THE BASIC PRINCIPLES OF SHIELDING

A DASH OF MAXWELL’S
A Maxwell’s Equations Primer
Part 6

ASSESSING THE EMC PERFORMANCE OF PCB SHIELDS
by Electromagnetic Modeling

History of CISPR

CDM Testing of SMALL INTEGRATED CIRCUITS
Wide Variety of Products for Your EMC Testing Needs

Save Time and Money by Shopping From A Single Source

Com-power offers a wide variety of products for compliance testing. We provide quick delivery, the best warranty in our industry, and very reasonable prices.

OTHER PRODUCTS INCLUDE:
Spectrum Analyzers & Receivers • Power Amplifiers • Turntables • Masts & Tripods • Product Safety Accessories

Contact us at 714.528.8800 or sales@com-power.com
www.com-power.com

114 Olinda Drive, Brea, California 92823 • tel 714.528.8800 • fax 714.528.1992 • sales@com-power.com
WHAT’S INSIDE

12 The Basic Principles of SHIELDING

20 A DASH OF MAXWELL’S
A Maxwell’s Equations Primer: Part 6

28 ASSESSING THE EMC PERFORMANCE OF PCB SHIELDS
by Electromagnetic Modeling

36 The History of CISPR

44 CDM Testing of SMALL INTEGRATED CIRCUITS

10 SPECIAL REPORT:
Another Opinion on Automobile Sudden Unexpected Acceleration EMI Connection

4 NEWS IN COMPLIANCE

47 THE FUTURE OF EMC ENGINEERING

48 EVENTS

49 BUSINESS NEWS
Ham Radio Operator Keeps His License

A Seattle, WA man has been allowed to renew his amateur radio operator license after a nearly two year battle with the Enforcement Bureau of the Federal Communications Commission (FCC).

The licensee, David Titus, experienced a troubled childhood that included criminal convictions for sexual abuse of other children, but had subsequently held an amateur radio operators license for 20 years without incident. However, the Enforcement Bureau held up his application for renewal on the grounds that his status as a Level 2 sex offender was contrary to the personal character required of license holders.

The Commission is authorized to consider a licensee’s character when evaluating whether to award an amateur radio operator’s license or approve one for renewal. However, in a lengthy and detailed ruling issued on March 9th, FCC Administrative Law Judge Richard Sippel found that Titus had provided sufficient evidence of his rehabilitation in connection with his past criminal offenses, and that the Enforcement Bureau’s efforts to revoke his licensee should be stayed.

“The evidence supports the conclusion that Mr. Titus is now...rehabilitated,” noted Sippel in his ruling. “He now is a 35-year-old adult whose last conviction was adjudicated while he was only 18 years old. The fact that he has lived in the community for 15 years without being charged with a crime is substantial and reliable evidence of his rehabilitation.”

Further, Sippel wrote, “an overall record of compliance with Commission rules and policies is relevant in assessing character. Mr. Titus has held an Amateur Radio license for 20 years, and there is no credible or reliable evidence even suggesting that he ever has used or ever would dare to use ham radio communication as a means to contact minors for illicit purposes.”

FCC Seeks Comment on Changes to Amateur Radio Rules

In recognition of the vital role that amateur radio operators have played following natural and man-made disasters, the Federal Communications Commission (FCC) is seeking to broaden their ability to participate in government-sponsored emergency preparedness and disaster readiness drills and tests.

In a Notice of Proposed Rulemaking (NPRM) issued on March 24th, the Commission proposed amending its amateur radio service rules to allow amateur radio operators to participate in emergency and disaster preparedness drills, regardless of whether the radio operators are employees of those organizations participating in the drill.

The Commission has proposed the rule change since the current regulations prohibit amateur radio operators who are employees of public safety agencies, hospitals, and other entities from participating in emergency preparedness drills and test, and to transmit messages on behalf of their employers during such tests.

Such regulations stem from the view that the Amateur Radio Service was primarily designated for “amateurs,” that is, “persons interested in radio technique solely with a personal aim and without pecuniary interest.”

In the NPRM, the Commission emphasizes that its proposed changes “do not disturb the core principle of amateur radio service as a voluntary, non-commercial communication service.” “Rather,” the NPRM continues, “we believe that the public interest will be served by a narrow exception to the prohibition.”

FCC Releases Quarterly Reports on Consumer Inquiries and Complaints

The Federal Communications Commission (FCC) has released its quarterly report on inquiries and complaints made by consumers to the agency’s Consumer & Government Affairs Bureau during the third quarter of calendar year 2009.

The Bureau regularly tracks inquiries and complaints from consumers on matters within the scope of the Commission’s jurisdiction. In the area of wireline telecommunications matters, the Bureau is particularly interested in instances of “cramming” (the placing of unauthorized, misleading or deceptive charges on a telephone bill) and “slamming” (the practice of changing a subscriber’s telecommunications service provider or calling plan without the subscriber’s permission). The Commission also tracks violations of the Federal Telephone Consumer Protection Act (TCPA), which includes regulations covering both the “Do Not Call” registry and unsolicited fax advertisements.

During the period from July through September 2009, the Bureau received 34,925 total complaints regarding wireline telecommunication services, with 29,874 complaints in the area of TCPA issues alone, and 7414 complaints in connection with unsolicited fax advertisements. This compares with 39,546 total complaints during the July-September 2008 period, with 33,449 involving with TCPA issues.

In the area of inquiries, the Bureau also received 12,754 inquiries in connection with wireline telecommunications, including 7335 inquiries dealing with
TCPA issues, during the period from July through September 2009. This compares with 24,981 total inquiries during the third quarter of calendar year 2008, of which 18,441 were related to TCPA issues.


Court Strikes Down FCC’s Net Neutrality Rules

A United States District Court of Appeals has struck down the underpinnings of the Federal Communications Commission’s (FCC’s) so-called “net neutrality” rules for Internet service providers, potentially paving the way for stricter regulations intended to ensure that all legal Internet traffic is treated equally.

In a unanimous decision issued on April 6th, the Court of Appeals for the District of Columbia Circuit ruled that the Commission exceeded its statutory authority when it sanctioned Comcast Corporation back in 2008. In that action, the FCC ordered by a 3-2 vote that Comcast cease its efforts to slow broadband throughput rates for customers who were downloading large data files from peer-to-peer sharing services.

The Court, in overturning the Commission’s action against Comcast, ruled that Congress had not accorded the FCC the power to regulate the network management practices of Internet service providers.

Custom Shields and Metal Parts.

Fotofab’s process of photochemical etching offers speed, flexibility and precision unmatched by traditional manufacturing methods.

- Print to part in 1 day - we’re that fast!
- Fotofab’s technical staff will drive your project - even without a print.
- Complex features, non-standard sizes and company logos are free.
- Fotofab can form, plate and package your parts...

Just tell us what you need!
In a statement following the Court’s ruling, the FCC agreed that “today’s Court decision invalidated the prior Commission’s approach to preserving an open Internet.” However, the statement continued, “the Court in no way disagreed with the importance of preserving a free and open Internet; nor did it close the door to other methods for achieving this important end.”

One possible method would be for the FCC to revise its definition of broadband Internet access from an “information” service to a “communications” service, thereby subjecting Internet service providers to the same regulatory oversight as phone companies. Such an action would, no doubt, prompt legal challenges from Internet service providers.

A separate option would be for Congress to pass legislation empowering the FCC to regulate Internet service providers.

The complete text of the Court’s ruling against the FCC is available at http://online.wsj.com/public/resources/documents/comcastfcc.pdf.

**FCC Announces Broadband Action Agenda**

In support of its National Broadband Plan issued in March, the Federal Communications Commission (FCC) has now released a more detailed, tactical plan to implement the Plan’s key recommendations.

The Commission’s “Broadband Action Agenda” provides a roadmap for the completion of more than 60 separate rulemaking and other notice-and-comment proceedings required to achieve the primary goals of the National Broadband Plan. Those goals include:

- Promoting world-leading mobile broadband infrastructure and innovation;
- Accelerating universal broadband access and adoption, and advancing national purposes;
- Fostering competition and maximizing consumer benefit across the broadband ecosystem;
- Advancing robust and secure public safety communications networks.

In addition to completing the individual agenda items, the FCC says that it will simultaneously work on a number of initiatives that support the Plan that don’t require formal agency proceedings.

The Commission says that executing its Broadband Agenda will lead to more affordable high-speed Internet access for more Americans, promote innovation, investment, and competition, and advance the use of broadband Internet access in support of key national priorities, such as public safety, healthcare and education.


**Phone Jamming Device Attracts FCC Sanctions**

A web-based electronics retailer has been assessed a penalty of $25,000 by the Federal Communications Commission (FCC) for marketing illegal cell phone jamming equipment.

According to a Notice of Apparent Liability for Forfeiture issued on April 20th, the Commission cited Phonejammer.com for willful and repeated violations of regulations banning the marketing within the United States of radio frequency devices designed to intentionally interfere with licensed cellular and PCS (Personal Communications Services) operations.

Phonejammer first received a citation from the Commission in May 2008, based on a review of the company’s website by FCC investigators. The citation ordered the company to cease its efforts to market illegal phone jamming devices in the United States, and warned of possible monetary forfeitures for failing to comply with the terms of the citation.

Then, as a result of interference complaints in late 2009 directly connected with equipment sold by Phonejammer, the Commission initiated an investigation against the company. Phonejammer denied the Commission’s charges but, surprisingly, failed to attest to the truth and accuracy of the information contained in its Response to the Commission, even under the threat of penalty for perjury.

The Commission’s current decision to levy financial penalties against the company stems from a March 2010 interference complaint in Florida, which led to equipment directly connected with Phonejammer.


**FCC Inquires on Survivability of Broadband Infrastructure**

Under the auspices of the American Recovery and Reinvestment Act (ARRA) of 2009, the Federal Communications Commission (FCC) has launched an investigation into the survivability of the nation’s broadband service network.

In a Notice of Inquiry issued on April 21st, the Commission says it seeks “to enhance our understanding of the present state of survivability in broadband communication networks and to explore potential measures to reduce network vulnerability to failures in network equipment or severe overload conditions.”

The Commission says that it specifically interested in better understanding the stresses that would be placed on the broadband infrastructure in natural and man-made disasters, when the need for reliable, effective
communication would be most critical. According to the Commission, it is specifically tasked under the ARRA to explore ways in which broadband infrastructure and services can “advance consumer welfare…public safety and homeland security…and other national purposes.” Hence, the need to investigate broadband survivability.

Comments on the Commission’s NOI regarding broadband survivability must be filed on or before June 5th.


Commission Moves to Ease Video Device Regulations

Seeking to foster a more competitive marketplace for so-called “smart video” devices, the Federal Communications Commission (FCC) is seeking comments on specific steps it can take to facilitate the development and sale of such devices for use with any video programming distributor.

In today’s media marketplace, consumers are accessing video from multiple sources, including the Internet, DVDs, and programs provided by multichannel video programming distributors (MVPDs). However, many MVPDs utilize a proprietary interface between their systems and smart video devices, thereby limiting their usefulness and leading to an unnecessary proliferation of equipment serving mostly the same purposes.

The Commission believes that a standardized interface will allow consumer to more easily bring together video from a wide range of sources for selection, recording and viewing. Specifically, the Commission has proposed the development of an “AllVid” adaptor that could serve as an interface between the MVPD’s services and consumer-owned smart video devices.

According to the Commission, such an adaptor would allow MVPDs to continue to upgrade their services, and consumers to switch from one service provider to another, all without having to change the consumer’s smart video device.

Comments on the Commission’s NOI must be filed on or before June 20th.


EU Commission Reissues Corrected Standards List for EMC Directive

The Commission of the European Union (EU) has issued a correct version of its list of standards that can be used to demonstrate conformity with the essential requirements of the EU’s directive on electromagnetic compatibility (also known as the EMC Directive).


Updated Standards List Published for EU’s ATEX Directive

The Commission of the European Union (EU) has published an updated list of standards that can be used to demonstrate conformity with the essential requirements of its directive concerning equipment and protective systems intended for use in potentially explosive atmospheres.

The directive, 94/9/EC, which is also known as the ATEX Directive, applies to “machines, apparatus, fixed or mobile devices, control components and instrumentation…and detection or prevention systems which…are intended for the generation, transfer, storage, measurement, control and conversion of energy and/or the processing of material,” and “which are capable of causing an explosion through their own potential sources of ignition.”

The updated list of standards was published in the April 16th issue of the Official Journal of the European Union, and replaces all previously published standards lists for the ATEX Directive.


Regulations for Ecodesign of Fluorescent Lamps Amended by EU Commission

The Commission of the European Union (EU) has also amended its regulations relating to the ecodesign requirements for certain types of lamps and ballasts.

In Commission Regulation (EU) No 347/2010 issued on April 21st, the Commission extensively amended Annexes I, II, III and IV originally found in Regulation (EC) No 245/2009. These Annexes detail the technical requirements of the regulation, including minimum efficacy values, lamp lumen maintenance factors, lamp survival factors, and energy efficiency index requirements.

According to the Commission’s Regulation, the changes were warranted “in order to avoid unintended impacts on the availability and performance of the products covered by the Regulation.” In addition, by amending the Regulation, the Commission hopes to eliminate confusion regarding the ecodesign requirements for non-directional household lamps.

The Commission’s Regulation, along with the complete text of the amended

EU Commission Issues Measurement Methods for Ecodesign of Certain Lamps

The Commission of the European Union (EU) has published a list of documents to provide ‘transitory measurement methods’ for compliance with its directive relating to the ecodesign requirements for certain types of lamps and ballasts.

The directive, 2009/125/EC, details essential requirements for the ecodesign of fluorescent lamps without integrated ballasts, high intensity discharge lamps, and those lamp ballasts and luminaries that operate such lamps.

The Commission’s communications, published in the April 10th issue of the Official Journal of the European Union, references a number of European EN standards, as well as documents issued by the International Commission on Illumination. The Commission says that the listed transitory measurement methods will ultimately be replaced by harmonized standards.


Potential Fire Hazard Leads to Recall of Extension Cords, Power Strips

The Howard Berger Company of Cranbury, NJ has issued a voluntary recall for about 12,000 indoor and outdoor electrical extension cords and power strips manufactured in China.

According to a recall alert issued by the U.S. Consumer Product Safety Commission (CPSC), the extension cords and power strips have inadequate coating material around the cords, and copper conductors that are smaller than required, posting a fire hazard to consumers.

Berger says that it has not received any reports of incidents or injuries related to the recalled electrical products, but that it has issued the recall to prevent any future incidents.

The electrical cords and power strips were sold through hardware and discount stores nationwide from August through October 2009 for between $1 and $20.

To view the CPSC notice regarding this recall, go to http://www.cpsc.gov/cpscpub/prerel/prhtml10/10184.html.

Companies Recall Scuba Regulators, Computers

Two companies have issued voluntary recalls of scuba diving technology equipment that pose a potential drowning hazard to consumers.

Tabata USA, Inc. of Long Beach, CA has recalled about 250 of its scuba tank regulators. The first stage balance chamber plug of the regulator can reportedly loosen from the scuba regulator, causing a high-pressure leak and creating unstable pressure.

Separately, Mares USA of Boca Raton, FL is recalling about 600 of its air dive computers. An O-ring in the high pressure air connector can reportedly fail and leak air, causing a slow loss of breathing gas.

There have been no reports of incidents or injuries related to either of the recalled products.

To view the CPSC notice regarding the recall of the scuba regulators by Tabata, go to http://www.cpsc.gov/cpscpub/prerel/prhtml10/10195.html.

To view the CPSC notice regarding the recall of dive computers by Mares is available at http://www.cpsc.gov/cpscpub/prerel/prhtml10/10197.html.

CPSC Recognizes ‘Firewalled’ Conformity Assessment Bodies

The U.S. Consumer Product Safety Commission (CPSC) has voted to recognize four additional ‘firewalled’ testing laboratories, authorizing them to conduct testing of children’s products under the recently amended Consumer Product Safety Act (CPSA).

Under the CPSC’s laboratory recognition process, testing laboratories that are owned, managed or controlled by a manufacturer must demonstrate that their test results are sufficiently ‘firewalled’ from the parent company to avoid any potential conflict of interest. Such testing labs must also be accredited as compliant with ISO/IEC 17025, which details accreditation requirements for independent testing laboratories.

The firewalled testing laboratories newly recognized by the CPSC are:

- MeadWestvaco Safety, Health and Environmental Laboratory (Miamisburg, OH)
- Dongguan Zensee Printing Limited DPI Laboratory (Dongguan, Guangdong, China)
- Testing Laboratory, Mattel Bangkok Limited (Samut Prakarn, Thailand)
- Chang An PL Lab of Foshen Nanhai Mattel Consultancy Service Co. Ltd. (Dongguan, Guangdong, China)

With this action, the Commission has now recognized 11 firewalled testing laboratories, and nearly 250 independent third-party testing labs.

Let Panashield help you with your EMC facility project.
Our experienced personnel will provide technical support to guide you through design, supply and certification.

EMC Chambers
RF Shielded Enclosures
Military Test Chambers
Avionics Test Chambers
Free Space Chambers

Reverberation Chambers
P3 RF Sliding Doors
Turnkey Services
Facility
Relocations/Upgrades

Tel: 203.866.5888  Fax: 203.866.6162
help@panashield.com

www.panashield.com
Another Opinion on
Automobile Sudden Unexpected Acceleration EMI Connection

There has been much to do about the sudden unexpected acceleration EMI connection. There is no shortage of opinions on this subject. We’ve heard from manufacturers and their EMI consultants as well as from many recognized industrial and academic EMI experts. Most manufacturers have been very supportive of each other but have been very careful not to utter direct EMI related statements as they would rather not be seen in the spotlight of any investigations aimed in their direction. I guess they think that the EMI gods have decided to target just one automobile manufacturer.

I am writing this letter because I believe that, all too often, we can get too close to a problem and overlook some obvious possibilities. Anyone that has done system and subsystem EMI trouble shooting knows, there are interactions/resonances within a single box as well as between subsystem and system boxes that can add to or subtract from the overall EMI signature of the equipment under test (EUT). Of course that works both ways making it both an emissions and susceptibility issue but the later is of most concern here. That’s pretty basic. The way the EMI compliance test system works today, when we take a product to an EMI Test House for compliance confirmation, we expect and get testing performed to a single threat over the entire relevant standards driven test range, to the “minimum” test levels that the standards allow. In fact the basic goal of today’s anechoic test chamber designs is to eliminate all signals except those that are part of the test process. This might be acceptable for stationary EUT such as refrigerators, stereos, PCs, TV, recorders etc. That is not to say that automobiles are not tested to higher standards, they are. More on this later.

In the mechanical engineering arena (e.g. The European Union Machinery Directive) a single fault condition is not allowed unless the safety function is maintained. In other words, the box must fail safe. The point is, because machinery is more robust than electronics, failures are fewer and more predictable, even though they share environments. In the EMI environment the same criteria must be considered along with the anticipation of multiple threats. This process will be complicated by the fact that EMI complications are more numbered and complex. In any case the product must always fail safe.

In the real world, when you have a “EUT on wheels” chances are, sometime in its travels, it is going to encounter “multiple EMI threats” (1, 2, 3 or 4 maybe more) simultaneously and just like the individual box environment mentioned above, sometimes the threats can combine, subtract and negate each other. Other times these culprit signals might add or combine in such a manner that allows them to break through the single threat tested EUT, as this condition is not tested for. It is much like a chemical reaction. One chemical added to a solution may make no noticeable difference but together with another chemical or chemicals it can change the original solution to something totally different. The number of threats can be changed with location and EMI environmental conditions.

Try this: Just as an exercise, the next time you are sitting at a stop light at a busy intersection surrounded by department stores, gas stations and other industrial sights, see if you can identify the number of potential EMI threats. e.g. is a big rig behind you with the driver keying his CB Radio? Is the wireless burglar alarm in the hardware store across the street turned on? Is the red light in front of you smart enough to sense traffic patterns? Are there high tension electric power cables or microwave towers in the area? You get the idea?

More possibilities: Now suppose a production line is being held up because some particular EMI filter components are out of tolerance or maybe not available and a substitution is made. How about if some shielded wires or some non-metallic connectors were shipped by mistake to the manufacturer? These are real issues that manufacturing people must deal with every day. I only mention a few to give you a flavor for the unpredictable. Chances are, not one of these mishaps will have any effect on the performance of the end product. Also there is always a tremendous amount of pressure to get the product out the door. The proper way to prove EMI compliance is to re-test these products. In the present day manufacturing culture this is highly unlikely. Chances are in this whole process an EMI Engineer was never even consulted. These types of decisions are made...
every day by well intentioned individuals who are trying to do the right thing. These issues will get resolved and not always favorably. The product will almost always get shipped.

Now we have a number of automobiles on the streets and highways, with their EMI defenses compromised. Some may drive for years with no problems and some may be susceptible to multiple EMI events from day one. Some could cause the subject condition. Over time some of these issues may be addressed, after the fact, with recalls or Technical Notes to the dealers. Some will not.

Remedies: One way to find the cause of such problems is to recreate the exact EMI conditions that triggered the event in the first place. This of course, is difficult (but not impossible) because some of the threats may be moving in different directions at the same time. This also explains why, once an event like sudden unexpected acceleration occurs and the automobiles’ ignition is turned off (reset), and then re-started; the problem disappears. This, in my opinion, renders the “floor mat over the accelerator pedal defense” moot. If it was really the cause, it would still be there after the automobile was restarted (it is a mechanical condition). Another possibility is to select or create a suite of tests (at the correct levels for the application) which would assault the EUT with multiple threats at the same time. From this approach a more real world set of tests could be developed to address these real world problems.

Unfortunately there is not much that today’s standards authorities can do when the foxes have the keys to the hen house. In 1947 the FCC came to the conclusion that there were not enough public complaints on “ignition noise” to take any action. Over the years the FCC allowed the automakers (who were, of course, the closest to the problem) to call the shots. Committees were formed and disbanded but the one constant was that the automobile manufacturers held on tight to the control of test levels. The SAE (automotive standards) Specifically SAE J551, now -2, became the default automotive EMI authority in the US. The SAE as well as their global counterparts have done a fine job over the years trying to create and maintain the relevant standards. That, in itself, is not the problem. I believe the problem lies in the immunity levels being too low and the single threat method of testing being insufficient but most importantly, I question those that control the outcome.

The auto manufacturers have worked together on test levels for EMI over the years. Further, they perform most of their own EMI testing citing the high cost of test facilities and proprietary design preservation. This from the people who over the last 20 years have been dragging their feet on improving overall fleet gas mileage and suddenly, in the last year, have broken the 30 miles per gallon barrier on many of their models.

The one thing we can count on is that the automobile manufacturers will continue to declare their commitment to the safety of their automobile customers. They will continue to sell this notion on the airwaves in the form of our favorite TV commercials, but their true focus is the bottom line. Until an accredited independent organization with enough authority is allowed to step in and tell the automobile manufacturers what the realistic levels of immunity for ground vehicle applications must be, anything else is just an excursive in “due diligence” which in this context is just another legal defense strategy. Even if NASA gets involved, unless they are given complete policy making control, the results are already in.

Solution: Guess what boys; it is time to man-up and use the required bonding and shielding techniques used successfully by the military for decades.

I have to close by quoting a wise old engineer who said, before you can begin to solve any engineering problem you first “gotta wanna”.

Contact Information : compliancehelp@yahoo.com

---

Want to receive IN Compliance for free?
Subscribe using this code to receive your print or digital subscription for free.
www.incompliancemag.com/subscribe
JUN10
expires June 30, 2010
Today’s electrical and electronic devices are subject to mandatory EMC requirements throughout the world. Many devices operate at high frequencies and are very small. They are placed in nonconductive plastic cases providing no shielding. Essentially, all these devices cannot meet these mandatory requirements or they may cause interference to other devices or receive interference causing susceptibility problems without a proper program of EMI control. This program consists of identifying the “suspect” components and circuits that may cause or be susceptible to EMI. This is completed early on in the program to allow for an efficient design in keeping the cost of dealing with EMI as low as possible. A complete EMC program consists of proper filtering, grounding and shielding. This article will discuss the latter, but the other factors cannot and will not be ignored or given insufficient priority.

The article will look into what EMI is and how to design to control it using shielding in conjunction with proper design. Various shielding materials and their uses will be discussed.

**WHAT IS EMI?**

EMI (Electromagnetic Interference) is a process by which disruptive electromagnetic energy is transmitted from one electronic device to another via radiated or conducted paths, or both. In electronic components, devices and systems, EMI can adversely affect their performance. The goal of all electronic designers is to achieve EMC (Electromagnetic Compatibility) in their designs. Not only to assure proper operation, but to meet the various mandatory EMC requirements imposed by legislation around the world.

EMI can simply be a nuisance such as static on a radio, or it can manifest itself as dangerous problems such as interference with aircraft control systems, automotive safety systems, or medical devices.

Remember, it is always more efficient and less expensive to deal with EMI at its source. The farther away you get from the source or the farther down the design chain you are, the more difficult and expensive it is to mitigate the problems.

**THE PROBLEMS**

The trend in today’s electronic devices is faster, smaller, and digital rather than analog. Most equipment of today contains digital circuits. Today’s digital designer must create a circuit board that has the lowest possible EMI, combined with the highest possible operating and processing speeds; generally keeping it as small as possible. Design of the printed circuit board (PCB) is the most critical EMC influencing factor for any system, since virtually all active devices are located on the board. It is the changing current (accelerating electron movement) produced by the active devices that result in EMI. The faster the digital speed, the greater the required circuit bandwidth, and the more difficult it is to control both radiated emissions and susceptibility. In this regard, it is useful to first consider the relationship between operating frequencies and radiated emissions. The fundamental frequency for each active device and its associated circuitry must be considered. But the harmonics of these devices can be 10 to 100 times greater in frequency than their fundamentals. The odd harmonics, 3, 5, 7, 9, etc. times the fundamental, are especially troublesome. As a result, increases in EMI with the evolution from analog to high speed digital circuits have been dramatic. RF energy levels at the higher frequency harmonics of analog devices are negligible. The harmonics of an ideal Gaussian wave shape, albeit more a mathematical concept than a practical reality, fall off very quickly at the higher frequencies.

A cosine-squared wave shape, approximately equivalent to that produced by a linear power supply or other analog continuous wave (CW) source having some harmonic distortion, exhibits high frequency harmonic amplitude falloff of 60 dB per decade of frequency. Moving from analog circuits to low speed digital circuits has no significant effect at the fundamentals level, but RF amplitudes increase at the higher harmonic frequencies because falloff occurs at 40 dB per decade rather than 60 dB. In moving from low speed to high speed digital operation, high frequency radio frequency (RF) levels increase even more as harmonics fall off at just 20 dB rather than 40 dB per decade. Given today’s extremely fast rise times, one can see that the high frequency harmonics are much greater than in the past.

**SOME SIMPLIFIED MATH**

Radiation emitted by electronic devices results from both differential and common mode currents. In semiconductor devices, differential mode currents flowing synchronously through both signal and power distribution loops produce time variant electromagnetic fields which may be propagated...
along a conducting medium or by radiation through space. On simple one- or two-layer PCBs, loops are formed by the digital signals being transferred from one device to another that return by means of the power distribution traces. Loops are also created by PCB traces that supply power to these devices. Common mode radiation results from voltage drops in the system that create common mode potential with respect to ground. In addition, parasitic capacitive coupling, a hard-to-control phenomenon that occurs between all conductive materials, makes external cables act like antennas.

The radiated EMI levels created by the active circuit loops on the board are proportional to the square of the highest created frequencies. These frequencies are determined by the data pulse rise time, and contain significant RF energy at typically 10 to 15 times the operating speed. The rise time also determines the circuit bandwidth. For small circuits whose dimensions are less than the dimensions at resonance, the plane wave emission levels generated by these loops may be calculated by the following equation:

\[ E = \frac{1.3 A I F^2}{(DS)} \]

Where:
- \( E \) = microvolts/meter
- \( A \) = radiating loop area in cm\(^2\)
- \( I \) = current in amps
- \( F \) = frequency in MHz
- \( D \) = measurement distance in meters
- \( S \) = shielding effectiveness ratio

Radiated susceptibility, on the other hand, increases linearly with the offending frequency. For small circuits whose dimensions are less than the dimensions at resonance, the maximum voltage induced into the circuit by a narrowband incident plane wave within its passband is given by:

\[ V_i = \frac{2 \pi \varepsilon A B_{pb}}{\lambda S} \]

Where:
- \( V_i \) = volts induced into the loop
- \( \varepsilon \) = field strength of incident wave in V/m
- \( A \) = circuit capture area in square meters
- \( B_{pb} \) = passband bandwidth response
- \( \lambda \) = wavelength in meters of incident wave
- \( S \) = shielding effectiveness ratio

Outside of the circuit passband, narrowband signal effects will be determined by the circuit attenuation response. Broadband signal effects will be determined by both the attenuation response and the circuit bandwidth. Of course, circuit attenuation can be increased with the installation of shielding.

By examining the two formulæ, we can draw some conclusions. For emissions, the field strength is controlled by the specification that must be met or by the highest allowable emissions for the environment in which the device must operate. The distance is set either by the specification, such as three meters for the FCC part 15 requirements, or by the distance from the source to the receptor of the radiated energy. Generally, these factors are beyond the control of the device designer. Of course, 1.3 is a constant and cannot be changed. We now come to factors that the designer can control. We see that frequency is squared; therefore, emissions increase exponentially as frequency increases. This explains why high frequency devices and circuits are the most troublesome. Emissions also increase linearly with current. Therefore, one must place high frequency and high current circuits at the top of the EMI suspect list. However, emissions also increase with loop area. By far, large uncontrolled and even unknown loop areas have proven to be the biggest reason for emission failures.

We see that the designer must control the loop area once the frequency and current have been established. Especially for high frequency and high current circuits, the loop area must be kept to a minimum. This must be done at the beginning of the design. It is far too difficult and expensive to do this once the PCBs are designed, and even manufactured.

Once the frequency, current, and loop area have been set, and the circuit does not meet its emissions requirements, we now see that there is only one factor left in the equation that can bring the circuit into compliance: shielding!

For susceptibility, we see that the same good design practices as for emissions apply. In this case, the voltage induced into the circuit is a function of field strength which is controlled either by the specification or the circuit’s environment. The bandpass bandwidth response is controlled by the choice of components and other circuit design components such as the choice of the active components, and inactive components.
Our products have always outlasted and outperformed the competition, now we’re giving them another problem.

We’ve shrunk our “S” amplifiers giving you more power with an even greater price-performance ratio.

Our new 1 to 4.2 GHz “S” Series solid-state amplifiers are giving the competition a lot to worry about. These new, smaller amplifiers simply give you more for your money than any amp on the market.

They’re lighter, more portable, and up to 50% smaller. Yet they’re available with all the power you need – up to 800 watts. Our new design is more efficient. These amplifiers use less energy, which is good for you, good for the environment, and bad for our competition.

Our “S” Series amps are smarter, too. When you need more power, you can add additional amplifiers, instead of tossing out your amp and starting all over. And you can use the amps independently, even in different locations, for those tests that don’t require as much power. This is a unique, flexible, money-saving feature that we call Subampability™.

Our competitors have some other choice words for it. But that’s their problem.

To learn more, visit www.ar-worldwide.com or call us at 215-723-8181.

ISO 9001:2008 Certified

rf/microwave instrumentation

Other ar divisions: modular rf • receiver systems • ar europe

USA 215-723-8181. For an applications engineer, call 800-933-8181.

In Europe, call at United Kingdom 441-908-282766 • at France 33-1-41-91-75-10 • en v GmbH 189-614-1710 • at Benelux 31-172-423-000

Copyright © 2008 AR. The orange stripe on AR products is Reg. U.S. Pat. & TM. Off.
such as ferrite chip beads or filters. Again, we see that loop area is a factor. The larger the loop area, the more efficient the pickup of the circuit and generally, the more susceptible it will be. Finally, we see again that once the circuit design is finalized, if it is still susceptible, the only factor left in the formula is shielding!

**SHIELDING**

Shielding is a conductive barrier enveloping an electrical circuit to provide isolation. The “ideal” shield would be a continuous conductive box of sufficient thickness, with no openings. Shielding deals almost exclusively with radiated energies. Shielding Effectiveness (SE) is the ratio of the RF energy on one side of the shield to the RF energy on the other side of the shield expressed in decibels (dB).

For sources outside of the shield, the absorption and reflection of the shielding material, in dB, are added to obtain the overall SE of the shield. For sources within the shield, roughly only the absorption of the shield can be considered.

The absorption of the shielding material at frequencies of concern is controlled by:

- Conductivity
- Permeability
- Thickness

The reflectivity of the material at the frequencies of concern is controlled by:

- Conductivity
- Permeability

However, this is only true for our “ideal” shield. Two other major factors are:

- “Apertures” - holes or slots in the enclosure.

- The mechanical characteristics and effectiveness of the gaskets used on the enclosure.

“Mechanical characters” is pointed out because the biggest reason that RF gaskets do not perform as specified is because of improper installation, such as “putting a gasket where a gasket was never meant to go.” This is because many times, an RF gasket is used as a “fix” after the design has been set. As we saw in the formulas, shielding is necessary after all other factors in the circuit have been established. Sadly, it is also viewed that way. Rather than design in shielding and gasketing, it is used as a last desperate effort to get the device into compliance; adding the reason for so many failures in shielding and gasketing efforts.

Shielding, which is noninvasive and does not affect high-speed operation, works for both emissions and susceptibility. It can be a stand-alone solution, but is more cost-effective when combined with other suppression techniques such as filtering, grounding, and proper design to minimize the loop area. It is also important to note that shielding usually can be installed after the design is complete. However, it is much more cost-effective and generally more efficient to design shielding into the device from the beginning as part of the design process. It is important to keep in mind that the other suppression techniques generally cannot be added easily once the device has gone beyond the prototype stage.

The use of shielding can take many forms ranging from RF gaskets to board-level shields (BLS). An RF gasket provides a good EMI/EMP seal across the gasket-flange interface. The ideal gasketting surface is conductive, rigid, galvanically-compatible and recessed to completely house the gasket.

A device housed in a metal case is generally a good candidate for RF gasketing materials. When electrical and electronic circuits are in nonconductive enclosures, or when it is difficult or impossible to use RF gasketing, BLS provides the best option for EMI suppression. A properly designed and installed BLS can actually eliminate the entire loop area because the offending or affected circuit will be contained within the shield.

**APERTURES**

Apertures, or holes, have SE. The SE of an aperture and ultimately the entire electronic enclosure is determined by the size, shape and number of the apertures. The formula is:

$$SE_{ap} = k \log_{10}\left(\frac{\lambda}{2L}\right)$$

Where:

- $\lambda$ = Wavelength
- $k$ = 20 for a slit or 40 for a round hole
- $L$ = Longest dimension of the aperture
If there is more than one hole, we subtract from the original formula: the total number of holes within half a wavelength.

Apertures are placed in electronic enclosures for many reasons. Apertures are required for viewing, controls, meters, wire entry, etc. One reason is simply the seam around the perimeter of the cover(s). To maintain the conductivity across the seam, we generally need to use RF gasketing. RF gasketing is also used around display panels, shielded connectors, and other apertures in the enclosure.

**RF GASKETS**

Although there are hundreds of gasket varieties based upon geometry and materials, there are four principle categories of shielding gaskets: beryllium copper and other metal spring fingers, knitted wire mesh, conductive particle filled elastomers and conductive fabric-over-foam. Each of these materials has distinct advantages and disadvantages, depending upon the application. Regardless of the gasket type, the important factors to be considered when choosing a gasket are RF impedance \((R + jX, \text{ where } R = \text{ resistance, } jX = \text{ inductive reactance})\), shielding effectiveness, material compatibility corrosion control, compression forces, compressibility, compression range, compression set, and environmental sealing. However, many other factors may come into the selection decision.

Below is a comprehensive list of selection factors.

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

---

**MuShield** is a small company that tackles big problems. Our team is a talented mix of engineers with extensive experience in the field of magnetic shielding. This enables us to build, test, and deliver a product that works within a reasonable time frame. Visit us online at [www.mushield.com](http://www.mushield.com).

---

**The Basic Principles of Shielding FEATURE**
**Metal RF Gaskets (Fingerstock) and Spring Contacts**

Metal RF gaskets are made from various materials. They generally have the largest physical compression range and high shielding effectiveness holding steady of a wide frequency range. CuBe is the most conductive and has the best spring properties. They can be easily plated for galvanic corrosion considerations.

Fingerstock and spring contact products are ideal for high cycling applications requiring frequent access, with hundreds of standard shapes available as well as cut-to-length and modified standards.

**Wire Mesh and Knitted Gaskets**

Wire mesh gaskets can be made from a variety of metal wires, including monel, tin-plated-copper clad-steel or aluminum. They are cost-effective for low cycling applications and offer high shielding effectiveness over a broad frequency range. They are available in a wide variety of sizes and shapes with the knit construction providing long lasting resiliency with versatile mounting options.

Conductive cloth knit offers close-knit stitch of the metalized nylon, providing a highly effective EMI shield, as well as a smooth, soft surface. Copper Beryllium (CuBe) Mesh offers superb resiliency for consistent, point-to-point contact requiring the lowest compression forces.

Elastomer Core Mesh combines excellent shielding performance with a high degree of elasticity.

**Oriented Wire**

Oriented wire is a conductive elastomer in which individual conductive wires of either Monel or aluminum are impregnated into solid or sponge silicone. Oriented wire provides EMI protection and seals against moisture or rain on cast or machined surfaces.

**Fabric-over-Foam (FoF)**

FoF EMI gaskets offer high conductivity and shielding attenuation and are ideal for applications requiring low compression force. Typical FoF EMI gasket applications include shielding or grounding of automotive electronic equipment seams and apertures. There are a wide range of shapes and thickness to meet any design need.

**Electrically Conductive Elastomers**

Conductive elastomers are ideal for applications requiring both environmental sealing and EMI shielding. They provide shielding effectiveness up to 120dB at 10GHz with a wide choice of profiles to fit a large range of applications. Conductive fillers include, but are not limited to:

- Carbon (C)
- Passivated aluminum (IA)
- Silver-plated aluminum (Ag/Al)
- Silver-plated copper (Ag/Cu)
- Silver-plated glass (Ag/G)
- Silver-plated nickel (Ag/Ni)
- Nickel-coated carbon (Ni/C)
- Silver (Ag)
- Elastomer options include:
  - Silicone rubber
  - Fluorosilicone rubber
  - Ethylene propylene diene monomer (EPDM)
  - Fluorocarbon rubber, Viton, or Fluorel

**Form-in-Place (FiP)**

Form-in-Place (FiP) EMI gaskets can be dispensed onto any conductive painted, plated, or metallic surface of an electronics enclosure that requires environmental sealing, has complex or rounded surfaces, or has miniature devices requiring a precision gasket; thus, protecting the enclosure against internally and externally radiated interference and environmental elements.

**Board-Level Shielding (BLS)**

If done well, PCB level shielding can be the most cost-efficient means of resolving EMI issues. As a low cost, and most common shielding method, a variety of board-level metal can-type shields have been used to eliminate EMI radiation from entering or exiting sections of a PCB. This method has primarily employed solder-attached perforated metal cans being attach and soldered to the ground trace on a PCB directly over the electrical components that need to be shielded.

The can-type-shields are often installed in a fully automated fashion via a surface mount technology process at the same time the components themselves are installed onto the PCB using wave soldering, or solder paste and a reflow process. Such cans offer very high levels of shielding effectiveness, are typically very reliable, and are widely used in the industry. Board-level shielding metal cans can consist of tin or zinc plated steel, stainless steel, tin-plated aluminum, brass, copper beryllium, nickel silver or other copper alloys.

**Combination Shielding Products**

Combination shields offer two or more technologies combined into one convenient form. These shields are made by molding conductive elastomer walls onto metal shield cans to provide any compartment geometry needed. In addition, even more
complex applications involve welding spring contact/fingerstock to shield cans to seal compartments in ultra-low profile applications.

CONCLUSION

Basic shielding theory is really not so basic. A comprehensive knowledge of EMI control, circuit design, mandatory specifications, environmental issues and other factors must be considered. Shielding requires a conductive enclosure around a circuit, device, apparatus, or even entire buildings to control EMI. The most cost effective shielding is applied at the source of the problem. However, that is not always possible.

Once the design is established and there are EMI issues, many times, shielding is the only solution. Today there are a myriad of choices for shielding materials from BLS to metal and/or “conductive plastic” enclosures. In most cases, when shielded enclosures are required, RF gasketing is also necessary to provide a conductive interface across the enclosure’s apertures.

Simply trying to pick off-the-shelf shielding materials is not an option. There are many factors involved in the selection of RF shielding materials and RF gaskets. In fact, if one is not intimately familiar with the materials and mechanics of shielding, then it is best left to the experts in the shielding industry.

REFERENCES

• Instrument Specialties’ Engineering Design and Shield Product Selection Guide: 2000
• Laird Technologies’ Web Site: 2010

Gary Fenical is an EMC Technical Support Engineer with Laird Technologies, as well as an NARTE Certified EMC Engineer. Mr. Fenical has been with Laird Technologies for 26 years. He is a specialist in RF shielded enclosures and has been responsible for the design and/or measurement and quality control of hundreds of large-scale shielded enclosures as well as a number of shielded equipment cabinets and housings. He was instrumental in the design and construction of Laird Technologies’ state-of-the-art World Compliance Centers. Mr. Fenical has authored many articles on EMC Requirements for Medical Devices, Mutual Recognition Agreements and Guidelines to meet the essential requirements if the EU EMC Directive. He has also authored several seminars on the EU EMC Directive, International Compliance, and Designing for EMC and EMC Requirements for Medical Devices which have been presented worldwide. He holds the patent for the invention of heat-treated beryllium-copper knitted wire mesh gasket.
A Maxwell’s Equations Primer

Part 6
The Method of Moments
The Method of Moments has become one of the most powerful tools in the RF engineer’s arsenal. In this chapter, we make the transition from theory to practice, first by attempting to compute the characteristics of a “short dipole” by hand, and then by demonstrating that a computer can do that in just a few seconds.

In our last article, we calculated the emissions from a “short current element” (Figure 1). The far field emissions were:

\[
H_\phi = \frac{1}{4\pi} \frac{I^* \ell \sin \theta}{cr} \left( \frac{j \omega}{c^2 r} \right)
\]

\[
E_\theta = \frac{1}{4\pi \varepsilon_0} \frac{I^* \ell \sin \theta}{c^2 r} \left( \frac{j \omega}{c^2 r} \right)
\]

Where:
- \(H_\phi\) = Magnetic field in the \(\phi\) direction (A/m)
- \(E_\theta\) = Electric field in the \(\theta\) direction (V/m)
- \(I^*\) = The “retarded current,” \(I^* = I_0 e^{j(\omega t - \beta r)}\)
- \(r\) = Distance from the current element to our observation point in meters
- \(\ell\) = Length of current element in meters
- \(\omega\) = Frequency in radians per second = \(2\pi f\)
- \(c\) = Speed of light (m/s)
- \(\varepsilon_0\) = Permittivity of free space

The “short current element” differs from the “short dipole” in that the current element has constant current along its length. In contrast, the short dipole has no plates and consequently its current varies from a maximum at the center (where the drive is) to a minimum at its ends.

We will use the current element, however, to calculate the characteristics of the short dipole. To this end, we divide the short dipole into segments, each with constant current. By knowing the characteristics of the short current element we should be able to calculate the characteristics of the short dipole, or any antenna for that matter, from superposition.

**Figure 1:** The starting point for our analysis is the short current element shown. It is a small, center driven antenna (small, that is, compared with the wavelength) loaded with plates at its ends. This produces a radiating element whose current distribution is relatively constant over its length.

**Figure 2:** Our current element (a) has constant current along its length. For most antennas the current varies along the length (b). Nonetheless, almost any antenna can be approximated by one made up of constant current elements in a piece-wise linear fashion as shown in (c).
To use the Method of Moments, we start with this now familiar equation:

\[ E = -\Delta V - \frac{dA}{dt} \]

Where:

- \( E \) = Electric field in V/m
- \( V \) = Voltage
- \( A \) = The vector potential

In our last chapter we calculated the vector potential produced by a short current element aligned with the z axis. It was:

\[ A_z = \frac{\mu_0 I^* \ell}{4\pi r} \]

The vector potential is aligned with the currents that produce it. Since our current element only has currents flowing in the z direction, the vector potential is also aligned in the z direction.

Our first task is to calculate the electric field produced at a given point along the z axis, say observation point \( m \) in Figure 3. Due to the “skin effect,” the current in the current element flows only in its outer skin. We will make the assumption that all the current in our current element is flowing in a filament placed a distance \( a \) from the z axis, \( a \) being the diameter of the current element (Figure 3).

At observation point \( m \), the vector potential is:

\[ A = \frac{\mu_0 I^* \ell}{4\pi \sqrt{(z_m - z_n)^2 + a^2}} \]

Our next step is to relate the vector potential at observation point \( m \) to the electric field there. To do that, we need to explore once again what is meant by the vector potential.

The vector potential is a hypothetical construct, a mathematical tool. Because it is just a mental construct, we can define it any way we want. Fields can be defined by specifying their curl and their divergence. For the vector potential these are:

\[ \nabla \times A = B \]
\[ \nabla \cdot A = -j\omega \mu_0 \varepsilon_0 V \]

Having defined the vector potential,\(^1\) we can derive the electric field at observation point \( m \) as follows:

\[ E_m = -\Delta V - \frac{dA}{dt} \]
\[ \frac{dA}{dt} = j\omega A \]
\[ \Delta V = \frac{\partial V}{\partial z} \]
\[ \nabla \cdot A = \frac{\partial A}{\partial z} = -j\omega \mu_0 \varepsilon_0 V \]
\[ \frac{\partial^2 A}{\partial z^2} = -j\omega \mu_0 \varepsilon_0 \left( \frac{\partial V}{\partial z} \right) \]
\[ \frac{\partial V}{\partial z} = -\frac{1}{j\omega \varepsilon_0 \mu_0} \left( \frac{\partial^2 A}{\partial z^2} \right) \]
\[ E_m = \frac{1}{j\omega \mu_0 \varepsilon_0} \left( \frac{\partial^2 A}{\partial z^2} + \beta^2 A \right) \]

\[ \beta^2 = \frac{1}{1 + \mu_0 \varepsilon_0} \]

\(^1\) In a previous chapter we defined the divergence of the vector potential as being equal to zero. In that case, we were dealing with static fields, therefore \( \omega = 0 \).
The vector potential $A$ is, in turn, a function of the current $I$. Therefore it should be possible to state the electric field at observation point $m$ in terms of the current at point $n$. J. H. Richmond [4] has done that, calculating that it is equal to:

This field develops a voltage at observation point $m$ equal to:

$$V_m = E_m \Delta z$$

Since $V_m$ is a function of $I(z_n)$, we can restate the voltage in terms of a “mutual impedance” $Z_{mn}$:

$$V_m = Z_{mn}(z_n)$$

Where:

$$Z_{mn} = j \frac{377 \Delta z}{8 \pi^2 \lambda} \left( \frac{e^{-j2\pi \Delta z}}{\Delta z^2} \left(1 + j2\pi \left(\frac{r}{\Delta z}\right) \left(2 - \frac{a^2}{r^2} - 4\pi^2 \left(\frac{a}{\lambda}\right)^2\right) \right) \right)$$

Or alternatively,

$$Z_{mn} = j \frac{377(\Delta z)^2}{8 \pi^2 \lambda} \left( \frac{e^{-j2\pi r}}{r^3} \left(1 + j2\pi \left(\frac{r}{\Delta z}\right) \left(2 - \frac{a^2}{r^2} + 4\pi^2 \left(\frac{a}{\lambda}\right)^2\right) \right) \right)$$

Where:

$$r = \frac{r}{\lambda}, \Delta z = \frac{a}{\lambda} \text{ and } a = \frac{a}{\lambda}$$

2 In a milestone in the study of electromagnetic theory, H. C. Pocklington [3] published in 1897 what became known as Pocklington's Equation. Each segment $n$ along a wire aligned with the $z$ axis contributes a vector potential element $\partial A_z$:

$$\partial A_z = \frac{\mu_0 I(z_n) e^{-jbr} dx}{4\pi r}$$

Each differential element $\partial A_z$ creates a differential element $\partial E_z$ at an observation point $m$:

$$\partial E_z = \frac{I(z_n)}{j 4 \pi \varepsilon_0 \varepsilon_0} \left( \frac{\partial^2}{\partial z^2} G_{mn} + \beta^2 G_{mn} \right) dz$$

Where:

$$G_{mn} = \frac{e^{-jbr}}{r_{mn}} \text{ and } r_{mn} = \sqrt{(z_m - z_n)^2 + a^2}$$

$m = \text{observation point}$

$n = \text{source point}$

$G$ is known as Green's function.

To find the total electric field at an observation point $m$, $\partial E_z$ is integrated:

$$E_z = \frac{1}{4\pi \varepsilon_0 \varepsilon_0} \int_{-L/2}^{L/2} \left( \frac{\partial^2}{\partial z^2} G_{mn} + \beta^2 G_{mn} \right) (z) dz$$

We now place a perfectly conducting metal wire of length $\Delta z$ at observation point $m$. Being perfectly conducting, no voltage develops across it. This happens because the impressed field $E_m$ causes current to flow in the conductor. This in turn causes a voltage drop across the segment's self impedance, $Z_{mm}$. This voltage drop is just equal and opposite to the voltage caused by the impressed field $E_m$.

Said another way:

$$V_m(\text{internal}) + V_m(\text{external}) = 0$$

$$V_m(\text{internal}) = I(z_m) Z_{mm}$$

$$V_m(\text{external}) = I(z_n) Z_{mn}$$

$$I(z_m) Z_{mm} + I(z_n) Z_{mn} = 0$$

Where:

$I(z_m) = \text{The current in the wire segment at point } m$

$I(z_n) = \text{The current in the segment at point } n$

$Z_{mm} = \text{The “self impedance” of the segment at point } m$

Figure 4: If we place a perfectly conductive wire at observation point $m$, it serves to “short out” the electric field produced by the current element at point $n$. This happens because the conductive wire produces its own field internally which offsets the electric field produced by the current element.
The mutual impedance between the segments at points \( m \) and \( n \)

Extending the analysis to an antenna with \( N \) segments, each contributing to the field at observation point \( m \), we have:

\[
I(z_1)Z_{m1} + I(z_2)Z_{m2} + I(z_3)Z_{m3} + \cdots + I(z_N)Z_{mN} = \sum_{n=1}^{N} I(z_n)Z_{mn} = 0
\]

We now consider the voltages on each one of the segments. Given \( N \) such segments, self and mutual impedances relate the current on each segment to the voltages on all others, forming a matrix:

\[
\begin{align*}
I(z_1)Z_{11} + I(z_2)Z_{12} + I(z_3)Z_{13} + \cdots + I(z_N)Z_{1N} &= V_1 \\
I(z_1)Z_{21} + I(z_2)Z_{22} + I(z_3)Z_{23} + \cdots + I(z_N)Z_{2N} &= V_2 \\
I(z_1)Z_{31} + I(z_2)Z_{32} + I(z_3)Z_{33} + \cdots + I(z_N)Z_{3N} &= V_3 \\
\vdots & \quad \vdots \\
I(z_1)Z_{NN} + I(z_2)Z_{N2} + I(z_3)Z_{N3} + \cdots + I(z_N)Z_{NN} &= V_N
\end{align*}
\]

This matrix makes the Method of Moments possible. Once the mutual impedances are calculated the matrix can be solved and the currents on each of the segments determined. Once the currents on each segment are known, the total fields, both electric and magnetic, can be calculated by superposition.

We will use the Method of Moments to analyze a short dipole modeled (somewhat crudely) as consisting of three co-linear wire segments (Figure 5). Each segment is \( 0.033\lambda \). All 3 together are \( 0.1\lambda \). The diameter \( a \) equals \( 0.001\lambda \). A voltage source equal to 1 volt is set in the center of Segment 2. Using the above analysis, we can state:

\[
\begin{align*}
I_1Z_{11} + I_2Z_{12} + I_3Z_{13} &= 0 \\
I_1Z_{21} + I_2Z_{22} + I_3Z_{23} &= V_0 = 1 \\
I_1Z_{31} + I_2Z_{32} + I_3Z_{33} &= 0
\end{align*}
\]

Only segment 2 has a voltage associated with it. All the other segments, being perfectly conducting and without sources, have no voltage associated with them.

Noting that \( Z_{13} = Z_{31} \), we can calculate \( Z_{13} \) by plugging in these numbers: \( r \approx 0.066\lambda \), \( a = 0.001\lambda \), \( \lambda = 1 \), and \( \Delta z = 0.033\lambda \). The result is:

\[
\begin{align*}
Z_{13} &= \frac{277(\Delta z)^2}{8\pi^2} \left( \frac{e^{-j2\pi(\Delta z)/\lambda}}{\gamma} \right) \left( \left( 1 + j2\Delta z/\lambda \right) - 2 - \frac{a}{\gamma} \right)^2 + 4\pi^2\left(\frac{a}{\gamma}\right)^2 \\
Z_{13} &= \frac{277(0.033)^2}{8\pi^2} \left( \frac{\cos(2\pi(0.033)/\lambda)}{\gamma} \right) \left( \left( 1 + j2\Delta z/\lambda \right) - 2 - \frac{a}{\gamma} \right)^2 + 4\pi^2\left(\frac{a}{\gamma}\right)^2 \\
Z_{13} &= 0.33 + j296
\end{align*}
\]

Similarly, \( Z_{12} = Z_{21} = Z_{23} = Z_{32} \) and, according to this formula, is equal to:

\[
Z_{12} \approx 1.02 + j296
\]

For the “self impedances” \( Z_{11} = Z_{22} = Z_{33} \) however, we run into a problem. The term \( r^2 \) combined with the relatively long segment length makes the solution unstable. To deal with this, we could divide our short dipole into smaller segments. Choosing 11 segments for example, our matrix becomes:

![Figure 5: A small dipole is shown divided into three segments. Our first task in applying the Method of Moments is to calculate the self and mutual impedances of the segments.](image-url)
But solving for all those variables will require a lot of computation, so it may be a good time to turn to our computers.

There are a number of very good computer programs that employ the Method of Moments.\(^3\) We will use a program called EZNEC [2]. We input the same parameters as above, dividing our short dipole into 11 segments and setting \(\lambda\) equal to one meter. That is done by entering the data into the start screen (Figure 6). The frequency of 299.793 MHz is the equivalent of a one meter wavelength. We have chosen to place the wire in free space (the program has the option of simulating an antenna over earth). In the “Wires” dialogue box we enter the position of the one wire that makes up our short dipole, it starts at \(X=.05\) meter, ends at \(X=-.05\) meter and is \(.001\) meter in diameter. Using the “Source” dialogue box, we place our 1 volt source in the middle of the wire.

\[I(z_1)Z_{11} + I(z_2)Z_{12} + I(z_3)Z_{13} + \cdots + I(z_{11})Z_{111} = 0\]
\[I(z_1)Z_{21} + I(z_2)Z_{22} + I(z_3)Z_{23} + \cdots + I(z_{11})Z_{211} = 0\]
\[I(z_1)Z_{31} + I(z_2)Z_{32} + I(z_3)Z_{33} + \cdots + I(z_{11})Z_{311} = 0\]
\[I(z_1)Z_{61} + I(z_2)Z_{62} + I(z_3)Z_{63} + \cdots + I(z_{11})Z_{611} = 1\]

\[I(z_1)Z_{111} - I(z_2)Z_{112} + I(z_3)Z_{113} - \cdots - I(z_{11})Z_{1111} = 0\]

The pattern resembles a broad figure eight, typical of a dipole, even a short one. A host of other parameters are calculated including the impedance seen by the one volt source (2.081 –j1397 ohms). The antenna has a very low radiation resistance (2.081 ohms) and “looks” capacitive to the source (-j1397 ohms).

REFERENCES

2. EZNEC, Version 3.0. EZNEC can be purchased from Roy Lewallen, W7EL, P.O. Box 6658, Beaverton, OR, 97007.


Glen Dash is the author of numerous papers on electromagnetics. He was educated at MIT and was the founder of several companies dedicated to helping companies achieve regulatory compliance. Currently he operates the Glen Dash Foundation which uses ground penetrating radar to map archaeological sites, principally in Egypt.

Copyright Ampyx LLC

Figure 6: EZNEC opens with a screen that allows parameters such as the driving frequency, wire loss and type of ground to be entered. Separate dialogue boxes allow the antenna to be defined.

Figure 7: The output of EZNEC can provide the current on each segment, the fields generated, the pattern of the fields and such other parameters as the antenna’s impedance as seen from the source.
EPILOGUE

Morphing Maxwell’s

In this series we hoped to provide the reader with a roadmap to get from the place where an engineer typically starts – with a knowledge of circuits and math – to the Method of Moments. A second aim was to help the engineer understand the technical papers written in the field. Such papers often start with some statement of Maxwell’s Equations in one of its various forms – integral, differential, etc. – without much introduction. We hope that that missing introduction can now be found here.

But there are some forms of Maxwell’s Equations that we did not touch on. So here, for good measure, are a few more:

We derived Maxwell’s Equations in what we called their “computational” form:

\[ E = -(\nabla V + \frac{\partial A}{\partial t}) \]
\[ B = \nabla \times A \]
\[ V = \frac{l}{4\pi \varepsilon_0} \sum_{n=0}^{n=N} \frac{P_n}{r_n} V_n \]
\[ A = \frac{\mu_0}{4\pi} \sum_{n=0}^{n=N} \frac{J_n}{r_n} l_n a_n \]

But the equations can also be stated in this form, which relates the electric and magnetic fields to the scalar potential (voltage) and vector potential (A):

\[ E = -(\nabla V + \frac{\partial A}{\partial t}) \]
\[ B = \nabla \times A \]
\[ V = \frac{l}{4\pi \varepsilon_0} \int_{V} \frac{\rho e^{-j\beta r}}{r} \, dV \]
\[ A = \frac{\mu_0}{4\pi} \int_{V} \frac{J e^{-j\beta r}}{r} \, dV \]

We also discussed the definition of the vector potential, something that is made up and which we could have defined any way we wished. We chose to define it as:

\[ \nabla \times A = B \]
\[ \nabla \cdot A = -j\omega \mu_0 \varepsilon_0 V \]

For the “static” case, \( \omega=0 \), so;

\[ \nabla \times A = B \]
\[ \nabla \cdot A = 0 \]

To derive an expression for the vector potential in term of currents, we used these equations:

\[ \nabla^2 V = -\frac{\rho}{\varepsilon_0} \]
\[ \nabla^2 A = -\mu_0 J \]

But these equations were for the static case. Where \( \omega \) is not zero, these equations become:

\[ \nabla^2 V + \mu_0 \varepsilon_0 \omega^2 V = -\frac{\rho}{\varepsilon_0} \]
\[ \nabla^2 A + \mu_0 \varepsilon_0 \omega^2 A = -\mu_0 J \]

Finally, some technical papers will analyze phenomenon using what are known as Hertz vectors. The Hertz vector (\( \Pi \)) is defined as:

\[ A = \mu_0 \varepsilon_0 \frac{d\Pi}{dt} \]
\[ \Pi = \Pi_0 e^{j\omega t} \]
\[ A = j\omega \mu_0 \varepsilon_0 \Pi \]

Therefore any expression in terms of \( A \) can also be expressed in terms of the Hertz vector \( \Pi \).
Assessing the EMC Performance of PCB Shields by Electromagnetic Modeling

by
David P. Johns, PhD
CST of America Inc.
and
Scott Mee
Johnson Controls Automotive Electronics

PCB SHIELDING

In the past EMC Engineers have relied on metallic enclosures to contain electromagnetic fields and meet radiated emissions limits in military and consumer products. Modern commercial electronics products typically use molded plastic enclosures since they are considered to be aesthetically more pleasing than a metal enclosure, but also to save weight and cost.

With correct PCB layout, differential signaling and common mode filtering on cables, it is sometimes possible to meet commercial EMI requirements without employing any shielding in the enclosure. However with the increased complexity, component density and speed of logic, designers are frequently coating the plastic enclosure with a thin conductive layer to provide a level of shielding. In addition, metal shields may be placed directly over noisy and sensitive components on the PCB, to further reduce emissions and improve immunity.

A conductive coating in principle can be very effective. In practice, the seam between the two halves of a clam-shell type enclosure or between the enclosure and the PCB reference plane limits the shielding effectiveness. This is due to poor electrical contact at the interface, caused by inadequate pressure, low contact surface area and gaps due to unevenness in the formed parts or the coating.

In a high density compact electronics system, such as a cell phone, it may be necessary to place solid metal EMI enclosures over noisy components to reduce emissions, or over sensitive components to improve immunity. This can be particularly important when multiple radio communications systems are closely located and radio frequency interference (RFI) must be minimized. The shielding performance of metal enclosures also strongly depends on electrical contact to the PCB. The enclosure typically includes a number of tabs to connect to the PCB and there can be gaps between successive tabs. Furthermore, the enclosure may be perforated, typically on the top surface, to provide ventilation and this may compromise the shielding performance, especially at high frequencies.

The relative shielding effectiveness of various PCB shield strategies will be investigated in this article by applying 3D electromagnetic field simulation, based on the time-domain 3D Transmission-Line Matrix (TLM) solver. Solving the EM fields in the time-domain enables the system impulse response to be extracted from a single computation. Fourier transform can subsequently be applied to yield the broadband peak radiated field or emissions. Shielding effectiveness can be calculated by comparing the radiation with and without the shield present.

We will first calculate the shielding of a conductively coated plastic enclosure and explore the degradation in performance with increasing seam impedance. We will then investigate the use of component shielding in a GSM cell phone application to isolate two sensitive PCB components from the antenna fields. Finally we will model a graphics PCB used in an
automotive display system, where a metal cover is placed on one side of the board to shield noisy digital circuits.

**CONDUCTIVELY COATED CLAM SHELL ENCLOSURE**

For this first application a plastic enclosure 8cm wide, 12cm long and 6cm high is coated with a conductive Nickel film of thickness 0.001 inch (0.0254 mm). For thin conductive coatings, it is important to assess the magnetic field shielding effectiveness, since it is possible that the skin depth of the surface current is larger than the conductive film thickness. The skin effect causes the effective resistance of the conductor to increase with the frequency of the current. At 1 MHz in Nickel, the skin depth is about 0.12 µm. The skin depth (δ) is inversely proportional to the square root of frequency (f) and conductivity (σ). Increasing frequency results in smaller skin depths.

\[
\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}
\]

The frequency-dependent diffusion of current through the thin conductive coating is represented accurately in the TLM model by a special thin panel boundary condition. It is not necessary to use volume mesh cells to capture the film thickness so this speeds up the calculation and reduces the computer memory required to solve the problem.

In reality, the enclosure contains a groove to hold a conductive gasket which makes electrical contact between the two mating halves of the enclosure. This is modeled by an equivalent conductive seam model in the TLM electromagnetic simulation. The model allows for the transfer impedance of the joint to be varied and the impact on shielding performance assessed. The two halves are screwed together in all 4 corners with conductive screws and it is assumed that there is good electrical contact at these points.

Due to the thin conductive coating and skin depth effect, the magnetic field shielding effectiveness is the primary concern for this study. To assess the magnetic shielding, a 20cm radius transmitter loop is located 5cm away from one of the walls and a similar receiver loop placed at the geometric center of the enclosure. The transmitter loop is driven with a 1V source and series 1 Ohm load and the receiver loop is terminated in a 1 ohm load. The mutual inductive...
coupling between the loops with the enclosure removed is first solved to obtain a reference result. The enclosure is then inserted and the fields re-calculated. The magnetic shielding effectiveness is determined by normalizing the results, or subtracting dB.

\[
\text{Shielding (dB)} = \text{Reference Result (dB)} - \text{Shielded result (dB)}
\]

Results are provided for seam transfer impedance values of 0, 1, 10, 100, 1000 milli Ohm-m. The results show a progressive reduction in shielding performance with increasing seam transfer impedance. The voltage developed across the seam \((V)\) is proportional to the surface current flowing over the seam \((J_s)\) and the transfer impedance \((Z_t)\).

\[
V = J_s \times Z_t
\]

If the seam impedance is zero, in other words perfect electrical contact between the two halves of the enclosure, the seam voltage will be zero and the shielding will be purely based on the inherent ability of the conductive film to attenuate the fields. From the curve in the graph plot, we can observe that the conductive film provides approximately 30dB shielding at 100 KHz. The shielding effectiveness improves with increasing frequency and this is due to the skin depth effect. At high frequencies the skin depth is smaller than the film thickness and the current is confined to the external surfaces of the enclosure.

The field plot in Figure 3 shows the magnetic field vectors at 1 MHz with a 10 milli Ohm-m seam transfer impedance. The magnetic field is mainly coupling through the seam and this is limiting the shielding performance of the enclosure.

The TLM simulation requires approximately 10 minutes run time on a core 2 Duo T9600 based laptop. The model uses 10,500 mesh cells and requires only 13 MB of computer RAM.

**RFI Shielding in a GSM Cell Phone Application**

The next application is a cell phone with a dual-band Printed Inverted F Antenna (PIFA) antenna, tuned for the GSM frequencies 850 and 1900 MHz, typically used in North America.
Assessing the EMC Performance of PCB Shields by Electromagnetic Modeling

The model is used to investigate the isolation of two sensitive electronics components located nearby to the antenna element. Component A is located approximately 10mm away from the PIFA antenna element and component B is directly under the element. Wire traces are used to model nets at the component locations and the induced voltage and current monitored. The wires are arranged diagonally to ensure that different polarizations of the field are captured.

Simulation is used to predict the reduction in coupling when metal shields are placed over the components. The PIFA antenna is essentially a folded monopole, with an inductive stub used to compensate for the capacitance between the radiating element and PCB reference plane. The near field impedance is relatively high, so mutual capacitance between the antenna element and victim traces could be the coupling mechanism of concern. The metal covers serve as electric field shields and shunt the RF current to the reference plane.

The covers are not perfect shields, due to the use of 1mm diameter round perforations to provide ventilation for cooling of the internal electronics. There are also small gaps between the metal tabs used to make contact to the PCB reference plane. The results in Figure 5 plot the coupling to the two components when a constant 1 Amp (0dB) current is driven into the PIFA antenna.

With no shields present, the received current is approximately 48dB down at the antenna resonances of 850 and 1900 MHz. The metal enclosures provide around 38dB to 44dB shielding at 850 MHz, increasing the isolation to 86dB (component A) and 92dB (component B). The shielding effectiveness reduces to 28 dB at 1900 MHz, but this still improves the isolation to 76dB (both components). It is not surprising that the shielding is less for higher frequencies since the ventilation holes and spaces between contact tabs become electrically larger.

The surface current density is plotted in Figure 6 at the antenna resonant frequencies. Notice that the current prefers to flow along the sharp metal edges of the antenna element and corners of the metal cans, indicated by the orange-red coloring. This is a well known effect for high frequency currents. The electric field will be strong at the metal edge discontinuities, so it is possible that there is capacitive coupling from the edges of the antenna element to the edges of the metal enclosures.

The GSM cell phone simulation requires 15 minutes run time on a core 2 Duo T9600 based laptop and uses 25 MB RAM. This produces the shielding results of the entire spectrum from DC to 2.6 GHz.
PCB SHIELDING IN AN AUTOMOTIVE DISPLAY SYSTEM

The final example is concerned with the shielding of a graphics PCB used in an automotive display cluster. The PCB is approximately 10 x 6 cm and has multiple layers. For the electromagnetic analysis we focus our attention on the emissions generated by the DRAM clock net, which is routed on one of the outer layers. The net is essentially a microstrip conductor surrounded by a reference plane structure and this is intended to provide return paths for the high frequency currents and thereby reduce the emissions. Nevertheless, some field will inevitably “escape” and lead to radiation from the PCB. To contain the fields, a metal shield of size 7 cm x 5 cm is placed over the PCB. It is critical that the shield does not short out components and traces on the PCB, so contact can only be made to the reference plane at certain locations. For this design, contact is made at the 4 corners of the shield and also the middle points along the two longer edges. Therefore, we do not expect the shield to be perfect, but we would certainly hope for some level of shielding across the frequency band of interest.

In reality the DRAM clock signal has a certain frequency and rise/fall time which generates a spectrum of discrete frequencies including the fundamental and harmonics. We could drive the model with this transient signal, but it is often more useful to excite the net with a pseudo-impulse which contains all frequencies up to the limit of the model. This ensures that any narrowband peaks in radiated emissions are detected. The impulse response of the electric field observed at a point 1 m above the PCB is shown in Figure 8. The response includes all the reflections and resonances associated with the PCB and shield structure.

The radiated field is monitored at a single point 2 cm above the metal shield (near field probe) and at multiple points scattered around the PCB on a 1 m radius (far-field probes). The field is also scanned continuously on a 1 m radius to determine the peak radiated emissions.

The graph plot in Figure 9 shows the shielding effectiveness as observed by the probe 2 cm above the metal shield. The metal enclosure provides good shielding at low frequencies, and this is due to the observation point being located in the “shadow” of the electromagnetic field. For other components placed in this location we can expect very good isolation. The shielding steadily reduces with increasing frequency and in fact negative shielding is seen at 2.1 GHz. Negative shielding can occur when one or more half wavelengths match one or more physical dimensions of the structure. Reflections back and forth between opposing boundaries generate standing waves, producing cavity resonances and build up of field strength.

The shielding derived from the 1 m emissions scan is not as effective. This is due to radiation from the air gaps formed between the shield and PCB reference plane. The distant 1 m observation points are in the path of the radiated field. The air

**Figure 7: Automotive Display System Graphics PCB Model With and Without Shield**

**Figure 8: Typical Impulse Response from the Time-Domain TLM Analysis**

**Figure 9: Shielding Effectiveness Observed 2 cm above the PCB/Shield**
A personal invitation to find your way to the 2010 IEEE Symposium on Electromagnetic Compatibility being held July 25 - 30, 2010 in beautiful Fort Lauderdale, Florida. Learn a lot and have fun too!

Leading Edge Info On:
- Electromagnetic Interference
- Electromagnetic Environments
- Lightning
- Electromagnetic Pulse
- Grounding & Bonding
- Transient Suppression
- Spectrum Management
- RF Radiation Hazards
- Electrostatic Discharge

For Complete Event Details Visit www.emc2010.org
gaps can essentially be considered to be slot antennas that will radiate very efficiently when the wavelength is comparable to the slot length.

The surface current density and peak electric field distribution is plotted in Figure 11 at 867 MHz for the cases without and with the shield present. 867 MHz is chosen because the DRAM clock net exhibits a resonance around this frequency and shielding of the radiated fields is important. The field plot clearly shows very little field escaping beyond the shield. The scale is from -100dB to 0 dB. The deep blue regions are -100dB down on the peak electric field.

The peak electric field distribution is plotted in Figure 12 at 2.1 GHz for the cases with and without the shield present. At this frequency the air gaps between successive electrical contact points are just the right length to resonate and radiate electromagnetic waves. Comparing the two field plots it is clearly seen that the shield actually increases the emissions at this particular frequency (negative shielding effectiveness). Notice the high field strength in the PCB/shield gaps and propagation of the fields beyond the shield.

The PCB/shield simulation requires a 2 hour run time on a dual quad-core computer and uses 275 MB RAM. This produces the shielding results over the entire spectrum from DC to 5 GHz.
**SUMMARY**

We have shown through 3 application examples how electromagnetic modeling can be effectively used to assess the performance of PCB shields. In all cases, the simulation run times and computer memory requirements are quite reasonable and this enables multiple iterations to be solved quickly to determine trends in the results. The ability to display the surface currents and fields can provide greater insight and verification of the dominant coupling mechanisms. There is tremendous value in simulating EMC problems early in design and revealing potential issues before manufacturing and testing. In the applications considered here, it has been shown that a PCB shield can be effective over certain bands, but it can have the opposite effect and increase emissions for certain frequencies. It is important for EMC Engineers to understand the limitations of proposed solutions when making decisions in product design reviews.

Dr David P. Johns is the VP of Engineering and Support for CST of America and is based in CST’s Boston MA location. He received his PhD in Electromagnetic Analysis from Nottingham University (UK) in 1996 for developing a new 3D frequency-domain Transmission-Line Matrix (TLM) method for solving electromagnetic fields. He contributed to the development of CST’s 3D time-domain TLM code MICROSTRIPES and in particular efficient techniques for modeling current diffusion, apertures and wires. David has over 20 years of electromagnetic simulation experience and specializes in the modeling of real world EMC/EMI problems. He is a regular speaker at IEEE EMC conferences and chapter meetings and recently the co-chair of the IEEE EMC Symposium Workshop “How to simplify real-world complex systems into realistic, solvable, accurate models.”

Scott Mee received his BSEE in 1998 from Michigan Technological University (MTU) with focus areas in RF communications and electromagnetics. Since his graduation he has been working for Johnson Controls in EMC test development, A2LA/AEMCLRPA accreditations, EMC design and simulation. Currently he is the Global Manager of the EMC expert team in the Automotive Electronics group at Johnson Controls. Scott is an IEEE EMC Society member and has been a contributing author to numerous technical papers and presentations on EMC. He served as a co-chair of the technical paper committee for the 2008 IEEE EMC symposium and an automotive EMC special session chair for the 2007 IEEE EMC Symposium. Scott is a NARTE certified EMC Engineer and his interests include EMC design, simulation, pre-compliance testing and product debugging.
History of CISPR

Don Heirman, Don HEIRMAN Consultants
Manfred Stecher, Rohde&Schwarz-retired
INTRODUCTION

The history of the International Special Committee on Radio Interference (CISPR) is one that extends over 75 years. There have been papers written over the years on its history. The one that is used as the basis for this article was presented at the 2005 Zurich EMC Symposium. The title was “A History of the Evolution of EMC Regulatory Bodies and Standards”, written by the authors of this article [1]. Manfred provided the majority of the research on CISPR up to the time of the Zurich symposium and Don continued the history up to the present time. This article will then present a brief history of CISPR from its inception to the present time.

HISTORY OF THE CISPR

There was general agreement that the most important international problem was to secure uniformity in the methods of measurement and in the specification of limits to avoid difficulties for the exchange of goods and services [2]. In 1933 an ad-hoc conference of interested international organizations was held in Paris to decide how the subject of radio interference should be dealt with internationally. It was agreed to form a Joint Committee of the International Electrotechnical Committee (IEC) and the Union Internationale de Radiotéléphonie (UIR, International Sound Broadcasting Union). The first meeting of the CISPR (then called “Comité International Spécial des Perturbations Radioélectriques”) (only in 1953 in view of the importance of television, the last word was replaced by “Radioélectriques”) was in June 1934 in Paris, with representatives of six national committees of the IEC (Belgium, The Netherlands, Luxembourg, France, Germany and UK), the UIR and of other international organizations such as the International Union of Producers and Distributors of Electrical Energy (UNIPEDE), the International Conference on Large High Tension Electric Systems (CIGRE), the International Union of Railways (UIR) and of the World Power Conference. The Comité Consultatif International de Radio (CCIR) did not wish to become a full member. During the first meeting, two Subcommittees (SCs) (A on limits and B on measuring methods) were founded [3]. The proposal to “measure the high-frequency interference voltage at the terminals of the interfering electrical appliance” and to “evaluate the attenuation of the interference between the source and the input terminals of a receiver on the basis of statistical experimental data” was proposed by Germany and The Netherlands. International work continued until 1939 (with meetings held in Berlin, December 1934 and April 1935; in London November 1935 and May 1936; Brussels in March and December 1937; and in Paris in July 1939). The recommendations of CISPR were contained in the proceedings of the meetings and Reports RI Numbers 1 to 8 cover the period up to 1939.

The CCIR did not become a CISPR member, but later (in 1966) they adopted a recommendation (433), that as far as possible, administrations should take into account the recommendations, reports and publications of the CISPR and that national regulation concerning interference suppression should be based on the measuring methods and apparatus described by the CISPR. There was and is a clear division of work: interference between radio services or between transmitters of the same service is in the province of the CCIR (now ITU-R) and not the CISPR. The member nations of the ITU have signed the International Telecommunications Convention, urging the national administrations to keep radio interference levels as low as possible and which is a basis for national laws on interference suppression.

Agreement was reached on the CISPR delta network that makes it possible to measure the symmetrical (differential mode) and asymmetrical (common mode) component of the disturbance voltage [2]. In 1937, provisional limits were proposed for the symmetrical voltage of 3 mV from 160 to 240 kHz and of 1 mV from 550 to 1400 kHz and for the asymmetrical voltage of 1,5 mV both from 160 to 240 kHz and from 550 to 1400 kHz. In 1939, twelve copies of the first CISPR measuring receiver (designed in Belgium) were ready. Its frequency range included the long wave and medium wave bands (150 to 1500 kHz) and it had essentially the characteristics of today’s CISPR quasi-peak measuring receiver for Band B (0,15 to 30 MHz) with 9 kHz bandwidth and 1 ms charge time and 160 ms discharge time constant of the detector. However, the spread of results of measurement on a standard commutator motor in different countries was disappointing.

International CISPR work restarted in 1946 – now including a strong delegation from the USA, Canada, Japan and, since 1956, the USSR also took part in the meetings. In 1956, delegates from 17 countries took part in the meeting. In the meeting of 1946, it was recognized that measurements would be required for frequencies greater than 1.6 MHz and that major receiver design would be required for frequencies greater than 20 to 30 MHz. At this meeting the measurement of the RF voltage at the mains terminals of an appliance using the 150 Ω V-network was proposed [4]. In 1950, it was decided CISPR should be formally constituted as a special committee of the IEC [5]. The recommendations and reports continued to appear in the proceedings of the plenary meetings and the numbers RI 11 to 14 covered sessions in Paris 1950, London 1953, The Hague 1958 and Brussels 1959. Considerable progress was made on the specifications for measuring receivers and techniques for the frequency ranges 0,15 to 30 MHz and 30 to 300 MHz and both CISPR publications 1 and 2 appeared in 1961. In 1953, a steering committee was formed to aid the chairman and SC C on Safety Aspects of Interference Suppression was added. In 1956, a strong delegation from the USA, Canada, Japan and, since 1956, the USSR also took part in the meetings. In 1956, delegates from 17 countries took part in the meeting. In the meeting of 1946, it was recognized that measurements would be required for frequencies greater than 1.6 MHz and that major receiver design would be required for frequencies greater than 20 to 30 MHz. At this meeting the measurement of the RF voltage at the mains terminals of an appliance using the 150 Ω V-network was proposed [4]. In 1950, it was decided CISPR should be formally constituted as a special committee of the IEC [5]. The recommendations and reports continued to appear in the proceedings of the plenary meetings and the numbers RI 11 to 14 covered sessions in Paris 1950, London 1953, The Hague 1958 and Brussels 1959. Considerable progress was made on the specifications for measuring receivers and techniques for the frequency ranges 0,15 to 30 MHz and 30 to 300 MHz and both CISPR publications 1 and 2 appeared in 1961. In 1953, a steering committee was formed to aid the chairman and SC C on Safety Aspects of Interference Suppression was added. In 1958 eight working groups were established. Reference [2] gives the status of work up to 1970 as follows:

- WG 1 on Radio Interference Measuring Equipment which until 1967 defined all measuring receivers from 10 kHz to 1000 MHz including publications 1 through 4.
- WG 2 on Interference from ISM Equipment. Radiated emission limits were published as recommendations in the frequency range 0,15 to 1000 MHz.
- WG 3 on Interference from Overhead Power Lines and High Voltage Equipment.
• WG 4 on Interference from Ignition Systems and Internal Combustion Engines. Until 1970, limits were given for 30 to 300 MHz. At this time, limits were also considered up to 1000 MHz. Limits for interference to radio reception on the vehicle itself were under discussion, but it wasn’t until 1995 when CISPR 25 appeared.

• WG 5 on Interference and Immunity Characteristics of Audio and TV Receivers.

• WG 6 on Interference from Motors, Domestic Appliances, Lighting Apparatus and the like. Interference in the frequency range up to 300 MHz was a difficult item because different countries used different measurement methods, ranging from open site field-strength measurements, stop filter tuned supply cord substitution measurements, as well as earth current measurements to terminal voltage measurements. Finally, agreement was reached on a method proposed by Meyer de Stadelhofen of Switzerland, Chairman of the WG [6]. Limits were also approved for thermostatically controlled apparatus emitting discontinuous disturbance, e.g. irons and refrigerators using the counting of clicks and applying click weighting.

• WG 7 on the Impact of Safety Regulations on Interference Suppression. The chairman of this WG was a member of the IEC Committee on Safety (A.C.O.S.).

• WG 8 on Statistical Methods and Correlation between Measured Value and Disturbing Effect. A recommendation on the Significance of a CISPR limit was approved in Leningrad (1970) which implied that type approval may be made on the basis of measurements of a single sample whereas conformity of production should be ensured on a statistical basis.

• WG 9 on Terminology which contributed a chapter to the International Electrotechnical Vocabulary (IEV).

• WG 10 on Lists of Complaints. This was necessary in order to harmonize the national lists of complaints for better comparability.

In the period of 1961 – 1973 CISPR saw the appearance of Recommendations in Pub. 7 (1966), Reports and Study Questions in Pub. 8 (1966) and National Specified Requirements and Legal Regulations in Pub. 9 (1966). In addition to the Pubs. 3 and 4, Pub. 5 specifying the peak, average and RMS detectors appeared in 1968. In 1973, CISPR was reorganized by reconstituting the WGs as Technical SCs, each with its own national secretariat, thus sharing the administrative burden which hitherto had fallen on the CISPR secretariat.

Period 1973 to 1986. In 1973, the decision was made to incorporate all measuring receiver details and the common measurement techniques into one publication (No. 16) covering the work of SC A and to create self-contained publications including reports, recommendations and limits and specialised measurement methods. Thus, Pubs. 11 to 15 came into existence on the subjects of ISM, motor vehicles, radio and TV receivers, household appliances and fluorescent lighting and covering the work of SCs B, D, E and F. The work of SC C on high voltage lines appeared at a later stage in Pub. 18. It had also become evident that digital electronic equipment, microprocessors etc. could be a serious source of interference to radio reception and this was recognised in 1975 by creating a working group reporting first to the steering committee and later to SC B. This working group was reconstituted in 1985 as SC G with the terms of reference to include Information Technology Equipment. SC G was responsible for Pub. 22, the first edition of which appeared in the same year, doing away with the problem of NB/BB discrimination and establishing for the first time limits for QuasiPeak and Average detections in conducted emission measurements. The first international commercial immunity product standard was published in 1985 - Pub. 20 for the immunity of sound and TV broadcast receivers - to which the Italian NC provided many contributions [7].

(From left) Ray Garret, a member of the Australian organizing committee of the CISPR meetings held in Sydney in 2007, as well as a member of the Australian CISPR delegation, is shown with Don Heirman, newly elected CISPR Chairman; Dr. Ralph Showers, head of the US delegation to the CISPR plenary meeting in Australia and past CISPR Chairman; and Peter Kerry, outgoing CISPR Chairman from the United Kingdom.
History of CISPR FEATURE

Period 1987 to 2004. In these years, much effort was expended in the development of CISPR Pub. 16 to become “The CISPR Handbook”. Measurements in the field of EMC for a long time were known as an “estimation with expensive test equipment”. Therefore, the work concentrated on improving the reproducibility of measurements by adding requirements for test site validations, requirements for measurement uncertainty and by improving the definitions of the test methods and setups. Major steps forward were the publications of CISPR 16-4:2002 on measurement uncertainty and of reports on compliance uncertainty in CISPR 16-4-1:2004. SC G developed the CISPR 24:1997 “Immunity of ITE”, using the test methods in IEC 61000-4-x as basic standards. Also, SC F published CISPR 14-2:1997 “Immunity of Household Equipment, etc.” In 1999, CISPR created a new SC H on the development of limits. In 2000, SC C was dissolved and the merging of SCs E and G was decided to form a combined SC I taking into consideration that multimedia equipment was in the scope of E and G. Most of the CISPR work is well described by the publications developed from the early 1990s until the present day:

- Rules and Procedures of CISPR (withdrawn with most of the material placed in Annex K of the Supplement to the ISO/IEC Directives)
- Limits and measurement methods: ISM
- Automobiles and ignition system emissions
- Emission of sound and TV receivers
- Emission of household appliances etc.
- Immunity of household appliances etc.
- Emission of fluorescent and lighting eq.
- Test methods of EMI filters
- Overhead power lines, phenomena, limits, test methods, suppression (3 parts)
- Microwave oven substitution measurement
- Immunity of sound and TV broadcast receivers
- Mobile radio reception in presence of impulsive noise
- Emission of IT equipment
- Determination of limits for ISM equipment
- Immunity of IT equipment
- Emission limits for radio reception in cars
- ISM equipment – guidelines for emission
- TR: Immunity of TV receivers – methods of objective picture assessment
- TR: Test method on EM emissions from fluorescent lamps
- Database on the characteristics of radio services

Generic emission standards:
- CISPR 61000-6-3 Emission for residential, commercial and light-industrial environments
- CISPR 61000-6-4 Emission for industrial environments

PERIOD 2004-PRESENT

CISPR continues to evolve with a focus on controlling the emissions from a wide variety of products as can be seen by the short descriptive titles of its publications noted above. A particular burst of activity has come from the need to expand the application to products that have multiple ways in which RF energy can be emitted. In addition, functions that heretofore were found in specific products have now been incorporated into modern consumer products. This has led to naming the merging of receivers and information technology into what is now termed “multimedia”. At the same time, there are many ways in which communication can now be sent, such as by incidental emissions from a microprocessor, to intentional emissions for radio services, to conveying information over a telecommunication port, to signal and control over the mains network.

The major activity in the past six years has been in the following areas (this list is not meant to be exhaustive but to give a broad perspective of the types of ongoing activities):

1. Specifying new test facilities (and appropriate emission limits) including fully absorber lined rooms (FARs),
reverberating chambers, absorber lined (over the conducting ground plane) open area test sites (called the free-space open area test site or FSOATS), TEM waveguides, and those that are to be used for antenna calibration.

2. Expanding measurement instrumentation uncertainty into compliance uncertainty in applying test standards.

3. Defining better test instrumentation calibration, especially the calibration of antennas used to measure radiated emissions from products being tested.

4. Specific measurement techniques for complex products that define those with multimedia application (generally comprised of ITE and receivers).

5. Determining the interference potential and ways to control it when signals are placed on telecommunications cables and the mains (this is referred to as powerline telecommunications or powerline communications - PLT or PLC).

6. Addressing the emissions from automobiles and the concern for handling the electric vehicle charging system to ensure acceptable disturbance levels to radio services.

7. Incorporating EMC into such mega projects as SMART GRID to ensure the interoperability of this system in controlling the use of power.

8. Continuing the application of product immunity appropriately based on basic standards published by the IEC Technical Committee 77 (EMC).

The list goes on including maintaining test methods and limits for ITE, appliances, RF lighting, and industrial/scientific and medical equipment. For further information on CISPR, visit: http://www.iec.ch/dyn/www/?p=102:17:0:::FSP_SEARCH_TC:cispr. This web site has several links under “CISPR Dashboard” to contact the chairman and subcommittee chairs to see publications issued, and so forth. A link is also provided that identifies the national committees which are members of CISPR. The site http://www.iec.ch/zone/emc/cispr_guide_09_2008.pdf provides guidance on the use of CISPR standards.

NEXT CISPR MEETING

To continue with all of its activity, CISPR works throughout the year mostly by electronic means and a smattering of face to face meetings. However, for conducting a full range of business, resolving major actions and reporting progress, an annual face to face meeting is held. At these meetings, over 200 technical experts and national committee representatives typically attend.

This year’s CISPR meeting will be in the United States in Seattle, Washington during October 6-15, 2010. Over 20 countries will be sending delegates including, of course, the US. This meeting will be held in conjunction with the annual IEC General Meeting where the business of the IEC is conducted along with that of up to 100 technical committees. The host is the US National Committee of the IEC. They have graciously accommodated CISPR’s request for meeting space and support to increase the success of the CISPR meetings. Attendees are assigned by their national committee as there is a need to clearly identify experts that are named by their national committee to participate.

SUMMARY

This article has brought up to date the history of CISPR and how its standards were developed with an indication when key events occurred along the way. Its history is rich in accomplishments and service to the international EMC standards community. Challenges still remain. But the authors believe that when the CISPR history is updated in the future, clear progress in its EMC standardization work will be evident by the wide spread use of its standards.

Don Heirman receives the prestigious Lord Kelvin award at the 2008 IEC General meeting in Sao Paulo, Brazil. The then president of the IEC, Jacques Régis (left) of Canada, presented the certificate and medal to Mr. Heirman. Don follows in the footsteps of another well regarded CISPR Chairman, Dr. Ralph Showers, who received the Lord Kelvin award in 1998. The award was first presented in 1995.
REFERENCES


3. Minutes of the first meeting of the CISPR 1934


7. Private communication between Manfred Stecher and Prof. Ermanno Nano, Italy.

ACKNOWLEDGEMENT

IN Compliance would like to thank Janet O’Neil of ETS-Lindgren for her assistance in coordinating the publication of this article.

Donald Heirman is president of Don HEIRMAN Consultants – a training, standards, and educational electromagnetic compatibility (EMC) consultation corporation. He chairs, or is a principal contributor to, US and international EMC standards organizations including ANSI ASC C63® (chairman) and the International Electrotechnical Commission’s (IEC) Special International Committee on Radio Interference (CISPR) where in October 2007 he was named the chairman of CISPR moving from his previous role as its Subcommittee A chairman responsible for CISPR Publication 16. He is a member of the IEC’s Advisory Committee on EMC (ACEC) and the Technical Management Committee of the US National Committee of the IEC. In November 2008, he was presented with the prestigious IEC Lord Kelvin award at the IEC General Meeting in Sao Paulo, Brazil. This is the highest award in the IEC and recognizes Don’s many contributions to global electrotechnical standardization in the field of EMC. He is a past president of the IEEE Standards Association (SA), past member of the SA Board of Governors and past member of the IEEE’s Board of Directors and Executive Committee. Mr. Heirman may be reached at phone +1 732-741-7723 or by e-mail at d.heirman@ieee.org. For more information, visit www.DonHeirman.com.

Manfred Stecher was born in Munich, Germany in 1942. He received the Dipl.-Ing. Degree in electrical engineering in 1967 from the Technical University of Munich. In 1967 he joined Rohde & Schwarz, Munich. He was engaged in the development of EMI and signal monitoring test receivers and field strength meters, became group leader in 1980, and was responsible for the development of test receivers and accessories - hard and software. Since 1985, he has been a member of various German national standardizing committees on EMI instrumentation and measurement methods and since 1990 he has been an active member of various CISPR Subcommittees (mainly CISPR/A on measurement equipment and methods, but also CISPR/D and /I) and has contributed to ITU-R Study Groups on radio monitoring (mainly Study Group 1). He retired from Rohde & Schwarz in 2007. Presently he is Chairman of CISPR/A, the CISPR Subcommittee on EMI measurement instrumentation and methods. He has published approximately 150 papers in the field of EMI and signal monitoring. He holds several patents and has been awarded the DKE needle and the IEC 1906 award for his standardization activities. He is a senior member of the IEEE EMC Society and has been awarded a Certificate of Acknowledgement for contributions to the development and standardization of EMI measurement techniques. He may be reached by phone at + 49-8177-8632 or by e-mail at Manfred.Stecher@rohde-schwarz.com.
Electromagnetic Compatibility Comes of Age

by R. M. Showers, IEEE EMC Society Founder

The science of electromagnetic compatibility has been in existence for several decades. As an art, it goes back much further, perhaps to the time of Edison when he was just beginning to experiment with practical electrical devices. I am sure that with some of his more sophisticated devices undesired interactions took place because of inadequate shielding or filtering. Certainly, with the advent of radio, incompatibility problems occurred as a result of the poor quality of transmitters and receivers. Perhaps the first formal recognition of electromagnetic compatibility problems occurred when the telephone and power companies found they had mutual coupling problems when their lines were carried on the same utility poles. Later on, the increasing use of the radio spectrum called for formal controls administered by departments in the post, telephone, and telegraph offices in many countries, or through the Federal Communications Commission in the United States.

Until recently, problems in electromagnetic compatibility were solved by specialists having familiarity with the equipments and systems which exhibited interactions and who received relatively little recognition for their accomplishments, except when their efforts failed, in which case the recognition was not particularly complimentary. Furthermore, these experts worked under extremely trying conditions, especially when called upon to solve problems that had arisen because of poor design of equipment, improper application and use of equipments, or because of sudden changes in environmental conditions which they were powerless to do anything about. In particular, they were usually called upon to solve problems “after the fact,” when, if they had been called in on initial design and systems engineering stages, the problems encountered could have been entirely avoided. Except for the technical areas that have been mentioned and in the area of military electronics, where achieving electromagnetic compatibility was essential because of the high concentration of equipment and its frequently highly sophisticated nature, the EMC engineer obtained few rewards for his efforts. His accomplishments were attained through sheer dedication.

We are now on the threshold of a new era. Evidence of this fact includes the following: (a) the recent establishment of a new technical committee in the International Electrotechnical Commission on electromagnetic compatibility, TC 77, (b) interest demonstrated in the past several years by many manufacturers in determining what electromagnetic compatibility characteristics their equipment should have both from the point of view of their emission characteristics as well as their susceptibility characteristics, (c) increasing emphasis on the application of electromagnetic compatibility requirements in international trade, (d) the re-establishment of a group concerned with radio noise in Commission 8 of URSI, and finally (e) the recognition that electromagnetic characteristics of the environment must be described and controlled along with many of the other traditional characteristics such as temperature, pressure, humidity, chemical contamination, etc.

If the concept of a new era is accepted, then one might well take a few moments to reflect upon the status of the field of technology and perhaps speculate on what the future holds. In the first place, with new recognition, one should recognize new responsibility. The EMC engineer will be required to define this area of competence clearly in relation to other areas of specialization, and to show all the potential users how his work can contribute to the solution of their problems. His services must be packaged in such a way that their value will be recognized. This may not be easy since the EMC area has so many dimensions. All types of electronic and electrical equipment are involved, and the techniques can be applied in early design stages, in development stages, in production phases, and in installation stages. Furthermore, the technology changes relatively rapidly. For example, the increased use of digital transmission techniques as compared to analog techniques requires new technology.

Frequency ranges have changed, bandwidths have changed, and correspondingly methods of avoiding interference problems have changed. While much change has taken place over the last 15 years or so, we can expect more extensive application of digital techniques in the coming years.

It is because of examples such as this that this conference and other conferences like it are important. They are evidence of the dynamic nature of the discipline and provide opportunities for practitioners of the field to exchange notes on new problems, new methods of analysis, and new methods of solution. They also provide opportunities for persons with limited experience in the field to quickly become aware of the state of the art.

At this point, one may well ask—what is the future of the field? It lies in several areas which can be grouped into four categories: first, developments in adequate quantitative theories applicable to fundamental electromagnetic phenomena; second, development of new and improved techniques in electromagnetic compatibility control including methods of measurement of emission and susceptibility levels; third, development of components; and fourth, development of standards.

The theoretical problems include more accurate solutions of shielding properties of various configurations. Exact solutions for the shielding effects of coaxial structures are still not readily available to the practitioner. In the same general area, currently there is much effort on shielding from transient fields. Another area which still needs work is the theory of grounding. Here, the general principles are well understood but quantitative information on the optimum ground arrangements under particularly operating conditions is still not generally available.

Techniques of measurement and control of interference are needed in many areas. While the regulatory authorities have devoted much attention to the protection of radio broadcasting, control of
Electromagnetic compatibility in industrial operations is only beginning to get the attention that it deserves in the public market place. Undoubtedly, individual engineers working in particular companies have treated many of the problems which are likely to arise, but there does not appear to be available as general a body of knowledge as is needed. In addition, further work is needed in the development of techniques of measurement of both emission and susceptibility characteristics of all classes of equipment, especially with regard to their broadband and pulse characteristics.

In the component area, new types of wiring and cabling, including strip lines and means of protecting such lines, new methods of interference suppression, especially of the impulsive type, integrated circuits, and the development of optical waveguides can have major impacts on the field.

Finally, particular emphasis should be placed on the area of standardization. It is not appropriate to review the importance of establishing standards. Clearly, they have an important function in encouraging trade through the economies which are affected in manufacturing and in engineering. In line with the theme of this particular presentation, I should like to refer to the often quoted statement that, in fact, standards are an expression of the state of the art. Before one can write a standard, there must be a technology available which has general application. It must be based upon aspects of the science and the art which are widely understood and accepted. Until that state has been reached, standards cannot generally be written which are significant. Extensive work in standards is done at various levels within individual companies, within particular industries, and at national levels. At this conference, it is well to emphasize the international aspect. In the electromagnetic compatibility field, CISPR has been active for about 40 years. Its effectiveness in producing standards of general applicability is probably one of the more outstanding achievements of this kind of effort. The documents are highly respected and reflect work performed at a high technical level. In the past 10 years or so, the importance of the electromagnetic compatibility discipline has received broad recognition in the electro-technical field. A number of IEC technical committees have shown an interest in preparing standards related to their particular scopes. Because of the cross-disciplinary nature of the problems involved, the IEC has recognized the importance of centering this activity in a separate technical committee, and the formation of TC 77 was approved last year. This committee had its first meeting in Bucharest in September 1974.

At the present time, there is no apparent conflict in scopes between the CISPR and TC 77. TC 77 has undertaken to deal with low frequency phenomena; in particular harmonics of the power line frequency up to perhaps as high as 2500 Hz, and flicker phenomena which occur at a few cycles per second. While the phenomena involved are not new, the fact is that the problems caused by these effects are assuming increasing importance, especially in view of the development of solid-state techniques for power control. These devices, unless very carefully designed, are likely to introduce substantial harmonic and pulsing currents into the power supply system. These can react not only on sensitive equipment connected to the same power line, but can also create substantial problems in the power distribution equipment and control techniques associated with that equipment. Solutions to these problems are necessary and can be expected to have substantial economic impact. It is therefore necessary that all of the available expertise be assembled to discuss them.

While TC 77 is concerned with some rather special problems at the moment, at the meeting in Bucharest the delegates were surveyed with regard to their general interest in other problems. The response was substantial. Included were problems in tele-control, industrial equipment, electronic data processing control, radio communications, machine tools, medical equipment, and other areas. The spectrum of interest extended well into the megahertz range and clearly overlaps the areas of concern of CISPR in many respects. Just how this work will be developed in the future is the subject of study of a special Committee of Action working group.

It is perhaps of interest to speculate on standards developments in the immediate future. First, the need for industrial standards will be met in large measure by reference to the basic techniques used in controlling radio interference. For example, the fundamental basis for setting limits for protection of broadcasting has been levels of field strength to be protected. For the development of electromagnetic compatibility standards, clearly the criteria can be different. In industrial areas the objective is not the protection of broadcasting field strengths, but the obtaining of mutually compatible levels of emission and susceptibility. Although these may vary from industry to industry and from one location to another location in any given industry, there is surely a need for standards that can be invoked generally.

These standards cannot be set independently of those applied in broadcasting, since industrial equipment is already limited for this purpose. But, because of its location, it is permitted higher emission levels than in the home. In line with this, sensitive equipment used must have good susceptibility (immunity) characteristics, but a rational basis for establishing appropriate limits does not yet exist.

The program for this symposium contains a large number of papers which directly relate to this question of setting standards for achieving electromagnetic compatibility in various specific environments including urban, industrial and commercial areas, hospitals, aircraft and other, including pertinent measurement techniques. It is clear that rapid advances can be expected in the near future.

Practitioners in the field can look to opportunities to contribute to these efforts in the future, and they will be stimulated quite substantially by the outputs of these efforts.

This speech was the Keynote Address given by Dr. Ralph Showers at the 1st Symposium and Technical Exhibition on Electromagnetic Compatibility held in Montreux, Switzerland, from May 20-22, 1975. At the time, Dr. Showers was with the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, PA. Dr. Showers was active as the Chair of CISPR as well as the Chair of the American National Standards Institute (ANSI) Accredited Standards Committee C63® (electromagnetic compatibility).

Reprinted with permission of the IEEE EMC Newsletter, Winter 2009, Issue 220
Integrated circuits are classified for ESD robustness using a variety of tests. The most popular tests are Human Body Model (HBM) and Charged Device Model (CDM). These two ESD classifications are intended to indicate how well a circuit will survive ESD stresses in manufacturing environments which include basic ESD controls. HBM is the oldest of the ESD tests, but factory ESD control experts generally agree that CDM is the more important test in modern, highly automated, assembly operations. The amount of stress for CDM scales with the size of the device. For that reason “conventional wisdom” on CDM has often stated that you don’t need to test very small integrated circuits because the peak currents get vanishingly small. In last month’s article for IN Compliance [1] we presented an article showing that the peak current for very small devices does not become vanishingly small as often thought. Measurements with a high speed oscilloscope demonstrated that peak currents remain surprisingly high even for very small devices although the width of the pulse gets very narrow. In the past these high peak currents were missed due to the use of 1 GHz oscilloscopes as called for in the standard for the field induced CDM test [2], the most popular form of CDM testing.

This article will discuss how testing small devices is very difficult and then present some of the ideas that have been tried to improve the testability of small devices using the field induced CDM test method.

Figure 1: Photograph of a small chip scale package in a CDM tester (Orion)

Figure 2: Ratios of peak current and total charge with vacuum hole (WH) and without vacuum hole (NH)
THE PROBLEM OF TESTING SMALL DEVICES

The higher than expected peak currents observed for very small integrated circuits was not good news for ESD test engineers responsible for testing very small devices, with dimensions on the order of small single digit millimeters. Figure 1 shows a small 8 ball chip scale package on a field induced CDM tester. The pogo pin which must touch each of the pins being tested represents a significant fraction of the size of the entire integrated circuit. It is obvious that it would not take much of a touch to move the device being tested; requiring repeated repositioning of the device.

During field induced CDM testing it is customary to hold the device under test (DUT) in position using a vacuum. For very small devices the vacuum often does not hold the device very securely. Additionally, the vacuum hole represents a significant fraction of the size of the DUT and can affect the device stress. When the vacuum hole represents greater than about 18% of the area of the DUT the amount of stress begins to fall. Figure 2 compares the amount of stress, measured as either peak current or total charge, between devices that are over a vacuum hole and those that are not over a vacuum hole. [3]

The use of vacuum to hold devices during CDM testing therefore presents two problems. First of all it doesn’t work, and even if it did it starts to affect the test results. Two methods have been tried in the industry to improve testability of small devices, mounting the small package on a holder of some kind or holding the device in place with a support structure or template. The two methods will be discussed below.

SMALL DEVICES ON HOLDERS

CDM measurements have been made on a 6µSMD under three conditions, the device only, the device mounted on a 14DIP Conversion Board and on a 36LLP Surrogate Board. These are shown to scale in Figure 3. CDM waveform...
measurements, Figure 4, were made on the three options at 500 V with an 8 GHz oscilloscope. The results show that mounting on a board does increase the stress applied to the integrated circuit. The increase in stress for the 36LLP Surrogate is fairly modest and might be considered a realistic tradeoff for ease of handling and more reliable test results. The increase in stress from mounting on the 14DIP Conversion board is many times more severe and probably an unacceptable compromise. The good news is that the 36LLP Surrogate was actually easier to handle than the 14DIP Conversion board which tended to move during testing.

**SUPPORT TEMPLATE**

The second method of handling small integrated circuits is to use a support template. The concern with support templates has been; how much does the presence of a dielectric change the capacitance of the integrated circuit to the field plate due to the higher dielectric constant material around the small device. The capacitance between the DUT and the field plate is the determining factor in the amount of stress on the DUT.

Figure 5 shows a 6µSMD constrained inside of a template in a CDM machine. The DUT now sits in a carefully machined hole in an insulator, which is held in place on the CDM machine’s field plate using vacuum. Figure 6 shows waveforms captured with and without an FR4 support template for a 6LLP package at 500 V using an 8 GHz oscilloscope. This shows that the template creates very little increase in the stress to the integrated circuit under test.

**CONCLUSIONS**

Testing very small integrated circuits for CDM using the field induced method presents significant challenges. Mounting a very small device on a circuit board can improve handling significantly but care has to be used not to make the board too large or the device will be stressed much more severely than if the device was tested without the board. The use of a template to hold the device in place during testing produces very little overstress. The manufacture of the template to hold the device securely during the testing can be a challenge. ■

**REFERENCES**


Robert Ashton joined the Discrete Products Division of ON Semiconductor as a Senior Protection and Compliance Specialist in 2007, having previously spent 3 years in the position of Director of Technology at White Mountain Labs, a provider of ESD and latch-up testing of integrated circuits. Prior to that, Robert was a Distinguished Member of Technical Staff at Agere Systems, Bell Labs Lucent Technology, and AT&T Bell Labs, in integrated circuit technology development. Robert has published numerous articles on ESD testing of integrated circuits, test structure use in integrated circuits and CMOS technology development, and has presented tutorials on ESD, latch-up, and Transmission Line Pulse testing at IEEE and ESD Association conferences. In addition, Robert is an active member of ESDA Working Group 5 for Device Standards, ESDA Working Group 14 for System Level Test as well as the JEDEC Committee 14.1 ESD and Latch-Up Working Groups and the IEEE Surge Protection Device Committee.

Robert received his B.S. and Ph.D. in Physics from the University of Rhode Island in Kinston, RI, USA in 1971 and 1977.

Marty Johnson returned to National Semiconductor in 2006 working in ESD device design debug and supervising the ESD Characterization Lab. He currently is supervisor of the ESD Qualification & Characterization Lab. From 2001 to 2006, he worked at Philips Electronics (Semiconductor Division) focusing on WLR and TLP characterization. During his tenure at Philips he was the corporate representative to the Reliability Technology Advisory Board (RTAB, now ISMI) and its chairman in 2004. From 1978 to 2001, he worked for National Semiconductor spanning the semiconductor reliability spectrum from basic reliability qualification through wafer level reliability to ESD and Latch-up. He is also active on the JEDEC ESD Team (JC-14.1), the Joint ESDA/JEDEC HBM and CDM teams and the JEDEC Latch-up Standards team.

Marty received his B.S. Physics from Midland Lutheran College in 1973, his M.S. Physics from the University of Tennessee Space Institute in 1975 and his M.S. in Electrical Engineering from the University of Nebraska in 1978.

Scott Ward joined Texas Instruments in 2007 to work in the field of device-level ESD testing and ESD testing standards development. He has since expanded his work to include factory ESD control and handling. Prior to Texas Instruments, Scott worked for Cypress Semiconductor in San Jose, CA. At Cypress, his work included ESD and Latch-up design and characterization; as well as device testing standards development. Since 2003, he has been a member of the ESDA Working Group 5 standards committee (device testing). Scott joined the JEDEC ESD standards task force in 2005. Scott is an ESDA member, attending every EOS/ESD Symposium since his first in 1996. Scott began his career at ZiLOG in 1995, designing on-chip ESD protection networks.

Scott Ward joined Texas Instruments in 2007 to work in the field of device-level ESD testing and ESD testing standards development. He has since expanded his work to include factory ESD control and handling. Prior to Texas Instruments, Scott worked for Cypress Semiconductor in San Jose, CA. At Cypress, his work included ESD and Latch-up design and characterization; as well as device testing standards development. Since 2003, he has been a member of the ESDA Working Group 5 standards committee (device testing). Scott joined the JEDEC ESD standards task force in 2005. Scott is an ESDA member, attending every EOS/ESD Symposium since his first in 1996. Scott began his career at ZiLOG in 1995, designing on-chip ESD protection networks.

Scott has an M.S. in Electrical Engineering from the University of Idaho and a B.S. in Electrical Engineering from Montana State University.
The Future of EMC Engineering
by Mark I. Montrose, Montrose Compliance Services, Inc.

Why FR-4 is Obsolete for Tomorrow’s Technology

A discussion topic between designers, namely those who only do circuit design and have no interest in the field of EMC, and compliance engineers attempting to meet regulatory compliance requirements, is the use of FR-4 as the core material for printed circuit board construction. Fiberglass Resin (FR) is low cost and has been used in almost every electrical product for decades, with exceptions such as military and satellite applications, harsh environmental conditions, and other unique uses. The disagreement lies with the extent that we can use FR-4 in high frequency applications and should we be concerned more with electrical performance or manufacturing and assembly.

There are six variations of weave structures available during core construction. fiberglass strands are first woven in an x- and y- axis and then held together by a resin. Depending on the ratio of fiberglass to resin, the assembly will perform differently under specific operational conditions. A primary parametric concern for electrical performance is dielectric loss. Most FR-4 weave constructions have a high dielectric loss that minimizes signal propagation generally from 2 GHz and above. Also, depending on the weave structure, the quality of ensuring an optimal RF return path is another concern.

The reason why FR-4 is becoming obsolete for today’s products deals not with dielectric loss or weave structure, but the RoHS Directive in Europe, China, and soon North America. The Restriction of Hazardous Substance Directive makes the use of lead illegal regardless of application. Typical solder consists of PbSn (tin-lead). Since use of PbSn solder is now illegal, an alternative solder material composition is required. The metallurgy of this alternate material leads to microscopic problems known as Tin Whiskers. What occurs over time is small metallic whiskers will grow from a soldered joint and may bridge circuits causing system failure. NASA has much documentation on tin whisker growth as well as the Raytheon Corporation. Perform an Internet search on tin whiskers to learn more about this topic.

Another concern why FR-4 is becoming obsolete for technologies of the future is that in order to use the new solder, higher processing temperatures are required to ensure melting during reflow. With higher process temperatures, the resin used to hold the fiberglass stands together will start to evaporate and delamination of the copper from the core occurs. This is now a reliability concern. So should we worry more about electrical performance or manufacturing capabilities for high technology products using FR-4?

Mark I. Montrose is an EMC consultant with Montrose Compliance Services, Inc. having 30 years of applied EMC experience. He currently sits on the Board of Directors of the IEEE (Division VI Director) and is a long term past member of the IEEE EMC Society Board of Directors as well as Champion and first President of the IEEE Product Safety Engineering Society. He provides professional consulting and training seminars worldwide and can be reached at mark@montrosecompliance.com
June 7 - June 10
Three-Day Functional Safety Training Event Explains IEC 61518 & IEC 61511
TÜV Rheinland
Boxborough, MA
www.incompliancemag.com/events/100607

June 8
Understanding Ground Resistance Testing
AEMC Instruments
Toronto, Canada
www.incompliancemag.com/events/100608_1

June 8
International Approvals Round Table Complimentary Invitation
TÜV Rheinland
Portland, OR
www.incompliancemag.com/events/100608_2

June 9
Setting up Safe Workstations
Associated Research, Inc.
Webinar
www.incompliancemag.com/events/100609

June 10
International Approvals Round Table Complimentary Invitation
TÜV Rheinland
Seattle, WA
www.incompliancemag.com/events/100610_1

June 10 - June 15
ESD Association June Meeting Series
ESD Association
Chicago, IL
www.incompliancemag.com/events/100610_2

June 15 - June 16
ANSI C63.10 Workshop
Underwriters Laboratories
Northbrook, IL
www.incompliancemag.com/events/100615_1

June 15 - June 16
Globalability: The Key to International Compliance
UL University
Hartford, CT
www.incompliancemag.com/events/100615_2

June 15 - June 16
Grounding & Shielding of Electronic Systems
LearnEMC
Greenville, SC
www.incompliancemag.com/events/100615_3

June 15 - June 18
MIL-STD-461F: Methods and Procedures
Washington Laboratories Academy
Cleveland, OH
www.incompliancemag.com/events/100615_4

June 16
Test Area and Personnel/Common Electrical Product Safety Tests Seminar
Associated Research, Inc.
Lake Forest, IL
www.incompliancemag.com/events/100616

June 17
Printed Circuit Board Layout for EMC and Signal Integrity
LearnEMC
Greenville, SC
www.incompliancemag.com/events/100617_1

June 17
International Approvals Round Table Complimentary Invitation
TÜV Rheinland
Raleigh, NC
www.incompliancemag.com/events/100617_2

June 17 - June 18
Suspect Counterfeit Detection, Avoidance and Mitigation
University of Oxford, Department for Continuing Education
Oxford, United Kingdom
www.incompliancemag.com/events/100617_3

June 17 - June 19
6th China International Automotive Electronics & Testing Technology show (AES 2010)
Shanghai Exhibition Center
Jing An, China
www.incompliancemag.com/events/100617_4

June 21
International Approvals Round Table Complimentary Invitation
TÜV Rheinland
Grand Rapids, MI
www.incompliancemag.com/events/100621

June 23
International Approvals Round Table Complimentary Invitation
TÜV Rheinland
Cincinnati, OH
www.incompliancemag.com/events/100623

June 24
Data Acceptance Program and ISO/IEC 17025 Requirements and Implementation
UL University
Northbrook, IL
www.incompliancemag.com/events/100624
EMI/RFI Shielding Allows Airflow and Heat Dissipation of Electronic Components

MAJR Products has introduced MAJR Shield®, an EMI/RFI Board Level Shield that allows significant airflow and heat dissipation of electronic components. Thermally, MAJR Shield incorporates either straight honeycomb with stand-off fence mounting for convection “chimney effect” heat dissipation or angled honeycomb for forced air applications – both configurations provide high EMI/RFI shielding performance.

MAJR Shield is design for applications where EMI/RFI shielding and heat dissipation is needed. MAJR Shield is also used for electronics that require long life by targeting airflow to reduce component operating temperature.

Operational frequencies are ever increasing in electronic devices and due to inherent skin effect heat is becoming more of an issue along with radiated emission levels. Heat must be removed from chips as soon as possible to avoid improper operation, failure, or premature product life. Shielding is need to protect against crosstalk and to meet FCC and CE regulations. The MAJR Shield product can accomplish both heat dissipation and shielding functions at the source. For further information contact MAJR Products: tel: 814-763-3211 or visit www.majr.com.

High Impedance Ferrite

The very high impedance, multi-turn FerriShield ferrite from Leader Tech offers a massive amount of EMI suppression in a very small 1.25” x 1.23” x 1.25” package. The bisected, snap-on design offers three pass-through openings for cables with a diameter up to .203” (5.8mm).

To boost impedance a cable can be “looped” through 1, 2 or 3 of the ferrite openings. A single pass through the SS28B2035-3 ferrite provides 340 ohms of impedance at 100MHz. If the same cable is passed through additional holes, impedance is equal to the square of the number of turns. Depending on circuit load and frequencies involved, much of the increase can be realized. For more information, call (813) 855-6921 or visit www.leadertechinc.com.

New Thermal Conductivity Tape

LORD Corporation has announced the availability of a new low modulus, high thermal conductivity adhesive. Created in response to a market need for a more flexible, high thermal conductivity adhesive, MT-815 can be used in a variety of applications including as a thermal adhesive for large die, in die attach applications, or as a solder replacement.

The first in a series of new low modulus, thermal conductivity adhesives from LORD Corporation, MT-815 has a modulus of <1 GPa, allowing it to be more flexible and therefore less likely to crack or delaminate under the stresses of temperature cycles. MT-815 was also formulated to achieve thermal conductivity of >10 W/m-K, creating a new class of flexible adhesives with high thermal conductivity. For further information call (877) ASK LORD or visit www.lord.com/electronics.

EM TEST Group Expands Business

EM TEST Group has acquired Lüthi Elektronik-Feinmechanik AG, expanding its capabilities as a supplier EMC measuring and testing equipment in the fields of conducted immunity testing and emission measurement.

Lüthi AG, headquartered in Frenkendorf, Switzerland, is a manufacturer of coupling/decoupling networks for conducted immunity testing and emission measurement as well as of EMC measuring clamps and accessories. With this acquisition Lüthi AG becomes a part of the EM TEST Group of companies; however, it will to be operated independently and the Lüthi brand will remain. A new managing director, Mr. Benedikt Hänggi, will take over the operations from the former owners, the Lüthi family, who wish to retire. All Lüthi employees will be retained in order to secure the manufacturing know-how and the expertise necessary to produce high-quality Lüthi products.

The EM TEST Group has been a Lüthi partner for many years as a reseller matching Lüthi products with EM TEST systems. Synergies of this merger coupled with an enlarged distribution network will insure continued global growth of the Lüthi brand.

WP Wireless Antenna Solutions

Master Distributors has announced that it is an authorized distributor of WP Wireless antennas, which are designed and manufactured primarily for the fast-growing machine to machine (M2M) market. M2M uses telemetry or telematics that is accomplished using networks, especially public wireless networks.

WP Wireless helps customers diagnose radio frequency (RF) problems and offers the optimum antenna solution to meet the customer’s performance criteria. The company has access to all antenna technologies, including ferrite, printed circuit board (PCB), stamped metal, low-loss materials and low-temperature co-fired ceramic (LTTC), ceramic, and wire.

WP Wireless designs and manufactures M2M antennas for all major wireless protocols in use today, including GSM, CDMA, WCDMA, WiFi, Bluetooth, ZigBee, ISM, and GPS. WP Wireless’s wide variety of successful M2M antenna applications include: Hospital patient monitoring systems; Devices designed to alert both owners and service centers of potential automobile mechanical problems; Smart Meters that allow utility companies to read customer meters remotely and effectively manage a city’s power grid and water supplies; Shopping carts that will notify customers of their running totals, give in store directions to where items are located and even notify the customers when they are near special sale items. For more information please visit www.masterdistributors.com.

Reliable, Economical Electronic Connector

One of the best ways to connect an LCD to a circuit board is through the use of a high density, low resistance elastomeric interconnect device. With a remarkable 500 conductive layers per inch, Fujipoly’s Series 2005 Zebra® Carbon Connector is a great option for densely packed boards typically found in smaller consumer and hand-held commercial electronics. The highly reliable and economical electronic
connector exhibits a resistance of 2.37 ohms•inch typical and operate across a broad temperature range of -58°F (-50°C) to 257°F (125°C). Free samples and a complete product catalog can be requested at www.fujipoly.com!

New MOSFET Shrinks Its Footprint for Portable Designs

Fairchild Semiconductor has introduced a portfolio of high performance MicroFET MOSFETs packaged in an ultra-compact and thin footprint (1.6mm x 1.6mm x 0.55mm). Designers can select the MicroFET MOSFET that optimally suits their application and design needs. This new portfolio contains a number of commonly used topology choices, including, single P-Channel and Schottky diode combo, single N-Channel and Schottky diode combo, dual P-Channel, dual N-Channel, complementary pair, single N-Channel and single P-Channel.

These MicroFET MOSFETs are designed with Fairchild’s PowerTrench® MOSFET process technology, a technology yielding exceptionally low values for RDS (ON), total gate charge (QG) and Miller Charge (QGD) – enhancements, the company reports, that result in superior conduction and switching performance and excellent thermal efficiencies. For further information visit http://www.fairchildsemi.com/cf/sales_contacts.

40GHz Low-Loss RF Coaxial Cable Assembly

Crystek has introduced the CCK40 Series Cable Assembly, a new addition to their line of Low-Loss RF coaxial cable assemblies. Designed to operate up to 40GHz, the CCK40 features rugged stainless-steel solder-clamp construction and heavy duty strain reliefs. This low-loss cable provides an attenuation value of 0.90dB/ft. at 40GHz. The CCK40 Series cable offers shielding effectiveness of greater than -90dB with an operating temperature range of -55 to +85°C (extended range of -55 to +125°C available through special order).

The CCK40 Series cable offers a minimum bend radius of 1.0 in. and is available in-stock with 2.92mm (K) connectors. Crystek's stocking distributors also support a large variety of other coaxial cable assemblies in a variety of configurations. For further information: tel: 800-237-3061 or visit www.crystek.com.
Whatever The Shielding Application... We’ve Got You Covered.

For reliable EMI/RFI shielding performance, turn to the most experienced manufacturer in the shielding industry: ETS-Lindgren. No other shielding company provides the product development, design/consultation, engineering expertise, and quality testing that result in the industry’s most effective EMI/RFI protection from interference.

It doesn’t matter where on the RF Spectrum you test, we have the attenuation solution you need. Whether it is Cellular, Bluetooth, Wi-Fi, UWB, WiMAX, MIMO or the next standard on the horizon, ETS-Lindgren can provide unmatched shielding performance every step of the way.

Contact is at 630.307.7200, or visit our website at www.ets-lindgren.com.

Enabling Your Success™

ETS-LINDGREN™
An ESCO Technologies Company

www.ets-lindgren.com

Phone +1.512.531.6400 • info@ets-lindgren.com
Offices in the US, Finland, UK, France, India, Singapore, Japan, China, Taiwan

©2010 ETS-Lindgren
A Partner You Can Count On

With more than 5,000 chambers worldwide, we have the experience, knowledge and capabilities to provide our customers with the finest shielded enclosures available.

We are committed to uncompromising quality control, quick and accurate response to client needs and reliable, competent, on-time service.

EMC Chambers
Compact 3, 5 and 10 Meter
Near Field/ Far Field Chambers
Reverberation Chambers
Military Test Chambers
For 416 E