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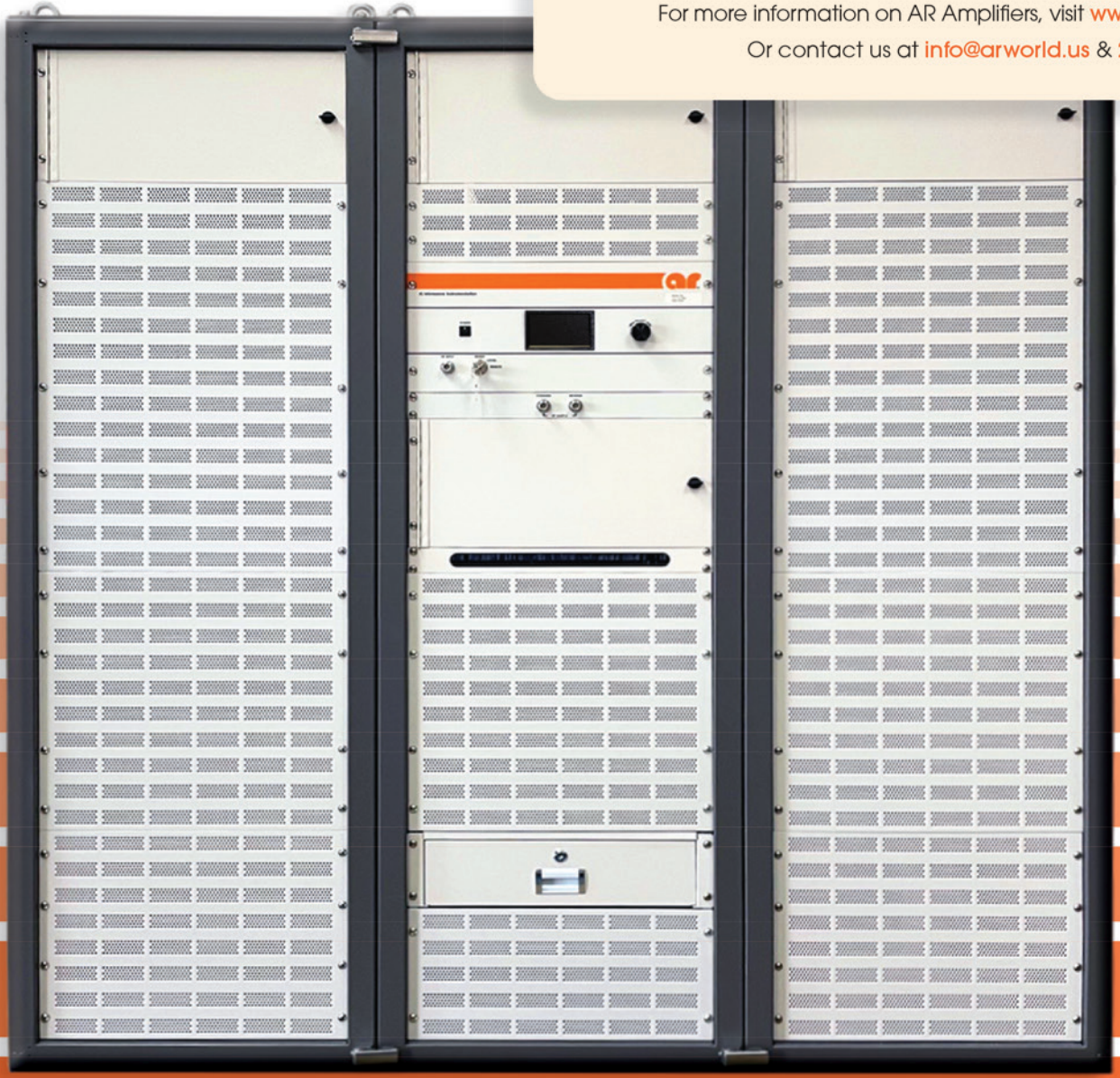

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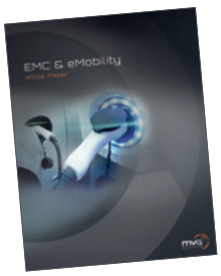

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CONTENTS

UN Says Electronic Recycling Efforts Are Falling Short

The global production of electronic waste (E-waste) is rising five times faster than current recycling efforts. That's the key finding of the most recent report by the United Nations Institute for Training and Research (UNITAR) and the International Telecommunications Union (ITU).

The report "Global E-Waste Monitor 2024" paints a troubling picture of the world's current efforts to efficiently recycle E-waste. According to the report, less than one quarter (22.3%) of E-waste in 2022 was properly collected and recycled. At the same time, the annual generation of E-waste is rising by over 2.6 million tons each year and will exceed over 80 million tons by the year 2030, an increase of 33% in just eight years.

Further, the report predicts that E-waste collection and recycling rates will drop to just 20% of all generated E-waste by 2030, due in large part to disparate recycling efforts among countries that are the largest producers of E-waste in the world.

Providing one glimmer of hope, the report predicts that the benefits of E-waste collection and recycling efforts would dramatically exceed their cost, provided that collection and recycling efforts could achieve a threshold rate of 60% by 2030.

FCC Investigates Amazon, Others for Marketing Wireless Signal Jammers

The U.S. Federal Communications Commission (FCC) is reportedly investigating Amazon and a number of other online retailers and drone technology companies for their alleged sale of illegal radio frequency devices.

The FCC's actions align with an investigation conducted by NBC News that found more than a dozen different companies marketing devices for sale that interfere with licensed communications systems by sending out competing radio signals. These radio frequency jammers, as they are called, can be used to block Wi-Fi networks or to disable security cameras or unmanned aircraft systems (UAS, also known as drones).

Radio frequency jammers have the potential to interfere with licensed radio communications services, including public safety services and networks, and are expressly prohibited from being marketed or sold in the U.S. under federal law and FCC rules.

According to an article posted to the NBC News website on the network's investigation, an FCC spokesperson acknowledged that the Commission has several ongoing investigations into illegal jammer sales. "We have several ongoing investigations into retailers, including Amazon, for potential violations of Commission rules related to the marketing and sale of equipment without FCC authorization," said Jonathan Uriarte, the FCC spokesperson.

FDA Publishes White Paper on AI and Medical Products

Recognizing the growing deployment and use of artificial intelligence (AI)-enabled technologies, the U.S. Food and Drug Administration (FDA) has published a white paper on the use of AI in medical products and devices.

The white paper "Artificial Intelligence & Medical Products: How CBER, CDER, CDRH, and OCP are Working Together" is an effort to map out a strategic plan for the "responsible deployment and use of AI and AI-enabled technologies in the health and human services sector." The white paper sets forth a strategic plan with policies and frameworks for the regulation and oversight of AI-enabled technologies used in medical products.

The FDA's AI and Medical Products white paper was jointly developed by various FDA Centers, including the Center for Biologics Evaluation and Research (CBER), the Center for Drug Evaluation and Research (CDER), the Center of Devices and Radiological Health (CDRH), and the Office of Combination Products (OCP).

FDA Proposes Ban on Electrical Stimulation Devices

The U.S. Food and Drug Administration (FDA) is once again seeking to ban the use of electrical stimulation devices in treating certain mental health issues.

According to a proposed rulemaking published in the Federal Register, electrical stimulation devices (ESDs) designed with the intent of reducing or stopping self-injurious or aggressive behaviors in humans "present an unreasonable and substantial risk of illness or injury." Specifically, the FDA says that ESDs "present a number of psychological risks including depression, anxiety…and physical risks such as pain, burns, and tissue damage."

If adopted, the new rules would require the removal of ESDs from the U.S. market and would prohibit the legal sale or marketing of such devices in the future.

The FDA first issued a ban on ESDs in 2020, but the rule was vacated in a court challenge. The FDA says that its current actions fall under the updated version of the Federal Food, Drug, and Cosmetic Act (FD&C Act) that more clearly asserts the FDA's authority to issue such bans.

FCC Implements Voluntary Cyber Labeling Program for Smart Products

The U.S. Federal Communications Commission (FCC) has approved the creation of a voluntary labeling program for connected smart devices that meet rigorous cybersecurity requirements.

The FCC's "U.S. Cyber Trust Mark" Program will enable manufacturers of internet-enabled devices to qualify their products in accordance with rigorous cybersecurity requirements based on criteria developed by the National Institute of Standards and Technology (NIST). Devices that meet those requirements will then be permitted to apply the Cyber Trust Mark to their products, similar to the Energy Star logo currently applied to energy-efficient appliances.

According to the FCC, the Cyber Trust Program is intended to help consumers make informed decisions regarding their purchases of internet-enabled devices, while also providing an incentive for manufacturers to meet higher cybersecurity standards.

DO MEASUREMENTS VALIDATE SIMULATIONS?

Or Do Simulations Validate Measurements?

Dr. Bruce Archambeault is an IEEE Fellow, an IBM Distinguished Engineer Emeritus, and an Adjunct Professor at Missouri University of Science and Technology. He has taught numerous seminars on EMC and Signal Integrity around the world. Dr. Archambeault has authored or co-authored a number of papers in computational electromagnetics, mostly applied to real-world EMC applications. He is the author of the book "PCB Design for Real-World EMI Control" and lead author of "EMI/EMC Computational Modeling Handbook." He can be reached at bruce@brucearch.com.

By Bruce Archambeault

I expect the title of this article might raise a few eyebrows! It is very common for people doing simulations to make a measurement of a similar set up to validate the simulation. This is a reasonable precaution since modern simulation tools will give a very accurate answer to whatever question it is asked. The real issue is did the tool user understand the problem well enough to capture the important features, and did the user understand the tool well enough to use it correctly.

However, we usually do not expect a measurement to be validated. After all, measurements are a great emotional comfort! I have seen many test laboratories claim measurement uncertainty in the 1.5 to 2 dB range. However, whenever I ask an experienced EMC test person how well they might expect to correlate between two different laboratories, I often get a response that anything better than 8 dB is ok, and certainly, I have never been told that better than 6 dB is expected! This tells me what the "real" laboratory accuracy is. And this is when all the equipment is functioning to specification.

When we look at a typical EMC chamber, we all know and accept that the chamber effects can be +/- 4 dB from the theoretical. This alone could account for 6 dB or more difference between laboratories! When we add the difference between different antenna's response to the nearness of the metal chamber floor as it travels up/down the antenna mast (which can be as much as 4 dB), the potential for site-to-site variation continues to climb. Then we have an antenna factor that was probably measured in a different test environment than where we use it, cable loss, receiver accuracy, etc. So maybe when a simulation is not validated in the test laboratory, we should simply try another test laboratory? (I am NOT recommending this practice! But I think you see my point.)

Obviously it would be cost prohibitive to improve all the things in the previous paragraph so the site-to-site repeatability is reduced to 1-2 dB. However, I do think we should be careful to understand exactly how accurate the measurements are and not place too much credibility in the numbers resulting from such measurements.

Again, all the above assumes the equipment is operating correctly. I recently heard a story where a salesman was demonstrating a comb generator source to a potential customer in their chamber. The receiver measured fine over a portion of the total frequency range. However, there was one band where there were no comb harmonics! It turned out that the receiver had a broken band, and the operators were not aware of it and had been using the receiver with the broken band on product measurements for a while. I have also heard many stories of how a cable from the antenna had a broken connector without operators realizing it. This points to the importance of having (and using) a test artifact on a regular basis.

Usually, benchtop measurements are better controlled with fewer chances for error (although the examples above could also happen in a benchtop setting). However, these measurements often introduce other, more subtle issues. Many years ago, I wanted to make measurements of the impedance between power and ground-reference planes on a printed circuit board (PCB) in order to validate some simulations of the same PCB. The measurements were very different than the simulation results, and this was because the measurement VNA had 50-ohm ports. I had not loaded my simulation ports with 50 ohms. (Why would anyone ever put 50 ohms between power and ground reference?). Once I modified the simulation to include the loading, the simulation and measurements agreed very well. This was a clear example where the measurement changed the thing I was trying to measure!

Of course, the story is not completely one-sided. Simulations can have subtle issues that can cause errors.

Years ago, I was involved in a project at IBM where we wanted to know the impedance of vias transitioning through 250 mil thick PCB up to 50-60 GHz. Test equipment, probing techniques, and de-embedding probe effects were not as advanced as they are now. So a group of five engineers teamed up to do simulations on the via structure using five different simulation techniques since it is commonly accepted that if very different simulation techniques give the same result, it is likely the correct result.

The simulation techniques we used included the Method of Moments, the Partial Element Equivalent Circuit technique, two different Finite-Difference Time-Domain tools, and the Finite Element Method. Figure 1 shows the initial results. Since the goal was to have data up to 50-60 GHz, the agreement above 10 GHz is not good.

Some careful analysis discovered that the various techniques/engineers all made assumptions about the geometry that made sense to them individually but were slightly different from each of the others. First, it is important to understand that no simulation technique uses round objects, even if the software tool displays a round object. The round object must be converted to rectangular or triangular objects in order for the solution software to properly grid the object. Users should always check the gridding to see that this conversion has been done correctly.

In the above instance, one of the engineers converted the round via, via pad, and via keep out to a square that would fit inside the round object. Another converted the round to a square where the round fit inside the square. Another engineer made the area of the round the same as the area of the square. Once these differences were understood, and the models modified so that all were using the same dimensions, then the simulations all agreed very well. The main point is that each engineer, being very experienced in modeling/simulation, made assumptions that seemed reasonable. The tools gave very accurate answers to the models, but the models were not 100 percent correct!

Another common issue with simulation tools are the source and load ports. A 'lumped' port is basically a port that connects at a point. Figure 2 shows an example of a simple microstrip trace using a lumped port. While this is fine for some applications, the current that is spread across the width of the trace

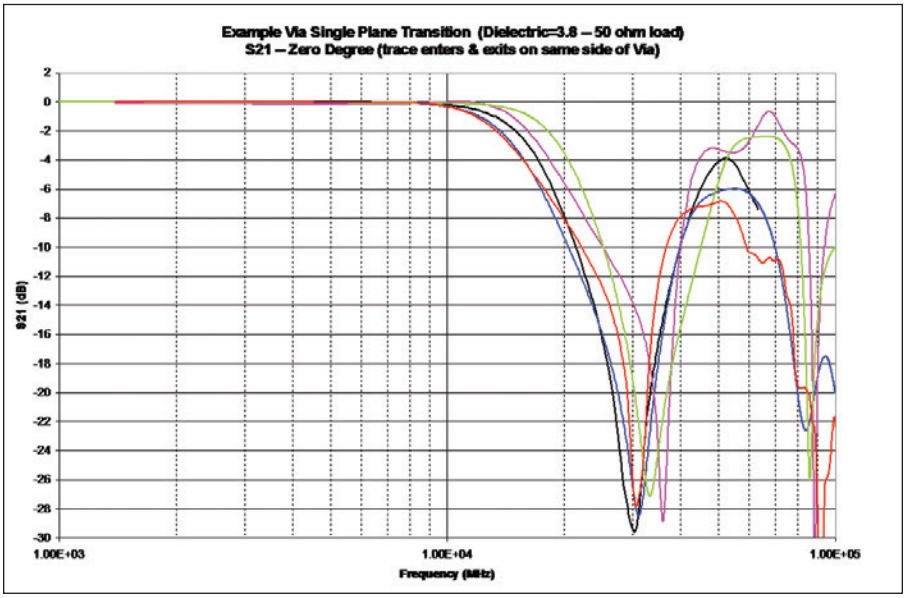

Figure 1: Initial Via Model Results

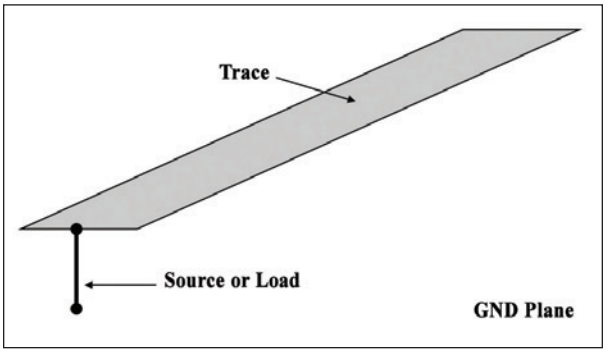

Figure 2: Lumped Port on Simple Microstrip Model

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Exodus AMP4071P-1KW Pulse Amp: Designed for Pulse, EMC/EMI Mil-Std 461, Pulse Radar apps. Superb Pulse Fidelity (up to 100usec), duty cycles to 10%, min. 60dB gain. Monitoring: Forward/Reflected power (Watts & dBm), VSWR, voltage, current, temperature. Compact 5U chassis.

Exodus AMP2071A-LC, 80–1000 MHz, 750W, 500W P1

Exodus AMP2071A-LC: 80-1000MHz, >750W, >1000W nominal, >600W P1dB, 60dB gain. Monitoring parameters: Forward/Reflected power, VSWR, voltage, current, temperature. Weight <40kg, dimensions 19"W x 27"L x 8.75"H."

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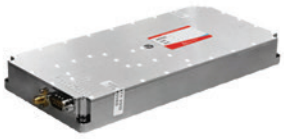

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There are many ways to make errors, both with measurements and with simulations. Engineers should constantly double-check themselves and not assume that either gives the correct answer.

must neck down to all flow through the point connection. This will increase the inductance of the connection by increasing the current density in that region. Figure 3 shows an example of this effect.

This increase in inductance can be avoided when a number of ports are used in parallel, often called a 'face' port. The impedance must be adjusted to provide the correct desired impedance, with many in parallel.

The other commonly used port is a 'wave' port. This type of port is often used to drive or load a transmission line in a printed circuit board model because, when used properly, it will automatically ensure the EM modes are correct. One important point is that the circumference of the wave port is a perfect electrical conductor (PEC). This will connect any metal object that touches the edges of the port. For example, if a stripline is intended to be modeled, and the upper reference is considered a power plane, and the lower reference a ground-reference plane, then the two planes would not physically be connected, but the wave port would force them to be connected.

Another potential issue with wave ports is their size. Users must ensure that they are large enough to allow the correct modes to be created. Figure 5 shows two examples of a PCB with a wave port. Figure 5a shows a small wave port, while Figure 5b shows a larger wave port. Figure 6 shows the electric field with the small wave port. Note that the fields are strongest between the microstrip and the wall of the wave port (PEC), and this is not correct. Figure 7 shows the correct fields are created when the wave port is larger.

CONCLUSION

There are many ways to make errors, both with measurements and with simulations. Engineers should constantly double-check themselves and not assume

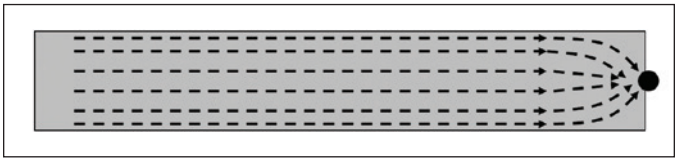

Figure 3: Current across the trace width must narrow to the single point of contact

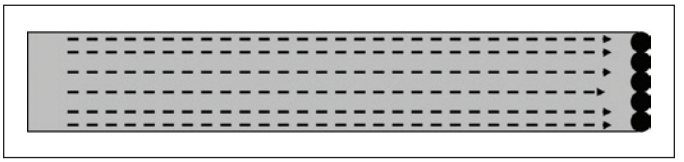

Figure 4: Current does not narrow when a number of ports are used in parallel

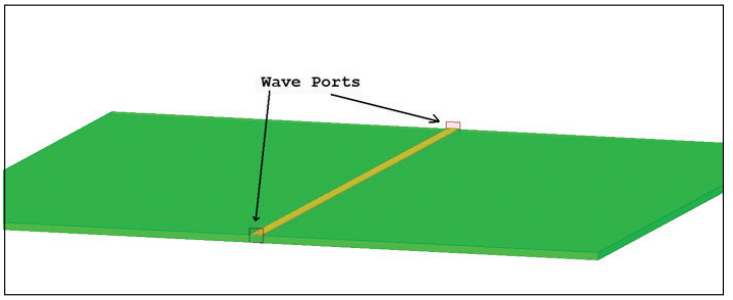

Figure 5a: Small wave port

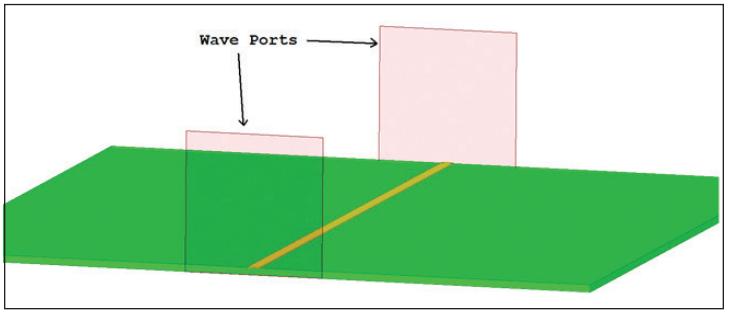

Figure 5b: Large Wave port

that either gives the correct answer. Measurements are often considered the "gospel" but while they can be considered "real world," they will often change the thing they are trying to measure. Understanding how the measurement devices work and where issues can be created is extremely important to make sure that the results are correct.

On the other hand, simulations will usually not change the thing they are try to measure, but subtle issues can creep in the model, yielding incorrect results. These simulation tools are extremely powerful, and should be a tool in the engineer's tool box, but they cannot be used as simply as a screwdriver! Training on the simulation technique to understand its strength and its weaknesses is vital.

The bottom line? Question everything.

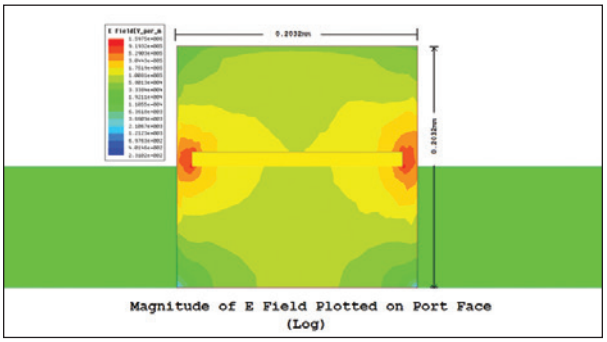

Figure 6: Incorrect electric fields due to too close PEC walls of wave port

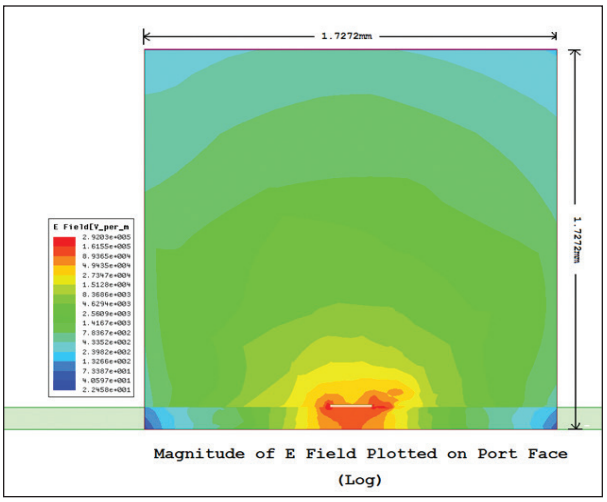

Figure 7: Correct electric field modes for microstrip trace

FUNCTIONAL SAFETY: OVERVIEW AND METHODS

A Guide to Understanding Functional Safety Basics

Functional safety (FS) is a complex, and oftentimes a confusing, subject even for those familiar with product safety and certification. With good reason, there are numerous functional safety standards that apply to various product types and applications, each with their own nuanced requirements. Some end-product standards specify one or more FS standards to use for embedded controls, while others leave it open to interpretation.

In short, FS evaluations are required whenever a control—regardless of whether it is electronic, pneumatic, hydraulic, or another type—is used to achieve safe operation of a product. Depending on the application specifics and the end-product standard, functional safety may only encompass hardware controls or include both hardware and software.

Some simple examples include thermal limiting controls on a heater, pressure limit controls on an air compressor, or interlock sensors that disconnect a machine when a door is opened. More complex examples include safety stops of machinery, collision detection systems for collaborative robots ("cobots"),

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By Michael Hamilton

sensing systems to prevent a robotic vacuum cleaner from falling down a flight of stairs, or the object detection/avoidance systems of autonomous vehicles.

While these examples represent a wide range of complexity and refer to different FS standards for evaluation, the good news is that the core functional safety process is similar for almost all projects.

This article will examine the process flow for an FS evaluation and provide an overview of each major step. Although it would take multiple books to go through every step of FS in detail, the expectation is that the following details will provide an understanding of the basic process.

Commonly Used Functional Safety Standards

IEC 61508: Electrical, electronic, and programmable electronic systems
IEC 60730 Annex H: Commercial & residential appliances
IEC 60335 Annex R: Household appliances
ISO 13849: Machinery
IEC 62061: Machinery
ISO 26262: Automotive road vehicles
IEC 61511: Safety instrumented systems
UL 991: Solid state controls
UL 1998: Software in programmable components

OVERVIEW

The FS evaluation process is shown in the flowchart in Figure 1 on page 16. The approach will vary depending on the certification scheme and whether the product is being evaluated for a third-party certification mark or a manufacturer's self-declaration.

Steps 1 through 6 may be conducted by the system designer, system integrator, safety engineer, or others appropriately qualified on the product development side. If seeking third-party certification, steps 7-9 may be conducted by a third-party safety evaluator or similar service providing independent product certification. Clients who are self-declaring may choose to do this as part of their own internal review.

This FS process may be part of a larger product safety evaluation, or it may be a stand-alone FS evaluation, depending on the product and its specific application. In an ideal scenario, these steps would be conducted as part of the design concept phase before the first circuit is drawn or any lines of code are written. Often, these steps occur after a product has been developed or even after the product is already on the market. The benefits are significant when the FS process is considered sooner, meaning a proactive approach yields lower overall time to market and development costs versus taking more of a reactive approach to fixing issues at the end.

The first three steps are intended to compile all relevant information, construct a risk assessment with a ranking of hazards, and identify controls mitigating the hazards. In the subsequent steps, the control systems are identified and evaluated to show they meet the required level of protection necessary for the hazards involved. Any safety critical software (including firmware) aspects of the design need to be properly documented as well. A review of the complete documentation package, plus any required environmental testing (EMC immunity, thermal cycling, etc.), will be conducted to help ensure continuing safe operation per the specific FS standard.

STEPS 1-2: COLLECT DOCUMENTATION AND REVIEW FUNCTIONALITY

The first two steps compile all relevant documents. These include, but are not limited to, schematics, printed circuit board trace layouts, the concept of operations, key performance attributes, block diagrams, piping and instrumentation diagrams (P&IDs), and installation/maintenance/operating instructions. If the product is in the design phase, identifying the major functions and any expected safety functions is considered the starting point. For example, for a robotic vacuum cleaner, one particular safety function might be an "edge detection sensor to prevent a fall down the stairs."

STEP 3: CONDUCT THE RISK ASSESSMENT

The Risk assessment (RA) is the key step of any FS evaluation and is shared among any FS assessment. There are many different terms for RAs (a review of these could fill a paper on their own—a few of the common formats include hazard and risk analysis, layers of protection analysis, process hazard analysis, fault tree analysis, etc.), but no matter which format is used, the main attribute is that the RA should identify all hazards the product may present through its lifecycle. A product's lifecycle may consist of installation, commissioning, normal use, maintenance, decommissioning, and any others as applicable to the product and its intended use.

Once the hazards are identified, they are ranked based on the severity of injury, the frequency of exposure,

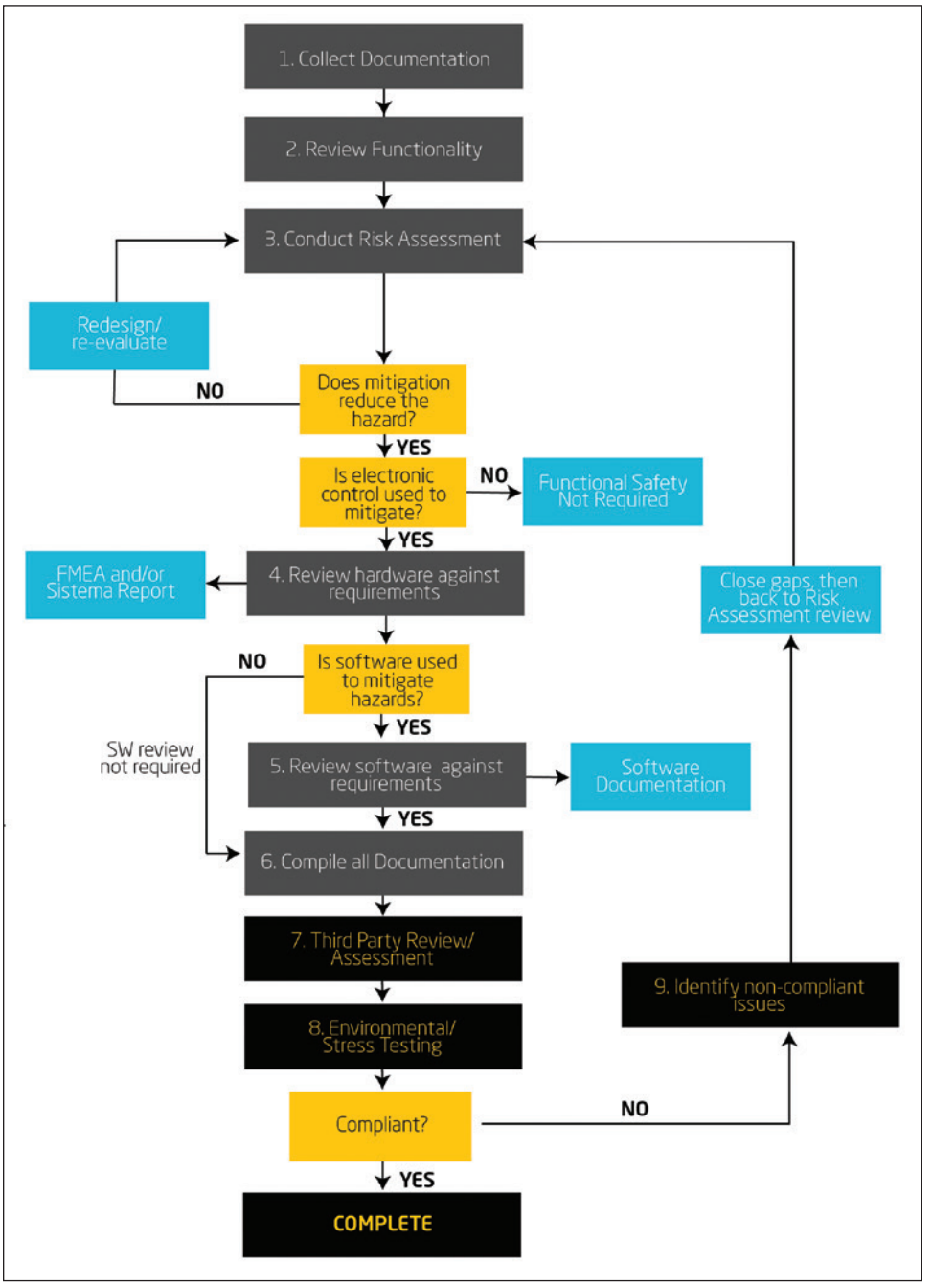

Figure 1: Functional safety process flowchart

and the likelihood of occurrence. Some standards and products also include risks of property damage. These ratings will identify which hazards present an unacceptable level of risk and where mitigation means are required.

Any mitigation means should be identified and referenced, along with a notation of whether any of these mitigation means include functional safety aspects. For example, mechanical guarding of a hazard would not be considered an FS mitigation, while providing a light curtain to guard against the same hazard would be considered FS. This is because a stationary mechanical guard does not depend on an electronic, hydraulic, or pneumatic control to provide its safety function, whereas the light curtain depends on sensors and control logic to provide this safety function.

This activity in the RA will also identify if additional risk reduction measures are required to bring the total hazard down to an acceptable level. Hazard levels, acceptable risk, and other aspects of the RA will vary from product to product as influenced by the application. Some references on best practices for conducting an RA are the standards ISO 12100 - Safety of Machinery - General Principles for Design - Risk Assessment and Risk Reduction, or ANSI B11.0 - Safety of Machinery.

The rating of the hazards will directly correlate to the safety level requirements of the FS controls. This should make intuitive sense, as a hazard that will cause a scrape or cut is much different than one that will cause death or permanent injury. It is important to note that the acceptability of injury varies among different products and their intended use. FS controls that mitigate more severe hazards generally need to be designed with higher reliability, and the FS standards may impose other, more stringent requirements on such controls. This will be illustrated through an example in Step 4 below.

In summary, the output of the RA will include the identification of:

- Hazards and risk rankings
- Mitigation means
- Functional safety controls
- Required performance levels for the FS controls

In Figure 1, two decision trees follow the output of Step 3. The first decision will determine whether the reduction measures sufficiently reduce the hazards:

- If no, redesign and re-evaluate
- If yes, then the next decision tree is used to determine if electronic controls are used (i.e., FS controls)

RISK ASSESSMENT WORKSHEET

Ref #	Hazard, location, activity, persons exposed			INITIAL RISK										Risk Classification
	Risk	Persons	Activity	Degree of possible harm (DPH)		Frequency of Exposure (F)		Possibility of avoidance		Likelihood of occurance		Initial Risk score		
1a	cutting finger on fan blade	operator	opening cover for cleaning	A&E likely to fully recover within a month	4	> Weekly	3	Unlikely	2	Possible	3	2.91		Medium

Figure 2: Example of a line item from a risk assessment showing the required performance level of safety control

If there are no electronic pneumatic or hydraulic controls, then the system does not contain any FS controls, and the product does not require an FS evaluation. If there are electronic pneumatic or hydraulic controls, then you would move forward with the hardware review in Step 4.

STEP 4: REVIEW HARDWARE AGAINST REQUIREMENTS

For systems where FS controls are identified as mitigating hazards, the hardware will need to be first evaluated to help ensure it meets the requirements of the standard for the hazard being mitigated. This will vary depending on the end-product safety standard. In essence, the standard will outline a set of requirements for the hardware (and software, discussed in later steps) based on the level of risk involved. Different standards identify these levels of risk with differing terminology, as shown in Table 1.

Let's consider an example: evaluating a product to ISO 13849 (Safety of Machinery).

From the chart in Table 1, we know this standard uses PLa through PLe ratings for the performance level of controls. A rating of PLa applies to controls mitigating low-risk hazards, up to a rating of PLe for controls mitigating the most severe hazard risks. If the system uses a control where the calculation made during the risk assessment results in a low level of hazard mitigation—say PLa—then it may be acceptable to use a single-channel circuit architecture with lower reliability components. But, if the hazard is more severe, such as shown in Figure 2, a PLd or PLe level of safety will be required. For these higher performance levels, this particular standard will require redundancy, diagnostic coverage, and reduction of common cause failure modes as defined in the standard.

IEC 61508	Safety Integrity Level	SIL 1, 2, 3, 4
IEC 62061	Safety Integrity Level	SIL 1, 2, 3
ISO 13849	Performance Level	PL a, b, c, d, e
ISO 26262	Automotive Safety Integrity Level	ASIL A, B, C, D
UL/IEC 60730	Protective Class	Class A, B, C
UL 1998	Software Class	Class 1, 2

Table 1: Functional safety standards and their risk level terminology

	ISO 13849 requirements				
Risk reduction measures taken	SRP/CS	S	F	P	PLr of SRP/CS
Interlock switch and relay to disable power to fan when cover is opened.	Yes	S2	F1	P2	PLd

In this instance, the FS control used (as noted in the "Risk reduction measure taken" column) is an interlock that will mitigate the "medium" level hazard based on this particular RA ranking. The required PL for this hazard is calculated as "PLd," as shown here. The standard ISO 13849 includes the methodology for this calculation based on S, F, and P (Severity [shown as DPH in Figure 2], Frequency of Exposure, and Possibility of Avoidance). The FS control used is an interlock that will mitigate the "medium" level hazard based on this particular RA ranking.

The rating of each hazard would typically be done as part of the risk assessment, so that during this step the primary task is to review the hardware design to verify it meets the requirements necessary for its performance. The evaluation of hardware may be done by referring to manufacturer reliability data for off-the-shelf components, conducting failure mode and effect analysis (FMEA) of custom-built components, conducting a SISTEMA review (SISTEMA is a software tool for the application of ISO 13849), or by using other acceptable, industry-recognized methodologies.

The output from this step is documentation showing that the hardware effectively provides the required level of performance for each of the hazards identified.

STEP 5: REVIEW SOFTWARE AGAINST REQUIREMENTS

The decision tree at the output of the hardware evaluation requires the identification of any software that is used as part of the control systems. If the control is purely hardware, then Step 5 can be skipped. If software is used, most standards include requirements for software documentation, validation, and verification.

In general, the requirements for FS software are based on effective practices in coding, error checking, process documentation, version control, and methods for validation and verification (V&V) at various stages of the development lifecycle. The product development lifecycle V-model is often referenced here to ensure that appropriate V&V for software is conducted at each stage of the design process. Some standards also include requirements for coding techniques, such as defensive coding practices.

The output of this step will be a set of documents showing compliance with the software development process.

STEP 6: COMPILE ALL DOCUMENTATION

At this point, all the documentation should be compiled and ready for submission to a third-party certifier, or if self-certifying, taking the next step

Non-compliances discovered during testing or construction review may lead to design changes. These design changes should be further reviewed to determine if any changes are required from the previous risk assessment.

to incorporate it into a technical data file. Typical documentation includes hardware design documents, schematics, bill of materials, PCB trace layouts, risk assessments, FMEAs, and reliability calculations. Also included in this compilation would be all of the required functional safety management documentation, which varies depending upon the FS standard being used but generally includes system-level specifications, architecture specifications, development plans, safety requirement specifications, design and coding standards, system and module test documentation, integration and validation test plans with test results, the software source code itself, and any other required documents required by the standard.

STEPS 7-8: THIRD-PARTY REVIEW AND ASSESSMENT AND TESTING

If independent third-party certification is used, then the next step of the process is for the certification body to review the submitted documentation package. If all documents have been finished in a complete and consistent manner, the certifier should be able to follow the risk mitigation from start to finish. Certifiers may have questions or send documents back for revision or clarification if any issues are found.

One of the most important takeaways from this activity is to provide traceability: the documentation should provide supporting evidence and a clear rationale for the decisions made.

For example, if a machine presents a risk of injury due to high sound levels, the RA should cite the sound level measurement requirement (such as an OSHA requirement), the measurement made, and any other supporting information that provides a clear understanding of the assessment performed.

As mentioned earlier, functional safety also generally requires operational, thermal, and environmental testing—often specific testing for electromagnetic compatibility (EMC), including impulse and immunity testing. This testing would be conducted at this point in the evaluation.

STEP 9: IDENTIFY NON-COMPLIANCES

Non-compliances discovered during testing or construction review may lead to design changes. These design changes should be further reviewed to determine if any changes are required from the previous risk assessment, hardware, or software requirements. Any changes should be documented and reviewed through the same process flowchart with all necessary updates, and by performing repeat testing and recertification where appropriate.

If no non-compliances are determined, barring further compliance issues, then the FS evaluation is considered complete.

CONCLUSION

This article provides a high-level overview of the functional safety process, giving readers general guidance help along the certification path, and aid in effective communication and supporting dialog guidance with third-party certification authorities.

GLOSSARY

- *Failure mode and effects analysis (FMEA)*—A methodology to identify possible failures in a design, typically applied to hardware to analyze safe or unsafe failures when faults are injected.
- *Hazard*—Potential source of harm to persons, property, or the environment. A hazard can be qualified in order to define its origin (e.g., mechanical hazard, electrical hazard) or the nature of the potential harm (e.g., electric shock hazard, cutting hazard, toxic hazard, fire hazard). (ISO 13849-1:2015, 3.1.11)
- *Layers of protection analysis (LOPA)*—A methodology for assessing adequacy of protection layers used to

mitigate a risk. Includes evaluation of the frequency of potential incidents and the probability of failure of protection layers. Typically used in the process industry. (Handbook of Fire and Explosion Protection, Dennis P. Nolan, 2019).

- *Required performance level (PLr)*—The performance level required in order to achieve the required risk reduction for a safety function. (ISO 13849-1:2015, 3.1.24)
- *Risk*—Combination of the probability of occurrence of harm and the severity of that harm. (ISO 12100:2010, 3.12)
- *Risk assessment*—Overall process comprising risk analysis and risk evaluation (ISO 12100:2010, 3.17). This is a methodology for identifying the risks and hazards of a product or process, the severity of the hazards, any mitigation methods, and may include scoring of functional safety control requirements.
- *Safety function*—The function of the machine whose failure can result in an immediate increase of the risk(s). (ISO 12100:2010, 3.30)
- *Safety integrity level (SIL)*—Discrete level (one out of a possible four) for specifying the safety requirements of functions in a safety-related system. SIL 4 has the highest level of safety integrity and SIL 1 has the lowest. (IEC 61508-4:1998, 3.5.6)
- *Safety-related part of a control system (SRP/CS)*—The combined safety-related parts of a control system start at the point where the safety-related input signals are initiated (including, for example, the actuating cam and the roller of the position switch) and end at the output of the power control elements (including, for example, the main contacts of a contactor). Also known as an SRCS. (ISO 13849-1:2015, 3.1.1)

THERMAL RUNAWAY ENERGY RELEASE AS A FUNCTION OF THE STATE OF CHARGE

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INTRODUCTION

Advancement in lithium-ion (Li-ion) batteries has resulted in them being the power source of choice in consumer electronics. These types of batteries have the advantage of high power and energy densities. As the chemistry of Li-ion batteries advances, so does their capacity and energy density. The higher the energy content and the smaller and tighter the internal components, the higher the potential risk, magnitude, and consequences associated with battery failure events.

A major failure mechanism that can lead to fires and explosions is a thermal runaway event. In large battery packs, many cells can be packed in close proximity to each other. If one of the cells goes into thermal runaway, the energy released can heat up neighboring cells, which may lead to a thermal cascade throughout the battery pack. A pack design that mitigates this hazard may incorporate cell-to-cell gaps filled with insulating materials, potting compounds, or specialty materials designed to transfer the energy generated during the battery failure to less critical areas of the pack to be dissipated safely. From a risk assessment standpoint, it is generally expected that a single-cell failure within a large multi-cell battery pack might be rare but inevitable. This potential for failure propagation introduces an increased risk of property damage and safety issues. Thermal runaway events can result in the venting of flammable gases, which can generate fire or even an overpressure event if ignited in a confined space. The propagation of failures increases the total energy released during the event, as well as the volume of flammable gases and ejecta released.

As such, an accurate evaluation of the energy yielded during a thermal runaway event is beneficial for the design of battery-powered consumer electronics for both performance and safety. Accurate energy yield estimates are a valuable parameter for a wide range of design tasks, such as but not limited to:

- Comparing failure characteristics of cells of different formats, batches, or from different vendors
- Evaluating the energy release mechanism (i.e., Is the energy released within the cell casing or in the gas and ejecta?)
- Designing safer battery packs that minimize propagation of failure events to neighboring cells, and
- Generating reliable inputs for mechanical/thermal models of devices and/or battery packs.

The energy released during a battery thermal runaway event can be assessed by evaluating the sensible and chemical energy during the failure. Traditionally, two techniques are used to quantify the energy released such as (1) oxygen consumption calorimetry (OCC) [1], and (2) accelerating rate calorimetry (ARC).

OCC has been used for many years to estimate the energy released during combustion by collecting and analyzing the oxygen, carbon dioxide, and carbon monoxide concentrations of the exhaust gases. This technique can be used to obtain an estimate of the chemical energy associated with the combustion of the flammable vent gases released during a thermal runaway event. It should be noted that additional complexity is associated with OCC testing of Li-ion cells given cell composition, non-standard reaction paths, and generation of oxygen during the thermal runaway failure.

Thermal runaway occurs when the internal temperature of a cell increases in an uncontrolled manner, leading to the cell's failure and unintended side effects, such as the release of dangerous gases, fire, or an explosion.

An ARC is an instrument designed to characterize the self-heating behavior of materials and reaction kinetics. This method has become highly utilized to understand the thermal runaway processes of batteries. ARC can be used to study a variety of variables that affect thermal decomposition and thermal runaway characteristics. If ARC testing is performed with the battery sample in a sealed vessel, the overall energy release from the thermal runaway event can be estimated using the heat capacity of the sample in conjunction with the temperature rise of the sample, the temperature rise of the ARC vessel, and the known heat input into the system. It should be noted that depending on the amount of vent gases released and the nature of the ARC test conducted (e.g., in an inert environment or in air), the combustion energy associated with the flammable gaseous species may not be fully captured.

This work provides an overview of a relatively novel experimental apparatus, fractional thermal runaway calorimetry (FTRC), designed to measure the energy output and mass ejections associated with a thermal runaway event. Compared to ARC, which relies on relatively coarse temperature measurements in a sealed vessel, the FTRC provides better estimates of the thermal runaway energy given the high-fidelity temperature mapping of each section of the apparatus. For this reason, the FTRC can provide additional information on the energy fractions of failures associated with (1) vent gases and ejecta compared to the cell body and (2) the positive and negative terminals of the cell.

BATTERY THERMAL RUNAWAY

Thermal runaway occurs when the internal temperature of a cell increases in an uncontrolled manner, leading to the cell's failure and unintended side effects, such as the release of dangerous gases, fire, or an explosion. In the initial stages of thermal runaway, the solid electrolyte interface (SEI) layer decomposes in an exothermic reaction, followed by an exothermic reaction between the intercalated Li-ion cell and electrolyte. As positive electrode material reacts with the electrolyte, oxygen is generated inside the cell and the electrolyte decomposes and the cell disintegrates. During the process of thermal runaway initiation, the rising temperature generates gases, which are released through pressure relief vents in the cell when the internal pressure reaches the design relief pressure or if the cell enclosure fails. For Li-ion cells, these gases are hot and combustible, which is not only a hazard in itself but one that can propagate the failure to other cells in the pack.

All thermal runaway events are a result of elevated temperature in the cell. This temperature rise can be caused in many ways, including, but not limited to:

- External heating from a high ambient temperature, thermal abuse, or external fire
- An internal cell defect resulting in an internal short circuit which can cause heating at the site of the defect
- A surge in charge/discharge current and the resulting heat generated
- Improper electrical connection at the tab of a battery that can cause increased electrical resistance, generating heat at the contact location or
- Mechanical damage to the cell which can lead to internal shorts, resulting in heat generation.

During thermal runaway, the cell produces gases that build up within the cell. Some cells, such as cylindrical cells, are designed with vents that open to release gases when a certain internal pressure is reached. Occasionally, these relief vents fail via obstruction or inadequate venting area, which may result in the rupture of the cell casing. For particularly energetic failures or for weak and/or flawed cell casing designs, the rupture of the cell casing may lead to the release of ejecta and vent gases from the negative

terminal of the cell (i.e., in the case of negative side rupture) or from the side of the cell (i.e., side rupture). Such abnormal failure modes may result in a drastically different energy breakdown during failure and require careful consideration for the design of appropriate mitigation strategies to handle the thermal runaway energy. Cell formats, such as pouch cells, are not designed with vents but rather weak points in the external pouch that release gases when internal gas pressure rises. The peer-reviewed scientific literature provides insights into the typical vent gas volume released during a thermal runaway event involving cylindrical, pouch, and prismatic cells [2-11]. The gas production ranges between approximately 1 L and 3 L per Ah of battery capacity. The major constituents include CO_2, CO, and H_2, together with non-negligible amounts of hydrocarbons (e.g., CH_4, C_2H_4, C_2H_6, plus longer chain hydrocarbons) [2]. The interested reader should refer to references [2-11] for a comprehensive overview of experimental data on vent gas volume and composition, vent gas release rates, as well as the effect of the state of charge (SOC) on the main thermal runaway parameters.

METHODOLOGY

An FTRC is a battery testing apparatus specifically designed by the National Aeronautics and Space Administration (NASA) to measure the energy output and mass ejections associated with a battery thermal runaway event [12][13]. The FTRC is equipped with interchangeable cell chambers that can accommodate cells with various form factors and capacity (e.g., 18650 cells, 21700 cells, D cells), as well as different cell triggering mechanisms ranging from external heating to nail penetration and internal short circuit devices. The cell chamber is centrally located and is interfaced on either side with (1) ejecta mating assemblies, (2) ejecta bore assemblies, and

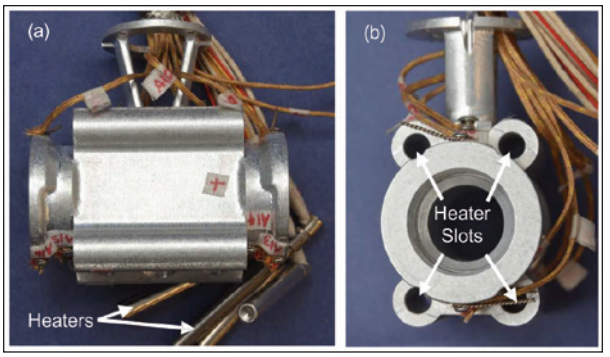

Figure 1: Photograph of an FTRC apparatus: Close-up view of the FTRC 18650 cell chamber: (a) side view, (b) axial view.

(3) rod-and-baffle assemblies. The cell chamber is equipped with four cartridge heaters that can be used to trigger a thermal runaway by raising the cell temperature. An FTRC apparatus equipped with a standard 18650 cell chamber is fundamentally a symmetric device that can evaluate energy releases associated with cell failures encompassing top venting, bottom venting, or both. Modifications to the cell chamber design can be implemented to provide a means to estimate energy releases associated with side casing ruptures. Figure 1 shows two close-up views of the 18650 cell chamber displaying the cartridge heaters and the four slots in the chamber for the heaters.

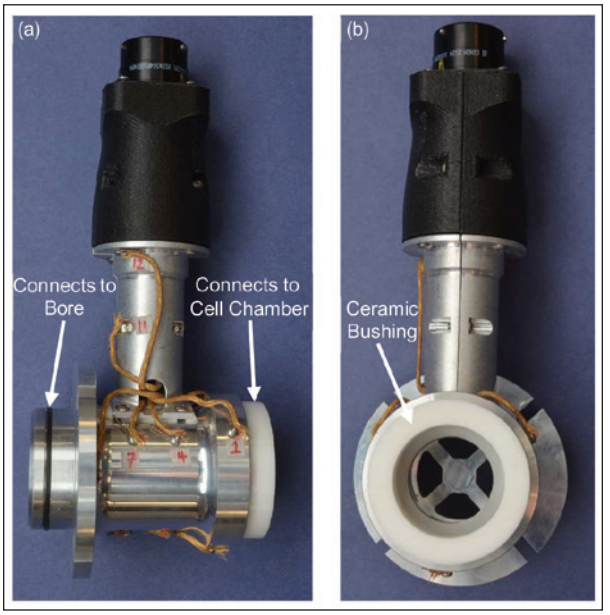

Figure 3: Photograph of an FTRC apparatus. Close-up view of an ejecta mating; (a) side view, (b) axial view.

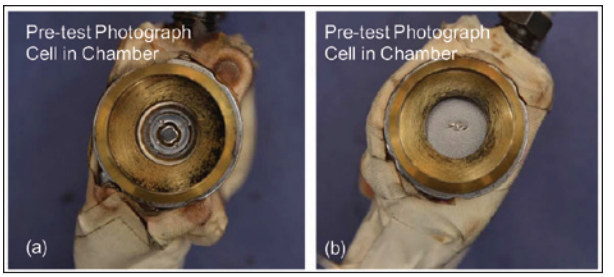

Figure 2: Photograph of an FTRC apparatus. Close-up view of the FTRC cell chamber containing an 18650 cell: (a) positive cell terminal, (b) negative cell terminal.

Figure 2 shows close-up views of the cell chamber containing an 18650 cell and displays both the positive and negative cell terminals.

The operation of the FTRC is based on simple physical principles. The various assemblies of the FTRC are all composed of known materials with known masses and thermal properties. The temperatures of these components are recorded throughout a test run. Since the material composition of the assemblies is well known, it is understood how much energy must be added to the assemblies to cause a given rise in temperature. Thus, by measuring the temperature of the components, it is simple to

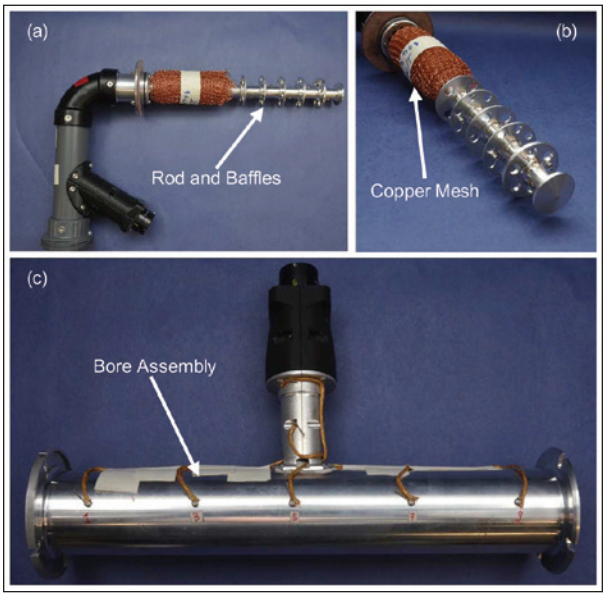

Figure 4: Photograph of an FTRC apparatus. Close-up view of an a rod-and-baffle assembly and associated bore assembly; (a) rod-and-baffles, (b) rod- and-baffle close-up showing the copper mesh and aluminum baffles, (c) bore assembly.

compute how much energy was transferred to each component (i.e., how much energy the cell released).

The FTRC cell chamber (see Figure 1 and Figure 2) is connected to the ejecta mating assemblies via ceramic bushings that provide a certain degree of thermal isolation between the sub-assemblies while guaranteeing the continuity of the flow path for the vent gases ejected during the battery failure event. The ejecta mating assemblies (see Figure 3) are designed to capture large debris and ejecta released during the cell failure. Figure 3 shows close-up views of an ejecta mating displaying (1) the ceramic bushing that interfaces with the cell chamber and (2) the opposite mating component that connects with the bore section of the calorimeter.

Figure 4 shows close-up views of a rod-and-baffle assembly and associated bore. The bore assemblies and rod-and-baffles assemblies are located downstream of the ejecta mating. They are designed to extract sensible energy from the vent gases by creating a tortuous flow path encompassing (a) a series of aluminum baffles and (b) copper mesh windings.

Figure 5 shows a photograph of a fully assembled FTRC equipped with an 18650 cell chamber. Note the two copper mesh windings are shown prior to their installation in the rod-and-baffle assembly of the FTRC. The fully assembled device is placed in a dedicated insulated casing to minimize heat loss during the test (see Figure 6 on page 28).

The energy generated during the battery failure can be evaluated in terms of total energy yield, fractional energy yields associated with the battery body and positive/negative vent gas, and ejecta. The cell energy yield is obtained by solving an energy balance equation for all the sub-components of the calorimeter based

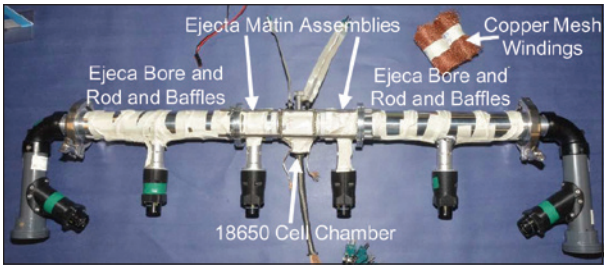

Figure 5: Photograph of an FTRC apparatus equipped with an 18650 cell chamber in the center of the device

on the mass, specific heat, and temperature increase experienced by each sub-assembly. More specifically, the sub-assembly temperature increase is measured by type-K thermocouples attached to the hardware of the calorimeter in multiple locations. The data collection system relies on seven multipin connectors that deliver the signals to several National Instrument data acquisition cards. The post-processing algorithm utilizes the temperature data collected by 104 temperature channels logged at a frequency of 20 Hz and six voltage channels logged at a frequency of 1600 Hz.

Figure 6: Photograph of an FTRC apparatus. View of the insulating casing utilized to enclose the calorimeter prior to each test.

TEST RESULTS

This section summarizes the FTRC tests performed on 17 cells at different SOCs. Testing conditions and cell properties are summarized in Table 1. All tests utilized 18650 format lithium-ion cells with nominal capacities of 2.6 and 3 Ah. Cells were charged to a target SOC by first putting each cell through a full discharge-charge cycle and measuring the full cell charging capacity. Each cell was then charged to the desired fraction of the measured capacity using coulomb counting of the applied current. Charging to 100% SOC was done using a constant current constant voltage (CCCV) charging protocol:

- Cells A were charged at a constant current of 1.3 A, a voltage limit of 4.2 V, and a current cutoff of 0.13 A.
- Cells B were charged at a constant current of 3 A, a voltage limit of 4.2 V and a current cutoff of 0.15 A.

Discharge to 0% SOC was done using a constant current (CC) discharge:

- Cells A were discharged at a CC of 1.3 A and a lower voltage limit of 2.75 V.
- Cells B were discharged at a CC of 3 A and a lower voltage limit of 2.5 V.

Cells were tested utilizing two different abuse methods:

- *Nail penetration:* Cells were penetrated using a conductive stainless-steel nail with a diameter of 3 mm. The nail was sharpened to a 30-degree angle. The nail was inserted into the middle of the cylindrical face of the cell at a rate of 80 mm/s. In some cases, nail penetration tests at low SOCs did not result in thermal runaway. Therefore, only 100% SOC nail penetration tests are reported here.
- *External heating:* FTRC cell chamber is equipped with four cartridge heaters with the total rated power of 1 kW. These heaters are used to increase the temperature of the chamber, which in turn heats the cells. Heaters were operated at their maximum power until cell failure occurred, or until a cell surface temperature reached 300 °C. The energy supplied by the heaters was measured during the test and was ultimately subtracted from the total energy of the system to calculate the energy released by the cell.

Cell Properties	Abuse Method	State of Charge	Number of Tests Executed
Cell A Format: 18650 Capacity: 2.6 Ah Nominal Voltage: 3.7 V	Nail Penetration	100%	3
	External Heating	100%	1
		75%	1
		50%	1
		25%	1
Cell B Format: 18650 Capacity: 3.0 Ah Nominal Voltage: 3.6 V	External Heating	100%	2
		80%	2
		50%	2
		30%	2
		0%	2

Table 1: Test conditions and properties of tested cells

ENERGY YIELD AS A FUNCTION OF SOC

Figure 7 shows the total energy release by two different cell models tested under different abuse conditions. Figure 7a shows the energy as a function of SOC, while Figure 7b shows the energy release as a function of charging capacity measured by coulomb counting during the charging process. We observed that the energy release increases with SOC. Additionally, tested cells can release a significant amount of energy even at 0% SOC. Furthermore, we observed that the nail penetration abuse method resulted in higher total energy release for the tests done at 100% SOC on cells A.

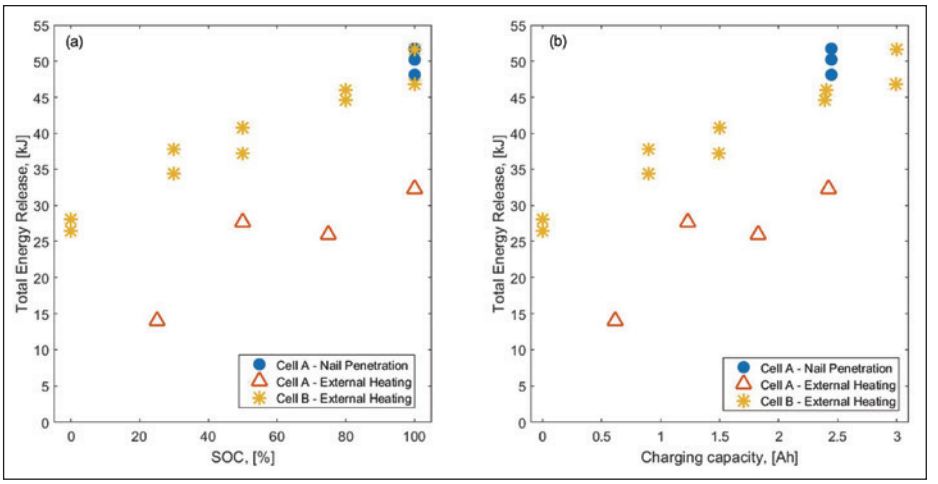

Figure 7: Total energy released by tested cells plotted as a (a) function of SOC and (b) charging capacity

Figure 8 shows variation in the total and fractional energy release as a function of SOC for cells B. Higher SOC led to more material being ejected from the cell casing (positive ejecta), demonstrating that

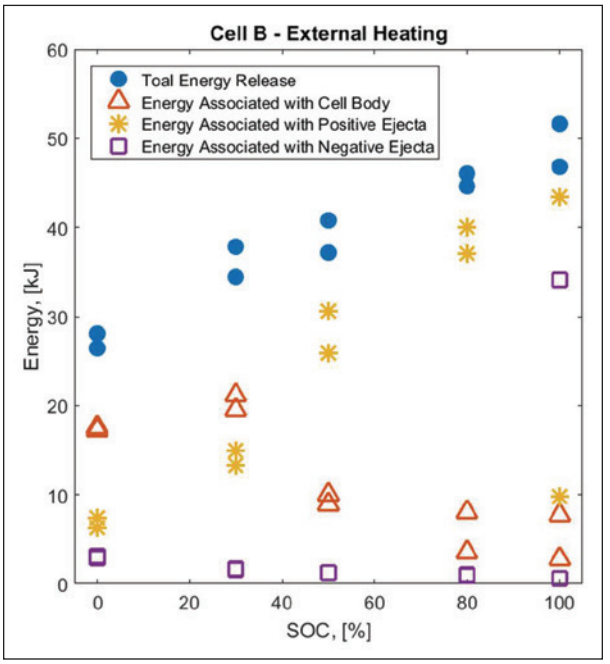

Figure 8: Total and fractional energy release by cells B plotted as a function of SOC

the majority of the energy release was associated with ejecta. In contrast, lower SOCs saw the majority of the energy release remaining within the cell body, showing a higher cell body energy release for 0% and 30% SOC compared to 100% SOC. This finding indicates that understanding the energy release as a function of SOC could be important for system designs where the energy release in the cell body is of high importance, since low SOC failures may represent a worst-case scenario for such applications.

The voltage and current during cell charging were logged as a function of time, making it possible to measure the total amount of energy delivered to the cell during charging. An important metric to consider with respect to the energy release is the comparison between the total energy delivered to the cell during charging and the energy released by the cell as a result of the abuse. Figure 9 shows the ratio between the energy released during the thermal runaway and the energy supplied to the cell during charging. We observed a decreasing trend of this ratio with the increase in SOC, with the ratio approaching 1 – 1.5 at 100% SOC.

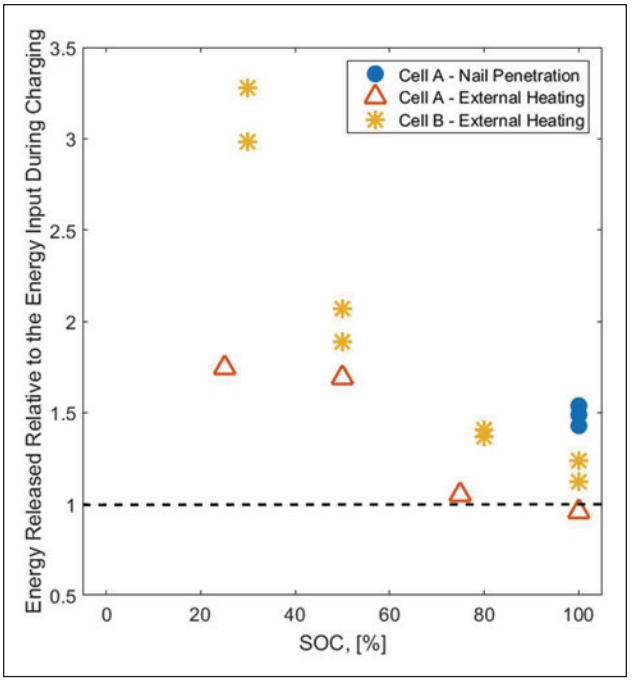

Figure 9: Total energy released by tested cells relative to the energy input during charging, plotted as a function of SOC

CONCLUSIONS

This work presents an experimental framework to characterize the energy released during a thermal runaway event of a lithium-ion battery cell that is agnostic of the battery chemistry. This fractional characterization of energy during thermal runaway is an important parameter that can inform the design of battery-powered consumer electronics from both safety and performance standpoints. The application of FTRC to the study of the energy release at different states of charge provides a unique look at the cell failure mechanisms. Several findings are identified as a result of this study:

- While the energy release by the cell increases at higher SOC, a significant portion of energy is still released even at 0% SOC
- At high SOCs, most of the energy is associated with ejecta and gases, while at low SOCs, the majority of energy is contained within the cell body and
- The ratio between the energy released by the cell and the energy supplied to the cell during charging decreases with the increasing SOC

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HOW MANUFACTURERS AND RETAILERS CAN COLLABORATE TO PROVIDE QUALITY PRODUCTS AND CONDUCT EFFECTIVE RECALLS

Working Together Can Improve All Aspects of Safety

Several months ago, I chaired an online seminar discussing the relationship between manufacturers and retailers in handling product safety issues.[1] In addition, years ago, when I was an in-house lawyer, and more recently as a product safety lawyer, I've had a number of experiences with retailers that sold my company's or my client's products. This article will address some of the issues discussed during that online seminar, as well as some of my individual experiences in dealing with retailers.

In addition, I will discuss a new product safety initiative just announced by Amazon which offers a useful summary of techniques that can be utilized by manufacturers and retailers to make safer products and engage in more effective recalls.

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By Kenneth Ross

The first thing to point out is that each retailer has different procedures for how they deal with manufacturers and consumers. Therefore, my experience in dealing with retailers and manufacturers might differ from other companies depending on the circumstances and the companies involved. Despite that, this article will point out some of the issues that need to be considered by manufacturers when dealing with retailers who sell their products.

SALES/PURCHASE CONTRACTS

In discussing the duties and responsibilities of manufacturers, distributors, dealers, and retailers, you must first look at the contracts between each party. The contract could be a sales contract issued by the manufacturer and agreed to by the purchaser, or it could be a purchase order issued by the retailer or other purchaser and agreed to by the manufacturer. Either way, here are some of the important provisions that should be carefully scrutinized and discussed by all parties.

The first issue involves sales by a manufacturer to a retailer. If the retailer sells the product and does nothing to that product, their duties and responsibilities, as well as their potential liability, are minimal. The law says that a retailer has no duty to test and inspect the products they sell and is not liable for any subsequent injury unless they knew or should have known that the product was hazardous.

However, there are some retailers that voluntarily assume additional duties through actions such as assembling the product or advising the consumer about how to safely use the product. Thus, they assume some responsibility for doing it correctly and, if they do it incorrectly, they can be held liable.

Agreements between a dealer or distributor and a manufacturer are a little different. Dealers or distributors usually have responsibilities that go beyond those of a normal entity in the chain of distribution. For example, they may agree to provide warranty service, give safety orientations and training to purchasers, provide normal maintenance, and provide repair services outside of the warranty. Also, dealers or distributors have divided loyalties because they are advocates for their customers with the manufacturer as well as representatives of the manufacturer to the retailer.

Whether a manufacturer sells to a dealer, distributor, or retailer, the relationship should be clearly defined after it has been established. Further, the contract should reflect the duties, rights, and responsibilities of all parties in the distribution chain and clearly allocate the risks between the parties.

Issues of Financial Responsibility

In the event there is an accident or safety issue, the goal is for the party at fault to pay for the loss and protect the party that was not at fault. Many times, there may be shared responsibilities or there may be no one at fault. In such cases, each of the parties may need to defend themselves if they are sued.

Therefore, the contact between the manufacturer and dealer, distributor, or retailer should include a provision about who is financially and practically responsible when problems arise. If a purchaser just sells the product as received from the manufacturer, it makes sense for the manufacturer to indemnify and hold harmless that purchaser for all liability. If it is possible for the purchaser to do something that might create a safety issue, then the contract should be written to allow for the manufacturer to refuse to indemnify the purchaser if there is evidence that the purchaser did something that contributed to the injury.

Over the years, I have had problems with purchasers who wanted to be indemnified and held harmless for all product liability claims and litigation filed against them, even if their personnel did something that made the product unsafe, thus causing an accident. One example from my days as an in-house lawyer involved the sale of power tools. Sometimes, the retailer would assemble the product incorrectly. Or they would tell the customer that they can remove the guard when they get the power tool home because it just gets in the way. Another example is a retailer that placed a picture of the power tool in their advertisements, showing the product without the safety devices that were required for safe use. In all of these cases, it isn't fair for the manufacturer to fully indemnify the retailer.

Many retailers say to manufacturers that, if you want us to buy your product, you must agree to our indemnification and hold harmless requirements. And many manufacturers do not want to raise the issue during contract negotiations. That can be a mistake if there is an incident clearly caused by the retailer's personnel, yet the retailer still expects the manufacturer to fully indemnify them and hold them harmless.

In addition, a sales contract between a manufacturer and a retailer should include a provision regarding insurance coverage for the retailer, dealer, or distributor that will cover them in the event they are sued. The amount and type of insurance, the acceptability of the insurance company, and the amount of the deductible or self-insured retention are issues of negotiation. However, it would also be fair for the retailer, dealer, or distributor to provide insurance coverage to the manufacturer in case one of their actions caused the accident.

Post-Sale Duties and Responsibilities

A further area to discuss during contract negotiations is the respective duties and responsibilities of the manufacturer and retailer after the sale of the product.[2] Again, this is a topic that the manufacturer's sales force might be reluctant to discuss at the beginning of a relationship. Typically, the retailer will want the manufacturer to be responsible for all costs associated with a recall or other field action.

However, there are many issues that remain to be clarified, such as the retailer's responsibility to 1) report incidents to the manufacturer, 2) accept returned products that have been recalled, 3) place posters in the store or in the store's computer when a recall has been undertaken; 4) post social media information as required by the U.S. Consumer Product Safety Commission (CPSC); 5) email or mail letters to customers of the recalled product where they have contact information; 6) issue refunds; and 7) dispose of recalled products that have been returned to the store in accordance with CPSC requests.

If the manufacturer is responsible for paying for all recall costs, there should be an understanding before a recall commences about what these costs could be and how they can be minimized.

The CPSC has ramped up responsibilities for both manufacturers and retailers to communicate or attempt to communicate with consumers. Most of these new procedures involve enhanced use of social media to get the message out about the recall. This raises the question of who pays for social media, who is responsible for posting the messages and monitoring the responses, and where that information should go.

Additional Concerns

Other issues involve whether the manufacturer has to pay the retailer for the labor costs to place posters in the store and whether the manufacturer has to pay the retailer for the cost of mailing recall notices to known customers. Certainly, emailing customers would be a lot cheaper than sending traditional mail to that customer. Also, more retailers now have the ability to contact their customers electronically, especially retailers that are membership warehouses or that have customer loyalty programs.

Additional issues in the post-sale area that could be included in the applicable contract involve whether the manufacturer has to pay storage costs if the recalled product or the inventory is quarantined in the retailer's warehouse. Also, a number of retailers send reports of incidents to the CPSC on a regular basis. There should be a clear understanding between the manufacturer and the seller as to what information the retailer should obtain from the consumer, whether they should try to retrieve the product if possible and who receives it, whether the manufacturer can contact the consumer, and whether the retailer can file this report with the CPSC without first telling the manufacturer about these incidents. All of these things are

important to decide during contract negotiations or before the manufacturer's products are first sold.

Lastly, who has the responsibility to decide whether a recall or other corrective action is necessary? There can be situations where the manufacturer does not believe that a report to the CPSC or a recall is necessary, and the retailer disagrees. What happens then? The law says that both the retailer and the manufacturer have an independent duty to report to the CPSC. So, one or both entities may report. These situations may not be covered in the sales contract, but there should at least be an understanding of what each party is entitled to do in this situation.

If the manufacturer is a foreign company with no legal presence in the U.S., then the distributor or dealer is an importer and could be the party that receives notice from the retailer. In that case, someone must decide which party undertakes an investigation and reports the matter to the CPSC if a report is necessary.

Many retailers have established procedures that apply to all companies they purchase from. Therefore, the manufacturer may not be able to negotiate different procedures that would be employed in the event of a safety issue in the field. But a discussion should be undertaken, at least to ensure that the manufacturer understands what they should do and what the retailer will do.

PRIVATE-LABELED PRODUCTS

There are a number of other problems that arise if the manufacturer is selling the product using the retailer's name or trade name. In that situation, the retailer usually is the importer of record and any safety issues that arise about that incident would probably go directly to the retailer. In addition, if the CPSC has instituted an investigation involving a particular incident, they would contact the retailer and not the manufacturer. In that case, who should file the report with the CPSC? The retailer or manufacturer?

Another complexity occurs in cases in which the CPSC wants a recall undertaken, and the manufacturer refuses to do so. In such cases, the CPSC might then issue a unilateral press release that would name the retailer. Or, in the case of a private labeled product, the press release would be issued using the retailer's name in the headline. Again, these issues should be discussed well before they arise so that there are no disagreements about who is responsible for doing certain things and who has the right to determine what to do.

Without contracts describing the rights and responsibilities of each party to the contract, everyone is left to wonder what they have to do and what happens if a loss occurs. Some type of contract or memorandum of understanding that sets forth basic guidelines at least gives each party an idea of the parameters of the relationship.

ONLINE RETAILERS

The significant growth of online retailers has added challenges to the relationships that must be established to deal with safety issues. There are no store personnel helping the consumer purchase the product and helping them understand how to set it up or how to use it safely. There is no store to take back the product and issue a refund or provide a replacement. There is no one the consumer can easily talk to about an incident or near miss that they had. It is harder for the "store" inventory to be quarantined and destroyed or returned. And some online retailers generally prefer to directly contact their consumers about recalled products and do not want to provide contact information to the manufacturer or the CPSC.

Thankfully, online retailers have been improving their websites and procedures to deal with many of these challenges. Amazon has officially announced a number of new initiatives in this area, but other online retailers and brick-and-mortar retailers have also made improvements in the pre-sale and post-sale safety procedures they employ.

On July 25, 2023, Amazon announced a new page on their website for customers entitled "Your Recalls and Product Safety Alerts."[3] Even though Amazon proactively notifies each of its customers about product recalls and safety alerts, this page allows customers to view in one location all of these communications for products they purchased.

Amazon's July 2023 announcement explained the use of this page by saying:

> *"If a recall is announced or a product safety alert is issued, Amazon customers will receive a personalized email with details about the recall and see an alert*

banner on top of their 'Your orders' page. This banner will link to their personal 'Your Recalls and Product Safety Alert' page for more details about potential safety hazards, as well as to the recall notice for options such as a refund, return, or repair."

The announcement also said, "With this new feature, we are able to directly reach 100% of customers who have bought a recalled product in our store and provide clear instructions on what to do next."

Other retailers have recall notices on their websites, but most of them cannot post these notices on the order page of the consumer unless the consumer has an established online account with that online retailer.

Last, Amazon offers a Recalls Logistics Service where they can issue refunds such as Amazon gift cards on behalf of the selling partner and manage return logistics. Of course, the manufacturer must pay Amazon for that service. Some other retailers may do that, too, but Amazon's logistics capabilities are very extensive, making returns and replacements fairly easy.

Amazon followed up its July 2023 announcement with another one on February 14, 2024. This document, entitled "A blueprint for private and public sector partnership to improve product safety for consumers,"[4] is a thoughtful discussion of the difficulties of providing safe products to consumers, as well as Amazon's ideas on how to improve product safety while still selling products to consumers.

First, Amazon discussed how they can detect and prevent the sale of unsafe or defective products on their website. On this point, they said:

"We also have robust policies and processes in place to make sure the products they want to list for sale meet applicable compliance and safety requirements. We continuously monitor our store for potentially unsafe or noncompliant products, including when we receive new information from sellers about products and brands, and from safety and regulatory bodies. These proactive efforts use a combination of advanced machine learning, safety, and compliance experts."

Amazon also listens to feedback from customers and others to identify potential safety issues that were missed by their proactive controls. This raises an interesting question about whether manufacturers should monitor Amazon reviews of their products or let Amazon contact the manufacturer if they believe there is a safety concern. It is clear to me that, where feasible, manufacturers should monitor these reviews (maybe just the one-star and two-star reviews) to see what issues are being discussed and not wait for Amazon to contact them. This recommendation would also apply to any other retailer's website where their products are being sold.

This blueprint does not say that Amazon will contact the manufacturer if they believe that there is a product safety issue, nor does it say that they will contact the CPSC as other retailers do. However, in 2021, Amazon established a streamlined process (called the A-z- Guarantee[5]) for resolving personal injury or property damage claims due to a defective product. This process is described as follows:

"To request compensation for property damage or personal injury that you believe was caused by a defective product purchased on Amazon, contact us, and we will help you report the safety incident. You'll receive a request from us to upload evidence supporting your claim to a secure portal, and Amazon or our third-party administrator will reach out to you in a few days. We'll work with you directly or through our external claims administrator to collect information, investigate the claim, and attempt to facilitate a resolution with you, and if necessary, our selling partner and their insurance providers."

As a manufacturer, it would certainly be better for Amazon to contact them immediately if a claim is made under their program and allow the manufacturer to investigate and resolve any valid claim with the customer. If you sell to Amazon, you should talk to them about how this procedure would work in connection with any of your future claims. In addition, you should talk to any other retailer about how claims, complaints, and incident reports will be handled by the retailer's personnel.

In the event of a product recall, Amazon's product safety blueprint has a number of proposals to modernize the recall process. They say that the current regulatory requirements are not effective, noting that the CPSC estimates a 6% effectiveness rate for all types of consumer product recalls. Amazon then says:

"They are insufficient in ensuring that retailers know what products are being recalled, they do not have a high enough bar for how retailers must notify customers to make them aware of the recall, and it can be more difficult than necessary for customers to understand what action they should take to protect themselves."

The blueprint seeks to have manufacturers better identify the product to be recalled and they criticize the CPSC procedure of hanging posters in stores and issuing press releases to get the message out. Of course, since Amazon knows what products were bought by specific customers, they can more easily communicate with those customers. Most retailers do not have that ability. Even retailers with membership or customer loyalty programs sometimes do not have adequate contact information for many customers, or the contact information is out of date.

Amazon's blueprint also dealt with instructions and on-product warnings that Amazon believes are inadequate. To improve these communications, Amazon says:

"To better educate our customers about how to use products, Amazon has started to incorporate messages from safety experts into our shopping experience so customers can make more informed decisions both during the purchase process and after they receive the product and are using it."

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"Similarly, we are experimenting with post-purchase messages like emails or push notifications that explain what actions to take to minimize safety risks with short, easy-to-understand usage information."

It is not stated as to who engages these product safety experts, who approves the safety messages to customers, and who creates post-purchase messages. In all cases, the manufacturer should confirm that the safety information transmitted by Amazon is consistent with the information in the product's warning labels and instructions.

Finally, Amazon also wants manufacturers to provide safety information digitally so it is always available, complete, can be updated as needed, and is in the customer's preferred language.

CONCLUSION

The contract and any underlying policies and procedures govern the relationships between the manufacturer and other entities in the chain of distribution. While a manufacturer's product safety personnel do not normally get involved in contractual matters, they should. Such personnel should be knowledgeable about what their company agrees to with any retailer, dealer, or distributor and who has the responsibility for each aspect of safety throughout the life of the product. They should incorporate the details of the agreement into their own procedures and should consider making improvements to their procedures or the procedures of any of the purchasers.

Also, I recommend that readers review the three Amazon documents discussed in this article, as well as any other publicly available best practices in design, sales, and recalls issued by other retailers, manufacturers, or trade groups. Technology is enabling more effective and efficient ways to communicate with consumers before and after sales and should be considered by everyone. This will improve the safety of finished products, as well as products that are already in the hands of consumers.

ENDNOTES

1. See https://www.productsafetyprofessionals.org/webinar-archive for a video of this webinar that took place on February 7, 2024.
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3. https://www.aboutamazon.com/news/how-amazon-works/amazon-creates-new-page-to-share-recalls-for-customers
4. https://www.aboutamazon.com/news/policy-news-views/how-amazon-is-improving-product-safety
5. https://www.amazon.com/gp/help/customer/display.html?nodeId=GS3GYAU8JGDBGWH2

IMAGE THEORY: RADIATION FROM HERTZIAN DIPOLE ABOVE GROUND PLANE

By Bogdan Adamczyk

This article presents the derivation of the radiated far fields from a Hertzian dipole antenna above the ground plane using image theory.

1. HERTZIAN DIPOLE ANTENNA

An electric dipole, often referred to as a Hertzian dipole, shown in Figure 1, consists of a short, thin wire of length l carrying a constant current $\hat{I}$ positioned symmetrically at the origin of the coordinate system and oriented along the z-axis.

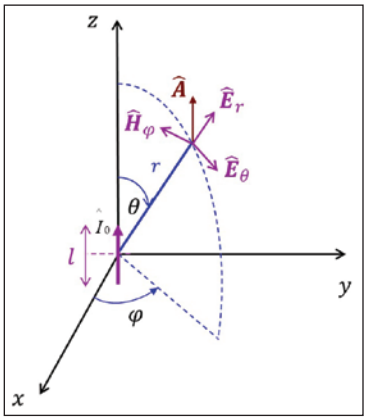

Figure 1: Hertzian dipole

Ideally, the wire is infinitely short; practically, a wire of the length $l << \lambda/50$ (λ = wavelength) can be considered a Hertzian dipole.

The far field of a Hertzian dipole has only a θ component (in a spherical coordinate system) and is given by [1].

$$E_\theta = j\frac{I_0 l}{4\pi}\eta\beta \sin\theta\left(\frac{e^{-j\beta r}}{r}\right) \qquad \text{Eq. 1}$$

The complete derivation of this result is given in [2].

2. IMAGE THEORY

In image theory, a radiating antenna (actual source) is placed at some distance *h* from a perfect conducting plane. An image of this antenna (virtual source) is placed below the conducting plane at the same distance, *h*, as shown in Figure 2 [3].

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Because of the reflecting ground plane, the total field at an observation point *P* is the sum of the direct wave and the reflected wave. Obviously, there are no fields below the ground plane.

Instead of obtaining the total field by summing the actual direct and reflected waves, we add the direct wave from the actual source and the direct wave from its image (virtual source) to obtain the same result (above the ground plane). When considering the virtual direct wave, we pretend that the ground plane does not exist and, therefore, the virtual wave has a direct, unobstructed path to the observation point.

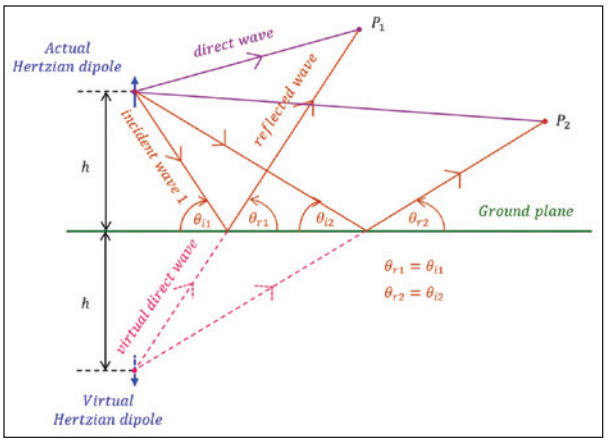

Figure 2: Hertzian dipole and its image

Why are we using this approach? Because the calculation of the fields using the actual waves is quite complicated, whereas the calculations using image theory are quite simple, as we shall see.

3. RADIATION FROM HERTZIAN DIPOLE ABOVE GROUND PLANE

Consider the geometry shown in Figure 3.

The source is an infinitesimal dipole of length l, carrying a constant current I_0. The observation point P is in the far field. The direct component of the E field at the observation point is, [2]

$$E_\theta^d = j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r_1}}{4\pi r_1} \sin\theta_1 \qquad \text{Eq. 2a}$$

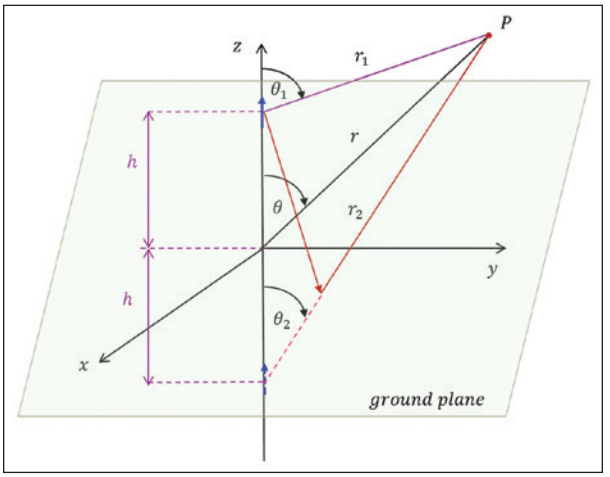

Figure 3: Direct waves from the Hertzian dipole and its image

The virtual component is

$$E_\theta^v = j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r_2}}{4\pi r_2} \sin\theta_2 \qquad \text{Eq. 2b}$$

The total field at the observation point is

$$E_\theta = E_\theta^d + E_\theta^v = j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r_1}}{4\pi r_1} \sin\theta_1 + j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r_2}}{4\pi r_2} \sin\theta_2 \qquad \text{Eq. 3}$$

In the far field, $r >> h$ and the lines from the actual and virtual dipoles to the observation point may be considered parallel, as shown in Figure 4.

This is often referred to as the parallel-ray approximation.

Obviously, we have

$$\theta_1 = \theta \qquad \text{Eq. 4a}$$

$$\theta_2 = \theta \qquad \text{Eq. 4b}$$

From Figure 5, we have

$$r_1 = r - h\cos\theta \qquad \text{Eq. 5a}$$

$$r_2 = r + h\cos\theta \qquad \text{Eq. 5b}$$

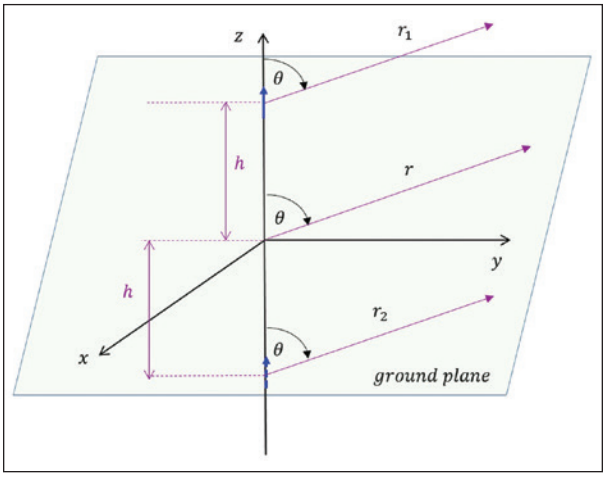

Figure 4: Parallel-ray approximation

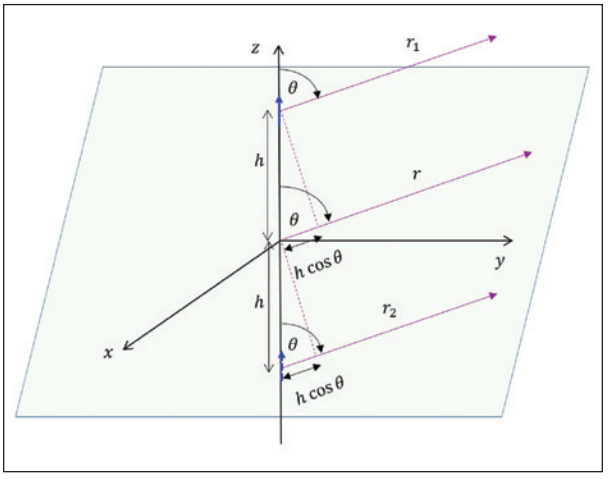

Figure 5: Parallel-ray approximation geometry

We will use the approximations in Equations 4 and 5 when substituting for r_1 and r_2 in the phase component of the expressions in Equation 3. That is,

$$e^{-j\beta_0 r_1} \cong e^{-j\beta_0(r-h\cos\theta)} \quad \text{Eq. 6a}$$

$$e^{-j\beta_0 r_2} \cong e^{-j\beta_0(r+h\cos\theta)} \quad \text{Eq. 6b}$$

When approximating the amplitude components, we may further approximate r_1 and r_2 as

$$r_1 = r \quad \text{Eq. 7a}$$

$$r_2 = r \quad \text{Eq. 7b}$$

Thus,

$$E_\theta = E_\theta^d + E_\theta^v = j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r_1}}{4\pi r_1}\sin\theta_1 + j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r_2}}{4\pi r_2}\sin\theta_2$$

$$= j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0(r-h\cos\theta)}}{4\pi r}\sin\theta + j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0(r+h\cos\theta)}}{4\pi r}\sin\theta$$

$$= j\eta_0 \frac{\beta_0 I_0 l}{4\pi r}\sin\theta\left[e^{-j\beta_0(r-h\cos\theta)} + e^{-j\beta_0(r+h\cos\theta)}\right]$$

$$= j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r}}{4\pi r}\sin\theta\left[e^{j\beta_0 h\cos\theta} + e^{-j\beta_0 h\cos\theta}\right] \quad \text{Eq. 8}$$

Using the Euler identity for a cosine function, we arrive at

$$E_\theta = j\eta_0 \frac{\beta_0 I_0 l e^{-j\beta_0 r}}{4\pi r}\sin\theta\left[2\cos(\beta_0 h\cos\theta)\right] \quad \text{Eq. 9}$$

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VOLTAGE TO CURRENT CORRELATION FOR CDM TESTING

By Lena Zeitlhoefler, Theresa Lutz, Friedrich zur Nieden, Kai Esmark, and Reinhold Gärtner for EOS/ESD Association, Inc.

NEW APPROACHES FOR CDM TESTING

It is now well known that testing for CDM ESD evaluation is becoming a bigger challenge. Previously, (*In Compliance Magazine,* March 2021) Capacitively Coupled TLP (CCTLP) was described as an alternate approach. It offers many advantages compared to the standardized field-induced CDM setup according to the JS002 standard [1]. Testing of a package, bare die, or wafer is enabled with high reproducibility. The failure correlation between CDM and CCTLP has been investigated based on peak current stress levels and not by a charging voltage level [2]. If testing with an alternative CDM method as CCTLP is done to reproduce JS002, the CDM charging voltage must be transferred into peak current levels.

Lena Zeitlhoefler received her master's degree in Electrical Engineering from the Technical University of Munich in 2017. Her studies included the physics of CDM and CDM simulation and is now on the ESD team at Infineon Technologies.

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Kai Esmark has more than 20 years experience in the field of ESD and EOS. He is Senior Principal for "Overvoltage Robust Design" in the Automotive business group of Infineon Technologies in Munich

Reinhold Gärtner received his diploma in physics from the Technical University of Munich in 1987. After working as an independent ESD consultant, he joined Siemens Semiconductors in 1996, now Infineon Technologies.

DEVICE AND TESTER CAPACITANCE

A measure for the severity of the CDM stress is the effective capacitance C_{eff} of a device [3]. C_{eff} characterizes the amount of exchanged charge between DUT and test setup at a specific stress level (e.g., V_{CDM}) in a specific testing environment.

Products can be categorized with respect to C_{eff} in an FICDM setup because of the direct relation to the peak current for a given test voltage, as described in [4].

During a CDM stress, different capacitance values play a role according to the three-capacitances model, as shown in Figure 1.

The three capacitance values determine the effective capacitance C_{eff}. The DUT capacitance C_{DUT} is defined as the capacitance from the device to the field plane. The static capacitance value for C_{DUT} is extracted from a Finite Element Method (FEM) simulation according to the three-capacitances model shown in Figure 1. Differences between C_{eff} and C_{DUT} capacitances either extracted from FEM-simulation or calculated as parallel plate capacitance C_{plate} (A is the area of the DUT, and d is the thickness of the FR4 dielectric layer) are demonstrated based on the metallic circular coin modules (height 1.27 mm, diameters see Table 1).

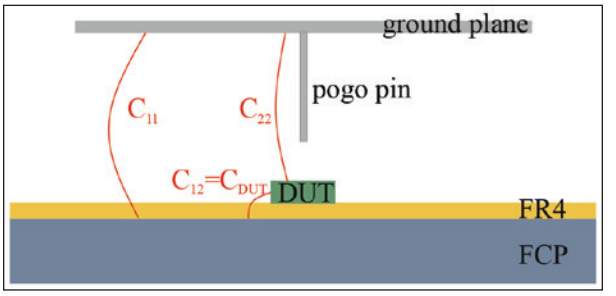

Figure 1: Three-capacitances-model of the CDM tester

P1	P2	JS	P4	JL	P5	P6	P7	P8
2.29	4.49	8.89	18.03	25.37	36.05	43.04	51.02	62.52

Table 1: Coin diameter in mm, height of coin: 1.27 mm

The FEM simulation of C_{DUT} does not coincide with the simple plate capacitor formula since fringing effects are also considered, especially for small devices. C_{DUT} also shows a linear dependency on the area-capacitance relation. In contrast, C_{eff} values show saturation with increasing area or volume of a DUT. As a result, not only the area of the bottom surface contributes to the capacitance but also the sidewalls and, therefore, the volume.

IMPACT OF DEVICE DIMENSIONS

To calculate the CDM discharge current from the volume, the device area is considered as the maximum edge length *a* x *b,* including the pins and mold compound (Figure 3). For a bare die product that does not go into a final package, the area is calculated from the edge length of the silicon accordingly.

Statistical analysis of CDM testing data shows the relevance of device area and volume for predicting stress current levels in a CDM test since the height *h* of the device has a non-neglectable influence on the discharge current. A database with over 15 million CDM waveforms has been used to evaluate the relation between area, volume, peak current, and the effective capacitance C_{eff}. The area and volume of about 10000 different device types can be derived from the package dimensions included in the database. For each device type, only the waveforms are evaluated, showing the maximum positive peak current I_{peak} out of several CDM discharges for a positive charging voltage level of 500 V. According to the measurement results, the peak current reduces with the increasing height of the device.

This can be shown using the set of nine cylindrical solid metal coins P1 to P8 with different diameters and volumes (see Table 1)[5]. The coin reference for the peak current still gives a reasonable orientation for the maximum peak current. Figure 4 shows the dependency of the effective capacitance C_{eff} on the volume. For very flat packages, the limit of the coins is exceeded but still gives a meaningful value. The coin with the smallest volume and, therefore, lowest C_{eff} reaches the lowest peak current and vice versa. For devices, this means that their C_{eff} with the according current can be related to the current of the coins. As shown, the device height is becoming relevant for the estimation of the stress current level, therefore, the volume is introduced as the preferred parameter. Thus, the volume value can be used to estimate the expectable peak current with respect to the coin values as shown in Figure 5.

CONCLUSION

A practical solution is presented for the problem, how CDM targets can be translated to current test levels. CDM current test levels are important as they allow using alternative CDM testing methods, such as CCTLP. The first testing proposal is a simple

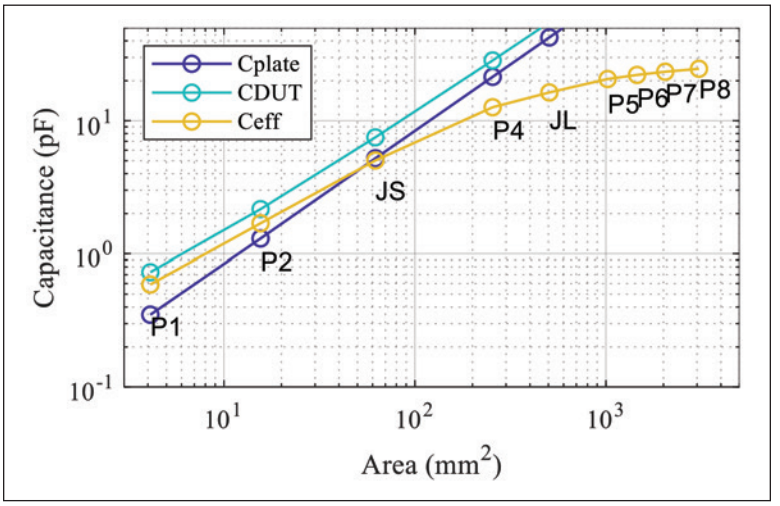

Figure 2: C_{eff}, C_{DUT}, and C_{plate} related to the area of coins

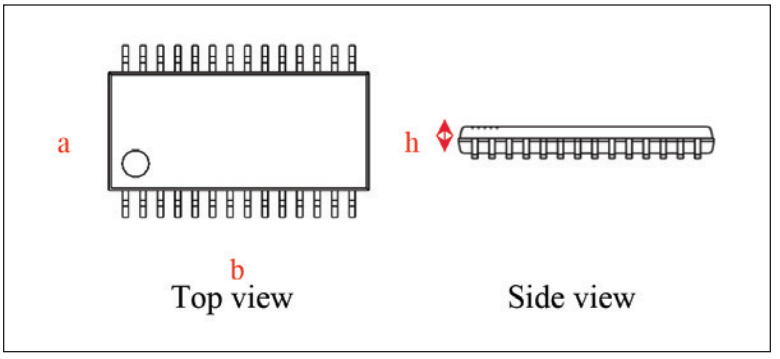

Figure 3: Definition of device area $A = a \times b$ and volume $V = A \times h$

approach, representing the worst case: Increase the CCTLP testing voltage until the peak current value is reached at the product pin given in Figure 5.

To avoid over-testing, these levels can be lowered based on the second proposal if details of the electrical properties on-package and on-chip are known. C_{eff} values can be predicted by FEM simulation even before devices are available.

The full paper was published in [6].

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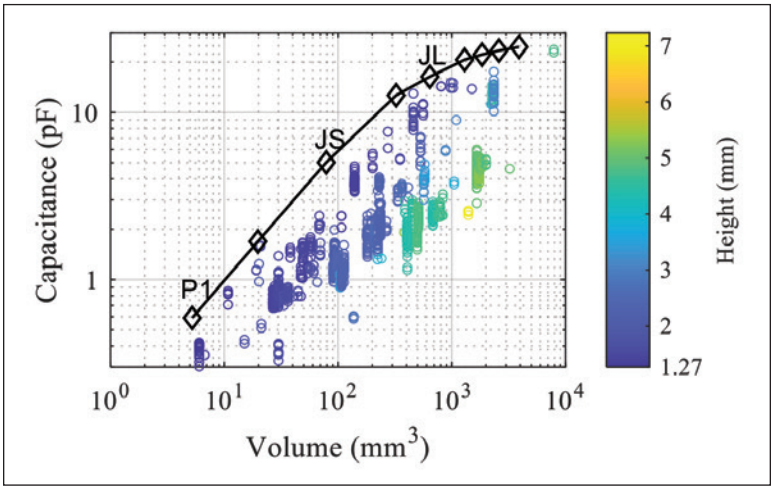


Figure 4: Effective capacitance vs. device volume for $h > 1.27$mm. The influence of the device height on the effective capacitance is illustrated per color.

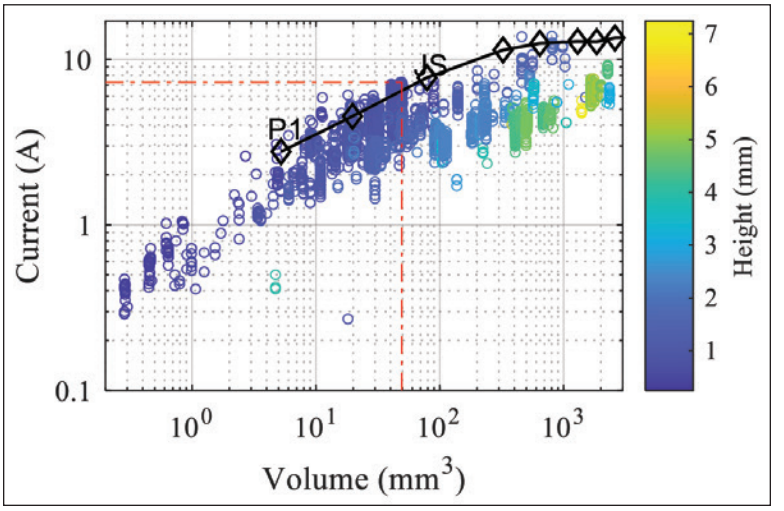


Figure 5: Current vs. volume with illustrated dependency on height.

USING RF MONITORING PROBES TO TROUBLESHOOT TRANSIENT FAILURES

By Dr. Min Zhang

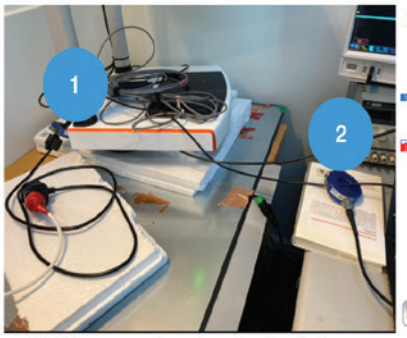
Our previous column (see "Using a Near-Field Probe to Troubleshoot Transient Failures," *In Compliance Magazine*, February 2024) introduced a valuable technique for troubleshooting electric fast transient (EFT) failures at the PCB level. However, in large systems, such as big cabinets housing numerous electronic components, employing the near-field probe method can be time-consuming and, depending on the voltage level, potentially unsafe (for instance, when dealing with high-voltage circuits requiring isolation). In such scenarios, an alternative approach is necessary. This "Troubleshooting EMI Like a Pro" column presents a technique suitable for use in such situations.

Large systems typically consist of interconnected PCBs or modules linked by cables. Placing RF current probes at various wire connection points enables the tracing of current flow during transient events. These RF current probes must be terminated to the 50-ohm impedance of an oscilloscope. Transient events vary in type, with their frequency response indicated by rise time. For instance, electrostatic discharge (ESD) exhibits the fastest rise time (sub-1 nanosecond), while electric fast transients typically have a rise time of about 5 nanoseconds. Both types suggest unpredictable RF current flow, especially in low-impedance systems. However, engineers often have a reasonable estimation of the route. Therefore, multiple RF probes can be utilized to trace the current flow.

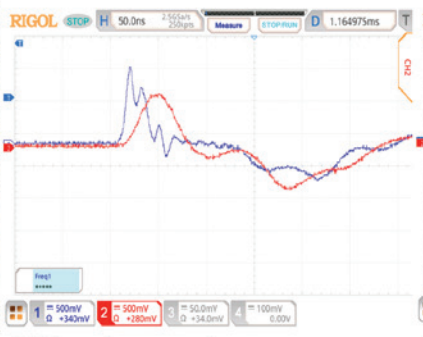
Dr. Min Zhang is the founder and principal EMC consultant of Mach One Design Ltd, a UK-based engineering firm that specializes in EMC consulting, troubleshooting, and training. His in-depth knowledge in power electronics, digital electronics, electric machines, and product design has benefitted companies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

Ideally, a pair of matched probes should be used, as they possess nearly identical transfer impedance. However, obtaining such a pair is often challenging and may require engaging with probe manufacturers and incurring a premium cost [1]. Nonetheless, two probes of the same model can suffice, provided their transfer impedance is reasonably close.

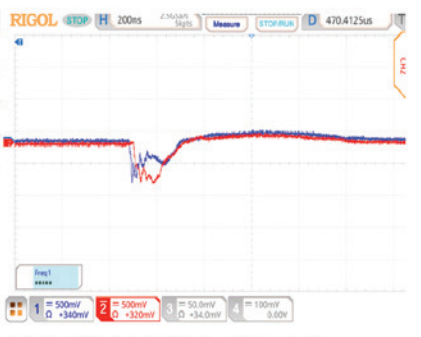
More crucial is ensuring the correct placement of the probes so that their markings align with the current's polarity. RF current probes exhibit directional



(a) Two current probes located at
1. mains entry
2. The USB Link



(b) Currents measured
blue trace - current measured at location 1
Red trace - current measured at location 2



(c) Currents measured - after the fix
blue trace - current measured at location 1
Red trace - current measured at location 2
Note that the polarity changes due to the polarity change of the transient voltage

Figure 1: Case study 1

properties, and the polarity of the probe output is determined by the current flowing through them, with reversed probes showing a mirrored output. Since the goal is to trace transient current accurately, proper probe orientation is essential.

The bandwidth of the current probe should be sufficient to capture the transient event, often requiring a 1 GHz probe. Consequently, a 1 GHz oscilloscope is preferred, although a 500 MHz scope is usually adequate for troubleshooting. Given the typically large transient currents, probe sensitivity is not a priority; a small transfer impedance, such as 0dBΩ, is ideal as it provides true current readings on the oscilloscope without requiring mathematical conversion.

In large and complex systems, the need for additional probes may arise. However, it's impractical for manufacturers to have more than two probes. As an alternative, one can place one probe at the transient noise entry point and then relocate the second probe to various key locations. After capturing results at each position, engineers can compare them. This allows for a comprehensive understanding of the current path.

In our first example, a unit experienced susceptibility issues during an EFT/burst test. When the transient noise was injected into the unit via its mains lead, the connected laptop via a USB link froze, rendering it unresponsive. In this case, it was logical to place the first RF probe at the mains entry point and the second probe on the USB link. Currents during the transient event were captured, revealing overshoot and ringing on both cables. Introducing high-impedance components such as ferrite cores in a multi-turn configuration reduced the overshoot and ringing, ensuring normal communication between the computer and the unit.

In our second case, an electric vehicle was in charging mode when an EFT generator applied a common-mode transient to all wires (as part of the immunity test in charging mode). Consequently, the vehicle's horn started blaring, indicating susceptibility failure. Given the size of the truck, three probes were placed at locations where the transient signal was likely to penetrate. Tests were repeated with probes placed in different positions. Upon observing a significant level of current consistent with the waveform at the mains entry, it was evident that the path required attenuation.

During transient events, secondary effects may occur due to the complexity of the unit [2]. It is also worth mentioning that the ringing observed during the test often presents the most significant issue as it indicates resonance—a common cause of emission and immunity failure.

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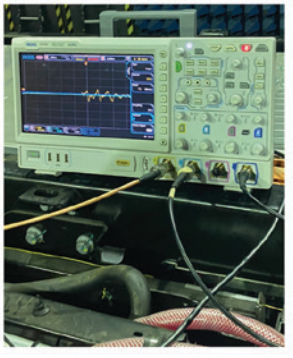
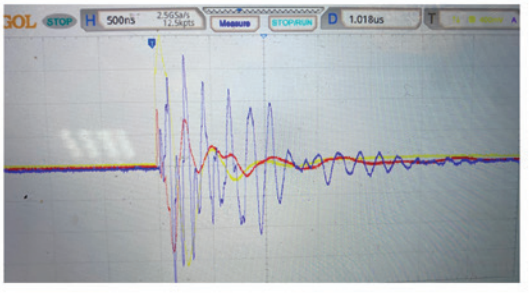
2. Doug Smith, "ESD and EFT Internally Regenerated by Power Supplies." https://emcesd.com/tt2015/tt061616.htm

(a) An EFT generator is used to inject pulse into the truck chassis, via the PE wire of the on board charger.



(b) Three RF current probes were placed in key paths of the vehicle chassis connections.



(c) Resonance indicates "ground" issues.

Figure 2: Case study 2

Banana Skins

445 Electronic Articles Surveillance (EAS) systems interfere with disabled aid

My work includes the installation of induction loops for hearing aid users. The availability of these is almost the only way of complying with the Disability Discrimination Act in public buildings which have an amplification system.. Many hearing aid users will not, for example, attend a Church which does not have a working loop system. These generate an audio magnetic field which is received by a special pick-up coil in the hearing aid.

One of the more widespread sources of interference to induction loops is the security system used in larger shops and libraries. The library building in Halesowen has a small theatre on the top floor. Tests reveal a 1kHz audio signal throughout the whole building including the whole of the theatre. The source of this is the security system to stop theft of books. These consist of a pair of coils which form a "gateway" through which all books have to be carried.

The flagship library in Bournemouth town centre has this security system. The necessary induction loops fitted to the desks where the Library Staff issue books for borrowing have to be at least 5 metres away from these. Otherwise the background whistle is intolerable. On one visit there, I happened to have an induction loop monitor with me. Out of curiosity, I tried the desk loop and found that the background whistle was intrusive even at the furthest point on the counter.

On another occasion, I happened to need a new bulb for my car, and visited one of Birmingham's car parts shops on my way home from a service job. Seeing a similar security coil system in the shop, I went back in with a loop monitor and found that the whistle was audible out in the car park as well as at the cash desks where shops are now having loops fitted.

Getting cynical in my old age, I think that the audio spectrum falls off the bottom end of the 9kHz or 150kHz lower limit of a lot of EMC specifications, and so does not enter people's thinking. On the other hand, specifications that limit noise emissions into mains supplies seem irrelevant when someone is designing an audio magnetic radiator such as is used in these security gateways.

(*Sent in by Robert Higginson of AREAC, 2nd August 2007)*

446 Some more examples of medical interference

- A video system used for endoscopy experienced random episodes of interference during electrocautery.
- Cardiopulmonary bypass blood pumps stopped unexpectedly during surgery.
- An infusion pump changed rate when a cellular phone was placed on the instrument stand.
- A fetal hearth monitor located in a nursery experienced incorrect readings. A wireless base station had been placed on a wall outside the nursery.

(Taken from the PowerPoint presentation "Medical Equipment Immunity Assessment by Time Domain Analysis," Mireya Fernández-Chimeno, Miguel Ángel García-González and Ferran Silva, 2007 IEEE International Symposium on Electromagnetic Compatibility, 8-13 July 2007, Honolulu, Hawaii, ISBN: 1-4244-1350-8, IEEE EMC Society: https://www.emcs.org. These examples were previously reported by Silberberg J.L, in: "What Can/ Should We learn from Reports of Medical Device Electromagnetic Interference?" Proceedings on Electromagnetics, Health Care & Health, Paper 10.2.1.3, Montreal, Quebec, Canada. 1995.)

447 Fibre-optics used in 'EMI-Immune' Aircraft Program

Maryland-based Optelecom-NKF, Inc. has announced that its Electro-Optics Systems Group has received a contract from Parker Aerospace for optical fiber control system architecture design in support of the Electromagnetic Interference (EMI) immune aircraft program, designated AVE3I. The Parker Aerospace contract is part of an Air Force Research Laboratories (AFLR) program to develop EMI-immune aircraft. Parker Aerospace is under contract to GE Aviation, the prime contractor in the Air Force contract. The AVE3I program is scheduled to advance in several stages through design, laboratory demonstration, and, potentially, flight demonstration.

According to Bill Ziegler, the Electro-Optics Group's Program Manager, "This contract continues our long-standing emphasis on developing optical fiber-based systems to protect aircraft from the threats associated with EMI."

(Extracted from "Optelecom-NKF Wins Contract in Support of EMI-Immune Aircraft Program," EMC News, *Interference Technology's Online Guide to EMC, August 5th 2007.)*

448 EMP could threaten existence of civil society in the US

Over the past seven years, a substantial number of articles have been written by this author and others identifying the threat and importance of intentional electromagnetic interference (IEMI). The major conference for this topical area was the AMEREM Conference in July 2006 in Albuquerque, New Mexico. This is the major conference in the world dealing directly with high power electromagnetic environments, effects, and protection, including IEMI and all types of nuclear EMP.

A second area to be discussed in this article is the work of the Congressional EMP Commission in the United States. As part of their study, they examined the historical record of information including data from high-altitude nuclear tests performed by the United States and the Soviet Union in 1962, and they directed research to evaluate the susceptibility of today's critical architecture. They completed their work in 2004 by describing the HEMP threat to the U.S. infrastructure, and they took up their work again in May 2006 to review the response to their initial report and to encourage those responsible for the critical infrastructure to develop mitigation methods to deal with the threat.

The terminology of the electromagnetic pulse has evolved over the years, but today the generic term for all types of nuclear generated electromagnetic transients is EMP. Of interest here is the EMP caused by a high-altitude burst, generally defined as one occurring at a burst height greater than 30km. At this altitude, the radiation produced by the nuclear burst would not reach the earth's surface, but several types of electromagnetic signals would. Because the burst is at high altitude (in space), this type of EMP is usually referred to as HEMP. The concern is that these high-level electromagnetic fields will create serious problems for computers and other electronic systems on the earth's surface, including the critical infrastructure (power, telecommunications, transportation, finance, water, food, etc.). This is the focus of the EMP Commission in the United States and the IEC subcommittee 77C in Geneva.

While the EMP Commission studied all major aspects of the critical infrastructure, they determined that the power system was the most critical because of its connection to all of the other major infrastructures such as communications, transportation, emergency services, energy distribution, water/food, etc. After considerable study, the commission concluded:

1. HEMP-induced functional collapse of the electrical power grid risks the continuing existence of U.S. civil society.
2. Early-time HEMP transients are likely to exceed the capabilities of protective safety relays.
3. Late-time HEMP could induce currents that create significant damage throughout the grid.
4. The national electrical grid is not designed to withstand near simultaneous functional collapse
5. Procedures do not exist to perform "black start" after and EMP attack as restart would depend on telecom and energy transport, which depend on power.
6. Restoration of the national power grid could take months to years.
7. HEMP-induced destruction of power grid components could substantially delay recovery.

The HEMP threat is one of a few potentially catastrophic threats to the United States.

(Extracted from: "2007 Update on intentional electromagnetic interference (IEMI) and high-altitude electromagnetic pulse (HEMP)," by Dr William A Radasky, Ph.D., P.E., Interference Technology's EMC Directory & Design Guide 2007*, pages 143-148. For the Congressional Report itself, visit http://www.globalsecurity.org/wmd/library/congress/2004_r/04-07-22emp.pdf, http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf, and http://www.fas.org/sgp/crs/natsec/RL32544.pdf)*

449 Explosive material probe and implantable medical devices

An 'In Vitro' study was made of the electromagnetic interactions between a hand-held probe used for detecting explosive materials, and implantable medical devices such as pacemakers. The probe uses a quadrapole nuclear resonance technique, and was tested with fifteen devices from three major manufacturers. Testing has been completed and a number of interactions were found. The severity of the interactions has yet to be determined.

(Adapted from "Wireless EMC in the Medical Industry" by Hank Grant et al., speaking in the "Current EMC Issues in Healthcare" workshop session of the IEEE 2002 International EMC Symposium, Minneapolis, August 19-23 2002.)

450 Wireless phone and medical devices

- Specific recommendations for cellular telephones:
  - Designate locations where they can be used without concern of interference;
  - Prohibit patients and visitors from using cell phones and similar devices within highly-instrumented clinical areas;
  - Consider whether or not cellphones and similar devices should be permitted in general patient care areas;
  - Consider allowing wider use of cell phones and similar devices by clinical staff;
  - Instruct staff to maintain a minimum distance of 1 meter (3 ft) – but preferably greater;
  - Consider cordless phone use.
- Specific recommendations for walkie-talkie and FRS (family radio service) devices:
  - Prohibit use by patients and visitors;
  - Allow use by necessary staff:
  - Do not allow use in 'talk' mode within 6 to 8 meters (20 to 25 ft) of highly instrumented areas;
  - Ensure that staff are aware that walkie-talkie transmissions can penetrate walls, floors, and ceilings, which may affect medical devices in adjacent rooms or floors.

(Adapted from "ECRI's Updated EMC-Healthcare Recommendations & Utility of Ad-Hoc Testing" *by Art Augustine, speaking in the "Current EMC Issues in Healthcare" workshop session of the IEEE 2002 International EMC Symposium, Minneapolis, August 19-23 2002.)*

451 Value of Ad-Hoc EMC testing in hospitals

Ad-Hoc testing is important in healthcare because many older medical devices that are still in use in hospitals were not designed or tested for EMC and even newer medical devices that meet EMC standards can experience electromagnetic interference in use.

For example:

- Wireless PDA interfered with 42% of tested critical care medical devices (Juett, S. "Healthcare EMI war stories/due diligence," AAMI 2001 Conference and Expo, June 2001, https://www.aami.org.)
- Critical function of four of 33 medical devices disrupted by cell phone at 25cm or greater (Morrisey et al., "Characterisation of electromagnetic interference of medical devices in hospital due to cell phones", Health Physics, vol. 82, no. 1, pp. 45-51, Jan 2002.)
- RF wireless LAN interfered with three of 44 medical devices tested (Rice, W.P. "2.4 GHz RF WLAN EMI in medical devices," J. Clkin. Eng., vol 25, no. 5, pp 260-264, Sep/Oct 2000.)

(Adapted from "Status of the Second Edition of the ANSI C.63.18 Ad-Hoc Test Method" by Jeffrey L Silberberg, speaking in the "Current EMC Issues in Healthcare" workshop session of the IEEE 2002 International EMC Symposium, Minneapolis, August 19-23 2002.)

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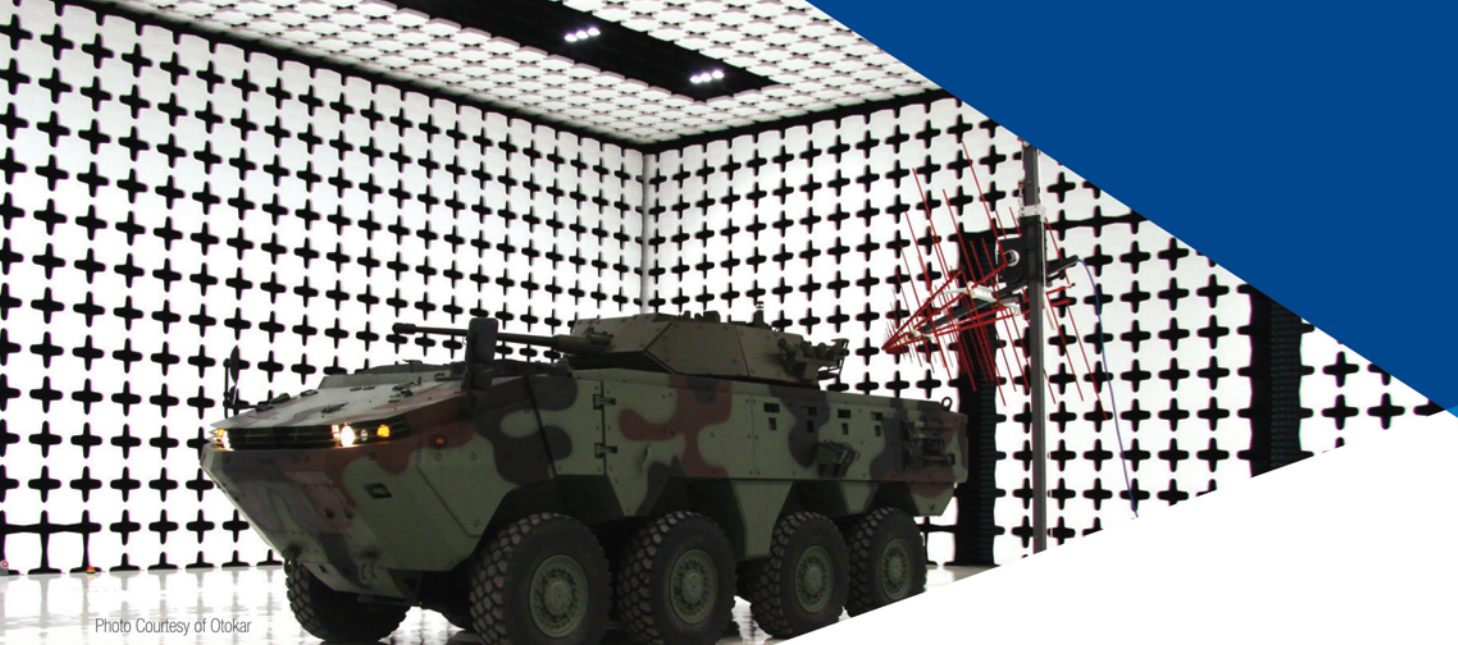

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