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The Effect of Standards on Safety and Product Liability Litigation

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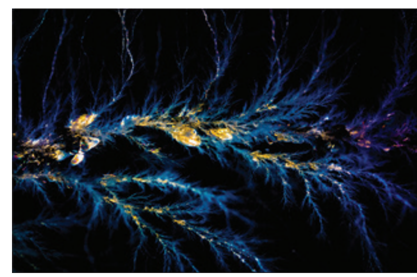
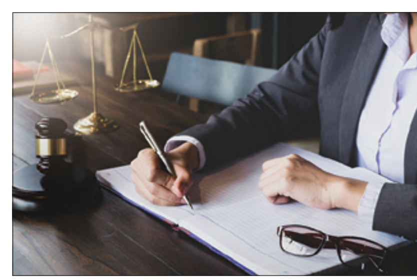




FCC Acts to Speed Access to New Wireless Technologies

The U.S. Federal Communications Commission (FCC) has taken action to facilitate expedited access to new and advanced wireless technologies.

In a Report and Order, the FCC updated the agency's radio frequency device marketing and importation rules to accelerate the release of new wireless devices. Under the revised rules, manufacturers will be allowed limited marketing and pre-sales of wireless devices to consumers as long as the devices are not actually provided to consumers until they achieve full compliance with FCC equipment authorization requirements.

In addition, the revised rules will allow limited pre-authorization importation of radio frequency devices into the U.S. for certain pre-sale activities, such as packaging and shipping to retail locations.

The Commission says that the changes will give product developers more flexibility to engage in crowdfunding and other currently popular forms of project marketing while giving consumers quicker access to new wireless devices.

FDA Issues Guidance on Remanufacturing of Medical Devices

The U.S. Food and Drug Administration (FDA) has released a draft guidance detailing the agency's view of what constitutes a "remanufactured" medical device and to help clarify regulatory requirements applicable to such devices.

The draft guidance, "Remanufacturing and Servicing Medical Devices," defines remanufacturing as "the processing, conditioning, renovating, repackaging, restoring or any other act done to a finished device that significantly changes the finished device's performance or safety specifications, or intended use."

"Servicing," on the other hand, is defined in the draft guidance as "the repair and/or preventative or routine maintenance of one or more parts in a finished device…for the purpose of returning it to the safety and performance specifications established by the original equipment manufacturer (OEM) and to meet its original intended use."

The FDA notes that this distinction is important in determining what regulations apply in evaluating the safety and performance of remanufactured medical devices. In brief, the draft guidance details that "the FDA enforces requirements under the FD&C Act and its implementing regulations on entities engaged in remanufacturing, including but not limited to registration and listing, adverse event reporting, the Quality System (QS) regulation, and marketing submission."

You Can't Make This Stuff Up: Discarded E-Waste Reused in Fashion

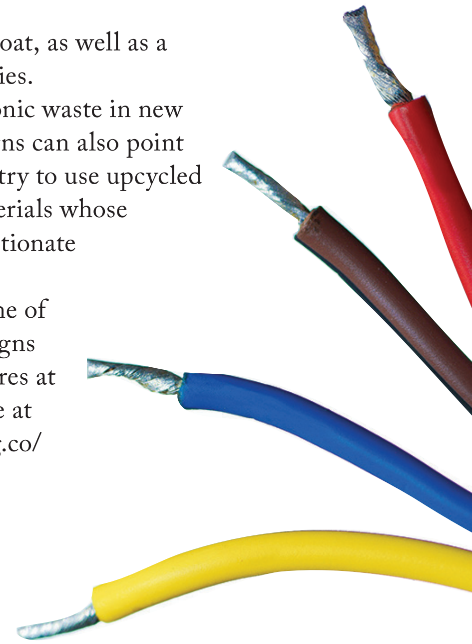
As we look for more ways to reduce electronic waste (E-waste) from electrical and electronic devices and components, a fashion designer in the United Kingdom has reportedly found a way to weave segments of discarded electrical wires into high-fashion dresses and accessories.

According to a posting earlier this year on the Intelligent Living website, the unique lace designs created by Alexandra Sipa, a recent graduate from London's Central Saint Martins University, were inspired in part after her earphone wires broke several times. At one point, she started collecting discarded electrical wiring at construction sites and a local recycling center.

Then, Sipa began using the wires to weave intricate, lace-like materials that reflected traditional techniques from her home country of Romania. She used those materials to create a number of garments, including a dress, a vest, and a ruffled coat, as well as a handbag and several accessories.

In addition to using electronic waste in new ways, Sipa says that her designs can also point the way for the fashion industry to use upcycled waste in place of natural materials whose creation can have a disproportionate impact on the environment.

You can see pictures of some of Sipa's innovative fashion designs using discarded electronic wires at the Intelligent Living website at https://www.intelligentliving.co/discarded-electrical-wires-exquisite-dresses.



Report Says E-Waste Will Decline Due to Pandemic

International researchers have determined that one positive impact of the COVID-19 pandemic last year will be a marked reduction in the future amount of e-waste attributable to electrical and electronic devices.

In a report published earlier this year by the United Nations University (an autonomous entity under the scope of the UN General Assembly) and the UN Institute for Training and Research (UNITAR), researchers estimate that global sales of electronic products actually fell by between 6-8% during the period from January-September 2020.

According to the report, this unprecedented decline in sales will eventually prevent nearly 5 million tons of electronic waste from being generated in future sales-related e-waste, a reduction of more than 6% from the estimated e-waste generated under a "business as usual" scenario.

The report also predicts that, although temporary, the likely reductions in e-waste will have the most positive impact in global regions where e-waste mismanagement contributes to significant environmental and health impacts.

NIST Uses Radio Signals to Detect Hidden Images

Researchers at the U.S. National Institute of Standards and Technology (NIST) have identified a method for using radio signals to detect and image hidden and moving objects.

According to an article published on the NIST website, the NIST method is a variation on radar technologies, in which a transmitter sends an electromagnetic pulse and then uses reflections received to estimate the distance to the reflecting object. However, unlike conventional multisite radar setups which use one transmitter and several receivers to triangulate the location of an object, the NIST method uses multiple transmitters operating at frequencies from 200 megahertz to 10 gigahertz but only one receiver.

NIST researchers believe that their discovery could lead to technologies that could be used to help firefighters and other first responders locate victims inside of burning buildings and identify potential escape routes. The technology could also be used to track missiles, space debris, and other objects moving at hypersonic speed.

FDA Seeks Budget Increase Especially for Medical Device Review

The U.S. Food and Drug Administration (FDA) is seeking an increase of over $550 million in its total proposed budget for fiscal year (FY) 2022, reflecting in part a significant increase in its budget for oversight and administration of its medical device review programs.

According to a posting on the website of Medical Design & Outsourcing, the FDA's total proposed budget of $6.5 billion includes $571 million for the Center for Devices and Radiological Health (CDRH) and over $105 million for the Office of Regulatory Affairs (ORA).

In its budget proposal to Congress, the FDA is also reportedly seeking increased authority to obtain accurate supply chain information on critical medical devices. The agency says that access to this information can help to preemptively address device shortages while also extending the agency's oversight of counterfeit medical devices.

FDA Issues Guidance on Medical Device Safety in MRI Facilities

The U.S. Food and Drug Administration (FDA) has issued its final guidance on assessing the safety of medical devices used in facilities using magnetic resonance imaging (MRI) technologies.

Published in the U.S. Federal Register, the Guidance, entitled "Testing and Labeling Medical Devices for Safety in the Magnetic Resonance (MR) Environment," is intended to cover implanted medical devices, external medical devices such as insulin pumps and oximeters that are fastened to or carried by patients entering a room where MRI scans are conducted, or other medical devices that may be used by healthcare professionals during MRI scans.

In addition to providing recommendations for addressing potential safety hazards associated with medical devices used in the MR environment, the guidance also includes safety labeling information that should be included in device premarket submissions.

DONALD L. SWEENEY

Donald L. Sweeney passed away peacefully surrounded by his family. A native of Clinton, Iowa, and a longtime Glenview, Illinois resident, Don graduated from the University of Illinois in Urbana-Champaign with a degree in Electrical Engineering before embarking on a career of supporting high tech companies, Gates Radio, Collins Radio, AT&T-Teletype, and Extel Corporation before, with his wife Marilyn and son Corey, started his own company, D.L.S. Electronic Systems, today one of the largest independent testing and consulting laboratories in North America.

Don was very active in the American Council of Independent Laboratories as a member of the Conformity Assessment and Product Certification Section. He was a strong supporter and advocate of the Institute of Electrical and Electronic Engineers (IEEE) Electromagnetic Compatibility (EMC) Society, serving the Society in many roles for more than forty years, including the Board of Directors for 18 years, on standards and symposium committees, serving as Angel to several EMC Society chapters, as well as chapter chair of the Chicago EMC Society. Don received the prestigious Laurence G Cumming Award for outstanding contributions to the administration and overall success of the IEEE EMC Society and EMC Education and was an original inductee into the IEEE EMC Society Hall of Fame.

Don was a founding chairman of the U.S. Council of EMC Laboratories (USCEL) and certified by iNARTE as an EMC engineer. He also passed on his expertise by teaching EMI Design at the University of Wisconsin, Oakton Community College, and independently globally for over 35 years. His technical training programs, along with published papers, articles, contributions to the book Controlling Radiated Emissions by Design, and his chapter in the Digital Avionics Handbook Understanding the Role of RTCA DO-160 in the Avionics Certification Process are used and implemented on electronic designs to this day, in military, avionics, radio, wireless and other high-tech applications and products.

Don was an inspiration to his community, serving as Elder at North Branch Bible Church in Glenview, building homes for Habitat for Humanity, playing Santa Claus for Breakthrough Urban Ministries, assisting the homeless, and sponsoring several children for the South Shore Drill Team. Don sponsored regular visits to his testing laboratories for college students, including the Electrical Engineering department of Purdue University. He was a mentor and made his wisdom and experience available to many young engineers. Don and the D.L.S organization hosted a town hall meeting, presided over by congressman Brad Schneider, addressing both technical support of industry, as well as humanitarian concerns.

Don is survived by his wife Marilyn, his son Corey, his brother Richard, and numerous nieces and nephews.

BATTERIES GONE WRONG – ASSESSMENT, MITIGATION, AND EXPECTATIONS

A Review of Options to Improve Lithium Battery Safety Performance

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Russ Gyenes is a Principal Engineer at Energy Assurance LLC specializing in failure analysis and can be reached at russ@energy-assurance.com.

By John C. Copeland and Russ Gyenes

In the world of product safety, it could be said that there are two basic approaches to risk mitigation, proactive and reactive, with proactive being the preferred choice. Most would agree with the adage that "an ounce of prevention is worth a pound of cure," but in truth, this oversimplifies the reality in which product manufacturers operate. As with most things in life, things are rarely black and white but rather a continuous spectrum of shades of gray.

To this, there are many competing aspects in all commercial product ventures. Could you make a product that was fully reliable under all conditions? Perhaps, but the odds are that it would be a commercial failure as it would take an inordinate amount of time to produce and be prohibitively expensive.

In today's market, the traditional characteristics of safety, time to market, quality, cost, reliability, manufacturability, testability, and usability (to name a few) still apply. But these have been further augmented by more modern concerns of environmental impact, sustainability, social responsibility, and others. We mention these not to offer any judgment but only to note that the expectation that a product will perform flawlessly over its lifecycle is a difficult proposition given the myriad of competing needs.

The battery industry is no different when it comes to satisfying market requirements. With batteries having become ubiquitous in our daily lives as the world has migrated to all things becoming portable, the challenge for providers of these products has increased. With the advent of high-energy, rechargeable lithium-ion chemistries, battery performance has dramatically increased, but so have the risks.

No longer are battery packs simple devices. In most modern electronic products, they are better characterized as complex components of an integrated system with one key difference – most other components of such systems rarely have the ability to spontaneously overheat and burn (i.e., go to "thermal runaway") with little to no warning, potentially resulting in personal injury, product damage, and the associated legal and market liabilities.

HOW DO WE ASSESS BATTERY SAFETY RISKS?

In focusing on the safety risks, what are the options for risk mitigation in the battery space? Ideally, these begin early in the design phase. Clearly, there is no substitute for a good design using high-quality components. In the world of batteries, safety-critical components such as the cell, safety circuit, and passive protective devices such as fuses, positive temperature coefficient (PTC) devices, and other thermal devices are the initial focus. Mechanical considerations also come into play to help ensure that the cell is accommodated within its specified limits including levels of protection against reasonably foreseeable external use conditions.

To ensure that such efforts are yielding the desired result, testing of both the components and the battery pack assembly is key, covering the aspects of safety as well as long-term reliability and performance. This testing should be initiated early in the product development process so that, if issues are uncovered, there is the time and flexibility to adjust the design, followed by retesting to verify the efficacy of the changes and to ensure that other problems were not inadvertently introduced. As the development process progresses, production samples should be built and evaluated to understand if manufacturing variations can create unanticipated safety risks.

At a minimum, battery packs will be tested to the transportation requirements found in UN 38.3. Testing to one of the 62133-2 series of standards (IEC, EN, UL) is also commonly performed and is required for regulatory approval in many global markets.

In many cases, this design-build-test-adjust process is performed by the component and battery pack manufacturers and is sometimes augmented by external testing laboratory resources. For more complex systems, the end-device manufacturer may also be involved early in the process to ensure system aspects do not negatively impact battery safety.

TESTING BATTERIES FOR REGULATORY APPROVAL

As the design stabilizes, regulatory approval at the battery pack level is usually the next layer of risk mitigation. A key input to this process is the approval of the component cell as it represents the greatest single safety risk. Regulatory testing typically involves small sample sizes and is not meant to serve as a statistically significant sample size to find outliers in a large population but rather is meant to find gross issues such as design or process defects that have escaped detection in the early stages of product development.

Common testing protocols involve a combination of electrical, mechanical, and thermal overstress. Some involve the application of faults to better assess the inherent safety robustness of the battery pack. Other tests attempt to evaluate the product for stresses that might be common to a specific industry or use case. At a minimum, battery packs will be tested to the transportation requirements found in UN 38.3. Testing to one of the 62133-2 series of standards (IEC, EN, UL) is also commonly performed and is required for regulatory approval in many global markets.

Testing to such standards is usually conducted by accredited third-party testing laboratories with the end result being the authorized application of the testing lab's mark to the product. This approval facilitates regulatory acceptance by government authorities and may also be a prerequisite for commercial entities such as retailers and distributors to offer the product for sale. Some approvals also require periodic post-market inspection of production facilities to ensure the design is still being manufactured as originally qualified. Infrequently, a testing laboratory or regulatory agency may mandate retesting when significant changes to the relevant test standards are implemented.

THE CHALLENGES OF BATTERIES AS END-PRODUCT COMPONENTS

The discussion up to this point is intended as background for what is typically done in a normal battery pack product development cycle. The level to which these actions are implemented directly correlates to a base level of risk mitigation for safety events once the product is released into the market. This does not mean that there are any guarantees that there won't be field problems, but the level of exposure is certainly reduced as more product safety information is proactively discerned and addressed.

What if the battery pack is simply a purchased component and the purchaser was not involved in the design process and may not even have any visibility into the production of the battery pack? Similarly, what if the purchaser is procuring an end device that has an embedded battery pack? These are both very common situations for retailers and distributors who typically have very limited internal engineering resources.

Certainly, buying such products from reputable sources and checking for the presence of the requisite safety marks is a good start, but is it sufficient? Modern supply chains are global. Therefore, discerning where a product was manufactured and by whom can be a challenge in itself. This means that regardless of the actual manufacturer's liability, a retailer's or distributor's brand can be put in jeopardy by a single video posted on social media that quickly goes viral. How can product risk be mitigated in this situation?

The general answer is to work backward beginning with production samples. A product teardown of new product samples by a knowledgeable third party can aid in assessing what risks exist with purchased products where the detailed design knowledge is not available. Although every product is different, an evaluation of a product from a portable energy safety perspective might include such items as:

- Verification of any regulatory marks on the product. Was the testing actually done and is the regulatory status current?
- Evaluation of insulating methods including their integrity and consistency
- Evaluation of conductor sizing
- Review of manufacturing quality indicators that might equate to latent defects
- Review of the safety circuit or other protective devices for proper operation under abnormal conditions such as over-voltage, over-current, short-circuit, and under-voltage
- Review of the charging circuit design. Does it subject the battery or cell to improper conditions?
- Determination of the cell manufacturer and type. This also includes an assessment of whether the cell might be counterfeit
- Cell examination (radiographs and/or CT scans), teardown, and construction analysis
- Review of the mechanical design of the product in terms of its ability to protect the safety-critical components
- End-user instructions and safety warnings

WHAT ABOUT BATTERY PERFORMANCE ISSUES?

In addition to a review of safety concerns, performance relative to competing market options should be evaluated through benchmarking. This is typically done in parallel with the safety review and is focused on how a user is expected to employ the product in expected use cases. Competing samples are drawn from the market ensuring that they are of the same price tier to ensure that the comparisons are valid. A custom evaluation plan is drafted and might involve visual inspections, functional checks, and even comparisons of long-term electrical or mechanical reliability.

Many times, the criteria are drawn from marketing assertions as shown on the products' packaging. Examples might include the number of hours that the device will operate in a given mode before needing to be recharged and how long that recharge might take. The evaluation can also go much further, perhaps considering the relative drop performance from a given height or the number of charge-discharge cycles before a loss of function is detected.

As a general rule, safety concerns tend towards the absolute given the nature of such risks to people and property. Conversely, performance concerns lend themselves towards a more relative evaluation against other competing market options.

ANTICIPATING THERMAL RUNAWAY RISKS

Given the above processes for minimizing risks through proper design or post-production design evaluations, are there other proactive risk mitigation actions that warrant consideration from a product safety perspective? Consider this – even if all of the above steps are followed with the best of intentions, what happens if things still go wrong? More specifically, what

Figure 1: Thermal runaway containment chamber

is the effect to the end product and nearby users if a cell goes into thermal runaway when the device is in use? Second, what happens if a cell goes into thermal runaway during the transportation and shipping process? Most designers can only guess as definitively knowing what happens is rarely directly investigated.

To answer these questions, there are two general methodologies. Simulation is an option but requires very advanced electrochemical and thermal modeling. Our experience is that this tends to be cost-prohibitive for most organizations and thus is only seen in relatively large companies where such expertise is available in-house. What about direct testing? Like simulation, it has barriers for implementation as well, the most obvious being concerns related to personnel safety and expertise, as well as having the appropriate facilities to provide the proper test containment of high-energy events while being able to document their effects.

With the right facilities and expertise available, a determination must be made about how to force the cell or battery into thermal runaway. Overcharging and surface heating are two common methods, although the design of the product and the chemistry of the cells will guide what method is most appropriate. Other considerations for such testing involve what data is to be collected and how. Video evidence is considered by most clients to be the most useful. It should be further supported by appropriate logging of relevant temperatures and possibly other product parameters, as well as forensic documentation of the actual effects to the end-product.

Figure 2: Lithium cell metal can fragment after thermal runaway

Designing and testing cells and batteries properly from a safety perspective, including understanding the impacts should a thermal runaway event occur, are the best risk mitigation tools that we have at our disposal.

Once again, the goal is to use the information obtained to determine if design improvement should be made to minimize the chances of personal injury or property damage during a thermal runaway event.

Although the above is presented in a relatively clinical fashion, the danger of injury and property damage is very real. Depending on the energy level of the particular sample, an exploding cell can produce temperatures above 1200 °C (2192 °F) and deadly shrapnel particularly in the case of large-format cells with metal cans. Readers are strongly cautioned to not attempt such testing without the proper expertise and containment equipment.

THE IMPORTANCE OF FAILURE ANALYSIS

Designing and testing cells and batteries properly from a safety perspective, including understanding the impacts should a thermal runaway event occur, are the best risk mitigation tools that we have at our disposal. Even with those best proactive efforts, things will still go wrong. The real question is how often. True failure rates for cells and batteries are not publicly available as companies keep such information confidential. But anecdotally, high-quality lithium-ion cells have a rough order of magnitude (ROM) failure rate somewhere around 1 in 10 million, while lesser quality cells are likely to have poorer field performance. With over eight billion cells being produced globally every year, the math is inescapable that bad things will happen.

These factors make clear the importance of using retrospective methods to gain insights into what happened, how it happened, and why it happened. These methods collectively fall under the heading of lithium battery failure analysis.

Failures in the field can happen at any point in the battery's life cycle and can vary significantly in severity and frequency. Responses to such issues also vary accordingly, ranging from simply replacing a product under warranty to retrieval of the product for a full forensic evaluation. For minor issues, it may be determined that a product change is not warranted. Conversely, safety issues may mandate a full product recall and rework of the design. In the end, failure analysis actions provide after-the-fact knowledge for organizations from which to make decisions that will impact future risk.

THE VALUE OF THIRD-PARTY EXPERTISE

Like thermal runaway testing, cell and battery failure analysis involves expertise, processes, and tools that may not be readily available to most organizations. Because of the uniqueness and the infrequency of need, expertise tends to be primarily resident in third-party test labs that specialize in portable energy. Conducting cell and battery failure analysis through an expert third party offers a number of benefits, including:

- *Reduction of personal bias:* A third-party test lab has no vested interest in the outcome of the analysis, nor do they have intimate knowledge of the product or company's history.
- *Independent verification:* A third-party lab can help to independently verify the findings of an internal team or a supplier.
- *Resource utilization:* As noted previously, field safety events are generally an infrequent occurrence. Having an internal team staffed with the proper expertise and equipment to respond to such a rare event is generally not possible or even desirable.
- *Diligence:* In the most severe of cases such as potential product recalls, it may be valuable for the company to have an independent party involved to minimize negative perceptions regarding objectivity.
- *Focus:* Having failure analysis conducted by an external party may permit the company's internal

teams to remain focused on the day-to-day operations of their mainline business.

- *Process rigor:* An external testing lab will have already developed the processes and methods for orderly evaluation and documentation of field failures, with specific expertise in evidence preservation.
- *Breadth of experience:* Because of their focus on failure analysis spread across multiple clients over time, a third-party testing lab will generally have a wider range of technical experience when it comes to what constitutes typical versus atypical findings.

WORKING WITH A THIRD-PARTY EXPERT

When working with a third-party failure analysis provider, you will be asked to provide more than the failed unit to facilitate the investigation. It is important to be as open and honest as possible. Your provider should be accustomed to handling confidential materials and should be willing to work under a non-disclosure agreement (NDA) to protect all proprietary information.

In terms of the supplemental information, basic product information is the starting point. This might include specifications and similar documents to support the work along with any relevant details regarding product history. These will not be used to prematurely assume conclusions, but rather to supplement the physical evidence and help prioritize the investigatory efforts.

Information on the specific unit along with incident details are also very important to piecing together what happened. How was the unit configured? Was it operating in a particular mode? Did the unit demonstrate anything unusual prior to the event? It is best to provide all of the information that is available and let the failure analysis team draw their own conclusions regarding relevance. It is important to realize that as the investigation moves forward, the relevance of such information may change as more information is learned.

The actual failed units will need to be delivered to the laboratory. In this situation, more is better. It is possible that there may be multiple failure modes at play and having additional samples may help to isolate these. It is also important to preserve the evidence as much as possible by limiting unnecessary handling, examining, or actual tampering which might further damage the unit and lead to erroneous findings.

Proper packaging is a must. It is best if all components of the reported system can be provided, i.e., the failed cell or battery, the end-device if applicable, charging devices and cables, etc., as it is possible that the root cause of the failure may have been external to the cell or battery that failed. Samples should be marked or segregated so that it is clear which components go together. In addition to the failed systems, it is also good if a fully functional new system can be provided for purposes of comparison.

What should you expect from your third-party expert? Every investigation is unique, and your provider should work with you to generate a project scope that meets your needs, and they should limit their efforts to that scope. Considerations include specific concerns, communication frequency, deliverables, and budget.

Be aware that the actual work of failure analysis involves a mix of analytical tools such as fault tree analysis (FTA) combined with empirical methods such as x-ray imaging, CT scanning, optical microscopy, product dissection (battery pack and cell teardowns), quantitative measurement, circuit testing, and replication testing. Not every tool is appropriate for every situation. Your provider will provide guidance on these technical aspects. In the end, your provider should provide your team a clear, unbiased analysis report that details the investigation and its associated findings.

What should you not expect from your provider? First, don't expect speculation. This is a "just the facts" activity. If the evidence doesn't support it, your provider shouldn't be offering it up. Second, keep in mind that not every investigation yields the root cause or even the true failure mode. Depending upon the condition of the evidence and nature of the

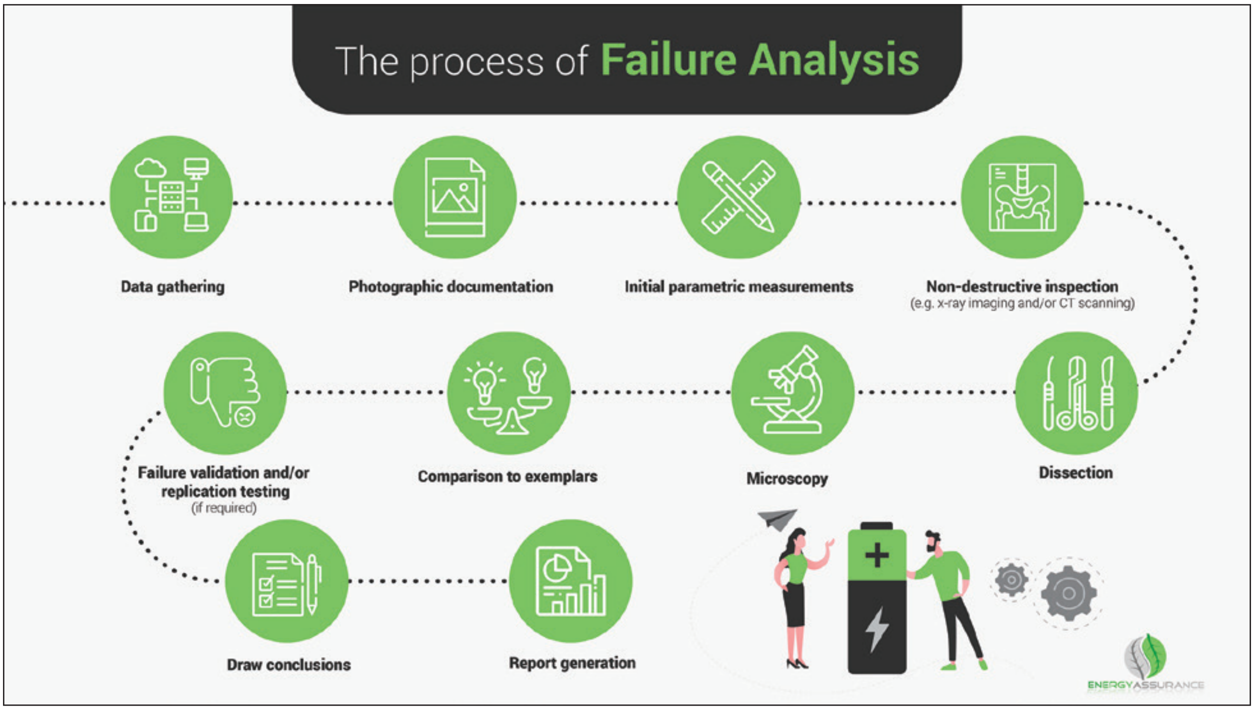


Figure 3: An overview of the lithium cell failure analysis process

incident, it simply may not be feasible to reach this level of understanding. Conversely, the efforts may seek to eliminate likely root causes thus narrowing the possibilities.

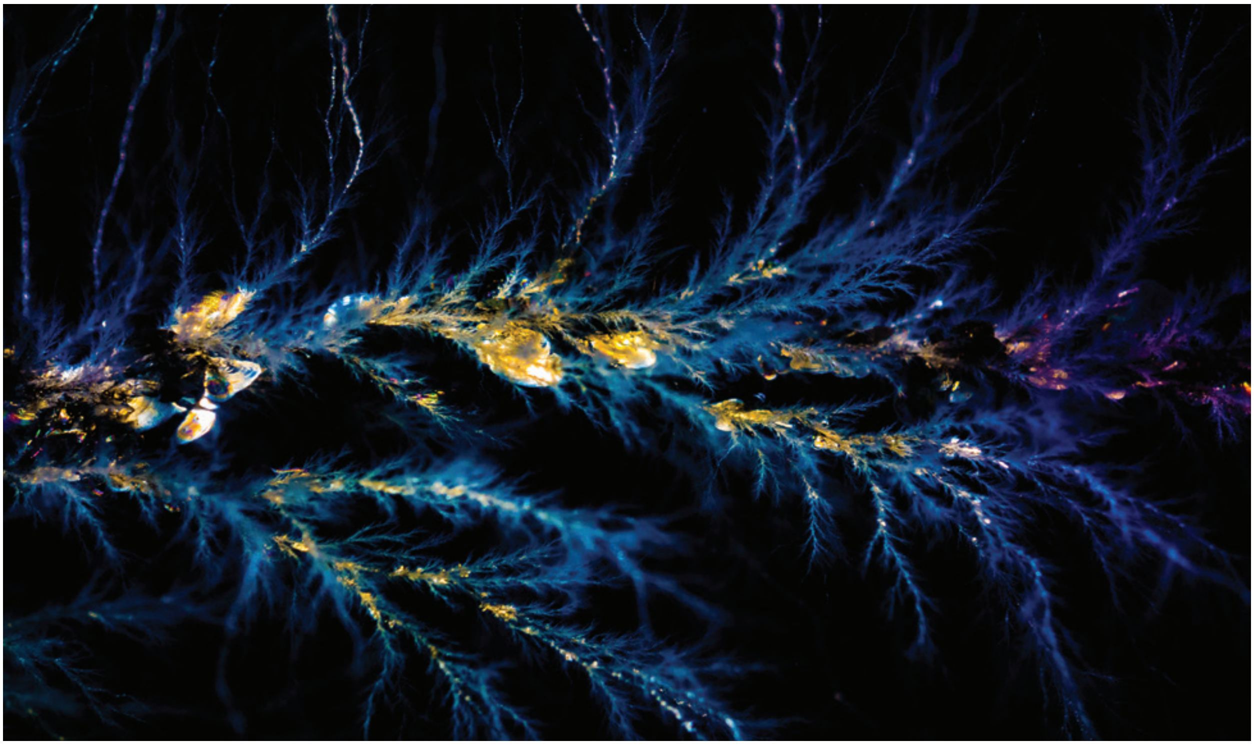
Third, don't expect your provider to tell you if this issue will repeat in the future. A risk analysis to predict the likelihood of future failures requires a different set of information, although data from the failure analysis investigation may serve as key inputs into that analysis. Finally, don't expect your provider to tell you what actions to take, although the root cause data from your provider may serve as a basis for your team to make those decisions.

FINAL THOUGHTS

In conclusion, there is a wide array of proactive and reactive steps that can be taken to minimize and mitigate product risks associated with modern lithium-ion cells and battery packs. On the front end, these include the proper design for safety, use of high-quality cells and components, thorough testing from the component to the system level to include thermal runaway evaluations, and third-party certifications where appropriate.

When problems do occur in the field, consider the engagement of a reputable third-party failure analysis organization that specializes in cells and batteries. Their team of experts can help to assess what happened, how it happened, and possibly even why the incident occurred. In turn, your organization can use this information to objectively determine appropriate responses, both immediate and longer-term, to mitigate risk to your customers, your product, and your brand.

ELECTRICAL FIRE PATTERNS IN VEGETATION



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INTRODUCTION

Depending on the technical discipline, patterns created by the flow of electrical current have been referred to as dendrites, water trees, or fern patterns—the general term is Lichtenberg figures [1]. The terms dendrite and water tree are generally applied to dielectric failures [2], while the term fern patterns have been applied to patterns sometimes formed in epidermis from a lightning strike. The term fulgurite [3] refers to patterns of fused silica formed from a lightning strike to a soil or sand surface.

Dielectric breakdown of the ethylene propylene rubber (EPR) insulation of electrical power transmission cables has been variously described in the literature as water trees and dendrites. The pattern of formation was first realistically modeled in 1984 and referred to as the dielectric breakdown model [5]. Dendrite patterns can form in circuit assemblies by the stress of an electric field [2] and in electrical insulators (dielectrics) from electric field stresses [5].

Apparently undocumented in the literature (modern art notwithstanding) is that the flow of electric current can

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By Louis F. Bilancia

cause Lichtenberg figures in plants (Figure 1). However, branching patterns can also be formed by plant disease. The distinction between organically formed patterns in plants and electrical patterns is that the electrical patterns are formed by pyrolytic [6] alteration of the cellulosic substrates (vegetation) through heat generated by the flow of electrical current.

Physicist Georg Christoph Lichtenberg first recorded the patterns in his journals after observing patterns formed in red phosphorous and sulfur dust on flat surfaces in 1777. These are variously described in the literature as Lichtenberg figures.

On occasion, persons struck by lightning develop fern-like patterns on their skin [7]. Such patterns do not always form and the mechanisms that govern their formation are not understood. Sometimes the patterns fade away and sometimes they are permanent (Figure 2).

DEER CREEK FIRE

Deer Creek Fire Investigation

On August 25, 2005, a wildland fire broke out in the Deer Creek area east of Selma in Josephine County, Oregon. Investigation revealed that the fire was caused by a livestock fence energized by an electric fence controller.

Figure 1: Example of Lichtenberg figures on 3mm diameter wild mustard stem

The area of origin was identified by fire investigators Mr. Chuck Miller and Mr. Carl Roberts, and they identified the area of origin as a place where blackberry stalks had not been adequately trimmed to clear the electrically charged fence wires (Figure 3 on page 22). The blackberry and wild mustard plant stalks were collected by the investigators. The immediate significance of Lichtenberg figures observed on the surface of the plant stems was not fully recognized and prompted laboratory inspection. Laboratory testing demonstrated that the application of electrical energy from exemplar fence chargers was able to duplicate these patterns and that temperatures were hot enough to cause ignition of dried vegetation.

The Deer Creek Fire Cause

The electric fence controller was a Sentry 2000 Weed Cutter, model number 10-9-110, serial number 44601. Date codes indicated that it was manufactured about September of 1975, and no UL, CSA, or other National Recognized Testing Laboratory (NRTL) marks were found.

Figure 2: Example of Lichtenberg figures resulting from being struck by lightning

The Sentry 2000 fence controller functioned via a step-up transformer that converted the 120-volt 60-Hz line power to approximately 2200 volts AC (Figure 4). A circuit timer caused the output voltage to alternate between approximately 2200 volts AC (approximately 1.36 to 1.52 seconds) and 700 volts AC (approximately 0.72 to 1.04 seconds.). The power output of the Sentry 2000 was measured to be approximately 12 watts with a 100 kilohm load, and the maximum current was 60 milliamperes with a 1 ohm load.

After measuring the output, the incident Sentry fence controller was not used for further testing. A functional exemplar device was located—it was a BullDozer WD-56A, serial number 77678. The unit had the date code "8 87," indicating it had been manufactured in August 1987, and no UL, CSA, or NRTL marks were found. The electrical output alternated between 1498 volts AC and 900 volts AC with no load (Figure 5).

Figure 3: Vertical view of the area of origin—photograph courtesy of Oregon Department of Forestry

Livestock touching an energized fence wire receives an electrical shock, which is meant to deter them from breaking through the fence. Vegetation contacting the fence also produces a path to the ground. In late summer, the vegetation dries out and poses a potential fire hazard if ignited.

A portion of the fence perimeter used woven plastic with embedded stainless-steel wires (note the melted white plastic of the electrified fence wire circled in Figure 3 and a close-up in Figure 8). Laboratory testing of exemplar plastic fence material indicated that it was high-density polyethylene with a melting temperature of approximately 125 degrees C (257 degrees F). Once ignited, the sample burned readily with self-sustained combustion producing flaming drips.

Figure 4: Sentry 2000 Electric Fence Controller

Figure 5: BullDozer single strand wire and potted blackberry test setup—also shown are a high voltage probe, a camcorder, and a thermal imaging camera

Both the wild mustard stalks (Figure 6), the blackberry stalks (Figure 7), and the test blackberry stalk (Figure 8) showed Lichtenberg figures characteristic of electrical currents flowing through or over the plant.

Deer Creek Exemplar Testing

The BullDozer fence controller test setup is shown in Figure 5. The controller was connected to a live potted blackberry stalk by two steel electrodes. The electrodes were spaced approximately 12.7 cm (5 inches) apart. Smoking, scintillation, smoldering, and pyrolysis of the blackberry stalk were observed within 30 seconds of energized output from the fence controller. After about 30 minutes of operation, horizontal bands of deep pyrolysis adjacent to the electrodes, surface discoloration, and fine electrical arc pyrolyzed tracks were observed. These marks matched those found on both the incident blackberry and wild mustard plants. The formation of additional electrical arc tracking and Lichtenberg figures continued to develop for the duration of the test (Figure 9). One thermographic image revealed a spot temperature of approximately 300 ˚F at the electrode with the controller connected between the electrode and the soil.

Additional testing with the electrodes approximately 12.5 cm apart was conducted and thermographic images showing the temperature profile and spot temperature were recorded (Figure 9). Scintillation, arcing, subsurface heating, and arc track Lichtenberg figures were substantially similar in both electrode tests. Use of the "night shot" mode on the camcorder revealed broader areas of heating below the epidermis of the plant stalk. The spot temperature of the hot electrode was observed to reach over 391 ˚F. Use of the "night shot" mode on the camcorder revealed broader areas of heating below the surface of the plant stalk.

The visible physical dimensions of the electrical scintillation were below the resolution and sample rate of the thermal camera; however, the color of the incandescent material indicated temperatures of at least 1,000 ˚F.

BURNT PEAK FIRE

Burnt Peak Fire Investigation

A wildland fire occurred on July 29, 2009 in the Burnt Peak area just north of Lost Creek Lake in Jackson County, Oregon. Fire investigators placed the origin of the fire along the path of a high-voltage

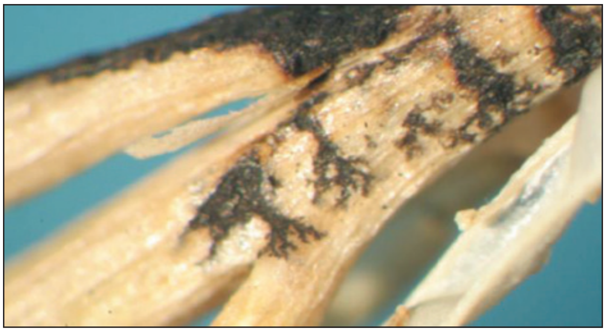

Figure 6: Lichtenberg figures in the incident wild mustard stalk

Figure 7: Lichtenberg figures in incident blackberry stalk

Figure 8: Blackberry testing showing the formation of Lichtenberg figures—note the figures form on both sides of the electrode

power transmission line at the base of an 80-foot-tall Douglas fir tree. A laser-scan survey verified the spacing between the treetop and the transmission line ere close enough to have made contact (Figure 10). The tree had grown tall enough that lateral sway in both the wires and in the tree itself had caused the power transmission lines to intermittently contact the top of the tree. The National Electric Safety Code (NESC), Article 281[8], requires vegetation clearing along the path of power transmission lines to prevent such contact; however, the required lateral clearance as measured on the ground did not take into account seasonal growth in the tree and lateral sway (Figure 11).

The tree was harvested, cut into sections, and stored for later examination. Examination of the most

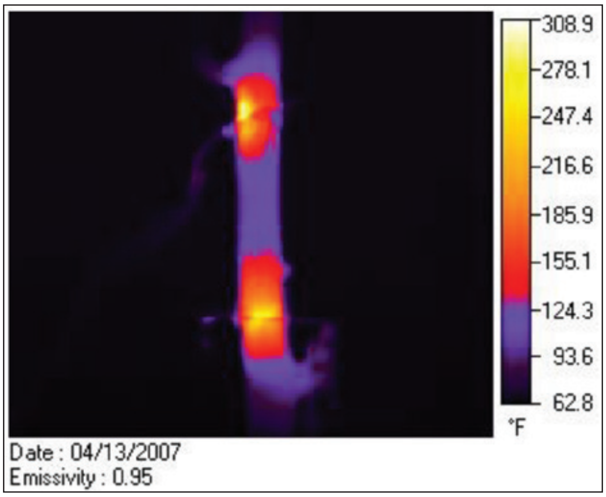

Figure 9: Micron thermograph of the BullDozer blackberry test

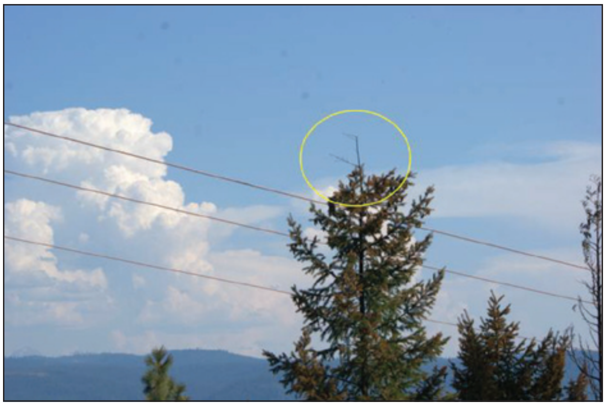

Figure 10: Incident Douglas fir (note the burned tree tip)—photograph courtesy Oregon Department of Forestry

recent three years of growth at the tip of the tree showed alligator burn patterns and, more subtly, Lichtenberg patterns (Figure 12). The cause of the fire was confirmed to be due to smoldering brands falling from the tree where it had come into contact with the transmission line.

BLAND MOUNTAIN FIRE

Bland Mountain Fire Investigation

On August 20, 2004, a wildland fire occurred in the vicinity of Bland Mountain in Douglas County, Oregon. Fire investigators placed the origin of the fire adjacent to a fence electrically energized by a Dyna-Charge Model 900 electric fence charger. The fire started on an open west-facing slope at approximately 4:50 pm. The Dyna-Charge fence controller was listed as being in compliance with UL 69.

The conditions at the Bland Mountain lookout were 79 °F and 45% RH (relative humidity) with a 1–3 mile per hour (0.45–1.30 m/s) southeasterly breeze.

The key feature offered by this kind of fence charger is the notion that the short duration of the pulses makes

Figure 11: Reconstructed section of the treetop—each tag indicates a year of growth: 2009 on the left, 2006 on the right

Figure 12: Incident Douglas fir tree trunk showing a Lichtenberg figure—the trunk was approximately 2 inches at this location, and the black marks at the top of the image is a scale in 16ths of an inch.

ignition unlikely. Nature, however, proved to be more variable and presented conditions that eventually did lead to ignition.

The Dyna-Charge fence controller was UL listed as being in compliance with UL 69. In conversation with a UL representative, I was reminded that testing to a standard does not confer any assurance that the test conditions replicate real-world conditions.

Bland Mountain Dyna-Charge/Zareba Testing - Overview

An exemplar for the Dyna-Charge 900 was identified as a Zareba A100 LI fence controller. Zareba appears to have acquired the Dyna-Charge design (Figure 13). The incident unit was energized to confirm proper operation, and further testing was performed using the exemplar Zareba unit. Initial testing was in accordance with UL 69. The purpose of the tests was to determine whether the Zareba could ignite dried vegetation under laboratory conditions. The Zareba was rated to provide six (6) joule pulses suitable for energizing 100 miles of fencing. The unipolar pulses were approximately 13 kV in amplitude and approximately 120 µs in duration. Current pulses under some loads reached approximately 23 amperes.

Bland Mountain Dyna-Charge/Zareba Testing - UL 69 Test Procedure

While UL 69, Standard for Electric Fence Controllers, governs the testing and compliance certification of electric fence chargers, such testing standards cannot anticipate all possible field conditions that might cause ignition. The standard provides for testing the propensity for discharge-caused ignition; however, it primarily deals with the electrical safety and fire hazard posed by the equipment itself, and not as might be caused by the discharges along the fence line.

The basic procedure is to prepare a block (or dowel) of wood by first desiccating and then soaking it in a saline solution of prescribed concentration (Figure 14).

Figure 13: Dyna-Charge/Zareba fence controller

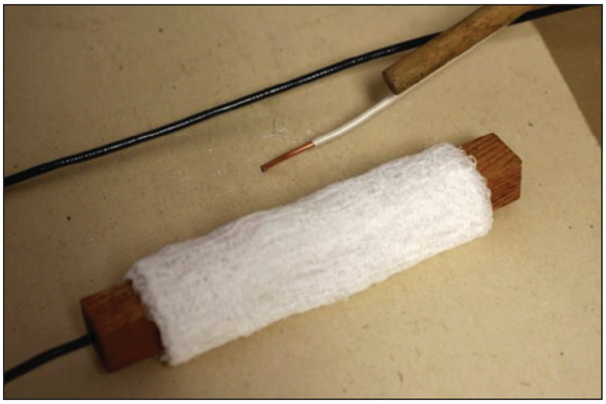

Figure 14: UL 69 Test block

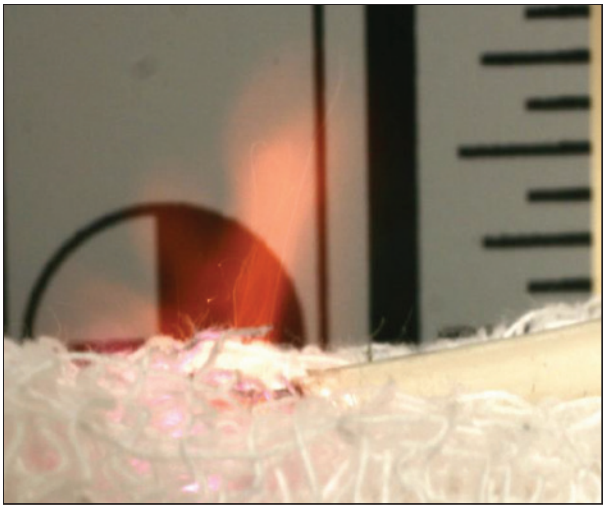

Figure 15: Hot gas plume and embers ejected from the UL test fixture in an extended time test, and the scale marks are 1/16 inch (approx. 1.58 mm)

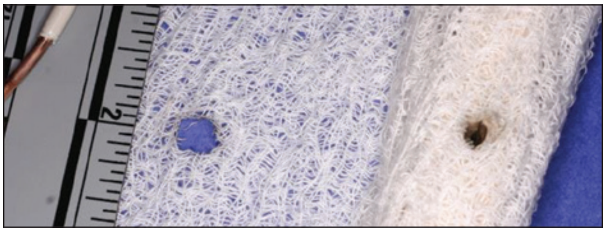

Figure 16: Extended UL 69 test showing singed cheesecloth

The block is again dried and wrapped in cheesecloth. One of the electrode wires is inserted into a hole drilled in the block, while the other wire rests on the outside of the cheesecloth. Testing continues for 15 minutes; if no ignition or charring of the cheesecloth occurs, then the device passes the test.

UL 69 Test Results

The Zareba A100 LI easily passed the requirements of UL 69 sections 22 and 32. However, when the bench test was extended in duration, the pulse discharges eventually penetrated the wooden block. Each subsequent pulse ejected an incandescent plume with microscopic brands (incandescent embers (Figure 15). Given a suitable first fuel, such as cottonwood fluff, or the fortuitous delivery of a brand into a clump of dry grass, this could result in ignition.

The UL 69 standard does not guarantee that the device cannot, or will not, cause fire under all field conditions. A pulse every 1.25 seconds, day in and day out, will amount to over a million pulses in 14 days. Each six-joule pulse poses an opportunity for the pulse to ignite an errant piece of vegetation or cottonwood seed fluff.

The testing was allowed to continue, and after about 15 minutes, the charger pulses burned a hole in the side of the wooden test block (Figure 16). Incandescent ejecta was observed. Even though the ejecta charred the cheesecloth test material, they did not cause ignition under laboratory conditions.

PARTING OBSERVATIONS

It would be too easy if all electrical currents through live vegetation formed Lichtenberg figures. The AC power from the transmission lines and the neon-sign high-voltage fence controllers can form Lichtenberg figures but do not always do so. The 13 kV pulses from the Zareba controller did not produce Lichtenberg figures but instead produced potentially incendive plumes that erode plant material without leaving Lichtenberg figures.

While researching the early stages of ignition associated with electric arcs, Dr. Thomas Pratt mentions in his book, *Electrostatic Ignition,* that arc has multiple factors to be considered, including inductance. In conversation with engineers at Zareba (2007), inductance was not part of their fence model, nor was it part of the UL 69 standard. The series inductance of the fence wire for the Bland Mountain fire was measured to be 1 mHenry.

Also, while researching how brands, embers, or smoldering ignition (initiated by electrical current) could transition to open flame, clues were found in two sources: Jack Sanderson's Fire Findings [9] and Dr. Babrauskas' *Ignition Handbook* [10]. Sanderson reported trying to replicate the conditions for smoldering ignition of denim on a chair cushion, and, out of 500 trials, none of them transitioned to open flame. He reported that with the addition of a ceiling fan producing a nominal 2.1 mile per hour (approximately 0.94 m/s) breeze, ignition occurred "fairly dependably." Dr. Babrauskas mentions that transition from smoldering to open flame happened most frequently with a 2 to 3 mile per hour breeze in wildland fires. And, as mentioned earlier, brands are incandescent embers that can be lofted by a breeze or can fall to the ground and act as an ignition source. They are particularly incendive.

The Deer Creek fire was on a south-facing grassy slope in late summer, and the Burnt Peak fire also occurred on a slope. It is likely that an up-slope breeze helped these fires transition from smoldering to open flame.

In wildland fires, seasonal vegetation (such as cottonwood fluff), ambient humidity, and vegetation moisture content are significant variables. A means to directly assess moisture content should be employed—that is, the vegetation samples can be weighed on-site before being bagged, and similarly, exemplar vegetation of comparable dimension and quantity could also be weighed before being bagged.

SUMMARY

Electrical currents form Lichtenberg figures visible in the epidermis of several very structurally different plants, including trees (Douglas Fir), Himalayan Blackberry, and wild mustard.

Lichtenberg figures form in plants by resistance heating due to the flow of electrical current. Pyrolytically formed Lichtenberg figures can be, and normally are, obliterated by subsequent combustion of the base material.

Patterns of initial similar appearance may form due to botanical diseases; however, electrically formed patterns show material loss. Identification may require microscopic examination.

Temperatures created by the flow of current from the tested electric fence controllers were sufficient to cause ignition. While the probability of ignition may be low under some conditions, the continuous long-term persistence of an ignition source plus the continuous variation in the environmental conditions provided multiple repeated opportunities for ignition.

An investigator should anticipate collection of incident equipment, vegetation, wiring, and exemplar equipment and should also take weather measurements and moisture content of potential first ignited fuels.

Laboratory tests showed that even the UL 69 test caused the ejection of incandescent embers during discharges from some fence charger models (like the Zareba).

Pulsed fence chargers caused discoloration of the blackberry stalks but did not create Lichtenberg figures.

Manufacturers may need to test their products beyond the letter of the UL standards to accurately determine product safety, as UL test standards are minimum requirement standards.

When testing the mutual competency of an ignition source and potential first-fuels-ignited, ambient humidity and the test fuel moisture content must be adequately understood and controlled.

ACKNOWLEDGMENT

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THE EFFECT OF STANDARDS ON SAFETY AND PRODUCT LIABILITY LITIGATION

Using Standards to Defend the Product

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By Kenneth Ross

Product liability has created problems for manufacturers and product sellers for many decades. These problems have been exacerbated by the expansion of product liability laws throughout the world. In addition, there has been a proliferation of safety regulatory requirements, starting in the United States (U.S.) and then moving to the European Union. In addition, countries such as Japan, China, Australia, Canada, Brazil, and South Africa have all recently established or strengthened their product safety regulatory regimes and requirements.

This all creates additional challenges for manufacturers who want to comply with all laws, regulations, and standards in any country where they sell their products. Such companies may also need to consider safety requirements in countries where they do not sell products if they believe that these requirements establish a floor for safety that they want to meet.

This article will discuss the basic kinds of defects that can be alleged in any product liability case, the law as it pertains to compliance with standards, and some tips on how to deal with the issue of standards compliance.

U.S. THEORIES OF LIABILITY

Manufacturing Defects

A manufacturing defect exists if the product "departs from its intended design even though all possible care was exercised in the preparation and marketing of the product." In other words, even if the manufacturer's quality control was the best in the world, if the product or any of its components departed from its intended design, it most likely had a manufacturing defect. The plaintiff need not prove that the manufacturer was negligent, just that the product was defective and that the defect caused harm. The focus is on the product, not on the conduct of the manufacturer.

Common examples of manufacturing defects are products that are physically flawed, damaged, or incorrectly assembled, or that do not comply with the manufacturer's design specifications. The product turned out differently from that intended by the manufacturer. If that difference caused injury, the manufacturer is likely to be held liable and there are very few defenses.

Design Defects

A product is defective in design if a foreseeable risk of harm posed by the product or a component "could have been reduced or avoided by the adoption of a reasonable alternative design" and the failure to use this alternative design makes the product not reasonably safe. An alternative definition used by some courts is that a product is defective in design if it is dangerous to an extent beyond that which would be contemplated by the ordinary consumer.

These tests are much more subjective than the test for manufacturing defects and this subjectivity is the cause of many of the problems in product liability today. Manufacturers cannot easily determine how safe is safe enough and cannot predict how a jury will judge whether they were reasonable or whether they should have made a safer product.

Warnings and Instructions

The third main kind of defect involves inadequacies in warnings and instructions. The definition is similar to that of design defects and says that there is a defect if foreseeable risks of harm posed by the product or component "could have been reduced or avoided by… reasonable instructions or warnings" and this omission makes the product not reasonably safe.

There are two kinds of design defect cases, those involving "inadvertent design errors," and others involving "conscious design choices."

Again, this is a subjective test that makes it difficult for a manufacturer to know how far to go to warn and instruct about safety hazards that remain in the product.

LAW OF DESIGN DEFECTS

There are two kinds of design defect cases, those involving "inadvertent design errors," and others involving "conscious design choices." Design errors are like manufacturing flaws and are easily treated by the courts. The design was wrong because someone made a mistake. The mistake created a hazard, and someone was hurt. In that case, there is virtually no defense, and the manufacturer would usually settle the case.

The more important type of design defect involves conscious design choices. In these cases, the design turned out as intended by the designer and manufacturer. It had the level of safety expected by the designer for the intended use. However, the product still hurt someone who claims that the product should have been made safer. The plaintiff argues that an alternative safer design should have been used and the court must decide whether this alternative was preferable.

The development of the law in this area has caused confusion. There are several tests that have been developed for helping courts and juries decide whether there was a defective design.

Testing for Design Defect

As previously mentioned, the predominant test in the United States for determining whether a product was "reasonably safe" involves whether there was a reasonable alternative design available. In many states, to answer this question, the jury is instructed to consider the following factors:

- Usefulness and desirability of the product
- Safety of the product, that is, the likelihood that it will cause injury and the probable seriousness of the injury
- The availability of a substitute product that performed the same function and was safer
- Ability of the manufacturer to eliminate the unsafe characteristic of the product without lessening its usefulness or making it too expensive
- User's ability to avoid harm by being careful when using the product
- User's awareness of the risk, either because it is obvious or because of suitable warnings and instructions
- Feasibility by the manufacturer to spread the risk by way of price increases or purchasing insurance

These factors provide a more comprehensive and understandable basis for a jury to make a decision. They also provide more guidance to the litigants to evaluate their case. And, as importantly, they provide a basis by which a manufacturer can evaluate the safety of its product before sale and decide whether it is "reasonably safe."

Compliance With Laws, Regulations, And Standards

Another way that a manufacturer decides that its product is safe enough is if it complies with laws, regulations, or standards. In fact, many engineers believe that such compliance is sufficient by itself. As will be discussed, some of the time, that is not correct or at least is questionable.

Laws and regulations are always mandatory, and standards can be mandatory or voluntary. As part of the initial analysis, a manufacturer must identify those that apply to its product. Sometimes, that is not easy to determine or there are numerous and conflicting ones that must be reconciled, especially if the product is sold internationally.

Compliance with official laws and regulations that apply to the product's design, such as those passed by a state or federal legislature or standards that have been adopted by a governmental agency, is mandatory. If the product does not comply and this noncompliance caused injury, the manufacturer can be liable. Unfortunately, on the flip side, compliance with all applicable laws, regulations, and mandatory standards is not, for most products, an absolute defense in a product liability case. Therefore, a jury could come back and say a manufacturer should have exceeded laws and regulations pertaining to safety.

Industry standards, which are normally voluntary unless adopted by a governmental agency, including certifications issued by UL, ETL, or others, are considered by the law to be minimum not maximum requirements. As a result, compliance with voluntary standards and certifications is also not an absolute defense although it might be helpful to prove that the product was reasonably safe if this evidence is allowed to be presented to the jury.

As with laws and regulations, noncompliance is a problem if it caused or contributed to the injury. The reason is that the standard establishes a reasonable alternative design, and the manufacturer has to justify why it didn't comply. In addition, the plaintiff can also argue that mere compliance resulted in a defective product and that a manufacturer should have exceeded the standards.

DOES COMPLIANCE EQUAL SAFETY?

An analysis of recalls of consumer products undertaken between 2016 and 2020 showed that the vast majority of recalls were based on an unsafe product and not a non-compliant one. Therefore, while compliance is important, it does not guarantee safety. So, while the manufacturer must meet or exceed laws, regulations, and all applicable safety standards, determining when to exceed a standard requires a complex analysis that will always be criticized if there are accidents and there is an alternative design that would make the product safer.

But many times standards are not the answer or are not that helpful. Here are a few reasons:

- The vast majority of products do not have mandatory safety standards that are applicable to the product. Out of about 15,000 products overseen by the U.S. Consumer Product Safety Commission (CPSC), the CPSC has only issued or adopted about 70 mandatory standards.
- Where a standard applies, it may not apply to the entire product. So, for example, UL standards mostly deal with the electrical part of a product and maybe nothing else. So, a UL certification will be good evidence that the electronics are at least compliant with a UL standard, but it does not guarantee that other parts of the product are safe.
- Many standards are performance standards but allow the manufacturer to design it any way they want. And the standard may allow a manufacturer to use one of several acceptable safety features. This allows the plaintiff to argue that the safety feature selected was not the best choice and that another alternative would have been better.
- Standards are sometimes not clear and are subject to interpretation.
- There are overlapping standards and inconsistent standards from country to country.
- Some standards are not really requirements, but merely guidance on how to do something. For example, the ANSI Z535.4 standard on warning

In the U.S., compliance with safety standards adopted by the CPSC is mandatory. If you don't, you must report the non-compliance to the CPSC and may have to recall the product.

labels is very flexible and allows for exceptions. It is also a design standard; therefore, it is possible to comply with the Z535.4 design and have legally inadequate content. On the other hand, there are other labeling standards and laws that provide for specific required language for certain hazards, but these requirements may also be deemed inadequate.[1]

- Some standards have very specific requirements that are a bare minimum, and the manufacturer is prevented from exceeding the standard while still being able to claim that they complied with the standard's requirements. The result is that they are required to manufacture a potentially defective product so they can say they are compliant.
- And many standards are just made up without any technical or scientific analysis or testing on whether the requirements are likely to result in a safe product. They are merely educated guesses.

In the U.S., compliance with safety standards adopted by the CPSC is mandatory. If you don't, you must report the non-compliance to the CPSC and may have to recall the product. And where mandatory standards have been adopted, the manufacturer usually must retain an independent third-party testing laboratory and obtain confirmation that the product complies. If the product doesn't comply, the manufacturer must then decide whether to have another laboratory test the product and, if it does and the product complies, be required to explain the inconsistent test results.

With some products, the CPSC testing laboratory itself will conduct testing to confirm compliance. If their testing produces a different result from that of the third-party testing laboratory, the CPSC test results will prevail, and you may have to recall your product because of this non-compliance.

Organizations like Consumer Reports (CR) also test products to their own standards, which may differ from comparable voluntary standards or CPSC-mandated standards. So, it is possible that the manufacturer will obtain a third-party laboratory test result confirming compliance and then CR tests the product and concludes that it is unsafe because it doesn't comply with CR's testing protocol. In such a case, which test result takes precedence, and what do you do about this non-compliance? The manufacturer has to deal with this inconsistency from a safety and a marketing standpoint.

DOES COMPLIANCE PROVIDE AN ABSOLUTE DEFENSE TO LITIGATION?

Unless the specific law includes a provision saying that compliance will prevent any injured party from suing for product liability, manufacturers of compliant products can still be sued. There are virtually no laws that include such a limitation and governmental regulations and mandatory and voluntary standards would rarely, if ever, have such a limitation.

So, let's assume that you comply and have a testing laboratory confirm compliance. Do you have a problem? With some allegations, such as strict liability, conduct is not relevant and therefore compliance with standards would not usually be admissible. Where negligence is alleged, evidence of the manufacturer's conduct can be placed into evidence. But, in that case, the plaintiff can still argue that the standard was minimum and that you and your competitors could and should have made a safer product that would have prevented the accident.

If your competitors make a safer product by exceeding the standard and you don't, then you could also have a problem. You would need to explain why your less safe product is safe enough,[2] and why you didn't comply with the state of the art.

WHAT TO DO?

CR had an interesting special report on testing of products for safety and gaps in the system.[3] It cited a 2020 survey it conducted that said that 96% of Americans believe that the products they buy for their home comply with a required safety standard and that

97% of respondents expect manufacturers to have tested their products for safety before selling them.

However, unless the product has a certification mark or logo on the product itself, consumers will not know what products have been tested and whether they comply with safety standards. Of course, consumers will also not know if the standard is adequate or is the bare minimum, or whether the standard applies to all aspects of a product that contribute to or detract from safety.

In the past, there have been a number of observers who believe that meeting or exceeding the requirements of standards is done mostly for marketing. The CR study results above confirm that. In addition, if a manufacturer wishes to work with a retailer that insists that the product be certified by an independent third-party, the manufacturer will need to do so, even if they are confident that the product is safe and does not require further testing.

Despite all of these limitations on the effectiveness of standards and the ability to defend the product, it is imperative that you comply and make a reasonable judgment as to when you need to retain a testing laboratory to test your product, or whether you can conduct testing yourself. In all cases, you need to document what you did to select the applicable standards, how you confirmed product compliance, and, if the product is not compliant, why you still believe that it is reasonably safe.

On the question of when to exceed standards, that is a big unknown. Even if there are standards to consider, the manufacturer should undertake a risk assessment so that they can determine if the standards are adequate to reasonably assure a safe product, or whether exceeding the standards' requirements is needed. Certainly, if comparable products produced by competitors exceed the requirements of a given standard, then you need to do so unless you have good proof that a less safe design is safe enough.

In addition, if you sell a safer product outside the U.S. because of more stringent standards in that country, then you need to decide whether you should also sell that safer product in the U.S. Safer products sold elsewhere are evidence of a safer alternative design and can create admissible evidence by the plaintiff's expert that you could have sold that foreign version in the U.S.

CONCLUSION

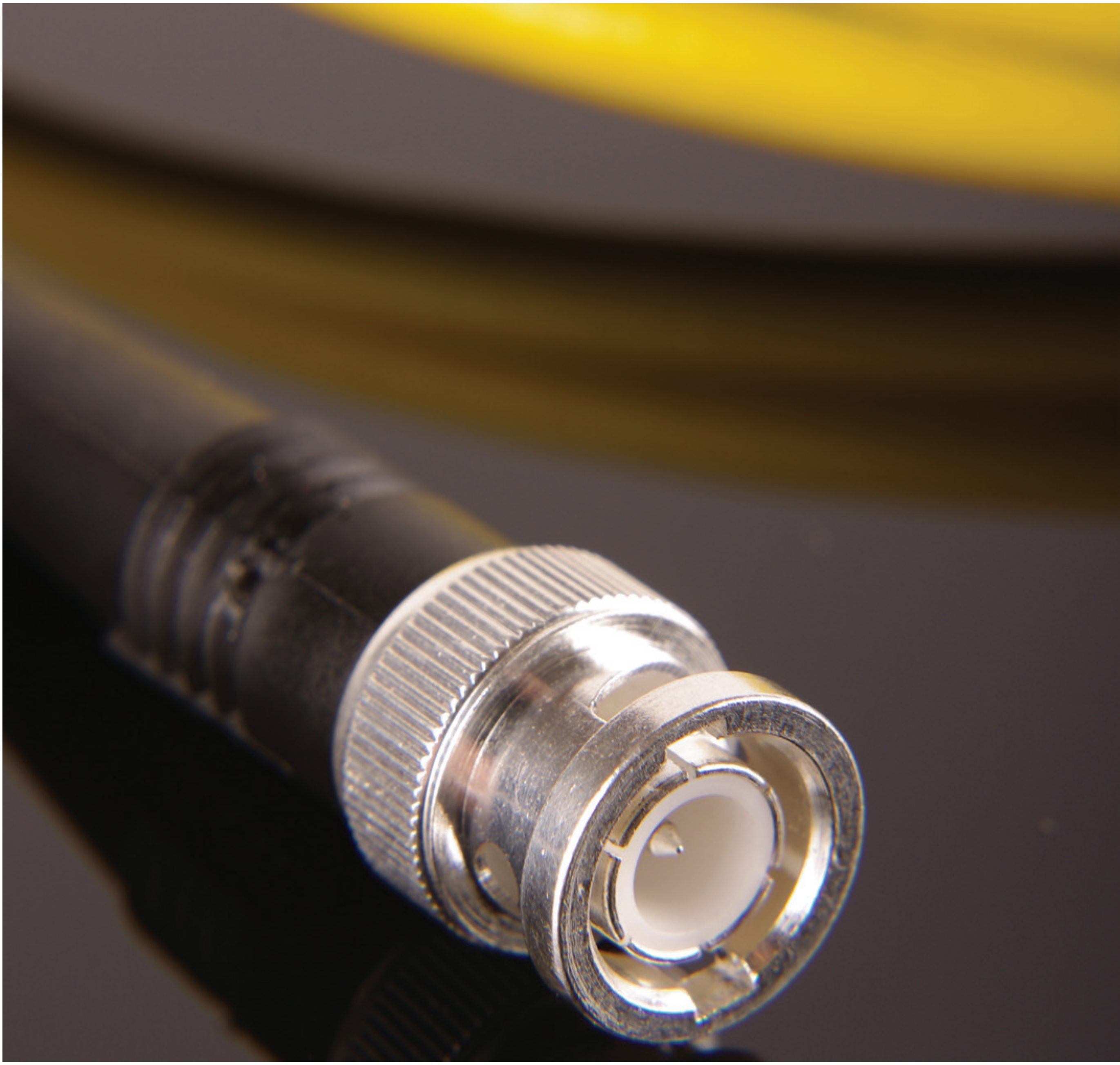
Product liability in the U.S. is based, in large part, on the plaintiff offering a safer design and arguing that the manufacturer should have sold this safer product. While standards are important, compliance with them does not necessarily result in a safe product. Manufacturers have the difficult task of deciding how safe is safe enough while also trying to meet the standards that are common in the marketplace for their products and how to not add unnecessary safety that puts the manufacturer at a competitive disadvantage.

ENDNOTES

1. ANSI Z400.1/Z129.1-2010 and Federal Hazardous Substances Act
2. See "The Risks of Optional Safety," *In Compliance Magazine*, May 2021.
3. *Consumer Reports*, June 2021, page 44.

RF TECH TIP: BNC VERSUS THREADED CONNECTORS

Investigating the Shielding Performance of Coaxial Connectors Used in Radiated Measurements



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By Ken Javor

A rule-of-thumb in EMC and RF (hereinafter termed "The Rule") is that bayonet connectors (BNCs) leak above 10 MHz and are thus to be avoided for radiated measurements. Threaded connectors such as TNC, N, and SMA are used for radiated test work. Having said that, to this day my test facility has some old biconicals and rod antennas with BNC connectors. What's going on?

On one hand, there is The Rule. On the other hand, it doesn't seem likely that the manufacturers of otherwise fine test equipment would use a leaky connector.

A measurement of connector leakage performance – BNC vs. threaded – is revealing.

One might imagine a connector leakage test to look like Figure 1, where a signal is piped through a length of coaxial cable, and the radiation due to that signal is measured externally.

A measurement like that shown in Figure 1 will indeed verify The Rule. But that isn't the actual problem when the BNC connector is on an antenna. The issue there is transfer impedance because the potential problem with a leaky connector is that the same field that impinges on the antenna will also impinge on the coaxial connection to the receiver. And if the induced external cable current gets inside the coaxial transmission line, it will corrupt the radiated measurement. And it turns out that certainly in the rod and biconical antenna ranges a BNC connector is suitable for this application and doesn't leak much more than a threaded connector as long as it isn't defective.

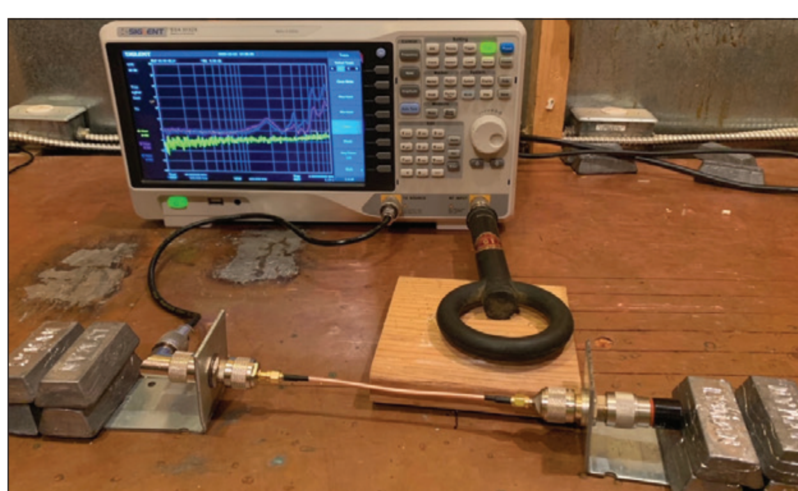

Figure 1: Measurement of connector leakage

So, perhaps counter-intuitively, BNC connectors leak less from the outside in than from the inside out.

The balance of this Tech Tip presents data substantiating the preceding statements. And as a fringe benefit, we find that BNC connectors can make serviceable connector savers for smaller diameter cables terminated in fragile SMA connectors.[1]

COAXIAL CABLE USED AS PART OF THE RADIATED MEASUREMENT SYSTEM: TRANSFER IMPEDANCE MEASUREMENTS

Transfer impedance measurements on cables evaluate the performance of the cable shield as well as that of the connectors. These two components of total transfer impedance are in series with each other and add linearly. Therefore, if evaluating the transfer impedance contribution of one connector versus another, it is critical that the shield component of transfer impedance be constant.

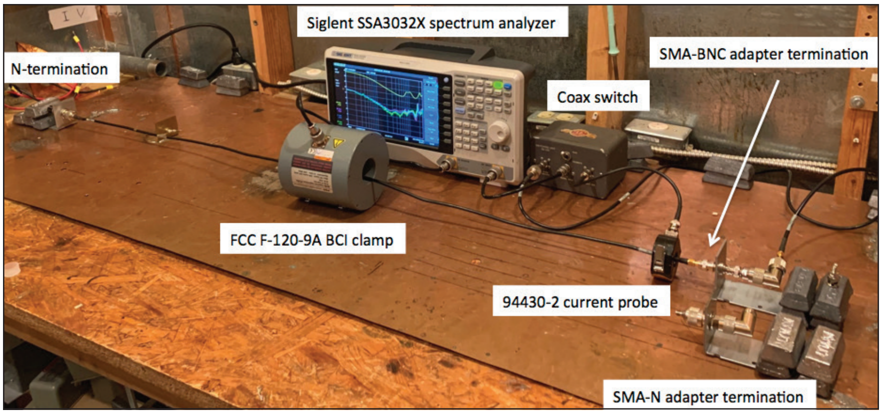

Figure 2a: Overall transfer impedance set-up

The optimal way to achieve that is to use the same exact cable, and change connectors. This is achievable with a cable using a threaded connector such as SMA, and then adapting to other threaded and bayonet connectors, as was done in this investigation.

Figures 2a, 2b, 2c, and 2d show the measurement. LMR-195 50 Ω coaxial cable with an N connector at one end and SMA at the other has its termination bonded to a ground plane at each end. A bulk cable injection (BCI) clamp induces an RF potential on the cable shield, and a current probe

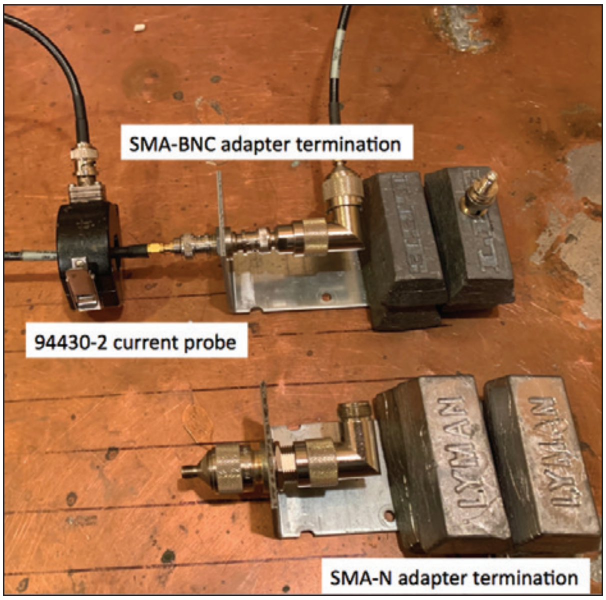

Figure 2b: Interrogation end

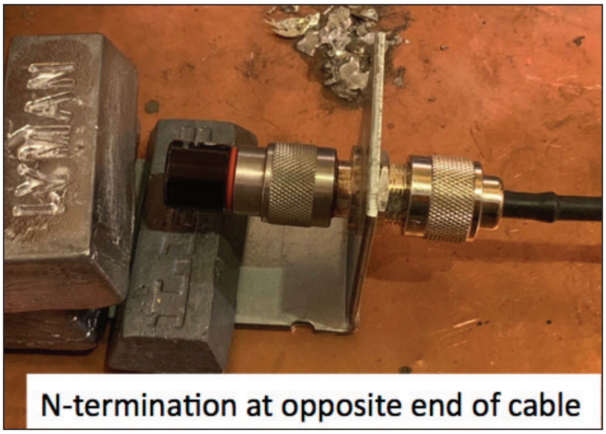

Figure 2c: Opposite and cable termination

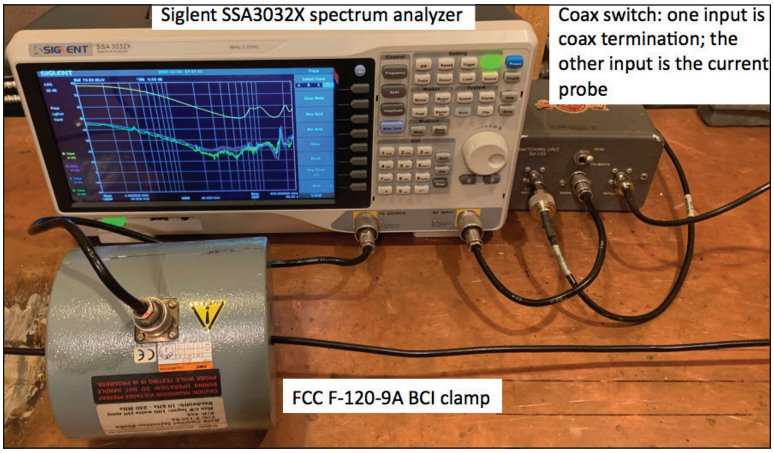

Figure 2d: Instrumentation details

monitors the resultant current at the connector of interest. Both current and the induced potential between coaxial center conductor and ground are displayed on a spectrum analyzer (Figures 3 and 5). Voltage and current may be compared to assess transfer impedance. For this investigation, transfer impedance nominal value is not of great interest; it is the change when swapping out a threaded (N) for a bayonet (BNC) connector, or the effect of wiggling a connector, that is of primary interest.

In Figures 3a and 5, the yellow curve represents current. The 94430-2 current probe has a 0 dBΩ transfer impedance from 1 – 250 MHz, so the reading in dBuV is also the current in dBuA. In Figure 3a, the pink curve is the RF potential measured using an SMA-to-N adapter, and the blue curve is the RF potential using an SMA-to-BNC adapter. There is very little difference between BNC and N traces over this frequency range.

Figure 3b is more interesting, being the same as Figure 3a but with an added (green) trace. This trace is also the RF potential measured using an SMA-to-BNC adapter but a different model, and the results are significantly worse. The erratic green trace was arrived at by wiggling the coax cable, resulting in a loosening of the threaded connection between the cable's SMA connection and the SMA-to-BNC adapter. The jogs in the trace should not be interpreted in the frequency domain but understood to be time-domain perturbations, recorded using a max hold function as the cable was wiggled. Figure 4 explains the mystery.

In Figure 4, the left-hand adapter has knurled stock close to the threading that may be gripped by pliers while torquing the cable's SMA male connector onto the adapter SMA threading. The middle adapter has beveled stock close to the threading that may be gripped by a wrench while torquing the cable's SMA male connector onto the adapter SMA threading. The right-hand adapter has no grip of any kind available, and thus comes loose under any sort of vibration, even that applied by hand. The adapters at left and center gave rise to the blue curves in Figures 3a and 3b, even under persistent hand-induced vibration, whereas the adapter on the right resulted in the green curve of Figure 3b, under the same sort of stress (…the Ugly!).

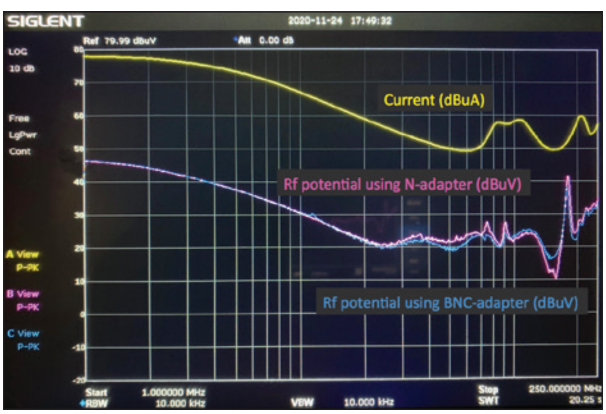

Figure 3a: Transfer impedance test results. Subtract current in dBuA from various RF potential in dBuV to yield transfer impedance in dBΩ. Dip in current above 10 MHz is transmission line effects; transfer impedance not accurate there but the figure of merit is one potential vs. the other for constant induced current.

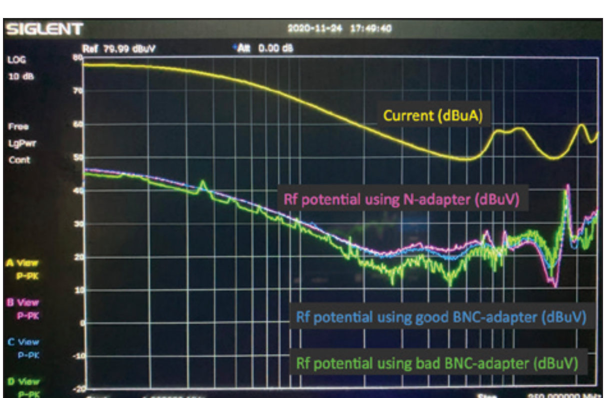

Figure 3b: Identical to Figure 3a except added the green trace which is a max hold of the author wiggling the interrogated end of the cable while sweeping

Figure 4: The Good, the Good, the Bad and…

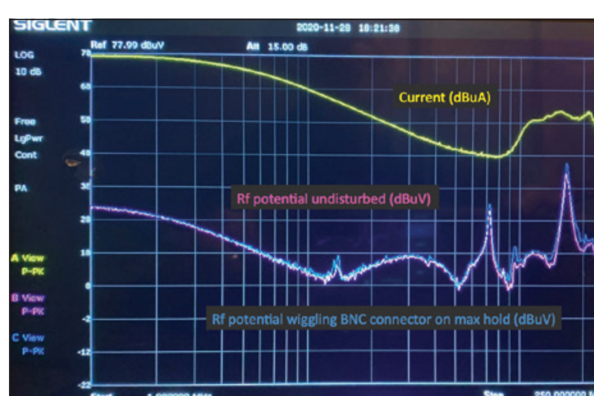

Figure 5: Same as Figure 3b but using a similar length of LMR-195 coaxial cable with BNC connectors at both ends with no SMA-to-BNC adapters

Finally, Figure 5 is similar to Figure 3a, except the cable has BNC connectors – no SMA-to-BNC adapters. Wiggling the BNC connectors introduces slightly higher relative transfer impedances than in Figure 3b where wiggling the BNC connector does not affect the shield-to-connector termination as much (except for the Figure 3b green trace case of the ugly adapter).

COAXIAL CABLE USED AS PART OF THE RADIATING TEST SET-UP: ASSESSMENT OF RADIATION FROM COAXIAL CONNECTION

The obvious close probe measurement for leakage from a connector is a loop probe placed adjacent to the leaky connector while the test coax is driven directly from a tracking generator into a 50 Ω dummy load as shown in Figure 6. This would have worked, except the only probe available was an Empire Devices MP-105 rated for use from 20 MHz to 1 GHz and it was not sensitive enough below about 100 MHz for the purpose of this measurement.

So instead, as shown in Figures 7a and 7b, a current probe was placed around the entire cable, measuring the common mode current, of which

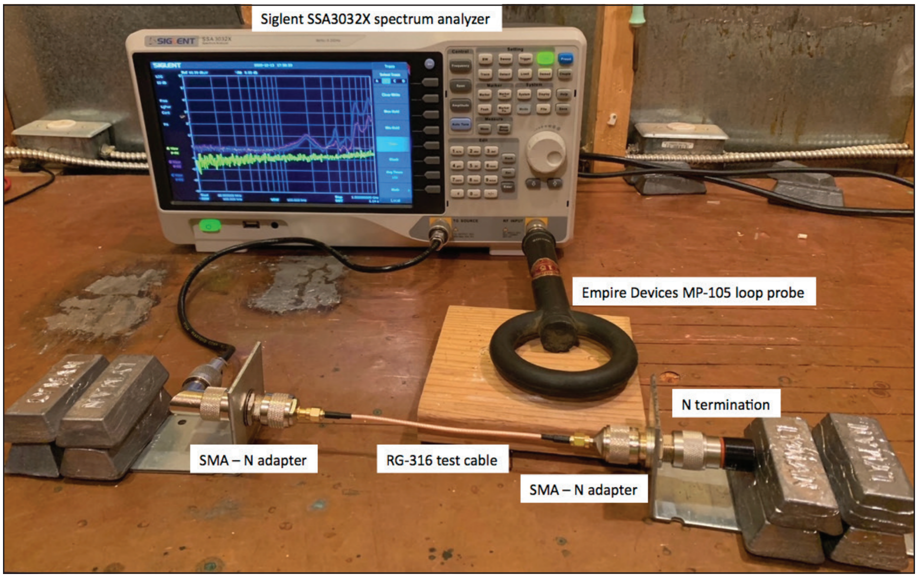

Figure 6: Magnetic field measurement of coaxial connector leakage from an internal signal outward

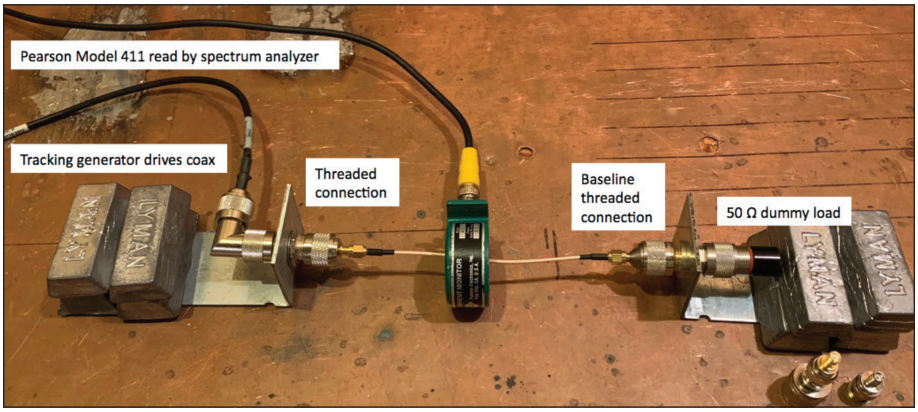

Figure 7a: More sensitive replacement for Figure 5 set-up (current probe transfer impedance -26 dBΩ from 1 Hz to 20 MHz)

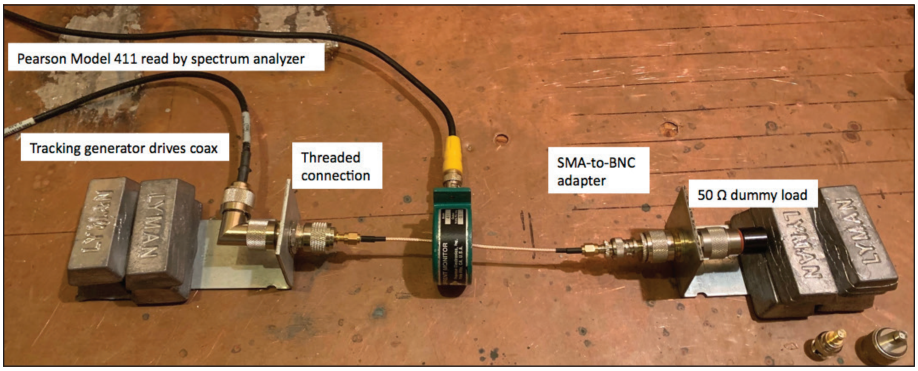

Figure 7b: Identical to Figure 7a, except one of the cable terminations changed to BNC

there should theoretically be none at the frequencies where we worry about a connector leaking, that is, at and above 10 MHz.

Figures 7a and 7b require some explanation. For the purpose of this demonstration, the idea is that if the connectors don't leak at all there should be no common-mode current, that is, the center conductor and shield current are equal and opposite, and net flux picked by the current probe is nil. This is only true at higher frequencies where the shield path is a more attractive path than the ground plane beneath it, as explained by Henry Ott in his seminal 1976 book, *Noise Reduction Techniques in Electronic Systems*,[2] and demonstrated practically annually at EMC Symposia.

Independent of which adapter is selected, we see identical behavior from 10 Hz to ~10 kHz, where the shield starts being the more attractive path.[3] Ott's treatment shows the roll-off continuing indefinitely; here we run into noise floor but we can see that the good quality SMA-BNC adapter leaks some compared to the threaded baseline (Figures 7a and 8a versus Figures 7b and 8b), as low as 100 kHz but almost 10 dB by 1 MHz and likely more at 10 MHz but we are noise floor limited. The poor quality SMA-BNC adapter (Figure 8c) leaks a lot. Comparison of the degradation near 10 MHz amongst Figures 8a, 8b, and 8c on page 42 show significantly worse radiated *emission* performance by BNC connectors vs. the radiated susceptibility transfer impedance measurements in Figures 3 and 5.

CONCLUSION

When using coaxial cable as part of the radiated emission measurement set-up, BNC connectors provide quite decent performance compared to threaded. While this limited set of test data shows

good performance to 1 GHz, most applications will use threaded connectors at UHF. The point is that if an EMI test antenna uses a BNC connector, there should be no concern, and there is no contradiction with "The Rule."

However, when the coaxial cable is not part of the measurement system but part of the radiating system instead (and we wish to minimize radiation that could be picked up by the measurement system), then just like the old rule says: above 10 MHz, threaded connectors are the order of the day.

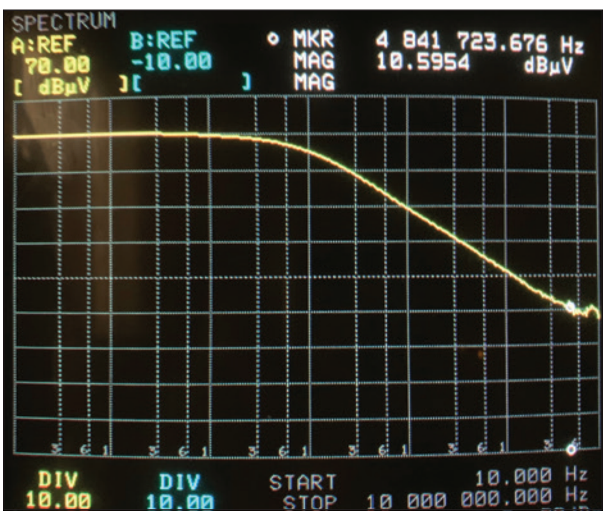

Figure 8a: Common mode current using threaded connections at both ends

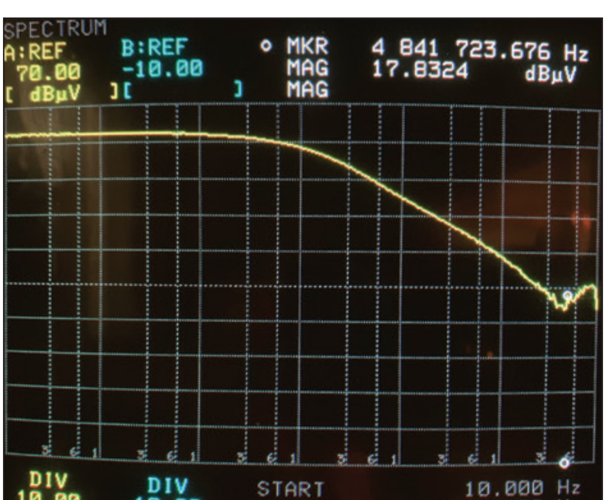

Figure 8b: Common mode current with SMA-BNC adapter at one end

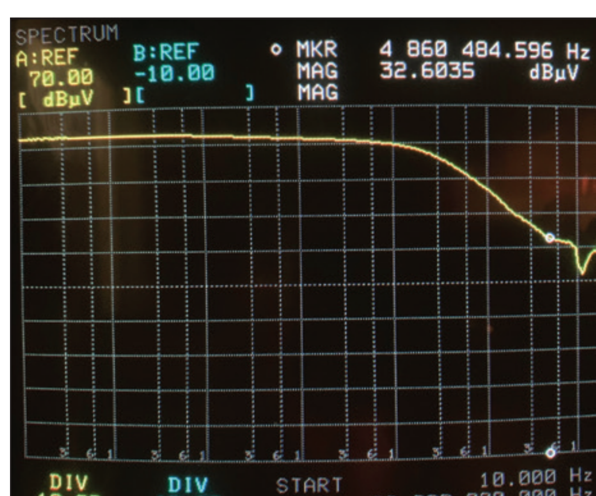

Figure 8c: Ugly common mode current with the "bad" SMA-BNC adapter of Figure 4

ENDNOTES

1. The concept of a connector-saver is extremely valuable for very high cost, low loss cable used at microwave and millimeter frequencies. There the connector saver will be a female-to-male SMA adapter, but the important point is that if you break or wear out the adapter, the original high $$$ cable is still intact. But given the fragility of SMA connectors used in a test environment, connector savers are a good idea for even everyday cable types such as LMR-195, or RG-58. Even though the dollar value associated with the cable is low, if it is part of a measurement system with calibrated loss values read into measurement software files, it is worth preserving that piece of cable.
2. Henry Ott, *Noise Reduction Techniques in Electronic Systems*, 1976, Wiley-Interscience.
3. The low frequency plateau is easily quantified: 15 dBm source (122 dBuV) across 50 Ω load at end of coaxial cable causes a current of 122 dBuV – 34 dBΩ = 88 dBuA. We read that with the Pearson Model 411 current probe with -26 dBΩ transfer impedance from 1 Hz to 20 MHz (+/-3 dB), arriving at a reading of 88 dBuA + -26 dBΩ = 62 dBuV.

EVALUATION OF EMC EMISSIONS AND GROUND TECHNIQUES ON 1- AND 2-LAYER PCBs WITH POWER CONVERTERS

Part 4: DC/DC Converter –EMC Countermeasures – Radiated Emissions Results

By Bogdan Adamczyk, Scott Mee, and Nick Koeller

This is the fourth article in a series of articles devoted to the design, test, and EMC emissions evaluation of 1- and 2-layer PCBs that contain AC/DC and/or DC/DC converters, and employ different ground techniques [1, 2, 3]. In this fourth article, we are still focused on the DC/DC power converter board (2-layer PCB). In this article, we will evaluate the implementation of several EMC countermeasures and present the radiated emissions results according to CISPR25 Class 5 limits.

1. INTRODUCTION

In the first article in the series, [1], we defined the overall design problem. The second article, [2], focused on the details of the 2-layer DC/DC converter design.

The third article [3] presented the radiated and conducted emission results from the baseline design which did not contain any EMC countermeasures. The results showed multiple failures in both radiated and conducted emissions. This fourth article presents a systematic approach to improve these failures by populating the PCB with optional EMC countermeasures on component pads that have already been designed into the PCB layout and showing their impact on the radiated emissions. The countermeasures are presented in an order that we would typically follow in an EMC diagnostic session where, due to time restrictions, not every single permutation of EMC countermeasure will be tested. The EMC countermeasures are illustrated in Figure 1 as purple dashed boxes labeled EMC-A through EMC-F.

The impact of these countermeasures is discussed next. The article concludes with a brief description of what can be expected in the next article in the series.

2. EMC-A & EMC-E INPUT AND OUTPUT CAPACITOR IMPACT

Radiated emissions were measured in the frequency range of 150 kHz – 30 MHz. The baseline results

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Scott Mee is a co-founder and owner at E3 Compliance which specializes in EMC & SIPI design, simulation, pre-compliance testing and diagnostics. He has published and presented numerous articles and papers on EMC. He is an iNARTE certified EMC Engineer and Master EMC Design Engineer. Scott participates in the industrial collaboration with GVSU at the EMC Center. He can be reached at scott@e3compliance.com.

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

(Figure 4a) show a high level of emissions in the 25 - 30 MHz band. To attempt to reduce these emissions two capacitors C9 = 1 nF (EMC-A) and C4 = 1 nF (EMC-E) were populated. The radiated emissions measurement taken with these countermeasures populated is shown in Figure 2. See Figure 6 in the 3rd article in the series for a reference legend to interpret plots in this article [3]. This Figure was not duplicated in this article to save space.

Typically, these 1nf capacitors help filter the noise in higher frequencies. However, as the plot in Figure 4b shows, they had a minimal impact on radiated emissions performance in the upper-frequency range of this band.

3. EMC-A INPUT INDUCTOR IMPACT

Next, we targeted emissions in the lower frequency range of 0.9 - 2 MHz. A 1 µH input inductor, L2, was placed. The radiated emissions measurement taken with this countermeasure in place is shown in Figure 3.

Typically, this inductor helps to reduce emissions in this range by filtering the input and attempting to prevent noise from getting onto the harness where the 2-meter wire length acts as an effective re-radiator. However, as Figure 5b shows, it had a minimal impact in the 150kHz – 30MHz range.

The results of this testing suggest that the noise that is causing emissions at these lower frequencies is either radiating directly from the PCBA (Printed Circuit Board Assembly) or common-mode emissions (rather than differential mode noise) conducting out on the wire-harness. This leads us to our next countermeasure of shielding the switching inductor L1. Due to the ineffectiveness of both the 1uH inductor and the 1 nF capacitors, they were removed from the sample before testing the next countermeasure.

4. EMC-C SWITCHING INDUCTOR IMPACT

Next, the switching inductor, L1, was changed to a Vishay 3232 IHLE 5.6 µH. These inductors have an integrated E-field shield that is tied to the ground on both sides of the inductor. They offer a way to capture the emissions that radiate directly from the switch inductor and boast a 20 dB E-filed reduction at 1 cm [4]. The radiated emission results with the switching inductor changed to a Vishay 3232 IHLE 5.6 µH are shown in Figure 4 on page 46.

As the plots show, the inductor had a substantive impact, not only in the 0.9-2 MHz range but also in the 25 – 30 MHz range. Because the objective of this shielded inductor is to reduce the emissions by capturing the electric field, a significant improvement was observed in the monopole antenna range (150kHz-30MHz). This justifies changing the measurement setup to the biconical antenna to evaluate the improvements in the 30 – 300 MHz

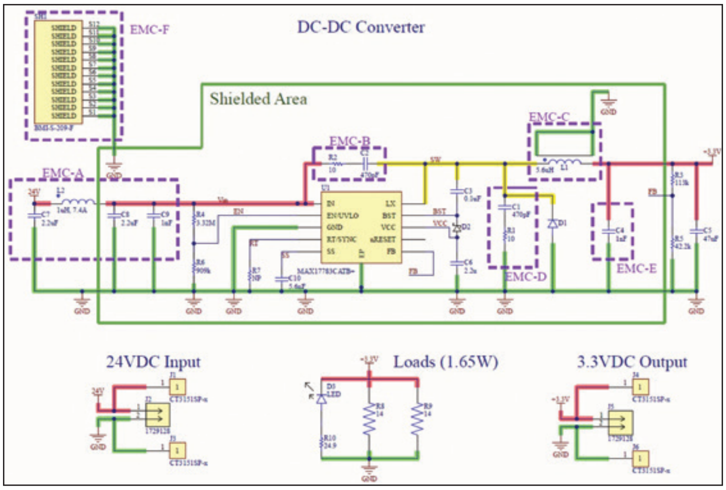

Figure 1: DC/DC schematic with EMC countermeasures

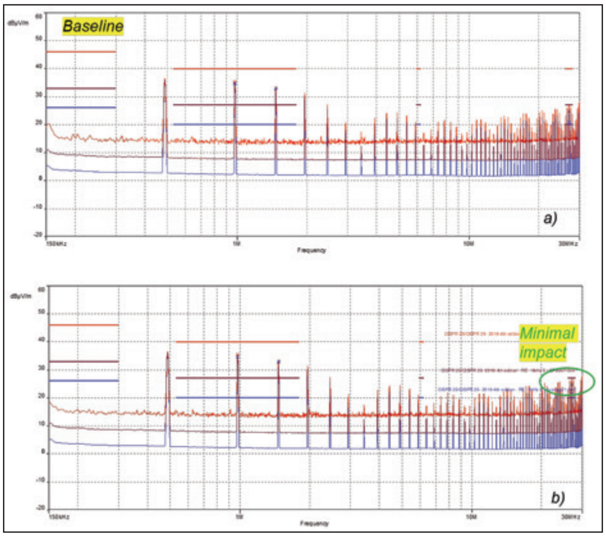

Figure 2: RE results: a) baseline b) with C9 = C4 = 1 nF caps

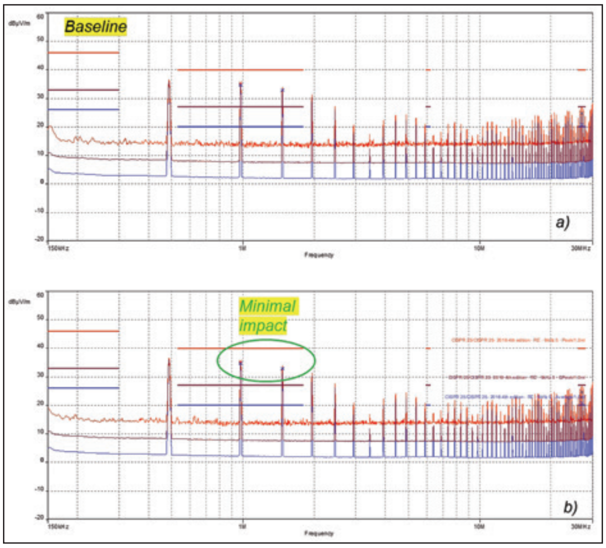

Figure 3: RE results: a) baseline b) with input inductor L2 = 1 µH, and C9 = C4 = 1 nF caps

range. The results are shown in Figure 5 (Note: From this point forward, measurements above 300 MHz are not captured due to passing results in baseline testing).

As Figure 5 shows the IHLE 5.6uH inductor is also successful at reducing emissions in the 30 – 70 MHz band, but it is not as successful around 180 MHz. As the noise in this range is likely due to ringing in the switching waveform, we often recommend the use of a snubber (series R-C) circuit with the purpose of dampening the ringing waveform and reducing the high-frequency content of the signal. The IHLE 5.6uH inductor is removed from the PCB during the evaluation of snubbers to clearly see the impact of the snubbers.

5. EMC-B & EMC-D SNUBBER IMPACT

A snubber was placed across the catch diode D1: R1 = 10 Ω, C1 = 470 pF (EMC-D). These values were chosen based on experience gained from work on other SMPS designs. These values have not been optimized nor calculated using the various methods available, but in a time-restricted scenario, they provide a good starting point and allow us to see if a snubber can make a positive impact. The radiated emissions test results are shown in Figure 6.

This shows a significant reduction in the emissions measured with the antenna in the vertical polarization around 36 MHz but has minimal impact on the horizontal polarization. This also shows a smaller reduction in emissions around 180 MHz.

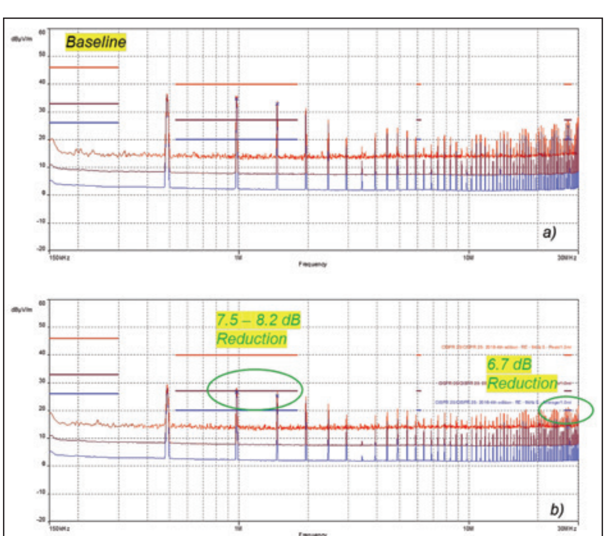

Figure 4: RE results: a) baseline b) with L1 = 5.6uH IHLE

Next, the snubber is removed from its location across the catch diode and placed across the FET which is internal to the IC. This snubber is placed on the placeholders R2 and C2 (EMC-B). The radiated emissions results are shown in Figure 7.

This shows a slight reduction in the emissions measured with the antenna in the vertical polarization around 36 MHz but has minimal impact on the horizontal polarization. This also shows a reduction in emissions around 180 MHz.

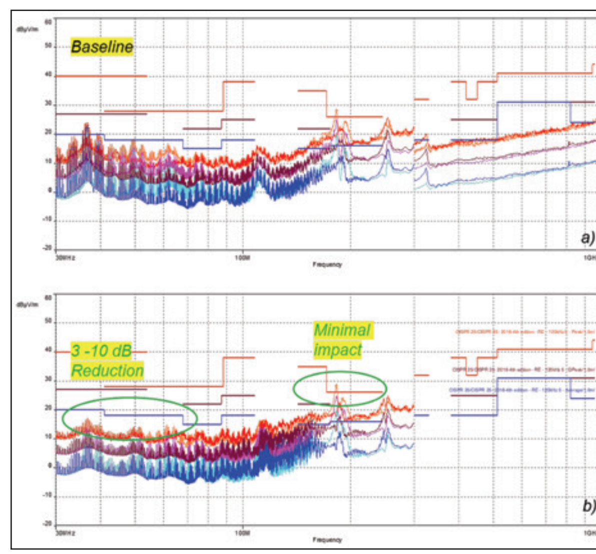

Figure 5: RE results: a) baseline b) with L1 = 5.6uH IHLE

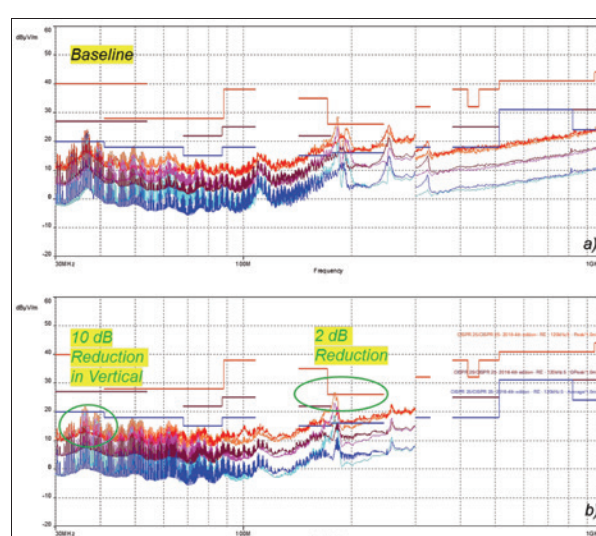

Figure 6: RE results: a) baseline b) with R1 = 10 Ω, C1 = 470 pF

The last step in evaluating these snubbers was to populate the placeholders for both the FET snubber (EMC-B) and the catch diode snubber (EMC-D) combined. The radiated emissions results are shown in Figure 8.

This shows a significant reduction in the emissions in the 30 – 80 MHz range and around 180 MHz. This technically passes CISPR 25 Class 5, but due to expected lab-to-lab variation greater margin is desired in the average measurement around 180 MHz before finalizing the design.

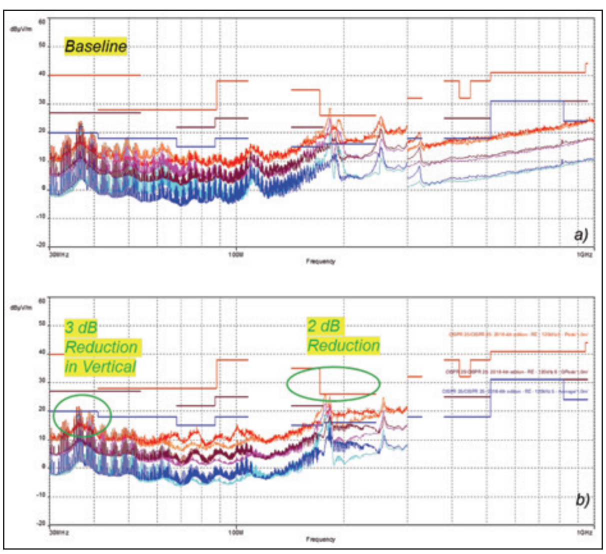

Figure 7: RE results: a) baseline b) with R2 = 10 Ω, C2 = 470 pF

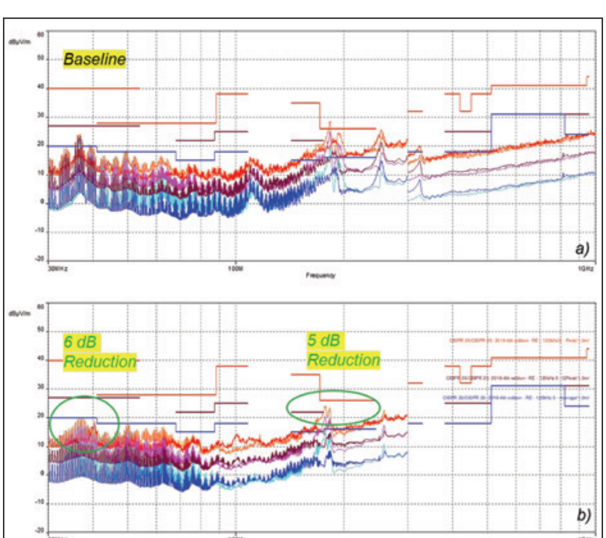

Figure 8: RE results: a) baseline b) with R1 = R2 = 10 Ω, C1 = C2 = 470 pF

Note: Due to the RE chamber scheduling constraints, the radiated emission tests described in the previous sections had to be temporarily put on hold. Since the conducted emissions chambers were available at the time, we began performing the conducted emissions testing and implemented EMC countermeasures to address these failures. The evaluation of the conducted emissions-related countermeasures will be described in the next article. Upon the completion of the conducted emissions testing, we returned to the radiated emissions testing. The radiated emissions testing that was resumed and described next contains the EMC countermeasures implemented during the conducted emission testing. One of these countermeasures was the removal of the RC snubber, as other conducted emissions countermeasures rendered it unnecessary. The other countermeasures are described in the next section.

6. EMC-A, EMC -E - CONDUCTED EMISSIONS COUNTERMEASURES IMPACT

Conducted emissions countermeasures resulted in the addition of two 2.2 µF capacitors in parallel with C7 and C8. Additionally, the input inductor L2 was changed to 2.2 µH; also, C9 and C4 were populated with 10 nF capacitors. The switching inductor L1 was also populated with a Vishay 3232 IHLE 5.6 uH inductor. The input filter and inductor changes provided much benefit to the conducted emissions. These results will be shown in detail in the next article in the series. For now, we will continue to focus on the radiated emissions results.

Figure 9 on page 48 shows the radiated emission measurements in the 150 kHz – 30 MHz range while Figure 10 shows the results in the 30 -1,000 MHz range.

The conducted emissions countermeasures were very effective at reducing radiated emissions in both the 150kHz – 30MHz and 30MHz – 300MHz ranges. These DUT modifications are preserved for the following sections of this article.

7. EMC-F - IMPACT OF THE SHIELD FRAME

Next, a shield frame SH1 was soldered to the PCB on the perimeter over the shielded area shown in Figure 10 on page 48. This is EMC countermeasure EMC-F. This is in addition to the conducted emissions countermeasures previously described.

It is important to note that the shield frame was placed without a shield lid in this first evaluation. This is being evaluated, since in some cases, sufficient emissions reductions can be achieved with only the frame component. Figure 11 shows the radiated emissions results in the frequency range 150 kHz – 30 MHz, while Figure 12 shows the results in the range 30 – 1,000 MHz.

The addition of the shield frame to the conducted emissions countermeasures provides significant decreases in emissions in the range of 150kHz – 300MHz and makes the emissions low enough to pass CISPR 25 Class 5 radiated emissions limits.

If this SMPS was a product that was intended for sale, the next step would be to start removing the EMC countermeasures one by one to reduce the Bill of Materials (BOM) cost of each unit produced. An example of this would be trying to remove the IHLE 5.6 uH inductor in favor of a cheaper inductor. In our previous trials, this increased emissions in the 0.9 – 2MHz range above the average limit. An evaluation was performed by exchanging the IHLE

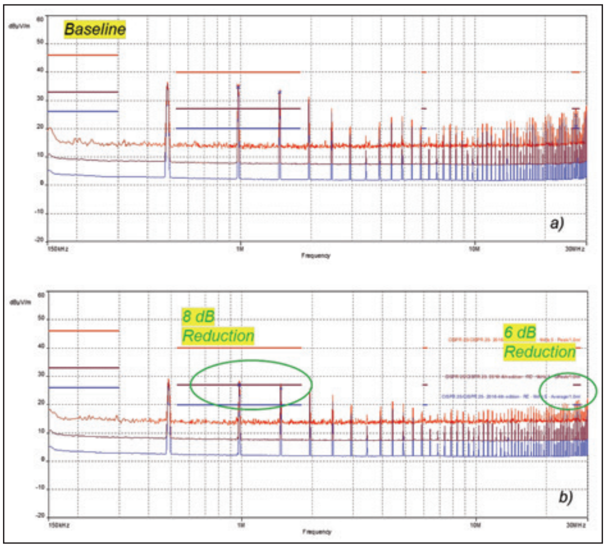

Figure 9: RE results 150 kHz – 30 MHz: a) baseline b) with conducted emissions countermeasures

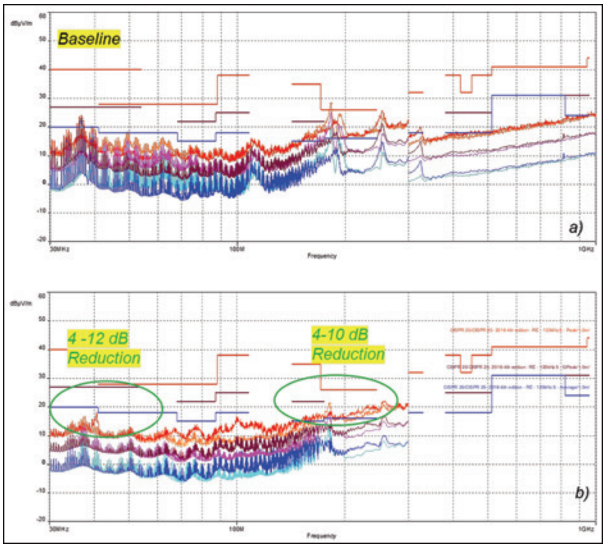

Figure 10: RE results 30 – 1,000 MHz: a) baseline b) with conducted emissions countermeasures

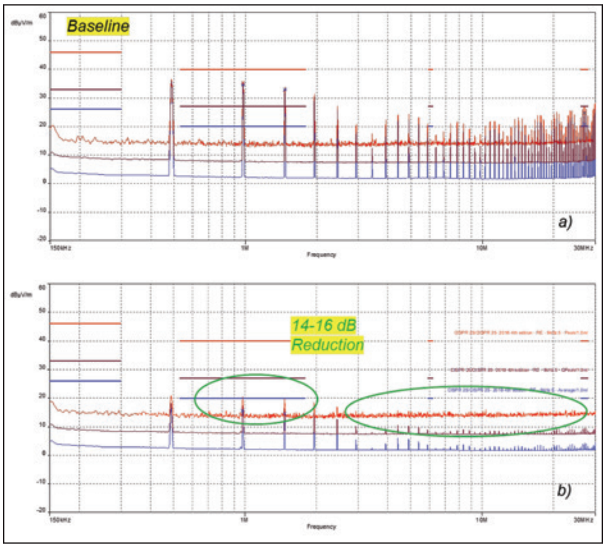

Figure 11: RE results 150kHz – 30 MHz: a) baseline b) with a shield frame and conducted emissions countermeasures

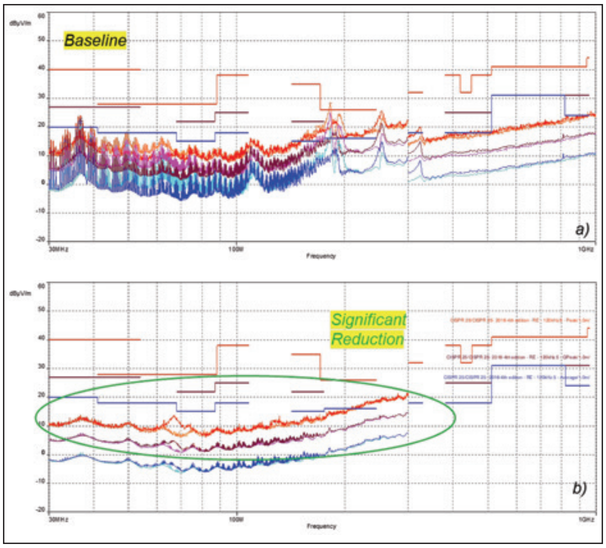

Figure 12: RE results 30-1,000 MHz: a) baseline b) with a shield frame and conducted emissions countermeasures

5.6 uH E-field shielded inductor (L1) for the original IHLP 5.6uH magnetically shielded inductor (L1) and a shield lid was placed on the shield frame. The radiated emissions results with the shield lid and L1 swapped are shown in the frequency range 150 kHz – 30 MHz in Figure 13.

This shows that the shield with the lid in addition to the conducted emissions input filter greatly reduces emissions in the range of 150 kHz - 30 MHz. Placing the shield lid does not negatively affect the emissions in the range of 30MHz – 1000MHz (passing with margin) and therefore are not shown in this last evaluation.

Based on the results presented in this article, we recommend finalizing the design to meet radiated emissions requirements (CISPR25 Class 5) with the following countermeasures populated on the baseline design:

EMC A – Front End Filter
C7 = 2.2uF (with additional 2.2uF or change to 4.7uF)
L2 = 2.2uH
C7 = 2.2uF (with additional 2.2uF or change to 4.7uF)
C9 = 10nF

EMC-B – Internal FET snubber
Not populated

EMC-C – Shielded Switch Inductor
Preserve original IHLP 5.6uH magnetically shielded inductor

EMC-D – Catch diode snubber
Not populated

EMC – E – Output high-frequency capacitance
C4 = 10nF

EMC-F – Shield frame and lid
Populate both frame and lid

Additional effort can be applied to this configuration of EMC countermeasures to further optimize for cost while meeting EMC requirements. If the target application does not require the stringent levels of CISPR25 class 5, it may be possible to remove the EMC shield in favor of cheaper countermeasures. A full analysis has not been performed on this design to pursue these potential objectives.

8. FUTURE WORK

The next article will be devoted to the conducted emissions results.

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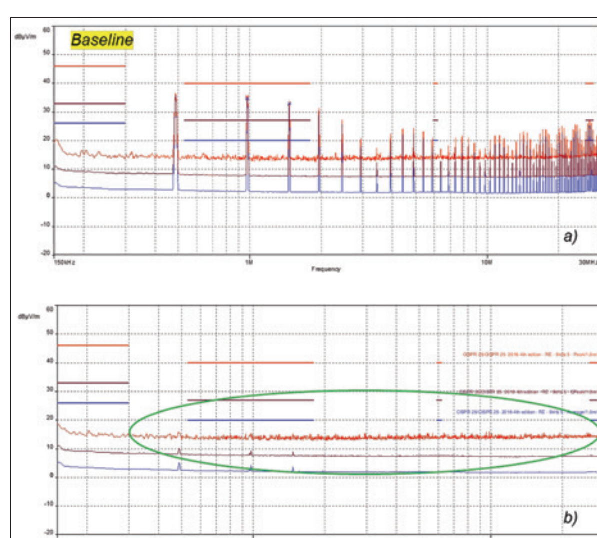

Figure 13: RE results 150 kHz - 30 MHz: a) baseline b) with a shield frame and lid, 2.2 uF capacitors added in parallel with C7 and C8, C9 = C4 = 10nF, and L2 = 2.2 uH

AUTOMATED LATCH-UP VERIFICATION IN 2.5D/3D ICS

By Dina Medhat for EOS/ESD Association, Inc.

Dina Medhat is a Technical Lead and Technologist for Calibre Design Solutions at Siemens Digital Industries Software. In addition to over 35 publications, she holds a U.S. patent. Her research interests include reliability verification, electrostatic discharge, emerging technologies, 3-D integrated circuits, and physical verification.

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

OK, LET'S START WITH THE BASICS. WHAT IS LATCH-UP, AND WHY DO DESIGNERS CARE ABOUT IT?

In today's tightly packed layouts, most integrated circuits (ICs) end up with parasitic bipolar transistors (pnp and npn) somewhere. Latch-up is a short circuit, or low-impedance path, created by interaction between these transistors. Latch-up susceptibility can unnecessarily cause damage from electrical overstress (EOS) events. Unintended latch-up paths can lead to the risk of electrical damage or unexpectedly trigger during an electrostatic discharge (ESD) event. So checking for latch-up protection is now a mandatory verification requirement. Electronic design automation (EDA) tools already provide automated latch-up design rule checking (DRC) for 2D IC layouts. However, 2.5D/3D ICs present new and very different challenges when trying to apply these same rules with the same tools. It's not impossible, but new latch-up verification flows are needed. That's where my work focuses.

HOW DO YOU PROTECT AGAINST LATCH-UP?

There are two key types of latch-up design rules—fundamental and advanced [1,2]. Fundamental (local) latch-up design rules focus on the physical dimensions of parasitic pnpn networks. Advanced latch-up design rules fall into two primary categories: external and mixed-voltage latch-up. External rules evaluate separation between an external injection source and victim circuit, so we have to be able to identify that injection source [3,4]. Mixed-voltage rules determine compliance by evaluating voltage difference, which can be critical in power sequencing operations [5,6]. In 2D ICs, we typically use manual markers to provide the required information. These markers are always subject to human error and are even harder to apply accurately in 2.5D/3D IC designs. My colleagues and I are focused on the development of automated latch-up physical verification flows for 2.5D/3D ICs that do away with markers entirely.

WHAT MAKES 2.5D/3D IC LATCH-UP VERIFICATION DIFFERENT?

Actually, for fundamental rules, it's not. 2.5/3D IC dies (Figure 1) are often designed on different technology nodes from different foundries. Consequently, local latch-up physical verification simply means applying appropriate local latch-up design rule checks (DRC) for every die separately.

2.5D/3D IC latch-up challenges come from the advanced latch-up design rules. In 2.5D/3D active dies, two types of off-chip interfaces exist: external IOs (communicate signals externally) and die-to-die IOs (communicate between active 2.5D/3D dies). Die-to-die IOs have no connection to package pins—they drive signals via micro-bumps, the interposer, and 3D traces. Automated latch-up checking must (1) recognize external IOs for every die from the assembly level, (2) identify external diffusions (latch-up injectors) inside every die topologically (external diffusion is connected to external IO directly or indirectly through resistors, diodes, switches,… etc.), (3) assign voltages to external IOs (or latch-up injectors) from the assembly level, and propagate these voltages to every die, (4) recognize that different dies have different advanced latch-up rules.

We propose two automated flows: (1) a topology-aware flow for external latch-up design rules, and (2) a voltage-aware flow for mixed voltage latch-up design rules, both starting from the assembly level, and based on automatic differentiation between external IOs and internal IOs, without using any layout markers.

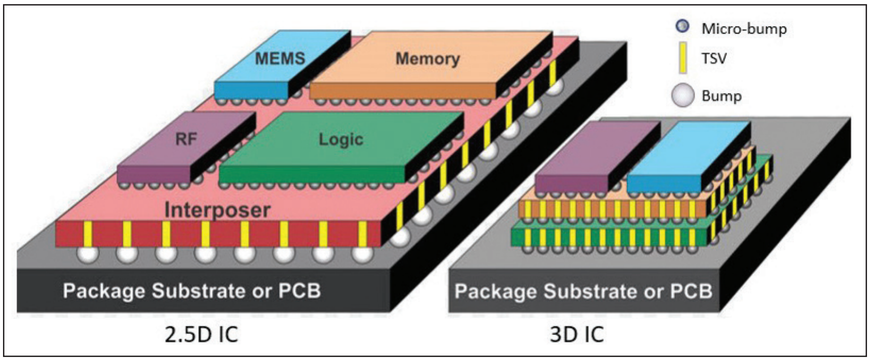

Figure 1: 2.5D and 3D IC designs.

WHY START AT THE ASSEMBLY LEVEL?

The assembly level provides the complete picture of how the dies are connected with each other, so that's where we differentiate between external and internal IOs. We assume internal IOs have low latch-up risk, so we perform appropriate latch-up verification on the external IOs only.

Layout cell-based extraction generates a layout netlist that describes the connections between dies, which we treat as black boxes. We identify external IOs and the port names of dies to which they connect at the assembly level, and generate a custom report for every die with its corresponding external IOs connections (Figure 2).

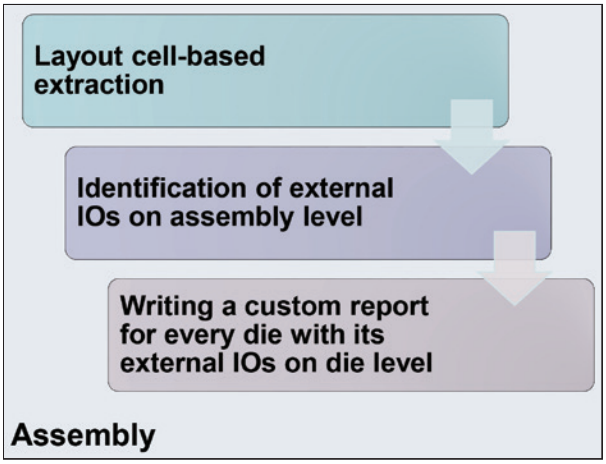

Figure 2: Analysis on assembly level.

THEN YOU MOVE ON TO THE SPECIFIC CHECKING FLOWS?

Exactly. First, though, designers create latch-up constraints spreadsheets for every die with the relevant information needed to drive the die analysis, such as voltage values for external IOs (Figure 3). We get the external IO net names from the assembly-level custom reports.

The topology-aware latch-up flow addresses external latch-up design rules for every die. Latch-up injectors and corresponding layout geometries are automatically identified in this flow. We can then perform external latch-up DRC measurements on relevant geometries and report violations for debugging.

The voltage-aware latch-up flow addresses mixed-voltage latch-up design rules for every die. We propagate voltages through devices from defined external ports to internal nodes in the design, enabling identification of direct/indirect connectivity of latch-up injectors. Layout geometries of the identified latch-up injectors are captured automatically. We measure the relevant geometries for mixed-voltage latch-up DRC, and report violations for debugging.

HAVE YOU TESTED THESE FLOWS IN THE REAL WORLD?

We've tested our verification flows on a design with five dies: four random-access memory (RAM) dies and a controller die intentionally designed with external latch-up and mixed-voltage latch-up design rules errors (Figure 4).

The two flows correctly identified all expected latch-up conditions, enabling designers to quickly identify and apply the correct fixes. For example, connections between IOs of controller die and IOs of RAM die that don't have any connections to the external world are considered internal IOs, so no latch-up risk is

## Topology Aware Latchup Constraints		
## Category	**Parameter Name**	**Parameter Value**
TALatchup_nets	Pad	autoDetect
	Power	vdd? Vcc?
	Ground	vss? gnd?
TALatchup_layers	pdiff_pins	psd
	nwell_layer	ntub
	nring_layer	nimplant
	ndiff_pins	nsd
	pwell_layer	psub
	pring_layer	pimplant

## Voltage Aware Latchup Constraints		
## Category	**Parameter Name**	**Parameter Value**
VALup_pads	Pad	autoDetect
	Power	vdd? Vcc?
	Ground	vss? Gnd?
VALup_voltages	5	vdd
	3.3	rda<1> rda<2> rda<3> rda<4>
	1.8	rda<10> rda<11> adr<0> adr<1>
	0	gnd adr<5> adr<4>
VALup_layers	pdiff_pins	psd
	nwell_layers	ntub
VALup_defaultSpacing	default_spacing	7
VALup_voltageSpacingTable	vstart_vstop_spac_1	0 1.8 4
	vstart_vstop_spac_2	1.8 3.3 6
	vstart_vstop_spac_3	3.3 5.0 7

Figure 3: Constraint spreadsheets are completed before the checking flows are run.

reported on them. Conversely, the flow correctly located P+ diffusions connected to external IO pads without proper protection, which the designers can correct by adding N+ guard rings.

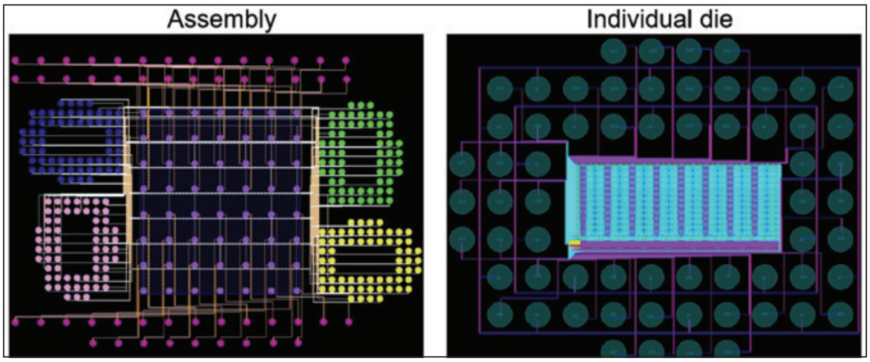

Figure 4: Layout of the assembly and one of the RAM dies in the test design.

CAN YOU SUM IT UP FOR US?

2.5D/3D IC verification can be challenging, but automated solutions like ours can not only reduce verification cycles but also improve the quality of the design. Our proposed flows provide a significant step forward by eliminating the need for manual markers and automating many of the verification steps. Implementing an automated latch-up verification solution for 2.5/3D IC designs ensures accurate and consistent latch-up protection, improving the reliability and product life of these products.

This article is derived from a paper presented at the 2020 EOS/ESD Symposium "Addressing Latch-up Verification Challenges of 2.5D/3D Technologies." For a more detailed discussion of the processes and the flow evaluations, you can access the paper here: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9241348.

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Banana Skins

347 Cellular telephones can interfere with medical equipment – Mayo Clinic concludes

OBJECTIVE: To assess the potential electromagnetic interference (EMI) effects that new or current-generation cellular telephones have on medical devices.

MATERIAL AND METHODS: For this study, performed at the Mayo Clinic in Rochester, Minn, between March 9, 2004, and April 24, 2004, we tested 16 different medical devices with 6 cellular telephones to assess the potential for EMI. Two of the medical devices were tested with both new and old interface modules. The 6 cellular telephones chosen represent the different cellular technology protocols in use: Code Division Multiple Access (2 models), Global System for Mobile communications, Integrated Digital Enhanced Network, Time Division Multiple Access, and analog. The cellular telephones were tested when operating at or near their maximum power output. The medical devices, connected to clinical simulators during testing, were monitored by observing the device displays and alarms.

RESULTS: Of 510 tests performed, the incidence of clinically important interference was 1.2%; EMI was Induced in 108 tests (21.2%). Interference occurred in 7 (44%) of the 16 devices tested.

CONCLUSIONS: Cellular telephones can interfere with medical equipment. Technology changes in both cellular telephones and medical equipment may continue to mitigate or may worsen clinically relevant interference. Compared with cellular telephones tested in previous studies, those currently in use must be closer to medical devices before any interference is noticed. However, periodic testing of cellular telephones to determine their effects on medical equipment will be required.

(Taken from: "Cellular telephone interference with medical equipment" *by Tri JL, Severson RP, Firl AR, Hayes DL, Abenstein JP. Division of Foundation Telecommunications and Network Services, Mayo Clinic College of Medicine, Rochester, MN 55905, USA. 29 Oct 05, Mayo Clin Proc. 2005 Oct;80(10):1286-90, received via: Interference Technology eNews Oct 27 2005.)*

348 Five interference anecdotes from Tim Haynes

Radar-controlled gun on board a refitted warship. VHF transmissions would make the gun guidance go wild, pointing it into the superstructure etc. Lucky it wasn't loaded.

My own experience. Radio ham, transmitting on a UHF channel 433.325MHz hears own voice on a VHF transceiver, which was not normal. Received voice comes and goes with the movement of traffic. By watching the cars around, determines that it only occurs when a particular car is nearby - a Fiat Coupé. I ran this on EMC-PSTC when it happened and got Ferrari and Fiat writing to me wanting to know if it was their vehicle causing the problem. This was probably RF and switching causing the problem in the ECU of the Fiat.

Dual technology (IR and microwave) movement detectors used to control the lights in (a house / an office) would also detect radio transmission from passing cars using VHF radio. Soon the lights were going on and off like Xmas tree lights as all taxi, fire, police, ambulance drivers "blipped" their transmitters on passing.

Radio ham sitting in Tesco's car park waiting for wife to arrive with shopping. Talking on local UHF ham repeater. Man comes to his BMW7 series and with a flourish "blips" the remote unlock. Nothing happens. Another flourish. Still nothing. Walks around the car - checks number plate - yes it is his. Another flourish – nothing. Radio ham stops transmitting and leans out of the car window say "it will work now". Aggravated flourish! car unlocks and owner starts to load shopping.

Ham goes back to transmitting. Owner shoves shopping trolley into empty parking bay and gets into car. After two to three minutes, owner gets out of car and checks all doors are shut and gets back in. Gets out again and looks pitiful. Radio ham stops transmitting, leans out of window and say " it will start now!". Owner looks puzzled, gets into car and starts it first time, drives off at speed. Radio ham gets out of his old, non-electronic, car and paints another circle with black and blue quadrants in it on the front wing. Pulls flaps down on flying helmet and returns to reminiscing about days as fighter pilot. (This one is part true and part poetic license - you can decide which parts are which!)

(A collection of anecdotes sent in on 10th November 2005 by Tim Haynes.)

349 New Pentagon system suspected of interfering with garage door openers

A widespread problem with a mysterious radio signal that caused some garage doors in the Ottawa region to stop working has vanished. The powerful radio signal causing the problem stopped transmitting on Thursday afternoon, around the time CBC News contacted the U.S. Embassy to ask if it knew anything about it. The embassy denies that it had anything to do with it.

The signal was being transmitted at 390 megahertz, a frequency used by the Pentagon's new Land Mobile Radio System. The same frequency is used by garage doors openers, which started to malfunction around the city about two weeks ago. A similar problem has popped up around military bases in the States.

The world's biggest garage door manufacturer, the Chamberlain group, took the problem seriously enough to fly design engineer Rob Keller to Ottawa from its Chicago headquarters, with machinery to try to track the signal. But by the time he got there, the signal was gone.

(Sent in by Doug Milligan, Senior Control Engineer, JNUP, who found it on CBC News "Garage doors work after mysterious radio signal disappears," *Mon, 07 Nov 2005 13:01:24 EST.)*

350 Mobile phone ban continues on flights

The ban on the use of mobile phones by passengers on planes is set to continue. New tests by the Civil Aviation Authority confirmed that phones are still a threat to aircraft. The latest study found that the use of mobile telephones can adversely affect navigation and communication functions, producing significant errors on instrument displays and background noise on audio outputs. The CAA study recommended that as well as the usual on-board warnings about the use of mobiles, there should also be reminder notices in airport departure lounges and warnings by check-in staff.

The research backs up reports from pilots, who have stated that interference from mobiles has caused: false notification of unsafe conditions - for example, incorrect baggage compartment smoke alarm warnings; malfunction of aircraft systems; interrupted communications due to noise in the flight crew headphones; distraction of crews from their normal duties due to increased work levels and the possibility of having to invoke emergency drills.

Dan Hawkes, an avionics specialist at the CAA who supervised the research, said: "The tests demonstrate that mobile telephone use near an aircraft's flight deck or avionics equipment bay can adversely affect systems that are essential for safe flight. "For safety reasons the current policy of prohibiting the use of mobile telephones by passengers while the aircraft's doors are closed for flight must continue."

(Copyright (c) Press Association Ltd 2003, All Rights Reserved. 06/05/2003 13:31)

351 TETRA radio system interferes with amateur radio

The roll-out of Tetra (Airwave) in Manchester is making itself known. I travel down the M60 between the A627M to the west of Bury, 2 or 3 times a week. I travel back and forth to work 5 days a week using the same route. I've used the same Amateur Radio transceiver (Kenwood) in my car for the last 5 years. What has changed? At various locations on the M60 and in Oldham, Ashton and Stalybridge, the 430MHz band is unusable for a number of miles on certain roads. The only way to get rid of the damn digital out of band carrier noise, is to switch on the ctcss (continuous tone coded squelch system), probably the equivalent on switching the fog lamps on! We are finding that increasingly it is necessary to take this course of action, or listen to the noise for the next few miles.

(Sent in by Graham Eckersall of Barcrest, on 10th Feberuary 2003.)

352 Enhanced immunity testing required to overcome telecom failures

The International Telecommunications Union publishes the ITU-T Recommendations, which include the "K Series" of recommendations on the resistability (EMC immunity) of telephone-related equipment. Recently (Nov 2004) an amendment was published to its Recommendation K.20, which covers equipment installed in telecommunications centres. It seems that despite passing the very thorough and quite tough immunity tests in K.20, including the 'enhanced levels', a new design of line card installed in 1999-2000 suffered a large number of IC failures by 2002. Three years of intensive study resulted in a new test that reproduced the type of damage seen, and cards that have been modified to pass this new test seems to be much more reliable as a result.

The new test involves applying a voltage at the AC power frequency between two external ports (connectors for external telecommunication cables). The generator is 'floating' – not connected to the earth of the equipment under test as in the usual K.20 tests. Coupling resistors of between 100 and 200 ohms are used, and the voltage applied for periods of around one-third of a second. The voltage is increased gradually from low levels, until it exceeds the voltage at which the secondary protection devices in the equipment operate. In the case of the failing line cards above, the damage was replicated with coupling resistors of 140 ohms and a voltage of 145V rms.

(Taken from: ITU-T Recommendation K.20, "Resistibility of telecommunication equipment installed in a telecommunications centre to overvoltages and overcurrents" Amendment 1, November 2004, "Floating transverse power induction and earth potential rise test for ports connected to external symmetric pair cables". For manufacturers of equipment that could be connected to long signal, data or control cables, especially if those cables exit a building, applying the relevant K series immunity tests should help improve reliability. Some of them are similar to IEC 61000-4 series tests, but some are very different and/or much tougher.)

353 Digital box interference riggers 'SOS' alert and helicopter search

A faulty TV digital box sparked a rescue mission from RAF Kinloss by sending out a signal identical to those transmitted by vessels in distress. The Kinloss site in Moray, which co-ordinates rescue operations across the UK, detected an "SOS" call from the Portsmouth area on 5 January.

A coastguard helicopter spent two hours searching the harbour area before the signal was traced to dry land. An RAF spokesman said the signal had been a "complete freak". Telecoms regulator Ofcom was asked to look into the signal and confirmed the source.

RAF spokesman Michael Mulford said the Aeronautical Rescue Co-ordination Centre at the airbase had picked up the beacon from one of five orbiting satellites. He said it was transmitting on the major emergency frequency. "We traced it to Portsmouth Harbour, checked and found out there were no vessels in the area or missing planes." The rescue centre then contacted Ofcom, which was able to establish it was coming from a household.

"Digital boxes shouldn't be sending out signals, let alone maydays" Ofcom spokesman Mr Mulford added: "This is very very unusual, it's a complete freak and the odds of a digibox sending out such a signal must be astronomical. "The guy who owns it really should do the lottery because the chances of sending out a signal from a digibox and sending out precisely and exactly on a major emergency channel are far more than 14 million to one."

Ofcom has since removed the £50 Freeview box for tests. An Ofcom spokesman said: "This is a real one-off as digital boxes only receive signals. "They shouldn't be sending out signals, let alone maydays. The householder was happy to hand it over to our engineers who are trying to get to the bottom of the defect."

(Taken from BBC News / Scotland, Sunday, 15 January 2006, 13:03 GMT. This was sent in by both Graham Eckersall of Barcrest and by Alex McKay of Technology International (Europe) Limited, who got it from Claire Ashman of RFI.)

The regular "Banana Skins" column was published in the EMC Journal, starting in January 1998. Alan E. Hutley, a prominent member of the electronics community, distinguished publisher of the EMC Journal, founder of the EMCIA EMC Industry Association and the EMCUK Exhibition & Conference, has graciously given his permission for In Compliance to republish this reader-favorite column. The Banana Skin columns were compiled by Keith Armstrong, of Cherry Clough Consultants Ltd, from items he found in various publications, and anecdotes and links sent in by the many fans of the column. All of the EMC Journal columns are available at: https://www.emcstandards.co.uk/emi-stories, indexed both by application and type of EM disturbance, and new ones have recently begun being added. Keith has also given his permission for these stories to be shared through In Compliance as a service to the worldwide EMC community. We are proud to carry on the tradition of sharing Banana Skins for the purpose of promoting education for EMI/EMC engineers.

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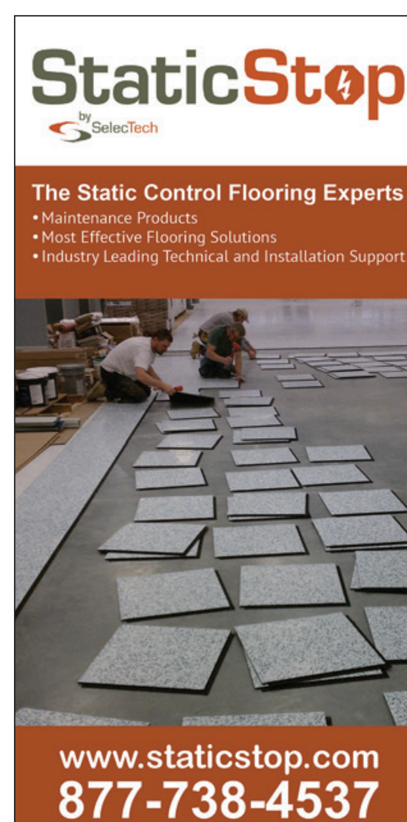

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