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FCC Denies Amateur Operator Appeal to File Petition due to Length

The maximum length for an appeal is 25 pages

The U.S. Federal Communications Commission (FCC) has denied a request from an amateur radio operator in California seeking to file an excessively long petition in connection with the dismissal of his amateur license renewal application.

According to an Order issued by the Commission in late August, the petitioner, William F. Crowell, sought permission to file a petition in excess of 25 pages related to an Order by a Chief Administrative Law Judge (ALJ) in early July dismissing his amateur license renewal application. Under Commission rules, appeals of a dismissal order issued by an ALJ are limited to 25 pages. But Crowell asserted that his appeal "involves approximately 16 important issues of Constitutional, statutory and regulatory interpretation applicable to the amateur radio service," and requested permission to file a 35-page appeal.

Under the Order, the Commission denied Crowell's request, stating that the ALJ's six-page dismissal "does not suggest that the issues involved here are unusually complex."

Crowell has reportedly engaged with the FCC over a variety of issues related to his amateur status. According to a posting on the ARRL website, Crowell has sought the disqualification of the ALJ assigned in connection with his license renewal for 10 years, claiming bias. More recently, Crowell was also fined $25,000 by the FCC in 2016 for intentionally interfering with the transmission of other radio amateurs. Crowell did not deny making the transmissions, but argued that "those transmissions were protected by the First Amendment of the Constitution."

FDA Streamlines Device Malfunction Reporting

As part of its effort to streamline the process for reporting malfunctioning medical devices, the U.S. Food and Drug Administration (FDA) has finalized a new program that will allow quarterly reporting of malfunctions on a selected basis.

In a press release issued by the FDA, the agency says that it has finalized the terms of its Voluntary Malfunction Summary Reporting Program. Under the Program, manufacturers of medical devices with eligible product codes will be allowed to submit certain device malfunction medical device reports (MDRs) on a quarterly basis and in summary form.

The FDA says that the Program is expected to significantly reduce the number of reports that those manufacturers will be required to submit to the agency, while still providing the FDA with sufficient information to monitor the safety of medical devices on the market. The FDA also says that the new approach to malfunction reporting may also make it easier for the general public to understand related medical device malfunctions, since they will be grouped together in the summary reports.

The FDA notes that only manufacturers of medical devices bearing product codes that have existed for at least two years are potentially eligible to participate in the Program.

More Than "Seven Dirty Words"?
(From our "You Can't Make This Stuff Up Department")

Our guess is that few people remember the late comedian George Carlin's 1972 skit generally entitled "Seven Words You Can Never Say on Television" (and even fewer people remember what Carlin's seven words were!) Nevertheless, the U.S. Federal Communications Commission (FCC) has decided to name its newly launched podcast series "More Than Seven Dirty Words."

According to a press release issued by the FCC, the new series will "feature interviews with FCC officials and staff and others in the communications space to share untold stories, explain important policy issues, and maybe even do the impossible: make telecom interesting!!! (We've added the emphasis and exclamation marks here!)

The FCC has posted on its website a brief (4 minute) introduction to the podcast series, as well as the first episode about the FCC's response to the devastation wrought by Hurricane Irma and Hurricane Maria on Puerto Rico last September. You can access the podcasts at https://www.fcc.gov/news-events/podcast.

As for Carlin and his "seven words," it is widely reported that his routine ultimately led to the U.S. Supreme Court decision in FCC v. Pacifica Foundation in 1976 that detailed the authority of the FCC in dealing with broadcast content deemed indecent. You can view Carlin's original "seven words you never say on television" skit on YouTube.

TRANSMISSION LINE REFLECTIONS: BOUNCE DIAGRAM

By Bogdan Adamczyk

This article explains the creation of a bounce diagram for a transmission line circuit (see [1] for transmission line reflections).

Consider the circuit shown in Figure 1.

When the switch closes the forward voltage wave travels toward the load and reaches it at $t = T$ (T = one-way travel time). Since the line and the load are mismatched a reflection is created and travels back to the source, reaching it at $t = 2T$ *(assuming zero rise-time)*. Since the line and the source are mismatched, another reflection is created which travels forward to the load reaching it at $t = 3T$.

This process theoretically continues indefinitely; practically, it continues until the steady-state voltages are reached at the source and at the load. A *bounce diagram* is a plot of the voltage (or current) at the source or the load (or any other location) after each reflection.

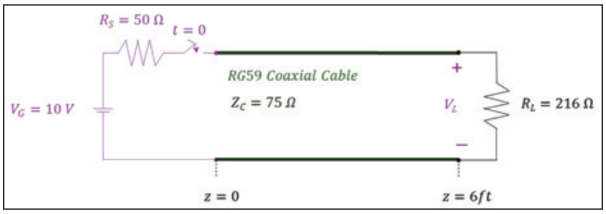


Figure 1: Circuit used to create bounce diagram

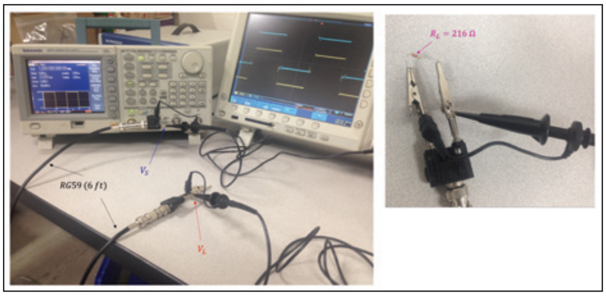


Figure 2: Experimental setup

Dr. Bogdan Adamczyk is a professor and the director of the EMC Center at Grand Valley State University (http://www.gvsu.edu/emccenter) where he performs EMC precompliance testing for industry and develops EMC educational material. He is an iNARTE certified EMC Master Design Engineer, a founding member and the chair of the IEEE EMC West Michigan Chapter. Prof. Adamczyk is the author of the textbook "Foundations of Electromagnetic Compatibility with Practical Applications" (Wiley, 2017). He can be reached at adamczyb@gvsu.edu.

The experimental setup for reflection measurements is shown in Figure 2.

The initial voltage at the location $z = 0$ is

$$V^{+} = V_G \frac{Z_C}{R_S + Z_C} = (10)\frac{75}{50+75} = 6\,V$$

This is shown in Figure 3.

The reflection coefficient at the load is

$$\Gamma_L = \frac{R_L - Z_C}{R_L + Z_C} = \frac{216-75}{216+75} = 0.4845$$

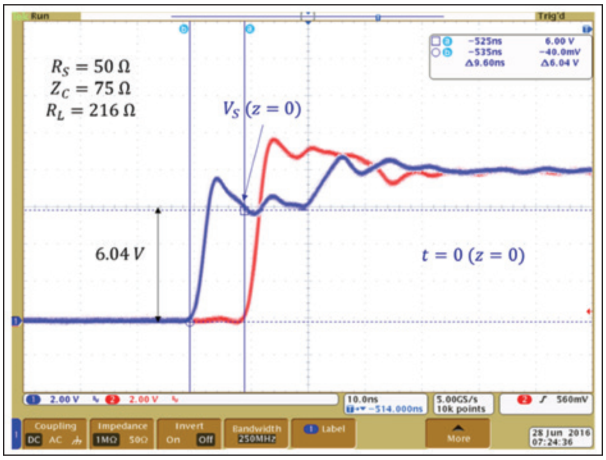


Figure 3: Initial voltage wave at $z = 0$

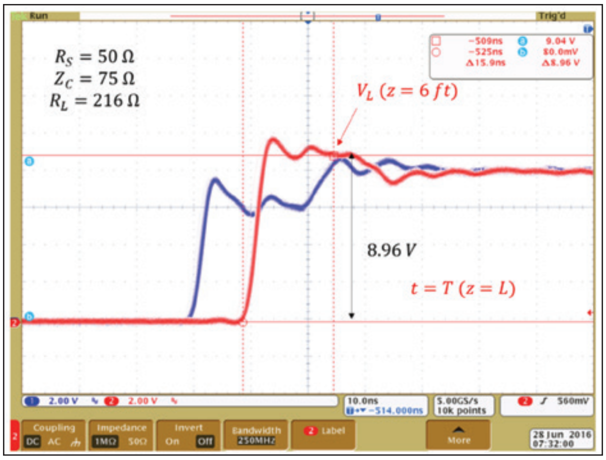


Figure 4: Voltage at the load at $t = T$

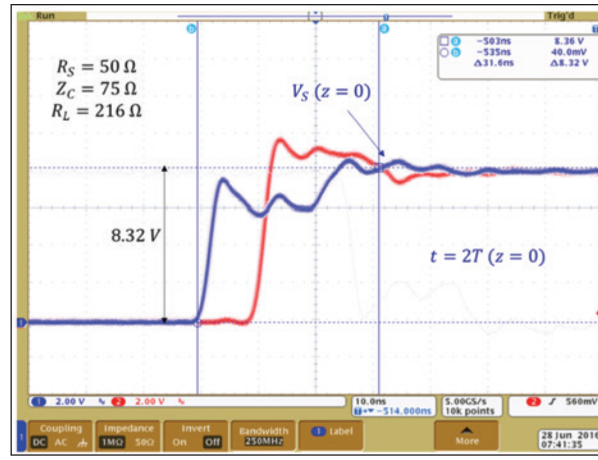


Figure 5: Voltage at the source at $t = 2T$

The initial voltage wave of $6V$ travels to the load and reaches it at $t = T$ creating a reflection

$V^- = \Gamma_L V^+ = (0.4845)(6) = 2.907\ V$

The total voltage at the load (at $t = T$) is

$V_L = V^+ + V^- = 6 + 2.907 = 8.907\ V$

This is shown in Figure 4.

Voltage reflected at the load ($V^- = 2.907\ V$) travels back to the source. The reflection coefficient at the source is

$$\Gamma_S = \frac{R_S - Z_C}{R_S + Z_C} = \frac{50 - 75}{50 + 75} = -0.2$$

The re-reflected voltage at the source is

$V^{-+} = \Gamma_S V^- = (-0.2)(2.907) = -0.5814\ V$

The total voltage at the source at $t = 2T$ is

$V_S = V^+ + V^- + V^{-+} = 6 + 2.907 - 0.5814 = 8.3256\ V$

This is shown in Figure 5.

The voltage reflected at the source ($V^{-+} = -0.5814\ V$) travels toward the load where it will create another reflection which will travel toward the source. This process will continue until the steady-state is reached.

The bounce diagram showing the voltages at the source and the load after each reflection is shown in Figure 6.

Figure 7 shows the voltages at the source ($z = 0$) while the Figure 8 shows the voltage at the load ($z = L$) during the period $0 \le t < 8T$.

It is apparent the source and load voltages eventually reach the steady state. Recall that a transmission line can be modeled as a sequence of in-line inductors and shunt capacitors (assuming a lossless line) [2], as shown in Figure 9.

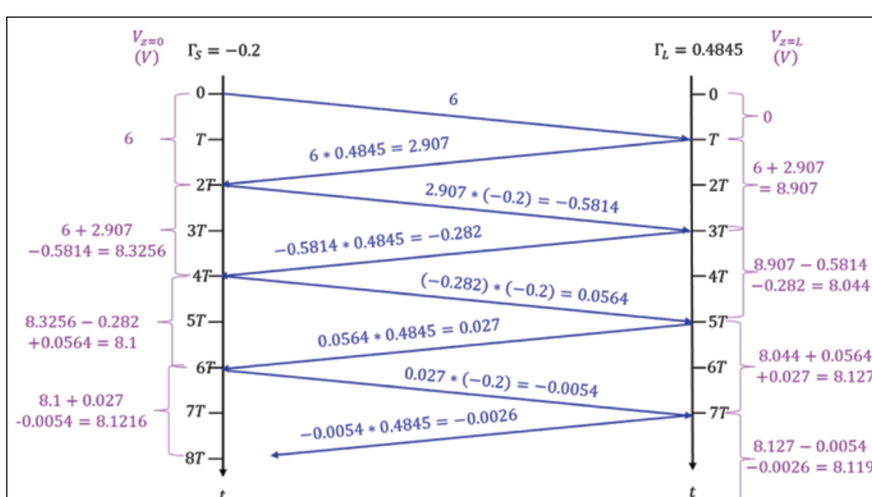


Figure 6: Bounce diagram: voltages at the source and the load

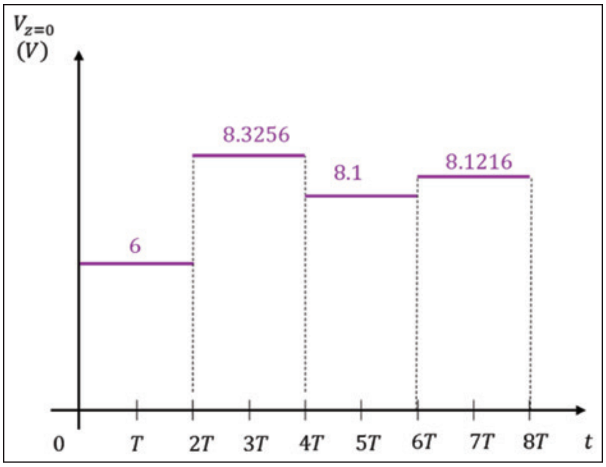


Figure 7: Voltage at the source during $0 \le t < 8T$

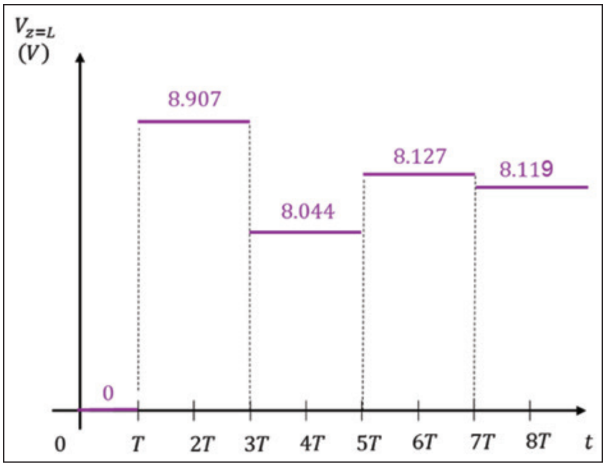


Figure 8: Voltage at the load during $0 \le t < 8T$

Under dc conditions (steady-state when driven by a dc source) inductors act as short circuits and capacitors act as open circuits.

Thus in steady state the circuit in Figure 1 is equivalent to the circuit in Figure 10 where the transmission line is modeled as an ideal conductor.

The steady state value of the voltage at $z = 0$ is the same as the value at $z = L$ and can be obtained from the voltage divider as

$$V_{SS} = \frac{216}{50+216}(10) = 8.1203\ V$$

Note that both the source and the load voltages converge to this value as the reflection process approaches a steady state.

REFERENCES

1. Adamczyk, B., *Transmission Line Reflections at a Resistive Load*, In Compliance Magazine, January 2017.
2. Adamczyk, B. *Foundations of Electromagnetic Compatibility with Practical Applications*, Wiley, 2017.

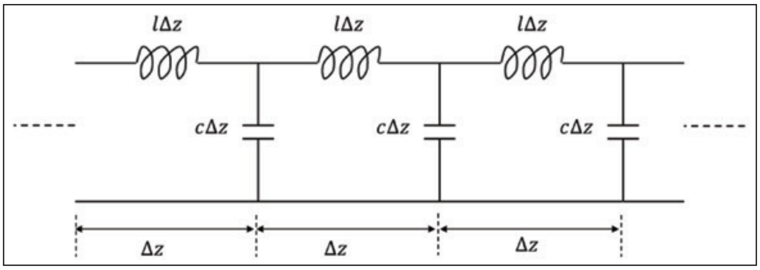


Figure 9: Circuit model of a lossless transmission line

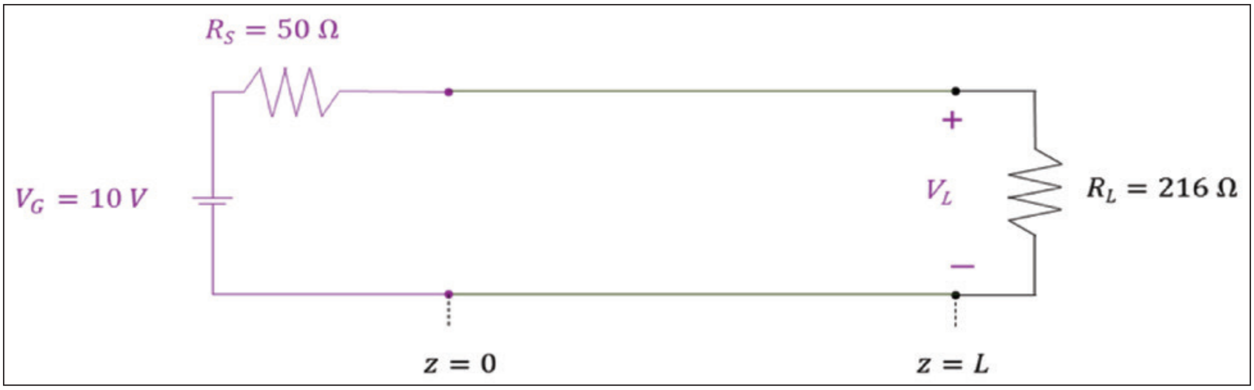


Figure 10: Equivalent circuit in steady state

ABSENCE OF IC ESD SENSITIVITY DATA HAS REACHED A CRITICAL STAGE

By Ted Dangelmayer on behalf of EOS/ESD Association, Inc.

ESD sensitivity data is not readily available to the public from IC suppliers to determine if a company's ESD control program can handle its components. A recent review of publicly available datasheets revealed that an estimated 70% of datasheets included HBM withstand voltages and an estimated 10% included CDM sensitivities. This is creating a serious problem that is escalating rapidly with technology advancements as discussed further in Section 3.0. It is essential to know when component sensitivities fall below manufacturing capability levels. Both manufacturing and board level design teams need this information in a timely manner to avoid quality and reliability excursions.

EOS/ESD ASSOCIATION, INC. INITIATIVE

The absence of device ESD sensitivities in the public domain has reached a critical stage as demonstrated through IC threshold trends and in the case study discussed in this article. EOS/ESD Association, Inc. (ESDA) started an initiative to encourage IC suppliers to make the data readily available. ESDA formed a small group of industry leaders to evaluate and recommend actions to address the lack of data concern. This article is one of the actions aimed at educating the industry, including IC suppliers, of the importance of making device ESD sensitivities available in the public domain. Another action was the development of a new standard practice by ESDA's standards working group WG5.0 – Device Testing. The final document is expected to be released in late 2018/early 2019 and will be designated "ANSI/ESD SP5.0-2018 - Reporting ESD Withstand Levels on Data Sheets." This document was written by industry experts with the intent to provide IC suppliers with guidelines that could be used to publish the data and a common representation of the information so that device users know what to expect. Other standards device testing working groups are looking into the possibility of adding requirements for manufacturers to have a process for obtaining ESD device sensitivity data. The ESDA/JEDEC joint working groups for HBM and CDM standards are considering a statement that would strongly recommend that publicly available product datasheets report minimum CDM and HBM sensitivities.


Ted Dangelmayer is the president of Dangelmayer Associates, LLC and has assembled an ESD consulting team consisting of the foremost authorities in virtually all ESD areas of both product design and manufacturing. He is currently president of the Northeast local chapter of EOS/ESD Association, Inc., a member of the ESDA education Council, ESDA Marketing Team, Advanced Technologies Team and ESDA Publicity Team.

IC DEVICE THRESHOLD TRENDS

This section is a reproduction (with some modification) of the ESD Technology Roadmap [1].

The requirements for increased performance (devices that operate at 1 GHz and higher) and the increase in the density of circuits (Moore's Law) on a device caused problems for traditional ESD protection circuits. This has been exacerbated with the continued scaling of the technologies toward sub-22 nm feature sizes in order to achieve higher density and performance. As a result, both human body model (HBM) and charged device model (CDM) target levels had to be lowered to accommodate these features. Also, radio frequency (RF) circuit operations will continue their growth, with these pins only tolerating a very low capacitive load from ESD cells. Due to these trends, ICs are expected to become even more sensitive to ESD events in the years 2020 and beyond. Therefore, it is anticipated that the prevailing trend will continue in this manner for meeting increased circuit performance demands at the expense of the designed ESD protection levels.

EOS/ESD Association, Inc. Device ESD Threshold Roadmaps

The following graphs show the device ESD design sensitivity trends based on the most relevant and important ESD models used by device manufacturers as part of the device qualification process: HBM and CDM. The sensitivity limits are a projection by engineers from leading semiconductor manufacturers.

Human Body Model (HBM) Roadmap

The projections for HBM design (typical min and max) are indicated in Figure 1. Although design improvements were made from 1978 through 1993, representing a learning curve process, advanced circuit performance effects started to take place around this time, eventually degrading the levels. The max levels represent what is typically possible from technology scaling for designs without the high-speed circuit performance requirements, and min levels represent the constriction coming from designs needing to meet the high-speed circuit performance demands.

ESDA Charged Device Model (CDM) Roadmap

The technology impact on CDM not only comes from the required IO speeds but also from package size effects. Larger packages will experience higher discharge currents at a given stress voltage level. Although the chart does not cover all IC package types, Figure 2 illustrates the combined IO design and package effect as projected for a 22 nm technology node. The color scheme adopted in Figure 2 is based on the validation that 250 volts CDM is safe for production areas [2]. This map would change as the technology is further scaled or package sizes become even larger. For example, note that for today's packages of 3000 pins (~3000-3500 mm^2) or more (not uncommon for a microprocessor) in a land grid array (LGA) or ball grid array (BGA), high speed IOs at the 22 nm node would barely meet a CDM target level of 125 volts. An additional package effect, decreasing thickness, was not included here for simplicity. In the figure, the current values indicated for each type of IO design represent the maximum withstand current value for meeting the performance constraints at the I/O based on the particular IO design. These design current values are then translated into CDM voltage levels that are possible to meet depending on the package size variations.

Based on the above, the projections for CDM sensitivity levels (typical min and max) are indicated in Figure 3 on page 14. As shown in the figure, the CDM target has been modified to 250 volts, reduced from the previous 500 volts. But a target of 125 volts will be realistically needed in the future.

A closer observation Figure 3 might suggest that as we look ahead to 2020, there will really be no significant change in the typical range for CDM sensitivity limits. While the belief is that the *range* may not

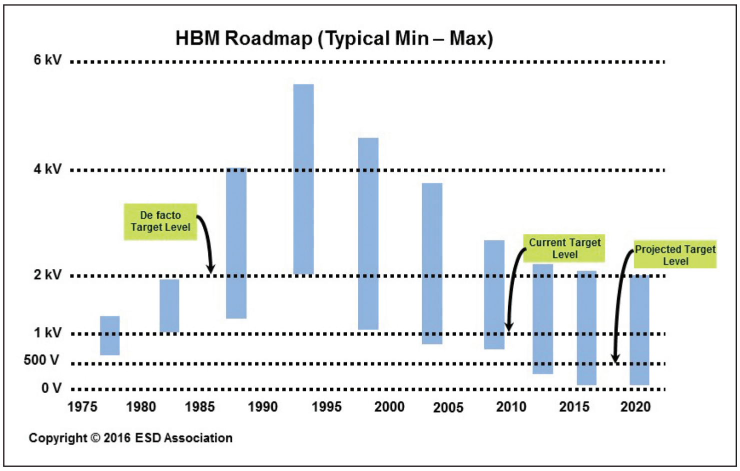


Figure 1: Overall Human Body Model Sensitivity Limits Projections

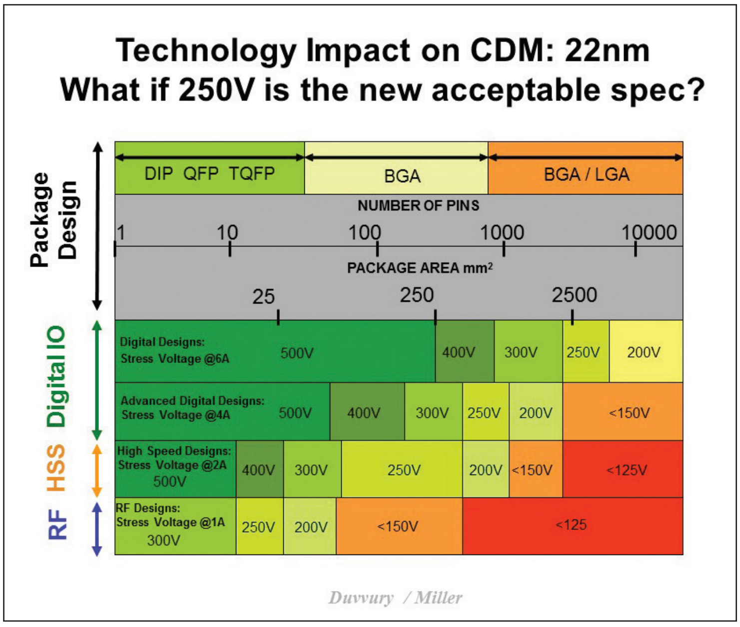


Figure 2: Combined Projected Effects of Technology Node (22 nm), IO Design, and IC Package Size on CDM

change dramatically by 2020, the *distribution* of products within this range may vary with a change in the mix of companies remaining on today's traditional technologies and those who continue to push for technology advancements through the need for higher performance devices and growth in package size/complexity through multichip packages such as 2.5D and 3D [3, 4]. Figure 4 is a first look into how this distribution of products could conceivably look by 2020. The bottom *two* groups for CDM distributions are of higher concern. Thus, the industry needs to be better prepared for a relatively larger population of sensitive CDM devices by the year 2020.

CASE STUDY: CIRCUIT BOARD MANUFACTURING STOPPAGE DUE TO LACK OF ESD SENSITIVITY DATA [5]

A new circuit board design was introduced to manufacturing without device ESD sensitivity data. As a result, manufacturing was unaware that a high-speed device on the board had a 15 V CDM sensitivity, which is well below the scope of ANSI/ESD S20.20. The result was extreme fluctuations in circuit board assembly yields (Figure 5) during ramp up of a one-billion-dollar product line. Between the months of June and September, the removal rate varied dramatically between 10 and 30 percent. In actual lot-to-lot observation, *some lots showed 100-percent drop out*.

Due to the high failure rate of these devices, the cost implications were very high. Therefore, a detailed investigation was undertaken. Through failure analysis, it was confirmed that the devices were failing due to ESD damage. A special detailed audit was conducted, and a team of people experienced in different aspects of the issue were consulted. An assessment of the manufacturing line was undertaken and corrective actions aimed at general improvements of the existing ESD control process were compiled. Based on that action plan, a task force was assembled and assigned to correct deficiencies in the line and to provide status reports weekly to executives. Because of the extreme seriousness of this situation, the weekly reports were channeled to high-level executives in the company.

Initially, many special handling precautions were added or enhanced (Table 1) totaling over $300,000. Yet, even with this special attention and with the fullest compliance with the procedures, yields continued to fluctuate dramatically from June through September (Figure 5).

The solution to this problem was found in the introduction of a customized "shunt" which consisted of a static dissipative foam cover for the device configured to tie all device leads together. The shunt was placed on top of a device immediately after the solder reflow oven where it remained until electrical test. The yields improved dramatically and approached 98%.

The simplicity of this solution is particularly striking in contrast to more complex and costly alternatives. The incremental cost for the shunt was $1,000. The annual dollar savings realized on the production line reached $6.2 million per year for this one device on this one line.

One additional benefit derived from this case was the impact that it had on the design community. Asked to justify a withstand voltage of 10 volts CDM, designers responded by redesigning the device and raising the level of sensitivity to 750 volts HBM and 100 volts CDM, a remarkable accomplishment. Board level design changes were made to accommodate the capacitive load from the new protection circuitry and maintain the system performance.

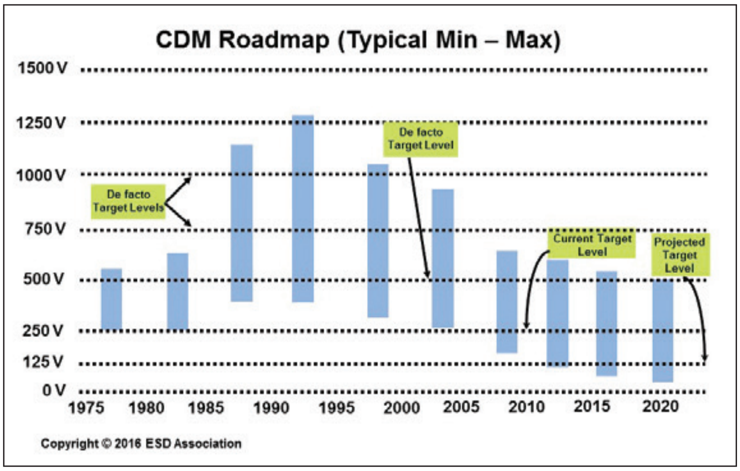


Figure 3: Overall Charged Device Model Sensitivity Limits Projections

If the device sensitivity had been known prior to initial production, this crisis could have been averted. The device could have been redesigned and/or it would have been possible to anticipate the challenges in production. A more orderly set of counter measures could have been phased in, evaluated and refined without the extraordinary time sensitive pressure during ramp up of a billion-dollar product line.

CONCLUSION

With the downward trend in IC ESD thresholds as discussed, it is essential to know, prior to initial production, when component sensitivities fall outside the scope of the document. The absence of device ESD sensitivity data in the public domain has reached a critical stage and will only worsen with technology trends towards the expanding use of extreme ESD sensitivities. Therefore, it is strongly recommended that manufacturing quality executives require notification of any such devices to avoid a production crisis such as the case study described above. Likewise, it is strongly recommended that IC suppliers make the data readily available either in publicly available data sheets utilizing the standard practice being developed by EOS/ESD Association, Inc. or in other documentation in the case of custom devices.

REFERENCES

1. ESD Technology Roadmap; https://www.esda.org/standards/complimentary-downloads/view/1869.
2. Industry Council on ESD Targets, White Paper 2: "A Case for Lowering Component Level CDM ESD Specifications and Requirements," March 2009, http://www.esda.org/white-papers.
3. Global Semiconductor Alliance, "Electrostatic Discharge (ESD) in 3D-IC Packages", Version 1.0, January 2015, http://www.gsaglobal.org/working-groups/3d-ic-packaging.
4. Nagata, M.; Takaya, S.; Ikeda, H.; Linten, D.; Scholz, M.; Chen, S.; Hasegawa, K.; Shintani, T. and Sawada, M. 'CDM protection of a 3D TSV memory IC with a 100 GB/s Wide I/O data bus', Proceedings EOS/ESD Symposium, 2014, p. 61 – 67.
5. ISBN 0-412-13671-6, G. Theodore Dangelmayer, ESD Program Management, 2nd Edition, p 63, 1999.

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

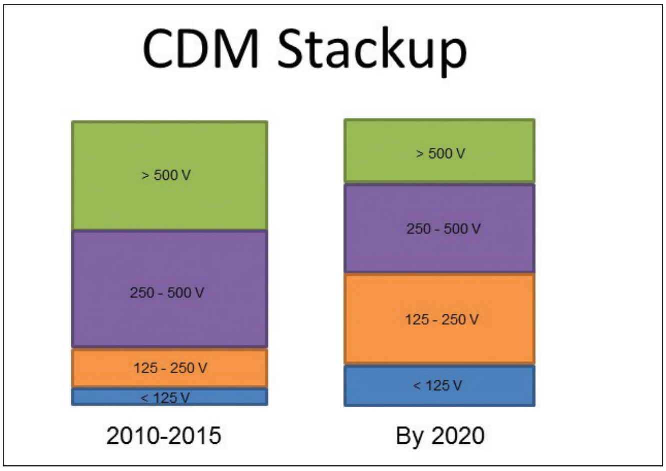


Figure 4: Forward Looking Charged Device Model Sensitivity Distribution Groups

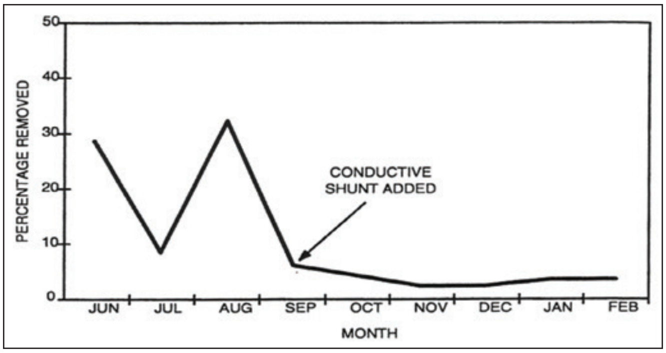


Figure 5: Circuit Board Assembly Yield Variation Due to ESD Damage

Enhanced ESD Training for Class 0	Added
ESD Flooring & Footwear	Enhanced
ESD Chairs, Garments, Carts	Enhanced
Room Ionization & Bench Top Ionizers	Enhanced
Constant Wrist Strap Monitors	Added
Daily SPC to Ensure Compliance to Procedure	Added
Dissipative Handling Materials & Containers	Enhanced

Table 1: Added or Enhanced Special Handling Precautions Totaling over $300K

LABEL EXPECTED LIFE, MAINTENANCE AND REPLACEMENT

By Erin Earley

Considerations for Safety Labels that are Visible Throughout the Lifecycle of Your Equipment and Products

So often in these 'On Your Mark' columns, we focus on product safety label design, like the intricacy of details surrounding symbols, language, comprehension and color. But there's a basic, physical element to consider that can have a large effect on both user safety and product liability exposure: the materials used to print your label. Even the best designed label is inadequate if it isn't durable. A safety label must be seen – and seen clearly – in order to be understood. This article will explore safety label expected life, maintenance and replacement, for labels that are visible throughout the lifecycle of your equipment and products.

Erin Earley, head of communications at Clarion Safety Systems, shares her company's passion for safer products and workplaces. She's written extensively about best practices for product safety labels and facility safety signs. Clarion is a member of the ANSI Z535 Committee for Safety Signs and Colors, the U.S. ANSI TAG to ISO/TC 145, and the U.S. ANSI TAG to ISO 45001. Erin can be reached at eearley@clarionsafety.com.

GUIDELINES FROM ANSI Z535

The ANSI Z535.4 Standard for Product Safety Signs and Labels, part of the overarching consensus standards that define today's best practices in the field of visual safety communication in the U.S., includes a section on "Expected life and maintenance" to help guide product manufacturers. ANSI Z535.4 states the following regarding product safety labels:

- **On "Expected life":** *"…shall have a reasonable expected life with good color stability, symbol legibility, and word message legibility".* Reasonable expected life should take into consideration whether the label *"…is permanent or temporary, the expected life of the product, and the foreseeable environment of use."* ***[ANSI Z535.4, Section 10.1]***
- **On "Maintenance":** *"…should be periodically inspected and cleaned by the product user as necessary to maintain good legibility for safe viewing distance…"* ***[ANSI Z535.4, Section 10.2.1]***
- **On "Replacement":** *"…should be replaced by the product user when they no longer meet the legibility requirements for safe viewing distance...In cases where products have an extensive expected life or where exposed to extreme conditions, the product user should contact either the product manufacturer or another source to determine a means for obtaining replacement signs or labels."* ***[ANSI Z535.4, Section 10.2.2]***
- **On "Product user instructions":** *"The manufacturer should include information on maintenance or replacement of safety signs or labels…"* as detailed in the sections of the standard noted above. ***[ANSI Z535.4, Section 10.2]***

YOUR PRODUCT'S LIFECYCLE – AND HOW RISK ASSESSMENT FACTORS IN

A key area to focus on from ANSI Z535.4 is that the expected life of the label should take into consideration the product's expected environment of use and lifecycle. If a label is faded or missing altogether, its warning, safety message or instructions are compromised. See Figure 1. Degradation can occur at any point over the product's lifespan. This is where your risk assessment process comes into play.

A thorough risk assessment will identify potential hazards and control actions related to them to protect those who interact with your product during its anticipated lifecycle: from delivery, installation, use and service to decommissioning and disposal. The durability and visibility of a label is directly related to the life of your product.

KEY CONSIDERATIONS FOR MAINTAINING LABEL INTEGRITY

When it comes to the real-world application of following today's best practices to ensure that your labels are visible throughout the lifecycle of your equipment and products, it's helpful to focus on three key areas:

- **Conduct a thorough risk assessment.** Accounting for the products' entire lifecycle, as noted above, will help to identify and determine specific label material needs. The key to choosing the right materials for your labels revolves around knowing the expected environment of use, the anticipated lifespan of the product, and the space restrictions and characteristics of the surface it's mounted on. Once these variables have been defined, a selection of materials can be tested for use.
- **Give thoughtful consideration to quality materials for the application at hand.** A typical label has numerous layers, all of which must be compatible with one another – and mindful of the application environment and exposure to foreseeable damage, which can occur from abrasion or wash-down procedures – to ensure a long life. See Figure 2. Common problems associated with labels include fading inks, degrading overlaminates, and use of the wrong adhesives. With electrical products, heat is often a concern as is corrosive chemicals – two of the main culprits behind destruction of a label's materials and adhesive. To achieve your durability objectives, an understanding of environmental and surface conditions, as well as the latest high-quality material options available, is needed.
- **Plan for maintenance and replacement.** Once your label or system of labels has been created, plan for continued durability maintenance. For product manufacturers, that means including information on maintenance, replacement, and installation of labels in collateral material provided with the product. That way, the end user can follow your recommended procedures for regular label reviews, and replacement as needed. It's not unusual for an end user to have personnel or third parties tasked with reviewing labels 'in the field' to identify and replace those with issues; your documentation can help account for key considerations and streamline the review and replacement process.

Remember, visibility is the first and last component of a legally "adequate" warning. Ultimately, your product user's safety, and your company's liability, depend on the durability and maintenance of your safety labels.

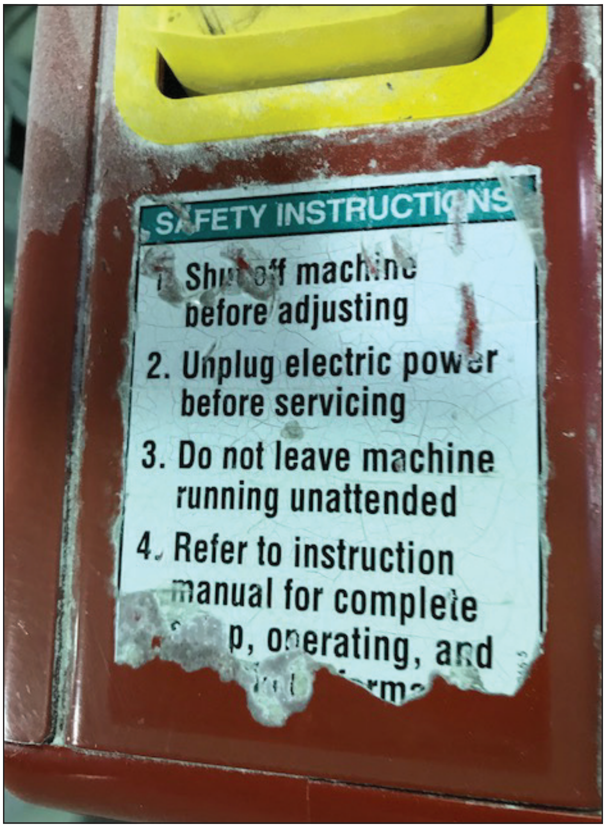


Figure 1: Example of a safety label that did not hold up to the life of the product and its environment of use

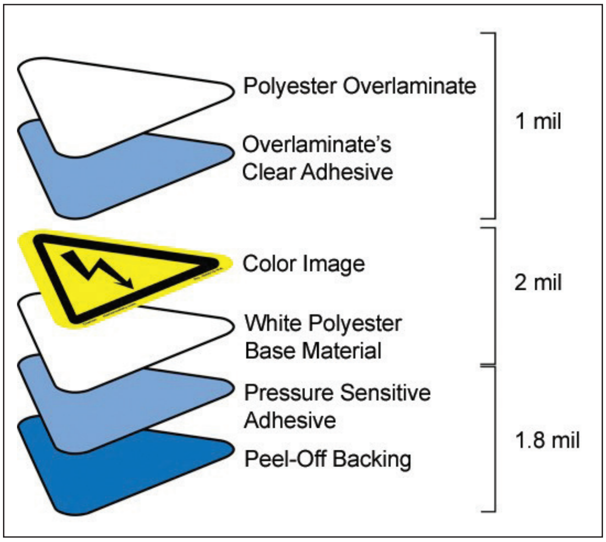


Figure 2: Diagram of the material elements of a typical, high quality product safety label

Banana Skins

Editor's Note: We regularly receive requests from readers to publish stories about real EMI/EMC problems faced by real engineers. We are pleased to bring you Banana Skins, a monthly column in In Compliance, and a 20-year tradition that began in the pages of the EMC Journal. We hope you enjoy the column and look forward to continuing the tradition of sharing these valuable stories.

106 1998 Grand Prix suffered interference

In the lead-up to the 1998 Grand Prix, electrical storms caused a spike in the power supply which sent major ripples across the facility's feed lines – crashing all race control computers. After the ensuing chaos, the problem was rectified and the race proceeded as scheduled but the experience left the Silverstone management adamant that this type of disturbance would not be repeated at future events.

(From "Grand Prix UPS weathers the storms", Electrical Products September 2000 page 34, Electrical Products & Applications: www.imlgrouponthenet.net.)

107 Twinkling antennas cause high levels of emissions

'Twinkling antennas' are a recent innovation in the mobile phone market. They incorporate one or more Light Emitting Diodes (LEDs), which are intended to illuminate when the mobile phone is transmitting. Reports from Mobile Phone companies using the 1800 MHz band have highlighted cases of interference from 900 MHz GSM mobiles. It has been suggested that the non-linear characteristics of the LEDs will cause a transmitting twinkling antenna to radiate harmonics.

(Tests carried out by the Radiocommunications agency on two 900 MHz cellphones fitted with twinkling antennas showed that…..) the ERP of the second harmonic….. exceeded the ETS 300 577 maximum.

(From EMC Matters, published by Brian Jones: emc@brianjones.co.uk. The full report of Project 564 and many other interesting documents may be found by hunting around the (legacy) Radiocommunication Agency's website hosted on Ofcom's site at: www.ofcom.org.uk/static/archive/ra/rahome.htm.)

108 Industrial microwave oven interferes with cell phone base station

In the UK 886 to 906MHz has been allocated as a band suitable for the operation of Industrial Scientific and Medical (ISM) equipment. ISM machines are at present allowed to emit 120dBμV/m (i.e. 1Volt/metre) measured at 30 metres from the wall of the building housing the equipment over this frequency range. This presents a problem as it occupies part of the band allocated to mobile phone operators.

The main users of the ISM band are organisations operating industrial microwave ovens. The ovens are used in food production although other uses such as vulcanising rubber are also on record. High power magnetrons are used as the source of microwave energy, the magnetrons are designed to operate at 896MHz. For process purposes the ovens are normally conveyor fed.

Consequently depending on the size of product being treated a large aperture exists at each end of the oven allowing relatively high levels of microwave energy to be emitted. The channel 30 mobile to base-station frequency coincides with the magnetron centre frequency. ……. The second oven at Griffith laboratories is of particular interest as the emissions are known to disturb the operation of a base station located in the vicinity.

(Extracted from: "Industrial Microwave Oven (ISM) Emissions and Mitigation Techniques", Dr D Welsh, Proceedings of EMC York 2000, 10-11 July 2000, www.yorkemc.co.uk.)

109 Australian telco has problems with inadequate immunity to EMI

The current Australian regime (for EMC compliance) only covers emissions requirements, but there has been extensive discussion about whether immunity should also be made mandatory. …..a submission from a major telecommunications network company (Telstra) outlined difficulties it has experienced in dealing with customer equipment susceptible to interference.

The ACA mandates interoperability, safety, and emissions standards but telecoms carriers have little control over the EMC quality of equipment connected to their network.

(From Chris Zombolas of EMC Technologies Pty Ltd: "Australian framework comes under review", Approval, Sep/Oct 2000 pp 7-8.)

110 EMI problems with early electronic ABS

When Ford began the development of an electronic anti-lock braking system in 1982, their engineers noted certain "concerns" about its behaviour when subjected to high levels of interference. (Ed: Such as those created by mobile radio transmitters of around 100W, either on-board or mounted on nearby vehicles.) Not only was it liable to fail, bad enough if a driver had come to rely on it, but it could do so in a particularly nasty manner, deactivating the system.

(Tom Shelley: "Screening protects anti-skid brakes", Eureka May 1987, pp 36-37, www.eurekamagazine.co.uk.)

111 High field strengths near vehicles' on-board transmitters

Fields in and around vehicles with onboard transmitters (at the maximum legal power of 110W) range mostly between 10 and 300 V/m, with some exceptions. Field strengths in and around vehicles adjacent to vehicles with transmitters range mostly between 5 and 100 V/m.

(From "How does EMI affect automotive electronics?" Microwaves, April 1980, pp 96, www.mwrf.com.)

112 Mobile phone use not recommended on aircraft

I'm tempted to think your article about mobile phones on aeroplanes was itself a flight from reality (19 August, p 18). The problem with cellphones is that they radiate at moderate powers which are capable of upsetting the operation of any of the semiconductors in any of the electronic systems in the aircraft.

Try this little experiment: phone a friend using your POT (plain old telephone landline) and then phone someone else using your cellphone. Hold the cellphone at various distances from the POT handset and its cables and see how far away it has to be before you can't hear the "blippety-blip" noises on the POT. According to the reported statements in the article, the possibility of interference in these little experiments would be "very low" when in fact it almost always occurs.

(Keith Armstrong: "Mobile menace", letters, New Scientist, 9 September 2000, www.newscientist.com.)

113 Mobile phones cause interference on the flight deck

As a captain of a brand new Boeing 737 aircraft, I can assure readers that the effects of mobile phones are very noticeable on the flightdeck. The chief problem is a series of rapid beeps from the handset when it "checks in" with a base-station. The handset does not need to be making or finishing a call to perform this function, it only needs to be switched on. The interference manifests itself as a loud and annoying interference, but since some of our navigation equipment works on the same frequencies, interference with navigational capabilities cannot be ruled out.

Another more worrying source of cellphone interference was not even mentioned in your report – mobile phones in air-traffic control centres. We had a case the other week on a Spanish sector where a mobile phone in the air-traffic control centre was continuously trying to check in with its base station and the interference was totally blocking the frequency.

Mobile telephones are an airborne menace, but you have to ask why aircraft systems are not better protected against interference in the first place. Thunderstorms can saturate our old-fashioned (but new) AM radios with static, and the ADF navigation equipment will direct the aircraft straight towards the nearest thunderstorm instead of the airfield. Is this really the high-tech field of aviation?

(Ralph Ellis: "Mobile menace", letters, New Scientist, 9 September 2000, www.newscientist.com.)

114 HV transmission lines cause shock hazards for nearby swimming pools

In general, an above ground pool is 6 to 12 times more hazardous than an in ground pool. Of the cases investigated, the majority of hazardous situations associated with pools were found to be above ground pools in close proximity to transmission line towers. It was recommended that all pools of the above ground type in close proximity to transmission lines be removed immediately.

(D.J.Woodhouse, K.D Newland, W.D. Carman, all from Energy Australia: "Development of a risk management policy for transmission line easements", ERA's Earthing 2000 conference, 21-22 June 2000, pp 6.7.7.)

115 Radio transmitting station interferes with railway train brakes

A European train operator had a problem on a section of track near a radio transmitting station. When a certain type of locomotive was passing by the radio station its main circuit breaker would open, causing it to brake. It was found out that the temperature sensors within the traction motors picked up the radio signal. The cables to these sensors weren't screened. A modification to this would have been very expensive as the sensors are mounted within the winding of the motors.

The solution chosen was to increase the time window for the signal to be above a certain limit before the control would take action. Due to the long time constant of the thermal behaviour of the system, this solution was acceptable and sufficient.

(Sent in by Jennifer Cortese, Melbourne, Australia, December 2000)

116 Diesel engine spurious start-up caused by taxicab transmitter

I was lying on my back underneath a diesel engine (part the emergency power generator of a hospital) with the sump off, doing some work on the bearings. There was not a lot of room between the engine and the floor. The diesel generator was turned off, that is to say the OFF pushbutton on the control panel had been pressed and the controlling PLC's display showed the OFF condition.

Suddenly, the diesel's starter motor operated and the engine began to run, with the crankshaft whirling around a couple of inches above my nose. Very cautiously, I slid out from underneath. I discovered that a 'bush taxi' that called at the hospital was responsible. These bush taxis had extra powerful radio transmitters fitted, so they could stay in touch with their base when very far away in the bush. Keying the powerful transmitter at the hospital entrance created enough interference for the generator's controlling PLC to think it had received the start command.

(Attendee at an EMC seminar in Sydney, Australia, November 2000.)

117 AS$8 million machine spurious start-up caused by transients

We were close to finishing the construction of an eight-million-dollar mining machine in a cavern in Australia. The operators of the mine had a central control room from which they wished to be able to exert manual control over any machine in the mine, even though the machines were automatic or had local control. Accordingly, the mine operators ran their own cables from their control room and connected them to spare inputs and outputs on the PLC for each new machine, also making the necessary software modifications themselves.

Suddenly, while we were standing by the machine, it started up of its own accord. Luckily, no-one was working on it at the time, although they could have been, but it was still a very serious issue as the machine had not yet been filled with lubricant and could easily have been wrecked. It turned out that no special precautions had been taken with the cables from the control room to the PLC, or with the software changes, and a transient interference with the new cables had caused our machine to start up unexpectedly.

(A different attendee at an EMC seminar in Sydney, Australia, November 2000.)

118 Spurious start-up of machine with 5 metre blades

I was visiting a company that made cutting machinery for carpet manufacturers. These machines had blades 5 metres wide, and very sharp. Adjusting the blades to get a good cut over the whole 5 metre width involved careful adjustments, and I noticed that some of the engineers would lie under the blade while making these adjustments.

I also noticed that the control panel (which used low-cost PLCs and not safety-critical types) was in 'single step mode' during these adjustments, and not 'locked-out' at its main electrical supply disconnector. I asked the Chief Engineer if they had ever had one of these machines start up on its own when in this mode, and he said that it had been known to happen, presumably due to transient noise on its mains supply or picked up by its cables.

(From an EMC Consultant who wishes to remain anonymous, February 2001)

119 Possibility of UWB interfering with GPS

I just had to write to you about the [November] editorial "Whose spectrum?". It is right on the mark. However, I would like to point out that there is another crucial difference between ultra-wideband (UWB) devices and hair dryers in addition to the list that Charlie Trimble so appropriately collected; if you choose to shield the hair dryer or otherwise filter its electromagnetic emissions, it still functions as a hair dryer!

If in the future, UWB is (heaven help us) given the desired rulemaking, becomes as pervasive as that industry dreams it will, and then is found to jam GPS at large distances, there will be no technical remedy, just a face-off between two competing industries. To follow the thread of your editorial, if we must grant UWB an FCC Part 15 exclusion just because we have a precedent with other emitters in the band, then we are truly facing a spectral "tragedy of the commons".

(Stephen Lazar of The Aerospace Corporation, writing to the editor of GPS World magazine, Page 6 of their January 2001 edition, www.gpsworld.com/gpsworld.)

(Editor's note: 'ultra-wideband' radio communications devices use a train of very brief pulses occupying many MHz, even GHz of spectrum simultaneously, using time-domain techniques to distinguish one transmission from another unlike traditional radio that uses frequency domain techniques. Their transmitted spectra look like wideband white noise at relatively low power, and the effect of large numbers of them is to raise the noise floor considerably, to the point where the weak signals from GPS could be jammed. Also see Banana Skins December 1998 issue. The same technology is also capable of being used as a 'personal radar' useful for all sorts of things, such as checking someone's heartbeat without

contact, or detecting people through walls. We will no doubt be hearing a lot more about UWB in the future.)

120 How EMC techniques saved hundreds of millions of dollars

The new series of Australian banknotes have a plastic film embedded in them, RF welded into place. When the new bank note production line was first used, the emissions from the RF welder (dialectric heater) upset other printing machines and ruined large numbers of banknotes. They called me in and I fixed the problem, improving their productivity and saving them from burning hundreds of millions of misprinted dollars!

(From Chris Zombolas, EMC Technologies Pty Ltd, Melbourne, Australia, www.emctech.com.au.)

121 Police frequency freaks hospital

Further to confirmation that mobile 'phones can indeed interfere with the navigation systems and electronics on board aircraft, news arrives that the UK's new £2.5 billion national police radio network is being urgently tested amid fears that it will interfere with vital hospital equipment and breath-test and radar speed machines. Until it is checked, police have been told to turn their new radios off in hospitals and near other vital equipment. There could also be problems at airports, ports and even in police control rooms.

The network uses a digital radio system called TETRA, or Terrestrial Trunk Radio. The handsets send out pulses at frequent intervals to the nearest masts, identifying their presence, but the pulses can affect the electronics of some types of equipment. The alarm was raised when Jersey police, who are already using Tetra, reported possible problems with their speed and drink-drive equipment. Scientists at the Defence Evaluation and Research Agency (DERA) have been commissioned to discover the level of interference and what else the radios could affect.

(From: The Times, January 2001, sent in by Harold Smart who saw it in the Royal Institute of Navigation Journal, January/February 2000 issue, www.ion.org.)

122 Interference clouds future of multi-billion police radio project

Police from the channel island of Jersey, which is going through pre-implementation testing of the TETRA technology, is advising its officers to be much more careful about using the equipment than was the case with previous kit. Because of fears of interfering with hospital equipment, the States of Jersey police have imposed tough rules on using equipment and ordered the lowest powered handset available.

The testing also threw up concerns that, according to a statement issued by the Jersey Police, "if a speed detection device suffered external radio interference, it was rendered inoperative". There are also concerns about breath testing devices. According to reports police are being advised that they can only do breath tests 10m from handsets or 35m from more powerful car transmitters. This has raised concerns that the system, the price of which has already been a source of discontent with the old bill, will be turned off in many situations.

The Police Federation has raised concerns that operational effectiveness and even police safety will be damaged, and not improved, by the introduction of the technology. A spokeswoman for the suppliers of the technology, BT Quadrant, said that the equipment used complied with international standards. She compared the equipment to GSM phones which also have to be turned off in hospitals.

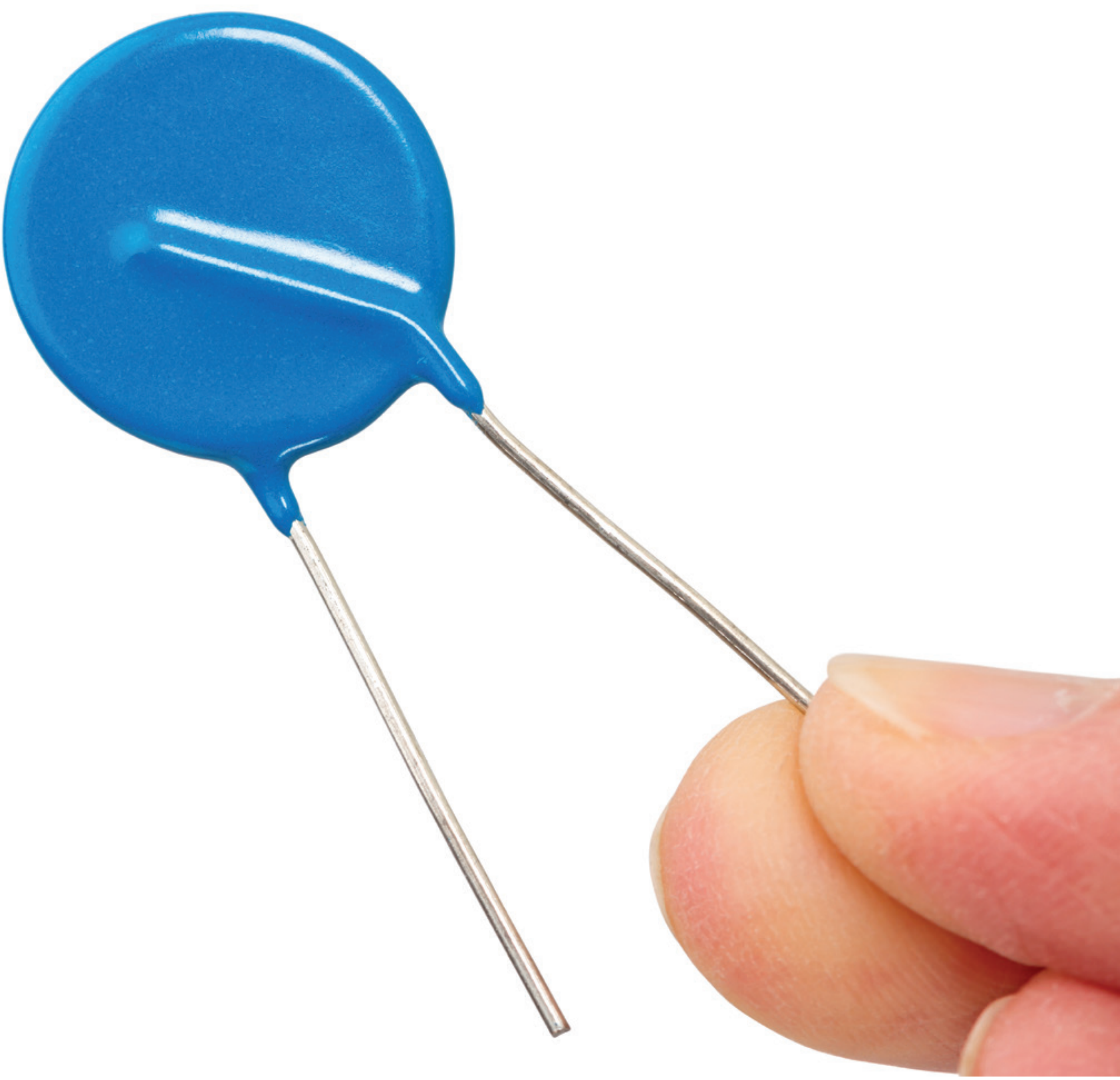
(Extracted from an article posted in The Register on 22nd Jan 01 by John Leyden, www.theregister.co.uk/content/5/16266.html, sent in by Graham Eckersall, G4HFG.)

The regular "Banana Skins" column was published in the EMC Journal, starting in January 1998. Alan E. Hutley, a prominent member of the electronics community, distinguished publisher of the EMC Journal, founder of the EMCIA EMC Industry Association and the EMCUK Exhibition & Conference, has graciously given his permission for In Compliance to republish this reader-favorite column.

The Banana Skin columns were compiled by Keith Armstrong, of Cherry Clough Consultants Ltd, from items he found in various publications, and anecdotes and links sent in by the many fans of the column. All of the EMC Journal columns are available at: https://www.emcstandards.co.uk/emi-stories, indexed both by application and type of EM disturbance, and new ones have recently begun being added. Keith has also given his permission for these stories to be shared through In Compliance as a service to the worldwide EMC community.

We are proud to carry on the tradition of sharing Banana Skins for the purpose of promoting education for EMI/EMC engineers.

NEW REQUIREMENTS FOR MOVs USED FOR SURGE SUPPRESSION ON AC MAINS PORTS



Joseph Randolph is an independent consultant with over thirty years of experience in the design of telecommunications equipment. His primary specialty areas are circuit design, lightning protection, international regulatory compliance, and compliance with industry standards such as Telcordia NEBS GR-1089 for carrier-class telecom equipment in the USA. He is a Senior Member of the IEEE and serves on the Telecom Advisory Committee of the IEEE Product Safety Engineering Society. Mr. Randolph can be contacted at jpr@randolph-telecom.com.

By Joseph Randolph

Metal oxide varistors (MOVs) are widely used for surge protection on the AC mains ports of electronic products. They are also commonly used in external surge protectors intended for use on the AC mains. MOVs have been very popular for many years due to their low cost and their remarkable ability to handle large surge currents.

Under existing safety standards in the U.S. and the European Union (EU) that are based on IEC 60950-1, Information Technology Equipment, the requirements for MOVs have been fairly stable for several years and are relatively modest. However, in both the U.S. and the EU, safety standards based on IEC 60950-1 are currently scheduled to be withdrawn in December 2020, and will be replaced by new standards that are based on IEC 62368-1, Audio/Video, Information Technology and Communication Equipment.

The new MOV requirements in IEC 62368-1 are more challenging to meet, so manufacturers need to prepare for the transition. Simply complying with the earlier MOV requirements based on IEC 60950-1 will not guarantee compliance with new standards based on IEC 62368-1.

Unfortunately, the new MOV requirements in IEC 62368-1 have caused much confusion due to the wording of Annex G.8 for MOVs. The intent of this article is to clear up this confusion to the extent possible. Note that this is just the author's interpretation of IEC 62368-1, and other interpretations are possible.

WHAT IS AN MOV?

An MOV is a 2-terminal device that has bidirectional electrical behavior similar to a configuration of back-to-back avalanche diodes. For example, an MOV rated to stand off 400 Vdc will typically conduct less than 1 mA at 400 Vdc, but it will conduct progressively more current at higher applied voltages.

The current might reach 1 A at 600 Vdc, 100 A at 700 Vdc, and 1000 A at 900 Vdc. There is not a sudden turn-on threshold. Rather, the conducted current increases exponentially as the applied voltage increases, and decreases as the applied voltage is reduced. Figure 1 shows some representative MOVs.

ALTERNATIVES TO MOVs

Another common surge suppression component that can survive very high surge currents is the gas discharge tube (GDT). GDTs achieve their impressive current handling ability by having an abrupt trigger voltage at which they switch into a conducting state that is almost a short circuit. This is sometimes referred to as a "crowbar" characteristic. Note that when a two-terminal surge protection component is conducting, the instantaneous power dissipation in the component is:

Power Dissipation = (voltage across component) x (current passing through component)

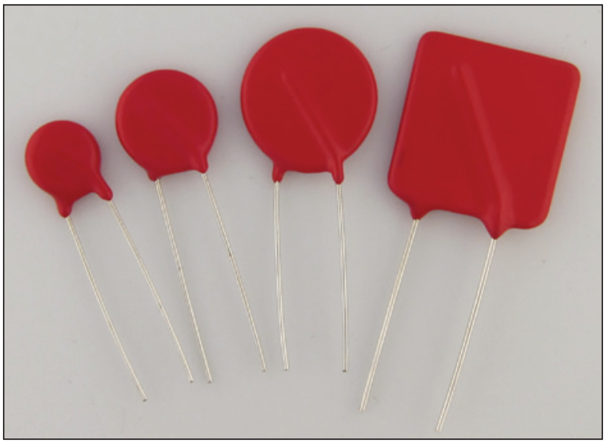


Figure 1: Examples of MOVs

So, unlike an MOV, the GDT tolerates large surge currents because, when triggered, the voltage across it drops to a low value. This keeps the instantaneous power dissipation low. The result is that for the same surge current capability, a GDT can be physically smaller than the corresponding MOV.

Once triggered into the conducting state, a GDT requires that the current drop to nearly zero to reset the GDT to the off condition. For applied 60 Hz AC waveforms, the current drops to zero twice per cycle, corresponding to every 8.3 ms, so this would appear to provide the required turn-off opportunity. Unfortunately, if an overvoltage condition keeps a GDT in the conducting state for more than a few seconds, the accumulated heat in the GDT will prevent it from turning off in response to the very short zero crossings of a 60 Hz AC mains waveform. So GDTs, by themselves, are not well suited as a substitute for MOVs connected to the AC mains.

Since an MOV does not have a crowbar characteristic, it must tolerate the simultaneous presence of high voltage and high current. This leads to very high instantaneous power dissipation on the MOV, but it provides reliable turn-off when the AC mains voltage returns to normal after the surge.

KEY MOV ELECTRICAL PARAMETERS

While the general behavior of an MOV resembles that of two back-to-back avalanche diodes, the amount of surge current that an MOV can survive is considerably higher. Since the turn-on characteristic of an MOV is gradual rather than abrupt, it is difficult to define a specific voltage at which the MOV is considered to be off. To address this soft turn-on characteristic, the industry assigns an MOV voltage rating that corresponds to the maximum AC rms voltage that the MOV will withstand continuously without conducting significant current. Both IEC 60950-1 and IEC 62368-1 require that the rated voltage of the MOV be at least 125% of the rated voltage of the equipment. So, for a 240 V rms mains circuit, the rated voltage of the MOV must be at least 300 V rms.

At normal applied mains voltages of 240 V rms, an MOV rated at 300 V rms will conduct less than 1 mA. However, if a surge is applied across the MOV, the MOV will momentarily conduct far more current and will limit the surge to typically less than 1 kV. Given that lightning surges on the AC mains can exceed 6 kV and can have peak currents that exceed 3000 A, an MOV's ability to limit such surges to less than 1 kV without damage is a very helpful first line of defense for surge protection.

While the nominal voltage rating for an MOV is usually the first parameter that a design engineer selects, the current handling capability is an often-overlooked consideration. In Figure 1, all of the MOVs shown are rated to continuously withstand 300 V rms (424 V peak). All of them have a nominal 1 mA threshold of 470 V dc. The difference in physical size (and cost) is that the larger MOVs can handle higher surge currents without damage. And, for any given surge current, the larger MOVs will have a lower clamping voltage.

When tested with a standard 8/20 us impulse surge, the smallest MOV in Figure 1 can handle 100 surges of 1000 A without being damaged, while the largest MOV can handle 100 surges of 3000 A. Furthermore, when tested with a 1000 A surge, the smallest MOV will limit the surge voltage to 1200 V, while the largest one will limit the surge voltage to 900 V.

So, in addition to selecting MOVs with suitable turn-on thresholds, designers must also consider both the size and number of surges to which the MOV is likely to be subjected in its lifetime. While a physically smaller 300 V rms MOV costs less than a larger one, it may not hold up well in real-world applications. Some of the requirements and tests in IEC 62368-1 are specifically designed to prevent designers from using undersized MOVs. To comply with the surge tolerance requirements in IEC 62368-1, most AC mains applications will require an MOV with a minimum disc diameter in the range of 14 mm to 20 mm.

MOV FAILURE MODES

As noted above, MOVs have a soft turn-on characteristic, and typically conduct a small amount of leakage current even at applied voltages that are well below their nominal threshold voltage. If an MOV is subjected to surges beyond its rating, permanent damage can occur that causes the leakage current to increase. In some applications, leakage currents of only a few mA can present a shock hazard.

Furthermore, if this leakage current gets high enough, there will be self-heating inside the MOV. As noted earlier, the instantaneous power dissipated in an MOV is the applied voltage times the current through the MOV. When an MOV is connected continuously across the AC mains, this self-heating can create positive feedback where higher leakage current leads to higher self-heating, which leads to even higher leakage current.

Subsequent surges can further accelerate this failure mode. At some point the MOV will go into a thermal runaway mode that generates considerable heat and destroys the MOV. In some situations, the heat produced by the MOV can cause nearby materials to catch fire.

Figure 2 shows an example of damage from an overheated MOV.

Figure 2: Overheated MOV

WHY ARE MOV REQUIREMENTS BEING CHANGED?

The evolving safety requirements for MOVs are directed at addressing two distinct aspects of the above MOV failure modes:

1. Electric shock
2. Fire hazard

If an MOV is connected between the AC mains and a reliable protective earth, an increase in the MOV leakage current will simply result in more leakage current being conducted to earth ground. However, if the earth ground connection is not reliable and is somehow not connected to earth, the leakage current through the MOV will allow conductive parts connected to the earth ground to rise to the AC mains voltage. This can present an electric shock hazard.

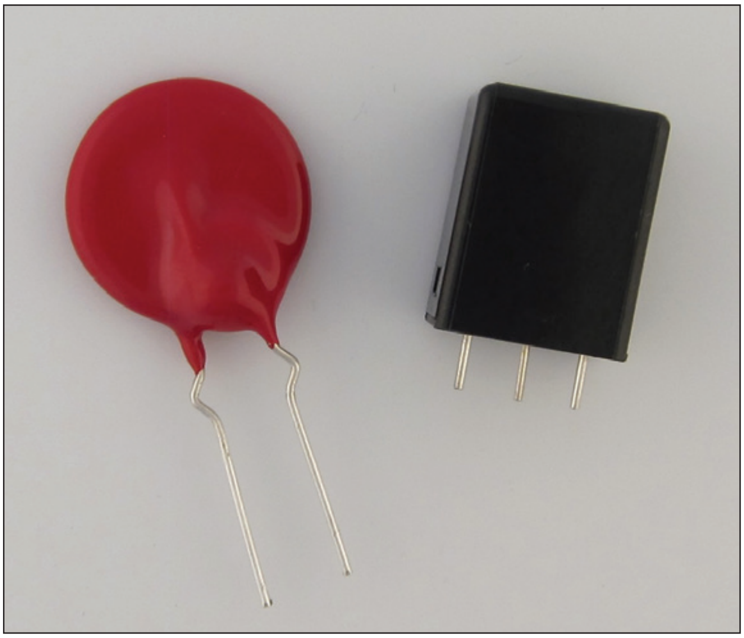


Figure 3: Examples of Thermally Protected MOVs

Regardless of whether the equipment is properly grounded, an MOV will typically generate a lot of heat once it goes into thermal runaway. Under certain conditions, this excessive heat can start a fire. So, safety standards are evolving to address the fire hazard as well as the risk of electric shock.

REQUIREMENTS THAT ADDRESS ELECTRIC SHOCK HAZARDS

Most ordinary office and household equipment powered by the AC mains use the familiar plug that is inserted to a standard wall outlet. Equipment that uses this type of AC mains connection is referred to in safety standards as “Pluggable Type A” equipment.

Type A plugs can have either two or three contact pins. The 2-pin version only connects to the AC mains, and is used when the equipment does not require a ground connection to ensure safety. The 3-pin version adds a ground pin for connection to earth ground. Often the ground connection for such equipment consists solely of this third pin on the AC mains plug.

It is known that sometimes the ground connection in the wall outlet is not properly connected to earth ground. Furthermore, some users will use a “cheater adapter” to connect a 3-prong plug to a wall outlet that accepts only 2-prong plugs. For these reasons, the earth ground connection achieved with a Pluggable Type A plug is not considered to be reliable.

As noted previously, if an MOV is connected from the AC mains to protective earth, the leakage current through the MOV will simply flow to protective earth. However, if the intended earth connection is not made, steps need to be taken to prevent possible electric shock to users when they touch conductive parts that are supposed to be grounded.

For Pluggable Type A equipment, the most common solution for preventing the MOV leakage current from becoming an electric shock hazard is to place GDT in series with the MOV. A GDT has almost no leakage current until the applied voltage gets close to the GDT turn-on voltage. So, if the GDT has a nominal turn-on voltage of 300 V rms, no significant leakage current will flow for an applied AC mains voltage of 240 V rms.

Some readers may wonder why it is not possible to simply use a GDT by itself without the MOV. As noted earlier, GDTs have difficulty turning off after a sustained surge event that has caused heating of the GDT electrodes. For situations where there is always 240 V rms across the protection arrangement, the GDT needs some help from the MOV to turn off.

REQUIREMENTS THAT ADDRESS FIRE HAZARDS

To limit the risk of fire, several options appear in the existing standards:

1. Put a simple fuse in series with the MOV to limit the maximum possible self-heating;
2. Couple a thermally-activated series fuse to the MOV package;
3. Keep the MOV sufficiently far away from any combustible material; or
4. Put the MOV in a fire enclosure.

Note that Option 1 has some practical limitations because any surge currents that the MOV is intended to handle must pass through the fuse. It is very difficult to design a fuse that will open at a sufficiently low current to control self-heating in the MOV, while also not fusing open for the typical surge currents that the MOV is intended to conduct.

Option 2 is an increasingly common compliance method. Several vendors of MOVs offer thermally protected MOVs (TP-MOVs) that have a thermally activated thermal fuse coupled to the body of the MOV. Figure 3 shows two examples of TP-MOVs. The slight bulge on the side of the red TP-MOV is the thermal fuse. In the black TP-MOV, the MOV and an external thermal fuse are closely coupled within the enclosure.

Options 3 and 4 are commonly used in products where there is adequate space to accommodate them.

KEY EXEMPTIONS FROM CERTAIN MOV REQUIREMENTS

The above discussion has addressed the most common configuration where a Pluggable Type A mains connector is the sole means of grounding, and the MOV turn-on thresholds are set to just above the peaks levels of the AC mains voltage.

The need to control MOV leakage current with a series GDT is significantly reduced if the equipment has a reliable ground. The requirement for a reliable ground can be met in several ways, such as requiring that a trained professional install the equipment, or by using an industrial Pluggable Type B mains connector.

For limiting the risk of fire, some standards will exempt an MOV that has a turn-on threshold far above the normal AC mains voltage. The rationale is that, if the likelihood of surge damage to the MOV is low, the risk of fire is adequately addressed. Using this option typically requires the MOV to have a nominal turn-on threshold that is above 1500 V rms, which has the effect of potentially limiting the usefulness of the MOV surge protection.

These exemptions will not be discussed further here, but they are worth investigating if the intended application might qualify.

BRIEF REVIEW OF STANDARDS DEVELOPMENT

The International Electrotechnical Commission (IEC) is a standards organization that includes over 100 member countries worldwide. The IEC publishes a wide range of reference standards including IEC 60950-1, Safety of Information Technology Equipment, and IEC 62368-1, Audio/Visual, Information and Communication Technology Equipment.

By themselves, these IEC standards have no regulatory power. However, member countries typically use the IEC standards as the basis for their national regulatory standards. This is how we end up with EN 60950-1 and EN 62368-1 in the EU, and UL 60950-1 and UL 62368-1 in the U.S.

IEC member countries typically adopt the latest version of an IEC standard after a delay of one or more years, since this requires a national technical review and sometimes legislative action to give the national standard the force of law. In adopting an IEC standard, some member countries make minor revisions to the IEC text. So, while all national versions of a given IEC standard are substantially identical, there can be minor differences among them.

The resulting differences in adoption dates and technical content make it difficult to make general statements about what is required in a specific country on a specific date. To keep things simple, this article will discuss only the IEC versions of 60950-1 and 62368-1. It turns out that even this apparent simplification does not completely resolve the problem.

EVOLUTION OF IEC 60950-1

The First Edition of IEC 60950-1 was originally published in 2001. The First Edition contained no explicit requirements for the use of MOVs in AC mains circuits.

A Second Edition was published in 2005. In the 2005 Second Edition, the use of MOVs in AC mains circuits was greatly restricted. MOVs were permitted to be placed across the AC mains, provided that a fuse was connected in series with the MOV. For MOVs connected between AC mains and earth ground, the earth ground connection had to be "reliable."

Note that the requirement for a reliable earth ground ruled out the use of MOVs connected from AC mains to the ground pin on the AC mains plug of ordinary Pluggable Type A office and household products.

The 2005 Second Edition was amended in 2009 to allow GDTs to be placed in series with MOVs when used with reliably grounded equipment, but the amendment did not allow this series combination to be connected from the AC mains to the ground pin of Pluggable Type A equipment.

A second amendment in 2013 allowed an MOV-GDT series combination to be used between the AC mains and the ground pin of Pluggable Type A equipment, provided that the GDT alone could pass the following tests:

- The GDT had to pass the electric strength test for basic insulation; and
- The GDT's external construction had to meet the creepage and clearance requirements for basic insulation.

For a typical application in a 240 V rms mains circuit, the requirements for basic insulation in IEC 60950-1 include an electric strength test of 1500 V rms, a creepage distance of at least 2.5 mm, and a clearance distance of at least 2.0 mm.

So, it was finally allowable to connect a series MOV-GDT from the AC mains to ground of ordinary

Pluggable Type A equipment, but the electric strength test for the GDT meant that the GDT had to have a breakdown threshold that exceeded 1500 V rms.

EVOLUTION OF IEC 62368-1

The intent behind IEC 62368-1 is to eventually replace IEC 60950-1 (as well as IEC 60065, which will not be discussed here) with a standard that approaches safety compliance using a different conceptual framework. IEC 60950-1 is generally regarded as a "prescriptive" standard that presents product designers with a set of prescribed design rules.

In IEC 62368-1, an attempt has been made to simply identify a set of known safety hazards, and then give designers the choice of several options for providing suitable protection from these hazards. This is why IEC 62368-1 is commonly referred to as a "hazards-based" standard. Designers who are only familiar with applying IEC 69050-1 will likely have some difficulty adjusting to the hazards-based framework of IEC 62368-1.

The First Edition of IEC 62368-1 was published in 2010, and a Second Edition was published in 2014. A Third Edition has been finalized for 2018 and is likely to be issued by the time this article goes to press.

In the 2010 First Edition of IEC 62368-1, the requirements for MOVs used in AC mains circuits were more extensive than those in IEC 60950-1. Specific surge tests were added to ensure that the MOV could tolerate expected lightning surge currents of 8/20 us duration, and long-term overloads of several hours.

And, for the first time, detailed requirements were added to address the risk of fire from an MOV.

It is a common misconception that any product that complies with IEC 60950-1 will also comply with IEC 62368-1.

Designers were provided the options of using a protective fuse of 10 A maximum, a restricted area surrounding the MOV, or a fire enclosure. For MOVs rated at voltages less than twice the maximum rated voltage of the equipment, a series of long-term overload tests were applied for up to four hours at voltages of twice the rated voltage of the equipment. For this long-term overload test, the circuit had to respond by becoming an open circuit.

In the 2014 Second Edition of IEC 62368-1, the requirements for MOVs were further expanded. One change was to require that any MOV connected between mains and earth ground of Pluggable Type A equipment must have a GDT connected in series with the MOV. The series GDT had to meet the requirements of basic insulation with regard to external creepage and clearance distance. Furthermore, the GDT had to meet the electrical strength test for solid insulation used in basic insulation.

This had the effect of increasing the required electrical strength of the GDT to 1768 V rms, as opposed to the 1500 V rms test that had applied under IEC 60950-1. It is not clear whether this change was intentional.

A second change expanded and clarified the long-term overload tests. A third change was the addition of a temporary overvoltage test of up to five seconds. For this test, it was allowable, but not required, for the circuit to fail open.

In the 2018 Third Edition, much of the wording of Annex G.8 has been revised, but the underlying requirements are mostly the same. Some of the specific component-level requirements allow the use of the 2017 edition of IEC 61643-331 as an alternative to IEC 61051-2. For the temporary overvoltage test, reference is now made to the 2011 edition of IEC 61643-11, rather than specifying all the test details directly within Annex G.8

In countries that have adopted a national version of IEC 62368-1, the current national version is generally based on the 2014 Second Edition of IEC 62368-1. This will begin to change after the 2018 Third Edition is issued.

Currently, manufacturers have the option of using national versions of either the Second Edition of IEC 60950-1 (as amended) or national versions of IEC 62368-1. At some point, presently scheduled for December 2020, IEC 60950-1 will be withdrawn and manufacturers will no longer have the option of using the standard to demonstrate safety compliance for new products.

It is a common misconception that any product that complies with IEC 60950-1 will also comply with IEC 62368-1. While this was a general goal for the First Edition of IEC 62368-1, some conflicts were present even in the First Edition. Considerably more conflicts were introduced in subsequent editions of IEC 62368-1. So, as the date approaches when IEC 60950-1 is withdrawn, it is important to be prepared to meet the requirements of IEC 62368-1.

REPRESENTATIVE PROTECTION CIRCUITS CONTAINING MOVs

The discussion that follows will compare representative AC mains protection circuits that comply with IEC 60950-1 (Second Edition, as amended through 2013) and representative circuits that comply with IEC 62368-1 (Third Edition, 2018). The discussion will be limited to Pluggable Type A equipment. Figure 4 shows four different protection circuits that illustrate the range of possible solutions.

Note that all the circuits in Figure 4 are for an AC mains voltage of 240 V rms. For a design that supports only the 120 V rms AC mains used in North America, some of the stated component voltage ratings could be lower. Also note that the stated voltage ratings for both the MOVs and GDTs are the AC rms stand-off voltage. While MOVs are commonly rated using an AC rms voltage, GDTs are commonly rated for a DC trigger voltage, so designers must keep this distinction in mind when selecting components.

Circuit A shows a very simple circuit that is permitted under IEC 60950-1. Note that since there are no MOVs connected between the AC mains and ground, there is no issue with electric shock hazards created by the MOV. An MOV connected across the AC mains can have high leakage current without presenting a risk of electric shock.

In IEC 60950-1, the fuse is apparently called out because of a desire to limit the risk of fire. However, the requirements for this fuse are not specified other than the requirement that the fuse must have “adequate breaking capacity.” It appears that the term “adequate breaking capacity” might refer to the rated current of the product, rather than any specific characteristic of the MOV.

Circuit B shows how Circuit A would typically be altered to comply with the Third Edition of IEC 62368-1. The key difference is that the MOV has been replaced with a TP-MOV. The use of a TP-MOV is not explicitly required in IEC 62368-1, but the tests that are used to evaluate the risk of fire are very difficult to pass without using a TP-MOV.

It is important to note that while Circuit A and Circuit B are shown being used with an ungrounded mains plug, they can also be used with equipment that has a grounded mains plug. The key limitation for these two simple circuits is that there cannot be any MOVs connected between the AC mains and the ground pin of the AC mains plug.

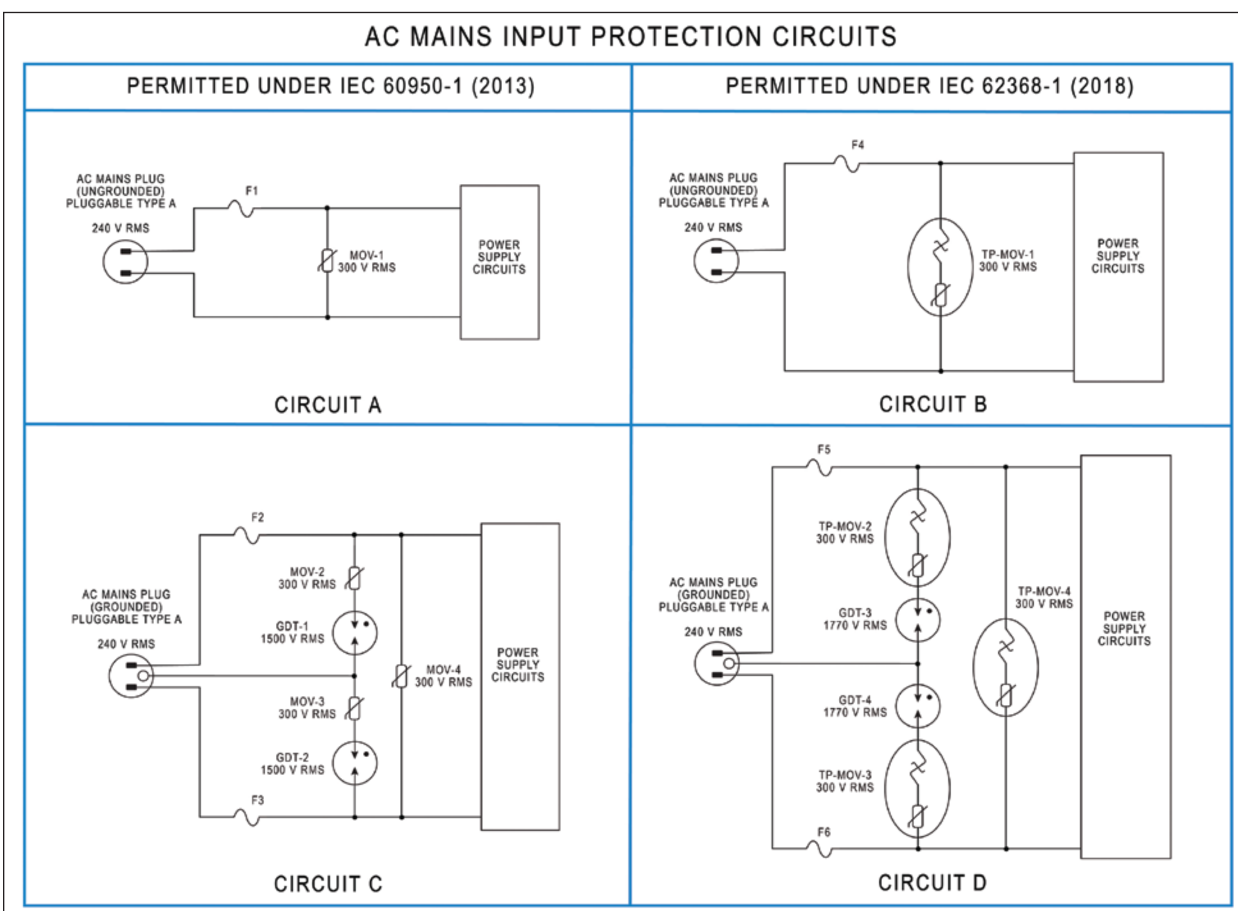


Figure 4: Representative Protection Circuits

A key goal of this article is to help readers of IEC 62368-1 understand the underlying safety concerns that the new requirements are trying to address.

Circuit C shows the much more complex configuration typically used to comply with IEC 60950-1 when there are MOVs connected to earth ground. Compared to Circuit A, the first change is that fuse F3 has to be added to limit the current through MOV-3. In addition, GDT-1 and GDT-2 have been added to block the MOV leakage current that could otherwise lead to electric shock if the equipment's ground connection is missing.

Circuit D shows how Circuit C would typically be modified to comply with IEC 62368-1. The key change is that the three MOVs in Circuit C have been converted to TP-MOVs. Another change is that the AC rms stand-off voltage of the GDTs has been increased.

It is useful to note that the more complicated arrangements of Circuits C and D are not necessarily required for adequate surge protection. Due to other requirements for safety isolation, most mains-connected power supplies have an isolation barrier rated at 3000 V rms that separates the power supply output circuits from the AC mains inputs. It is usually not difficult or expensive to ensure that this isolation barrier can withstand common mode surges (surges applied between the AC mains and earth ground) of 10 kV peak.

A surge tolerance of 10 kV peak for common mode surges is usually sufficient to eliminate the need for having surge protection components connected between the AC mains and earth ground. In most cases, the cost of upgrading the isolation barrier to withstand 10 kV peak will be far less than the cost of adding surge protection components between the AC mains and ground.

Note that most applications will still require some form of surge protection across the AC mains, similar to what is shown in Circuits A and B. This is because the input circuits of most power supplies connected to the AC mains have active electronics connected across the AC mains, and these electronics need to be adequately protected from differential surges across the AC mains.

SOME COMMENTS ABOUT MOV REQUIREMENTS IN IEC 62368-1

The MOV requirements in IEC 62368-1 are only a few pages long, but they are difficult for ordinary design engineers to understand. While the two main issues that the MOV requirements are trying to address are electric shock and risk of fire, it is not always clear which of these two hazards a given requirement is trying to address.

Indeed, a key goal of this article is to help readers of IEC 62368-1 understand the underlying safety concerns that the new requirements are trying to address. This understanding can be quite helpful when attempting to interpret the stated requirements. In particular, knowing the underlying concerns is helpful for understanding the various exemptions and alternate solutions that are permitted.

Another problem with the current version of the MOV requirements in IEC 62368-1 is an inconsistent use of terms and definitions. For example, certain tests that apply to an MOV may not apply to a TP-MOV or to an MOV connected in series with a GDT. It would be helpful if the term "MOV" could be clearly distinguished from "a protection circuit that contains an MOV."

In some other safety standards, a clear distinction is made between a surge protection component (a single component) and a surge protection circuit (two or more components connected together). This distinction is not always clear in the Third Edition of IEC 62368-1, and it creates room for different interpretations of the applicable requirements.

As a result, designers who expect to make the transition to IEC 62368-1 should plan to spend some time trying to understand how to comply with the MOV requirements, and should be prepared for possible differing interpretations among safety experts and test labs.

SUMMARY

For several years, safety experts have been increasingly concerned with the possibility that overstressed MOVs could lead to electric shock hazards and also the possibility of fire. Starting with the 2005 Second Edition of IEC 60950-1, successive safety standards have expanded how these two MOV safety concerns are addressed.

At present, most designers of information technology equipment (ITE) have the option of using national standards that are based on the 2013 version of IEC 60950-1, or alternate national standards that are based on either the 2014 or 2018 versions of IEC 62368-1. However, at some point in the future, most national standards based on IEC 60950-1 will be withdrawn, and the only applicable standards for ITE will be based on IEC 62368-1. In the EU and the U.S., the withdrawal of EN 60950-1 is presently scheduled for December 2020.

The important thing to keep in mind is that just because an existing design complies with IEC 60950-1 does not necessarily mean that the same design will comply with IEC 62368-1. The differences described here regarding MOVs are just one example of changes that will be required when transitioning to national standards based on IEC 62368-1.

THE EUROPEAN COMMISSION'S LATEST EMC DIRECTIVE GUIDANCE

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By Alex Martin

In March of this year, the European Commission, the executive body of the European Union, published its latest "Guide for the EMC Directive."[1] Updated to reflect the 2014 recast of the Directive, the Guide addresses various issues, not least what constitutes "inherently benign equipment" and "custom built evaluation kits." This article reviews the content of the new Guide, highlighting key changes from the previous edition of the Guide published in 2010.

BACKGROUND ON THE EMC DIRECTIVE AND THE NEW LEGISLATIVE FRAMEWORK

The EMC Directive is a longstanding EU law subject to periodic revision. The most recent update occurred in 2014, when the Directive was recast to align it with the New Legislative Framework (NLF).

The NLF supersedes the New Approach to Technical Harmonization and Standards ("New Approach") that had, from the mid-1980s onwards, provided for the setting of essential requirements in product legislation with more detailed rules regarding the application of these requirements to then be worked out and set in standards. The legislation would carry a presumption of conformity that could be invoked by product manufacturers when applicable, officially-referenced standards (harmonized standards) were followed in product design and manufacture. In other words, any product made to meet the requirements of applicable harmonized standards could be assumed to comply with the essential requirements of the law. When first published in 1989, the EMC Directive constituted a "New Approach Directive."

The NLF retains many of the concepts in the New Approach, not least of which are the concepts of essential requirements, CE marking, harmonized standards and the presumption of conformity.

However, the NLF evolves the framework by stipulating that NLF laws apply to four different types of economic operator: manufacturers, the authorized representatives of manufacturers, importers and distributors.

With this in mind, the recast EMC Directive of 2014 has a dedicated chapter – Chapter 2 – that specifies the obligations falling upon economic operators. This was a key change to the earlier, 2004 version of the EMC Directive, and proposed by the European Commission in its role as the initiator of EU legislation.

ABOUT THE EMC DIRECTIVE GUIDANCE

While the European Commission has the right of legislative initiative in the EU, it also prepares guidance to support the understanding and implementation of legislation. Such guidance is not legally binding, but nonetheless a source of interpretation and instruction for those affected by EU law. Most EU product legislation is supported by European Commission guidance and the EMC Directive is no different. In March 2018, the European Commission published the latest "Guide for the EMC Directive," which supersedes the earlier version of the Guide from 2010.

As expected, the 2018 Guide differs to the 2010 version with the inclusion of a section on economic operator obligations. This makes sense given that the obligations were introduced to the EMC Directive for the first time with its 2014 recast. However, this is not the only new section of the Guide and sections from the 2010 version have been revised. An overview of the changes is presented in Table 1 on page 36, and the rest of this article discusses each section of the Guide (excluding the disclaimer) in more detail.

SECTION 1: SCOPE

1.1 General

The 2018 "General" subsection is a little different to what went before in that it characterizes the main objective of the EMC Directive as being to "guarantee the free movement of equipment and to create an acceptable electromagnetic environment whilst ensuring that equipment will function as intended in that environment." The characterization of equipment "functioning as intended in that environment" is new and not something specified in the 2010 Guide; this

Section of the Guide	2010 Guide	2018 Guide
Disclaimer	Clarifies that the Guide is not legally binding and is no substitute for the law.	As 2010
Scope	Guidance divided between three subsections: general, defining the scope of apparatus, and defining the scope of fixed installations.	General guidance reduced while the information relating to "defining the scope of" apparatus/fixed installations is the same as in 2010. In addition, new guidance is introduced covering sections titled "geographic application," "placing on the market/ putting into service," and "equipment and products." A jammers case study is also a new subsection.
Essential Requirements	Presents an overview of mandatory requirements.	Also presents an overview of mandatory requirements.
Economic Operator Obligations	Not present.	Newly introduced section in light of the EMC Directive now having these obligations written into it.
Apparatus Conformity Assessment Procedure	Gives information including: the usual steps of an EMC assessment; information and documentation requirements; Declaration of Conformity and CE marking. More detailed guidance is provided for an EMC assessment where harmonized standards are not used or do not cover all protection requirements. Specific subsection on The concept of "holding at the disposal."	Largely the same content, although new guidance is introduced pertaining to risk analyses and risk assessment (as this is new to the 2014 EMC Directive) while Declaration of Conformity and CE marking guidance is revised in light of a model Declaration coming into being and CE marking requirements now being found in Decision No 768/2008/EC. In addition, there is newly introduced guidance regarding "information on identification" and "information concerning the use of apparatus." Specific subsection on The concept of "holding at the disposal" removed.
Fixed Installations	Guidance spans the relevant requirements and documentation needed for fixed installations, including the use of apparatus specifically for incorporation into a given fixed installation.	As 2010
Market Surveillance	Called "Enforcement of the EMC Directive." Gives information on the duties of Member State authorities in checking for compliant apparatus with specific comment regarding the use of apparatus at trade fairs.	Very similar to 2010, only the comment regarding the use of apparatus at trade fairs is removed.
Notified Bodies	Guidance spans the role, selection, coordination and the treatment of complaints towards Notified Bodies.	Again similar to 2010, although new subsections are introduced regarding sub-contracting and information exchange.
Annexes		Similar to 2010, although there is now guidance relating to the application of the 2014 EMC Directive alongside the 2014 Low Voltage and Machinery Directives. A new subsection on Organizations and Committees is introduced that describes the EU Association of EMC Notified Bodies and the "EMC ADCO" of EU Member State Market Surveillance Authorities.

Table 1: Similarities and differences between the 2010 and 2018 Guides

Guide merely talked of an "acceptable electromagnetic environment" in the EU.

Interestingly, the 2018 Guide introduces clarification absent from the 2010 Guide: that functional safety aspects based on electromagnetic disturbance are regulated under other EU legislation, notably the Machinery, Low Voltage and General Product Safety Directives.

1.2 Geographic Application

New commentary confirms that the EMC Directive applies in EEA-EFTA[2] countries while Mutual Recognition Agreements and/or Agreements on Conformity Assessment and Acceptance between the EU and a cosignatory (e.g., Canada, Israel, etc.) may provide for mutual recognition of EMC conformity assessment procedures when such Agreements address EMC.

1.3 Placing on the Market/Putting into Service

The 2018 Guide gives advice on both terms, mainly by way of extraction from the European Commission "Blue Guide" to product regulation.[3] Moreover, the 2018 Guide states that, legally, economic operator obligations only refer to equipment placed on the market – not equipment put into service.

This is helpful up to a point. For those manufacturers that first place electrical equipment on the EU market (by selling it to another business) before it then goes into service, it is clear that they are bound by relevant obligations. Uncertainty arises in instances where a business acts as both manufacturer and, subsequently, user of the equipment that it puts straight into service without any transfer of ownership.

1.4 Equipment and Products

This subsection includes entirely new guidance related to the Radio Equipment Directive (RED), namely that the RED covers most radio equipment and includes EMC essential requirements identical to those of the EMC Directive.

What is also worth reviewing is what is in and out of the scope of the RED. By and large, the RED applies to everything that was in the scope of its legislative predecessor, the R&TTE Directive,[4] plus some more items. Newly in-scope products include:

- Pure radio sound and radio TV receive-only equipment; and
- Equipment operating below 9 kHz.

As such, radio determination equipment is now included within the scope of the RED. However, some equipment that was within the scope of the R&TTE Directive is not in scope of the RED, most notably pure wired telecom terminal equipment. The EMC Directive applies to this equipment now.

Subsection 1.4 also spans guidance on "inherently benign equipment" and "custom built evaluation kits."

In the former case, it is worth contextualizing the origins of this phrase. This is Recital 12 of the 2014 EMC Directive, which states that the Directive "should not regulate equipment which is inherently benign in terms of electromagnetic compatibility."

Recital 12 therefore provides opportunity for exclusions, something that the 2010 Guide identified and discussed with examples. Consistent with the 2010 Guide, the 2018 Guide advises that "inherent benevolence" is conditional upon electrical equipment being:

- Incapable of generating or contributing to electromagnetic emissions which exceed a level allowing radio and telecommunications equipment and other equipment to operate as intended; and
- Able to operate without unacceptable degradation in the presence of electromagnetic disturbance normally present in its intended environment.

The 2018 Guide repeats the examples listed in the 2010 Guide (not reproduced here), but also adds the following:

- Corded headphones, loudspeakers without amplification, guitar inductive sensors without active electronic parts;
- Induction motors without electronic circuits;
- Electromagnetic relays without active electronic parts;
- Electromagnetic locks without active electronic parts; and
- Cathode ray tubes.

The 2018 Guide makes a new point too, which is that if a product under assessment is not among the listed examples and the EMC assessment establishes inherent benevolence, then the Directive shall not apply.

Regarding custom built evaluation kits, an interpretation of what constitutes such kits is offered for the first time. More specifically, the 2018 Guide outlines criteria for determining what is "custom built" and, subsequently, an "evaluation kit." The guidance is as follows:

"Custom built

i. A kit that has been built on the basis of a specific request from a specific customer or from a group of customers involved in a joint research and development project as for all or certain characteristics of the evaluation kit; or

ii. A kit that has been built for the specific requirements of a specific customer or a group of customers involved in a joint research and development project as for all or certain characteristics of the evaluation kit.

"Evaluation kits
A printed circuit board with an integrated circuit and support components to produce a working circuit for evaluation and development.

- *Destined for professionals (customers), to be used solely at research and development facilities*

  Research and development facilities meaning public or private research and development bodies.

- *For research and development purposes*

  Evaluation kits to be used in testing for further development/improvement of the function of the equipment under research and development."

A nonexhaustive list of examples of evaluation kits that do not benefit from the custom built evaluation kit exemption is given including "for users in general [in R&D departments]." Many types of evaluation kits are made in large numbers for "users in general." Typically, such users are electronic design engineers who use the kits to design new products that will benefit from the kits' integrated circuits. The "users in general" example is therefore noteworthy as it appears to exclude many or most of the evaluation kits on the EU market.

1.5 Defining to the Scope of Apparatus

Just like the 2010 Guide, the 2018 Guide also tackles the issue of "does CE plus CE equal CE?" when multiple products are combined into apparatus.[5] As in 2010, the 2018 guidance states that, when combined, two or more CE marked finished products do not necessarily constitute a "compliant" system. The 2018 Guide also moves on from this to state that, if a finished product is excluded from the EMC Directive but in scope of another EU law like the RED, then the product shall comply with that law when it is placed on the market.

New content also arises regarding components/subassemblies, which is subsection 1.5.3. Here it is stated that components/subassemblies are within the scope of the EMC Directive if two criteria are satisfied, namely that the components/subassemblies are:

- Intended for incorporation into an apparatus by the end-user; and

- Liable to generate electromagnetic disturbance or the performance of which is liable to be affected by such disturbance.

SECTION 2: ESSENTIAL REQUIREMENTS

The guidance is the same as in 2010.

SECTION 3: OBLIGATIONS OF ECONOMIC OPERATORS

While this section is entirely new, it really does not say that much. In fact, there are two sentences that convey two pieces of information: look to the Blue Guide regarding the basic obligations of economic operators, and that Section 4 of the Guide outlines EMC-specific obligations.

SECTION 4: CONFORMITY ASSESSMENT PROCEDURE FOR APPARATUS

Much of this is the same as was previously stated in the 2010 Guide, although there are some notable differences.

4.2 Risk Analyses and Risk Assessment

Subsection 4.2 of the 2018 Guide is entirely new. This reflects on the entry of a requirement for risk analysis in NLF legislation. The 2018 Guide states the following:

> *"The conformity assessment procedures for apparatus require the manufacturer to establish technical documentation. This documentation shall make it possible to assess the conformity of the apparatus to the relevant requirements, and shall include an adequate analysis and assessment of the risk(s). In EMCD [the EMC Directive] the concept of risk refers to risks in relation to the electromagnetic compatibility protection aims specified in Annex I "Essential Requirements" and not to safety. On basis of the knowledge of the relevant EMC phenomena for the apparatus and its intended operating environments the EMC assessment according to chapter 4.3 can be performed. This EMC assessment is considered to be an adequate analysis and assessment of the risk(s)."*

4.3 EMC Assessment

This section remains broadly the same as it was in 2010, although some new text is introduced pertaining to EMC assessment in practice. This is to be performed following a "defined methodology" with the guidance stating that:

> *"Any conformity assessment procedure requires the manufacturer to start with an analysis of the specific risks of the product to address them in order to comply with the essential requirements because not all products present the same risks.*
>
> *"Once the risks are identified and the manufacturer has determined the measures to address those risks in order to comply with the essential requirements he can choose to apply the harmonized standards applicable to his product or he can choose other technical specifications."*

There is also new information in subsection 4.3.2, Use of EMC harmonized standards. This is that conformity with harmonized standards listed in the

Official Journal of the European Union under the EMC Directive give presumption of conformity with the corresponding essential requirements of the Directive.

Similarly, new and different guidance is introduced in subsection 4.3.2.2, Relevant harmonized standards. The new information is that, should a manufacturer choose to apply one or more harmonized standards, then there is a preferred order for selection. This is:

- Product-specific standards (if available); then
- Product family standards (if available); then
- Generic standards.

In addition, clarification is offered that, for any given product, it may be necessary to apply several harmonized standards to cover the Directive's essential requirements. The 2018 Guide advises that the aspects that are generally required to be covered are:

- Radiated disturbances;
- Conducted disturbances at mains and telecommunication ports;
- Immunity to continuous radiated and conducted disturbances; and
- Immunity to transient phenomena.

4.4.2 Declaration of Conformity (DoC)

Unsurprisingly, new guidance exists here owing to the introduction of a DoC model structure. The model structure is reproduced in the 2018 Guide.

Furthermore, comment is made that "the DoC can take any form as long as the information prescribed in the model structure in Annex IV of the EMCD is included as a minimum."

There is new guidance too. This clarifies that, where apparatus is subject to more than one EU law that requires a DoC, then a single DoC shall be drawn up in respect of all relevant legislation. However, the single DoC can be "made up of a dossier containing all relevant individual EU Declarations of Conformity."

4.5 CE Marking

New guidance is given here, largely to reference and show consistency with one of the Regulations that form part of the NLF. This is Regulation (EC) No 765/2008; Article 30 of the Regulation lays down general principles for CE marking form and size.

4.5.3 Information for Traceability

The 2018 Guide offers new advice, which, for manufacturers, is that they are required to give their name, registered trade name or registered trade mark, and the postal address at which they can be contacted.

For apparatus made outside the EU, importers shall also indicate their name, registered trade name or registered trade mark and the postal address at which they can be contacted. In addition:

- All contact details shall be in a language easily understood by end-users and market surveillance authorities; and
- Traceability information shall be affixed on the apparatus itself. Failing that, it may be included on its packaging or in a document accompanying the apparatus.

4.5.4 Information Concerning the Use of Apparatus

New advice is presented, which is that apparatus is to be accompanied by:

- Information on any specific precautions that must be taken when the apparatus is assembled, installed, maintained or used, in order to ensure that, when put into service, the apparatus is in conformity with the Directive's essential requirements;
- A clear indication on restriction of use in residential areas (where appropriate also on the apparatus packaging) if the compliance with the Directive's essential requirements is not ensured in residential areas.

There is also a statement on language. This reads that the accompanying information shall be "in a language which can be easily understood by consumers and other end-users, as determined by the Member State concerned." Instructions and information, as well as any labelling, is also to be clear, understandable and intelligible.

SECTION 5: FIXED INSTALLATIONS

There is no new guidance on fixed installations; it all carries over from the 2010 Guide.

SECTION 6: MARKET SURVEILLANCE OF THE EMCD

Although the section title has changed, there is less guidance in 2018 and what guidance does exist is repeated from 2010 while also directing the reader to the Blue Guide.

SECTION 7: NOTIFIED BODIES

Much of the guidance is the same as in 2010, although there are new subsections regarding subcontracting and information exchange.

7.2 Subcontracting

The 2018 Guide clarifies that subcontracting does not entail the delegation of powers or responsibilities.

7.3 Information Exchange

The 2018 Guide explains that Notified Bodies are obliged under Article 34 and Annex III of the EMC Directive to provide specific information to certain organizations, notably other Notified Bodies plus notifying authorities. The Guide advises Notified Bodies to check with the Notified Body Coordination Group (EUANB) over what information they are expected to provide and how this is to be communicated.

ANNEXES

Some new information is noteworthy. In particular, there is newly introduced content regarding guidance on using a harmonized standard. This includes the following paragraphs:

> *"The harmonized standard may contain additional requirements that are not relevant to the presumption of conformity against the EMCD, however, the harmonized standard is required to maintain an annex which provides information on correlation of its technical requirements with the essential requirements of the Directive.*
>
> *"The requirements and limits of the harmonized standards are expected to be met when the equipment is tested to the specification in the standard. Based on the risk analysis and if the applied harmonized standard does not cover all the phenomena expected from the equipment, the manufacturer is required to address the residual risks not covered by the harmonized standards to ensure that all the phenomena are considered.*
>
> *"The only secure way for the manufacturer is thus to apply, without any deviation, the standards referred to, relevant for its equipment, while making the EMC assessment."*

There is also a clarifying statement concerning practice, specifically in the case of manufacturers that decide not to perform tests since they can satisfy themselves by other means. It is said that explanations have to be added to the technical documentation, and that these explanations should demonstrate how essential requirements are met.

IN SUMMARY

While not a major overhaul, the 2018 Guide brings some key changes to the advice that the European Commission had previously offered on the EMC Directive, including new interpretation in the case of custom built evaluation kits and components/subassemblies, more examples and greater contextualization (specifically with regards the NLF, but also dividing lines between the EMC Directive and the RED). This article has highlighted significant differences, quoting new guidance verbatim in certain instances to help orientate readers.

REFERENCES

1. https://ec.europa.eu/docsroom/documents/28323
2. European Economic Area and European Free Trade Association
3. Obtainable from: http://ec.europa.eu/DocsRoom/documents/18027
4. Radio and Telecommunications Terminal Equipment Directive
5. Under the EMC Directive, "apparatus" is a finished appliance, or combination thereof, made available on the market as a single functional unit, intended for the end-user. The 2018 Guide adds that a finished appliance is "any device or unit that delivers a function and has its own enclosure."

HOW TO GET THE RESOURCES YOU NEED

Securing Your Company's Financial Commitment for Test Equipment or Other Resources Can Be a Challenge: Here's How to Get Management Buy-in and Ensure the Success of Your Project

***Editor's Note:** An earlier version of this article was originally published in The EMC Journal in July 2008.*

A problem faced by all engineers and engineering managers is persuading your manager that you need a new item of test equipment, or you need to add something to a product that is not in its technical specification (for example to reduce financial risks such as high levels of warranty returns).

You have the best interests of your company at heart, and you know what is needed. But you are a technical person and your manager probably is not. Your manager sees the costs, but the only way you can describe the benefits is by using technical language that your manager does not understand.

Worse, your manager may believe that your use of technical language is an attempt to 'blind him/her with science' and, resenting this, be more likely to refuse your perfectly valid request out of hand.

Your manager needs you to provide justifications that use financial language – often so that he/she can then use the same arguments to persuade the bean counters (otherwise known as accountants) that run all engineering companies. *But you have to be the one that does it!*

Keith Armstrong is a senior contributor to In Compliance Magazine, and the founder and principal of Cherry Clough Consultants Ltd, a UK-based engineering firm that utilizes field-tested EMC engineering principles and practices to help companies achieve compliance for their products and reduce their potential risk. He is a Fellow of the IET and a Senior Member of the IEEE, and holds an Honours Degree in Electrical Engineering from the Imperial College, London (UK). Armstrong can be reached at keith.armstrong@cherryclough.com.

By Keith Armstrong
In Compliance Senior Contributor

THE HEART OF THE CHALLENGE

Make no mistake, modern electronics and other engineering is all about the money, and if you want your company to be successful you must learn to communicate in money terms.

But a scientific or engineering education often contains very little, if anything, about how to communicate with financial people. This is, of course, stupid – because scientists and engineers who cannot communicate effectively with their managers simply won't be very effective.

The problems caused by this language barrier almost always come up during my training courses on EMC design. All my training is aimed at helping engineering-based organizations become more successful financially. But, where additional investment is needed to help create financial success, the engineers attending my courses usually say that it typically won't be permitted by their bean counters (uh, I mean accountants!).

What they really mean, of course, is that they are unable to communicate effectively with their managers.

Except in the simplest cases, there is *no way* that your manager is going to learn enough about what you do to understand why investing cash resources in that test gear or design modification is going to benefit the company financially.

THE SECRET TO GETTING WHAT YOU WANT

So engineers must learn to present their arguments in financial terms. (Sorry, but there it is!) Every engineer needs to be able to describe their company investment needs in terms that their Financial Director (or Financial Vice-President) can understand. The FD (or F-VP) is really the person who runs the whole company, but usually knows almost nothing at all about what their company actually does or how they do it. As far as understanding the nerds in the Engineering Department, they might as well be Martians.

Since I learned how to justify expenditure on engineering over 30 years ago, I have not had a single capital application, design change request or request for additional personnel turned down, ever.

The trick, as I eventually learned, is to: 1) do your homework thoroughly; 2) account for all foreseeable effects on all departments of the company; 3) present all requests in financial terms *only*; and 4) show how the investment will pay back sufficiently well and in a timely enough manner.

PUTTING TOGETHER A WINNING PROPOSAL

Your typical proposal would be a document with the first (cover) page being a one-page 'Executive Summary' that is purely for getting attention, followed by detailed Appendices.

You only have about 10 to 20 seconds to get your message across to your manager. This means that your one-page Executive Summary cover page should be written in 12-point Arial or some other easily readable font, with 1.5 line spacing, 24-point paragraph spacing, and margins of at least 30mm. Use bold, italic, or larger fonts for titles and emphasis.

These rules do not allow many words, which is fine because the whole page should be able to be read ('scanned') within 10 seconds or so. No sentence should occupy more than one line of text. No paragraph should have more than three sentences. DO NOT TYPE USING ALL CAPITALS – it's as if you are SHOUTING!

The next important thing to know is that all financial people are gamblers. Why should anyone want to invest good money in an engineering company, when they could instead invest in supermarkets, oil, gas or steel manufacture, or property?

So your Executive Summary should be written accordingly. It must present the following financial information *in the order shown*:

1. The financial benefits to your company
2. The timescale over which the benefits will be realized (a simple graph is often best)
3. The probability of success (don't be shy, even a 50% chance of success is a very good bet for a gambler)
4. The total value of the investment required to achieve the above
5. The timescale over which the investment will be required (e.g. a simple graph)
6. Briefly say what the investment will be used for, using *commonplace* words (no jargon, technical terms or standards numbers)

In all the above, be direct and straightforward. Don't try to achieve the Nobel Prize for Literature. Just get your basic message across without ambiguity. Once you have their attention, they can read all the details, and caveats, in the carefully argued appendix (10-point Arial, single line spacing, 6-point paragraph spacing, for example). But if you don't get them interested in the first 10 seconds or so, the appendices and all the work that went into them will be wasted.

The final bullet point above might benefit from an example. Don't write: "0.1-26GHz four-port vector network analyzer" – say instead: "Test equipment needed for developing new products & improving production yields." You should put the proper description and technical specification for the 4-port VNA in the appendix.

THE APPENDIX IS WHERE YOU SHINE!

The appendix is where you write up the detailed technical and financial investigations and calculations you have done. Always make sure to summarize everything in financial terms, and make sure to use discounted cash flow analysis (look it up) over the sales life of the product, at least. In the case of arguments based on reducing financial risk, for example, from exposure to product liability lawsuits, the analysis should extend for at least 25 years. Some long-lived products, such as railway rolling stock, might need to use 50 years or more.

It is generally best to have an appendix with two sections:

a) The first section amplifies the five basic items in the Executive Summary, using about one page each, so each of these is itself likely to be a summary. Avoid technical language as far as possible, because your manager is likely to read this section – if your Executive Summary crossed his or her noise threshold and got them interested.
b) Your detailed calculations, using all the technical information you need. Your manager will almost certainly do no more than skim this to see how much effort you put into your proposal. But he or she will probably have it checked by an engineer they feel they can rely on, and not necessarily one in your company. *So it had better be as correct as you can make it!*

Doing the homework means that you need to understand all relevant areas of your company (design, development, purchasing, manufacturing, marketing, sales, warranty repair, field service, etc.), how they do what they do, and what are the financial implications for them of what you are proposing.

It's also helpful to understand some basic financial concepts as they relate to manufacturing companies, generally known as "management accountancy." These include cash flow, discounted cash flow, investment, break-even point, return on investment, etc. (as well as the trendy jargon that inevitably attends them, of course!)

Yes, I know it's more work, and I know you don't have the time. But you are an engineer, and engineers can do anything they put their minds to! Like any learning curve, doing it the first time is the hardest. Later on, riding high on the successful career you have achieved by learning to do this stuff, you will wonder why you ever thought it might be difficult.

CLOSING THE SALE

Engineers are often told there is no money available, whereas there almost always is – but only for proposals that are communicated effectively and appear to be a very good bet.

For example, in 2001, a UK manufacturer spent £100,000 (over $200,000 USD in value today) redesigning their range of products to comply with the new versions of the EMC immunity test standards. These new versions introduced testing for a range of surges, dips and dropouts in the mains power supply, amongst other things.

The manufacturer would not have bothered with the redesign, had it not been for the fact that it was necessary for compliance with the EMC Directive, and they were a law-abiding company. But they subsequently found to their complete surprise that their new designs saved them £2.7 million (over $5 million USD) in warranty costs *per year*. I have heard many similar stories over the years.

Imagine that in 1999 you were a senior engineer with that company, and had spotted the fact that the design of your products was lacking in what you thought was necessary to dramatically reduce warranty costs.

If you went to your Financial VP and said: "Please give me $200,000 to improve the EMC of our products, because I think they should be made immune to power line surges". You expect the F-VP to give you the $200k because you are employed as a senior engineer and so of course you know what you are talking about – but you would almost certainly be disappointed!

Most people never get past the "Please give me $200,000 to…." before their manager is shouting that there is no **** money, so go away and shut up.

Now imagine that you took the trouble to investigate the problem – and discovered that about $5 million of warranty costs *per year* could be attributed to surge damage that could be prevented by about $200,000 of redesign and testing.

Now, if you said to your F-VP: "We can achieve $5 million per year savings in warranty costs from next year, if you give me $200,000 for design changes and EMC testing right now", and provided the detailed data and calculation in a document – then you would almost certainly get the $200k and a pat on the back, almost regardless of the financial situation the company is in.

A 27-fold return *every single year* from one single investment is what the financial world calls a 'No Brainer'. Even if the odds of succeeding were 50/50, 30/70 or even worse, it is still a No Brainer! There is almost always money available for 'no brainer' gambles.

You don't need a Degree in Business Management to do all this, just 'Management Accountancy for Dummies' (if there isn't a book with that title, there should be), common sense and a grounding in reality. You can very quickly learn enough to amaze your managers that a mere engineer should be so knowledgeable about company finance, yet still find the financial pages of quality newspapers almost completely baffling.

It's really the language of gambling:

1. What could the winnings be?
2. How long will it take to win?
3. What are the odds?
4. What is the stake (the investment)?

SUMMARY

Good engineers are all very clever and grounded in reality, so learning the above stuff well enough is easy for them. If it all sounds like extra work – it is – but the rewards are well worth it.

It is just another learning curve, and engineers are good at learning, because they have to be just to keep up with technology. This business and financial stuff is different, for example you can't calculate it to five digits (well, you can, but only the first digit means anything) so you have to learn to be comfortable with fuzzier data and larger uncertainties.

Having all this business and financial stuff under your belt and effectively communicating engineering needs to managers (and managers' needs to engineers), will help make your company much more successful. And it may lead to pay raises and promotions for you! So take on the challenge, and good luck!

PRODUCT Showcase

2019

Product Resource Guide

When it comes to navigating your way through the design and testing stages of product development, there are a number of key product areas that you will need to be familiar with around the engineering lab.

From antennas and amplifiers, to filters and shielding, (and so much more) engineers are tasked with responsibility for a multitude of functions while on the path to producing compliant products for the marketplace.

This year, to help you quickly get up-to-speed and stay abreast with current technologies and methods, we focused in on a few primary products you are likely to encounter. We added deeper insights to operational principles as well as more detail regarding key factors for purchase consideration. Our aim is to help you make more informed buying decisions and ultimately run your lab more effectively and with greater confidence.

We hope you enjoy this year's guide!

Lorie Nichols
Editor/Publisher

2019

PRODUCT

RESOURCE GUIDE

with contributions by

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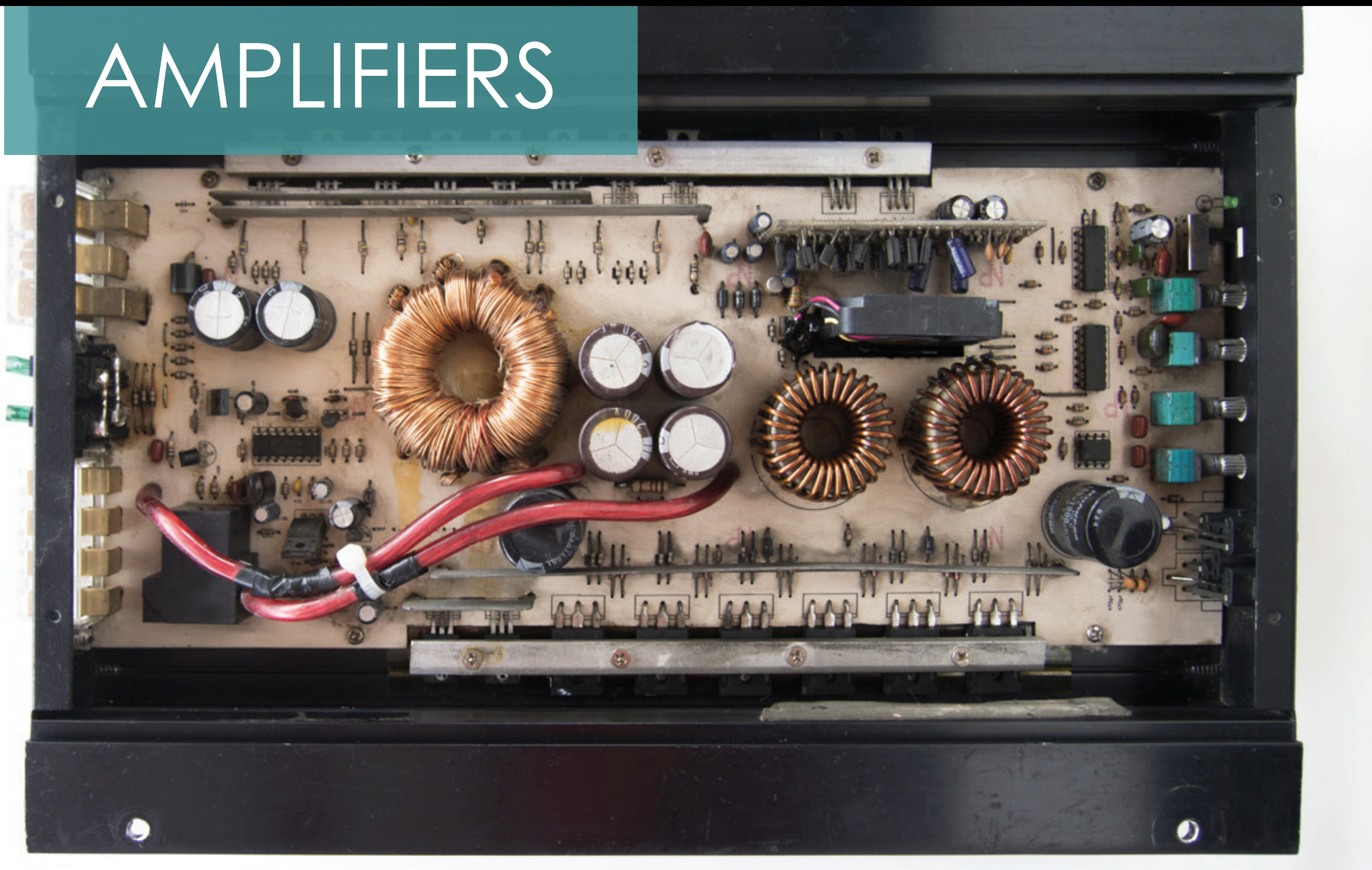


AMPLIFIERS

At some point in your EMC career you may very well be tasked with specifying broadband RF amplifiers for RF immunity testing and need to quickly get up-to-speed on the key factors involved in the buying decision before actually making the purchase of an expensive amplifier. There is nothing worse than finding out after you receive your brand-new amplifier and begin testing that you discover the amplifier selected doesn't fully accomplish what you expected it would and you're forced to come up with some costly and sometimes embarrassing work-arounds (like having to move the antenna closer to the EUT than is allowed in order to obtain the required field strength).

The RF amplifier is the workhorse of the EMC test laboratory. Not only does it have to be reliable and operate perfectly for many hours in any given day, it must also deliver the proper field strengths, over the correct frequency ranges, with minimum spurious harmonic emissions and with low distortion, sometimes into complete open or short conditions or into other inefficient loads (i.e. antennas). If the amplifier selected is not robust or does not fully meet your specifications, your testing process is not as efficient as it could be, and this could lead to increased test time, increased test cost, over-testing or under-testing of the equipment under test (EUT).

Before getting into some of the more technical aspects of RF amplifiers for EMC testing, let's first discuss delivery of the amplifier and the environment in which the amplifier will be installed.

Environment

If the amplifier requires water cooling, how will that be installed? If air-cooled, is there enough air flow space available around the amplifier to ensure that heat does not recirculate back into the amplifier? Is the air surrounding the amplifier relatively dust-free and is it kept at least 72°F (22.2°C) and below? Less dusty and cooler environments are better for the amplifier.

Power Sources

Are there adequate sources of clean power readily available? If not, have arrangements been made with the facilities department to locate the proper power source nearby.

Noise

How much noise will the fans of the amplifier generate and will this negatively impact any other work located in the area near it?

Installation

If the amplifier weighs a lot, how will it get from the delivery truck to its permanently installed location without getting damaged or causing damage? Will it arrive in a wooden crate and if so, how will it safely get removed from the crate? Consider having professionals install the amplifier in its permanent location and think about keeping the original packing crate in the event the amplifier must be returned to the manufacturer for repair.

Storage

Where will the original packing be stored after uncrating the amplifier? It should be easy to get to.

Location

Will the amplifier be located in a high traffic area and if so, how will you keep personnel from inadvertently bumping into it? Or even better, how do you plan to locate the amplifier out of the way of foot traffic in the first place?

Inputs and Outputs

Have you considered RF inputs and outputs to the amplifier? What is the maximum input drive level to the amplifier before damage occurs and how will inadvertent over-powering of the input be handled? How will the RF output of the amplifier be delivered most efficiently to the antenna for radiated tests or to injection probes for conducted tests?

Connectors and Cables

What types of RF connectors and cabling are required based on configuration and power rating of the amplifier? Are these connectors and cables currently available in-house or do they need to be purchased as well? When determining your output power handling requirements, be sure to factor in all of the line and connector losses present in the system.

Safety Considerations

Finally, have you considered installation of a door interlock to the EMC chamber so that if the chamber door is inadvertently opened while the amplifier is outputting RF energy that the RF output of the amplifier is disabled? This is a personnel safety factor and should not be over-looked.

Once all of the housekeeping requirements are thought through consider the specifications the amplifier must meet based on anticipated testing needs.

- What immunity standards do you need to perform?
- What are the test distances required (1m, 3m, etc.)?
- What are the required field strengths (i.e. 3V/m, 10V/m, 200V/m, etc.), frequency ranges, voltage standing wave ratio protection, linearity and harmonics requirements required by the chosen standards?
- What is the status of the standards?
- Is there an anticipated revision in the works that will require higher field strengths or testing to higher frequencies?
- Will margin testing to higher field strengths and/or higher (or lower) frequencies be required during product development in order to fully understand where the product fails?

Based on results of this investigation, try to select an amplifier that will meet current as well as these anticipated needs.

What antenna or antennas will be used?

Does your firm already own them or do they also need to be selected along with the amplifier? Selecting an antenna along with the amplifier could be an advantage since you can choose the most efficient antenna/amplifier pair. Unfortunately, you're often provided with an antenna that someone else purchased long before you got involved, and because of budget or other constraints, you just have to use that particular antenna.

Field Strength and Output Power

The most important characteristic to take into consideration when selecting a RF amplifier is the output power required to create a certain field strength at a certain frequency. This characteristic varies with frequency. It may take only 10W to generate 3V/m at one frequency, and 100W to generate the same field strength at some other frequency (the reasons are beyond the scope of this article).

Linearity

The next characteristic to consider is the linearity of the amplifier over the entire frequency range of interest. Linearity, the degree of proportionality between input and output, ensures the amplifier is capable of outputting a fixed increase in output power given the same increase in input power (there is a dB for dB increase in input power versus output power). At some point, called the 1-dB compression point, all amplifiers are said to go into "compression." The maximum amplifier RF output will be reached regardless of the RF input and the amplifier RF output will become saturated. A byproduct of running the amplifier into compression is the creation of harmonic and spurious emissions at frequencies other than the intended frequency. You may not even be aware these emissions are present and must carefully check for them using a frequency selective device such as a spectrum analyzer. The typical RF field probe used in compliance testing only provides a readout of the highest field strength present, not its frequency. This issue is important because you could be over-testing your EUT at some frequency you weren't intending to test at and not even know it. These issues are best avoided by selecting a RF amplifier with a large enough maximum output power that is well above the 1-dB compression point.

Voltage Standing Wave Ratio or VSWR

The final characteristic to consider when selecting a RF amplifier for EMC testing purposes is a rather complex one. This characteristic is called Voltage Standing Wave Ratio or VSWR and is caused by too much impedance mismatch between source and load. It mainly occurs due to the imperfect impedance mismatch of the load to the amplifier's RF output and in the case of radiated immunity testing the load is the antenna. If the antenna's input impedance were a perfect 50Ω across the entire frequency band, and assuming no other losses, this impedance would match the 50Ω output impedance of the amplifier, and all of the forward transmitted power from the amplifier would be absorbed by the antenna and radiated. However, since the antenna is not a perfect load, some or all of the forward transmitted power gets reflected back into the amplifier. This reflected power can cause serious damage to the amplifier through arcing, breakdown of components, or excessive heating. Modern RF amplifiers utilize fold-back circuitry to detect mismatch and decrease the output power of the amplifier until the magnitude of the reflected power is within safe levels. Be sure to consider protection against VSWR when selecting an RF amplifier.

References

1. Denisowski, An Introduction to EMC Amplifiers White Paper, Rohde & Schwarz, 2016
2. Smith, Do's and Don'ts in the application of high-power RF amplifiers in EMC test systems, AR RF/Microwave Instrumentation, 2009

Consider carefully documenting your selection of a RF amplifier. It is quite common to encounter a situation where the EUT is failing a RF immunity test and all fingers point to an imaginary issue with the test setup. Having documentation available to prove the test setup was sound will quickly get the team back on track and back into solving the real issue, a problem with the EUT.

FLATNESS:

Specifies how much the amplifier's gain can vary over the specified frequency range. Variations in the flatness of the amplifier's gain can cause distortion of signals passing through the amplifier.

HARMONIC DISTORTION:

Measurement of the harmonic distortion present and defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

NOISE FACTOR:

The measure of degradation of the signal-to-noise ratio (SNR) caused by components in a radio-frequency (RF) signal chain. It is a number by which the performance of an amplifier or a radio receiver can be specified.

DYNAMIC RANGE:

Power range, usually given in dB, between the smallest and largest output levels

GAIN:

The ratio between the magnitude of output and input signals.

LINEARITY:

The degree of proportionality between input and output.

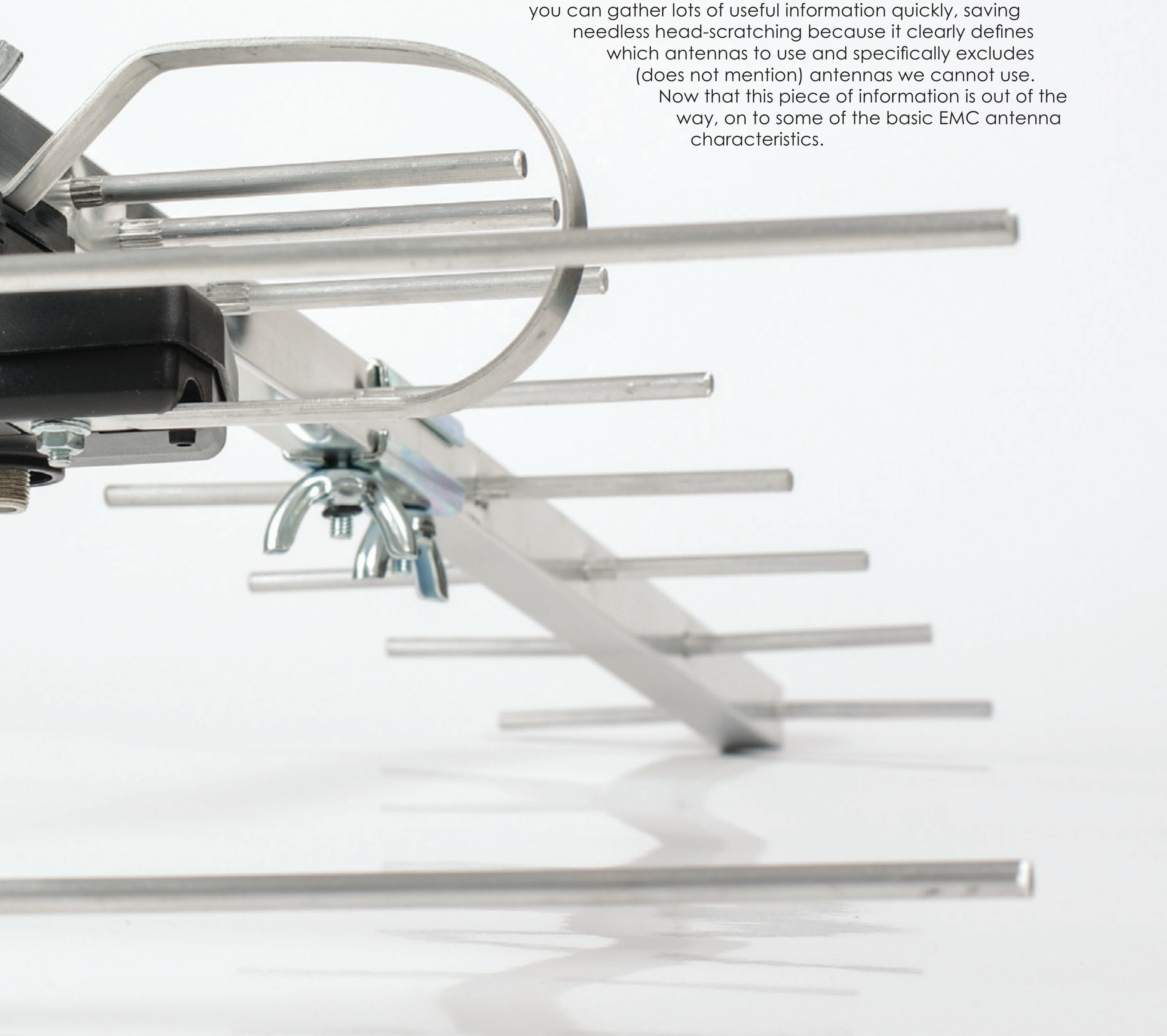
ANTENNAS

To the uninitiated, knowing what antenna to use for EMC radiated emissions and radiated immunity testing can be a bit tricky. At first, determining which EMC antenna is the most appropriate may take a considerable amount of time and effort, with the high probability of the researcher developing some grey hairs before it is all finally sorted out. Fortunately, it doesn't have to be this way. There are several basic antenna characteristics to take into consideration when selecting an EMC antenna. Knowing what these characteristics are before diving into your own antenna research will hopefully point you in the right direction and ultimately save some time, money, and a lot of grey hairs. At a minimum, you will be equipped to ask some great questions when contacting antenna suppliers to determine if their products will fully meet your EMC testing needs.

Don't be afraid to ask the antenna experts for help.

Let the Standards Guide You

Before getting too far into some of the more technical details surrounding EMC antennas, and trying to decide which antennas will suffice, one of the first things to determine is what EMC standard to apply. Look in the applicable standard for any information that will help identify which antenna to select in order to meet the requirements of the standard. Does the standard call out the required antenna specifications? For instance, MIL-STD-461G calls out by bandwidth, the antenna requirements for that particular frequency range. Specifically, from 10 kHz to 30 MHz, MIL-STD-461G says the 104 cm rod with impedance matching network is required. From 30 MHz to 200 MHz it states the 137 cm (from tip-to-tip) biconical antenna is required. The double-ridge horn, with a 69.0 by 94.5 cm opening, is required from 200 MHz to 1 GHz. Finally, the much smaller double-ridge horn, with a 24.2 by 13.6 cm opening, is required for frequencies between 1 GHz to 18 GHz. Notice that no log-periodic antenna is mentioned and that if you want to state you can perform EMC testing in accordance with MIL-STD-461G then you cannot use the log-periodic antenna or any other antenna not specifically described in the standard. The point of all this is that by referring to the standard, in this case MIl-STD-461G, you can gather lots of useful information quickly, saving needless head-scratching because it clearly defines which antennas to use and specifically excludes (does not mention) antennas we cannot use. Now that this piece of information is out of the way, on to some of the basic EMC antenna characteristics.



Antenna:

An antenna is a device that transmits and/or receives electromagnetic waves. Electromagnetic waves are often referred to as radio waves. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band that the radio system to which it is connected operates in, otherwise reception and/or transmission will be impaired.

MIL-STD-461 Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

FCC part 15 Federal Communications Commission (FCC) rules and regulations, mainly regarding unlicensed transmissions.

ANSI As the voice of the U.S. standards and conformity assessment system, the American National Standards Institute (ANSI) empowers its members and constituents to strengthen the U.S. marketplace position in the global economy while helping to assure the safety and health of consumers and the protection of the environment.

Biconical Antennas

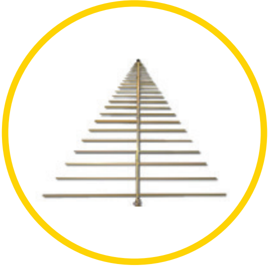
20 MHz - 18 GHz

A broadband antenna, suitable for FCC, MIL-STD, VDE, TEMPEST, and immunity testing.

Log Periodic Antennas

80 MHz - 7 GHz

Multi-element, directional antenna designed to operate over a wide band of frequencies.



BiLogical Antennas

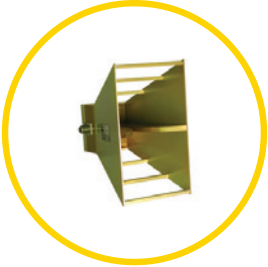
25 MHz - 7 GHz

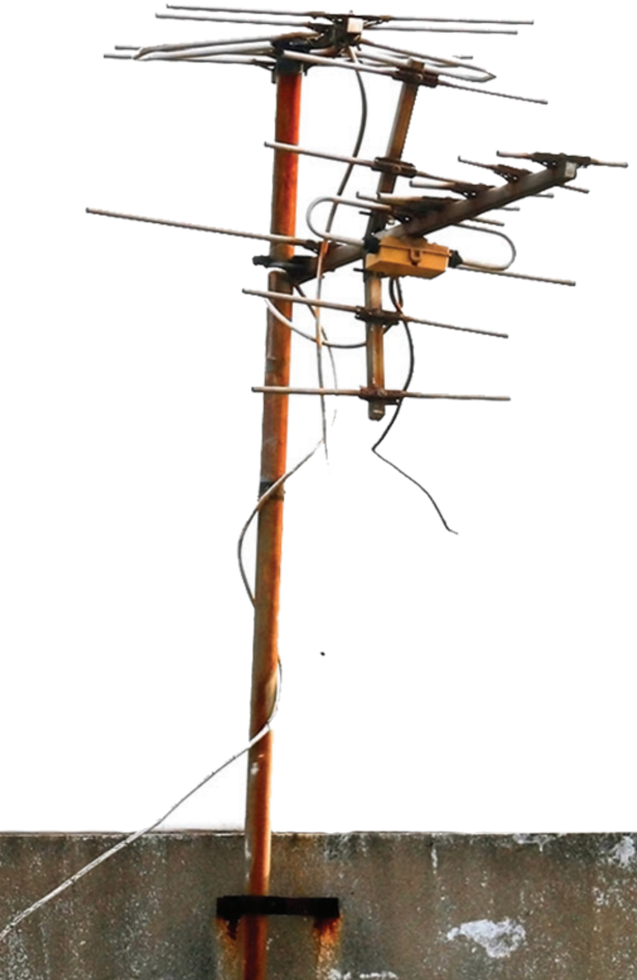
A combination of biconical antennas and log periodic antennas for broadband, high power, directional testing.

Horn Antennas

170 MHz - 40 GHz

For high power and gain applications, horn antennas have full broadband coverage in a compact frame.

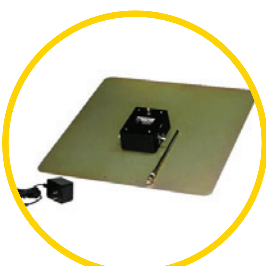




Dipole Antennas

25 MHz - 3 GHz

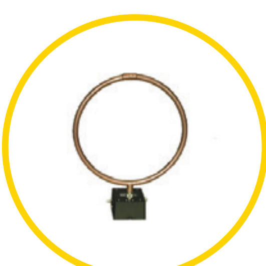
Simplest and most widely used form of antennas, ideal solution for site attenuation measurements



Monopole Antennas

100 Hz - 60 MHz

Used to perform shielding effectiveness and immunity testing for Military, FCC and TEMPEST standards.



Loop Antennas

20Hz - 30 MHz

Primarily used to measure the magnetic field strength at lower frequencies.

Antenna Images and Terms & Definitions courtesy of:

A.H. Systems, Inc.

ANTENNA FACTOR (AF):

The ratio of the incident Electromagnetic Field to the output voltage from the antenna.

BALUN:

An acronym for Balanced/Unbalanced. Typically an RF transformer used to couple a balanced transmission line to an unbalanced antenna system.

BEAMWIDTH:

Depending on the radio system in which an antenna is being employed there can be many definitions of beamwidth. A common definition is the half power beamwidth. The peak radiation intensity is found and then the points on either side of the peak representing half the power of the peak intensity are located. The angular distance between the half power points traveling through the peak is the beamwidth. Half the power is -3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth.

BROADBAND ANTENNA:

An antenna capable of operation over a wide band of frequencies.

DIRECTIVITY:

A measure of how focused an antenna coverage pattern is in a given direction. A theoretical loss-less antenna element, referred to as a isotropic element, has 0 dBi directive gain equally distributed in all 3 dimensions. In order to achieve higher directive gain, antennas are normally designed to focus or concentrate the antenna pattern only in the direction of the radio link, thereby maximizing energy usage.

Antenna Factor

For EMC radiated emissions testing, Antenna Factor (AF) is the most important characteristic to consider. AF is defined simply as the ratio of the incident electromagnetic field (E) to the output voltage (V) from the antenna. When you purchase a calibrated antenna, it is provided with a table and plot of its AF in dB/m versus frequency for both vertical and horizontal antenna polarities. This data is input into your EMC emissions testing software and is used to calculate actual field strength (E – in dB micro-volts per meter) that is emanating from the equipment under test (EUT).

The conversion of field strength from measured voltage using AF is a simple formula as shown below:

$$E\ (\mathrm{dB}\mu\mathrm{V/m}) = V\ (\mathrm{dB}\mu\mathrm{V}) + AF\ (\mathrm{dB/m}) + A\ (\mathrm{dB})$$

where A in dB is cable and connector loss present in the measurement system.

There is not much you can do about what the AF is for any particular antenna you choose. Just know what it is, how it is used in making emissions measurements, that it will be roughly the same for similar sized antennas (especially above 300 MHz), and that if your antenna gets damaged, then its AF may change and may need to be re-calibrated after repair.

VSWR and Gain

The second most important characteristic to consider with an EMC antenna is the Voltage Standing Wave Ratio (VSWR). This characteristic is more of a concern during RF immunity tests as the amplifier has to be able to withstand a certain amount of power reflected back into it from the antenna. As an electric wave travels through different parts of an ideal 50Ω RF system, it will encounter impedances other than 50Ω. At each interface, some fraction of the wave's energy will reflect back to the source (RF amplifier), forming a standing wave in the feed line. The ratio of maximum power to minimum power in the wave can be measured and is called the voltage standing wave ratio (VSWR). A VSWR of 1:1 is ideal as no incident power is returned back to the source. A VSWR of 2:1 results in only 10% reflected power and is considered about normal. A VSWR as high as 6:1, which equates to 50% incident power returned to source, may still be usable with the right RF power amplifier. Minimizing impedance differences at each interface and selecting an antenna with as low of a VSWR as possible will help in maximizing power transfer through each part of the RF immunity test system. In RF immunity testing we are more concerned with the field strength that can be achieved, and as VSWR increases, the level of RF amplifier output power required to achieve a desired level of field strength will also need to increase. This is particularly a troublesome issue with biconical antennas used in their lower frequency range (~25 to 50 MHz or so) and is something to keep in mind when trying to effectively match amplifier with antenna.

Along with VSWR, numerical antenna gain is something else to considered in determining the correct antenna and power amplifier pair. Depending on these factors, which vary with frequency, you may require a power amplifier with more output power.

Other Considerations

Some other things to think about regarding the use of EMC antennas is less technical and falls into the category of laboratory management. Each laboratory has its own requirements and you have to decide for yourself the best options to go with. For instance, will you use an antenna for emissions or immunity only, optimized for each purpose, or use an antenna specifically designed to perform both? If for both, then you may have to make some adjustments, like adding a high power balun (a device that provides a low impedance to differential current, and high impedance to common mode current) to your biconical antenna. Is there one antenna available that will improve test continuity and save in test setup time? One such antenna is the biconical/log hybrid (a.k.a. biconilog or bilog), that can be used over a larger frequency span than is covered by two separate standard biconical or log-periodic antennas. There are several manufacturers who produce these. Will the antenna (no matter what type) be used indoors or outdoors? If used outdoors, will the antenna and its positioning mechanisms have to withstand rain, dust, ultraviolet exposure, etc.? You may have several test sites and need to share equipment so how portable does the antenna have to be and how suitable is its packaging for this purpose? How large is the antenna and will it fit through the EMC chamber door? In order to avoid unnecessary damage from occurring, it's probably a good idea to get the antenna up off the floor and out of the way of other work when it's not being used for actual EMC testing. You may want to think about how the antenna will be stored when it's not in use. How will the antenna be transported back and forth to the calibration lab? It's probably a good idea to keep its original shipping crate and to budget for calibration and shipping charges as well. Finally, for radiated emissions measurements, have you determined your system's sensitivity and the minimum measurable level as determined by the noise floor of the receiver? You may have to use a preamplifier or preselector place near the output port of the antenna (prior to any long cable runs) in order to lower the effective system noise floor. This will ensure the test systems properly capture all signals emanating from the EUT because they won't be buried in the noise floor.

References

1. MIL-STD-461G, Requirements for the Control of Electromagnetic Interference, Characteristics of Subsystems and Equipment, Department of Defense Interface Standard, 11 December 2015.
2. Williams, EMC For Product Designers, Fifth Edition, Newness, 2017
3. Denisowski, An Introduction to EMC Amplifiers White Paper, Rohde & Schwarz, 2016
4. Mullineaux, The 10 Factors You Need to Consider When Selecting an EMC Antenna, A.H. Systems, EMC Live Test Boot Camp, 2015

CHAMBERS

A radio frequency "anechoic chamber" is a shielded room whose walls have been covered with a material that scatters or absorbs so much of the incident energy that it can simulate free space. Its origins can be traced to efforts to build aircraft which absorbed or scattered radar signals during the Second World War. Recent innovations such as the use of ferrite tiles, have greatly enhanced performance of these chambers.

Anechoic chambers may seem to operate through a bit of black magic, but the analysis of how they work is really quite straightforward. Assume for a moment that an electromagnetic plane wave (free space impedance = 377 ohms) strikes a wall at normal incidence. This can be modeled as a signal passing down a transmission line with a 377 ohm characteristic impedance as shown in Figure 1.

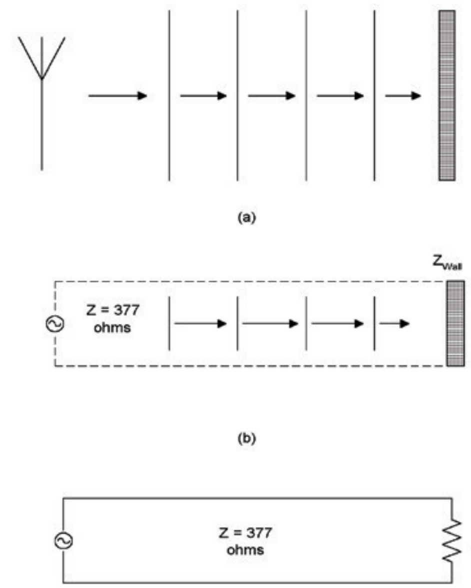


Figure 1: At (a), an antenna is shown radiating a plane wave that impinges on a metal wall at normal incidence. The antenna can be modeled as a voltage source and the resulting reflection computed using a transmission line circuit model as shown in (b) and (c).

To create a reflection-less chamber, we need, first of all, to understand how to send a signal down a transmission line and not have it reflect back. Since the shell of the anechoic chamber is metal, our transmission line model will have a shorted circuit at its termination. Since no energy is dissipated in our short circuit load, all of the signals sent down the transmission line will be reflected back. Our task is to find something put in front of the wall that absorbs or scatters this energy.

One of the methods first proposed to achieve this effect was through the use of the "Salisbury Sheet." The Salisbury Sheet is a sheet of paper that had been coated with a substance to give it a surface resistivity of 377 ohms per square. It is placed exactly one-quarter wavelength away from the metal wall. The Salisbury Sheet makes the reflected signal virtually disappear.

To see how the Salisbury Sheet works, look at Figure 2. Figure 2(a) shows a transmission line a quarter wavelength long with a characteristic impedance of 377 ohms. The load is a short circuit. Our voltage source also has a 377 ohm source impedance, divided into two resistors of 188.5 ohms each (Figure 2). When we turn the signal generator source on, a sine wave begins to propagate down the transmission line towards the load (Figure 2(b)). Since the characteristic impedance of the transmission line is also 377 ohms, the amplitude of this forward signal is reduced by half (at least initially) and is equal to V_0 /2. Reaching the load, a reflected signal is sent back. Because the transmission line is a quarter wavelength long, the reflected signal is exactly in phase with the transmitted one, and, as it passes backwards towards the source, the amplitude of the voltage along the transmission line doubles. At point A in Figure 2(a), exactly one-quarter wavelength away from the load, the transmission line has the impedance of an open circuit. For all practical purposes the transmission line is indistinguishable from no load at all -- it's invisible.

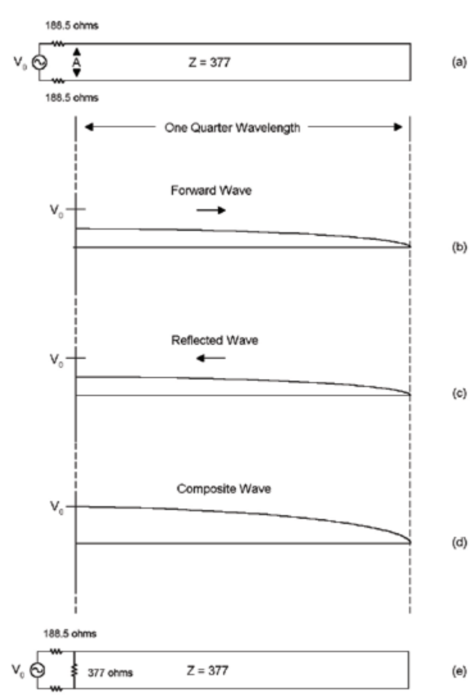


Figure 2: A shorted quarter-wavelength long length of transmission line (a "shorted stub") has the impedance of an open circuit as seen from the source. By placing a resistor of 377 ohms near the source as in (e), the impedance as seen from the source can be changed to 377 ohms.

As elegant a solution as a Salisbury Sheet is, its limitations are obvious. It only works at one frequency. In order to make the Salisbury Sheet work over a larger range of frequencies, several sheets can be used as shown in Figure 4. Here sheets of different surface resistivities are placed at one-quarter wavelength intervals from the metal wall. The transmission line equivalent of such an arrangement is also shown. The arrangement reduces the reflection coefficient from 1 to less than .1 (equal to a reduction of reflected signal strength of greater than 20 dB), and it works over a 2.5 to 1 bandwidth centered on λ.

Another approach is known as the "Jaumann Sandwich." Here both the resistances and the distances from the metal wall are tapered (Figure 5(a)). Reportedly, the Jaumann Sandwich can achieve a 20 dB reduction in reflection over a 5 to 1 bandwidth (Reference 3).

A modern implementation of these tapered techniques employs pyramidal absorbers (Figure 5(c)). The tapered shape of the pyramidal material performs a role similar to the tapered resistances of the Jaumann Sandwich. Many small reflections are created as the electromagnetic wave passes into the pyramid and these reflections tend to cancel out. To be effective, however, the pyramids must be at least one half wavelength long at the lowest frequency of interest. The size of the pyramid needed to achieve this effect is mitigated somewhat by the fact that the wavelength of the radio frequency signal as it passes through the pyramidal material is shorter than the free space.

It is reduced by a factor of: $\lambda_r = 1/\sqrt{\varepsilon_r}$

Where:

λ_r = Wavelength in media (that is, within the absorber)
ε_r = Permittivity relative to free space

Because of their size, providing for anechoic effects below 100 MHz requires the use of technologies other than pyramidal absorbers. In the last 20 years, ferrite tiles have become widely used as an absorbing mechanism.

The key here is for the ferrite tile to present an impedance approximately equal to 377 ohms. This is accomplished by making sure the ratio of the permeability to the permittivity is equal to that of free space:

$$Z = \sqrt{\frac{\mu}{\varepsilon}}$$

$$Z_{\text{free space}} = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377 \text{ ohms}$$

$$Z_{\text{in media}} = \sqrt{\frac{\mu_r}{\varepsilon_r}}$$

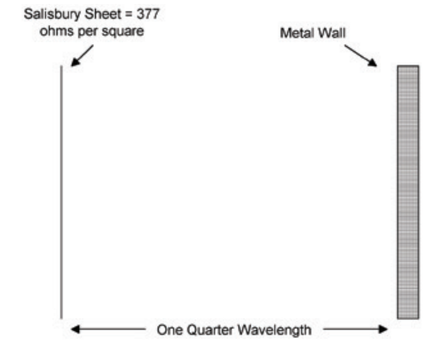


Figure 3: The Salisbury Sheet provides anechoic effects at one frequency. Placing a resistive sheet with an impedance of 377 ohms per square one quarter wavelength away from the wall results in impedance as seen from the source of 377 ohms.

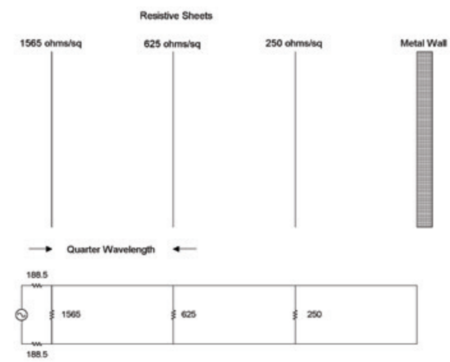


Figure 4: The use of several sheets of resistive paper widens the bandwidth of absorbent effects.

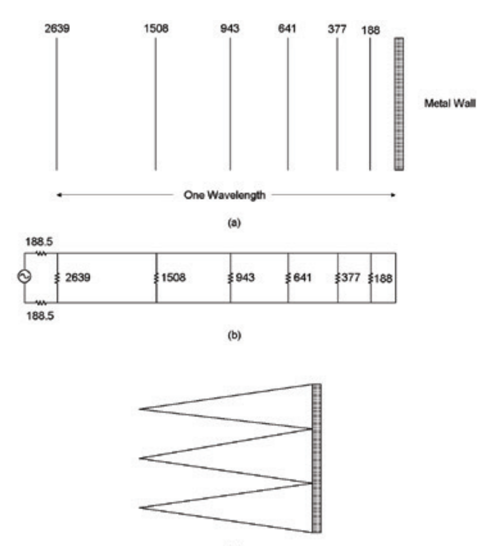


Figure 5: The Jaumann Sandwich uses a staggered array of resistive sheets and reportedly achieves a 20 dB reduction in reflected signal over a 5:1 bandwidth. For the case of normal incidence it can be modeled using the transmission line model in (b). Pyramidal absorbers use much the same effect to reduce reflection.

That, in turn, is achieved by keeping the ratio of mr to er equal to 377 ohms. By itself that won't prevent reflections however. What makes ferrite tiles work is that both the permeability and the permittivity are complex, so that the material is lossy. A typical ferrite material might have these properties:

$$\mu_r = \varepsilon_r = 60(2 - j1)$$

This results in a characteristic impedance of:

$$Z = 377\sqrt{\frac{\mu_r}{\varepsilon_r}} = 377\Omega$$

The complex permeability and permittivity results in loss as the wave passes through the ferrite tile. This loss is (Ref. 4):

$$Loss = e^{-\alpha d}$$

$$d = thickness\ of\ the\ material\ in\ meters$$

$$\alpha = Re\sqrt{j\omega\mu\sigma - \omega^2\mu\varepsilon}$$

$$\alpha = Re[j(\frac{2\pi}{\lambda})\sqrt{\mu_r\varepsilon_r}] = Re[j(\frac{2\pi}{\lambda})60(2 - j1)] = \frac{120\pi}{\lambda}$$

The conductivity of the ferrite tile can be considered to be zero. At 100 MHz, the loss for a one-centimeter ferrite tile would be:

$$Loss = e^{-\alpha d} = e^{-\frac{120\pi}{\lambda}(.01)} = e^{-1.26} = .28 = 11dB$$

Therefore, as the wave passes through the ferrite tile, it is attenuated by 11 dB. As it reflects off the metal surface behind the tile, the wave is attenuated another 11 dB, for a total of 22 db of loss. Ferrite tiles will retain this absorbent effect at all frequencies for which the permeability and the permittivity retain these values.

References

1. Ramo, Whinnery & Van Duzer, Field and Waves In Communications Electronic, John Wiley & Sons, 1965.
2. Holloway, DeLyser, German, McKenna & Kanda, "Comparison of Electromagnetic Absorber Used In Anechoic and Semi-Anechoic Chambers For Emissions and Immunity Testing of Digital Devices," IEEE Transactions on Electromagnetic Compatibility, February, 1997.
3. Kraus, Electromagnetics, Fourth Edition, McGraw-Hill, 1992.

ESD SIMULATORS

Electrostatic Discharge (ESD) simulators also known as "ESD Guns" play an important role in product development and their proper selection and use are considered essential to any Electromagnetic Compatibility (EMC) test laboratory. There are several different types of simulators to choose from, including those that test components according to the charged device model (CDM), human body model (HBM), or machine model (MM), and system level tests as described in standards such as IEC 61000-4-2 or ISO 10605. In this article we focus on ESD simulators that perform testing of complete apparatus in accordance with IEC 61000-4-2 and other system level test standards.

In addition to allowing test engineers/technicians to fully test a product in accordance with IEC 61000-4-2, ESD simulators allow EMC practitioners and product developers to quickly gain valuable information about the robustness of the equipment under test (EUT) to external transient electromagnetic phenomena. ESD simulators produce a severe high voltage, high current, high frequency content pulse. When this pulse is applied to the EUT, design deficiencies show up as automatic resets, program crashes, other unusual forms of product operations or by the product not meeting spec. Root cause analysis of these EUT failure modes often reveals failure mechanisms such as significant circuit loops, deficient power decoupling, and inferior grounding within the PCB. Other design deficiencies which result in failure of the ESD test include insufficient EMI suppression built into I/O ports, absent or incorrectly connected shields, incorrectly installed filters, and inadequate bonding of panels, covers or internal shields (just to name a few).

All of this valuable knowledge concerning the EUT's lack of robustness to EMI transients is obtained easily and quickly with one relatively simple tool – the ESD simulator.

With the ESD simulator there is no need to spend a considerable amount of time setting the EUT up in an EMC chamber, scanning over large frequency range, waiting patiently for long periods of time, while carefully observing the EUT until a valid failure occurs – all of which happens when performing a typical radiated or conducted radio frequency (RF) immunity test! With ESD simulators, development work can be accomplished on the spot, using a simple test setup and ground reference plane, with the added benefit that the same EUT design enhancements developed to pass ESD testing often help pass other forms of EMC tests to which the EUT will likely be subjected (RF emissions, RF immunity, electrical fast transient immunity, etc.).

Common ESD Immunity Standards

IEC 61000-4-2

Test Standard for Electrostatic Discharge (ESD) Immunity

ISO 10605

Test Methods for Electrical Disturbances From Electrostatic Discharge on Automotive Road Vehicles

RTCA/DO-160

Electrostatic Discharge for Airborne Equipment

MIL-STD-461G CS118

Personnel Borne Electrostatic Discharge (ESD)

ANSI C63.16

American National Standard for Electrostatic Discharge Test Method for Electronic Equipment

From the above discussion one can easily recognize the usefulness of the ESD simulator and how it can effectively be employed by product designers and developers in speeding-up product development times by allowing identification of product design weakness sooner than later in product development schedules.

If the purpose of the ESD simulator is to reproduce practical conditions, realistically, reproducibly and quickly, then what characteristics should one consider when selecting an ESD simulator to meet this purpose and your own testing needs? Everyone's situation is different so there isn't a one size fits all answer however, the following are some things to carefully consider when outfitting your organization with ESD simulators.

Although not exactly related to the ESD simulator itself, recognition that interpretation and skill of the ESD test engineer/technician is a key ingredient to effective ESD testing. User knowledge, experience and skills are more important than what ESD gun is selected and used to perform the test. For instance, the ESD test engineer/technician will know the ESD output pulse is a greater than 1 GHz phenomenon and that it is essential that the pulse return path of the simulator is fed back through the simulator's earth cable, and that the return cable of the simulator is always connected to the ground reference plane of the test setup. They will know that they should hold the simulator perpendicular to the EUT surface while zapping away at it, while at the same time making sure they are keeping the return cable far away from the EUT. They will know the standard requires performance of a pre-test verification and that by not following these and other accepted ESD test practices, they could potentially be over or under testing the EUT.

Once operator skill is addressed, it is time to concentrate on other characteristics of the ESD simulator that will best meet your testing needs. If there is going to be a lot of time spent performing ESD testing, then an ergonomic, lightweight, non-fatiguing design is an important consideration. Along with ergonomics, one should take a look at the display and determine if it is easy to view, easy to manipulate settings, and provides a status of successful air discharge and other important parameters (state of battery charge, the current voltage polarity setting, etc.).

Battery Power

If battery powered, how long can the simulator be operated before recharging is required?

Given a typical testing workload, is it several minutes, hours, or days? Most modern ESD simulators should operate for days on one charge.

Once discharged, how long will it take to fully charge the battery?

How many charge/discharge cycles can occur before the battery needs to be replaced entirely?

At its end of life, how will proper battery disposal occur?

Given this information, consider how many spare battery packs are required and if they can handle multiple removals and insertions into the simulator without incurring damage to either the battery pack or the ESD gun itself.

Discharge Voltage

Currently, the highest severity level set by product-specific standards is 8kV contact discharge, 15kV air discharge modes. Is the ESD simulator is capable of generating these test levels with margin?

IEC 61000-4-2 also calls for 10 single pulses at an interval of 1 second or greater between them. Is the simulator capable of performing this requirement?

Does the simulator also have the ability to operate in other repetitive or continuous modes of operation (capabilities that are advantageous during troubleshooting)?

Accessories

What types of additional options and accessories are available with the ESD simulator that may benefit reduced product development times? For instance, in extreme cases the real rise time of an ESD event may be faster than the typical 0.8ns as described in IEC 61000-4-2.

Is there a fast rise time tip available for the selected simulator in case the need arises for its use? For whatever reason, will it be necessary to hold the simulator a considerable distance away from the EUT during testing?

If so, a remote discharge tip may come in handy. Is it available for the ESD gun selected?

How about flexible tips for hard to reach test points? Are they also readily available?

Will a tripod and carrying case also be of benefit?

Can adapters be purchased which allow creation of E and H fields (also useful in locating design weaknesses) or will these devices need to be built in-house?

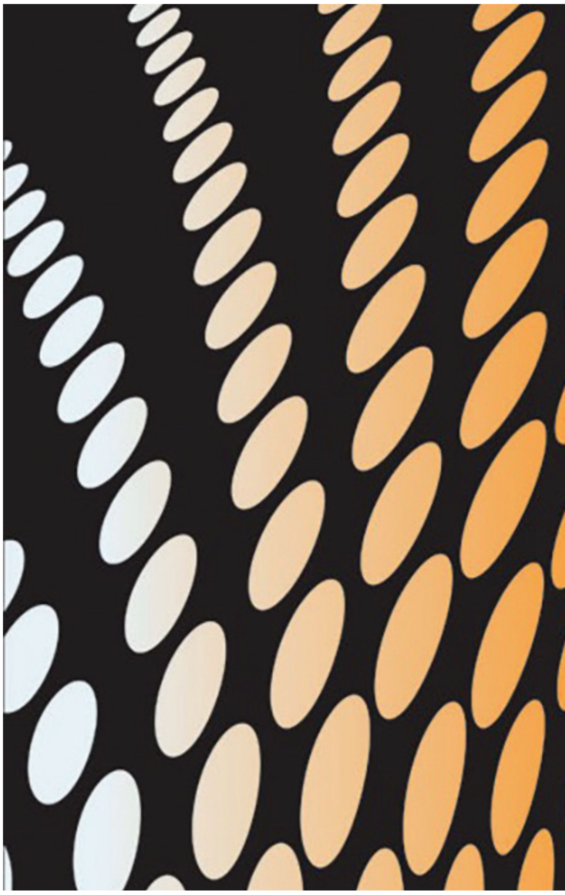
Discharge Networks

The discharge network and the discharge remover. IEC 61000-4-2 requires a 150pF/330Ω discharge network, which you should confirm is available with the chosen simulator.

Are there other types of networks available in case any other standard besides IEC 61000-4-2 needs to be performed?

Bleed Off Function

Does the simulator include an internal charge bleed off function or must you build or procure an external device on your own?



Product Maintenance

How will a more thorough, in between calibration cycle check of the simulator's output waveform get accomplished?

It is highly recommended that the current sensing transducer built as described in the latest version of the standard is obtained and used. It should be utilized frequently in between calibration cycles in order to be absolutely certain the waveform produced by the simulator is still within spec. It's not very fun finding out from the calibration lab that your ESD gun is out of spec. and you need to repeat testing on all of the products tested with it since the last date that a known good calibration was performed! Effective use of the transducer will alleviate some of this anguish.

Finally, what kind of warranty is provided and how will repairs be accomplished?

What is the turn around time for calibration and repairs?

How often will the gun get sent back to the manufacturer for calibration and where?

Should you purchase and have on-hand a backup simulator or simulators or should you rent them?

Should the backup simulators be of the same make/model so retraining of test personnel is minimal and perhaps test repeatability is maintained?

References

1. Mardiguian, Electrostatic Discharge – Understand, Simulate and Fix ESD Problems, Interference Control Technologies, Inc., 1986.
2. Williams, Some Considerations for ESD Testing, Elmac Services, undated
3. Teseq Advanced Test Solutions for EMC, NSG 438/438A ESD Simulator User Manual, 601-241I

FILTERS

There are many different types of filters used in electronics. These filter types include low-pass, high-pass, band-pass, band-stop (band-rejection; notch), or all-pass. They are either active or passive. In the realm of electromagnetic compatibility, the purpose of a filter is to establish a low-impedance path for RF current to return to the local source of energy, and/or to provide a high impedance to prevent RF currents from flowing on a cable. These so-called EMI filters are often used along with proper shielding to achieve electromagnetic compatibility (EMC) compliance for electrical/electronic products. Undoubtedly, the most useful filter type used in EMC work is the passive low-pass filter.

The other types of passive filters, such as high-pass, band-pass, and band-reject are not as common as the low-pass filter for EMC work and are not covered in this article. More information on these other filter types may be found through the references listed at the end of this article.

RC Low-Pass Filter

A low-pass filter is a filter that allows signals with a frequency less than a particular cutoff frequency to pass through it and depresses all signals with frequencies beyond the cutoff frequency. The most basic type of low-pass filter type is called an RC filter, or an L-type filter because of its shape, with the resistive element in the signal line and capacitor placed from line to chassis, these two circuit elements form the shape of an inverted L.

In an RC low-pass filter, the cutoff frequency occurs at resonance, where the capacitive reactance (Xc) equals the resistance ($X_c = 1/2\pi fC$, or $1/\omega C$, $\omega = 2\pi f$). Sometimes the resistor is not required and just a single capacitor placed across a line to reference ground without a resistor installed may be all that is required to suppress any unwanted noise. A device that presents the circuit with a high AC impedance, while at the same time not affecting signal quality can be used in situations where the voltage drop across the series resistor cannot be tolerated. This device is called a ferrite bead. In addition to their frequency limitation, ferrites can also become easily saturated when there is too much DC current present in the circuit. Ferrites are ineffective if they are saturated and if DC current is too high, using a ferrite as an element in the low-pass may not be an option. Also, depending on how high the impedance is of the source or load requiring filtering, ferrites may not work because they are considered low-impedance and won't work if circuit impedance is higher than their impedance.

Basic Filter Topologies

Besides the L-type passive filter there are a couple of other basic filter configurations. These multi-element filters are useful in situations where the range of frequencies involved is too large and impossible for a one component filter to fully attenuate successfully or the signal is too high in amplitude and that one filter element does not provide enough attenuation. Adding a second reactive component will increase the roll off to 12 dB/octave or 40 dB/decade. These types of filters are called various names such as double-pole, two-stage, two-element, or second-order filters. Filters with three reactive components will provide 18 dB/octave or 60 dB/decade attenuation. Four reactive component filters will provide 24 dB/octave or 80 dB/decade attenuation and so on.

Also, different filter shapes are used depending on source and load impedances of the circuit requiring filtering. These different types are used for impedance mismatching between circuit source and load input and output impedances and filter input and output impedances. Like the L-type filter, these other two types are both are named after their visual shapes on circuit diagrams. The first is the π-filter and the second is the T-filter low-pass filter.

Π Filter

The π low-pass filter looks like the Greek letter π. It has a capacitor from the line to be filtered to return, an in-circuit series element (resistor, inductor or ferrite), and then another capacitor from line to be filtered to return.

T Filter

The T low-pass filter looks like the letter T. It has an in-circuit element (resistor, inductor or ferrite) installed on the line to be filtered, a capacitor installed line to return, and then another in-circuit element (resistor, inductor, or ferrite).

Impedance Mismatching

As eluded to earlier, both source and load impedances must be considered in selecting the proper filter configuration (L, π, or T). If you are trying to install a low-pass filter into a circuit in order to suppress unwanted emissions and determine that it is

not solving the problem then be sure to check that an impedance mis-match exists. A high-impedance series component should face a low-impedance (i.e. capacitor) and vice versa. You may be asking yourself "What is considered low-impedance and what is considered high-impedance?" In general, impedances of less than 100 Ω are considered low and impedances greater than about 100Ω are considered high.

Selection of the cut-off frequency (fco)

It is important to also ensure that by adding a filter's impedance to circuit that it does not in turn create a signal integrity problem. In order to ensure this does not happen, be sure to select a cut-off frequency for the filter that does not also attenuate the intended signals used in the circuit. In order to prevent this issue from occurring, try to maintain at least the 5th harmonic of the intended signal (10th harmonic is ideal).

Differential Mode (DM) and Common Mode (CM) Noise Currents

DM signal currents are those out-of-phase currents which transmit intended data whereas CM signal currents are in-phase deliver no valuable data what-so-ever. Although they are much lower in amplitude than DM currents, CM currents are the main causes of regulatory radiated and conducted emissions testing issues.

In a perfect world, DM signals move along one side of a circuit track, and an equal and opposite DM signal moves back on the other side of the track. In order to prevent DM to CM conversion to occur, PCB layout must be perfect and no circuit discontinuities can exist. This ensures that complete canceling of the DM signals occur and no CM current is developed.

If suppression of DM noise is required then placing capacitors across the outgoing and return lines and/or an inductor in series with either outgoing or return line can be employed. This is called DM filtering. If installing a DM filter does not solve the noise problem, then the source of emissions may instead be CM noise.

CM signals are signals that exist in both outbound and return tracks of a circuit. Because they are in-phase, they do not cancel each other but add up substantially enough to cause EMI issues. Because CM noise is present line-to-ground. CM filtering often involves placing capacitors across each signal line to ground reference. and sometimes also using a CM inductor in the circuit. Any CM inductors placed into the circuit only act on the CM signals that are present, they do not affect the DM signals. If installing a CM filter does not solve the noise problem then the source of emissions may instead be DM noise.

Parasitics

When attempting to utilize a low-pass filter for EMI suppression it is imperative to also consider the non-ideal behavior of the components which make up the filter. Actual passive filter components such as a capacitor also contains some inductance and an inductor contains some capacitance. These parasitic elements of capacitors and inductors limit their useful bandwidth. For example, the reactance

of a capacitor decreases until it reaches its self-resonant frequency as frequency increases. Above its self-resonant frequency point the capacitor becomes inductive and it acts like an inductor because of the parasitic inductance found in its metal plates. A similar situation occurs in inductors. These parasitic effects are greater in leaded types of capacitors and inductors than with the surface mount technology (SMT) types that have almost no lead length.

Layout and Placement Concerns

Proper layout and placement can become the critical factor when attempting to effectively utilize passive low-pass filters for EMI suppression. Longer than necessary trace lengths add extra inductance and impedance which compromise the effectiveness of the filter similar to what occurs as described above regarding parasitics. It is therefore crucial to keep connections short. This means placing filter components as close as possible to the circuit to be filtered and not overlooking the length of the return trace. Locating the filter some obscure location far away from the offending signal source is not ideal in most situations.

In addition to keeping connections short, be observant of trace or wire routing that permits too much capacitive and inductive coupling to other noisy signal or traces. To prevent this crosstalk issue from occurring, place filter components right at the entry connector (I/O and power inputs). Placement of a filter deeper inside a circuit or system is just asking for trouble. When proper separation is not maintained, input and output sections are bypassed and the filter is no longer effective. As with a lot of problems encountered in EMC design and troubleshooting, do not rely on ground as being the ultimate zero-ohm impedance path and sink for noise. It is far better to understand the path of current flow and to keep loop areas small.

Conclusion

Low-pass filters are the most widely used type of filters in EMC work. There are several different configurations to choose from depending on several factors including frequency of the intended signals, source and load impedances, and common or differential mode noise sources present in the circuit. Factors that render low-pass filters ineffective include the non-ideal behavior of passive components, parasitic circuit elements, too much DC current present in circuits that use ferrites, using a filter with too low of a cut-off frequency thereby severely attenuating desired signals, and poor layout and placement.

References

1. Archambeault, *PCB Design for Real-World EMI Control*, Kluwer Academic Publishers, 2002
2. Frenzel, Jr., *Principals of Electronic Communications Systems*, Fourth Edition, McGraw-Hill, 2016
3. André & Wyatt, *EMI Troubleshooting Cookbook for Product Designers*, Scitech Publishing, 2014.
4. Montrose, *EMC Made Simple, Printed Circuit Board and System Design*, Montrose Compliance Services, Inc., 2014
5. Armstrong, “EMC Filters Guide,” *Interference Technology*, 2017
6. Montrose, *Printed Circuit Board Design Techniques for EMC Compliance – A Handbook for Designers*, 2nd Edition, 2000.

OSCILLOSCOPES

From the entire pool of test equipment available at our disposal as electronics engineers and technicians, the most useful is undoubtedly the oscilloscope. This one device is very powerful and can help us capture voltage measurements over time, very quickly and accurately – something that can't easily be done with any other device found in the laboratory. The oscilloscope is an essential tool used in manufacturing, design, troubleshooting, signal integrity, and if desired, in simply understanding how electronic circuits work.

Even though the modern oscilloscope looks complicated and scary with its entire set of buttons, knobs, probes and associated attachment points and colored display, it is, in reality, a very simple device to use. Don't let the complicated looks of an oscilloscope intimidate you! The key to becoming an oscilloscope expert is first understanding the basics and then building upon that basic knowledge. In this regard, the following brief article will cover some key points and common pitfalls new users encounter surrounding the basic use of oscilloscopes. It will help point you in the right direction. As time progresses and more time is spent actually using the oscilloscope, you will eventually become more proficient and comfortable taking almost any measurement.

To keep things simple, this article only covers conventional digital oscilloscopes known as Digital Storage Oscilloscopes (DSOs), with a raster-type of display. The older analog scopes that utilized luminous phosphor to display information and newer specialized oscilloscopes such as Digital Phosphor Oscilloscopes (DPOs), Mixed Domain Oscilloscopes (MDOs), or Mixed Signal Oscilloscopes (MSOs) are not covered in this article.

Grounding and Safety

Before getting too deep into the basics of oscilloscopes, understanding proper grounding and safety will help to not blow up your DSO or its probes. Improper connection of the probe ground across the chassis/safety ground can create a path for current flow, resulting in damage to the probe. In brief, the issue is that the metal part of the connector the probe connects into on the oscilloscope is directly tied to safety earth ground through the power cord of the scope. You can vary this connection yourself with an Ohm meter. It's a low impedance connection and when the circuit you are probing is also connected to safety earth ground a loop forms and the very low impedance allows the current from the circuit to get excessive. The current carrying capacity of the ground lead of the probe is quickly exceeded, and the lead wire abruptly opens and you will likely hear a loud POP! The best solution to this problem is to break the ground loop through isolation of the circuit under test or isolation of the oscilloscope ground. Since it's a safety issue if the safety ground on the oscilloscope is defeated, the best option is to make sure the circuit you're testing is floating (i.e. not tied to earth safety ground). Choose to either power up the test circuit with an isolated supply or with a battery. Be careful with applying power to the circuit under test with something like a USB connector as these types of devices are usually not isolated from ground and you will still have a ground loop problem.

Costs

The capability versus costs for oscilloscopes is getting better and better. A quick look on the internet reveals that you can obtain hundreds of megahertz of bandwidth and professional level functionality for under $500. This may be enough performance to get most of your probing done. As rise-times increase and measurements get more challenging you will have to pay for performance. When you budget for a new scope be sure to include costs to obtain the probes you need, calibration of the scope and probes, and shipping of the scope and probes back and forth to your calibration provider.

Performance

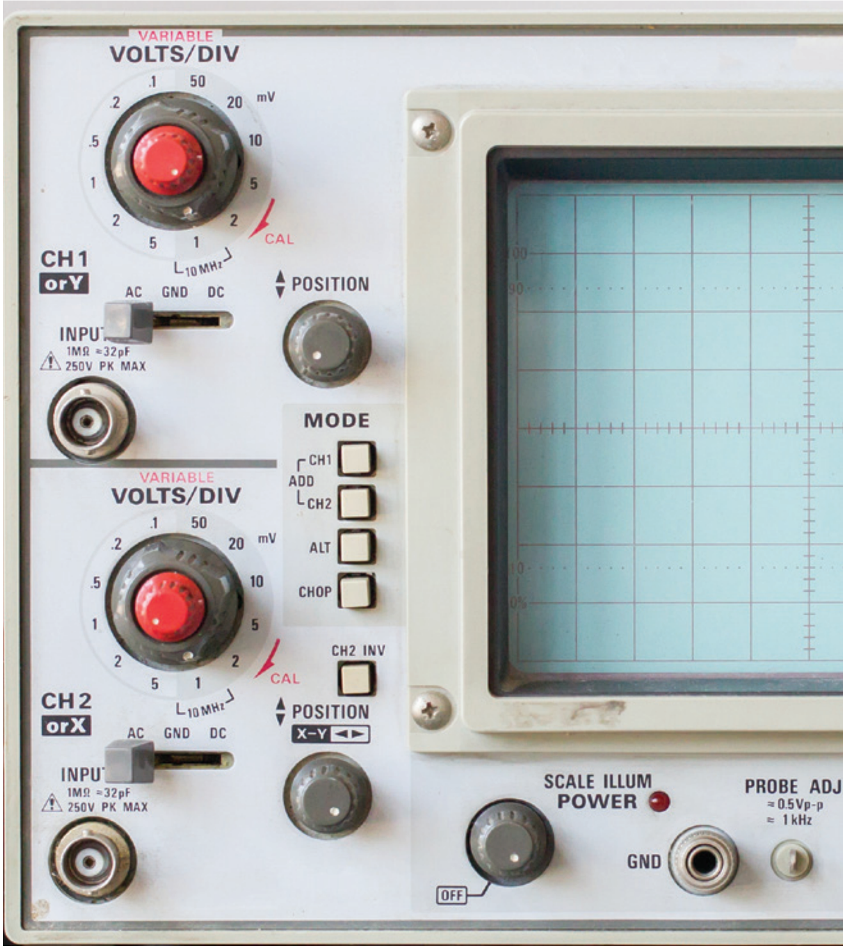
The rise times of the switching mechanisms in components we are using are getting faster and faster and the ability to effectively measure these rise times comes into question. You will often be asked if the oscilloscope has enough bandwidth. The typical formula used to determine adequate bandwidth of the oscilloscope is 0.35 divided by the rise time. For instance, needing to measure a pulse with a rise time of 1ns means the minimum bandwidth the oscilloscope should be around 350MHz. Of course, more bandwidth is always better.

WHAT IS AN OSCILLOSCOPE?

An oscilloscope measures voltage waveforms from voltage sensors such as the oscilloscope voltage probes which come with the device or some other sensors such as a load cells, current probes, sound level meter or other sensor. The graph of the oscilloscope measures voltage in the vertical axis and time along the horizontal. From the waveform captured you can obtain information such as frequency, amplitude, period, phase, distortion, noise, DC, AC, duty cycle (on time versus off time), rise/fall time, etc.

Volts/div

The volts-per-division (volts/div) control allows movement of the waveform up or down on the display based on a scaling factor. For instance, if the knob is set to 1 volt and the display is made up of 10 vertical divisions, then 10 volts can be displayed from top to bottom of the display. Note the reading could change based on the attenuation factor of the probe taking the readings. If a 10X (meaning 10 times) probe is used and the oscilloscope doesn't automatically correct for it, then you must multiply the resultant waveform reading by 10 in order to obtain the correct amplitude of that reading.



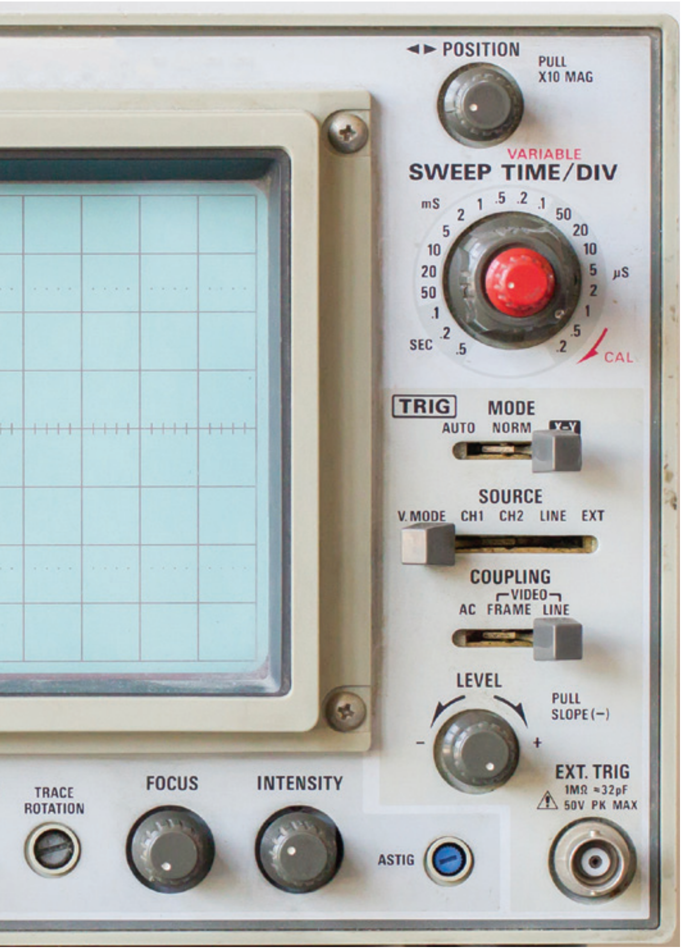
Input Coupling

Input coupling is another simply, yet commonly misinterpreted function found within the volts/div section of the oscilloscope. It refers to the method used to connect an electrical signal from one circuit to another, i.e. the connection from your test circuit to the oscilloscope. You can configure input coupling as DC, AC, or ground. AC coupling simply blocks the DC portion of a signal and you see the waveform centered around zero volts on the display. The ground setting disconnects the input signal from the vertical control thereby letting you see where zero volts is located on the display. The DC setting allows all of the input signal (DC and AC) to be displayed.

Sample rate

Specified in samples-per-second (S/s) refers to how frequently a DSO takes a snapshot or sample of the input signal. The higher the sample rate, the greater the resolution and detail of the displayed waveform and the less likely that critical information will be lost.

Besides the display, there are three other important functional blocks that make up the common oscilloscope. These functional blocks are the trigger block, the volts-per-division block and the seconds-per-division block.



Sec/div

The seconds-per-division (sec/div) function is what establishes the rate at which the waveform is moved across the display. As with the volts/div control described above, the sec/div control setting is also a scale factor. If the setting is 10ms on the knob, then each horizontal division on the display represents 10ms and the total screen width (also assuming 10 divisions total on the display) is equal to 100ms. Observing longer and shorter time intervals of the input signal is easily accomplished by changing the sec/div setting control knob.

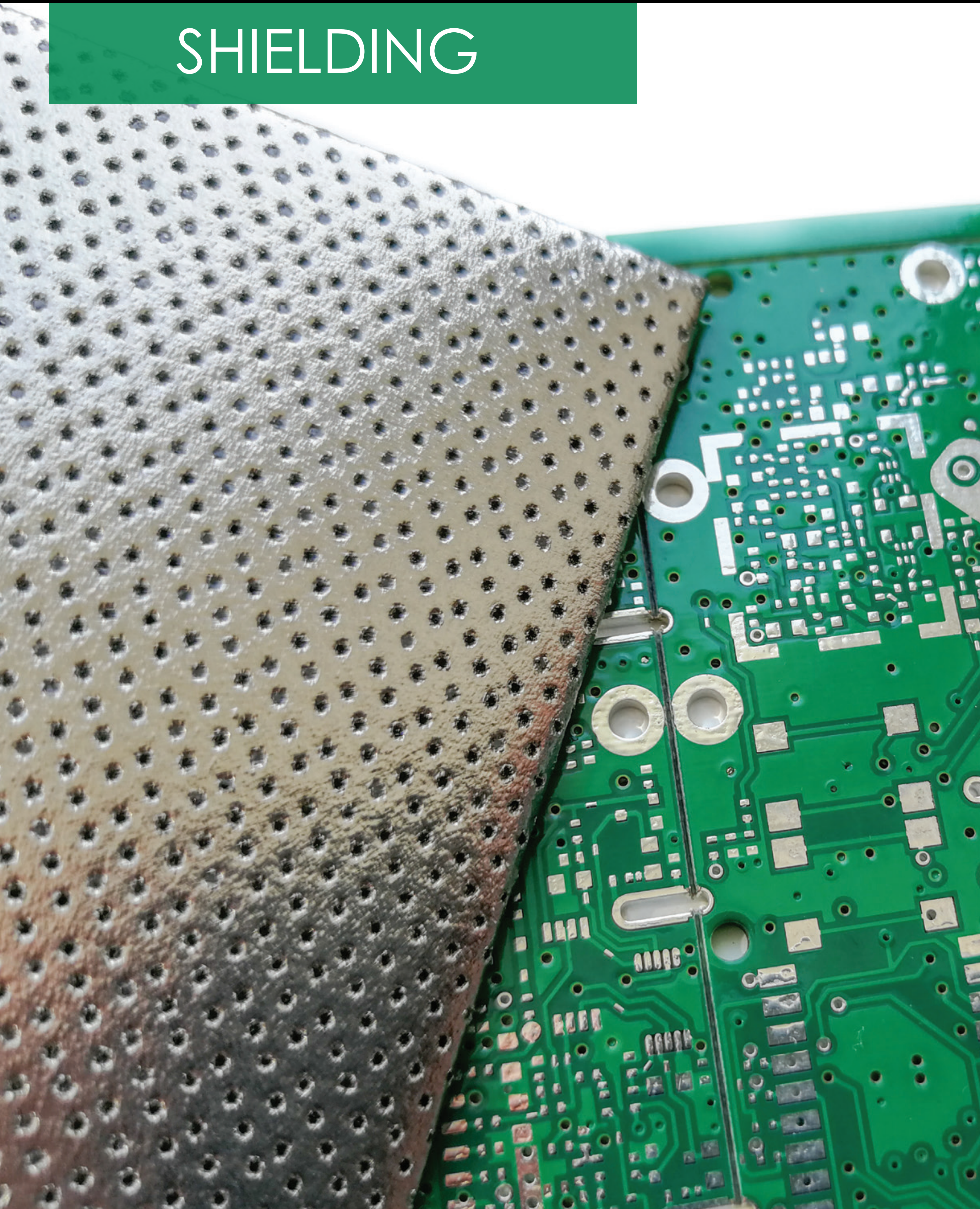
Trigger

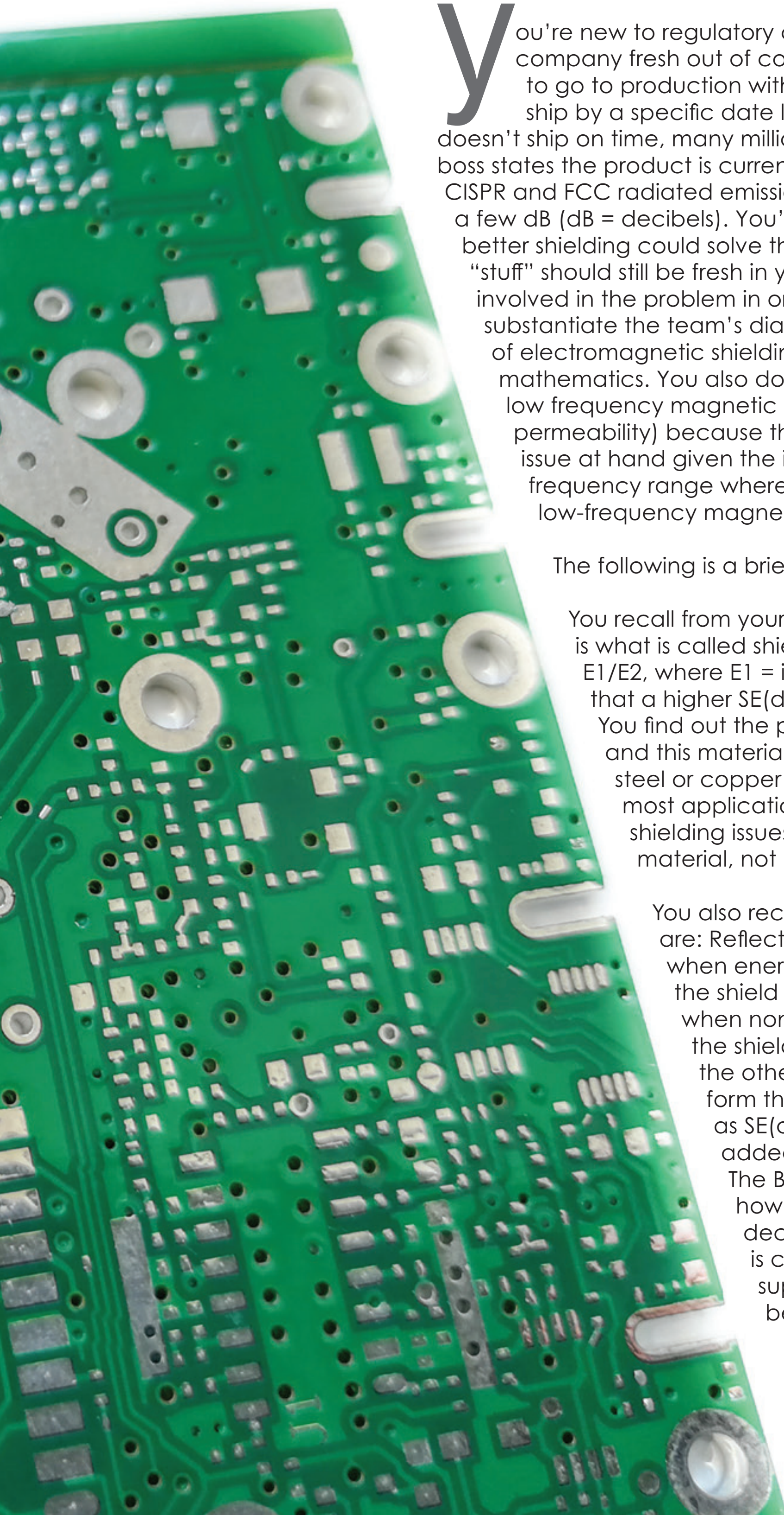
The trigger function is what is used to synchronize the horizontal sweep at the precise position of the signal, vital for unambiguous signal representation. The trigger makes recurring waveforms look stationary on the display by repetitively displaying the matching portion of the input signal. The most rudimentary and conventional form of triggering is called edge-type triggering. This is what you are most likely to use when first beginning to use the oscilloscope. There are many other specialized and sophisticated trigger types that respond to specific conditions and are what can really make the DSO a powerful tool. These triggers include slew-rate, glitch, pulse-width, time-out, runt-pulse, logic, setup-and-hold, and communication triggering just to name a few.

Probes

The most basic general-purpose type that you will encounter is the passive 1X or 10X probes. Be cautious of excessive capacitive loading of the circuit under test with these probes. For high-speed signal probing, active and differential probes are necessary. Logic probes are available when the capture of multiple channels of data is necessary.

SHIELDING





You're new to regulatory compliance engineering and you just joined the company fresh out of college. Your boss tells you the company is about to go to production with the latest and greatest product and it has to ship by a specific date looming in the very near future. If the product doesn't ship on time, many millions of dollars in lost revenue are at stake. Your boss states the product is currently in the final stages of type testing but is failing CISPR and FCC radiated emissions testing in the 30 to 1000 MHz range by at least a few dB (dB = decibels). You're told most of the engineering team believes better shielding could solve the problem. Since you just graduated and all this "stuff" should still be fresh in your head, your boss asks you to immediately get involved in the problem in order to help solve it. Before you head to the lab to substantiate the team's diagnosis, you decide to refresh your understanding of electromagnetic shielding without getting too bogged down in the mathematics. You also don't worry too much about the nuances of low frequency magnetic field shielding (material with a high relative permeability) because this is a specialized case and not relevant to the issue at hand given the information you have been provided (i.e. the frequency range where the problem that is occurring is too high to be a low-frequency magnetic field problem).

The following is a brief summary of what you come up with:

You recall from your previous studies that a key parameter in shielding is what is called shielding effectiveness (SE) and that SE(dB) = 20 log E1/E2, where E1 = incident wave, and E2 = attenuated wave and that a higher SE(dB) number equates to better shielding material. You find out the product is constructed with an aluminum chassis and this material along with other conductive materials such as steel or copper should provide more than enough shielding for most applications. You remember that most high-frequency shielding issues are the result of gaps or slots in the shielding material, not usually the material itself.

You also recall what the two primary shielding mechanisms are: Reflection (R) and Absorption (A). Reflection occurs when energy from the electromagnetic wave encounters the shield and is reflected back. Absorption is what happens when non-reflected energy from the wave is absorbed in the shield with only the remaining energy emerging from the other side. These two effects (or losses) combine to form the total shielding effectiveness, often expressed as SE(dB)=R(dB) + A(dB). There's a third term sometimes added to this equation called re-reflection (B) term. The B term could decrease the shielding expected however it only occurs in extremely thin shields. You decide to just ignore it in this case since the product is constructed of shielding material strong enough to support its own weight and the shield can obviously be considered thick.

Reflection Loss

First, you recall that higher conductivity materials result in higher reflection losses and that the distance of the EMI source from the shield also affects reflection losses due to what the impedance of the electromagnetic wave is at certain points in space (Note that distance from the source is not an issue with absorption loss – discussed later). A higher wave impedance, combined with lower shield impedance (in Ohms per Square) results in a higher reflection loss. Because the primary reflection occurs at the first surface of the shield in the case of electric fields, even very thin materials provide good reflection losses.

For a plane wave (an electromagnetic field located in the far field at a distance of approximately $\lambda/2\pi$, where λ = wavelength) that is entering a shield at normal incidence, the following equation is used to determine R:

$R = 20 \log Zw/4Zs$ (dB)

Zw = impedance of wave prior to entering shield

Zs = impedance of shield

As the angle of incidence of the impinging electromagnetic wave increases so does the reflection loss. You note that a lower shield impedance also results in a greater reflection loss and vice versa.

In the near field of the electromagnetic wave (distance < $\lambda/2\pi$), you recall that it's imperative to know the characteristics of the source (is it an electric field or magnetic field?), the highest frequency of interest and distance from source and shield. The reflection loss of an electric field decreases with frequency until the separation distance $\lambda/2\pi$, beyond which the reflection loss is the same as for a plane wave. In contrast, the reflection loss of a magnetic field increases with frequency until the separation becomes $\lambda/2\pi$.

Because an understanding of the above information is important in the determination of reflection loss, you take note that you need to determine the characteristics of the source (electric – wave impedance > 377Ω, magnetic – wave impedance < 377Ω, or plane – wave impedance of the medium or free space = 377Ω) during your troubleshooting activity in the lab.

Absorption Loss

Second, you recall that the material's permeability (μ), conductivity (r), thickness (t) and frequency of the electromagnetic wave all contribute to skin depth (SD) and therefore to absorption loss because A(dB) = 8.68 (t/SD). You note that skin depth is where electric current tends to flow on the outer surface of a conductor at higher frequencies and it is the depth where the field/surface current is attenuated by 37% or approximately 9 dB. You remember that another way to think about it is that the absorption loss in a shield one skin-depth thick is approximately 9 dB and that doubling the thickness of the shield doubles the loss in decibels. Also, absorption loss (dB) is proportional to the square root of the product of the permeability times the conductivity of the shield material and this loss increases with frequency and as well as with shield thickness. You recall that steel offers more absorption loss than copper of the same thickness.

The Effect of Apertures, Slots, Penetrations

Finally, you refresh your understanding of the guidelines associated with adding apertures and slots and other penetrations to shields. You know that at the high frequencies involved the inherent shielding effectiveness of the shield material is of less concern than what the leakage is through the apertures used to carry signals in and out of the product. You remember from your earlier studies that aperture control is the key to high-frequency shielding. You recall that the amount of leakage from an aperture is highly dependent on the maximum linear dimension and not the area of the aperture, the impedance of the electromagnetic wave and also its frequency.

Before you head to the lab to start troubleshooting, you jot down some of the prevailing rules of thumb to control leakage from shielded enclosures. They are: 1) Keep slots shorter than one-twentieth of a wavelength at the highest frequency of interest (1.5 cm or 2/3 in at 1000 MHz) to ensure at least 20 dB of attenuation; 2) Shield or filter all cables that enter or leave the shielded enclosure and tie shields to the enclosure; 3) Maintain electric contact across the seams of shielded enclosures in order to minimize leakage; 4) If possible, limit the number of apertures as shielding effectiveness decreases proportional to the square root of their number; 5) A large number of small holes produces less leakage than a large hole of the small total area; 6) Shields do not have to be grounded in order to be effective.

Summary

Now that you have refreshed your understanding of EMI/RFI shielding you're ready to head down to the lab to see for yourself what is actually going on. Most likely the shielding material itself is adequate but there are excessively long openings or slots, unshielded/unfiltered cables entering or exiting the shield, or a combination of both that compromise the shielding effectiveness and contribute to the product failing radiated emissions testing. Since the product is only failing by a few dB it should be easy for you to diagnose and correct in time to ship the product on time.

References

1. Gerke, D., Kimmel B., The Designer's Guide to Electromagnetic Compatibility, EDN, 2005.
2. Ott, H., Electromagnetic Compatibility Engineering, John Wiley& Sons, 2009.
3. Montrose, M., EMC Made Simple – Printed Circuit Board and System Design, Montrose Compliance Services, Inc., 2014.

Shielding Selection Factors

» Operating frequency	» Cost	» Shielding/grounding/other
» Materials compatibility	» Attenuation performance	» Electrical requirements
» Corrosive considerations	» Fastening/mounting methods	» Materials thickness/alloy
» Mandatory compliance	» Storage environment	» Space/weight considerations
» Operating environment	» Nuclear, biological, chemical	» Product safety
» Load/forces	» Cycle life	» Recyclability

SOFTWARE

This article is geared toward engineers, who for various reasons, tend to stay away from modeling and simulation software and focus more on actual EMC measurements in order to show that their designs meet EMC regulatory compliance requirements.

If you fall into this category, you are doing the companies, customers and yourself a huge disservice. Proving a design is valid only after it's already built often results in a costly and time-consuming test-analyze-fix-repeat process. Attempting to build a bullet-proof design that easily passes EMC requirements, when using previously established guidelines and outdated rules of thumb (and other brute-force methods), often results in unknowingly designing a product that is way over-designed (i.e. has a lot more design margin than it really needs). This one oversight ultimately results in a product that is too costly to manufacture and almost impossible to make a profit on. Alternatively, by using these same outdated guidelines and processes, you may unknowingly under-design the product and find out that too late that it fails mandatory EMC compliance testing requirements and yet another costly, time-consuming (and embarrassing) redesign effort is required. Redesign efforts that occur at the tail end of the product development process, just before the planned production release date, are not good. This rework results in costlier and harder to implement fixes, not to mention increased pressure and anxiety placed on an already stressed product development team scrambling feverishly to find viable solutions in time to meet the already late and promised customer ship date.

Most of this churn could be avoided by getting a little savvier in using some of the various simulation and modeling tools now available. There is a plethora electromagnetic modeling codes, circuit solvers, rule checkers, analytical modeling tools, web-based calculators and apps that we should carefully consider using prior to any prototype PC boards ever being ordered. The good news is that we don't need a lot of advanced training in electromagnetics in order to effectively use these tools. The bad news is that there is a ton of simulation and modeling tools available and understanding what to look for can be tricky. To ease your own research efforts, you may find the following helpful. It categorizes the modeling and simulation software tools that are currently available so that any engineer can more easily conduct further research and gain a better insight into the proper use and application of these tools. Note that you may already have access to some of these tools.

Numerical EM Modeling Tools and Techniques

Modeling and simulation tools of this type include 2D, 2.5D and 3D tools, static field solvers, time-domain and frequency domain codes, boundary element codes and the method of moments (BEM/MoM), finite element codes (FEM), finite difference time domain codes (FDTD), transaction level modeling (TLM), generalized multipole technique (GMT), finite-element time-domain (FETD) and Partial element equivalent circuit method (PEEC) codes, geometrical theory of diffraction (GTD), uniform geometrical theory of diffraction (UTD) and physical optics (PO) codes.

Analytical Modeling Tools

These tools include impedance calculators, interference and crosstalk estimators, and maximum emissions calculators.

EMC Rule Checkers

These tools organize and maintain rules for PCB layout and rules for system design.

Applications

The applications and uses for these modeling and simulation tools are many. For example, these tools can be used to model currents induced on cables, cords and wiring harnesses, model power inverter noise, specific radiated emissions tests, bulk current injection tests, high-frequency package parasitics and transient susceptibility. We can model an automotive infotainment system, and Gbps backplane connector, if so desired. Furthermore, these modeling and simulation tools can be used for EMC troubleshooting and educating engineering teams regarding the viability of solutions to the EMC design challenges faced in current product designs. This comes in handy when trying to prove to the rest of the product development team (often with conflicting requirements), that our solution to a problem is the best one to implement. This is an almost impossible task to accomplish if we wait until we have prototypes available to test and simply try to prove our point with test data. Simulation results backed by test data can be very powerful and almost impossible to argue against good data. On your own you can probably think of other valuable uses of these applications and may even find yourself tailoring some to fit you own particular needs.

Pitfalls

Modeling and simulation software should be considered as just another tool in our engineering bag of tricks and that it can and should be used to flush out issues in designs prior to making any substantial investments in tooling or prototypes. Keep in mind that modeling and simulation is not a magic bullet solution where we plug in everything we know about the problem into the system and it magically spits out the ideal solution. It takes the knowledge and experience of an engineer to break down problems into smaller chunks in order for our modeling and simulation efforts to be most effective. This may require a multi-stage model where the output of one model's simulation acts as input to the next. In this way, each part of the problem, and associated model, is fully optimized, resulting in a much more accurate combined solution. Engineers must first understand what the problem is to be solved, how to break it down into smaller chunks, and what modeling technique will best help to solve that specific problem. This simplifying activity may take extra practice and effort at first, especially for those of us who rather do things "old school" and are reluctant to change.

Additional Resources

The main point of this article is to emphasize to engineers to not overlook modeling and simulation as an important and viable tool in developing products that have to meet EMC compliance requirements. It also points out that learning and using these tools isn't necessarily reserved for only the advanced EMC practitioner. If you're interested and desire further information and training on this important topic, Dr. Todd H. Hubing Professor Emeritus of Electrical and Computer Engineering at Clemson University and Director of the Clemson Vehicular Electronics Laboratory provides a one-day course covering much of what has briefly been mentioned in this article. Details on this course can be found here: https://learnemc.com/computer-modeling-tools-for-electromagnetic-compatibility.

Further more, Bruce R. Archambeault, Omar M. Ramahi, and Colin Brench have written a book of this subject out titled "EMI/EMC Computational Modeling Handbook" which goes into much further detail than what can possibly be covered here.

References

1. Archambeault, B.R., PCB Design for Real-World EMI Control, Kluwer Academic Publishers, 2002.

PRODUCT MARKETPLACE

Log Periodic Antennas 80 MHz – 7 GHz

A.H. Systems' offers a great selection of Log Periodic Antennas. Whether testing inside a shielded enclosure or outdoors, the antennas will display efficient performance characteristics through the broad frequency range of 80 MHz to 7GHz. Visit our comparison web page http://www.ahsystems.com/catalog/comparison-log-periodic-antennas.php. This page will provide you with all the details you need to know about our log periodic antennas and help you choose the right antenna for your testing requirements.

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Doors by AP Americas are easy to operate, extremely rugged and guarantee extraordinary sound attenuation, even after many thousand closing cycles. The shielding effects are directly dependent on the contact pressure across a broad frequency range. Our doors therefore possess extreme torsional stability and a robust structure in order to achieve remarkably high and homogeneous contact pressure at the sealing surfaces. This produces outstanding sound attenuation. For instance, we are the only manufacturers that produces double-winged doors with 100 dB shielding up to 40 GHz.

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CST Studio Suite is an electromagnetic (EM) simulation product of SIMULIA, a Dassault Systèmes brand. It is used by leading companies in industries including aerospace & defense, high-tech and transportation & mobility to improve the EMC performance of their products and reduce development costs and time to market. The EM and multiphysics simulation tools in CST Studio Suite® are used both to design individual components and to analyze and optimize entire systems. More information at www.cst.com/emc.

PRODUCT MARKETPLACE

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PRODUCT MARKETPLACE

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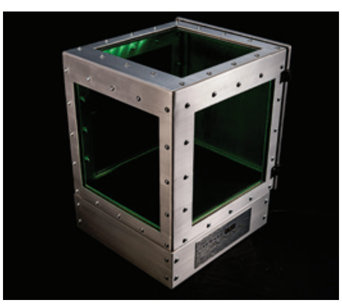

A Tremendous Belief in Innovation

The QuietBox-CL was designed for wireless applications and used to isolate outside noise for product demonstration. The transparent walls are RF attenuating and simplify product viewing/demonstrating. Adjustable coloured LED lighting showcases the product inside. This QuietBox can be customized to meet client requirements including a client themed colour scheme. Contact Raymond EMC today to see how we can fulfill your requirements.

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