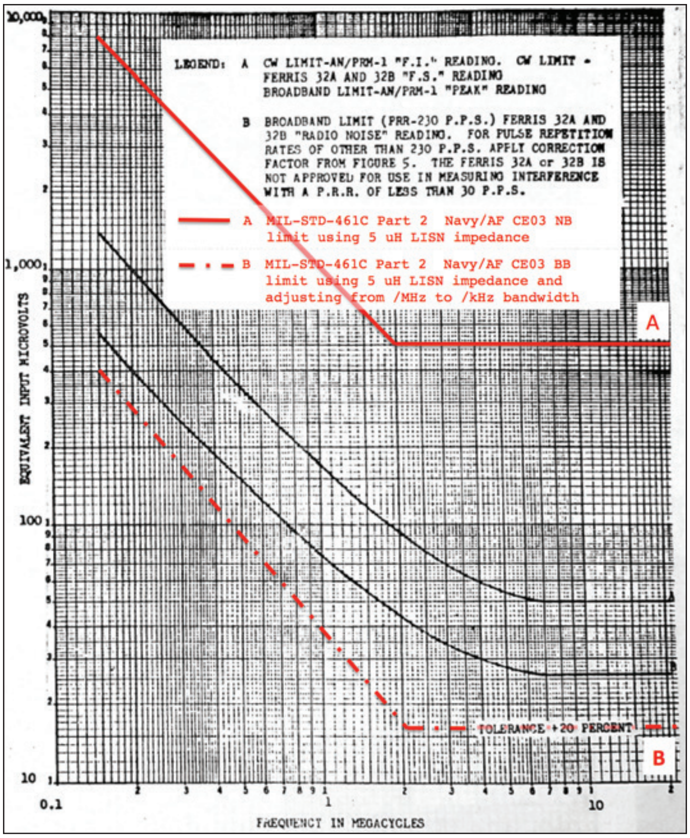


Figure 5: MIL-I-6181B conducted emission limits, with superimposed MIL-STD-461 CE03 limits.

But the conducted emission limits could not be relaxed as much as the conducted susceptibility limits had strengthened, because conducted emissions cause radiated emissions, and radiated emissions must be controlled to protect antenna-connected receivers. The narrowband CE limit in radio bands were relaxed to about 1 mV, where the -6181B conducted susceptibility started out. This amounted to at most a 26 dB relaxation. Paradoxically, the broadband limit became more stringent. The MIL-I-6181B broadband limit protected the 2 kHz BC-348 radio bandwidth. Later broadband limits protected wider bandwidths.

CONTROLLING RADIATED EMISSIONS – THE SCIENCE OF NEAR-FIELD MEASUREMENTS*

A huge advance in -6181B is described in detail in NADC-EL-5515. This is the concept that, when making near-field measurements, the way the measurement is made materially affects the result. The type of antenna, its physical size, orientation, and distance from the test sample all bear strongly on the measured test result. While this may seem obvious, earlier specifications allowed the use of various different antennas or pickup devices. This topic is complex, important, pertinent, and applicable to present practice in making radiated emissions measurements. As such, it merits its own separate treatment, which will be discussed in "(Re)Discovering the Lost Science of Near Field Measurements."

CONTROLLING AMBIENT LEVELS TO 6 DB BELOW THE EMISSION LIMIT*

Prior to MIL-I-6181B, the ambient level was required to be 14 dB below the emission limit.[19] With very low emission limits to begin with, this was very onerous.[20] The 6 dB requirement has a good rationale: a signal that would be measured right at the limit with a very low ambient is boosted by 1 dB when the ambient is 6 dB below the limit. That makes the -6 dB ambient limit a well-justified line in the sand. All that being

Many of the requirements in present-day standards with which the reader may be familiar have their origin in MIL-I-6181B but have evolved over time to look quite different. One such requirement is radiated (electric field) susceptibility.

said, when making a post-1993 MIL-STD-461/2 measurement system integrity check, the measurement system noise floor needs to be closer to 14 dB below the limit than 6 dB below the limit, because the measurement system integrity check is done at 6 dB below the limit. But that is noise floor vs. ambient, two very different quantities.

THE FIRST APPEARANCE OF AN AUDIO FREQUENCY CONDUCTED SUSCEPTIBILITY REQUIREMENT

A novel requirement in -6181B is the forerunner of modern audio frequency conducted susceptibility testing. This requirement and test method is the direct ancestor of MIL-STD-461 CS01/CS101, RTCA/DO-160 section 18 (commercial aerospace), and ISO-11452-10 (automotive). The test method did not utilize an audio amplifier. Instead, MIL-I-6181B used a signal source with 500 Ω output impedance driving a filament transformer (line voltage in, 6.3 Vac out, so about 20:1 turns ratio) to yield an output impedance of around 1 Ω.[21] This was further finessed down to 0.5 Ω in the 1957 MIL-I-6181C revision, where the modern treatment using a low impedance amplifier or power oscillator first appears.

THE FIRST APPEARANCE OF ANTENNA PORT EMI CONTROLS

Two antenna-port requirements first appear in MIL-I-6181B. These are filtering for the front end to improve out-of-band rejection (modern equivalents MIL-STD-461 CS103/104/105), and suppression of noise emanating from antenna ports (modern equivalent MIL-STD-461 CE106). Consider recent events where front-end filtering has not been applied. The GPS-Light Squared and FCC/FAA 5G vs. radar altimeter operation brouhahas are examples of what can happen, and these did not involve co-located radios and antennas on the same vehicle.

EVOLUTION*

Many of the requirements in present-day standards with which the reader may be familiar have their origin in MIL-I-6181B but have evolved over time to look quite different. One such requirement is radiated (electric field) susceptibility. The evolution of this requirement is traced in detail in the unabridged website version. In particular, one can trace the audio frequency amplitude modulation requirements universally used today for any sort of electronics being EMI-qualified to requirements specifically applicable to amplitude-modulated radio receivers.

CONCLUSION

It is the author's hope that this trip down memory lane inspires aspiring EMC engineers to study their craft and more fully understand it, as opposed to just copying the requirements of the last program, on the basis of not reinventing the wheel. For more information, search the unabridged version of this article on the author's website. Look for more information on the origin and use of LISNs in Part 2, and (much) more detail on radiated emissions measurements in subsequent parts. In any case, we should understand the principle behind the wheels we use. Or, as a senior engineer used to tell the author when he was young, "You've got to be smarter than what you're working on."

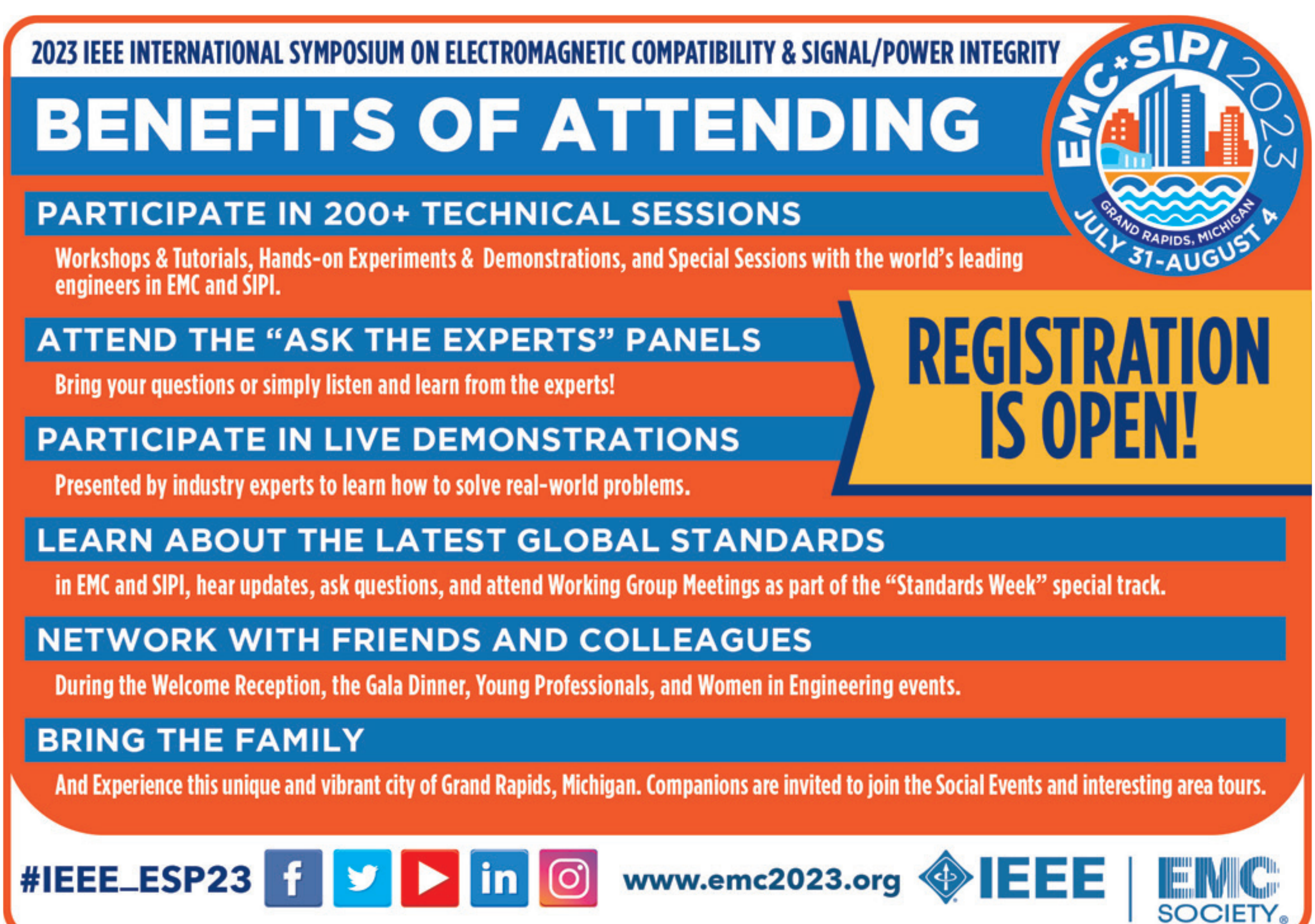
ACKNOWLEDGMENTS

The author wishes the thank reviewers for their time and effort in making this article useful. Any errors of omission or commission are the author's own.

NOTES AND REFERENCES

1. Explanatory note adapted from "EMI vs. EMC: What's in an Acronym," *In Compliance Magazine*, February 2014. Much more on the topic of how equipment EMI qualification relates to vehicle self-compatibility (EMC) demonstration may be found there.
2. All specifications/standards/books/handbooks referenced in this article are available at http://www.emccompliance.com or on request from the author.
3. The term "radio" as used in this article is shorthand for "antenna-connected receiver" meaning a device designed to receive information wirelessly over the airwaves. This includes voice and data radios, but also navigational aids, radar, and anything designed to connect to an antenna.
4. See Reference 2
5. MIL-I-6181B, Interference Limits, Tests and Design Requirements, Aircraft Electrical and Electronic Equipment, 29 May 1953
6. NADC-EL-5515, Final Report, Evaluation of Radio Interference Pick-Up Devices and Explanation of the Methods and Limits of Specification No. MIL-I-6181B, 10 August 1955
7. Much of the historical content was sifted from the author's earlier handbook, namely, "Introduction to the Control of Electromagnetic Interference," *EMC Compliance*, 1993.
8. For a detailed explanation of the difference between a specification or standard controlling electromagnetic interference vs. one controlling electromagnetic compatibility, see "EMI vs. EMC, What's in an Acronym," in the February 2014 issue of this magazine.
9. JAN-I-225, Interference Measurement, Radio, Methods Of, 150 Kilocycles to 20 Megacycle (For Components and Complete Assemblies, 14 June 1945
10. Insight into the times just prior to the adoption of MIL-STD-461 and -462 is found at White, Donald R. J. "A Handbook on Methods and Procedures for Automating RFI/EMI Measurements," White Electromagnetics, Inc. Rockville, MD, 1966. White was a pillar of the EMC community at a time when he was about the only pillar.
11. The reader may well ask what happened to MIL-I-6181A. It was released 23 January 1953, just four months prior to "B." The author has never found a copy, which is not surprising given the short lifespan. Some of the changes in "B" vs. the original release of MIL-I-6181 may have appeared in "A," but there is no way to know for sure. One may infer from the release of "B" four months after "A" that the "B" revision was quite comprehensive in scope, and further, we know from NADC-EL-5515 that the radiated emission portion was new for "B."
12. MIL-I-6181, Interference Limits and Tests: Aircraft Electrical and Electronic Equipment, 14 June 1950
13. Functionally, a slide-back peak detector may be thought of as a comparator circuit. One input is the detected (demodulated) signal envelope, and the other is a dc level derived from a potentiometer. The potentiometer is adjusted until the dc input to the comparator is at precisely the same level as the peak of the demodulated pulse train. At that point, no audio can be detected, and the dc level drives the meter deflection. In this way, peak detection is entirely independent of pulse repetition rate and duty cycle.
14. Parker, A. T. "A Brief History of EMI Specifications," presented at the 1992 IEEE EMC Symposium.
15. 12R2-3BC-112, Technical Order, Maintenance Instructions, Radio Receivers BC-224 & BC-348, 20 July 1945. Section IV, Theory of Operation, paragraph 3b, gives bandwidth information.
16. Instruction Book, Radio Noise and Field Strength Meter Ferris Model 32-B, Ferris Instrument Company, Boonton, NJ undated but no earlier than 1947. General Theory and Description section D Frequency Range, page 4.

17. The proper way to do it in the age of semi-automated receivers (for MIL-STD-461 prior to "D") is well described in an application note on the topic authored by Mr. John Zentner, retired from Wright Patterson Air Force Base. Mr. Zentner was the guiding technical force behind much of what became MIL-STD-461D and -462D. See ASD/ENA-TR-80, Identification of Broadband and Narrowband Emissions, 01 May 1980.
18. MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of, 31 July 1967, and MIL-STD-462D, Measurement of Electromagnetic Interference Characteristics, 11 January 1993. A little remarked but quite significant change between these two successive standards (no B or C releases) is that the original requires "all leads and cables shall be within 10 +/- 2 cm from the edge of the ground plane…" The "D" revision requires just the opposite: "… the cable closest to the front boundary shall be placed 10 centimeters from the front edge of the ground plane." The original release acts to maximize radiated emissions and susceptibility, while the "D" revision acts to put an upper bound on both.
19. See Reference 9.
20. See Reference 12.
21. For mains frequencies (60 & 400 Hz), a 500 Ω resistor was inserted between the mains source and the filament transformer. At other frequencies, the HP 205A audio oscillator could be configured with a suitable output and a 500 Ω output impedance: Hewlett-Packard Operating and Service Manual, Audio Signal Generator Models 205A and 205AG, copyright 1955.



ESD DESIGNERS' HEADACHE WITH MULTIPLE AUTOMOTIVE TEST REQUIREMENTS, PART I

A Review of ESD-EMC Co-Design Challenges

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By Gianluca Boselli

The trend toward society's "smart-electrification" is driving the need for ESD immunity at the system-level. IEC 61000-4-2 [1] defines how to perform the electrostatic discharge immunity test at the system level. Until about 15 years ago, protecting against such events involved implementing ad-hoc ESD protections (TVS – transient voltage suppressors) at board/system-level in proximity to the connectors interfacing with the "external world."

However, a new trend of implementing system-level robustness at the component level (i.e., on-chip) is quickly becoming standard practice, mainly stemming from the desire to reduce system/board design costs.

While this may sound like a logical step on paper, it poses enormous challenges to the component ESD designer in that:

- IEC 61000-4-2 is <u>not</u> applicable at the component level, so every company is struggling to understand/design proprietary characterization methods at the component level to extrapolate performance at system-level; and
- ESD designers are now responsible for the performance of systems that they neither build nor, in many cases, know anything about.

In the automotive world, the situation is even more challenging. In addition to ESD immunity at the system level (ISO 10605 [2], adapted from IEC 61000-4-2), there is a plethora of other requirements addressing immunity to both electrical disturbances (ISO 7637 [3, 4, 5]) and to RF disturbances (IEC 62132 [6]) that must be met.

This article is divided into two parts. This first part addresses the ESD design challenges stemming from ISO 10605 specs, while the second part will review the trade-offs between ESD design and EMC immunity requirements.

AUTOMOTIVE SYSTEM-LEVEL (ISO 10605) ESD DESIGN CHALLENGES

To address the demand for area-competitive on-chip IEC ESD Solutions (with targets in excess of 30A for Level-4 spec), the implementation of an SCR-based protection scheme is a must. Thanks to its low holding voltage, this solution is extremely advantageous in terms of power dissipation. However, this may come at a cost of a large swing between triggering voltage and holding voltage, which may cause non-uniform current conduction and render the solution ineffective. This will play a role in the specific differences between IEC 61000-4-2 and ISO 10605 from an ESD design perspective.

Different R&C Modules to Be Tested

ISO 10605 specifies four different RC combinations (R=330Ω, R=1.5KΩ, C=150pF, and 330pF), leading to pulse decay times ranging from 60ns to 600ns. The actual RC combination(s) required at the board/system level may not be known at the time of component design. The straightforward consequence is that the ESD designer needs to validate the ESD solution on all four stress waveforms, with completely different pulse widths, energy contents, and rise times.

In [7], it was reported that an HV SCR meeting IEC Level 4 requirements (corresponding to ISO with R = 330Ω, and C = 150pF) miserably failed all other ISO stress permutations with larger capacitance and resistors. The root cause was identified in the lack of power scalability of the HV SCR caused by a static filament formation for pulses in excess of 100ns. A first-order correlation between TLP stress duration and ISO level was also established (see Figure 1 on page 22, [7]).

To meet the performance target, a new architecture had to be devised with the obvious delay in product development efforts. A similar issue (i.e., lack of correlation between TLP and ISO test with R=1.5K Ω) was also reported in [8].

Rise-Time Sensitivity

While the four stress waveforms in ISO 10605 are fairly well defined, there is no guarantee that the same waveforms are actually exercised at the component level. This is the main conceptual issue behind the notion of implementing system-level ESD robustness at the component level, that is, the actual waveforms seen at the externally connected pins of the component are a function of the board/system-specific implementation (connecting traces and/or discrete components). In particular, inductive loads (i.e., long board traces, presence of common mode chokes, or discharges through long cables) will cause significant departure from the expected ISO 10605 waveforms, both in duration (can become much longer) and shape (oscillatory, instead of exponentially decaying).

Unfortunately, the behavior of ESD clamps components used for system-level robustness is a strong function of the stress waveform. The bottom line is that it is virtually impossible to guarantee ESD system-level robustness at a component level without knowing all the details of the system/board implementation. A consequence of this fact is that the practice of specifying system-level ESD robustness on a component's datasheet is useless and could be misleading.

A typical parameter impacted by system implementation is rise time seen at the component level. It was reported in [9] that large inductive loads on CAN pins could increase the rise time of an ISO 10650 stress to >50ns. These slow values impacted the triggering mechanism of the ESD cell, causing non-uniform triggering, hence failing to meet the specifications. Again, a novel layout with internal back-ballasting was devised to minimize the reliance of the ESD cell on rise time.

	R=330Ω C=150pF	R=330Ω C=330pF	R=1500Ω C=330pF
ISO Level	15KV	2KV	2KV
TLP I_{T2}	17A	2A	1.2A
	TLP Pulse =100ns	TLP Pulse =200ns	TLP Pulse =500ns

Figure 1: Long-pulse TLP can mimic the impact of the various combinations of the ISO test [7]

Common Mode Choke

Common mode chokes (CMCs) are often required to meet EMC emission requirements in differential communication busses (LIN, CAN, etc.), with a typical inductance of 100 µH. A CMC is placed directly in the ESD discharge path and, in principle, one would expect a beneficial high-frequency damping of the ESD energy. Unfortunately, a CMC displays a strong saturation behavior (due to the ferrite saturation), which results in a drastic reduction of the inductance over a certain threshold current. In addition, a CMC typically features an undesirable snapback characteristic for ESD current densities. This highly non-linear behavior can force the component-level ESD protection in and out of snapback multiple times, depending on the current density. This could lead to a non-uniform turn-on (Figure 2), causing premature failure of the component-level ESD protection [10].

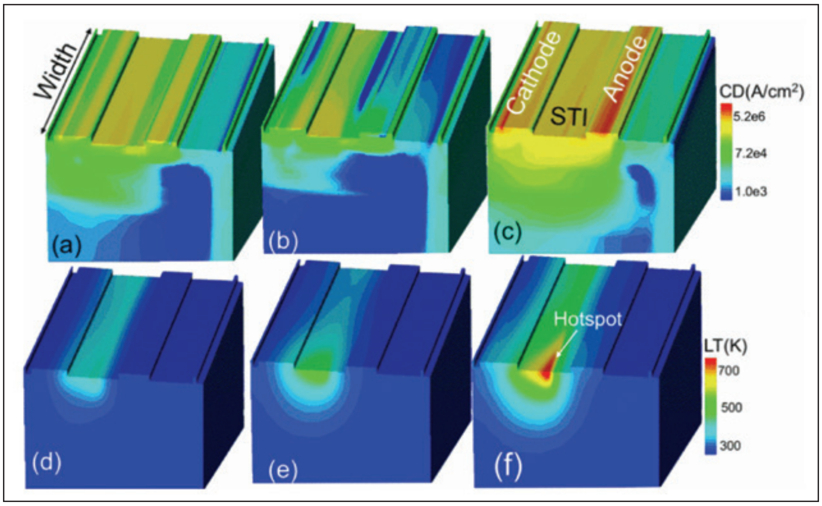

Figure 2: Current density and lattice temperature of an SCR subjected to a double triggering pulse, caused the CMC presence. It can be seen that the second pulse will cause filamentary conduction in the device, which is not able to meet the ISO specification target [10]

TRADE-OFFS BETWEEN ESD DESIGN AND EMC IMMUNITY REQUIREMENTS

The automotive environment is extremely harsh for electronic systems. To guarantee reliable operation in all possible conditions, strict EMC immunity requirements are enforced. From an ESD perspective, EMC immunity requirements sometimes conflict with ESD requirements, making ESD-IP co-design extremely challenging.

Immunity to Electrical Disturbances

As previously mentioned, ISO 7637 is used to characterize automotive systems against a variety of transient electrical disturbances that may occur in an automotive environment. These are caused by the various scenarios through which inductive loads (like the motor) or the battery can be switched/ disconnected. The most common test pulses are 1, 2a/2b, 3a/3b, 4, and 5a/b, which differ in terms of polarities, amplitudes, pulse width, and rise time. While all different, these test pulses feature an energy content far superior to that a component level rated (HBM, CDM) ESD cell can withstand [11].

However, component-level ESD cells designed to meet system-level ESD immunity can withstand a much higher energy level. Hence, it is becoming standard practice to have component-level ESD cells perform dual duty, i.e., to guarantee both ESD and EMC immunity to electrical disturbances. Hence, more and more component datasheets report robustness against ISO 7637 of pins that will connect to the external world.

The co-design of ESD immunity and immunity to electrical disturbances is not trivial. Besides the ability to withstand DC-like durations with test pulses 1, 2, and 5, slow rise times associated with them will require the ESD protection to be level-triggered.

The trend of progressively migrating both ESD and EMC immunity from the system/board to the component level is creating unprecedented challenges for the component ESD designer.

This implies the availability of a junction with appropriate breakdowns to support both ESD and EMC requirements.

Immunity to RF Disturbances

In addition to immunity to electrical disturbances, automotive systems must be robust in their defense against RF disturbances as well per IEC62132-4. A direct power injection (DPI) method is used to measure the electromagnetic immunity of an IC from 150KHz to 1GHz. The interaction between ESD immunity and DPI is not straightforward, as both ESD and DPI have fast-rising voltage edges, although with different amplitudes.

In [11], the case of a LIN pin passing ESD immunity but failing the DPI test was reported. It was found that the noise injected into the substrate (and then coupled to the LIN pin) by the RC-triggered ESD cell during the DPI test was the culprit for the test failure. A new, level-triggered ESD cell had to be devised to address the issue. In a similar fashion, in [12], a robust RC-triggered ESD cell failed DPI testing, mainly at low frequencies. A redesign of the RC-triggering circuit was needed to address the issue, as it was not possible to design an effective level-trigger ESD cell for ESD immunity.

From the above examples, it would seem that level-triggered ESD cells are necessary to meet DPI requirements. However, there are situations where RC-triggered ESD cells are highly desirable. One such scenario is when inductive fly-back protection is needed. This is typically the case for output pins driving inductive loads, such as external cables and/or chokes. When the power supply is switched off, it is convenient (i.e., no additional inductive flyback protection is needed) to release the energy stored in the inductors through the ESD cell. This is typically done through RC-triggering the ESD cell in MOS conduction mode to keep voltages at safe levels. As seen from the above example, functional requirements can lead to opposite design requirements on ESD cells.

CONCLUSIONS

The trend of progressively migrating both ESD and EMC immunity from the system/board to the component level is creating unprecedented challenges for the component ESD designer. Implications of EMC-ESD immunity co-design were reviewed here, along with several case studies. In Part 2 of this article, we'll review the trade-offs between ESD design and EMC immunity requirements.

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THE FUTURE OF WI-FI

How Wi-Fi 7 Will Make Innovative New Applications Possible

IEEE Standards Association (IEEE SA) is a collaborative organization where innovators raise the world's standards for technology. IEEE SA provides a globally open, consensus-building environment and platform that empowers people to work together in the development of leading-edge, market-relevant technology standards, and industry solutions shaping a better, safer, and sustainable world.

By IEEE Standards Association (IEEE SA)

Wi-Fi technology is based on the IEEE 802.11™ series of wireless connectivity standards that have revolutionized how we communicate and access information. Today, billions of Wi-Fi-enabled devices are in use worldwide, dramatically impacting how individuals, businesses, government agencies, and societies interact. It is no exaggeration to say that the IEEE 802.11 series of standards has significantly supported the deployment of high-quality global communications Wi-Fi technologies through inexpensive, equitable internet access.

Since its debut 25 years ago, Wi-Fi has played a vital role in helping us be connected at home, work, and in public places. You may recall a time when Wi-Fi wasn't so readily available, but today we expect a standard level of connectivity wherever we go – even in large outdoor spaces such as parks and baseball stadiums. Typical of technology, the earliest versions of Wi-Fi were considered slow by today's standards and its use was more limited. Today, we now use an enormous number of Wi-Fi-enabled devices – computers, smartphones, game consoles, health/fitness devices, and much more – for productivity, organization, entertainment, health, and even security.

In recognition of the Internet's 40th anniversary, we examine how the IEEE 802.11 series of standards has driven the evolution of Wi-Fi technology and how new additions to the series will enable greater Wi-Fi capabilities, making innovative new applications possible.

THE GENESIS OF WI-FI

Wi-Fi is a wireless local area network (WLAN) technology that enables digital devices within a certain area to communicate through wireless transmitters and radio signals. When a transmitter receives data from the internet, that data is converted into a radio signal that can be received and read by Wi-Fi-enabled devices. An exchange of information occurs between the transmitter and the device.

The origins of Wi-Fi can be traced back to a 1985 ruling by the U.S. Federal Communications Commission that released the bands of the radio spectrum at 900 megahertz (MHz), 2.4 gigahertz (GHz), and 5.8 GHz for unlicensed use by anyone. Technology companies built wireless networks and devices to take advantage of the newly available radio spectrum, but the lack of a common technical standard resulted in fragmentation because manufacturers' devices were rarely compatible.

In 1997, IEEE SA unveiled its groundbreaking IEEE 802.11™ technical standard and introduced Wi-Fi to the market, enabling wireless data transmission at up to 2 Mbit/s using an unlicensed 2.4 GHz radio spectrum.

The promising Wi-Fi technology and a new common technical standard were embraced by technology innovators, particularly Apple's then-CEO Steve Jobs, who was enamored by the idea of wireless connectivity for laptops. This led to Wi-Fi's first major commercial breakthrough in 1999 when Jobs and Apple introduced the first mass-marketed consumer products with Wi-Fi connectivity, the AirPort wireless base station, and iBook. At that time, the newly released IEEE 802.11b™ amendment to the original Wi-Fi standard pushed theoretical data rates up to 11 Mbit/s. Jobs showed off the world's first Wi-Fi-enabled laptop at MacWorld in New York City, demonstrating wireless Internet by passing the iBook through a hula hoop to a cheering crowd.

Just a few years later, Apple introduced an updated version of the AirPort base station. Based on the newly developed IEEE 802.11g™ specification, Apple's

The evolution of IEEE 802.11-based Wi-Fi standards continues today, providing much faster data transmission rates, longer ranges, and more reliable and secure connections.

new base station could communicate at 54 Mbit/s. When the updated base station was released in 2003, Jobs exclaimed that Apple kick-started the wireless revolution. While Jobs and Apple deserve credit for product innovation, the Wi-Fi revolution would not have been possible without the IEEE 802.11 standards family and the volunteers who made it happen.

The evolution of IEEE 802.11-based Wi-Fi standards continues today, providing much faster data transmission rates, longer ranges, and more reliable and secure connections. All IEEE 802.11 standard amendments are constructed in a manner such that devices which operate according to their specifications will be backward compatible with earlier versions, enabling any modern IEEE 802.11-based device to communicate with older products.

IEEE STANDARDS FOR WI-FI

The Wi-Fi Alliance ("Wi-Fi #") developed a naming convention to help the general public better distinguish between various IEEE 802.11 implementations:

- *IEEE 802.11™* is the aforementioned pioneering 2.4 GHz Wi-Fi standard from 1997, and it is still referred to by that nomenclature. This standard and its subsequent amendments are the basis for Wi-Fi wireless networks and represent the world's most widely used wireless computer networking protocols.
- *IEEE 802.11b™*, or *Wi-Fi 1*, was introduced in 1999 with Apple's announcement of its Wi-Fi-enabled base station and laptop computer. It also operated at 2.4 GHz, but it incorporated modulation schemes called direct-sequence spread spectrum/complementary code keying (DSSS/CCK). This helped reduce interference from devices such as microwave ovens, cordless phones, baby monitors, and other sources, and it also achieved higher data rates. Wi-Fi 1 enabled wireless communications at distances of ~38m indoors and ~140m outdoors.
- *IEEE 802.11a™*, or *Wi-Fi 2*, also introduced in 1999, was the successor to IEEE 802.11b. It was the first Wi-Fi specification to feature a multi-carrier modulation scheme (OFDM) to support high data rates, unlike Wi-Fi 1's single-carrier design. It supported 5 GHz operation and its 20 MHz bandwidth supported multiple data rates.
- *IEEE 802.11g™*, or *Wi-Fi 3*, was introduced in 2003. Wi-Fi 3 achieved faster data rates of up to 54 Mbit/s in the same 2.4 GHz frequency band as IEEE 802.11b, made possible by an OFDM multi-carrier modulation scheme and other enhancements. Additionally, Wi-Fi 3 appealed to mass market manufacturers and users because 2.4 GHz devices were less expensive than 5 GHz devices.
- *IEEE 802.11n™*, or *Wi-Fi 4*, was introduced in 2009. Wi-Fi 4 supported the 2.4 GHz and 5GHz frequency bands, with up to 600 Mbit/s data rates, multiple channels within each frequency band, and other features. IEEE 802.11n data throughputs enabled the use of WLAN networks in place of wired networks, a significant feature, enabling new use cases and reducing operational costs for end users and IT organizations.
- *IEEE 802.11ac™*, or *Wi-Fi 5*, was introduced in 2013. Wi-Fi 5 supported data rates at up to 3.5 Gbit/s, with still-greater bandwidth, additional channels, better modulation, and other features. This was the first Wi-Fi standard to enable the use of multiple input/multiple output (MIMO) technology, which enabled multiple antennas to be used on both sending and receiving devices to reduce errors and boost speed.

WI-FI 6 ADDRESSES NETWORK DENSITY DEEDS AND PROVIDES SPECTRAL EFFICIENCY

IEEE 802.11ax™, or *Wi-Fi 6*, is the most recent standard in the series, published in 2021. Wi-Fi 6-based devices – including IoT devices – are now being deployed in billions per year.

Although the theoretical data rate for Wi-Fi 6 is 9.6 Gbit/s, this standard is more focused on usage density rather than boosting speed. The pervasive use of Wi-Fi today creates issues whereby network performance can be degraded in areas of dense Wi-Fi traffic. Examples of problem areas include sports stadiums, concert halls, and public transportation hubs. But the issue isn't only in large venues. Homes are increasingly problematic due to the need for routers that must communicate simultaneously with a growing number of digital gadgets.

IEEE 802.11ax offers many enhancements including a multi-user mechanism that allows the 9.6 Gbit/s data rate to be split among various devices. It also supports routers sending data to multiple devices in one broadcast frame over the air, and it allows Wi-Fi devices the ability to schedule transmissions to the router. Mechanisms to support longer-range outdoor operations are also added.

Collectively, these features improve aggregate throughput and support the increasing use of Wi-Fi in data-heavy situations and in applications such as video and cloud access, where real-time performance and low power consumption for battery-powered devices are required. Of great importance and focus is the expectation for high-definition video to be the dominant type of traffic in many forthcoming Wi-Fi deployments.

WI-FI 7: THE NEXT EVOLUTIONARY STEP FOR WI-FI

Next to take center stage will be Wi-Fi 7.

There are numerous drivers for even faster, better Wi-Fi, including the rapid growth and adoption of the Internet of Things (IoT), with more devices expanding their capabilities through connectivity. Sensor technology embedded in IoT devices continues

From the user's perspective, Wi-Fi 7 will be much faster, have much lower latency, will support many more devices, and will perform much better in congested Wi-Fi spaces and where Wi-Fi networks overlap.

to become less expensive, more advanced, and more widely available. In turn, widespread availability and cost-effectiveness are pushing innovation of new sensor applications, including large-scale monitoring and detection.

In homes, an increasing number of commonplace items are transforming into connected devices every day. Today's modern smart homes include IoT thermostats, alarm systems, smart televisions, fitness, and home healthcare monitors, as well as other devices such as gaming systems and wireless speakers requiring speed and low latencies. Consumers will benefit from Wi-Fi 7 for gaming, AV/VR and video applications, and smart-home services.

For enterprises, Wi-Fi 7 will benefit IoT and IIoT applications, such as industrial automation, surveillance, remote control, AV/VR, and other video-based applications. Additionally, Wi-Fi 7 brings more flexibility and capabilities to enterprises as they engage in digital transformation.

Wi-Fi 7 is based on features defined in the *IEEE P802.11be™* draft amendment. A major evolutionary milestone in Wi-Fi technology, Wi-Fi 7 will provide quadruple – that's four times – faster data rates (~40 Gbit/s) and twice the bandwidth (320 MHz channels vs. 160 MHz channels for Wi-Fi 6). Wi-Fi 7 also supports more efficient and reliable use of available and contiguous spectrum through multi-band/multi-channel aggregation and other means. The standard features numerous enhancements to MIMO protocols and many other advancements and refinements of existing Wi-Fi capabilities.

The Wi-Fi 7 specification also features multi-link operation (MLO), which is similar to the carrier aggregation that mobile phone providers use to increase data throughput by combining the abilities of separate channels. MLO can elevate data rates to be seven times faster while also lowering latency and improving dependability because linked channels work in parallel.

Wi-Fi 7 also doubles Wi-Fi 6's eight independent streams of data to 16 spatial streams. It uses coordinated multiuser MIMO (CMU-MIMO), which is a significant improvement from multi-user multiple-input, multiple-output.

The new Wi-Fi 7 specification also uses multi-user resource unit (MRU) to avoid interference, allowing selective puncturing of overlapping portions of the spectrum to let the data flow only on frequencies that are clear. It can help raise data rates and reliability in congested Wi-Fi environments, such as in an apartment building or large office environment.

Summing up, from the user's perspective, Wi-Fi 7 will be much faster, have much lower latency, will support many more devices, and will perform much better in congested Wi-Fi spaces and where Wi-Fi networks overlap. Of course, to harness the benefits, users will need significantly faster internet speeds from their service providers.

But the IEEE 802.11 series work doesn't end here. The drive to improve Wi-Fi is a continuous focus of IEEE SA and its army of volunteer experts.

LOOKING AHEAD: IEEE 802.11 STANDARDS FOR NEW AND EMERGING WI-FI USE CASES

IEEE P802.11be, along with *IEEE 802.11ax* and future iterations of IEEE 802.11 standards, also could support many next-generation Wi-Fi applications. The IEEE 802.11 Working Group has established several special-interest groups to investigate many of them. Here are a few examples:

- The Artificial Intelligence/Machine Learning Topic Interest Group (AIML TIG) is focused on describing use cases for artificial intelligence/machine learning (AI/ML) applicability in 802.11 systems and investigating the technical feasibility of features enabling support of AI/ML. Developers and deployers of AI/ML protocols over wireless networks are expected to benefit from more optimized and efficient support for exchanging AI/ML-related data exchanges, such as reduced overhead and reduced delay. WLAN users, OEMs, and network operators are expected to benefit from improved user experience and higher efficiency of resources, and improved network performance.

- The Ambient Power for WLAN IoT Topic Interest Group (AMP TIG) is describing use cases for 802.11 ambient power-enabled IoT devices and investigating the technical feasibility of features to enable 802.11 WLAN support of ambient power-enabled IoT devices. Battery-free IoT technologies are expected to significantly reduce maintenance efforts of IoT networks and devices and extend the application scenarios featured as more environmentally friendly and much safer. This technology would see application in verticals such as agriculture, Smart Grid, mining, manufacturing, logistics, smart home, transportation, etc.
- The ***Ultra High Reliability (UHR) Study Group*** is investigating technology that may improve the reliability of WLAN connectivity, reduce latencies, increase manageability, increase throughput including at different SNR levels, and reduce device-level power consumption. Due to the growing importance of metaverse and AR/VR communications, the need for more throughput/data rate is in constant evolution. The study group started early in 2023; a task group is targeted to start in May 2023.

HOW IEEE SA SUPPORTS THE DEVELOPMENT AND LAUNCH OF WI-FI STANDARDS

Through our IEEE 802 LAN/MAN Standards Committee, IEEE SA develops and maintains networking standards and recommended practices for local, metropolitan, and other area networks. As Wi-Fi networks continue to progress on multiple fronts, so will IEEE Standards, to help to bring out the full potential of Wi-Fi technology and serve the future industry and human needs.

We welcome the involvement of participants from academia, government, and industry. For more information or to join the standards activity, please visit the IEEE 802 LAN/MAN Standards Committee webpage (https://standards.ieee.org).

CPSC GETS AGGRESSIVE ABOUT FAILURE TO REPORT

Civil Penalties Significantly Increase

The most important responsibility of any manufacturer or product seller under the Consumer Product Safety Act (CPSA) is to report product safety issues to the U.S. Consumer Product Safety Commission (CPSC) that meet the statutory requirements under the Act.

In the last few years, the compliance staff of the CPSC has reached settlements with a number of companies over allegations that they failed to either report relevant product safety issues or failed to report them in a timely manner. These settlements included significant civil penalties. Before I describe some of the specific allegations in these matters, I want to describe the reporting requirements.

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By Kenneth Ross

REPORTING REQUIREMENTS

Section 15(b) of the CPSA requires manufacturers, importers, distributors, and retailers to notify the CPSC immediately if it obtains information that reasonably supports the conclusion that a product distributed in commerce: 1) fails to comply with a voluntary standard upon which the Commission has relied under the CPSA; 2) fails to meet a consumer product safety standard or banning regulation; 3) contains a defect which could create a substantial product hazard to consumers; or 4) creates an unreasonable risk of serious injury or death.

The most important basis for reporting to the Commission is Section 15(b)(3), which requires reporting when the product has both a defect and the defect creates the possibility of a substantial product hazard. A Recall Handbook published by the CPSC in September 2021 provides a description of the law and regulations and other helpful information on how to analyze the need to report. (The complete title of the handbook is "Product Safety Planning, Reporting, and Recall Handbook," and is available at https://www.cpsc.gov/Business--Manufacturing/Recall-Guidance.)

REPORTING LAW AND REGULATIONS

Defect

The first question is whether there is a defect. To help a company decide whether they have a defect, the Commission's regulations say:

> *"At a minimum, defect includes the dictionary or commonly accepted meaning of the word. Thus, a defect is a fault, flaw, or irregularity that causes weakness, failure, or inadequacy in form or function. A defect, for example, may be the result of a manufacturing or production error; that is, the consumer product as manufactured is not in the form intended by, or fails to perform in accordance with, its design. In addition, the design of and the materials used in a consumer product may also result in a defect…A design defect may also be present if the risk of injury occurs as a result of the operation or use of the product or the failure of the product to operate as intended. A defect can also occur in a product's contents, construction, finish, packaging, warnings, and/or instructions. With respect to instructions, a consumer product may contain a defect if the instructions for assembly or use could allow the product, otherwise safely designed and manufactured, to present a risk of injury."*
>
> 16 CFR §1115.4

The CPSC regulations say that the term "defect" used in this section is not necessarily the same as the term "defect" in product liability law. But, in general, CPSC regulations do require product liability law and lawsuits to be considered in connection with a determination of whether a product is defective.

In addition, in 16 CFR §1115.4, the CPSC lists the following factors to determine whether the risk of injury associated with the product is the type of risk that would render the product defective.

1. The utility of the product
2. The nature of the risk of injury that the product presents
3. The necessity of the product
4. The population exposed to the product, and its risk of injury
5. The obviousness of such risk
6. The adequacy of warnings and instructions to mitigate the risk
7. The role of consumer misuse of the product, and the foreseeability of such misuse

8. The Commission's experience and expertise
9. The case law interpreting federal and state public health and safety statutes
10. The case law in the area of products liability
11. Other information relevant to the determination

The CPSC distinguishes products that hurt people but aren't defective by stating:

> *"We note, however, that not all products that present a risk of injury are defective. A typical kitchen knife is one example. A knife blade must be sharp for a consumer to cut or slice food. The knife's sharpness is not always a product defect, even though some consumers may cut themselves while using the knife. On the other hand, if the handle or blade of a particular knife is prone to breaking that may constitute a defect."*
>
> *CPSC Recall Handbook,* page 12

Substantial Product Hazard

The next question to be answered is whether this "defect" could create a "substantial product hazard." The Commission starts this analysis by stating:

> *"Because a product may be defective even when it is designed, manufactured, and marketed exactly as intended, a company in doubt about whether a defect exists should still report."*
>
> *CPSC Recall Handbook*, page 12

Then the regulations provide the following factors a manufacturer must consider in determining if there is a substantial product hazard:

1. Pattern of defect;
2. Number of defective products in commerce;
3. Severity of risk; and
4. Likelihood of injury.

Concerning the severity of the risk, the CPSC has said:

> *"The definition of a serious injury is set forth in 16 CFR 1115.5(c) and includes grievous bodily injuries or injuries requiring hospitalization, medical treatment, or missing work or school for more than one day."*
>
> *CPSC Recall Handbook*, page 13

In addition, some of the important limitations on these factors are statements to the effect that a defective product that has no risk of serious injury or has little chance of causing even a minor injury would not ordinarily constitute a substantial hazard. Also, the CPSC considers injuries that have occurred or could occur in determining severity. Last, determining the likelihood of future injury considers the "intended or reasonably foreseeable use or misuse of the product…" (*CPSC Recall Handbook*, page 13).

Non-compliance with Standards

Sections 15(b)(1) and (2) state that a manufacturer has a reporting responsibility if the product does not comply with a mandatory standard or banning regulation or does not comply with a voluntary standard that is relied on or has been adopted by the CPSC. While this non-compliance is reportable, it is possible to argue that there is no significant hazard and therefore no corrective action needs to be undertaken with products in consumers' hands.

Unreasonable Risk

There is an additional reporting responsibility that applies even if there is no defect and the product complies with all CPSC standards. Section 15(b)(4) requires a report if there is an unreasonable risk of serious injury or death. The critical term is "unreasonable," which is defined as follows:

> *"The use of the term 'unreasonable risk' suggests that the risk of injury presented by a product should be evaluated to determine if that risk is a reasonable one. In determining whether a product presents an unreasonable risk, the firm should examine the utility of the product, or the utility of the aspect of the product that causes the risk, the level of exposure of consumers to the risk, the nature and severity of the hazard presented, and the likelihood of resulting serious injury or death. In its analysis, the firm should also evaluate the state of the manufacturing or scientific art, the availability of alternative designs or products, and the feasibility of eliminating the risk. The Commission expects firms to report if a reasonable person could conclude given the information available that a product creates an unreasonable risk of serious injury or death."*
>
> 16 CFR §1115.6(b)

The applicable regulation, 16 CFR §1115.6(a), does not require that a product be defective before a reporting responsibility arises. However, for such reports, the regulation requires firms to consider:

> *"Reports from experts, test reports, product liability lawsuits or claims, consumer or customer complaints, quality control data, scientific or epidemiological studies, reports of injury, information from other firms or governmental entities…"*

The regulations then go on to say:

> *"While such information shall not trigger a per se reporting requirement, in its evaluation of whether a subject firm is required to file a report under the provisions of section 15 of the CPSA, the Commission shall attach considerable significance if such firm learns that a court or jury has determined that one of its products has caused a serious injury or death and a reasonable person could conclude based on the lawsuit and other information obtained by the firm that the product creates an unreasonable risk of serious injury or death."*

Therefore, experiences during product liability litigation must be considered in determining whether a report to the CPSC is advisable. This includes expert reports, deposition testimony, jury verdicts, judge rulings, and settlements. (See https://incompliancemag.com/article/product-liability-litigation-and-its-effect-on-product-safety-regulatory-compliance for an article on this subject.)

TIMING OF REPORT

If there is a situation that meets the threshold for reporting or the company does not know if they have a duty to report either under Section 15(b)(3) or (4), the CPSA requires companies to report immediately. The Commission defines this requirement as follows:

> *"A company must report to the CPSC within 24 hours of obtaining reportable information. The CPSC encourages companies to report potential substantial*

> *product hazards, even while their own investigations are continuing. However, if a company is uncertain about whether information is reportable, the company can take a reasonable time to investigate the matter. That investigation should not exceed 10 working days, unless the company can demonstrate that a longer time is reasonable under the circumstances."*
>
> *CPSC Recall Handbook*, page 8

In order to encourage manufacturers to report even when they aren't sure if they are required to do so, the Commission has said:

> *"Reporting a product to the CPSC under Section 15 does not automatically mean that the agency will conclude that the product creates a substantial product hazard or determine that corrective action is necessary. CPSC staff will evaluate the report and work with the reporting company to determine whether corrective action is necessary. Many of the reports received require no corrective action because staff concludes that the reported product defect does not create a substantial product hazard."*
>
> *CPSC Recall Handbook*, page 6

In any report to the CPSC, the company can clearly state that they do not believe that the product has a defect that could create a substantial hazard, but that they are still voluntarily reporting this matter to the CPSC. Unfortunately, the CPSC has recently gotten very aggressive in requiring recalls even for situations where a recall is arguably not warranted. Despite that, the CPSC states that a significant percentage of filings under section 15(b) does not result in a recall.

SECTION 37

Section 37 of the CPSA requires manufacturers of consumer products to report information about settled or adjudicated civil actions. Manufacturers and product sellers should be aware of the details of this section. However, normally a manufacturer or product seller will have already filed under Section 15(b) before the threshold for reporting under Section 37 is met. This is because litigation and the results of the resolution of litigation must be considered by companies and significant settlements or adverse verdicts could result in a report. (See *CPSC Recall Handbook,* page 9, and *16 CFR §1115.7* for more information on Section 37.)

CIVIL PENALTIES

Manufacturers and others in the chain of production and distribution need to make some critical decisions so they can meet their statutory obligations and avoid being charged with violating these requirements. This is particularly important as the CPSC has recently ramped up its efforts to fine those companies that violate these reporting requirements.

Since early 2021, the CPSC has significantly increased the number of cases where civil penalties are being sought. Given these efforts and statements from the current CPSC commissioners, manufacturers should assume that the CPSC will continue to look for cases where late reporting or failure to report might justify civil penalties.

The Commission is supposed to consider the following in determining the amount of penalties sought:

> *"… the Commission shall consider the nature, circumstances, extent, and gravity of the violation, including the nature of the product defect, the severity of the risk of injury, the occurrence of absence of injury, the number of defective products distributed, the appropriateness of such penalty in relation to the size of the business of the person charged, including how to mitigate undue adverse economic impacts on small businesses… "*
>
> 15 U.S.C. §2069(b)

Since early 2021, the Commission has settled four civil penalty cases for late reporting with the highest amount being $16,025,000 (there was an additional penalty for selling recalled products) and others being $6 million, $7.5 million, and $7.95 million.

In the case involving $16 million, the manufacturer reportedly received 150 reports of incidents including one death and 13 injuries before they reported. In another case, the manufacturer received reports of injuries for seven years before filing with the CPSC.

In 2018, there was a $27.75 million civil penalty agreed to but it involved multiple violations of the reporting requirements. Just prior to 2018, most civil penalties were in the range of $2 million to $5 million. However, in 2016, there was a civil penalty of $15,450,000 for a particularly egregious situation that ultimately also resulted in criminal prosecutions.

I reviewed a number of penalty matters for many years prior to 2021 and came up with some factual scenarios that were different than just a failure to report to the CPSC after learning of accidents. In some of these penalty cases, one of the following things occurred:

- The manufacturer made a design or manufacturing change (sometimes several times) because of a safety issue (in the eyes of the Commission, they were fixing a defective product) and didn't report to the CPSC or notify prior customers about the change.
- The manufacturer issued a dealer alert (sometimes several) concerning a safety problem but did not report to the Commission or alert its customers.
- The manufacturer supplied incomplete or inaccurate information to the CPSC when they investigated a safety issue.
- The CPSC had to request the manufacturer to provide information.

It is easy to review the publicly available information concerning civil penalties. The CPSC website at https://www.cpsc.gov/Business--Manufacturing/Civil-and-Criminal-Penalties shows civil penalty cases by fiscal year, product, and company. Therefore, anyone can review the facts surrounding each of these cases to better understand the trends and the facts on which these penalties were based.

CONCLUSION

Given the significant number of fines being levied and the increase in the potential for fines, it is clear that manufacturers and others in the chain of distribution should, when in doubt, err on the side of reporting.

As the CPSC has said over the years, a significant percentage of reports to the CPSC do not result in any corrective action. As a result, it makes sense for the company to seriously consider reporting to the CPSC even if there is a possible defect and a small chance of a serious injury. In that case, you can report, deny that it is a substantial product hazard, and argue that no corrective action is necessary.

Of course, it is possible that the CPSC will disagree and will encourage or try to force (by litigation) a manufacturer to undertake a remedial program. Or, as has happened a number of times recently, the CPSC can issue a unilateral press release on the safety issue involving the specific product involved.

Therefore, when in doubt, the prudent course of action may be to report early and cut off any chance of a late reporting fine. In that case, you are still able to argue that there is no defect or no substantial product hazard and that a corrective action on products in consumers' hands is not warranted. If that argument is not successful and the company refuses to do a recall, they could wind up with a unilateral press release which will encourage consumers to not use a product but will not actually institute a recall. Or it might result in no further action by the CPSC.

SMITH CHART AND INPUT IMPEDANCE TO TRANSMISSION LINE

Part 2: Resistance and Reactance Circles

By Bogdan Adamczyk

This is the second of the three articles devoted to the topic of a Smith Chart. The previous article, [1], introduced the concept of normalized load impedance and concluded with two equations describing the resistance and reactance circles. This article explains the creation of the resistance and reactance circles which are the basis of the graphical operations on the Smith Chart, like the one shown in Figure 1 [2].

The next two sections discuss the resistance and reactance circles and are based on the material presented in [3].

RELEVANT BACKGROUND

Figure 2 shows a typical model of a lossless transmission line.

With this transmission line we associate the load reflection coefficient, $\hat{\Gamma}$, given by

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

This load reflection coefficient can be expressed in terms of the normalized load impedance by dividing the numerator and denominator by the characteristic impedance of the line, Z_C.

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

or

$$\hat{\Gamma}_L = \frac{\hat{z}_L - 1}{\hat{z}_L + 1} \tag{1.3}$$

where

$$\hat{z}_L = r_L + jx_L \tag{1.4}$$

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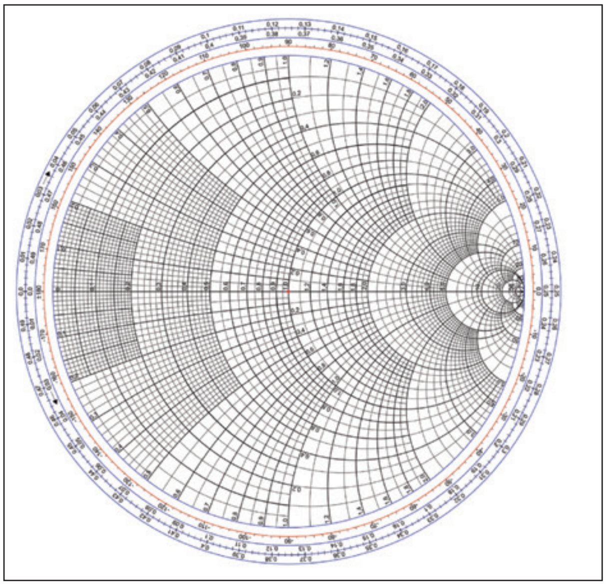

Figure 1: Basic Smith Chart

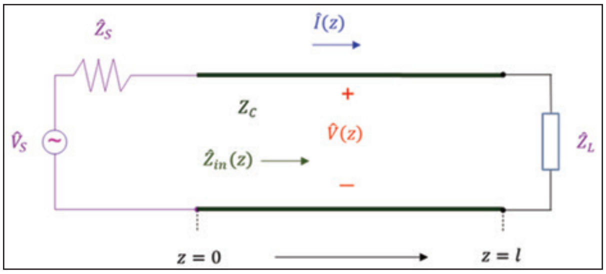

Figure 2: Typical model of a lossless transmission line

Normalized Resistance (r_L)	Radius $\left(\frac{1}{1+r_L}\right)$	Center $\left(\frac{r_L}{1+r_L}, 0\right)$
0	1	(0,0)
1/2	2/3	(1/3, 0)
1	1/2	(1/2, 0)
2	1/3	(2/3, 0)
5	1/6	(5/6, 0)
∞	0	(1,0)

Table 1: Radii and Centers of *r*-Circles

is the normalized load impedance, r_L is the normalized load resistance and x_L is the normalized load reactance.

From Eq. (1.3) we can express the normalized load impedance in terms of the load reflection coefficient as

$$\hat{z}_L = \frac{1+\hat{\Gamma}_L}{1-\hat{\Gamma}_L} \tag{1.5}$$

or, in terms of the real and imaginary parts as

$$r_L + jx_L = \frac{(1+\Gamma_r)+j\Gamma_i}{(1-\Gamma_r)-j\Gamma_i} \tag{1.6}$$

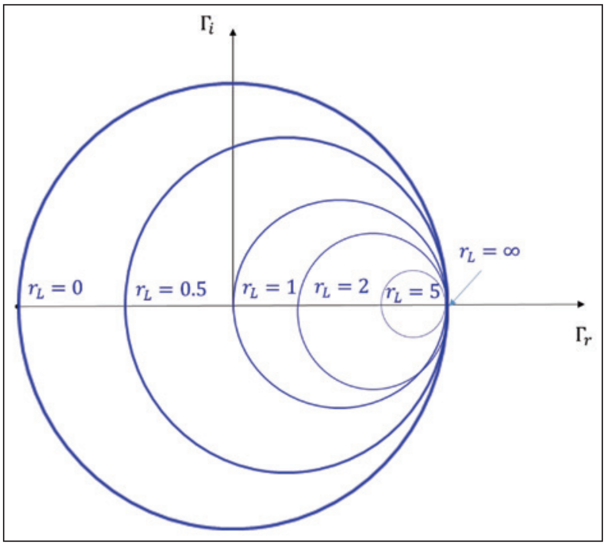

Figure 3: Typical *r*-circles

Equation (1.6) leads to the equation describing the resistance circle

$$\left(\Gamma_r - \frac{r_L}{1+r_L}\right)^2 + \Gamma_i^2 = \left(\frac{1}{1+r_L}\right)^2 \tag{1.7}$$

and another equation describing the reactance circle, [1],

$$(\Gamma_r - 1)^2 + \left(\Gamma_i - \frac{1}{x_L}\right)^2 = \left(\frac{1}{x_L}\right)^2 \tag{1.8}$$

Resistance Circles

The resistance circle, described by Eq. (1.7) has a radius

$$radius = \frac{1}{1+r_L} \tag{2.1}$$

and is centered at

$$(\Gamma_r, \Gamma_i) = \left(\frac{r_L}{1+r_L}, 0\right) \tag{2.2}$$

Let us calculate the radii and centers of the resistance circles for typical values of the normalized resistance r_L, [3]; this is shown in Table 1.

Figure 3 shows the plots of these circles on the complex Γ plane.

Observations: All circles pass through the point $(\Gamma_r, \Gamma_i) = (1,0)$. The largest circle is for $r_L = 0$, (which is the unit circle corresponding to). All circles lie within the bounds of Γ = 1 unit circle.

Let us identify some of these circles on the actual Smith Chart; this is shown in Figure 4.

The values of the normalized resistances corresponding to these circles are shown on the horizontal axis (and other places) of the Smith Chart as shown in Figure 5.

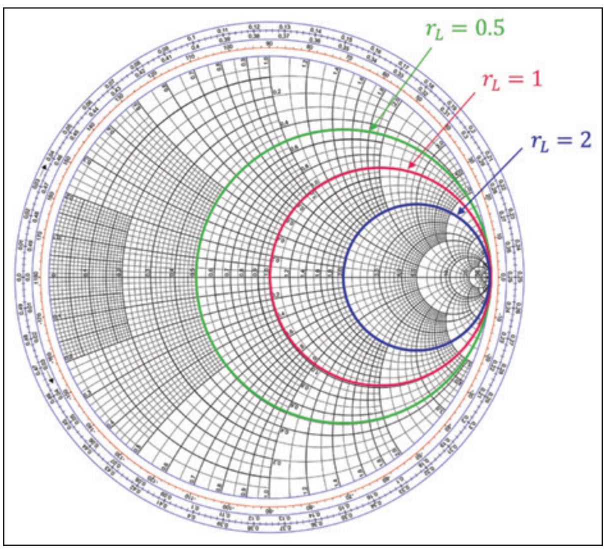

Figure 4: Selected *r*-circles on the Smith Chart

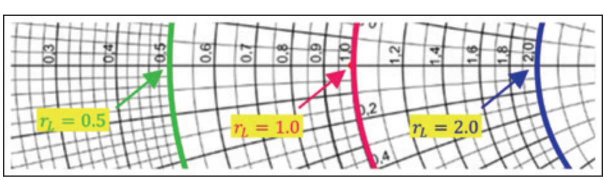

Figure 5: Normalized resistance values on the Smith Chart

REACTANCE CIRCLES

The reactance circle is described by

$$(\Gamma_r - 1)^2 + \left(\Gamma_i - \frac{1}{x_L}\right)^2 = \left(\frac{1}{x_L}\right)^2 \tag{3.1}$$

with the radius of

$$radius = \frac{1}{x_L} \tag{3.2}$$

centered at

$$(\Gamma_r - 1)^2 + \left(\Gamma_i - \frac{1}{x_L}\right)^2 = \left(\frac{1}{x_L}\right)^2 \tag{3.3}$$

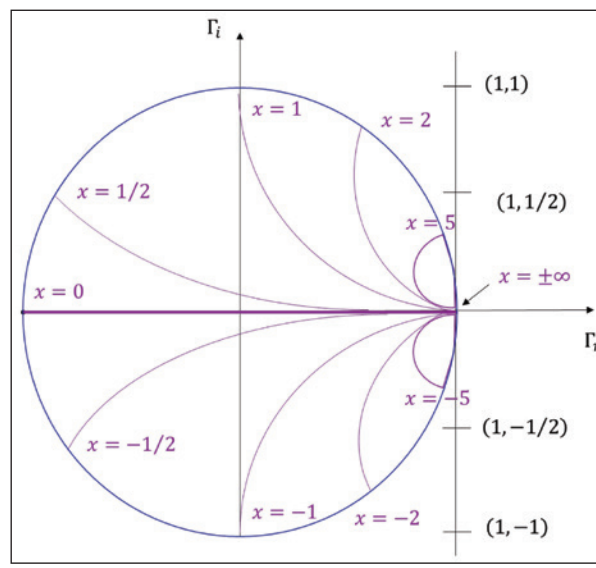

Figure 6: Typical *x*-circles

Normalized Reactance (x)	Radius $\left(\frac{1}{x}\right)$	Center $\left(1, \frac{1}{x}\right)$
0	∞	$(1, \infty)$
$\pm 1/2$	2	$(1, \pm 2)$
± 1	1	$(1, \pm 1)$
± 2	1/2	$(1, \pm 1/2)$
± 5	1/5	$(1, \pm 1/5)$
$\pm\infty$	0	(1,0)

Table 2: Radii and Centers of *x*-Circles

Let us calculate the radii and centers of the reactance circles for typical values of the normalized reactance x_L, [3].Note that unlike the normalized resistance (which is always non-negative), the normalized reactance can be positive (inductive load) or negative (capacitive load). Thus, Eq. (3.1) represents two families of circles, as shown in Table 2 and Figure 6.

Of interest to us is the part of a given reactance circle that falls within the bounds of

$\Gamma = 1$ unit circle.

Observations: The centers of all the reactance circles lie on the vertical $\Gamma_r = 1$ line. All reactance circles also pass through the $(\Gamma_r, \Gamma_i) = (1,0)$ point (just like the r_L circles).

Let us identify some of these partial circles on the actual Smith Chart; this is shown in Figure 7.

The values of the normalized reactances corresponding to these partial circles are shown on the perimeter circle (and other places) of the Smith Chart, as shown in Figure 8.

When we superimpose the resistance and reactance circles onto each other, we obtain Smith Chart shown in Figure 1.

The intersection of any *r*-circle with any *x*-circle corresponds to a normalized load impedance, as shown in Figure 9.

The next article will discuss the use of the Smith Chart in determining the input impedance to the transmission line at a given distance from the source or the load.

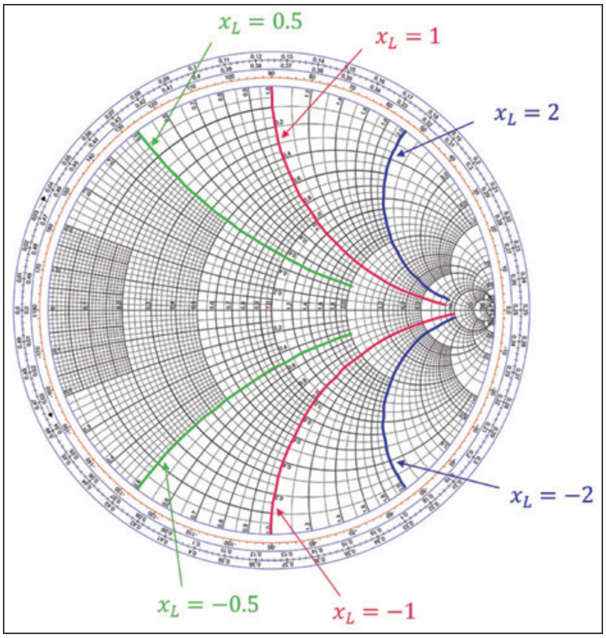

Figure 7: Parts of the selected x-circles on the Smith Chart

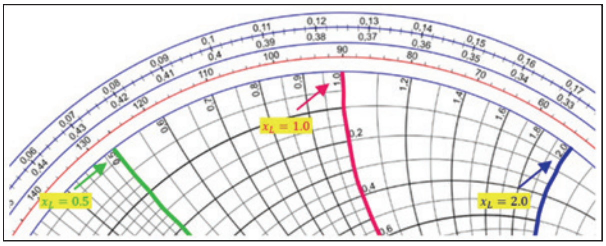

Figure 8: Normalized reactance values on the Smith Chart

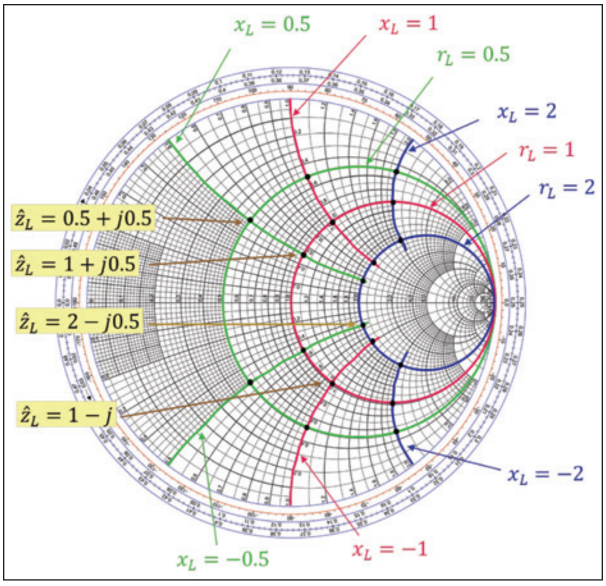

Figure 9: Normalized load impedance on the Smith Chart

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UPDATED TRENDS IN CHARGE DEVICE MODEL (CDM)

By Robert Ashton for EOS/ESD Association, Inc.


Robert Ashton is the Chief Scientist at Minotaur Labs, a provider of ESD and latch-up testing located in Mesa, Arizona. Robert is an active member of ESDA working groups for device testing standards and the JEDEC latch-up working group. He has been a regular member of the EOS/ESD Symposium technical program committee. He is currently serving as co-chair of the human metal model (HMM) working group.

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

Charged device events are by far the leading cause of electrostatic discharge (ESD) damage in modern electronics manufacturing facilities. If an integrated circuit contacts a conducting surface at a different potential, there is a discharge of current. Due to very low inductance and low resistance the discharge is very fast, often less than a nano second, but the currents can be up to several amps. Integrated circuits are required to have a certain level of robustness against charged device events to make them manufacturable. Charged device event robustness is measured using the charged device model (CDM) described in ANSI/JEDEC/ESDA JS-002-2022 [1]. In February 2021 Charvaka Duvvury and Alan Righter published an article in In Compliance Magazine outlining trends in CDM target levels and CDM testing [2]. Since that time, the Industry Council on ESD Target Levels released Version 3 of their white paper “A Case for Lowering Component-level CDM ESD Specifications and Requirements” (WP2 Version 3) [3]. This article provides an update on the trends discussed in the Duvvury and Righter article with insight from WP2 Version 3.

In the early days of CDM testing for reliability and qualification, the passing levels for qualification were often in the 500 V to 1000 V range. In 2009 the Industry Council on ESD Target Levels published the first version of their CDM white paper (WP2 Version 1) “A Case for Lowering Component-level CDM ESD Specifications and Requirements” [4]. WP2 Version 1 recommended 250 V as a reasonable target for CDM passing levels. WP2 Version 1 included significant data showing that with 250 V CDM levels integrated circuits could be handled in a manufacturing facility with basic ESD control with high yields. WP2 Version 1 also discussed how requiring higher passing levels restricted the level of performance that integrated circuits could obtain due to design constraints. Higher CDM levels require larger ESD protection circuitry and larger circuitry results in larger capacitance which restricts the bandwidth of high-speed interfaces. Since the release of WP2 Version 1 250 V CDM levels have largely been adopted by the electronics industry and there has been no negative impact from the adoption of 250 V CDM qualification levels.

In May of 2021, the Industry Council updated White Paper 2 to Version 3 (WP2 Version 3) [3]. WP2 Version 3 recommended a more nuanced approach due to advances and trends in the electronics industry. The Council continued to recommend 250 V CDM levels for most integrated circuits. For ultra-high-speed interface pins, however, the Council proposed a 125 V CDM level with the caveat that making the passing level as close to 250 V CDM as possible while meeting performance goals would have benefits in manufacturing. Figure 1, based on a figure from WP2 Version 3, summarizes the Council’s recommendations for CDM target levels as well as illustrates the ESD control levels provided by ANSI/ESD S20.20 [5], or similar ESD control standards IEC 61340-5-1 [6] and JEDEC JESD625 [7] as well as the advanced ESD process assessment procedures provided in ANSI/ESD SP17.1 [8].

WP2 Version 3 also discussed trends that are happening in the electronics industry that are going to continue to push CDM levels lower, placing more burden on manufacturers to control ESD to even more stringent levels. The remainder of this article will discuss those trends and the challenges they present.

a manufacturing environment. Integrated circuits with such high-speed interfaces should also be designed with the high-speed pins kept away from corners and edges of a package where they are most likely to experience charged device events.

ADVANCE TECHNOLOGIES AND ULTRA-HIGH-SPEED INTERFACES

Advanced technologies in the 7 nm and below range have even smaller ESD design windows to create ESD robust products. The ESD design window is essentially the voltage between maximum operating voltage and the voltage that will create permanent damage even for a very brief stress. A reduced ESD design window requires ESD protection structures with lower resistance, but lower resistance invariably results in higher capacitance as structures get larger. This conflicts with the push for higher speed interfaces.

High speed interfaces such as SerDes (Serializer/Deserializer) are pushing to higher and higher data rates such as 225 Gb/s. The maximum data rate versus capacitive loading from ESD protection circuitry is shown in Figure 2 as well as the CDM levels that can be obtained in the various data rate ranges. There is currently no way to design interfaces at such speeds and have 250 V CDM levels.

Handling integrated circuits with such high-speed data pins will require extra care in

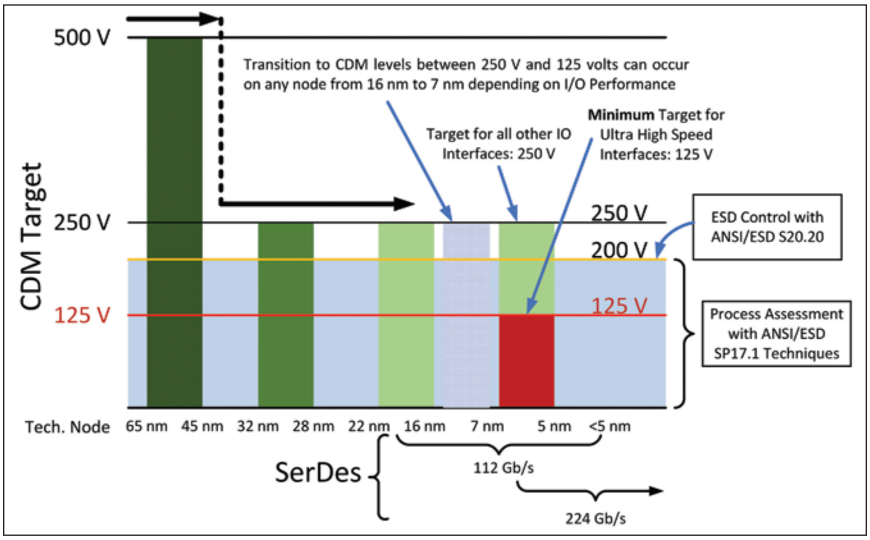

Figure 1: Graphical summary of the Industry Council's CDM target recommendations from WP2 Version 3.

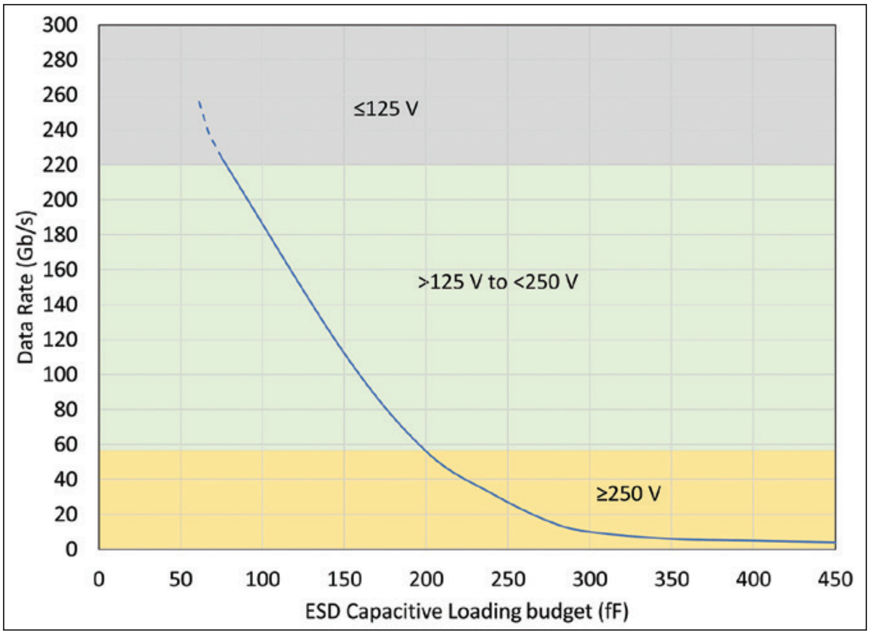

Figure 2: Data Rates of single lane SERDES vs. Allowed ESD Capacitive Loading Budget of high-speed IO circuits using non return to zero signaling. From [3]

2.5D AND 3D PACKAGES

Advanced packaging is presenting CDM challenges well beyond the 125 V CDM proposed for high-speed interface pins. 2.5D and 3D packages involve the stacking of integrated circuit dies within a package. The completed package will still require >125 V and 250 V CDM levels, but the interfaces between the dies in the package face their own CDM risks during manufacture. The die in 2.5D and 3D packages often have 10s to 100s of thousands of connections.

The density of interconnects restricts the area available for ESD protection elements resulting in even lower CDM robustness levels as illustrated in Figure 3. Copper micro bumps with pitches in the 40 μm to 10 mm range can only afford the area penalty which can deliver about 30 V or less of CDM robustness. Hybrid bonding, in which chips or wafers are bonded together with direct copper to copper connections, can be made with contact pitches well below 10 μm. With such fine pitches, the area available for ESD protection elements is reduced and it is only possible to provide CDM levels on the order of 5 V. Fortunately, these levels of factory control are only needed in a limited number of steps in a cleanroom environment, but the ESD control issues are extreme.

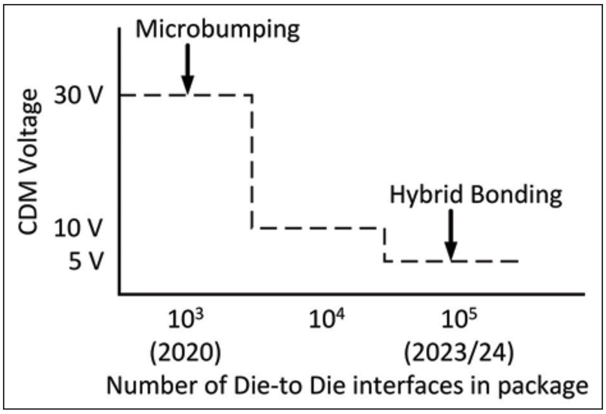

Figure 3: Expected die-to-die interface CDM robustness as the number of die-to-die interfaces in a package increases. Based on [3]

CDM TESTING

CDM testing is a challenge at low voltages. Given et. al. [9] have shown that at low voltage, the field induced CDM test method specified by JS-002 [1] gives very poor reproducibility in the stress waveform due to variability in the air discharge. Unfortunately, there is an increased need for accurate CDM measurements at low voltages. WP2 Version 3 encourages designers of ultra-high-speed buffers which cannot reach 250 V CDM not to drop their design target all the way to 125 V but to come as close to 250 V CDM as much as possible. Having the ability to accurately measure CDM levels between 125 V and 250 V with 10 or 20 V accuracy is therefore critical. Measuring CDM levels in the 10s of volts for 2.5D and 3D interfaces with the current field induced CDM from JS-002 is impossible. Fortunately, there are new developing options.

A modification of the field induced CDM has recently been introduced, Relay Pogo Contact CDM (RP-CCDM) [10]. In this method a small relay is included in the pogo pin of a field induced CDM tester. The method has been found to produce in specification waveforms but with significantly reduced variability at low voltages. This method promises to produce more reliable test results in the 100 V to 250 V range. Unfortunately, it is not expected that RP-CCDM will provide reliable measurements in the 10s of volts needed for 2.5D and 3D packaging.

Two other methods have also shown promise for low voltage CDM testing, low impedance contact CDM (LI-CCDM) [11] and capacitively coupled TLP (CC-TLP) [12]. Both methods use variations of very fast transmission line pulse testing to stress integrated circuit pins in which the stress is initiated in a relay removing the variability of air discharge. Additionally, both methods produce stress waveforms very similar to a CDM waveform but have very well controlled waveforms to low voltages. The two methods have been discussed in an earlier In Compliance article [13]. The challenge, especially for the Joint JEDEC/ESDA CDM working group which is responsible for JS-002, is to translate these two stress methods into equivalent CDM voltages. This work is underway in the working group.

Regardless of what low voltage CDM test method is selected by the industry, it will also be impossible to stress all interfaces of a silicon die intended for 2.5D or 3D as is common practice for standard packages. Some form of statistical sampling of interfaces will be needed. Additionally, functional testing of individual die intended for 2.5D or 3D application is an issue and performing ATE test after CDM testing may not be possible without completing the full package integration. It may be necessary to perform inference

As long as integrated circuits migrate to new technologies and advances are made in packaging more integrated circuit dies into a single package the CDM challenge is going to get harder.

tests on die-to-die interfaces on test chips and assume "correct by design" in actual products.

ESD FACTORY CONTROL

Regardless of what is done in terms of on-chip ESD protection design ESD factory control engineers will increasingly need to apply advanced ESD controls in assembly areas which in the past only needed basic ESD control. This will require additional efforts in terms of process assessment in all areas of a factory in which products with CDM levels below 250 V CDM are handled. The further below 250 V CDM, the more challenging the effort will be. The methods described in ANSI/ESD SP17.1 will need to be employed by a wider range of ESD manufacturing facilities.

SUMMARY

As long as integrated circuits migrate to new technologies and advances are made in packaging more integrated circuit dies into a single package, the CDM challenge is going to get harder. Circuit designers need to design for as high a CDM level as they can within the performance requirements of the product, factory ESD control experts will need to better understand the ESD risks in their processes and determine ways to maintain the lowest possible voltages, and ESD test engineers will need to develop test methods to accurately know the CDM robustness of the products being manufactured.

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FOUR USEFUL TIPS FOR USING AFFORDABLE BENCHTOP SPECTRUM ANALYZERS

By Dr. Min Zhang

Over the past few years, several equipment manufacturers have launched affordable benchtop spectrum analyzers that are useful for several aspects of EMI troubleshooting and pre-compliance work. These units are often priced between $1000 and $3000 (USD), depending on the frequency range and model types. In addition, some models include a few paid add-on options, such as a tracking generator, EMI filter, reflection loss bridge, etc. Among these options, the tracking generator and EMI filter are worth having if you do pre-compliance EMI work.

Wyatt has many blog articles on this subject including [1], and his "*EMC Troubleshooting Trilogy*" presents guidelines for selecting a spectrum analyzer. Another useful resource is Mayerhofer's "How to correctly use spectrum analyzers for EMC pre-compliance tests" [3]. Engineers can check out these articles (including the manufacturers' application notes) to familiarize themselves with a spectrum analyzer's basic and advanced functions.

In this column, we discuss several important features of a spectrum analyzer not covered in previous articles that are worth your consideration.

TIP #1: ALWAYS PERFORM A QUICK PRE-CHECK

Low-cost benchtop spectrum analyzers are particularly popular with small-to-medium companies that often don't have an EMC test engineer. But these EMI spectrum analyzers can often be "abused" in the following ways:

- When performing an EMI scan, the spectrum analyzer is connected to the LISN when the unit is turned on and off. This can be a problem because an inductive load's "kickback" voltage could introduce a significantly high level of transient voltage that may potentially damage the RF front of a spectrum analyzer. This also applies when the spectrum analyzer is connected to an RF current probe clamped on a motor winding.
- The EMI spectrum analyzer is used to measure conducted emissions from 150 kHz. Engineers notice the "ADC overload" measurement error during the measurement, but the measured signals often seem to be within the limit. This is most likely due to the high spurious levels of noise at relatively low frequencies. If the analyzer is left on during the measurement, there is a risk of damaging the analyzer.

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The components that often get damaged in low-cost benchtop spectrum analyzers are ESD-protective devices and the GaAs switches. The problem with a damaged front end is that the spectrum analyzer will appear to function okay because there will be readings across the spectrum. But the readings will be wrong (in terms of amplitude), and wrong harmonics also appear if the front-end ESD suppressors get destroyed.

Therefore, a quick pre-check of the spectrum analyzer is necessary. The procedure is simple and quick to perform. There are two ways of performing a pre-check.

- If the spectrum analyzer has enabled the tracking generator (TG) function, simply connect the TG output and the spectrum input using a coaxial cable and perform a TG scan. One should see a flat, straight line across the whole frequency range at the supplied TG power level (often between -20 dBm and 0 dBm). This is shown in Figure 1.

- If the spectrum analyzer does not feature the TG function, simply connect a function generator/signal generator to test a few selected frequency points. This requires a high-performance generator (to ensure the output waveform is sinusoidal).

TIP #2: USE TRANSIENT LIMITERS/HIGH PASS FILTERS/EXTERNAL ATTENUATORS

Knowing the potential risks of damaging the RF input stage of a spectrum analyzer, engineers often need to protect the equipment using some passive devices.

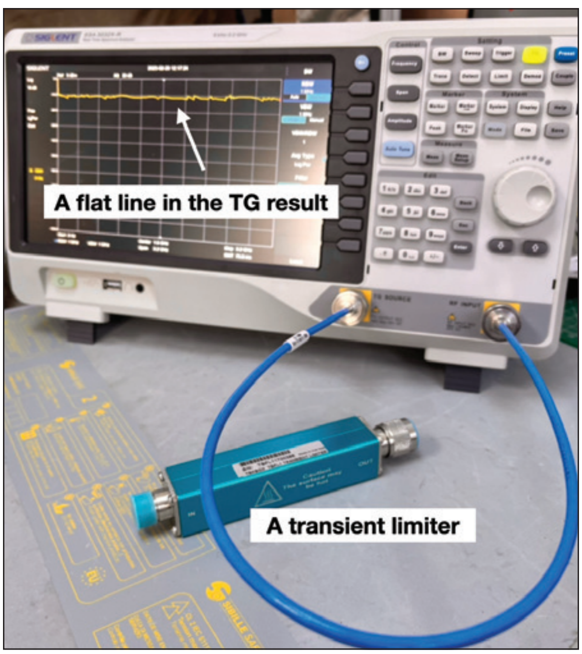


Figure 1

The popular device choices are transient limiters, high pass filters, and external attenuators. Effective as they are, consider the following issues when using these passive devices.

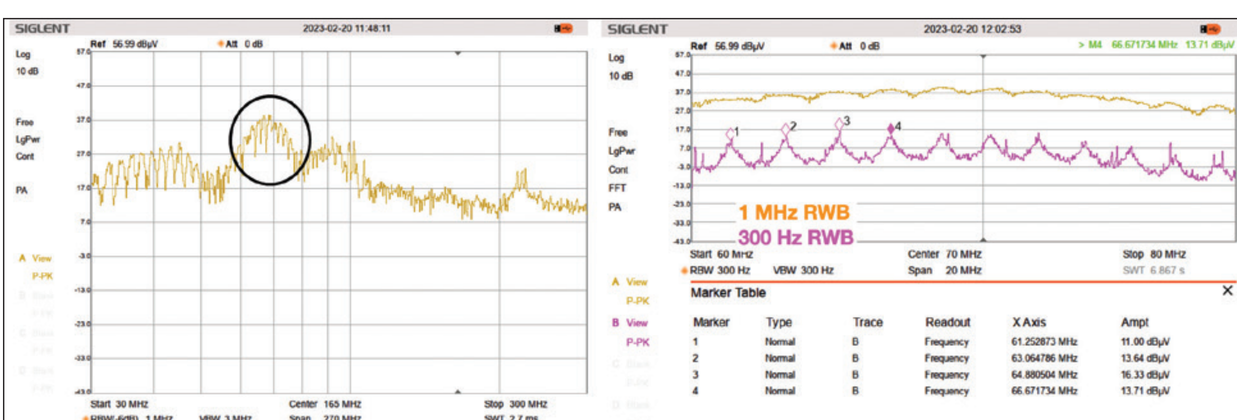
- Transient limiters and high-pass filters can introduce measurement errors and should be used cautiously [4].
- External attenuators do not have diode clipping issues, but they raise the spectrum analyzer's noise floor, reducing the system's sensitivity.

When using these passive devices, a "software" compensation value must be applied to the final measurement results. A common mistake is that the external factor is not scaled into the final result, causing a 10 dB or more difference in measurement.

TIP #3: "ZOOM IN" AND REDUCE THE RBW

An oscilloscope allows us to zoom in on the details of a time-domain signal. A spectrum analyzer can also be "zoomed-in," so a great detail hidden in the spectrum plot can be reviewed.

A typical case involves a radiated emission test, in which a resonance peak is observed in the frequency range of 60 and 80MHz in the plot of 30 – 300 MHz. To find the noise source that resonates at this frequency range, we can reduce the measurement range to this narrow frequency region and reduce the resolution bandwidth (RBW), as shown in Figure 2. In this case, a switching frequency of 1.8 MHz was observed, which pointed to a switched-mode power supply on the board under test.



(a) A resonant peak between 60 and 80 MHz (b) Reduce the frequency span and RBW

Figure 2

> Engineers should always be aware that spectrum analyzers produce RF noise. The mains cable of the spectrum analyzer conducts and radiates RF noise in the frequency range of 1 MHz and 300 MHz.

TIP #4: BE AWARE OF THE NOISE GENERATED BY THE SPECTRUM ANALYZER

Inexpensive benchtop spectrum analyzers are infrequently used in an anechoic chamber, so the measured results are always subject to ambient noise. Ambient noise is generated by nearby equipment, lighting in the room, and cables connected to the mains power supply.

There are effective ways of reducing ambient noise, which we'll discuss in detail in our next "Troubleshooting" column. But, in brief, engineers should always be aware that spectrum analyzers produce RF noise. The mains cable of the spectrum analyzer conducts and radiates RF noise in the frequency range of 1 MHz and 300 MHz. This can be measured by connecting an RF current probe on the mains cable.

Engineers who perform the test should differentiate the noise from the DUT and the test equipment used. In one case, when the author was testing a motor drive cable noise, the RF noise from the spectrum analyzer was coupled to the motor cable being measured, which led to misleading information.

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