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CONTENTS

FCC Steps Up Efforts to Provide Access to Robocall Blocking Tools

The U.S. Federal Communications Commission (FCC) is stepping up its efforts to stem the flow of unwanted and scam robocalls, calling on telecom providers to make public the robocall blocking calls they make available to consumers.

In a press release, the FCC's Consumer and Governmental Affairs Bureau reports that it has contacted major phone companies and third-party developers of call blocking tools and requested that they provide updated information on their efforts to enable consumers to block unwanted calls. The FCC is also seeking information on the effectiveness of blocking tools already in use, as well as steps that the companies have taken to ensure that call blocking technologies do not interfere with emergency services communications.

The data provided to the FCC by telecom providers is expected to be released in the Commission's second Call Blocking Report scheduled to be issued later this year.

The FCC also announced that it has issued in the past two months cease and desist letters to eight separate companies believed to be behind the transmission of multiple robocall campaigns.

FCC Makes Spectrum Available for Commercial Space Launches

The U.S. Federal Communications Commission (FCC) has adopted new rules to provide access to spectrum that can be used by commercial space launch vehicles during pre-launch testing and space launch operations.

Frequencies used to support communications during space launches have historically been allocated for exclusive use by federal agencies. Now, under the terms of a Report and Order and Further Notice of Proposed Rulemaking issued in late April, the FCC has added a non-federal, secondary allocation in the 2200-2290 MHz band that can be used by private space travel and satellite launch companies for communications purposes.

The FCC notes that non-federal operators will need to continue to coordinate their communications requirements through existing STA and NTIA processes until additional rules have been adopted that provide a new spectrum use coordination scheme.

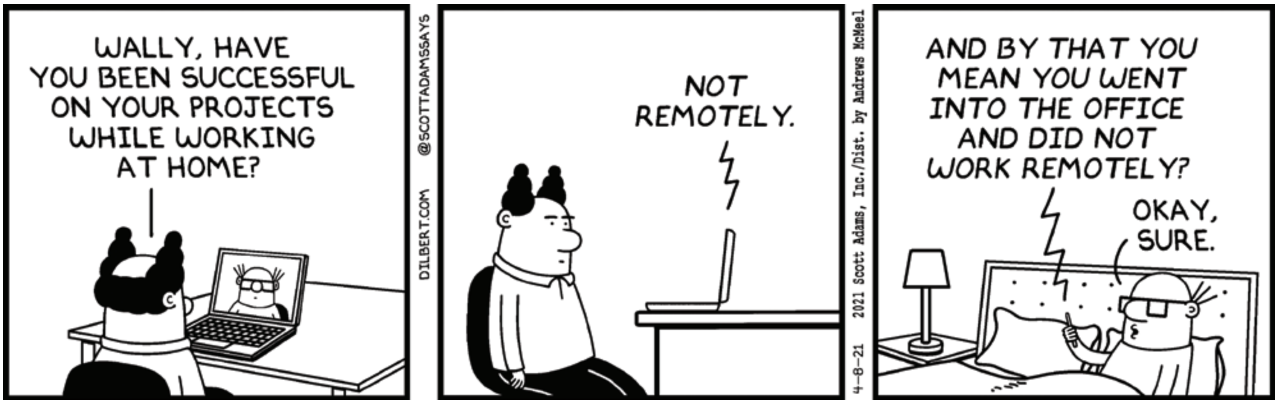
Congress Seeks to Designate National Amateur Radio Operators Day

The U.S. Congress is reportedly taking steps to officially recognize the important contributions made by amateur radio operators.

According to an article on the website of the ARRL, Congresswoman Debbie Lesko (AZ) has introduced a bipartisan resolution to designate April 18, 2022 as National Amateur Radio Operators Day. April 18th is the anniversary of the founding of the International Amateur Radio Union (IARU) which was established in 1925.

The resolution cites the Amateur Radio Emergency Service for providing "invaluable emergency communications services following recent natural disasters, including, but not limited to, helping coordinate disaster relief efforts following Hurricanes Katrina, Wilma, and Maria and other extreme weather disasters."

Lesko had introduced a similar bill last year at the request of Raymond Anderson, a 12-year-old radio amateur from Peoria, AZ.



FDA Reverses HHS Action to Exempt Certain Medical Devices from 510(k) Requirements

The FDA deemed the HHS proposal was based on flawed information lacking inadequate scientific support and containing multiple errors.

The U.S. Food and Drug Administration (FDA) has withdrawn a January proposal by the U.S. Department of Health and Human Services (HHS) to permanently exempt 91 separate medical device types from the FDA's 510(k) premarketing notification requirements.

According to a Notice of Withdrawal published in the U.S. *Federal Register*, the FDA took action to withdraw the HHS proposed exemptions in part because the HHS failed to notify the FDA of the proposed exemptions or consult with the agency. The HHS also reportedly based its exemption determinations exclusively on the number of adverse events reported for each device type in the FDA's Manufacturer and User Facility Device Experience (MAUDE) database.

The FDA notes that adverse event reports, while valuable, have limitations in making judgments about device exemptions, including incomplete or inaccurate data. The FDA also says that adverse event reports alone can be inaccurate due to under reporting of events or inaccuracies in the reports themselves.

Given the circumstances, the FDA deemed the HHS proposal was based on flawed information lacking inadequate scientific support and containing multiple errors. Hence, the determination to withdraw the proposed exemptions.

FCC to Permit "Hot Car" Sensors

The Office of Engineering and Technology of the U.S. Federal Communications Commission (FCC) has taken action that will allow for the eventual deployment of technology to help prevent serious injury to children inadvertently left in overheated cars.

Under the terms of an Order, the FCC has granted limited waivers to six manufacturers that will allow them to market short-range interactive motion sensors for unlicensed operation in the 57-64 GHz band. These in-cabin radars can then be linked to customized vehicular applications that can detect movement linked to a child or children that have been left in a vehicle or that have become trapped.

The waivers were requested by the device manufacturers since the sensors reportedly require higher power levels than those permitted under FCC rules.

According to data from the National Highway Traffic Safety Administration, more than 50 children died each year in 2018 and in 2019 as a result of being left unattended in a vehicle, with a much larger number suffering significant injuries. The majority of these incidents reportedly involved parents who forgot a child placed in a rear seating area of the vehicle, hence the potential value of in-cabin detection technology.

FDA Authorizes 50+ Testing Labs for Conformity Testing Pilot

The U.S. Food and Drug Administration (FDA) has now accredited more than 50 testing laboratories to participate in its voluntary Accreditation Scheme for Conformity Assessment (ASCA) pilot accreditation program.

As we've previously reported, the ASCA pilot program allows accredited independent testing laboratories to assess medical devices for compliance with certain FDA-recognized standards. The establishment of the ASCA was mandated under the 2017 FDA Reauthorization Act and is expected to help facilitate a more efficient review process for certain types of medical devices.

As of this writing, 53 testing laboratories located throughout the U.S. and in Canada, Japan, Germany, Israel, South Korea, and China are now authorized to conduct testing to one or more FDA-recognized versions of standards and test methods included under the scope of the ASCA pilot. The FDA is expected to continue to review and accredit additional testing laboratories and expand laboratory accreditations to include additional recognized standards during the pilot program.

Radio Frequency Exposure Rules to Take Effect

Rules issued in 2019 by the U.S. Federal Communications Commission (FCC) on the measurement of human exposure to radiofrequency (RF) emissions took effect in May.

As reported on the website of the ARRL, the rules do not change existing RF exposure limits. Rather, they impose a more thorough evaluation of RF emissions in potentially higher-exposure situations, including amateur radio operations, while also providing a more streamlined exemption process in low-exposure situations, such as with low-power devices, relatively large distances between the RF source and a person's body, and/or duration of exposure.

Originally released in December 2019, along with other rulings on human exposure to RF, the FCC's Second Report and Order also clarifies the calculation or measurement methodologies to be used to determine potential RF exposure levels in cases where exemptions do not apply. It also addresses post-evaluation RF exposure mitigation procedures, including access, signage, and training to help minimize the risk of excessive RF exposure.

PROTECTION OF HIGH VOLTAGE POWER SUBSTATION CONTROL ELECTRONICS FROM HEMP AND IEMI

An Approach Using EMC Standards

William A. Radasky, Ph.D., P.E., has worked in the field of high power transient phenomena for more than 50 years and has published over 500 reports, papers and articles during his career dealing with transient electromagnetic environments, effects and protection. He was awarded the Lord Kelvin Medal by the IEC in 2004, the Carl E. Baum Medal in 2017, and is an IEEE Life Fellow. He founded Metatech Corporation in 1984 and is the President and Managing Engineer. He can be reached at wradasky@aol.com.

By Dr. William A. Radasky

This article describes an approach for hardening high-voltage power substation control electronics from high-altitude electromagnetic pulse (HEMP) that would occur if a nuclear weapon were detonated in space. While we hope that this type of electromagnetic event never occurs, it is a possibility, and the impact on unprotected electronics and the power grids that they control could be severe. In the case of HEMP, a single high-altitude nuclear burst could expose thousands of power substations to high-frequency transients within one power cycle, creating essentially a simultaneous distributed event for which the power grid was not designed.

While the emphasis for this article will be on the protection from early-time (E1) HEMP, it will also discuss the additional efforts that can be made to protect the electronics from intentional electromagnetic interference (IEMI) produced by electromagnetic weapons. By considering both the E1 HEMP and IEMI together, we cover the main high frequency transient high-power EM (HPEM) threats that have become important in recent years.

As described in the work in IEC SC 77C, while high power electromagnetic (HPEM) disturbances are low probability events, they can be protected against with existing protection technology and often at low cost. The field of electromagnetic compatibility (EMC) is well established, and methods for shielding against electromagnetic fields and attenuating conducted transients are widely known. The main issue is to determine the requirements for these protective elements as they relate to E1 HEMP and IEMI.

This article focuses on the fact that the electronics found in the control houses of electric power substations are already exposed to high levels of natural power system EM transients and are therefore required to have immunity against high levels of radiated and conducted transients. The major generic EMC standards for establishing immunity tests and test levels for electronics placed in control houses are set forth in IEC 61000-6-5 [1]. By considering the basic immunity of the electronics in the control houses for EMC and the external HEMP and IEMI radiated field waveforms and their coupling to external cables outside of the control house and internal cables (thereby creating conducted transient disturbances), protection methods can be established. The recently developed IEC 61000-5-10 [2] provides different strategies for protection for both new and retrofit applications, relying on several other published IEC SC 77C standards.

In this article, we'll first review the basic HEMP and IEMI electromagnetic waveforms as discussed in our previously published article in *In Compliance* Magazine [3]. Next, we'll describe the basic layout of high voltage substations and the electronics found in a substation control house. Then, we'll discuss the EMC immunity requirements for the control electronics and how these can be leveraged to determine the specialized HEMP/IEMI protection methods. Following this discussion, we'll share and describe the techniques for rapidly assessing the existing shielding and penetration protection of an existing control house. Finally, we'll discuss some of the protection options available.

HEMP/IEMI ENVIRONMENTS

As described in [3], high-altitude HEMP is defined as three separate waveforms as shown in Figure 1 on page 12. The waveforms are described as early-time, intermediate-time, and late-time waveforms, and they are also described more briefly as E1, E2, and E3 HEMP. The IEC has standardized these waveforms, which can be found in IEC 61000-2-9 [5]. In this article, our focus will be on E1 HEMP, as the electronics in the control house are most impacted by this high-frequency waveform. There are possible effects on these electronics that could occur due to harmonics in the power supply system attributable to E3 HEMP, but this aspect is under evaluation in separate research projects.

Figure 2 describes in the frequency domain the relationship between early-time (E1) HEMP and IEMI environments that can be produced from electromagnetic weapons. It also indicates at lower frequencies the typical levels of lightning electromagnetic fields from very near cloud-to-ground strikes. It is important to understand that, while lightning currents and fields are very energetic, they do not extend significantly above 1 MHz in frequency content, as do both the E1 HEMP and IEMI. This means that most grounding and bonding methods used for lightning are not sufficient for the higher frequency content E1 HEMP and IEMI. This will be discussed later in this article.

LAYOUT OF HIGH VOLTAGE SUBSTATIONS AND CONTROL HOUSES

Power substations are built for transmission grids at high voltages above 100 kV and, in the United States, at extra high voltages (EHVs) above 345 kV. A majority of the power "moved" by transmission power lines in the U.S. is at a voltage of 500 kV. These higher voltages move high power levels over long distances from power plants to areas where power is needed by industry and homes (this is still true today, despite local renewable power sources). Inside the power substation fence, the high voltages are stepped down to lower high or medium voltages for distribution to customers.

There are also distribution substations found within towns and cities, but the focus of this article is on the transmission substations due to the much higher amount

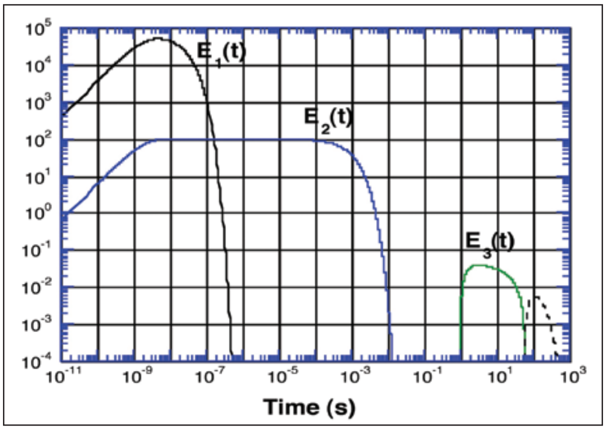


Figure 1: Graphical description of three analytic functions that describe the early-time (E1), intermediate-time (E2), and late-time (E3) HEMP as described in [4]

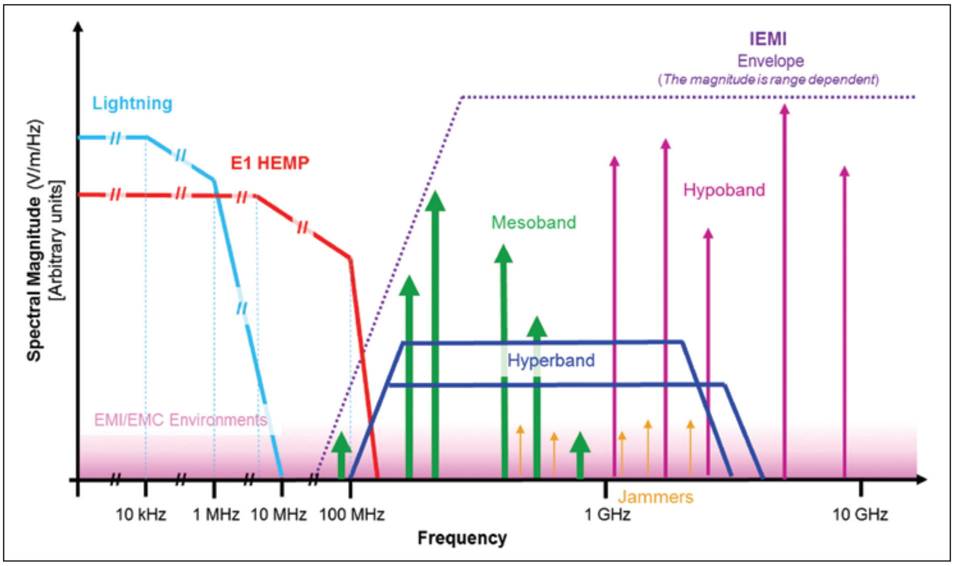


Figure 2: The relationship of IEMI electromagnetic fields in the frequency domain to the E1 HEMP and an example of nearby lightning EMP fields from a cloud to ground strike [6]

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of power passing through the substation. The loss of power flowing through a few transmission substations in a region can create a severe power supply/load imbalance that can result in a power blackout.

As long transmission lines arrive at a power substation, there are sensors on each line to monitor the current and voltage levels arriving at the substation (known as CTs and VTs). These sensors have low voltage cables attached that run (as shown in Figure 3) to a control building (often referred to as a control house), where these currents and voltages are monitored using mainly solid-state protective relays.

As a simple example, if the voltage on a line decreases rapidly and the current increases sharply, this could be an indication of a line being grounded to a tree, and the relay receiving this information will send a signal to a circuit breaker (along another cable) to disconnect the power line from the step-down transformer to avoid damage. These relays are programmed ahead of time to determine what levels will trigger such a response, and actions are taken automatically without human intervention. These protection relays are therefore critical to the operation of a power substation and the overall power grid.

Inside the control houses, most of the control cables used today are not shielded. However, there are often ground wires or cable meshes that are grounded to an internal grounding system inside the building (see Figure 4). From an E1 HEMP or IEMI point of view, grounding cables inside of a building is not the best approach as the induced currents from E1 HEMP and IEMI will flow on these cables inside the building and will create electromagnetic fields that can couple to the internal wiring and to the nearby electronics. In addition, the use of wires is not effective in grounding high frequency transients as the inductance of a grounding wire is more important

Figure 3: A trenway (or trench) containing multiple cables running from the power line sensors to the control houses which contain the protective relays. Covers are sometimes metal, but often concrete, fiberglass, or wood, and the bottom and sides of the trenways are usually nonmetallic.

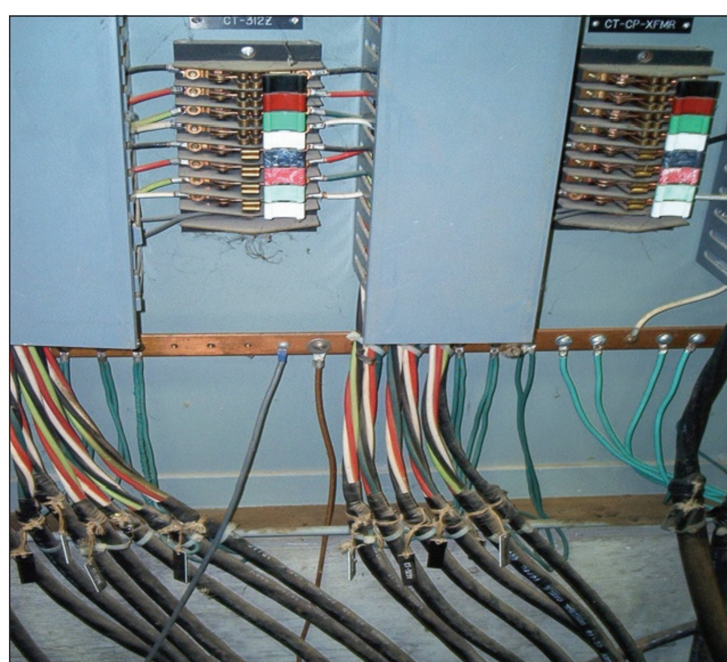

Figure 4: Typical cable grounding and junction box connections inside of a control house.

than the wire resistance. As we'll discuss later, using shielded control cables and grounding them outside of a building will greatly reduce the conducted and radiated EM disturbances that can create failures to the operating solid-state equipment.

It is important to understand that for both E1 HEMP and IEMI the electromagnetic transients are created external to the building. There, they couple to external cables, external antennas, and interact with the walls of the control house to penetrate to the inside through apertures (for air flow and doors, for example) and through nonmetallic walls such as concrete. Figure 5 illustrates the types of aspects that should be considered for the penetration of external fields and voltages into a control house.

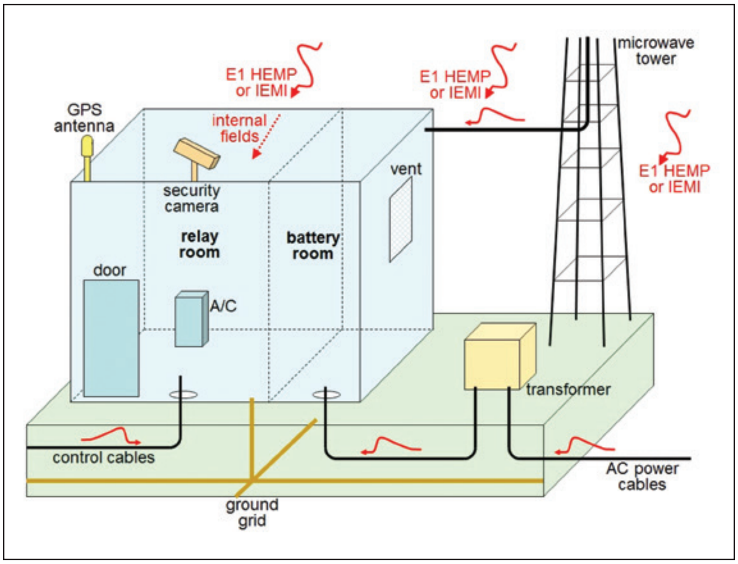

Figure 5: A general example of a typical control house showing the ways that E1 HEMP and IEMI environments could penetrate the building (AC enclosure is mounted on the external wall).

However, it is important to note that not all of the "penetration" features are equally important for E1 HEMP and for IEMI. For example, the coupling of E1 HEMP to buried cables is much stronger than for IEMI, as the IEMI fields at higher frequencies are significantly attenuated in the ground. On the other hand, wiring above the ground is well exposed to IEMI environments, and apertures in the walls of the building allow more penetration of the IEMI environments. GPS antennas are also at risk due to jamming by IEMI. Later in this article, we'll address in greater detail the protection options for these different types of radiated and conducted penetrations.

EMC IMMUNITY REQUIREMENTS FOR CONTROL HOUSE EQUIPMENT

It is well established that the "normal" electromagnetic environments are severe situations for electronics in power control houses due to the nearby presence of high voltage and current lines. While it might appear that the main EM disturbances are associated with 50 or 60 Hz, it turns out that connections and disconnections of high voltage circuits create a disturbance known as the electric fast transient (EFT) in low voltage control cables. The IEC test waveform for the EFT [7] is a 5/50 ns (10-90% rise time/50-50% pulse width) which is repeated at a frequency of up to 100,000 times per second. It is also noted that this same waveform is recommended for testing of conducted E1 HEMP transients (although only 1 or 2 pulses) [8], as it represents a typical conducted E1 HEMP waveform.

In addition, due to the presence of transmission lines and busbars within a substation, there is the possibility of nearby lightning strikes. Cloud-to-ground lightning strokes will create currents that will flow to the electronics through the control cables, and the IEC recommends a 1/50 microsecond voltage transient to test the low voltage electronics inside of a control house [9]. It is important to note that according to IEC 61000-6-5 [1] power substation equipment should be tested to the highest levels of these two tests due to their severe EM environment. IEC 61000-6-5 recommends many additional EMC immunity tests to be performed for power system electronics, but these two pulsed tests are the most important for their relationship to E1 HEMP and IEMI.

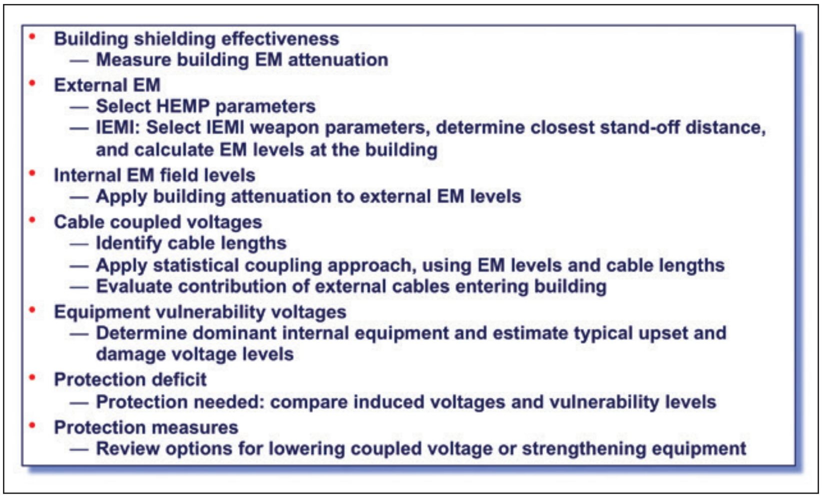

Figure 6: E1 HEMP and IEMI assessment procedure for establishing the amount of protection required for the electronics in a high voltage control house.

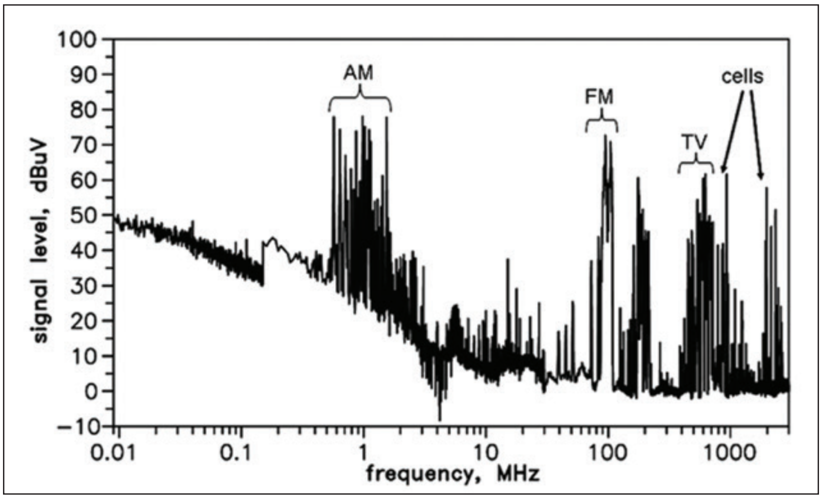

Figure 7: External measurements of radio signals outside of a control house for the E1 HEMP and IEMI frequency bands.

While it is important to reduce the external radiated and conducted environments associated with E1 HEMP and IEMI, we wish to make the important point that, due to the severe EMC tests required for the individual electronic "boxes," the reductions required for the radiated and conducted transients from E1 HEMP and IEMI are not as large as would be required for commercial or industrial electronics.

ASSESSMENT METHODS TO EVALUATE EM STATUS OF CONTROL HOUSES

For existing buildings, it is important to evaluate the situation with respect to the attenuation of electromagnetic fields and conducted currents and voltages as they relate to the specific threats of E1 HEMP and IEMI. Two initial aspects need initial attention: 1) the determination of the shielding effectiveness of the control house itself; and 2) the physical examination of the cables as they enter the building. Fortunately, most power companies use specific methods to construct their control houses and specific types of control cables, including trenches between the high voltage power lines and the control houses. In addition, power companies tend to ground and bond their cables in similar fashions. Of course, there can be older control houses still operating within a power company's region, and there can also be newer building and cable designs that are being introduced to their system based on new communications protocols for Smart Grid applications.

Figure 6 presents the steps required to perform a complete assessment for a control house for both E1 HEMP and IEMI. The first step is to evaluate the shielding effectiveness of the control house from 1 to ~100 MHz for E1 HEMP and from ~100 MHz to ~5 GHz for IEMI. There is a relatively new method available [10] to assess the shielding effectiveness of operating facilities with shielding levels below 50 dB, known as the commercial radio signal assessment method. This method uses measurements of local AM, FM, digital TV, and cellular signals both inside and outside of the building to estimate the amount of attenuation present (see Figure 7 as an example of external signals which are well above the noise).

Through frequency domain to time domain translations, this process can convert any external time domain transient to an internal room time domain transient, as long as the frequency range information

acquired is appropriate. This also does not require Federal Communications Commission (FCC) approval of special transmitters and allows a proper plane wave "simulation" of E1 HEMP conditions, as even at 1 MHz, the wavelength is 300 meters, which would require a transmitter standoff of much greater than this distance. Evaluations of this technique have been performed with good results and have been applied to over 100 control houses in the past ten years.

Once the shielding effectiveness has been evaluated over the frequency range of interest, one must then define the E1 HEMP and IEMI waveforms to be applied. IEC 61000-2-9 [5] provides a good example for E1 HEMP, and IEC 61000-2-13 provides several examples for IEMI threats [11]. In addition, since the IEMI EM weapon threat is a local threat, the closest approach to the control building needs to be evaluated. Satellite mapping tools can be used for this purpose.

Once the external EM threats are defined, the internal time field waveforms can be developed using the measured EM attenuation information. The next step is to evaluate the currents and voltages coupled to the internal wiring using coupling evaluations based on random orientations and polarizations performed for different cable lengths. Then, a probabilistic method can be used to select worst-case or average levels of coupling.

In addition to this coupling to wiring by fields penetrating the building, one must also consider the coupling to external control cables and other cables penetrating the building, such as conduits from security cameras and antennas. These levels can vary considerably based on the grounding and bonding of these cables as they enter. Also, for the control cables in trenches, IEC 61000-2-10 [12] provides information on the levels of E1 HEMP currents and voltages appropriate for above-ground and buried cables.

Once the coupled currents and voltages appearing inside the control house have been determined, these need to be compared to the immunity of the equipment. Fortunately, the standard IEC 61000-4-4 EFT waveform for EMC can be used as a proxy. It requires a fast ~4 kV pulse (5/50 ns) for power system equipment [7]. Recent testing has found that most protective relays satisfy this requirement, and some will be able to withstand higher levels, but it is difficult to establish specifically upset levels for all situations. Therefore, it is recommended that the immunity level for the internal electronics using the EFT waveform be used to determine whether any additional protection will be required for E1 HEMP or IEMI (last step of the assessment process in Figure 6).

PROTECTION OPTIONS FOR CONTROL EQUIPMENT

Once the assessment process is complete (and it must be done separately for both E1 HEMP and IEMI), there are a range of protection techniques that can then be deployed (see Figure 8). In particular, one needs to compare the levels of currents and voltages induced on cables inside of the building from the penetrating EM fields through the building walls to the current and voltage levels that are due to the external cable penetrations. If the external cables' currents and voltages are small due to good bonding and grounding techniques, then the focus must be on reducing the internal fields' coupling to the cables. If the reverse is true, then the focus needs to be on the external cables.

Since control houses are typically not very large and are often constructed of reinforced concrete, it is possible to add external metallic sheeting or

- **Improve the building/room shielding effectiveness**
  - **External metal sheeting**
  - **Internal metallic walls**
  - **Shield rooms or racks**
  - **New metallic building**
- **Improve shielding/grounding of internal cabling**
- **Apply cable ferrites on internal metallic cables**
- **Add filters and/or surge arresters at metallic cable connections (including antenna connections)**
- **Use fiber optic cables (w/o metal) inside**
- **Use high quality shielding and external grounding for external cables – Replace metallic cabling with fiber optic cables**
- **Improve security measures for IEMI (distance, monitoring, etc.)**

Figure 8: Examples of protection techniques to be applied after an assessment is complete.

internal "shielded" wallboard to increase the shielding effectiveness of the building. Also, if there is some extra-sensitive equipment inside the building, a shielded rack or room can be built inside. If there is a plan to upgrade the internal electronics to newer technologies, a last option would be to remove the existing building and rebuild it as a metal building, which tends to provide higher levels of protection. Note that this does not require a "perfect" 80-100 dB building, but rather a typical bolted metal building that can be built off-site and transported to an existing concrete pad.

Separately, since the resistive grounding for lighting transients is often not sufficient, all external cables should be evaluated to ensure that they are grounded properly for high frequency transients. For shielded control cables, one should ground them before entry into the building to metallic surfaces (using U clamps, not ground wires). If the building is of concrete construction, then a metal plate can be mounted on the side of the building and connected to the grounding grid. Ideally, the bonding should take place below the surface of the earth, so the cable itself is not exposed to the air after the bonding.

This procedure has been applied with good success for several existing control buildings. Of course, it is recommended that, if unshielded cables are used for the control cables, these should be converted to shielded cables or fiber optic cables (according to the new power substation communications standard IEC 61850-3 [13]). A recent design has used fiber optic control cables according to this new IEC standard, reducing its vulnerability to HEMP and IEMI [14].

Once the reductions of internal wire currents and voltages are completed, it is still possible that the reductions won't be sufficient with respect to the immunity of the equipment. In these cases, it may be possible to use internal wire metallic conduits, ferrites, and, in the worst case, surge arresters. The latter is not the best choice as there will be a need to test and replace surge arresters over time. Also, surge arresters designed for very fast transients are not easy to find and may be very expensive (most lightning surge arresters operate too slowly to be effective).

A final point to mention is that for the IEMI threat, distance between the attacker and the control house is very important, as the fields fall off rapidly from any EM weapon. All substations are fenced around the outside to keep the public away from hazardous electrical voltages, currents, and fields. In fact, many substations are now using solid fencing instead of chain link to reduce the potential threat related to attacks using firearms. A solid material will provide additional attenuation to an attacker at the fence position, and any effort to move further back to find an elevated position to illuminate a control house will extend the distance and reduce the field on “target.” As part of IEMI assessments, I have participated in evaluating the best locations for line-of-sight attacks on multiple control houses, and often the fields that would be directed on a control house can be reduced by factors of 2-10 based on extended ranges and opaque fencing.

SUMMARY

This article has described the basic threat information for both E1 HEMP and the EM weapon fields that can create IEMI. We have described the special problem of the high voltage control houses found within transmission substations and the importance of the reliable operations of the electronics inside.

Although the electronics inside the control houses are protected from natural high voltage transients, the frequency content and levels of the E1 HEMP and IEMI fields exceed the normal EMC protection methods found in these buildings today. This is mainly due to the fact that the EM shielding of the control houses is much higher for lightning fields than it is for E1 HEMP/IEMI, and the cable grounding techniques are only adequate for lightning.

This means that an assessment method is needed to evaluate the situation for existing control houses and their control cable system. In this article, we have detailed a method that has been applied to over 100 control house buildings. We have also presented several methods of improving the protection of these buildings from E1 HEMP and IEMI by examining different grounding methods, the use of shielded cables, the use of ferrites, etc., through laboratory and installation measurements.

Given that there are multiple methods available to reduce the susceptibility of the important equipment inside the control houses, it is possible to evaluate the effectiveness and the cost of these options. In addition, for those power companies who are upgrading the electronics and communications protocols in their substation control houses, it is possible to develop a specific protection approach that can be replicated over and over.

One last point I want to emphasize is that while E1 HEMP and IEMI are very unusual, and hopefully, low probability threats, the protection methods to be used are found within the EMC “toolbox.” Ultimately, it is a matter of defining the requirements for protection as opposed to developing new protection methods.

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10. Edward Savage, James Gilbert and William Radasky, "Expedient Building Shielding Measurement Method for HEMP Assessments," IEEE Transactions on Electromagnetic Compatibility, Vol. 55, No. 3, June 2013, pp. 508-517.
11. IEC 61000-2-13 Ed. 1.0 (2005-03-09): Electromagnetic compatibility (EMC) – Part 2-13: High-power electromagnetic (HPEM) environments – Radiated and conducted.
12. IEC 61000-2-10 Ed. 1.0 (1998-11-24): Electromagnetic compatibility (EMC) – Part 2-10: Environment – Description of HEMP environment – Conducted disturbance.
13. IEC 61850-3 Ed. 2.0 (2013-12): Communications networks and systems for power utility automation – Part 3: General requirements
14. Eric Easton, Kevin Bryant, and William Radasky, "Design approach for HPEM mitigation for electrical substations," IEEE EMC Symposium, Reno, Nevada, July 2020, pp. 439-441.

LIGHTNING AND RF ELECTRICAL BONDING

The Origin and Application of the 2.5 mΩ Requirement

The report on which this article is based was put together for internal government use some time ago. But the continued relevance of the information contained in that report recently became apparent when a discussion group on LinkedIn variously labeled the subject matter requirement (2.5 milliohm bond) mysterious, obsolete, "black magic," and ultimately, unnecessary. Apparently, the LinkedIn contributors had little or no idea of the historical context of the requirement and evoked, for this author, the quintessential "Dilbert" moment shown here.

The author was also reminded of a famous observation by Arthur C. Clarke, which is paraphrased as follows:

> "Any sufficiently obscure technology is indistinguishable from black magic."

To help provide some context for their discussion and in an effort to curb the all-too-frequent instinct to "move fast and break things," the author posted this report to the LinkedIn group, along with the following advice, which applies regardless of your field of endeavor, engineering or otherwise.

> "A rule of thumb for handling the 'mystery of engineering' is that a lack of understanding is not a condemnation of the misunderstood. Every engineering principle that has made it into a lasting standard had validity at some time. Whether or not it applies in a particular situation depends on the relationship of the problem at hand to the original problem addressed by the requirement.
>
> "Until the original application is fully understood, one has no basis for judging the applicability to any specific case.

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By Ken Javor

"In the broadest possible terms, reality exists independent of our perception and understanding. Sir Francis Bacon said some 500 years ago that 'Nature, to be commanded, must be obeyed.' The author's corollary to that is 'Nature, to be obeyed, must be understood'."

With that introduction and background, the following report presents everything one needs to know about the origin and application of the 2.5 milliohm electrical bonding requirement.

PURPOSE

The purpose of this report is to document the origins and rationale vs. present practice regarding the now ubiquitous 2.5 milliohm class L & R (lightning and radio frequency) bonding requirements used in aerospace, space, and military vehicles.

REFERENCE DOCUMENTS

Please see Table 1 below.

Reference	Document Number Date	Document Title
1	MIL-B-5087 09 November 1949	Bonding; Electrical (for Aircraft)
2	MIL-B-5087A (ASG) 30 July 1954	Bonding; Electrical (for Aircraft)
3	MIL-B-5087B (ASG) 15 October 1964	Bonding, Electrical, and Lightning Protection, For Aerospace Systems
4	DOT/FAA/T-89/22 September 1989	Fisher, F.A., Plumer, J.A., & Perala R.A. "Aircraft Lightning Protection Handbook"
5	NAVAER 16-5Q-517 circa 1946	Elimination of Radio Interference Problems in Aircraft
6	N/A 1990	Fisher, F.A., Plumer, J.A., & Perala R.A. "Lightning Protection of Aircraft" Lightning Technologies, Pittsfield, MA.
7	MIL-STD-461G 11 December 2015	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipments
8	RTCA/DO-160G 08 December 2010	Environmental Conditions and Test Procedures for Airborne Equipment
9	ISBN 0-471-01995 1997	Smith, A. A. "Coupling of External Electromagnetic Fields to Transmission Lines." Interference Control Technologies
10	ISBN 0-471-04107-6 1978	Vance, Edward F. "Coupling to Shielded Cables." Wiley-Interscience.
11	T.O. 16-1-45 25 June 1945	Handbook of Elimination of Radio Noise in Aircraft
12	T.O. 08-10-139 03 January 1943	Radio Transmitter BC-37E & Associated Equipment; Instruction Book for Operation and Maintenance of [Page 6, section 10.d (2)]

Table 1: Reference Documents

Note that, while MIL-B-5087B is long obsolete, the bonding classes survive in MIL-STD-464, and in NASA-STD-4003. MIL-B-5087 is not technologically obsolete, but it contained instructions on how to implement bonds, as opposed to bond performance, and the 1994 SECDEF Perry memo, "Specifications & Standards - A New Way of Doing Business," required military standards to be either performance or interface standards, but not "how to" standards.

HISTORICAL CONTEXT

Reference 1, section 3.3.1, says the rationale for their detailed lightning requirements is:

> "…to achieve a lightning bonding system such that a lightning discharge current may be carried between any two extremities of the aircraft without risk of damaging flight controls or of producing voltages within the aircraft in excess of 500 volts. (These requirements are based on a lightning current surge which reaches a crest wave of 100,000 amperes at 10 microseconds and drops to 50,000 amperes at 20 microseconds.)"

This requirement is unchanged in Reference 2 and is equivalent to maintaining 5 milliohms resistance. Reference 3, section 3.3.4, has similar wording, but note the change in assumed worst-case lightning attachment (resulting in a 2.5 mΩ requirement):

> "…to achieve protection against a lightning discharge current carried between the extremities of an airborne vehicle without risk of damaging flight controls or of producing sparking or voltages within the vehicle in excess of 500 volts. These requirements are based on a lightning current waveform of 200,000 amperes peak, a width of 5 to 10 microseconds at the 90-percent point, not less than 20 microseconds width at the 50-percent point, and a rate of rise of at least 100,000 amperes per microseconds (sic)."

The significance of the 500-volt number is explained in Reference 4, section 6.2.5, as follows: "Such a voltage did not present much of a hazard to the electromechanical and vacuum tube components in use when MIL-B-5087B was formulated." It should be emphasized that the 500-volt number goes back to References 1 and 2 in 1949/1954, when relays and vacuum tubes were the building blocks of electronic circuits on aircraft.

The need to limit the structure potential drop to 500 volts is because aircraft at that time used structure not only for power current return but also for signal current return. In the 1940s and 1950s, even the most sensitive signals – those picked up by an antenna and conducted to a radio receiver on an unshielded (no coax) wire – might use structure return. Thus, any noise on structure is in series with the desired signal, as depicted conceptually in Figure 1.

In Figure 1, lightning attaches to the aircraft at one end, and exits the other. In between, based on the lightning resistance requirement, the full-scale lightning current induces no more than 500 V across the aircraft, which potential is in series with any circuit using the lightning current-carrying aircraft structure for a return path (ground plane interference – GPI).

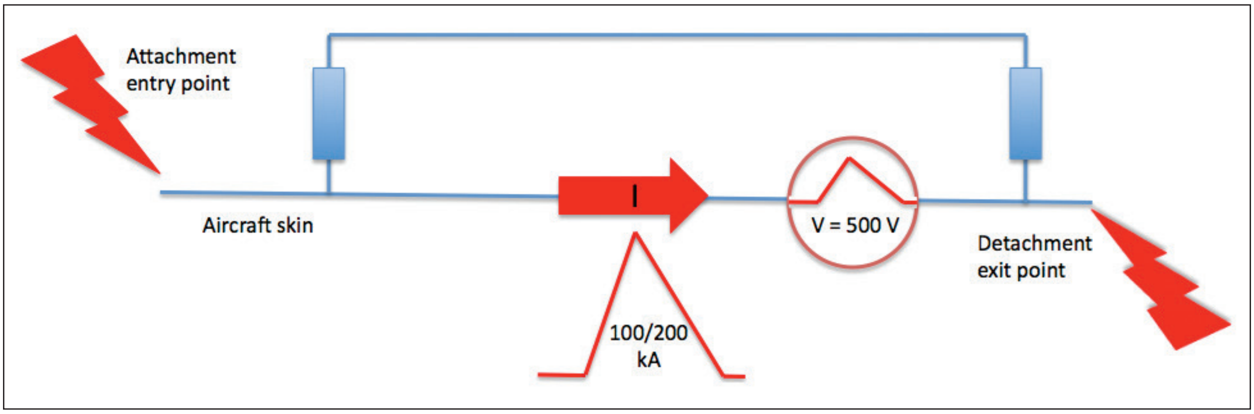


Figure 1: Effect of lightning attachment current on ground-referenced signal

Note that there is no need for any special bond provisions to structure in the circuit of Figure 1, other than that required to make the circuit function in and of itself. Imposing a class R bond does nothing to improve functionality under any circumstances of radiated susceptibility or ground plane noise, such as ground bounce or a lightning transient.

The practical application of the conceptual Figure 1 in the time period when References 1 and 2 were written and applicable is shown in Figures 2a and 2b (taken from Reference 5). These Figures show how noise couples into the receiver front end. Only in our case, it is lightning, whereas the Reference 5 discussion was about radio frequency interference.

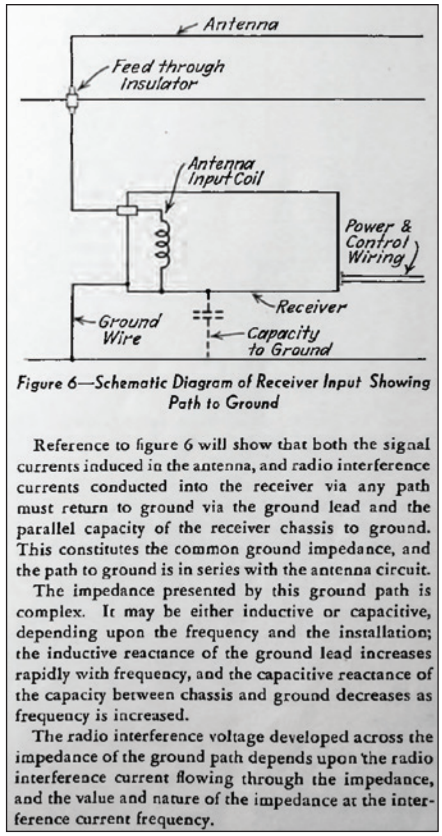


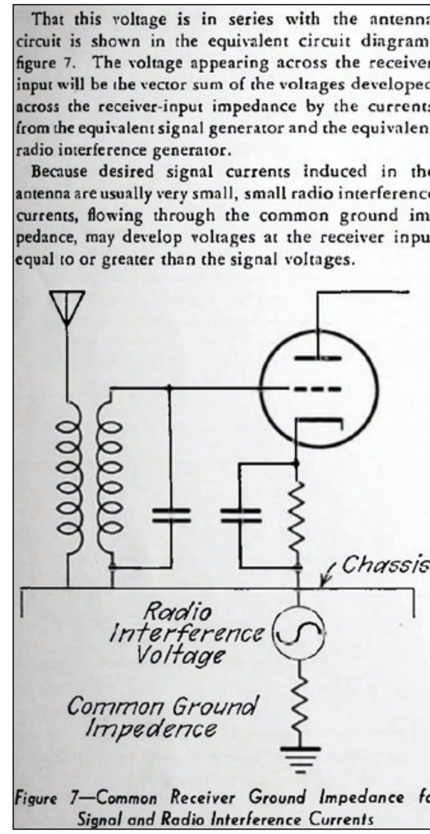
Figure 6—Schematic Diagram of Receiver Input Showing Path to Ground

Reference to figure 6 will show that both the signal currents induced in the antenna, and radio interference currents conducted into the receiver via any path must return to ground via the ground lead and the parallel capacity of the receiver chassis to ground. This constitutes the common ground impedance, and the path to ground is in series with the antenna circuit.

The impedance presented by this ground path is complex. It may be either inductive or capacitive, depending upon the frequency and the installation; the inductive reactance of the ground lead increases rapidly with frequency, and the capacitive reactance of the capacity between chassis and ground decreases as frequency is increased.

The radio interference voltage developed across the impedance of the ground path depends upon the radio interference current flowing through the impedance, and the value and nature of the impedance at the interference current frequency.

Figure 2a: Grounding excerpt from Reference 5


That this voltage is in series with the antenna circuit is shown in the equivalent circuit diagram, figure 7. The voltage appearing across the receiver input will be the vector sum of the voltages developed across the receiver-input impedance by the currents from the equivalent signal generator and the equivalent radio interference generator.

Because desired signal currents induced in the antenna are usually very small, small radio interference currents, flowing through the common ground impedance, may develop voltages at the receiver input equal to or greater than the signal voltages.

Figure 7—Common Receiver Ground Impedance for Signal and Radio Interference Currents

Figure 2b: GPI excerpt from Reference 5

We should note here that the lightning extremity-to-extremity resistance is precisely that – a resistance – not a single bond value. Figure 3 shows actual values for specific (unidentified and obsolete) aircraft. A comparison of resistance per unit length to total resistance is indicative of the degree to which the various models are "wide-body" or not. The larger the circumference, the more area there is over which the lightning current spreads (in a nose-to-tail strike) and the lower the resistance per unit length. The spread of lightning current over the entire circumference ensures no more than the 500 V criterion is encountered over any nose-to-tail path, and that all cables running fore and aft will see roughly the same end-to-end potential drop, no matter where along the periphery they are placed.

We should also note that the several sub-paragraphs under the lightning bonding sections in the first three references never mention the requirement of bonding an electronic equipment enclosure to structure. Instead, the subsections deal with how to achieve suitably low bonding resistances to protect the 500-volt value, and to ensure lightning currents flow in the intended bond paths. It is of critical importance to understand that this was the only lightning protection design technique of importance to electronic equipment at the time. It is something that References 4 and 6 don't adequately describe.

On this topic, References 4 and 6, section 5.5.1, say in part (the important part is italicized):

> "**Defined lightning threat:** AC 20-53 and MIL-B-5087 each defined the lightning threat as a 200 kiloampere (kA) peak current…
>
> Both documents required tests of critical components, such as fuel tank skins, access panels,

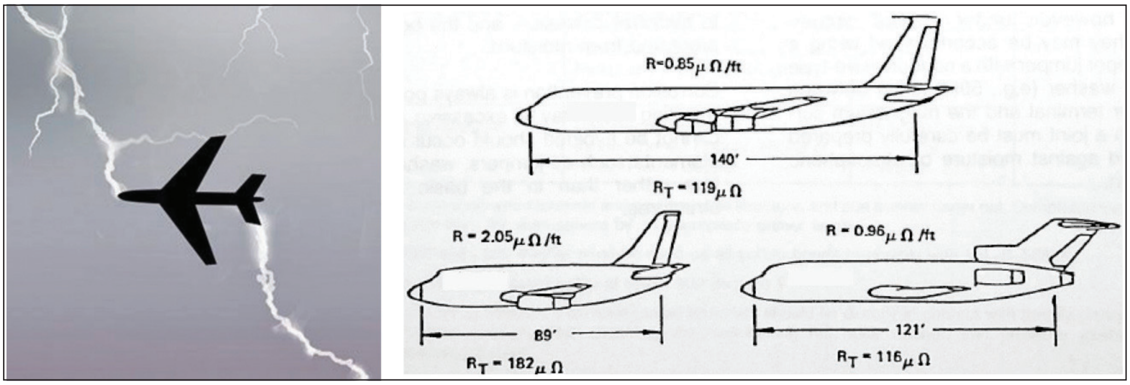


Figure 3: End-to-end resistance of some older aircraft
(photo from https://aviation.stackexchange.com/questions/888/what-happens-when-an-airplane-gets-struck-by-lightning)

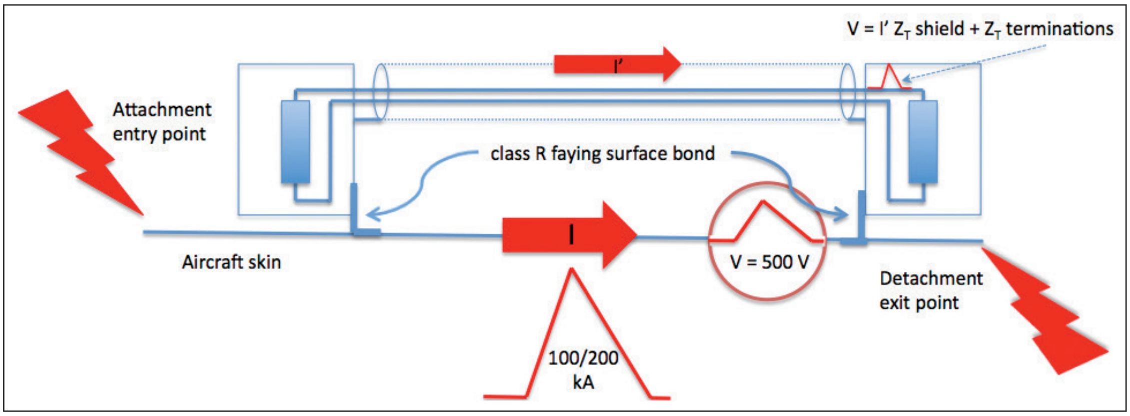


Figure 4: Effect of lightning attachment current on an above-ground signal

> filler caps, antenna installations, and other "points of entry" on the aircraft. *No attention was given to the effects of currents conducted through interior structures or systems, or to indirect effects of lightning on electrical and avionics systems. These latter effects were not well understood during this period*."

It is misleading to say, "*These latter effects were not well understood during this period.*" The only (indirect, resistive coupling) effect on a circuit using structure return was the transient ground potential, which the lightning resistance requirement limited to the target 500-volt potential. They understood what needed to be done, and they did it. The modern techniques of dedicated above ground returns and cable shielding discussed in the next section of this report were not in widespread use, and therefore there were no other indirect effects requiring control. It should be noted that class R bonding was specified, even though it would not have helped the types of circuits shown in Figures 1 and 2. There was some use of coax and EMI filtering. More on this in the next section.

Therefore, we can say that the (implied) 2.5 mΩ class L lightning requirement was the original lightning indirect effects requirement. There are plenty of other class L requirements in each of References 1 – 3 that control direct effects directly, especially fuel ignition.

MODERN USAGE

Modern aluminum aircraft continue to use structure for power current return and 28-volt discretes, but not signals, and definitely not radio signals, which use coax. And NASA spacecraft – at least in the author's personal experience – don't use structure even for power current return. So, our situation isn't as dire as portrayed in Reference 5, but we also no longer use robust vacuum tubes that can handle 500 volts for tens of microseconds. So, we have offsetting trends here. We have much more damage-susceptible circuits, solid-state replacing vacuum tube, but we also don't place structural noise in series with the desired signal.

When using dedicated above ground signal returns, a lightning transient will couple a potential/current onto an entire cable harness. If that harness is shielded, only that potential that couples within due to shield transfer impedance will be seen to be in series with the signal.

So, the use of dedicated returns and shields places two ameliorating conditions at our disposal. The first is that the full lightning current isn't induced across our signal return. The effect of this can be seen looking at Reference 7 CS117[1] transient levels, as compared to the full threat aircraft strike of 200 kA. The very highest induced current is 2 kA.

If we compare Figure 4 to Figure 1, the same lightning attachment to the aircraft skin is present, and the same induced GPI. But that doesn't matter as much anymore because the ground bounce is not directly in series with the above ground circuit. The ground bounce neither interferes with nor can damage the circuit components. A smaller current per Table VII from Reference 7 (Table 2 on page 28) has coupled to the cable shield and induces a line-to-ground potential which is the cable drive current multiplied by the shield transfer impedance in series with shield termination impedances. As per Figures 5a and 5b, excerpted from References 9 and 10, shield transfer impedance in the lightning spectrum can be worst-case bounded by shield dc resistance, so milliohms per meter. It now becomes critical to control the shield termination impedance, which is comprised of two series impedances: 1) the shield through the connector to the equipment enclosure; and 2) from the equipment enclosure to structure. Hence, the class R bonding requirements.

The actual effect of increasing the impedance versus the dc resistance is illustrated by a simple transfer impedance measurement.

In Figures 6a and 6b on page 30, the transfer impedance of the white 50 Ω coax was measured using its bnc connectors, and then inserting at the interrogated end a pair of bnc-to-banana adapters to simulate a shield pigtail termination. In this case, the dc resistance of the plug and jack adapters is at least

TABLE VII. CS117 Test and limit levels for multiple stroke and multiple burst lightning tests.

Multiple Stroke			
Applicability	**Test Description**	**Internal Equipment Levels****	**External Equipment Levels****
All equipment installations	Waveform 2 (WF2)/ Waveform 1 (WF1)	First Stroke V_L = 300 V (WF2) I_T = 600 A (WF1) I_T = 60 A* Subsequent Strokes V_L = 150 V (WF2) I_T = 150 A (WF1) I_T = 30 A*	First Stroke V_L = 750 V (WF2) I_T = 1500 A (WF1) I_T = 150 A* Subsequent Strokes V_L = 375 V (WF2) I_T = 375 A (WF1) I_T = 75 A*
All equipment installations	Waveform 3 (WF3) – 1 MHz and 10 MHz	First Stroke V_T = 600 V (WF3) I_L = 120 A (WF3) I_L = 24 A* Subsequent Strokes V_T = 300 V (WF3) I_L = 60 A (WF3) I_L = 12 A*	First Stroke V_T = 1500 V (WF3) I_L = 300 A (WF3) I_L = 60 A* Subsequent Strokes V_T = 750 V (WF3) I_L = 150 A (WF3) I_L = 30 A*
Equipment installations routed in areas with composite skin/structure.	Waveform 4 (WF4)/ Waveform 5A (WF5A)	First Stroke V_L = 300 V (WF4) I_T = 1000 A (WF5A) I_T = 300 A* Subsequent Strokes V_L = 75 V (WF4) I_T = 200 A (WF5A) I_T = 150 A*	First Stroke V_L = 750 V (WF4) I_T = 2000 A (WF5A) I_T = 750 A* Subsequent Strokes V_L = 187.5 V (WF4) I_T = 400 A (WF5A) I_T = 375 A*
Multiple Burst			
Applicability	**Test Description**	**Internal Equipment Levels****	**External Equipment Levels****
All equipment installations	Waveform 3 (WF3) – 1 MHz and 10 MHz	V_T = 360 V (WF3) I_L = 6 A (WF3)	V_T = 900 V (WF3) I_L = 15 A (WF3)
Equipment installations that utilize short, low impedance cable bundle installations.	Waveform 6 (WF6)	V_L = 600 V (WF6) I_T = 30 A (WF6)	V_L = 1500 V (WF6) I_T = 75 A (WF6)

Table 2: CS117 test and limit levels for multiple stroke and multiple burst lighting tests (Table VII from Reference 7)

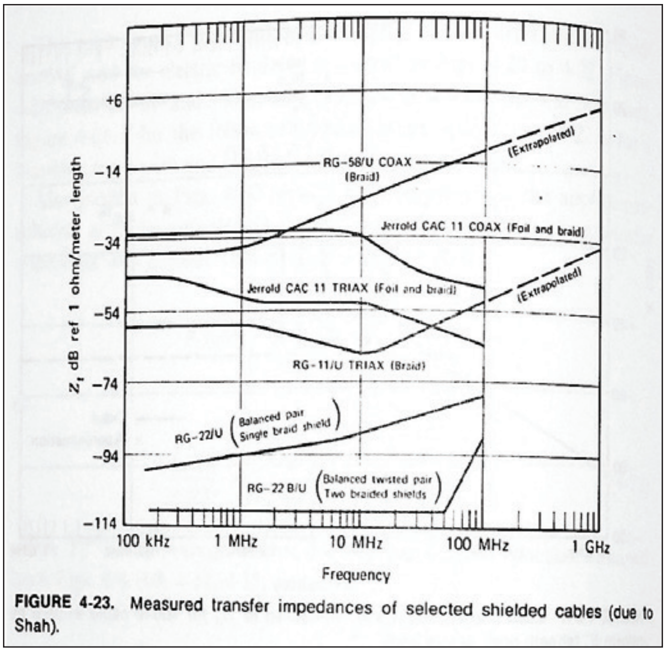


Figure 5a: Typical braided shield transfer impedance from Reference 9

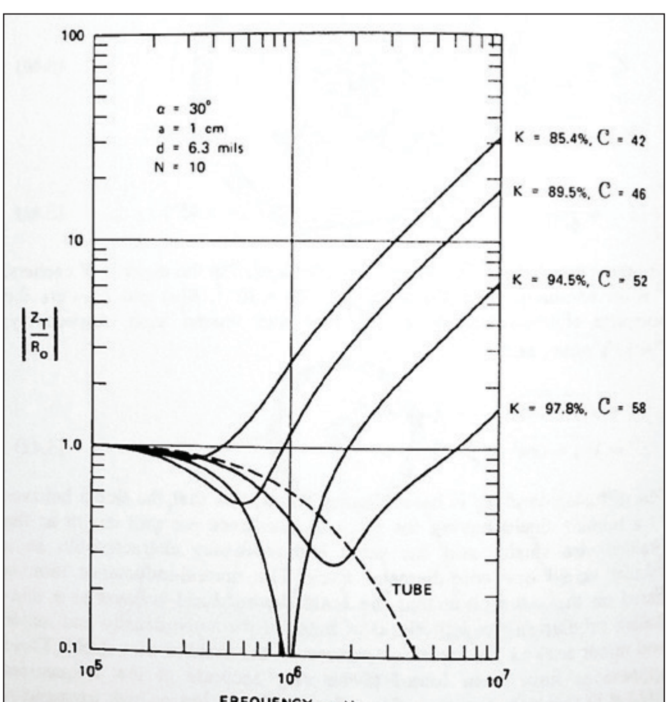


Figure 5b: Braided shield transfer impedance behavior from Reference 10

as low as that of an equal length of braided shield. The difference measured is in the impedance of the termination.

Figures 7a and 7b show that degradation is strongly frequency dependent. At 100 kHz, degradation in transfer impedance is 15 dB, while at 30 MHz degradation is 37 dB.

Figure 8 shows another common application that requires a class R bond: the use of filters with capacitive bypass to the equipment enclosure, and hence to structure. In order for the capacitor to be able to short noise currents to ground and provide an attractive path for said currents instead of the circuit component behind the filter, the capacitor plus all connections to structure must be very low impedance.

Well before Reference 1 was released, Reference 11 was recommending 2.5 mΩ bonds for communication electronics, and when using bond straps, ensuring a maximum 5:1 length-to-width ratio.

Because class R bonds are somewhat indiscriminately specified and used, it is worthwhile to quote exact wording for this requirement in References 1–3, as tabulated in Table 3 at the end of this report on page 32.

Several interesting facts may be gleaned from this tabular comparison of the three different revisions of MIL-B-5087:

- The first two revisions express the rationale or purpose of the requirement. The final revision does not.
- MIL-B-5087A's unique wording explains the rationale for the class R dc bond. It is clear that low rf impedance is the goal, and that the MIL-B-5087 2.5 milliohm value is a means to an end, not an end-in-itself. The 80-milliohm value is hard to fathom, since it is less than a nanohenry at 20 MHz, the upper end of the specified range. It is likely not coincidental that the range over which the bond impedance is specified is that of the Reference 12 WWII-era BC-375 transmitter that was designed

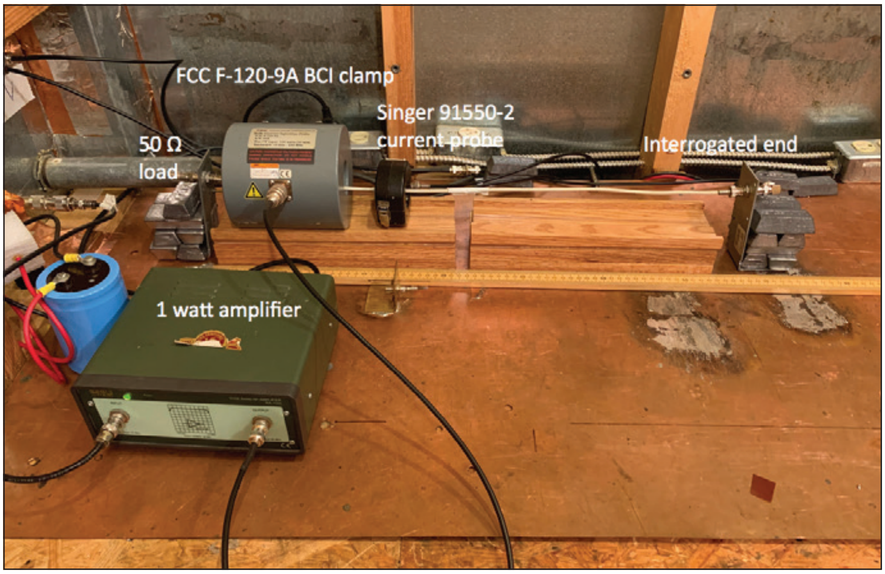


Figure 6a: Baseline transfer impedance measurement set-up

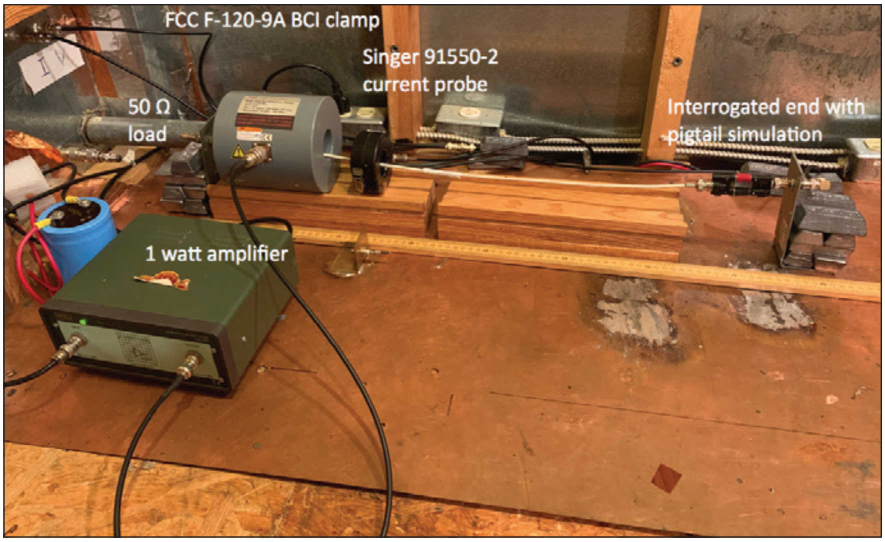


Figure 6b: Identical to baseline measurement except banana adapters added to simulate pigtail shield termination

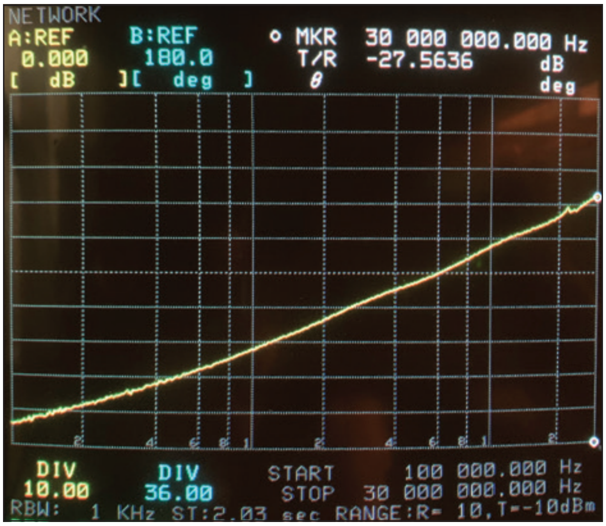


Figure 7a: Baseline transfer impedance test results for set-up in Figure 6a. Ordinate scale is transfer impedance in dB Ω. The network analyzer is taking the ratio of the coupled potential (T-input) to the induced shield current (R input).

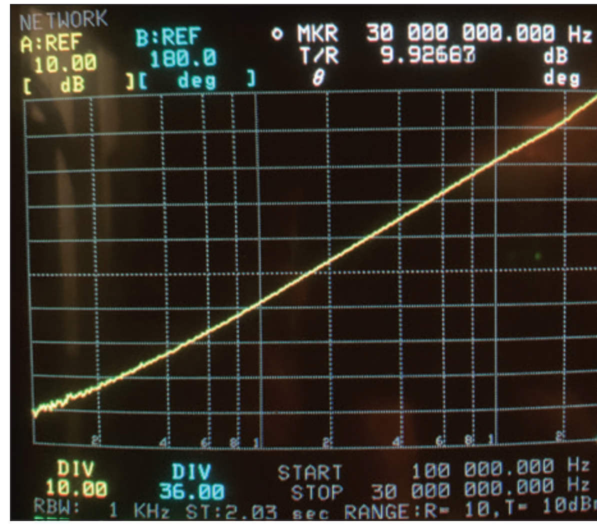


Figure 7b: Pigtail transfer impedance test results for set-up in Figure 6b. Ordinate scale is transfer impedance in dB Ω (note 10 dB offset in reference level)

to drive a high impedance antenna through an open-wire lead-in to the antenna.

- The addition of the rf impedance verification might have been the first such instance, certainly not the last. This particular approach has been attempted to be inflicted on many programs over the years, including the International Space Station. It doesn't end well. Very difficult to instrument in practice, the approaches of design in Reference 1 and dc measurement and design in Reference 3 work best, that is, the design is low impedance: faying surfaces, wide area to short length ratio bond topology.
- MIL-B-5087B is the only version to require a specific dc resistance (the now ubiquitous 2.5 milliohm requirement) for class R. This is the first place the value appears in any revision of MIL-B-5087, even though it was an end-to-end resistance requirement for lightning protection, but not so stated.
- It is often the case that a design looks good (faying surfaces) but doesn't quite meet the 2.5 milliohm target. Values will range from just over to several

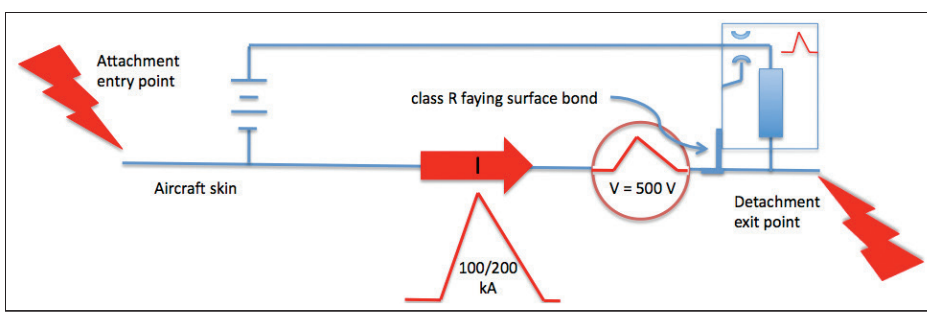


Figure 8: Effect of lightning attachment current on ground-referenced power

Ref.	Class R Bond Purpose	Class R Bond Requirement
1	3.2.1(d) Prevent the development of r-f potentials on conducting frames and enclosures of electrical and electronic equipment and on conducting objects adjacent to unshielded transmitting antenna lead-ins.	3.3.4.1 Equipment containing electrical circuits which may produce radio frequencies, either desired or undesired, must be installed so that there is a continuous low impedance path from the equipment enclosure to the aircraft structure. Bonding shall be accomplished by bare, clean metal-to-metal contact of all mounting plate, rack, shelf, bracket and structure mating surfaces so as to form a continuous, low impedance ground from equipment mounting plates. Bonding jumpers shall not be used. … 3.3.4.2 All conducting items having any linear dimension greater than 12 inches that are within 3 feet of unshielded transmitting antenna lead-ins shall have a low impedance bond to structure. Direct metal-to-metal contact with structure is desired, but if a jumper must be used, it shall be as short as possible.
2	Same as Reference 1 wording	3.10.1 Equipment containing electrical circuits which may produce radio frequencies, either desired or undesired, must be installed so that there is a continuous low impedance path from the equipment enclosure to the aircraft structure. Bonding shall be accomplished by bare, clean metal-to-metal contact of all mounting plate, rack, shelf, bracket and structure mating surfaces so as to form a continuous, low impedance ground from equipment mounting plates. If it is proposed that bonding be accomplished by other than metal-to-metal contact of the mating surfaces, the contractor shall demonstrate by a laboratory test that his proposed method results in an r-f impedance of less than 80 milliohms over a frequency range of 0.2 to 20 mc for 1 bond applied in the proposed manner. Bonding jumpers shall not be used… 3.10.2 All conducting items having any linear dimension greater than 12 inches that are within 1 foot of unshielded transmitting antenna lead-ins shall have a low impedance bond to structure. Direct metal-to-metal contact with structure is desired, but if a jumper must be used, it shall be as short as possible.
3	No rationale provided	3.3.5.1 All electrical and electronic units or components which produce electromagnetic energy, shall be installed to provide a continuous low-impedance path from the equipment enclosure to the structure. The contractor shall demonstrate by test that his proposed bonding method results in a direct current (dc) impedance of less than 2.5 milliohms from enclosure to structure. The bond from the equipment enclosure to the mounting plate shall also comply with these requirements, except that suitable jumpers may be used across any necessary vibration isolators. 3.3.5.2 All conducting items having any linear dimension greater than 12 inches or more installed within 1 foot of unshielded transmitting antenna lead-ins shall have a bond to structure. Direct metal-to-metal contact is preferred. If a jumper is used, the jumper shall be as short as possible. 3.3.5.3 Vehicle skin.- Vehicle skin shall be so designed that a uniform low impedance skin is produced through inherent rf bonding during construction. Rf bonding must be accomplished between all structural components comprising the vehicle, i.e., wings, fuselage, etc. Hatches, access doors, etc., not in the proximity of interference source or wiring shall be either bonded to or permanently insulated from vehicle skin, except for the protective static bond. Consideration shall be given to the design to operational vibration and resultant breakdown of insulating finishes or intermittent electrical contact.

Key: Unique to MIL-B-5087A   Unique to MIL-B-5087

Table 3: Tabulation of requirements in References 1-3

tens of milliohms. There is always a desire to waive the discrepancy with an excuse to the effect that the real goal is low rf impedance of a few ohms and the design by inspection meets that. The danger here is that a metal-metal faying surface bond should easily come in under 2.5 milliohms and, if it doesn't, a likely suspect is dirt, corrosion, or possibly inadequate etching away of paint or another surface contaminant. Long term, such impurities can contribute to bond degradation by allowing more impurities in (i.e., keeping the bond from being gas-tight), or galvanic action, especially combined with the bond not being gas tight.

- Similarly, bond meters come in different varieties. Those geared towards lightning verification often use quite high potentials, which can punch through a thin layer of insulating contamination and show a low resistance where a meter optimized for EMI work, with maximum potential of a few tens of millivolts, accurately records the behavior of the bond for EMI currents.
- MIL-B-5087B uniquely tries to make the aircraft skin a perfect ground plane and shield.
- The second paragraph in each version is in reference to the Reference 12 100 W rf transmitter that could output as much as 5000 V on an open wire antenna lead-in at a few hundred kilohertz; hence, capacitive coupling to nearby metal would have been an issue.

ENDNOTE

1. Borrowed almost intact from Reference 8, section 22.

SCIF AND RADIO FREQUENCY SECURED FACILITY DESIGN

An RF Shielding Design Guide to Navigating ICS/ICD 705 and NSA 94-106 Requirements

In recent years, we've noticed a growing confusion in the industry over sensitive compartmented information facilities (SCIF) design and performance requirements. Part 1 of this article is intended to bring some clarity to various documents and performance requirements from a radiofrequency (RF) shielding perspective to aid in the design and construction of these facilities.

INTRODUCTION TO SCIF SPECIFICATIONS

The two most referenced documents for SCIF design are ICD/ICS-705 Technical Specification for Construction and Management of Sensitive Compartmented Information Facilities.[1] and NSA 94-106 [2]. It has been our experience that these documents are often referenced interchangeably or in conjunction with each other.

In some cases, project documents will indicate that a facility has been designed to meet NSA 94-106 as identified in ICD/ICS-705. This is problematic as ICD/ICS-705 does not reference NSA 94-106, nor is ICD/ICS-705 intended to meet the requirements set forth in NSA 94-106. This article will analyze the purpose of ICD/ICS-705 and NSA 94-106 as it pertains to RF shielding and highlight some of the differences between the two standards.

Joel Kellogg is the Director of Business Development for Healthcare, Industry, and Government at ETS-Lindgren and has more than 20 years of design, production, and management experience. He can be reached at joel.kellogg@ets-lindgren.com.

By Joel Kellogg

SCIF OVERVIEW

It is important to understand that a SCIF can come in many different forms. In some applications, a SCIF may be a physical barrier or a physically secured room, and other applications may require acoustic and RF shielding enhancements. An Accrediting Officer (AO) and Site Security Manager (SSM) will evaluate the risk and vulnerability of a SCIF to determine the physical and technical measures that must be deployed for each SCIF application. Further, the Certified TEMPEST[3] Technical Authority (CTTA) will evaluate for TEMPEST requirements and provide direction on RF shielding requirements based upon risk of RF interference to the SCIF.

SCIF CONSTRUCTION METHODS AND RF SHIELDING PERFORMANCE REQUIREMENTS

While it is not uncommon for NSA 94-106 to be referenced as part of a SCIF project, the ICD/ICS-705 construction recommendations will not achieve the RF performance required under NSA 94-106, which include attenuation levels as high as 100 dB at 10 GHz.

In order to achieve the performance requirements under NSA 94-106, a six-sided shielding system with higher performance RF doors, filters, and appropriately treated RF penetrations is required. The details in ICD/ICS-705 show a more limited RF shielded partition using RF foil between layers of drywall with 6” to 8” returns at the floor and ceiling per Figures 1 and 2). This can become confusing if both standards are referenced as part of a project.

Beyond the limited shielded barrier presented in ICD/ICS-705, the technical specification identifies the use of 1800 Ultra Radiant Barrier for SCIFs manufactured by rFOIL® [4]. A review of the product data provided by the manufacturer demonstrates that the product can be used for ICD/ICS-705 but is not intended for use in NSA 94-106 applications.

The product data as depicted in Figure 3 on page 36 indicate the shielding material is not capable of providing 100 dB at frequencies greater than 1.5 GHz.

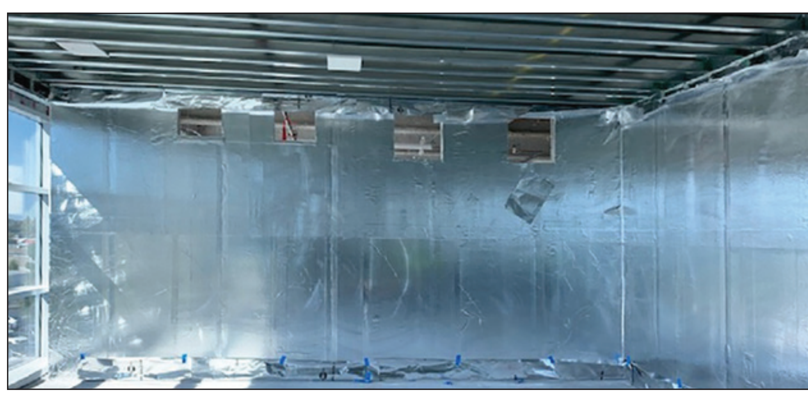


Figure 1: Example of ICD/ICS-705 RF shielding barrier installation

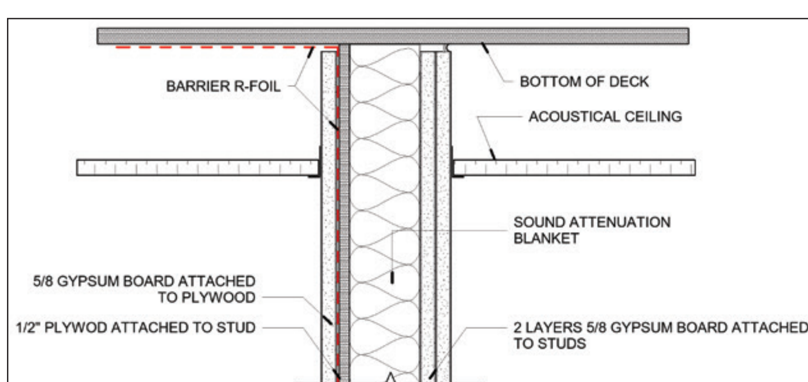


Figure 2: One of three wall sections presented in ICD/ICS-705 depicting an RF barrier

Additionally, it is unclear whether the material would meet the NSA 94-106 requirements below 100 MHz. Based on the trend in performance provided in the product data, it is unlikely that the material would meet the NSA RF performance requirements.

Lastly, the product data sheet appears to indicate that a smaller sample of material was tested on a steel RF shielded enclosure. This test would provide an indication of the material's performance under ideal circumstances but would not provide a clear indication of how performance would be impacted by various installation methods.

Beyond the product data, the construction methodology under ICD/ICS-705 should also be considered. ICD/ICS-705 identifies that the barrier be installed between two layers of drywall for the walls with the shielding material being turned at the floor and ceiling and extending several inches away from the wall. When the ceiling is comprised of a metal pan deck, it is often recommended that the shielding barrier be tied into the metal pan deck.

But the installation of the shielding barrier between two layers of drywall results in the shielding being perforated by the drywall screws utilized to install the second layer of drywall. Each perforation further degrades the overall shielding performance. This results in a less effective shielding system or Faraday cage and will not achieve the performance requirements of NSA 94-106.

IMPORTANCE OF RF SHIELDED COMPONENTS

ICD/ICS-705 only identifies an RF barrier when required and does not identify requirements for other RF shielded components including doors, filters, and penetrations such as waveguide air vents. The structure of ICD/ICS-705 renders these components unnecessary as they provide limited value from an RF shielding effectiveness perspective without a six-sided shielding system. Despite this, many projects identify requirements for these RF components when utilizing ICD/ICS-705 construction methods while referencing the NSA 94-106 shielding effectiveness or some other (often arbitrary) level of RF shielding effectiveness. These components may provide some value but, in terms of improving the RF shielding effectiveness, that value is often limited. For example, RF filters could attenuate unwanted conducted emissions, but will provide little improvement in overall shielding attenuation.

SECURITY CONSIDERATIONS

ICD/ICS-705 is intended to provide a level of security and often takes advantage of distances from the SCIF

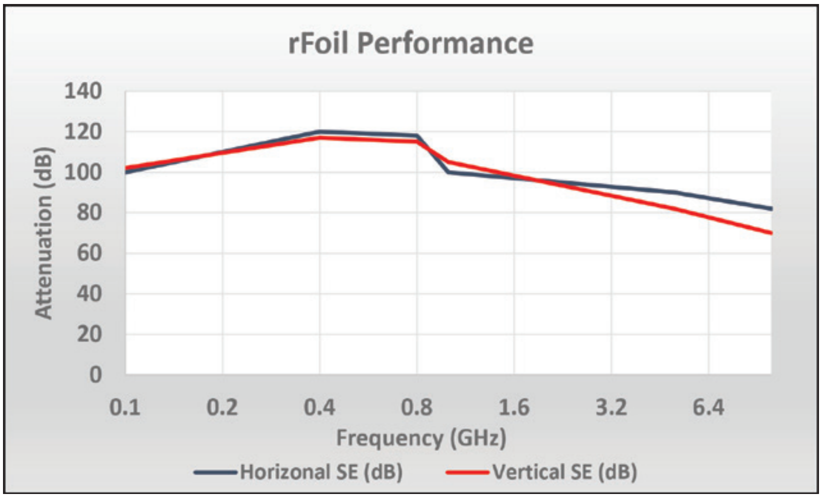


Figure 3: rFOIL RF shielding effectiveness product data[4]

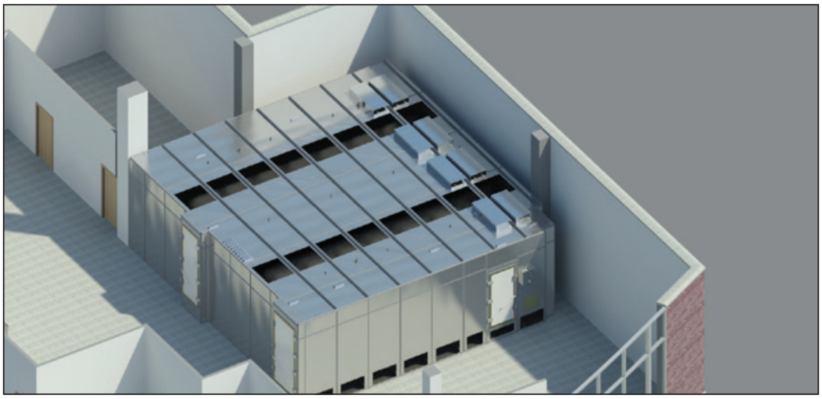


Figure 4: Example of a NSA 94-106 compliant RF shielding system integrated into a building

to the perimeter of a facility. But, by itself, the facility is not RF secure. A facility or space designated to meet NSA 94-106 is RF secure as it requires a six-sided shielding system, RF doors, penetrations, and filters to achieve the performance objectives set forth in NSA 94-106.

As shown in Figure 4, these shielding systems are often comprised of modular construction capable of providing 100 dB of attenuation up to 10 GHz and meeting the low frequency electric and magnetic shielding performance at frequencies as low as 1 kHz.

In addition to a six-sided RF shielded enclosure, other RF components will be required to achieve the RF shielding performance requirements as specified in NSA 94-106. These include RF shielded doors, RF shielded penetrations for HVAC, plumbing, and fiber, and RF filters for electrical, lighting, and building management systems. Examples of electrically filtered penetrations and RF treated sprinkler or plumbing penetrations are presented in Figures 5 and 6 on page 38, respectively. Without proper product selection and treatment of all these components, the secure space will be at risk of not complying with the NSA 94-106 performance requirements.

For a shielding system to comply with NSA 94-106, all aspects of the shielding must be identified and coordinated with the design team, the general contractor, and mechanical, electrical, and plumbing (MEP) subcontractors to ensure that all building systems and penetrations are properly addressed.

ICD/ICS-705 does not specifically identify requirements for treating penetrations through the shielding with most utilities passing through the shielding system untreated.

KEY DIFFERENCES BETWEEN ICD/ICS-705 AND NSA 94-106

Many projects reference both ICD/ICS-705 and NSA 94-106. As previously discussed, the requirements for each specification are quite different and should not be used interchangeably or in conjunction with each other. ICD/ICS-705 does not identify specific performance requirements while NSA 94-106 specifies performance requirements from 1 kHz to 10 GHz.

ICD/ICS-705 primarily provides direction on the construction of a SCIF with instructions on how to incorporate an RF barrier, but not a shielding system intended to meet NSA 94-106 RF performance requirements. This is evident by the construction methodology and materials identified in ICD/ICS-705.

A six-sided shielding system (Faraday cage) is required to meet the performance requirements under NSA 94-106, but ICD/ICS-705 simply calls for an RF shielding barrier on the wall. Further, the material specified in ICD/ICS-705 is not capable of achieving the NSA 94-106 performance objectives as noted by the rFOIL product performance data. Additionally, ICD/ICS-705 does not require the same level of RF treatment of doors, electrical systems, and mechanical penetrations as would be required under NSA 94-106.

Table 1 summarizes these key differences between ICD/ICS-705 and NSA 94-106.

CONCLUSION

As discussed above, referencing both ICD/ICS-705 and NSA 94-106 as part of a project can create much confusion in terms of project requirements. This can have significant performance and cost implications. Most general contractors lack expertise in RF shielding. These discrepancies can go unidentified, placing a project at risk of not meeting project requirements and potentially incurring large cost overruns unless an experienced RF shielding company or

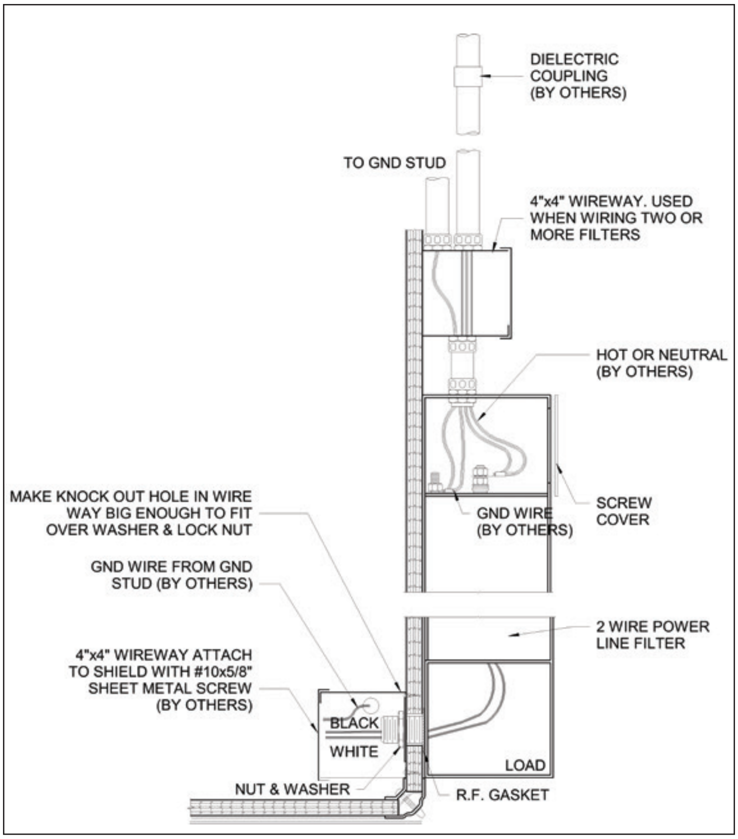


Figure 5: Example of a filter detail for electrical, lighting, and building management systems per NSA 94-106

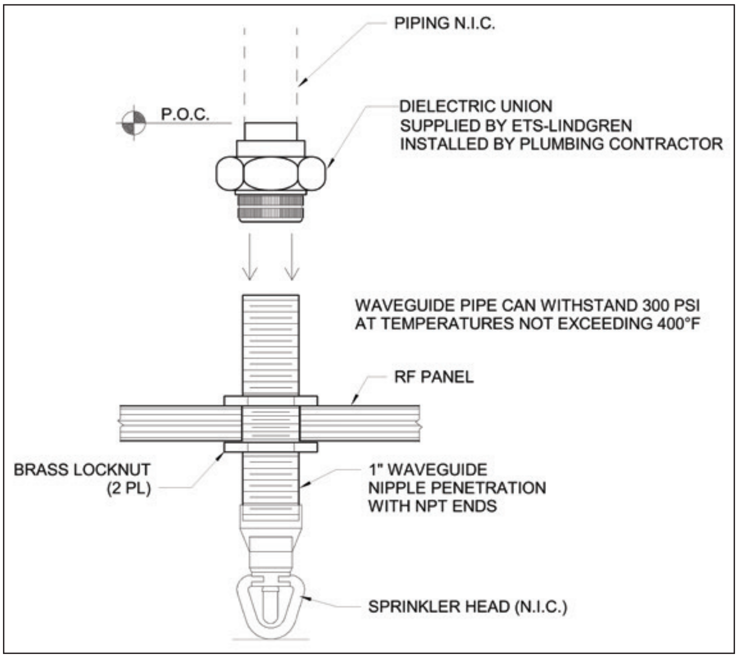


Figure 6: Example of a plumbing penetration for a sprinkler system per NSA 94-106

	ICD/ICS-705	NSA 94-106
Requires RF Shielding	Maybe*	Yes
Limited RF Shielding Barrier	Yes	No
Six-Sided Shielding Required	No	Yes
Requires RF Doors	No	Yes
Requires RF Filters	No	Yes
Requires RF Treated Penetrations	No	Yes
Includes Magnetic Field Performance Requirements	No	Yes
Includes Electric Field Performance Requirements	No	Yes
Includes Plane Wave Performance Requirements	No	Yes

Table 1: ICD/ICS-705 and NSA 94-106 Summary of Requirements

**The project CTTA will determine the SCIF requirement, which may or may not include an RF barrier.*

consultant is involved. Therefore, it is critical to clearly identify the project requirements and ensure that the differences between ICD/ICS-705 and NSA 94-106 are well understood.

REFERENCES

1. ICD/ICS-705 – *Technical Specification for Construction and Management of Sensitive Compartmented Information Facilities*, https://www.dni.gov/files/Governance/IC-Tech-Specs-for-Const-and-Mgmt-of-SCIFs-v15.pdf.
2. NSA 94-106 – not available for public reference.
3. TEMPEST is a U.S. National Security Agency specification and a NATO certification used in reference to secure facilities.
4. rFOIL product data, https://rfoil.com.

AVOIDING SUPPLY CHAIN DISRUPTIONS OF SAFETY-CRITICAL RECOGNIZED COMPONENTS

How a Proactive Approach Can Help Manage the Unexpected

When the COVID-19 pandemic struck in 2020, challenges arose in nearly every industry. Staffing levels were tested. Manufacturing output changed with little to no predictability. Demand for some products soared while others plummeted. One area severely impacted by COVID-19: global supply chains. Yet this was not the first, and certainly won't be the last, major event to shake supply chains, where disruptions can occur for any number of reasons: natural disasters, transportation complications, cybersecurity breaches, and, of course, a pandemic.

Supply chain interruptions can lead to any number of complications. They can disrupt production and impact costs, pricing, and revenue. The potential to damage a brand's reputation and customer/consumer relationships is also great. Yet, disruptions can happen at any time and with little or no warning. Manufacturers and product developers need to be prepared to effectively manage interruptions and their potential impact.

For most manufacturers, a preventive approach to help avoid supply chain disruptions is paramount and can be done by establishing multi-sourced suppliers to meet immediate, time- and budgetary-sensitive needs. A critical, often overlooked consideration is the identification and supply of components (including subassemblies) used in listed or certified electrical end-products. Understanding how components fit into the final product helps promote proactive supplier engagements. Knowing their application limits can also support efforts to proactively offset supply chain disruptions. And if the need to alter products arises, this knowledge will help manufacturers to make timely changes and address most certification concerns.

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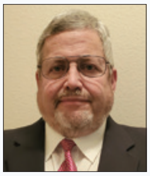

By Jim Bender

RECOGNIZED COMPONENTS

Electrical end-products have samples evaluated to applicable industry standards, then are certified as Listed by an authorized third-party certification body (CB). These products are typically ready to use from an end-user perspective, simply needing to be plugged in. Listed products often contain multiple recognized components to streamline the certification process. About 5-10% of components used in electronics are safety-critical and, as such, should be recognized.

Recognized components are used within listed products that meet certain application specifications. There are countless recognized components used in electronics including wiring, switches, power supplies, relays, interlocks, display systems, lithium batteries, plastics, and printed wiring boards. Using recognized components can help streamline end-product certifications and required field inspection obligations since recognized components do not need to be reassessed, except for application-specific compatibility.

Take, for example, a power supply considered safety-critical due to its voltage-isolating characteristics. A recognized power supply has been evaluated and found to meet certain requirements for safety, thereby avoiding the need for a full re-evaluation when the end-product is tested. This can save time and money by ensuring an effective certification process. Original equipment manufacturers (OEMs) should specify recognized components used in their products as well as the correct application standards that suppliers must meet to help avoid barriers to end-product certification.

If a recognized component becomes unavailable due to supply chain disruptions, finding a replacement part and moving on with product development or manufacture may not be as simple as it first seems because *not all recognized components are created equally*.

When it comes to recognized components, there are variations in cost and the recognitions themselves. All are similarly marked and generally appear safe for their intended application. However, it is possible that some components have not gone through the same level of scrutiny to assure that all end-application considerations have been addressed, particularly since the end-product is not always known. In such cases, a product may need to be evaluated for missing considerations that often result in delay to market and higher certification costs.

CONDITIONS OF ACCEPTABILITY

This potential risk can be avoided. To help ensure components fit an end-product's certification needs, it is critical to consider Conditions of Acceptability (COAs), as well as the application needs of the end-product.

COAs can provide assurances regarding strict third-party independent safety application compatibilities of a component by establishing additional evaluation requirements at the end-product level. Returning to the example of power supplies used in computer products, a manufacturer may select a recognized power supply assembly fully tested for electrical power input rating, leakage current, and ground continuity, but not temperature or abnormal component failures, which are central to electrical shock and fire risks. The power supply's recognized component certification report would clearly document COAs to assure the end product's certification testing evaluates the power supply for temperature and abnormal component failure.

COAs apply to most recognized components, almost without exception. Four commonly used safety-critical components found in electrical products illustrate the importance of COA considerations:

- **Power supplies:** A thorough investigation of a power supply should include power input ratings (including leakage current), temperature, output short-circuit protection, limited energy-availability enclosure-related accessibility protection, and abnormal component failures having fire or shock impact. Less expensive power supplies often cut costs by excluding some of these evaluations, which then results in cumbersome COA obligations and additional certification testing for an end-product utilizing the power supply.
- **Plastics:** Plastics have many characteristics depending on their end-product application use. For example, temperature, flammability rating, and thickness may not be important for plastics used for cosmetic and/or decorative purposes outside of an enclosure but are critical when used for or inside an enclosure near high-heat, power-consuming sources, typically requiring validation of the plastic's COAs.
- **Printed Wiring Boards:** Like plastics, temperature, flammability rating, and board thickness all contribute to defining a printed wiring board's COAs. Depending on the type and composition of the printed wiring board and safety specifics of the end product's electrical power producing circuits, complying to the required COA can be critical and of great importance.
- **Lithium Batteries**: Lithium batteries are typically evaluated for a variety of safety attributes due to their inherent risk of rupture and/or explosion if not properly designed into an end-product. Some of these considerations include temperature limits and protective considerations against inadvertent shorts and excessive currents capable of creating explosion. These include protective resister/diodes to minimize risks of overcharge and/or short circuit, depending on the enclosure and overall function of the end-product.

It is important for manufacturers to understand the safety-critical needs and expectations of components in relation to end-product expectations, from both a design integrity and certification perspective. Each recognized component will need to adhere to those requirements. Understanding component certification needs and COA expectations can help end-product manufacturers manage component suppliers and facilitate continued access to components, thereby assuring uninterrupted production and the ability to meet market demands.

COAs AND SUPPLY CHAIN MANAGEMENT

The best way to avoid supply chain disruptions, especially for recognized components and safety-critical parts, is to plan ahead. Truly, the best defense is a good offense. First and foremost, be sure to ask suppliers for COA lists so you can evaluate the suitability of their components in your end-product as certified. This is important not only when looking for backup, second sourced suppliers, but during the product development phase. This information, coupled with the knowledge of your product, is invaluable in your efforts to proactively avoid unanticipated issues.

When developing a specification sheet for procuring components, always include a dedicated section covering recognized component certification requirement and expectations. This includes third-party recognized certification and markings (i.e., ETL, UL, CSA, TUV, etc.), critical requirements related to applicable standards, and specific COAs, as documented in the component's certification report. It then becomes the supplier's obligation to share their COAs. This helps to set expectations up front while also requiring suppliers to acknowledge and adhere to manufacturing needs. This is the time to proactively determine if there are issues from a compliance perspective in using these components in end-products.

Thorough component specifications, including COA requirements, can also facilitate qualifying backup suppliers when and if you encounter supply chain issues. As part of the component's certification report, the supplier should be able to provide their COAs for reference. When requirements for components are easily accessible, they can be quickly referenced during the product certification process or during the manufacture of the product. It also helps avoid the need to quickly identify and qualify backup suppliers during the product design and development phase, further leveraging your plan-ahead supplier management strategy.

Imagine, if you will, two homeowners, each with a one-story house, who want to add a second story.

The first owner has the original blueprints and a builder at their disposal. The second does not. The first homeowner has information on the structural integrity of the home readily available and can more quickly and easily begin the process of adding a new story. The second homeowner needs to have additional assessments done by professionals—engineers, architects, contractors—before the second floor can be added, spending more time and money with the remodel. Manufacturers can be like the first homeowner by planning ahead and including supply chain disruption contingencies into their product design "blueprint."

When developing an end-product, specifications for critical safety recognized components should be considered and included in the original product assessment and certification. This will make it easier to replace and/or include any multi-sourced components when and if needed. Manufacturers can also identify anticipated replacement components when a product is initially developed, evaluated, and certified, so components are more easily swapped when necessary. Identifying backup components and including them in the original testing and certification can help avoid the additional testing (and costs) required when substitutions are made with components not included in the original certification report.

LIMITED PRODUCT CERTIFICATIONS

Even in the best of cases, with the best intentions, it is possible to be caught off guard when the component of a listed product on the market is suddenly unavailable. Without a backup component, manufacturers may need to find a suitable replacement on short notice to continue or resume manufacturing. The use of a component not included in the original certification, especially one that is safety-critical, will require additional considerations.

Should this situation occur, the OEM first needs to find a replacement component which conforms with the COA-related requirements of the recognized component that was previously in use. Always know the standards and end-product safety application needs and familiarize yourself with COAs that apply to your product. Always request the recognized component's COAs from the supplier to validate acceptance before submitting the end-product to a certification body for final assessment. Document COA supplier requirements and expectations in the specification sheet of the component supplier's procurement specification.

Once an alternate component is secured, the end-product will need to be evaluated to applicable safety standards, sometimes through a simple, paperwork type of evaluation and sometimes with a more complicated review, including laboratory testing. The use of an alternate component can change the product enough that its original certification may no longer be valid without additional investigation. The good news is there is an option called a limited product certification (LPC), or single batch certification.

An LPC applies when a limited number of products are manufactured or produced at a particular factory location. An LPC involves verifying full compliance to recognized standard(s) by assessing a representative sample including a review of components and possibly testing. Because an LPC applies to a specific number of units produced over a defined time, it can be used to cover revised products against the original certification until original suppliers and/or components are restored for normal production purposes.

CONCLUSION

Supply chain disruptions are inevitable. The coronavirus pandemic as well as several recent natural disasters have clearly demonstrated the impact that unanticipated events can have on the ability of manufacturers to produce and deliver their products and components as planned. But supplier issues do not need to tie a manufacturer's hands in these situations. Proactively acknowledging their likelihood and planning for the worst is prudent and can make a huge difference in avoiding disruptions in the first place. Managing continued component supply allows you to pivot more quickly, and easily maintain production needs.

Remember, not all components are created equal. Educating yourself on applicable standards, product, and component needs, and having a thorough knowledge of COAs and their importance in assuring seamless certification can reduce time and costs when the need for replacement components is required, and help secure the overall integrity and resilience of your supply chain.

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

Part 2: DC/DC Converter Design with EMC Considerations

By Bogdan Adamczyk, Scott Mee, and Nick Koeller

This is the second 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]. In this article, we first present a top-level schematic of an overall system and then focus on a systematic approach to a DC/DC converter design. Several EMC considerations are addressed at the schematic level, and recommended design improvements are provided to reduce the risk of failures during testing.

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1. INTRODUCTION

Most hardware designs begin with a baseline schematic based on the Integrated Circuit (IC) supplier's guidelines and application notes. These application notes show examples of how to implement the devices along with guidance on how to design and eventually translate the design into a Printed Circuit Board. The level of EMC consideration provided in the vendor design resources and datasheets of each component varies significantly and may not be comprehensive enough to ensure EMC compliance in all industries where the devices could be used. The staff at E3 Compliance will typically perform an EMC design review on designs in the early stages of development. The purpose of the design review is to identify EMC concerns or risks against the requirements and recommend design improvements to prevent EMC failures during testing. This is an important step to a successful product development process that helps streamline the pre-compliance testing where final EMC issues are detected and resolved before EMC Compliance testing.

In this article, we present the schematic for the overall system, followed by a detailed schematic

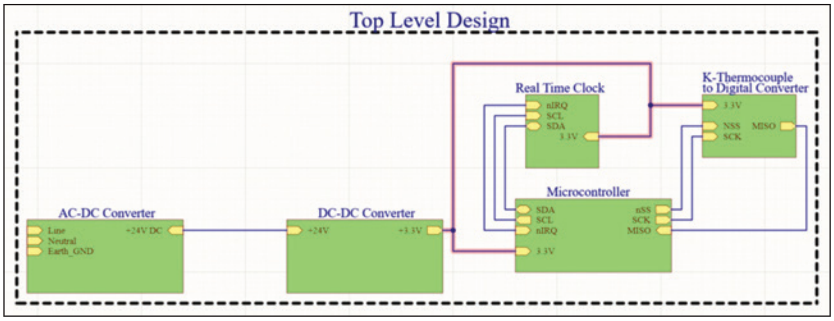

Figure 1: Top-level schematic

of a DC/DC SMPS. The design of a 24V-to-3.3 V DC/DC converter follows the design process philosophy where we start with a baseline functional schematic based on the IC manufacturer specifications. These specifications usually do not fully address non-functional concerns like thermal or EMC issues. We, therefore, address these issues and recommend design improvements to prevent failures during testing.

We conclude with a brief description of the next article.

2. SCHEMATICS AND DESIGN REQUIREMENTS

Figure 1 shows the top-level system schematic.

In this article, we focus on the DC/DC converter shown in Figure 2.

In our design, we use Texas Instruments TPS54360B step-down regulator with integrated high side *n*-channel MOSFET, [2]. The device implements constant frequency, current-mode control.

To begin the design process, the design requirements must be set. These are shown in Table 1.

Additional assumptions and design constraints are listed in Table 2.

3. DESIGN PROCESS

In this section, we describe the detailed design process for each regulator subsystem.

3.1. Switching Frequency

Selecting the switching frequency is the first step in the design. According to the device specification, the upper limit on the switching frequency is determined from two equations:

$$f_{SW(maxskip)} = \frac{1}{t_{ON}} \times \left(\frac{I_{OUT}R_{DC}+V_{OUT}+V_D}{V_{IN(max)}-I_{OUT}R_{DS(ON)}+V_D}\right) \quad (1a)$$

$$f_{SW(maxskip)} = \frac{1}{135\times10^{-9}} \times \left(\frac{0.5\times0.18+3.3+0.65}{30-0.5\times0.092+0.65}\right) = \quad (1b)$$

$$977.84\ kHz$$

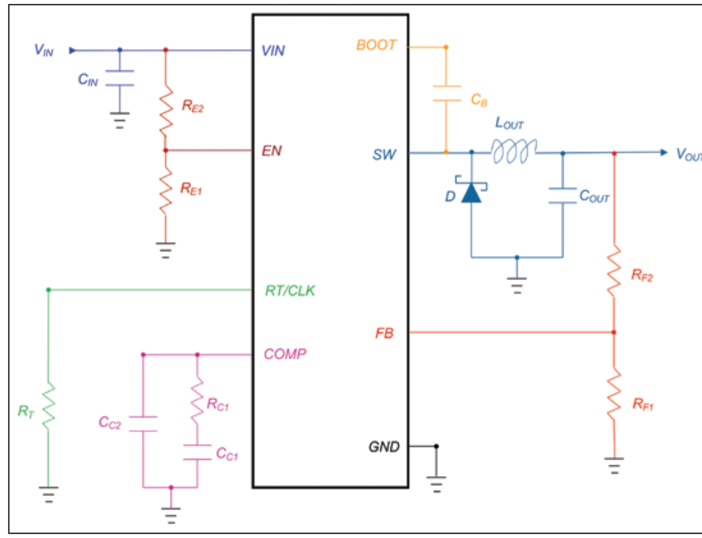

Figure 2: DC-DC converter simplified schematic

Parameter	Value
Input voltage	$V_{IN} = 24\ V$
Maximum input voltage	$V_{IN(max)} = 30\ V$
Output voltage	$V_{OUT} = 3.3\ V$
Minimum output voltage	$V_{OUT(min)} = 3.25\ V$
Maximum output voltage	$V_{OUT(max)} = 3.35\ V$
Output voltage ripple $(0.5\% V_{OUT})$	$V_{ripple} = 16.5\ mV$
Output current	$I_{OUT} = 0.5\ A$

Table 1: Design requirements

Parameter	Value
MOSFET ON time	$t_{ON} = 135\ ns$
MOSFET DS ON resistance	$R_{DS(ON)} = 92\ m\Omega$
Inductor DC resistance	$R_{DC} = 180\ m\Omega$
Peak inductor current	$I_{CL} = 0.9\ A$
Minimum load current $(0.75\ I_{OUT})$	$I_{OUT(min)} = 0.375\ A$
Maximum load current $(1.75\ I_{OUT})$	$I_{OUT(max)} = 0.625\ A$
Max protection factor for inductor current overload (increases OFF time)	$f_{DIV} = 8$
Diode threshold voltage	$V_D = 0.65\ V$
Short-circuit output voltage	$V_{OUT(SC)} = 0.1\ V$

Table 2: Design constraints

$$f_{SW(shift)} = \frac{f_{DIV}}{t_{ON}} \times \left(\frac{I_{OUT(max)}R_{DC}+V_{OUT(SC)}+V_D}{V_{IN(max)}-I_{OUT(max)}R_{DS(ON)}+V_D}\right) = 1{,}670.7\ kHz \tag{2a}$$

$$f_{SW(shift)} = \frac{8}{135\times10^{-9}} \times \left(\frac{0.625\times0.18+0.1+0.65}{30-0.625\times0.092+0.65}\right) = 1{,}670.71\ kHz \tag{2b}$$

The operating frequency should be lower than the lowest of the two values predicted by Equations (1) and (2). In our design, targeted switching frequency f_{SW} = 600 kHz.

The switching frequency is adjusted using a (timing) resistor to ground connected to the RT/CLK pin. The timing resistance for a given switching frequency is determined from:

$$R_T(k\Omega) = \frac{101756}{f_{SW}(kHz)^{1.008}} = \frac{101756}{600^{1.008}} = 161.13\ k\Omega \cong 160\ k\Omega \tag{3}$$

The switching frequency corresponding to the nominal value of R_T = 160 kΩ is calculated from

$$f_{SW}(\text{kHz}) = \frac{92417}{R_T(k\Omega)^{0.991}} = \frac{92417}{160^{0.991}} = 604.6\ kHz \tag{4}$$

3.2. Output Inductor

The minimum value of the inductor current is obtained from

$$L_{OUT(min)} = \frac{V_{IN(max)}-V_{OUT}}{I_{OUT}\times K_{IND}} = \frac{30-3.3}{0.5\times0.3} = 32.39\ \mu H \tag{5}$$

K_{IND} = 0.3 in Equation (5) comes from the regulator datasheet. In our design, we chose Wurth 744053330 inductor with a nominal value of L_{OUT} = 33 μH.

The inductor ripple current is calculated from

$$I_{ripple} = \frac{V_{OUT}\left(V_{IN(max)}-V_{OUT}\right)}{V_{IN(max)}\times L_{OUT}\times f_{SW}} = \frac{3.3(30-3.3)}{30\times33\times10^{-6}\times604.6\times10^{3}} = 147\ mA \tag{6}$$

The inductor ripple current is part of the current mode PWM control system, and the suggested minimum value of the ripple current for a 5 V regulator is 150 mA. Since we are designing a 3.3 V regulator, the value 147 mA is acceptable.

The inductor RMS current is calculated from

$$I_{L(rms)} = \sqrt{I_{OUT}^2 + \frac{1}{12}I_{ripple}^2} = 502\ mA \tag{7}$$

The peak inductor current is obtained from

$$I_{L(peak)} = I_{OUT} + \frac{I_{ripple}}{2} = 0.5 + \frac{0.147}{2} = 573.5\ mA \tag{8}$$

The Würth 744053330 inductor has a rated current of 900 mA and the saturation current of 750 mA, and thus the calculated values are well within these limits. (The maximum output current of 625 mA shown in Table 2 is also within these limits).

3.3. Output Capacitor

The output capacitor needs to satisfy several criteria. The first is the allowable change in the output voltage for a maximum change in the load current.

$$C_{OUT} > \frac{2\times\Delta I_{OUT}}{f_{SW}\times\Delta V_{OUT}} = \frac{2\times\left(I_{OUT(max)}-I_{OUT(min)}\right)}{f_{SW}\times\left(V_{OUT(max)}-V_{OUT(min)}\right)} = \frac{2\times(0.625-0.375)}{604.6\times10^{3}\times(3.35-3.25)} = 8.27\ \mu F \tag{9}$$

The output capacitor must also be sized to absorb the energy stored in the inductor when transitioning from a high to a low load current. This value is obtained from

$$C_{OUT} > \frac{2\times\Delta I_{OUT}}{f_{SW}\times\Delta V_{OUT}} = \frac{2\times\left(I_{OUT(max)}-I_{OUT(min)}\right)}{f_{SW}\times\left(V_{OUT(max)}-V_{OUT(min)}\right)} = \frac{2\times(0.625-0.375)}{604.6\times10^{3}\times(3.35-3.25)} = 8.27\ \mu F \tag{10}$$

The minimum output capacitance needed to satisfy the output voltage ripple is obtained from

$$C_{OUT} > \frac{1}{8f_{SW}}\frac{1}{\frac{V_{ripple}}{I_{ripple}}} = \frac{1}{8\times604.6\times10^{3}}\frac{1}{\frac{0.0165}{0.147}} = 1.8\ \mu F \tag{11}$$

The output capacitance should be larger than the largest value calculated in Equations (9) through (11). Additionally, we need to account for the derating of the output capacitor; thus, let's double the value given by Equation (10) to arrive at C_{OUT}(min) = 49.6 μF. This value will be later used when designing the compensation network.

To account for the safety margin in our design, we chose two output capacitors in parallel, each of the value C_{OUT} = 47 μF.

Maximum ESR of the output capacitor is calculated from

$$R_{ESR} < \frac{V_{ripple}}{I_{ripple}} = \frac{0.0165}{0.147} = 112\ m\Omega \tag{12}$$

In our design, we chose Murata capacitor GRM32ER71A476KE15L with an ESR of 3 $m\Omega$ at 100 kHz, which is well below the maximum ESR predicted by Eq. (12).

3.4. Catch Diode

The regulator requires an external catch diode between the SW pin and GND. The diode must have a reverse voltage rating equal to or greater than $V_{IN(max)}$. The peak current rating of the diode must be greater than the maximum inductor current. The diode must also have an appropriate power rating. The power dissipation of the diode is calculated from

$$P_D = \frac{(V_{IN(max)} - V_{OUT}) \times I_{OUT} \times V_D}{V_{IN(max)}} + \frac{C_T \times f_{SW} \times (V_{IN(max)} + V_D)^2}{2} \tag{13}$$

where c_T is junction capacitance. We chose a Schottky diode B260S1F from Diodes Incorporated. It is rated at the reverse voltage of 60 V, peak current of 2 A, V_D = 0.65 V, c_T = 75 pF.

Thus, the power dissipation of the diode is

$$P_D = \frac{(30-3.3) \times 0.5 \times 0.65}{30} + \frac{75\times10^{-12} \times 604.6\times10^3 \times (30+0.65)^2}{2} = 310.55\ mW \tag{14}$$

and is well below the power threshold for the rated voltage and current values.

3.5. Input Capacitor

The regulator requires a high-quality ceramic type X5R or X7R input capacitor with at least 3 µF of effective capacitance. The voltage rating of the input capacitor must be greater than the maximum input voltage.

In our design, we use two Murata GCJ32DR72A225KA01L, 2.2 µF, 100V, ceramic capacitors in parallel.

3.6 Bootstrap Capacitor

A bootstrap capacitor between the BOOT and SW pins is needed to provide the gate voltage to drive the high-side MOSFET. The recommended value is 0.1 µF. TI recommends a ceramic capacitor with X7R or X5R grade dielectric with a voltage rating of 10 V or higher.

In our design we use 0.1 µF, 50 V Murata GCJ188R71H104KA12D capacitor.

3.7. Undervoltage Lockout

According to the specifications, the input voltage range of the regulator is 4.5 V – 60 V. In our application, the input voltage to the regulator is 24 V (VIN). The regulator is enabled when the input voltage (VIN) rises above 4.3 V and disabled when this voltage drops below 4.3 V. The undervoltage lockout (UVLO) of 4.3 V can be adjusted with two resistors (forming a voltage divider) connected to EN pin, as shown in the schematic.

When adjusted to a non-default value of 4.3 V, the undervoltage lockout (UVLO) has two thresholds, one for power up when the input voltage is rising (UVLO start), and one for power down when the input voltage is falling (UVLO stop).

In our application, we chose UVLO start or V_{START} = 8 V and UVLO stop or V_{STOP} = 6.25 V. Then the values of the two resistors are calculated as follows. The value of the resistor between E V and VIN, R_{UVLO1}, is obtained from

$$R_{UVLO1} = \frac{V_{START} - V_{STOP}}{I_{HYS}} \tag{15}$$

I_{HYS} is internally set to 3.4 µA. Thus, in our design,

$$R_{UVLO1} = \frac{8-6.25}{3.4\times10^{-6}} = 514.7\ \approx 523\ k\Omega \tag{16}$$

The value of the resistor between E V and GND, R_{UVLO2}, is obtained from

$$R_{UVLO2} = \frac{V_{ENA}}{\frac{V_{START} - V_{ENA}}{R_{UVLO1}} + I_1} \tag{17}$$

I_{HYS} is internally set to 1.2 µA. Thus, in our design,

$$R_{UVLO2} = \frac{1.2}{\frac{8-1.2}{523\times10^3} + 1.2\times10^{-6}} \approx 84.5\ k\Omega \tag{18}$$

3.8. Feedback Pin

The FB pin monitors the output voltage by comparing it to the internal value of 0.8 V. The output voltage is set by a resistor divider from the output node to the FB pin. The current flowing through the feedback network should be greater than 1 μA to maintain the output voltage accuracy. The resistors comprising the voltage divider should have 1%, or better, tolerance.

If a low-side resistor, R_{LS} = 10 kΩ is used, then the high side resistor value, R_{HS}, is obtained from

$$R_{HS} = R_{LS}\frac{V_{OUT}-0.8}{0.8} \tag{19}$$

In our application, V_{OUT} = 3.3 V resulting in R_{HS} = 31.25 kΩ. The resulting current in the feedback circuitry is 80 μA.

3.9. Compensation Network

The COMP pin is connected to the frequency compensation connected to the COMP pin (see Figure 2). The compensation network internally provides input to the PWM circuitry, which controls the switching of the SW node and thus controls the current to the load. Specifically, the COMP pin voltage controls the peak current on the high side MOSFET.

To design the compensation network, we follow the procedure outline in the regulator specifications. First, several frequencies are calculated.

$$f_{P(mod)} = \frac{I_{OUT}(max)}{2\pi V_{OUT}C_{OUT(min)}} = \frac{0.625}{2\pi\times3.3\times49.6\times10^{-6}} = 607.7\ Hz \tag{20}$$

$$f_{z(mod)} = \frac{1}{2\pi R_{ESR}C_{OUT(min)}} = \frac{1}{2\pi\times1.5\times10^{-3}\times49.6\times10^{-6}} = 2{,}139.2\ kHz \tag{21}$$

$$f_{co1} = \sqrt{f_{P(mod)}\times f_{z(mod)}} = \sqrt{2{,}139{,}200\times607.7} = 36{,}055.4\ kHz \tag{22}$$

$$f_{co2} = \sqrt{f_{P(mod)}\times\frac{f_{SW}}{2}} = \sqrt{607.7\times302.3\times10^{3}} = 13{,}553.9\ Hz \tag{23}$$

The lower of the two values $f_{CO} = f_{CO2}$ in Equations (22) and (23) will be used.

The resistor R_{C1} in the compensation network is calculated from

$$R_{C1} = \frac{2\pi\times f_{co}\times C_{OUT(min)}}{gmps}\times\frac{V_{OUT}}{V_{REF}\times gmea} \tag{24a}$$

From the regulator specifications, we use

$gmps = 12\frac{A}{V}, gmea = 350\frac{\mu A}{V}, V_{REF} = 0.8\,V$. Thus,

$$R_{C1} = \frac{2\pi\times13{,}553.9\times49.6\times10^{-6}}{12}\times\frac{3.3}{0.8\times350\times10^{-6}} = 4{,}148.6\ \Omega \cong 4{,}120\ \Omega \tag{24b}$$

The capacitor C_{C1} in the compensation network is calculated from

$$C_{C1} = \frac{1}{2\pi\times R_{C1}\times f_{p(mod)}} = \frac{1}{2\pi\times4120\times607.7} = 63.56 \cong 68\ nF \tag{25}$$

The capacitor to ground, C_{C2}, in the compensation network is calculated from two different equations and the larger value is chosen.

$$C_{C2} = \frac{C_{OUT(min)}\times R_{ESR}}{R_{C1}} = \frac{49.6\times10^{-6}\times1.5\times10^{-3}}{4120} = 18.06\ pF \tag{26a}$$

$$C_{C2} = \frac{1}{R_{C1}\times f_{SW}\times\pi} = \frac{1}{4120\times604.6\times10^{3}\times\pi} = 127.78\ pF \cong 120\ pF \tag{26b}$$

4. COMPLETE REGULATOR CIRCUITRY

Figure 3 shows the complete circuitry of the designed regulator. Red-colored nets represent power input and output. Yellow-colored nets represent the switch node. Green-colored nets represent ground.

5. EMC CONSIDERATIONS

An EMC design review was performed to identify high-risk areas to meeting emissions requirements. During the review, a number of additional components were identified for filtering, damping switching effects, inductor technology, and shielding options. The schematic shown in Figure 3 was modified by superimposing the EMC considerations, shown as dashed boxes labeled *A* through *F* in Figure 4. The values of these EMC components are chosen based on experience but will likely need to be tuned in the laboratory through experimental measurements.

These considerations are addressed below.

EMC-A: A 1nF capacitor (C33) is added on the Vin pin (U1.2) for high-frequency decoupling to reduce the amount of high-frequency energy generated by the DC-DC Converter that can conduct into the 24 V bus. Additionally, a π filter, [3], is constructed by adding a 1 μH inductor (L4) between the two input capacitors (C31 and C32).

EMC-B: A snubber circuit (series Resistor R19 & Capacitor C26) is added from SW Node (U1.8) to Vin (U1.2) because the Internal MOSFET is placed between these pins. This snubber is used to control the ringing from the internal MOSFET that results from the step response to the RLC network.

EMC-C: The Würth Elektronik inductor (L3) may be replaced with a Vishay IHLP inductor which is magnetically shielded or an IHLE inductor which is E-Field shielded to reduce radiated and conducted emissions further.

EMC-D: A snubber circuit (series Resistor R20 & Capacitor C27) is added across the catch diode to reduce ringing across the diode junction [4].

EMC-E: A 1nF capacitor (C30) is added near the inductor (L3) on the 3.3 V bus to filter high-frequency noise from conducting out onto the 3.3 V bus.

EMC-F: A shield (SH1) may be added if the PCB layout and EMC components are not successful to reducing the emissions from the DC-DC Converter. This may be needed in some instances where the EMC requirements are very stringent or the supply may be closely co-located to sensitive receivers.

These EMC components are designed into the first prototype as optional components that will be evaluated during emissions testing. The EMC performance may have trade-off decisions to make with regard to other requirements such as thermal, reliability, manufacturability, and cost. An example would be selecting the snubber values to optimize the EMC and thermal performance. Not all of the EMC components will likely be needed, and efforts will be made to remove the unneeded components to optimize cost.

6. FUTURE WORK

The next step will be to fabricate and build the DC/DC converter PCB. Functional performance and the radiated and conducted emissions subsequently will be evaluated and discussed. Additionally, a summary of chosen EMC components required to gain compliance shall be reviewed.

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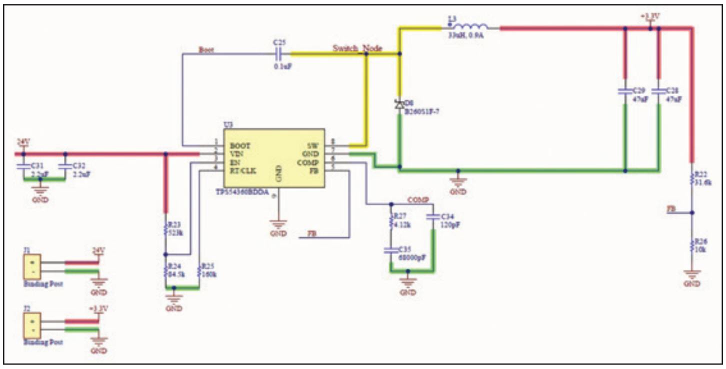

Figure 3: DC-DC converter circuitry

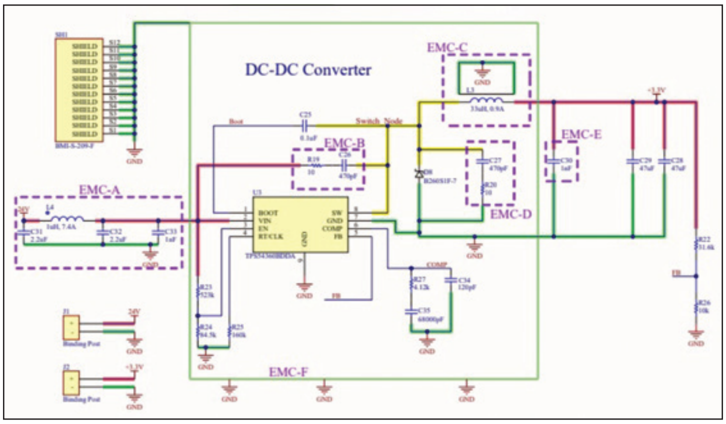

Figure 4: DC-DC converter circuitry with EMC considerations

THE RELATIONSHIP BETWEEN EMI/EMC AND ESD

By Alan Righter, Vladimir Kraz, and Shubhankar Marathe, on behalf of EOS/ESD Association, Inc.

Alan Righter is currently a Senior Staff ESD Engineer in the Corporate ESD Department at Analog Devices. He works with ADI design/product engineering teams worldwide on whole chip ESD planning/design, ESD testing, ESD failure analysis, and EOS/EIPD issues with internal and external customers. Alan has been active in the EOS/ESD Symposium as author/co-author of ten papers. He is also active in the Industry Council on ESD Target Levels.

Vladimir Kraz is a founder and a President of OnFILTER, a manufacturer of U.S.-made high-performance EMI filters. Vladimir holds advanced degrees in electrical and mechanical engineering. He has 24 U.S. Patents, and is an author of numerous papers about EMI, EOS, and ESD. Vladimir is a task force leader of SEMI EMC standards, and a member of the EOS/ESD Association, Inc. standards working groups, including the EOS working group.

Shubhankar Marathe received a MS and PhD in electrical engineering from the EMC Laboratory, Missouri University of Science and Technology, Rolla, MO, USA, in 2017 and 2019, respectively. In 2019, he joined Amazon Lab126, Sunnyvale, CA, USA, as an ESD system design engineer. Recently, he started road biking again and enjoys exploring new biking routes.

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.

The 2020 EOS/ESD Symposium in September 2020 featured a new EMC Special Session, held on the Wednesday of the Symposium, organized in cooperation between the EMC Society and EOS/ESD Association, and featuring EMC Society leaders as well as presentations/presenters from the recently held 2020 EMC Symposium.

This Special Session was planned to emphasize relationship between EMI/EMC and ESD (how EMI and ESD can be used together, what aspects of EMI can be considered in EMC solutions, and how the different EMI-related tests relate to ESD. This session featured a set of papers, short tutorials, and an interactive expert panel discussion, providing a platform to encourage participation with the intent to continue this in the future.

These papers covered topics from investigation for improvements for the IEC 61000-4-2 standard, triboelectrification effects on spacecraft, robotic scanning to study ESD induced soft failures, and soft failures generated from system transient testing. There were also five invited tutorials covering both the IEC test methods and evaluations and EMI measurements.

Papers [1]-[4] from the EMC Symposium were re-presented at the Special Session.

A first paper [1], "ESD Generator Tip Current Reconstruction Using a Current Probe Measurement at the Ground Strap," was presented by Shubhankar Marathe from the Missouri University of Science and Technology. It gave insight into how monitoring ESD generator discharge current during IEC 61000- 4-2 testing helps to better understand product failures. Acquiring the discharge waveform using an oscilloscope enables the operator to both document the current waveform that resulted in product failure and identify the presence of a secondary ESD event within the product. There are issues with acquiring this waveform reliably. For example, placing a current probe such as an F-65 current clamp at the tip of the ESD generator may change the discharge current waveform shape due to probe loading. In addition, the inclusion of an extra cable and current clamp increases physical weight at the tip of the ESD generator and reduces operator convenience during testing. To overcome the probe loading effect, a non-intrusive measurement method of positioning the F-65 current clamp at the ESD generator ground strap was first proposed. However, the configuration resulted in the captured waveform not including the initial high-frequency peak current directly. Therefore, mathematical processing was needed to reconstruct

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the initial ns-wide high-frequency current waveform which often leads to product failure. The goal of this work was to reconstruct the high-frequency discharge tip current waveform by measuring the current on the ground strap and applying deconvolution. The deconvolution method was first validated using circuit simulation. Second, measurements were performed with different ESD generators to determine the effectiveness of the reconstruction algorithm.

The second paper [2], "ESD Analysis and Evaluation of Typical Spacecraft Survival Suit Umbilical Tubing," was presented by Robert C. Scully from the Jet Propulsion Laboratory. He presented an assessment of the potential for the occurrence of triboelectrification effects resulting from gas and fluid flow through umbilical tubing attached to a typical spacecraft survival suit. The ESD assessment demonstrated that gas and fluid flowing through the umbilical tubing posed no threat to crew safety over expected operational time periods up to 150 hours.

The third paper [3], "Investigation of Electrostatic Discharge-Induced Soft-Failure Using 3D Robotic Scanning", was presented by Omid Hoseini Izadi from the Missouri University of Science and Technology. It discussed the development of a robotic ESD scanning system used for System ESD scanning of complex 3D objects. The system was shown to provide pseudo-2D plots that illustrated the ESD-sensitive locations of the device under test on a relative scale. It was observed using this system that disturbing different sensitive regions led to different soft-failure types. For example, determining the sensitive locations of a complex-shaped DUT helped to identify the disturbed circuitry and verify the effect of countermeasures in a repeatable way.

The fourth paper [4], "Experimental Validation of an Integrated Circuit Transient Electromagnetic Event Sensor," was presented by Shubhankar Marathe. It discussed the challenge of determining the components or coupling path within a system

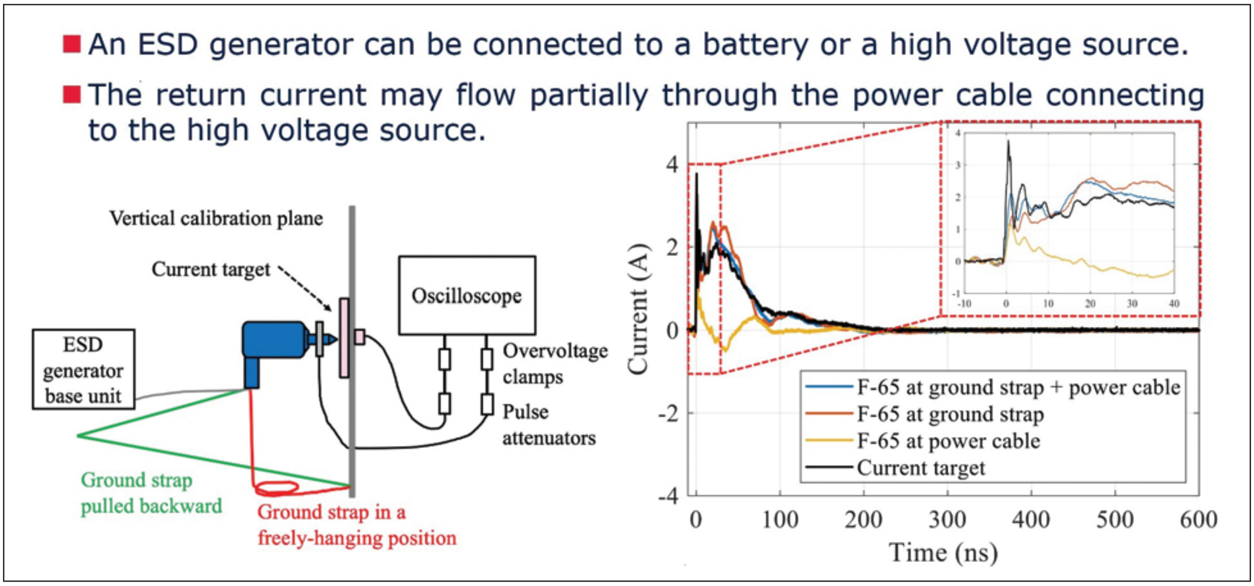

Figure 1: Current measured by the F-65 current clamp-on ESD generator ground strap and power cables.

responsible for soft failures during system transient testing. This challenge is in part because components are hidden deep within the product and measuring those internal voltages or currents during a transient test may not be practical. Also, adding cables to the system to make voltage or current measurements can be difficult and may alter the test results. To overcome this problem, a compact sensor was designed to measure the peak over- or undervoltage on a trace or pin during a transient electromagnetic event. The sensor was designed to wirelessly transmit the peak level of the event to a receiver outside the device under test using frequency-modulated electric and magnetic fields so that no cabling or other changes to the system were needed. A proof-of-concept of the sensor was implemented in an integrated circuit (IC) using 180 nm technology which measured the peak level of a negative transient event. The sensor operation was validated by direct injection to the sensor from a transmission line pulser. The sensor was also used to detect the peak voltage on a USB cable during a transient event on the cable-connected system. Tests showed that the sensor successfully detected and transmitted the peak level of the event and that the oscillation frequency (and thus the level) could be easily detected by a near-field probe placed outside the enclosure of the device under test.

A second portion of the EMC Special Session, coordinated by Ross Carlton of ETS-Lindgren, featured five short tutorials led by longtime EMC Society contributors.

The first tutorial, given by Ross Carlton, " gave an overview of IEC 61000-4-2. IEC 61000-4-2 is the most used System-Level ESD test method standard since it is used for most consumer, commercial, and industrial products. This presentation discussed the specified ESD waveform, test setup, test methodology, and reporting requirements. The application of this method for testing PCBs, IC package pins, and other unusual applications was discussed. This tutorial set the stage for several of the following tutorials.

The second tutorial, "System-Level ESD Design Considerations and a Means of Evaluation" was given by Colin Brench. This workshop discussed the impact of ESD events on the behavior of high data rate interfaces and how such events impact not only hardware design but also the firmware and software. Simple pass/fail tests give little indication of true performance, but when delivered under slightly different operating conditions, a deeper understanding is possible. Details of the improved test methodology were described and included an example of the process and results from a particular case.

The third tutorial, "Lessons-Learned in System-Level ESD Testing was presented by Derek Walton, SSC Labs, Harry Reid Engineering Laboratory, University of Nevada-Reno. The methodology specified for EMC testing is complex and contains many uncertainties that can impact the test results. This

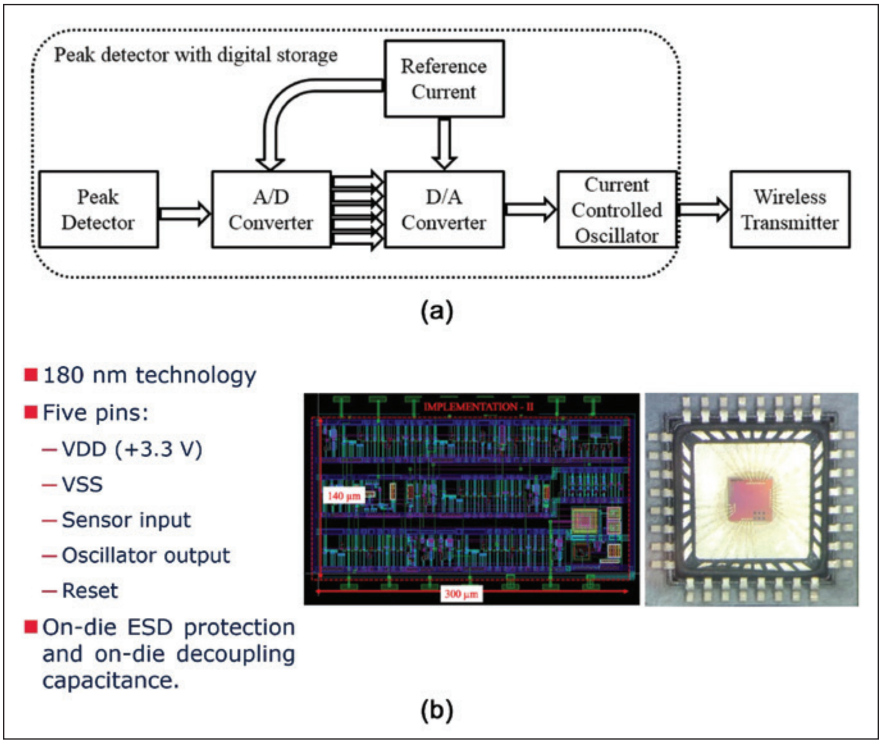

Figure 2: Experimental validation was performed on the designed digital storage sensor. a) Sensor block diagram b). Implementation details.

The final portion of the session was an interactive virtual "Expert Panel." This panel was very informative and featured many questions from the audience on EMC aspects of ESD and vice versa, referring to the presentations during the session.

presentation addressed these complexities and the lessons learned from years of testing a wide variety of products. Specific issues with how to properly set up and conduct the IEC 61000-4-2 test were presented and discussed.

The fourth tutorial, "System-Level ESD Failure Mechanisms and Mitigation Techniques" was presented by David Pommerenke, Graz University of Technology, Graz, Austria. With the premise being system-level ESD often leads to soft-errors (e.g., bit-errors, wrong resets, etc.) and even damage, this presentation offered guidance on finding the root cause of upsets frequently observed in immunity testing (e.g., ESD, EFT) and described various measurement techniques. Further, it was shown how measurements, revealing local sensitivities, can be used for the characterization and optimization of circuits and software.

The final tutorial, "EMI Measurements in Manufacturing Environment" given by Vladimir Kraz from OnFilter, provided, practical guidance on measuring and quantifying relevant EOS-causing EMI signals in a semiconductor or electronic manufacturing environment. The basic methodology, required tools, and the difference between correct and incorrect approaches was presented, involving measurements of EMI voltage and current. This tutorial provided practical support to a recently released Technical Report TR23.0-01 on EOS [5] that contains a significant section on EMI as a source of EOS. Measurements of EMI are quite different from those of ESD to which many members of EOS/ESD Association are accustomed. This tutorial "demystifies" measurements of high-frequency signals essential to managing EMI-caused EOS in any process.

The final portion of the session was an interactive virtual "Expert Panel" led by the above presenters and organizers. This panel was very informative and featured many questions from the audience on EMC aspects of ESD and vice versa, referring to the presentations during the session.

In all, the EMC Special Session was a great addition to the Symposium. Plans are for a second EMC Special Session for the 2021 EOS/ESD Symposium in Tucson.

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Banana Skins

333 BMW screen heater interferes with car radio

Q: The rear-screen heater in my BMW 3-Series causes so much interference when switched on that it's impossible to listen to the car radio. Our local BMW dealer suggested replacing the entire rear screen as at cost of more than £600. This seems drastic. — KR from Hertfordshire.

A: This is a known problem within the trade. It stems from the fact that the rear screen includes both the heating elements and the radio aerial. The high level of electrical current required by the heating elements is being picked up by the aerial. Fortunately, it is usually possible to fit one or more electrical suppressors into the heated rear window wiring, as close as possible to the window itself. These reduce the electromagnetic interference from the screen to a level where it shouldn't interfere with the aerial. This will cost much less than a new screen.

(Taken from 'Car Clinic', Sunday Times, March 13 2005, page 26, http://www.sunday-times.co.uk.)

334 EMI suspected of causing cancellation of shuttle launch

Just in case anyone in the EMC community was away from the media for the last few days, electromagnetic interference is one of the suspected culprits in a fuel sensor malfunction that resulted in the cancellation of the first planned space shuttle launch earlier this month. Four hydrogen fuel sensors read either wet or dry, and a dry reading from all four sensors triggers engine cutoff and an aborted launch. After the originally scheduled flight was called off on July 13, literally hundreds of engineers tried to recreate the electromagnetic environment in which one sensor failed intermittently. Reportedly grounding was improved, and the entire craft re-examined for possible sources of EMI.

Still, the exact cause of the intermittent failure was not identified, and NASA rules were modified so that lift-off could take place with three operational sensors. Fortunately, the intermittent fuel gauge glitch did not reoccur during Tuesday's lift-off. (Sadly, as we prepare our final copy, word of foam problems and cancellation of future flights has just been released to the media.) Clearly, NASA personnel face some daunting challenges in the months ahead. Moreover, every modification to the extremely complex craft alters the EM environment in which delicate instrumentation must function.

(From Interference Technology E-News, 29 July 05.)

335 Close proximity of cell phone corrupts data in keyfob, immobilising vehicle

I've always been suspicious of admonitions to turn off mobile phones on planes, in hospitals and so on, believing them to be yet more examples of the culture of bossiness that pervades modern life. It turns out that the bossy-boots are right.

You know how it is – one minute the car is working perfectly; the next – literally – it has conked. So it was last weekend when I was trying to transport four extremely heavy lead planters, overlooked by the removers, from the old flat to the new house. Various people emerged to have a look and offer advice, including the mechanic who lives opposite (who said Londoners aren't neighbourly?), but the nature of the conking-out remained a mystery. "It sounds as if it is trying to start, but isn't." said one man, helpfully (who said men know all about cars?). Then the AA man arrived – all yellow van and flashing lights, just like in the adverts – and solved the problem immediately. Had I, he asked, kept the car key anywhere near my mobile phone? Well, of course I had. Like most women I lug around a miniature version of my life in my handbag.

This was my mistake. The mobile phone signal had corrupted the chip in the key, disrupting the central locking system and knocking out the ignition. The thing was that none of us knew about this – not me, the neighbours, friends I have told about it, not even the mechanic. I pass on the information so that no one else finds herself stuck on a yellow line in the middle of London on a searingly hot day with a car that is going nowhere.

(From Rachel Simhon's column in the 'Diary' section of the Daily Telegraph, Saturday, July 16 2005, page 23.)

336 Modern EM environment creates problems for audio induction loops - examples

Being involved in providing audio induction loops for hearing aid users, I am interested in cases of audio magnetic interference. The modern electromagnetic environment has an increasing number of these.

While installing loop systems in a building in Wolverhampton Science Park I checked for possible interference. A coil of red-coated pyrotenax cable in the ceiling was interesting. That being part of the Fire Alarm installation, I used the monitor receiver to listen to the "Break-Glass" alarm point. Again, I heard the same digital noise right across the audio range. This kind of interference is a continuous background buzz for hearing aid users wanting to use an induction loop. This compares with listening to a car radio, or to a CD with a noisy fan in the room. In practice, the magnetic field from the Break-Glass would not be a problem. But the field from the cable routing and the coil of surplus cable just above someone's head could be.

We found a similar interference in a new building in Edgbaston High School. Most of the hall is clean, but there is one corner with significant digital noise. Again, it happens to be next to a storeroom containing the displays for the fire alarms. Otherwise, in that room, the fire alarm is cleaner than at Wolverhampton.

A case which may not be an audio magnetic field (I did not have the right detector available) was at my mother-in-law's. We heard that the Hi-Fi had developed a fault, and there was a buzz. I found this buzz on the cassette deck, though the radio was clean. Moving the BT DECT cordless phone cured the problem. The wiring for this, from the power supply as well as the phone line, seems to be the main radiator. Since it is plugged in to the same mains point as the hi-fi, separating the items is difficult. It is not clear whether or not this is magnetic interference. But cassette tape play heads are susceptible to magnetic fields. For example, with separate items, placing a tape player on top of an amplifier usually causes a loud hum from magnetic coupling to the amplifier power supply.

Audio induction loops are a common "aid for the disabled" using the audio magnetic spectrum coupling to a pick-up coil in the hearing aid. The target magnetic field is 100mA/m to match normal hearing aid microphone levels. Installers, and public buildings, use monitor receivers to check loop systems. One such monitor is the Ampetronic ILR2 which allows people with normal hearing to hear what a hearing aid user would hear.

I happened to have a loop monitor with me when I was shown around the brand-new library building in Bournemouth. They have the, now ubiquitous, standard screening arrangement to detect books being smuggled past the check-out. This generates such a strong magnetic field that the nearest induction loop on the counter has to be about 4 metres away. Any closer and the noise, a constant whistle at about 1kHz or so, is intolerable for hearing aid users.

Similar anti-theft screens, the familiar pair of (usually) grey loops you walk between entering or leaving larger shops are very common. Because check-outs are near the doors, this is likely to be a problem where hearing aid loop systems are fitted. I happened to visit a major car accessory shop in Birmingham, again with a loop monitor to hand. The whistle from the security screen could be heard out in the car park.

(*Sent in by Robert Higginson, 14 July 2005*)

337 Audio induction loops can interfere with other equipment

Audio frequency induction loops are an aid for hearing aid users which generate an audio frequency magnetic field. Often the siting of these is very restricted because of the way a building is built. While there is a specification for the field strength, this applies to normal listening position and there can be very high fields close to the loop cable. These fields can couple into other systems and equipment. Because EMC specifications are geared up for radio frequencies or mains power, high levels of audio magnetic fields are often forgotten.

We installed a desk loop system at an enquiries desk. These are supplied as kits, with a pre-formed loop coil usually located just underneath the desk, and driven hard so that the hearing aid picks up the spill field rather than the main field inside the coil. Having set the field to give the required "head height" signal, we found that the computer was responding to the magnetic field. The keyboard had a magnetic card reader used for staff to log-on. This was interpreting the audio signal as an erroneous user-name and password. Options were limited as there was only one tidy and vandal resistant place to put the loop. The solution was to move the keyboard away from the loop installation. In its normal place, the keyboard would be exposed to magnetic fields of several amps per metre.

Several years ago we installed a sound amplification system including induction loop in a church building. They also had a video projector, used with computers and video players with no problem. Recently they bought a new lap-top computer and the supplier offered a special package deal including a new projector. The new equipment picked up "hum bars" from the loop. The computer firm, apart from comments about "new regulations for loop installations" proposed the loop amplifier being switched off. We tried a range of other projectors and there was no problem. Only the Hitachi projector supplied packaged with the computer suffered hum bars. As an isolated equipment, a projector may pass susceptibility tests. But such equipment is never used in isolation, only as part of a system.

(*Also sent in by Robert Higginson, 14 July 2005. Also see Robert's article* "Are You Hearing Me? An aid for the disabled lacking EMC protection" *in the UK EMC Journal, June 1998, pp 14-16, available from the archives.)*

(The Editor notes that the immunity standard for professional audio, video and lighting equipment and systems, EN 55103-2, includes requirements for immunity testing with audio-frequency magnetic fields. But system integrators often use 'domestic' equipment that has not been made compliant with EN 55103-2, in their systems, and ignore their responsibilities under the EMC Directive by assuming that simply using CE

marked items of equipment will result in a compliant system – the so-called CE + CE = CE approach, which does not work and furthermore has no legal or technical justification.)

338 Plasma screens in waiting rooms interfere with ultrasound medical diagnostics

A new hospital, commissioned in 2002, had large plasma display screens in their waiting rooms, showing fish swimming. But ultrasound diagnosis equipment in the rooms on the other side of the walls that the plasma displays were hung on suffered from interference. Close-field probing with a spectrum analyser showed significant levels of emissions leaking through the wall from the waiting room plasma displays, so they were assumed to be the culprits.

Moving the ultrasound equipment to the far side of the room from the wall shared with the waiting room reduced the level of the interference. When the interference levels are too high for a particular test, the ultrasound operators have permissions to switch the plasma displays off.

(Sent in by Clive Griffiths, 15th June 2005)

339 Wireless devices interfere with office equipment in U.S.

USA delegate opened a discussion on the new work being promulgated in the US by ANSI to address immunity concerns from wireless devices when used in close proximity to office equipment. (This had originally been raised by Goldman-Sachs who found this problem in their offices).

The primary concern appears to be interference to telephone devices, although the draft ANSI standard is not limited to them alone. The standard being developed appears to be a product standard, not a basic standard. There is no chance of this being legislative but likely to remain a contractual issue.

This is a cause for concern to WG10 because of the risk of alternative test methods and attendant problems of multiple test regimes, inter-correlation, etc. It appears that this work has come about because of the lack of any immunity requirements in the US *(for household, commercial and industrial products – Editor)*. Similar environments in Europe where CE marking is required have not evidenced such susceptibility.

(A report from a delegate to the WG10 Meeting 25-29 April 2005, Beijing, China, "Maintenance of 61000-4-3").

340 Lighting system capacitors cause power system resonance hence failure of crane motor

Haag cite one experience where an intermittent failure was caused when the pulse driven motor of a crane went into resonance with the compensating capacitors of a nearby lighting system. It was interesting to note that because those involved were not familiar with the possibility of such mains linked resonances, all manner of costly time-wasting investigations were carried out and sources of blame sought, before the real culprit was found.

(From "Does Your System Have 50Hz Impedance Myopia," Ron Neale, EMC Engineering Europe, March 1998, page 5.)

341 Problems of excessive recovery times following mains interruptions

The point of the voltage interruptions tests in EN 61000-4-11, and the generic and product immunity standards that call them up, is that equipment should recover from such events as if nothing had happened, or at least as if they had just been switched on for the first time. Even for older equipment that pre-dated the above immunity standards, interruptions in the mains power is a rather obvious fact of life and designers could be expected to have designed accordingly. But recently I had to service a modified (and expensive) CD player that had some special system for background music.

There had been a 10-second-long power cut in Northampton, where it was installed, and the thing would not come back to life afterwards. Actually, it was not working when I collected it, but started working the next day (presumably after some capacitor had sufficiently discharged).

That 10-second power cut also put the Northampton traffic light system out of operation for a long time – increasing safety risks at road junctions. While working in the All Saints area of West Bromwich, we noticed several brief power cuts, the longest being perhaps only one second, and these appeared to put the traffic lights out of action for a lengthy period of time.

(Sent in by Robert Higginson, 13 September 05.)

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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Upcoming Events

June 6-11
International Microwave Symposium (IMS)

June 15-18
Applying Practical EMI Design & Troubleshooting Techniques

June 26
IEC International Special Committee on Radio Interference (CISPR)

June 28-30
Sensors Expo and Conference

July 20-23
2021 ESD Workshop

July 27-August 13
2021 Joint IEEE International Symposium on Electromagnetic Compatibility, Signal & Power Integrity, and EMC Europe (EMC+SIPI 2021)

July 28
The Battery Show - Digital Express

August 16-18
DesignCon 2021

August 16-19
Military Standard 810 (MIL-STD 810) Testing Open Course

August 23-26
Military Standard 810 (MIL-STD 810) Testing Open Course

Due to COVID-19 concerns, events may be postponed. Please check the event website for current information.