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# 2013

## EMC DIRECTORY & DESIGN GUIDE

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### DIRECTORIES



SPECIAL FEATURE:
## WOMEN IN EMC
OUTNUMBERED BUT UP FOR THE CHALLENGE

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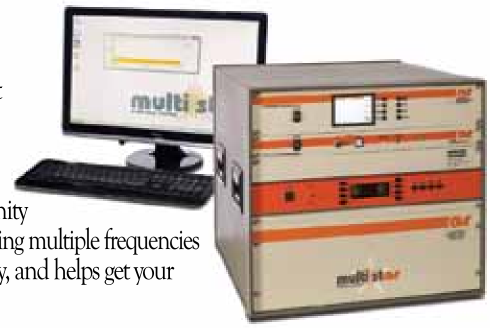


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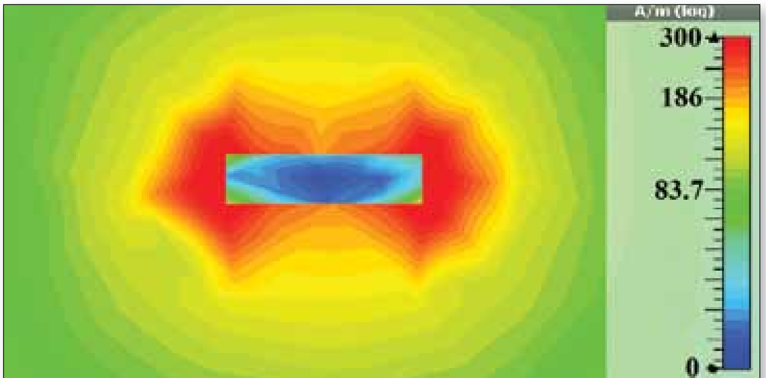


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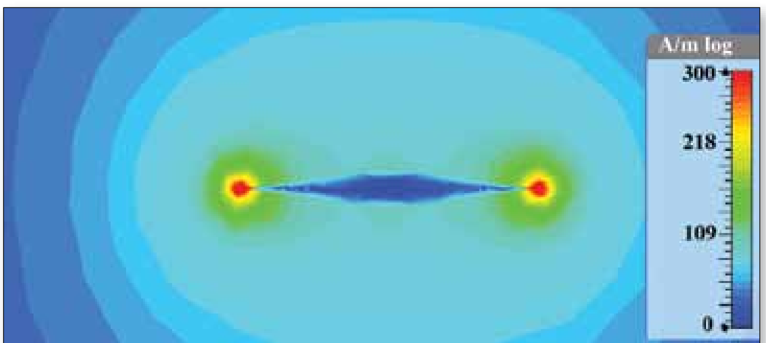


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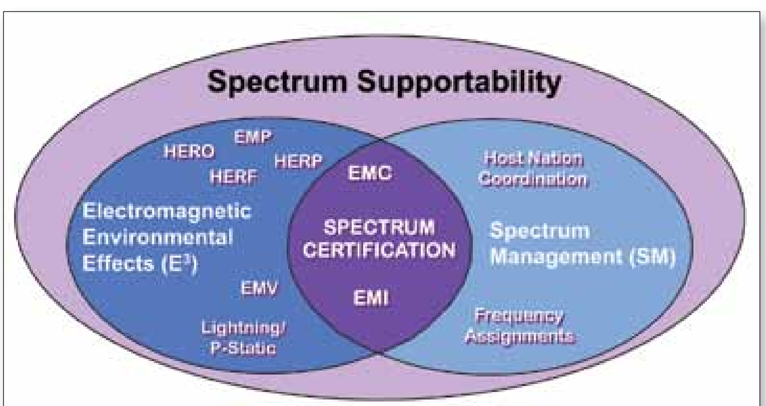


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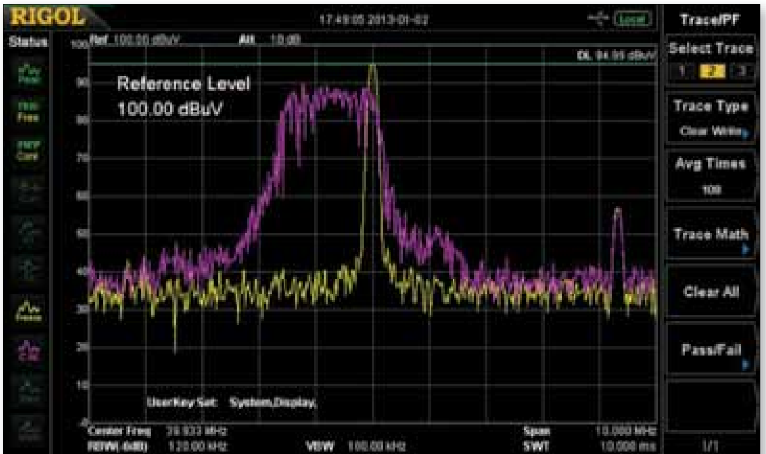


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# Hot Topics for the Future of EMC

**WELCOME TO** *Interference Technology's* 2013 Directory and Design Guide. In this year's directory, you'll find the familiar comforts of prior issues, as well as something a bit new.

As in previous editions, the directory includes our popular reference sections: a list of important upcoming events, newly released standards, and listings of professional societies and government personnel important to EMC. Of course, the Directory and Design Guide wouldn't be complete without the exhaustive list of products, services, and companies in the industry. The Products and Services section, which starts on page 108, is segmented by category and subcategory, so you can easily find what you're looking for. Once you have, the Company Directory (page 119) includes hundreds of listings of companies that provide those products and services, complete with locations and contact information.

Our technical articles this year are diverse and thought provoking. John Woodgate asks "Why should we consider EMC (and safety) early in the design stage?" by addressing a problem discussed in an email chain.

Bill Radasky discusses a hot topic — severe electromagnetic threats and protection methods — in his article "The Electromagnetic 'Triple Threat' and the Critical Infrastructures Revisited." The three threats include high-altitude electromagnetic pulse (HEMP) produced from a nuclear detonation in space; the intentional electromagnetic pulse (IEMI) produced by electromagnetic weapons used by criminals and terrorists; and severe geomagnetic storms produced by solar activity.

Following the successful launch of our new webinar series, Keith Armstrong answers in depth questions attendees asked during his presentation in November 2012 of "Cost-effective EMC Design by Working with the Laws of Physics." These questions came straight from you, and answers include practical information for the EMC engineer. If you would like to view the webinar itself, it is available on our website, www.interferencetechnology.com.

This year, in addition to our technical articles, we're including a new, non-technical feature article that details the challenges and successes of women in the EE/EMC field, "Women in EMC - Outnumbered but Up for the Challenge," on page 10. A small but growing minority in EE and EMC, women are becoming increasingly important contributors to the future of the industry. Interestingly, in Ken Wyatt's technical article, "Spread Spectrum Clock Generation — Theory and Debate" there is also a reference to the success of 1940s actress/engineer Hedy Lamarr and her contribution to solving the problem of torpedoes being jammed by RF signals during World War II. She helped develop a technique that formed the basis of frequency hopping spread spectrum systems today. Many other women, past and present, have been important contributors to EMC. Some of those women are detailed in our feature story.

I welcome your comments on this issue and suggestions for future editions. In the meantime, I hope you will find this year's Directory and Design Guide - whether your referencing the print edition or the mobile edition at www.interferencetechnology.com - to be a helpful assist to your workday. I can be reached at bstas@interferencetechnology.com.

**Belinda Stasiukiewicz**
*Editor*

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**USA**
1000 Germantown Pike, F-2
Plymouth Meeting, PA 19462
Phone: (484) 688-0300
Fax: (484) 688-0303
E-mail:
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**www.interferencetechnology.com**

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Beijing Hesicom Consulting Company
Cecily Bian, +86-010-65250537
E-mail: cecilybian_itc@163.com

**JAPAN**
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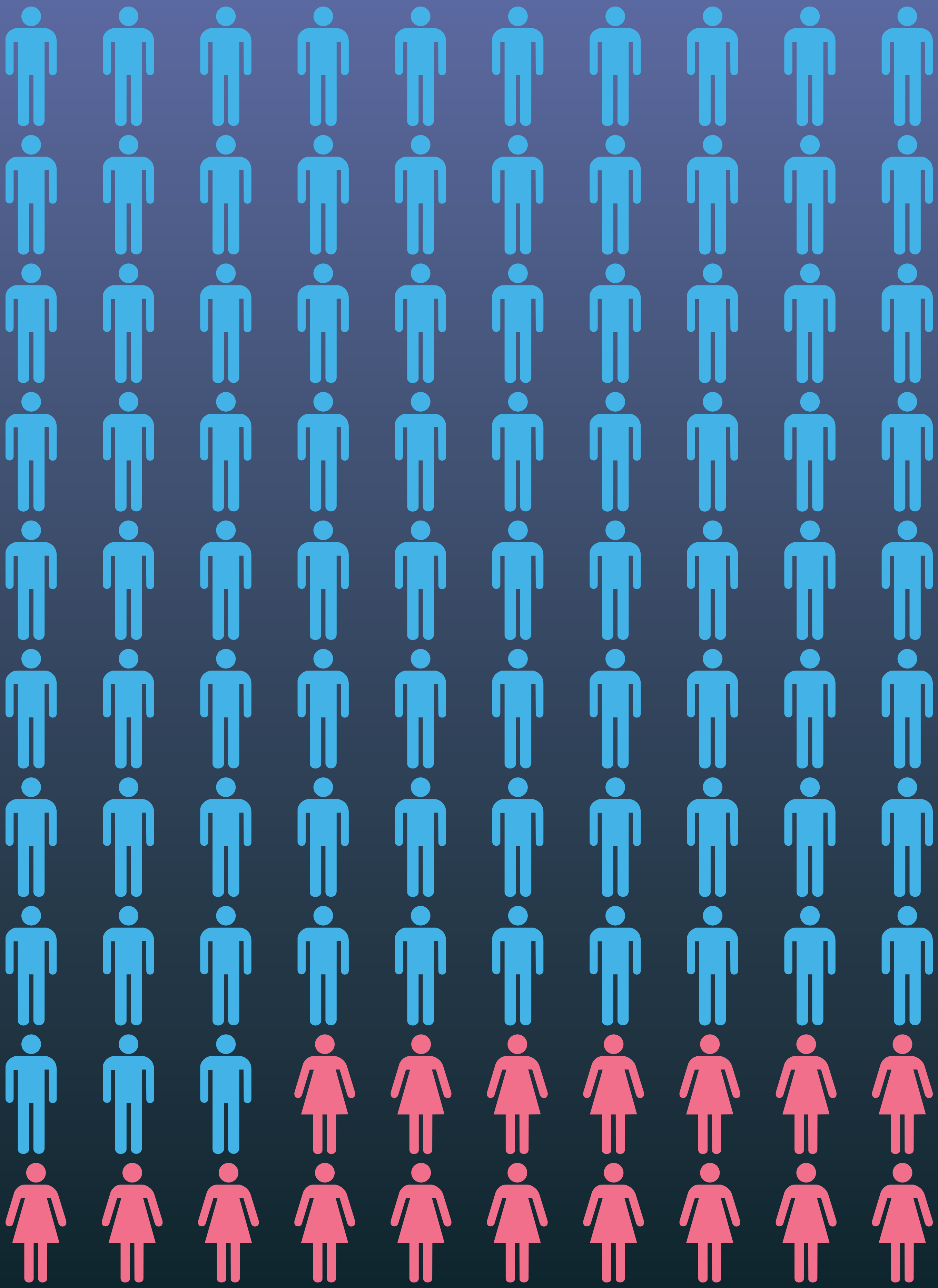




# WOMEN IN EMC

## OUTNUMBERED BUT UP FOR THE CHALLENGE

**Belinda Stasiukiewicz**
*Editor*
*Interference Technology*

◀ Seventeen percent of bachelor's degrees in engineering were received by women in 2009, according to the American Society for Engineering Education

**Aspire. Advance. Achieve.**

This is the slogan of the Society of Women Engineers. The organization, founded more than 60 years ago, is one of the leaders in the push to increase female interest in engineering. The society hopes that its members, and all female engineers in general, will aspire to become successful engineers, advance further in the field and achieve their goals.

For three days this coming October, the Society will host 6,000 women engineers in Baltimore, M.D., for its annual WE13 Conference – the "best way for women engineers to add to their own personal history of success."

### Full STEM ahead

Billed as an opportunity to network, start or advance careers, or merely experience highly rated professional development offerings, WE13, which takes place Oct. 24-26, is among several yearly events hosted by the Society of Women Engineers.

Karen Purcell, PE, an electrical engineer, entrepreneur and author from Reno, Nev., spoke at the society's regional "Ride the Wave of Innovation" conference in 2012, held in Honolulu, Hawaii. Her topic: "Unlocking Your Brilliance," which is the title of her recently-published book.

According to her website, Purcell draws on her personal experience to inspire women to enter the science, technology, engineering and math (STEM) fields with confidence.

Purcell is the founder and president of PK Electrical, and has a non-profit organization to help women create futures in the STEM fields – STEMpire. She thinks young girls are too often ushered into more nurturing professions, like teaching and nursing, rather than technical or mathematical fields.

"It's an unwritten bias; the way we've all grown up. Boys get the science play sets, but that doesn't mean the girls aren't going to be good [at engineering.] Exposing them to STEM may strike their interest," she said.

In an average college engineering class today, men typically outnumber women significantly — nearly 80 percent male, according to a Northeastern University study. Coursework with a focus on electromagnetic compatibility (EMC) has even less females present in classes.

Though these statistics are mirrored in industry, women are striving to increase their representation in the STEM fields.

**School factors**

According to the Northeastern University study, titled, "Women in Engineering in the United States: Overview 1990-2010," the percentage of female engineering enrollment remained predominately steady with a slight increase, from 16.5 percent in 1990 to 17.4 percent in 2006. In 2007, the same study found that the electrical and electronic engineering fields held one of the lowest percentages for women in the field, 8.6 percent, compared to the percentages for software or chemical engineering, which were 20.8 percent and 21.2 percent, respectively.

The presence of women in engineering varies throughout the world. While the Northeastern Study's numbers hold true for the U.S., other countries have more equal representation of both genders in the field.

According to an article by the University of Pennsylvania, 40 percent of engineers in China are female, while 58 percent of engineers in Russia are female. However, not every European and Asian country follows suit. France, for example, has a 27 percent rate of women engineers under the age of 30. The article suggests this concerns company leaders who need to hire; and the reason for the small numbers of women could possibly come from a "conflict between family and professional life."

An interesting argument to why women are represented less in engineering comes from economists Massimo Anelli and Giovanni Peri, who recently published a paper through the National Bureau of Economic Research titled, "The Long Run Effects of High-School Class Gender Composition." Anelli and Peri assert that typical schools with students of both genders make it less likely girls will choose a career like engineering.

The study analyzed a database of 30,000 Italian students who graduated from high school between 1985 and 2005. It found that girls who attend an all-girls school are more likely to choose a high-paying STEM major, while girls who attend a mixed-gender school are more likely to choose a humanities major, which will lead to a lesser-paying job.

Kate Stuckman, a senior at Texas A&M University, is among the few women who plan to enter the electrical engineering field. She is excited to make her mark in the industry and classes where "teachers always know my name."

"I was meant to be an engineer. I like math and the theoretical side of it," she said, "But I wanted to be doing something in society and applying theoretical concepts to solve real world problems."

Stuckman plans to pursue a master's and perhaps a Ph.D. in wireless communication and wireless coding research. She has found support from her professors, mentors and peers throughout her education.

"In electrical engineering I'm in the minority. But it hasn't been an issue at all," she said. "By no means do I give up my femininity. It's never been an issue of people underestimating my capabilities."

Stuckman does recognize that gender issues may come up in the workplace eventually, however.

"I have heard [of challenges] once you get into industry. It's such a male dominated field. But it's best to be prepared [for any situation]."

Sydney Baker, a senior engineering student at Worcester Polytechnic Institute (WPI), has also had a positive experience in school but anticipates the challenges her chosen career may bring.

"While the professors I have been in contact with have treated women fairly, I have found that my male peers have underestimated my skills from time to time," she said. "[But] as long as you worry about putting your best foot forward and making a name for yourself based on your own performance, I've found that gender does not matter."

Miryam Becker, an engineering student at WPI, says the school has a student body rate of 30 percent female, but she doesn't believe it affects students' perceptions or efforts.

"The women at WPI are here because they know that they have the same potential as men to do great things, even and especially in the field of engineering," she said. "The population difference is noticeable, even just walking around campus, but honestly the women here are just as motivated, passionate, and intelligent as the men so I do not feel out of place or lesser than anyone else. Everyone works hard and does their best, and that puts everyone on a level playing field."

**Industry gains, past and present**

In industry, women engineers are undeniably making a mark.

Candace Suriano, an EMC engineer and owner of Suriano Solutions, is the author of numerous papers on electromagnetic compatibility and hosted works shops at several IEEE EMC events. Her interests are primarily in the area of electromagnetic modeling, and she feels that women make great engineers.

**STATISTICAL TRENDS**
**WOMEN IN ENGINEERING ENROLLMENTS**

**After an increase in female engineering enrollment in the 1990s, the percentage of women studying in the field began to drop.**

| Year | Total Number of Engineering Students | Number of Women | Percent Woman |
|---|---|---|---|
| 1990 | 346,169 | 54,772 | 16.5% |
| 1994 | 328,463 | 60,931 | 18.6 |
| 1998 | 329,657 | 66,276 | 20.1 |
| 2000 | 353,118 | 69,506 | 19.7 |
| 2002 | 383,109 | 71,586 | 18.7 |
| 2004 | 384,792 | 69,490 | 17.8 |
| 2006 | 371,720 | 64,544 | 17.4 |

*Commission on Professionals in Science and Technology (CPST), Professional Women and Minorities, Nov. 2008.*

| Bachelor's Degrees | |
|---|---|
| **Year** | **Percentage %** |
| 2000 | 20.8 |
| 2002 | 20.9 |
| 2004 | 20.3 |
| 2006 | 19.3 |
| 2007 | 18.1 |
| 2008 | 18.0 |
| 2009 | 17.8 |

*Michael T. Gibbons, "Engineering by the Numbers, " American Society for Engineering Education, Dec. 31, 2009.*

"Women bring flexibility and a lower cost," she said. "Many women go in and out of the workforce or would like to work less hours; this lowers the cost of an engineer."

Suriano's sage advice to the aspiring female engineer is this: Learn to play with math. Use math games, work with tools and increase your ability to understand process engineering and how things are made.

The history of women in engineering had a late start in the 19th century. Women began receiving patents for inventions: Tabitha Babbit, an American toolmaker, invented the first circular saw in 1813; while English Sarah Guppy patented a design for bridge foundations in 1811. The first woman to receive an engineering degree was Nora Stanton Blatch Barney, granddaughter of famous women's right activist Elizabeth Cady Stanton, who received a civil engineering degree from Cornell University in 1905. These women were pioneers in the industry, and by the end of the 20th century, women were more visible in the engineering field. However, they are still the extreme minority.

**"IT'S AN UNWRITTEN BIAS; THE WAY WE'VE ALL GROWN UP … BUT THAT DOESN'T MEAN GIRLS AREN'T GOOD [AT ENGINEERING]"**

*Karen Purcell, electrical engineer, author*

**Fun at work**

For Mary Alcaraz, PE, LC, CEM, LEED, AP, going to work is fun – even after 23 years. The suburban Philadelphia, Pa. married mother of two is an electrical engineer with EwingCole, headquartered in Philadelphia.

Whenever the opportunity arises, Alcaraz urges young women to consider a career in engineering, including her own 12-year-old daughter.

"We need engineers in general," she said.

A Penn State graduate, Alcaraz is a supporter of Drexel University's co-op program, which provides six months of classroom training and six months out in the field.

"That way, students really get to know what they like," she said.

When she was a newcomer, Alcaraz said she didn't have any women mentors. Today, she tries to guide the younger employees.

In the last 10 years, Alcaraz said she's found herself working with more females. To her, the gender growth has been slow, but sure.

**Playing smart**

Girls' STEM interest is the focus of other women engineers who are trying to get young students to consider it as a career. In 2012, Debbie Sterling, a Stanford University engineer, founded GoldieBlox, Inc., a toy company that creates toys that develop skills and teach basic engineering principles through the adventures of a girl engineer, "Goldie."

"By designing construction toys from the female perspective, we aim to appeal to a broader audience of children and parents who previously considered engineering a 'boys' club.' By challenging this stereotype, we hope [Sterling and Goldie] will inspire more girls to become engineers," the company said on its website.

Purcell hopes students can follow her example and explore the field, at an age younger than she was when she started.

"I was doing well in science and math and I was fortunate to have a physics teacher in high school who suggested I consider engineering as a career," she said. "In college, it took until the end of sophomore year before guys realized 'she does know what she's doing.' "

Purcell believes girls today have more opportunities to explore engineering careers, due to the increase in technology and efforts extended to budding engineers. She references the Girl Scouts, which includes 2.4 million girls ages 5-17 and has created a STEM program in recent years that introduces math and science to scouts at a young age.

"Girl Scouts introduces girls of every age to STEM experiences relevant to everyday life. Whether they're discovering how a car's engine runs, how to manage finances, or exploring careers in STEM fields, girls are fast-forwarding into the future," the Girl Scouts website says.

The organization has also conducted in-depth studies on girls' views of technology. "Generation STEM: What Girls Say about Science, Technology, Engineering, and Math" is a national research report by research analyst Kamla Modi, Ph.D.; director of research and outreach Judy Schoenberg, Ed.M.; and senior researcher Kimberlee Salmond, M.P.P; which investigates girls' interest in STEM. The report consists of a literature review, focus groups and survey results from 1,000 girls across the country.

The study found that "Girls are overwhelmingly interested in STEM."

**Shaping solutions**

Regardless of whether women feel challenges of their gender in the workplace or not, the Society of Women Engineers continues to serve as a national organization dedicated to helping women succeed in engineering. The society recognizes the need for a support system where women can come together and make changes in their field.

According to a statement in its 2011 Annual Report, "As engineers, each day we shape solutions to a myriad of challenges. But more than that, we create products and services that shape lives all around the world. And, as the Society of Women Engineers, we collectively shape the lives of women in engineering and technology everywhere."

The Society of Women Engineers' chapters are also committed to hosting events and activities to pique girl's interest in STEM.

Stuckman is her chapter's internal vice president – she is responsible for delegating tasks and overseeing all of the officers who chair the society's numerous events.

"We have a high school summer camp, outreach programs for grades K-12 and a program that matches undergraduates to women in the industry," she said. "My job is making sure all programs run smoothly. We want to get kids more active in STEM activities," she said.

As Stuckman finishes her senior year at Texas A&M and prepares for graduate school and beyond, she, too, has some advice for upcoming engineers.

"Don't give up. Take advantage of the resources that are available to you. Find ways to meet other people and don't be intimidated," she said. "Don't feel like you're not as good as anybody else; prove them wrong. Go into it with an open attitude."

*-Rose Quinn contributed to this story*

# Simulation of GHz Insertion Loss Components; Cross-section Geometry Influence on Conductor Loss

**TRACEY VINCENT**
Application Engineer, CST

## ABSTRACT:

**TO ATTAIN** realistic estimations of simulated insertion loss, all insertion loss components need to be considered and accounted for. In particular the dielectric and conductor loss components can require careful material parameterization in order for 3D simulated loss to be realistic. An overview of these parameterizations is given, including a focus on the trace cross-section shape influence on conductor loss, an often overlooked phenomenon.

**Keywords:** Loss components, conductor loss, dielectric loss, tangent delta, edge effects, surface roughness, simulation, materials, parameterization.

## INTRODUCTION

As digital switching times continue to decrease, insertion loss, due to these higher frequencies, increases. The greater loss is caused by several physical properties, categorized by different loss components. Unfortunately it is often the case that one or more of these loss components are not adequately captured during simulation. This often results in a larger than expected measured loss. The loss components, and their physical properties, will be discussed and suitable, full-wave, simulation approaches detailed. 3D, full-wave, solvers are increasingly able to handle more complicated models with better and more detailed parameterization. In addition, certain models with millions of mesh cells can have reasonable run times made available by high performance computing.

There are four distinct high-frequency, GHz range, insertion loss components: radiative, reflected, conductor, and dielectric. Radiative and reflected losses relate to design/topology and are typically, with attention to relevant geometric features, accurately predicted by full-wave electromagnetic solvers. Dielectric and conductor losses depend on material parameters, process parameters, and design/topology. Dielectric loss is the proportion of the signal absorbed by the insulator or dielectric material - the substrate. The conductor loss is the signal that is absorbed by the conductor/metal - the trace; conductor loss can also be known as Ohmic or $I^2R$ loss. Dielectric and conductor losses are often inadequately parameterized for full-wave simulations.

The physical mechanism of Dielectric loss and the Dielectric loss parameter, tangent delta, are explored to give a good conceptual understanding of this loss mechanism; guidelines for simulating dielectric material are given.

The circuit topology influences the conductor loss component. Even at DC, the geometry of a conductor or trace determines the overall electrical resistance since resistance relates to length divided by cross-sectional area, the larger this area the smaller the DC resistance. The geometry factor becomes more complicated as frequency increases.At microwave frequencies, the skin effect causes the signal, within the metal trace, to concentrate at the conductor extremities and therefore becomes sensitive to the conductor topography at these extremities. A trace with a sharp edge may have significantly larger conductor loss than a curved edge, however, this phenomena is often not taken into consideration. Examples of traces with different cross section shapes are simulated and their results compared to illustrate this important aspect of conductor loss.

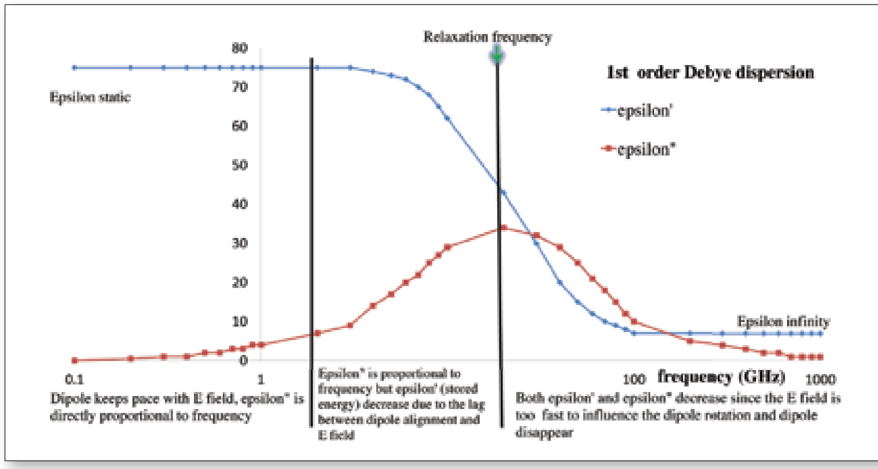
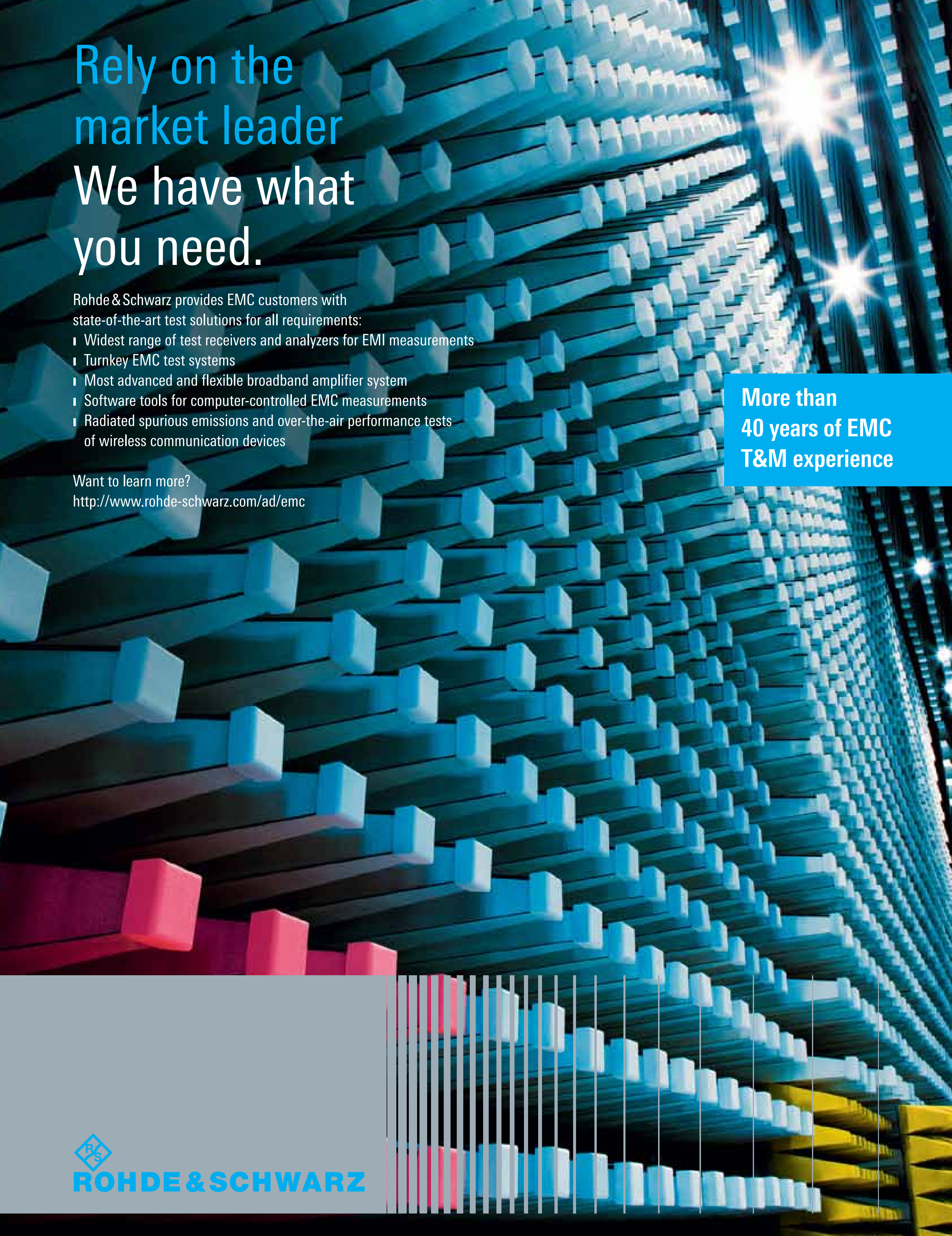



**FIGURE 1:** Illustration of Debye dispersion showing a single material relaxation

At frequencies at or greater than 10GHz, with materials of high conductivity such as copper, the skin depth is in the order of a micron. At this scale, the shape of the conductor material at the conductor extremities influences the flow of the signal [1,2]. This is considered as surface roughness and is recognized as an important and often underestimated contributor to conductor loss. The influence of surface roughness on conductor loss is mentioned but not explored in depth in this article.

Microelectronics circuits are designed using electro-



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magnetic simulation in order to decrease design costs and shorten the design process. Therefore, circuit design depends on the accuracy of simulation tools that allow circuit prototypes to be created quickly and inexpensively. EM simulation packages, such as CST, can estimate the total transmission loss if the care is taken with dielectric and conductor loss components.

## MATERIAL PARAMETERIZATION

To simplify simulations, and have them run quickly, materials are often characterized into basic materials types such as "Perfect Electrically Conducting" or "Vacuum". This approach is sufficient for many simulations; however, it can give inadequate estimations of insertion loss, particularly as frequency increases. Understanding the loss components (and their loss mechanisms) and translating that into careful material parameterization and model set up can be crucial for obtaining reasonable simulated insertion loss results.

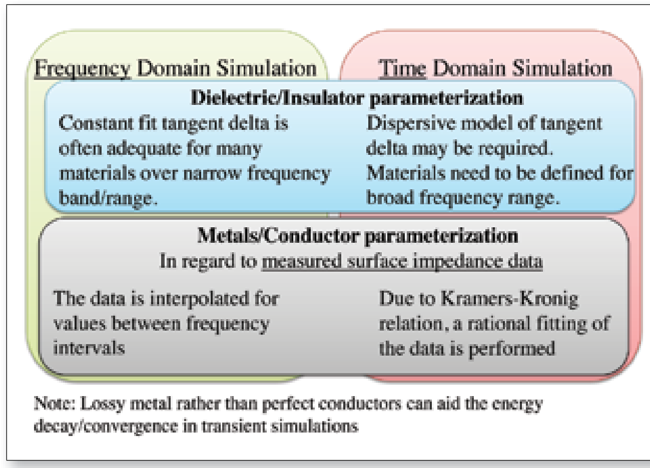


**FIGURE 2:** Overview of material parameterization with time and frequency solvers. Different solvers require different approaches to material parameterization.

## DIELECTRIC/SUBSTRATE

A dielectric is an electrical insulator that can be polarized by an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material as they do in a conductor, but only slightly shift from their average equilibrium positions causing dielectric polarization. When the value and direction of the field intensity E change, the dielectric polarization also varies in value and direction; during one cycle of an alternating field the polarization is established twice and disappears twice. The dominant polarizing mechanisms at microwave frequencies are electronic and atomic polarization: electronic polarization occurs in neutral atoms when an electric field displaces the nucleus with respect to the electrons that surround it, atomic polarization occurs when adjacent positive and negative ions "stretch" under an applied field. The relaxation time is a measure of the mobility of the dipoles that exist in the material. It is the time required for a displaced system aligned in an electric field to return to 1/e of its random equilibrium value (or the time required for dipoles to become oriented in an electric field). Constant collisions cause internal friction (the physical mechanism of loss in the dielectric material) so that the molecules turn slowly and exponentially approach the polarization orientation with the relaxation time constant. If the relaxation time is many times greater than the period of the alternation of the applied field, polarization is barely able to develop and the dielectric loss is very small. At low frequencies, where the relaxation time is considerably less than the time between peaks, the polarization follows the field and the dielectric loss is also small because the number of reorientations per unit time is small.

Since the polarization maximum does not occur simultaneously with the maximum of the field intensity, there is a phase shift between field intensity and polarization. Because of this there is also a phase difference between the field intensity and the electrical induction. The electrical induction vector lags behind the electrical field vector by a certain angle, which is known as the dielectric loss angle "tangent delta." The tangent delta value is the parameter that represents dielectric loss, it is given as the negative ratio between imaginary, epsilon, and real part, epsilon, of the complex permittivity.

For models that use frequency domain solvers, over a relatively narrow frequency band, the tangent delta value can be parameterized as "constant fit" if the tan delta over that frequency range is known and stable. In reality, no material exists that provides a broadband perfectly-constant tangent delta value. For broadband simulations or transient/time domain solvers (which will use a broad frequency band even if the frequency range if interest is narrow) the tan delta parameter often needs to be better parametized than constant fit; fast switching certainly involves a broadband spectrum.

For materials that exhibit a single relaxation time constant can be modeled by a first order Debye function/dispersion; an example is given by fig. 1.

For materials that exhibit two relaxations, e.g. both electronic and atomic polarization relaxation, a second order Debye dispersion can represent these by the summation of two separate first order dispersions.

If the tan delta of a material has been measured over a frequency range it can be entered as tabulated data, this is a good approach for complex materials such as FR4 [3]. More than one tangent delta value may be defined at different frequency points and the points in between interpolated. FR4 has substantial losses and the loss tangent is quite constant over a wide range of frequencies.

Materials can be complex with different features influenc-

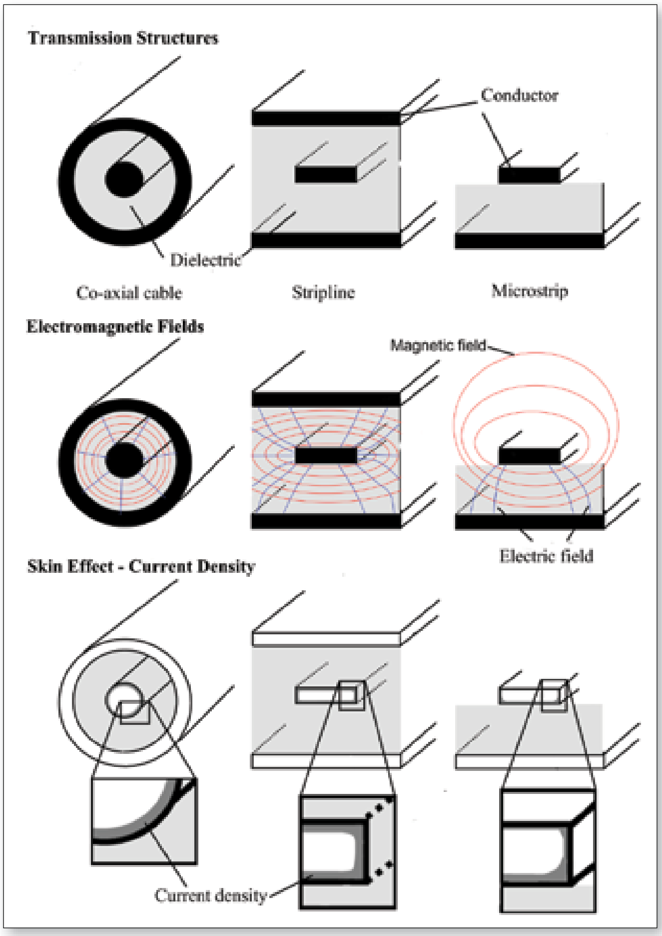


**FIGURE 3:** The distribution of the electric and magnetic fields, and the corresponding current density. The circuit structures are shown for comparison and are assumed to have similar conductivities, dielectric constants and operating at similar frequencies at similar scale.

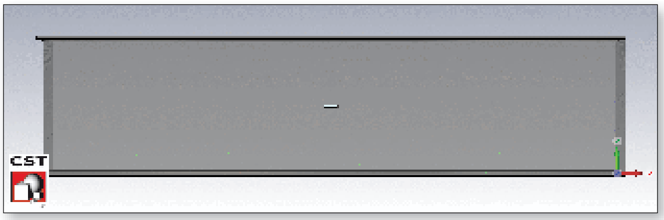


**FIGURE 4a:** Trace with rectangle cross section shape.


**FIGURE 4b:** Trace with almond cross section.

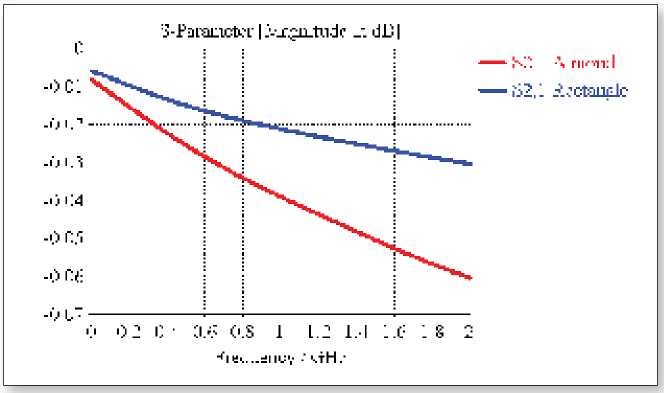


**FIGURE 5:** Insertion loss of almond shape trace and rectangle shape trace.

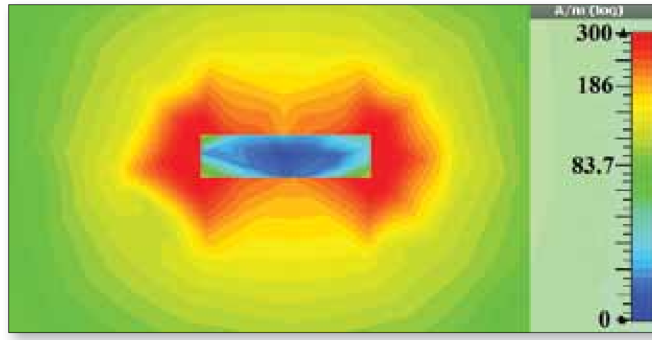


**FIGURE 6a:** H-field distribution across the rectangle trace cross section

ing the fields over different frequency ranges. It is possible to represent tangent delta with the help of other functions such as polynomials.

## CONDUCTOR/METALS - SURFACE IMPEDANCE MODELS

Surface impedance parameterization of metal materials relates the tangential electric and magnetic fields on surfaces of the signal trace. The effect of field inside the metal is described by equivalent currents on the surface of the signal trace. Highly conductive metals can be modeled in this way since the E and H fields only penetrate a small distance (the skin depth) inside the conductor. This approach simplifies the model by greatly reducing the number of mesh cells. The surface impedance representation of metals can be used accurately for many models but it does not capture certain geometries such as sharp corners, this is discussed later.

Tabulated surface impedance is given in form of a table with its resistance and reactance tabulated versus frequency. A frequency domain solver computes a linearly interpolated model across the given points. In a time/transient domain solver this table can correspond to "non-physical" or "non-causal" behavior. For example, due to uncertainty or measurement errors, the so called Kramers-Kronig relations could not be fulfilled. Therefore for the time domain simulation a rational fitting of the data will be performed, some material parameterization differences between time domain and frequency domain are given in fig.2. Tabulated surface impedance can also be generated to reflect the increased impact that surface roughness can impose on conductor loss.

## CONDUCTOR/METALS – GEOMETRY INFLUENCE ON CONDUCTOR LOSS

PCBs/packages are usually fabricated with silver, copper, and sometimes gold because all of these metals are highly conductive. The high conductivity of these materials does result in low conductor loss for the DC-kHz frequency region. At frequencies above the kHz region electromagnetic phenomena induce a skin effect that exacerbates the conductor loss component.

Skin effect is caused by alternating currents inducing magnetic fields internal to the conductor. The internal

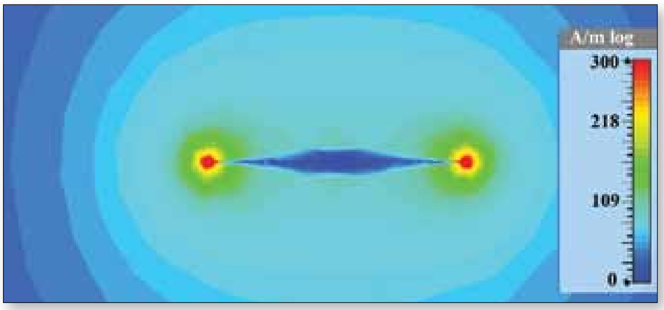


**FIGURE 6b:** H-field distribution across the almond trace cross section

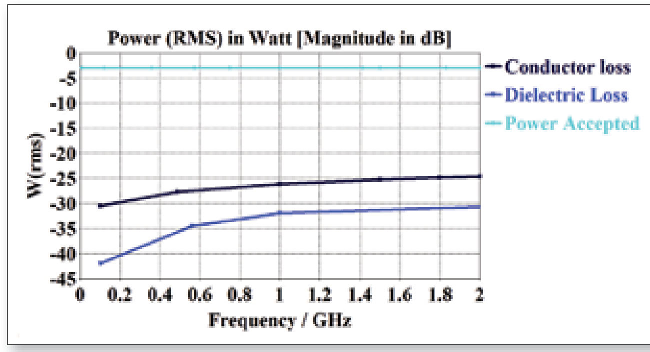


**FIGURE 7:** loss components of rectangular cross section stripline circuit. The radiative loss component in stripline structures is often small and assumed zero in this case.

magnetic field is in addition to the magnetic fields between the signal and ground plane conductors. These internal magnetic fields create induced current loops within the conductor. The current loops produce their own magnetic fields, which oppose the initial magnetic fields; this effectively pushes the current carrying electrons toward the surface of the conductor extremities.

There are many different structures that can be used to transmit high frequency signals. These include: coaxial cable, stripline, and microstrip. These structure have different cross section geometries and therefore, different loss results. In a coax cable topology at frequencies in the GHz region, the skin effect draws the current to the extremities of the center-conductor but since the center conductor is a cylinder, the current density is evenly distributed around the circumference. The stripline structure has the ground plane on both sides of the center conductor/trace. A stripline with rectangular cross-section causes the field, and therefore current density, distribution to be higher at the edges and sides, fig.3. The microstrip structure with its single ground plane causes the fields and current densities to be concentrated on the underside and lower edges of the trace.

The differences in cross-sectional area will lead to differences in conductor loss component. In particular, where the conductor area is limited such as at the corner, the current density increases, this is due to fringing fields [4]. The two current carrying conductors will exert a magnetic force on one another. The magnetic force/field loops around each conductor; therefore the orthogonal electric field is vertical underneath the current strip and horizontal at the edge - known as fringing field. The vertical and horizontal electric fields add; increasing the current density at the edge. It has been noted that a large amount of conductor loss can occur at the edges [5]. The mathematical solution states that current density increases at the conductor edge, becoming larger as the corner gets sharper [6].

The distributed magnetic and electric fields change as a function of frequency, which changes the current density distribution as a function of frequency. At frequencies close to DC the current density and resistance are evenly distributed across the conductor cross-section geometry. As the frequency increases the current distribution starts to change due to the changing electric and magnetic fields. The current density concentrates at the edges, fig.3; and this effect is often assumed to happen at a medium frequency in the order of 1-5 skin depths of the thickness of the conductor. The medium frequencies are also known as the transition frequency range. At medium and higher frequencies, where the conductor thickness is greater than five skin depths, the current density is assumed to be concentrated at the conductor surface of a skin depth. Both of these maco effects often need to be considered to accurately predict conductor loss[7].

Two stripline traces with the same cross section area, but different cross section shapes, were simulated and found to have significant differences in conductor loss. The stripline circuits have identical parameters: the dielectric is air so that dielectric loss can be neglected, ground-plane silver, they have the same length, and substrate height. One trace has a standard rectangular shape with a width of 0.1mm and height 0.025mm, fig. 4a, this is a common shape used for traces in simulations. The "almond" shape has a width of 0.2mm and height 0.025mm, fig. 4b; therefore, both shapes have a cross section area of 0.0025mm². The almond shape can be more true to some trace shapes for example thick-film print LTCC circuits.

Both stripline models were simulated in CST [8]. The trace was modeled as a normal material with 0.01 mesh cell size, resulting in1.3 million mesh cells for the rectangle trace model and 1.1million mesh cells for the almond trace model. The difference in transmission loss can be seen in fig.5. The rectangular trace has a smaller loss than the almond trace across the frequency band and this difference increases with increasing frequency. These stripline circuits were tested by Lim [9] and the almond trace loss was found to have 130% of the rectangular shape loss at 1GHz.

The H field plots in fig.6a-b, give an idea of the difference in current density between the two trace shapes. For both traces there is a concentration of H-field and therefore current density at the edges. There is a higher concentration of H-field/current density at the edges of the almond trace fig.6b, compared to the rectangular trace fig.6a.

Conductor loss is caused by the power dissipated due to the conducting surfaces of the line. The insertion loss of a microstrip line over a low-loss dielectric substrate at microwave frequencies is often dominated by the conductor loss.

In general, all of these loss components increase with frequency but at different rates. To separate these loss components from measured results is not a straightforward task but straightforward for simulation, fig.7. The losses are for a trace length of 10mm. The conductor loss is larger than the dielectric over this frequency range although the dielectric loss is increasing at a faster rate. The radiative loss component in stripline structures is often small and assumed zero in this case.

With all simulations, certain assumptions are made for each model. Often materials are considered defect free and homogeneous at a maco scale.

This is not always the case; further consideration to materials effects can be necessary depending on the material and process.

## CONCLUSIONS

Insertion losses can only be simulated accurately if all the loss components are accounted for. This often includes appropriate parameterization of the dielectric loss component (tangent delta) which depends on knowledge of the material characteristics and finding an adequate model to replicate the characteristic in the numerical computation. Different approaches to replicating the material characteristic are often required for different solver domains.

Signal trace shape can have a large influence over conductor loss and therefore impact total insertion loss. This is illustrated by two traces that have different conductor loss, even though these traces are identical apart from their cross-section shape. Conductor loss is often numerically calculated by a surface impedance method which does not capture geometry effects such as conductor contour/edge.

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# The Electromagnetic "Triple Threat" and the Critical Infrastructures Revisited

**DR. WILLIAM A. RADASKY**
Ph.D., P.E.
Metatech Corporation

## INTRODUCTION

**IN 2009** this author first used the term "triple threat" to describe three severe electromagnetic (EM) threats and the protection methods available to protect commercial installations from the high-altitude electromagnetic pulse (HEMP) produced from a nuclear detonation in space, the intentional electromagnetic pulse (IEMI) produced by electromagnetic weapons used by criminals and terrorists and from severe geomagnetic storms produced by solar activity [1]. This previous paper focused on the fact that while each of these three severe electromagnetic threats are low-probability events, their impacts could be so significant that some attention should be paid to protecting critical commercial assets.

As an aside, the term "triple threat" originally arose in the early 1900's with respect to American football players who could run, kick and throw the football. The term has been adapted to other sports and even to business where someone or something has the ability to produce three separate "capabilities". It may seem odd to apply this term in this context, but it turns out that these three electromagnetic threats, while being produced in completely different ways, can be protected against in similar fashions [1].

With regard to protection, it is well known that there are other day-to-day "problems" that can occur due to electromagnetic interference (EMI). Today we have the situation that there are more and more mobile emitters (e.g. cellular phones, tablets, etc.) and additional transmitters operating at higher frequencies such as: WIMAX, RFID, automobile radars, etc. In addition, each new design of computer equipment must consider some level of EMC immunity from these "new" everyday electromagnetic threats. As is well known in the EMC community, higher frequencies penetrate small seams (apertures) in equipment cases more easily, allowing higher levels of fields to reach circuit boards. While EMC board design has advanced over the years, it is necessary to reduce the level of EM fields that can reach a board to make protection solutions more manageable.

For these reasons this author believes that there is a need to consider electromagnetic protection at the building or room level against the high-frequency portion of HEMP and against IEMI, which can also have the benefit of reducing the threat of "everyday" EMI at the same time. In addition, if this type of protection is considered during the construction phase of a new building or addition, the added cost will be in the few percent range.

One of the most significant advances since 2009 with regard to this "triple threat" occurred on 14 January 2013 at a special seminar hosted by the Institution of Engineering and Technology (IET) in London. This seminar provided an opportunity for researchers in the UK to further their understanding of these threats after the recent enquiry by the House of Commons Defence Committee [3]. Dr. Anthony Wraight, an active member of IEC HPEM standardization activities in the UK, undertook the organization of this seminar, and it was successful in presenting a wide range of technical presentations relating to potential impacts and protection solutions. This paper will summarize the seminar and provides links for the readers to obtain additional information.

## THE SEMINAR PROGRAM

Title: Extreme Electromagnetics – The Triple Threat to the Infrastructures [2]

1. **Welcome and Introduction**
   *Dr. Anthony Wraight*
2. **Keynote Address:**
   **The Triple Threat to Critical Infrastructures**
   *Dr. William Radasky, Metatech*
3. **Space Weather - Nature's Electromagnetic Hazard**
   *Prof. Mike Hapgood, RAL Space*
4. **Geomagnetic Disturbances on the GB Transmission Network**
   *Dr. Andrew Richards, National Grid*
5. **Prediction of Extreme Geomagnetically Induced Currents in the UK high-voltage Network**
   *Dr. Ciarán Beggan, The British Geological Survey*
6. **A Survey of Advances in IEMI Source Research**
   *Prof. Edl Schamiloglu, University of New Mexico*
7. **Intentional EMI - Experiences from Research, Testing and Vulnerability Assessments in Sweden**
   *Dr Mats Bäckström, Saab AB and Royal Inst. of Technology (KTH)*
8. **Potential Implications of the Triple threat for Critical Infrastructures**
   *Colin Harper, QinetiQ*
9. **The STRUCTURES Project**
   **(Strategies for The impRovement of critical infrastrUCTUre Resilience to Electromagnetic attackS)**
   *Dr. John Dawson, University of York*
10. **Understanding and Managing the Risk and Resilience of Systems to EMP events**
    *Andy Titley, CMC and Dr James Kimmance, Parsons Brinckerhoff*

11. **Protection of Infrastructure from HEMP and IEMI disturbances through the Application of Standards**
*Dr. Richard Hoad, QinetiQ*

## DISCUSSION OF THE PRESENTATIONS

Dr. Anthony Wraight, the seminar organizer, introduced the purpose of the seminar and indicated that the talks were organized in logical blocks beginning with the description of the three electromagnetic threats. This was followed by 3 talks dealing with the threats of space weather and geomagnetic storms to the British high voltage power grid. The next two talks dealt with IEMI. Afterwards there were three talks dealing with implications of these electromagnetic threats and how to develop strategies for protection and resilience. The final talk of the day dealt with standards activities associated with these threats.

This author was privileged to be the keynote speaker to introduce the electromagnetic characteristics of the three threat environments in terms of how they are generated, their time waveforms, their frequency content and their respective areas of coverage. I also provided specific information on how each of the three electromagnetic threats could create wide-area power system blackouts and under some circumstances create damage to electric power system components, thus slowing the ability to recover from such an event. At the end of the talk, I mentioned that the mitigation concepts (including forecasting, protection, and recovery) for these threats are well known, although it is important to design any protection in a cost-effective manner. Standards have been developed in the IEC for HEMP and IEMI protection, and a later talk in the seminar discussed this in more detail.

Prof. Mike Hapgood from RAL Space presented an overview of space weather as it is initiated by the Sun, including several fascinating videos of recent solar eruptions. He also reviewed several historical examples of solar activity and their impacts on Earth; he felt that these events should lead us to a better understanding. He also made a strong point that the popular media is often not helpful to achieve understanding in that they often hype the possibilities from a solar event before the charged particles arrive at the Earth. While some earth-bound effects have occurred during recent solar events in this solar cycle, they have been relatively minor. This leads the public to think that the solar threat is "overblown". Unfortunately we know that severe storms have occurred in the past and will occur again someday. Prof. Hapgood made the point that in spite of difficulties with the popular media, it is important for the scientific community to accurately evaluate an arriving storm to provide situational awareness for the critical infrastructures.

Dr. Andrew Richards from the UK National Grid began his talk with a discussion of the different types of effects that could occur due to the "arrival" of a geomagnetic storm on the Earth. He then discussed the process of how the time varying geomagnetic fields couple to long high voltage power lines and may, under severe conditions, create problems in large transformers including: flux leakage, voltage instability, distorted a.c. waveforms, and potentially catastrophic damage. He also summarized the results of a geomagnetic storm study for the National Grid high voltage network, which includes over 1400 transformers. They classified the risk to each transformer by its design type, age and likelihood of observing a high level of Geomagnetically Induced Current (GIC) under different storm scenarios. He concluded his talk by summarizing their plans for both operational and engineering mitigation in the future.

Dr. Ciarán Beggan from The British Geological Survey spoke next with a presentation covering the generation of extreme Geomagnetically Induced Currents (GICs) in the UK high-voltage network, and the calculation of these events. He pointed out that the process of computing the electric fields in the Earth depends primarily on the dH/dt (horizontal component) and the local Earth conductivity. Their approach was to solve the problem in the frequency domain, which requires Fourier analysis of the time-dependent magnetic field fluctuations. The modeling of the UK power grid was described in terms of a preliminary model and a more recent detailed computational model. Using these models several extreme cases of possible future storms were considered from a probabilistic perspective. He also described the possible effects of the late-time (E3) portion of the HEMP, and concluded that due to its shorter pulse width, it was more likely to create a rapid power blackout instead of creating damage to many transformers.

The next set of talks dealt with IEMI, and Prof. Edl Schamiloglu spoke about advances in Intentional Electromagnetic Interference (IEMI) research. He surveyed narrowband sources, which produce high power microwaves (HPM) and could power IEMI weapons. He discussed the characteristics of different types of narrowband sources in terms of their peak power vs. their frequency of operation. In addition, he discussed the historical increase of peak power capability from these types of sources from 1940 to the present. The last portion of his talk was about more recent developments that have resulted in more compact sources, which are of concern with regard to the IEMI threat to commercial facilities.

Dr. Mats Bäckström next presented the background of the Intentional Electromagnetic Interference (IEMI) threat against the civilian infrastructures, including an overview of the comprehensive R&D on Intentional EMI that has been carried out within the Swedish defence community over the past 25 years. He spoke about both radiated and conducted threats including narrowband and wideband waveforms. In addition he discussed the problems of front door (e.g. antenna in-band) and back door (through unintentional paths) coupling interactions. He also reviewed some of the susceptibility studies performed in Sweden over the years to evaluate the performance of typical commercial electronics. In his concluding remarks he recommended that in the future the community should study the impacts of IEMI on complete systems, not only on particular pieces of equipment.

The next three talks covered the implications of these intense EM fields, and Mr. Colin Harper of QinetiQ began this discussion by describing how to evaluate the Triple threat against the functioning of modern societies. He reviewed some of the work performed by the US EMP Commission and several US Congressional Bills that have dealt with these severe EM threats, and he also discussed documented cases of IEMI attacks on commercial systems. He continued to mention the fact that the Smart Grid could present itself as an "easier target" for criminals due to the complex communications capability required for its operation. In the last part of his talk he indicated that several factors needed to be considered together including the technology capability of IEMI sources, their costs, and the types of effects that could result from their use. This information is needed in order to define the proper level of protection for each situation.

Dr. John Dawson from the University of York next gave a presentation covering a new EU project on Strategies for The impRovement of critical infrastrUCTUre Resilience to Electromagnetic attackS (STRUCTURES). This is a 3-year project that began in July 2012 and is to be completed by June 2015. The project has 12 partners and several end users participating. The project objectives are to: bring together existing research in IEMI; analyze risks to the critical infrastructures; evaluate protection and detection methods; produce guidelines for end users and policy makers, and interact with end users during the project.

Mr. Andrew Titley and Dr. James Kimmance from CMC and Parsons Brinckerhoff, respectively, presented their views of how to assess and manage severe risks to society. They pointed out that it is crucial to understand the nature, likelihood, consequences and uncertainties to perform a proper evaluation of the risks for a particular threat. They discussed the term, "emergent risks" which are different from those for which we can readily identify the frequency and consequence. The term "emerging" is used because these risks are related to new technologies and new dependencies on society. These emerging risks are also characterized by the absence of data or statistics, creating a difficulty in estimating the frequency and magnitudes of the consequences if they occur. In addition they discussed the important role of uncertainty and how it can affect our ability to evaluate the risks. The remainder of their talk covered how to put the various triple threats into the proper context for the evaluation of risk.

Dr. Richard Hoad of QinetiQ provided the last presentation of the day covering the standardization work accomplished in several international standards organizations. The largest number of standards covering the threat waveforms associated with HEMP and IEMI, their effects on equipment and systems, test methods to evaluate hardness or vulnerability, and protection methods have been prepared by the International Electrotechnical Commission (IEC) in Geneva. Dr. Hoad is the Secretary of IEC SC 77C, which has developed these standards. In addition, he mentioned the work of ITU-T in terms of developing protection standards for telecommunications facilities against the threats of HEMP and IEMI and also the work of Cigré to evaluate the threat of IEMI against the control electronics in high voltage power stations. It was emphasized that the electromagnetics community knows how to design protection against these extreme electromagnetic threats, but it is necessary to evaluate the requirements and levels of protection required.

## CONCLUSIONS

It is important to note that while the subject of the electromagnetic triple threat has been discussed for many years, this one-day seminar in London was successful in updating the work underway in the UK and several other countries in a technical fashion. It is hoped that those who have interest will download and read the presentations to further their understanding (go first to the link referenced below in [2]). This author hopes that this type of seminar can be repeated in the future to gauge the progress being made regarding this important problem.

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# Spectrum Supportability Risk Assessments

## Critical to DoD Program Milestone Approval!

**BRIAN FARMER**
President, EMC Management

### THE PROBLEM

**EARLY CONSIDERATION** of spectrum supportability in spectrum dependent (S-D) system acquisitions is a fundamental criterion that must be satisfied before the DoD develops and fields communications-electronics (CE) equipment and related weapons systems. Development or acquisition of systems that meet operational requirements, but fail to obtain spectrum supportability, means those systems will not be allowed to operate in the United States or in host nations. These systems create a potential for severe mutual interference between themselves and other spectrum users, squander resources, and delay fielding warfighting capabilities to field units.

"Spectrum Supportability" is defined as the assessment as to whether the electromagnetic spectrum necessary to support equipment is available for use by the system. The assessment requires, at a minimum, receipt of equipment spectrum certification, reasonable assurance of the availability of sufficient frequencies for operation from host nations, and a consideration of Electro-Magnetic Compatibility (EMC). Guidance for these requirements is found in DoDI 4650.01.

The Department of Defense has complementary policy instructions that provide additional assurance that spectrum supportability can be achieved. The interrelationship between Spectrum Supportability and E3 is depicted in the figure below. The primary overlap occurs during the mutual concern for achieving Electromagnetic Compatibility (EMC) and preventing EMI for S-D systems and equipment.

It's important to understand the critical nature of spectrum supportability and why DoD procurement offices must include this in any system planning involving radio frequency

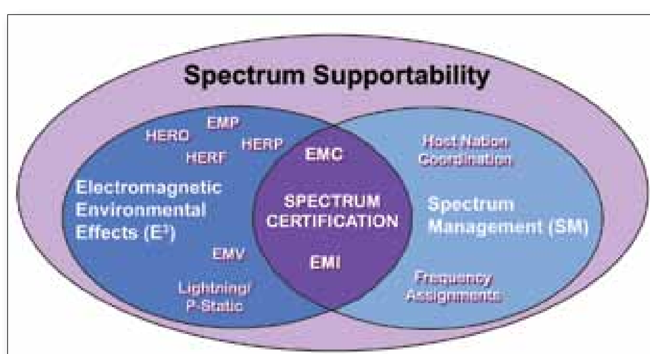
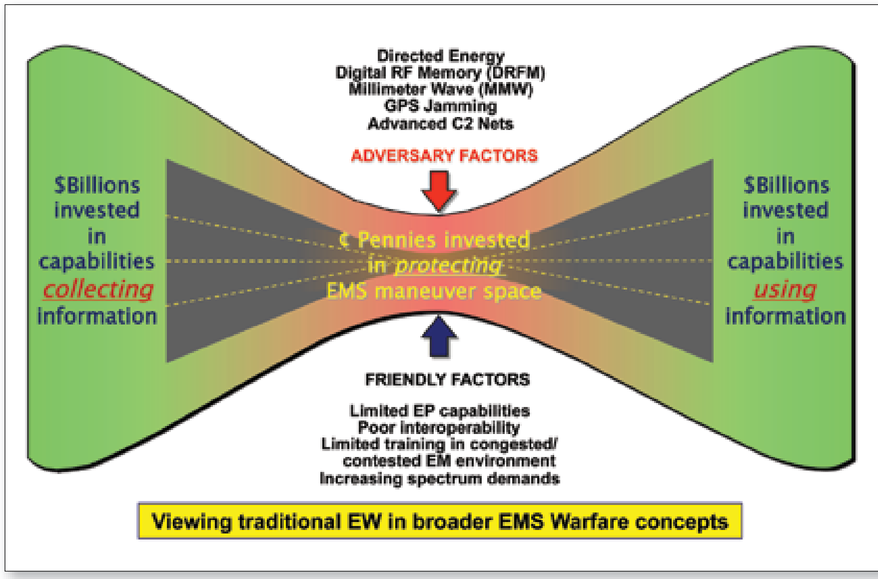



**FIGURE 1:** Spectrum Supportability and Electromagnetic Environmental Effects Overlap

(RF) transmission, reception, or control.

The other challenge we face, and another reason why it is so important to manage this resource is because we are constantly faced with competing users of our spectrum that want us to give up the spectrum we are using. Commercial factors, increased spectrum use by the military and even such things as directed energy weapons and GPS jamming contribute to an increasing pressure on military use of the EM spectrum. Nearly every operational capability and mission requirement demands spectrum use for collecting and distributing information of all kinds, in systems such as ISR assets and platforms and used in all domains – space, air, ground, maritime and even cyberspace. Countless billions of dollars have been invested in those capabilities. Likewise, billions of dollars have been invested in capabilities that ***use*** information, i.e. warfighting platforms across all those same domains. The electromagnetic spectrum provides the pipeline that affords mobility to that information is being squeezed and squeezed hard. The net result is an increasing restriction on the expected free flow of information through this pipeline down to a trickle, due to relative pennies on the dollar having been invested in ***protecting*** this EMS "maneuver space."




- Adversary factors listed represent technologies and methodologies that our enemies are developing, producing and using to deny us access to our information
- Friendly factors include limited electronic protection efforts, inadequate interoperability and cooperation, training restrictions in a denied EM environment, and increasing spectrum demands that are limiting available bandwidth

Spectrum access is fundamental to all DoD missions. On-demand access to the spectrum and electromagnetically compatible operations in the EM environment cannot be assumed. The first step is to realize that you need to plan and engineer this into your system or capability. Then you must make sure you have the resources on hand to deal with this. In the end, getting the experts involved early will save you money, time, and aggravation. There are many examples of how the failure to properly address spectrum supportability during the design, test and production processes have caused program impacts in the areas of schedules, missed Milestones, significant financial issues, and/or a system that was produced with significant operational constraints on its use.

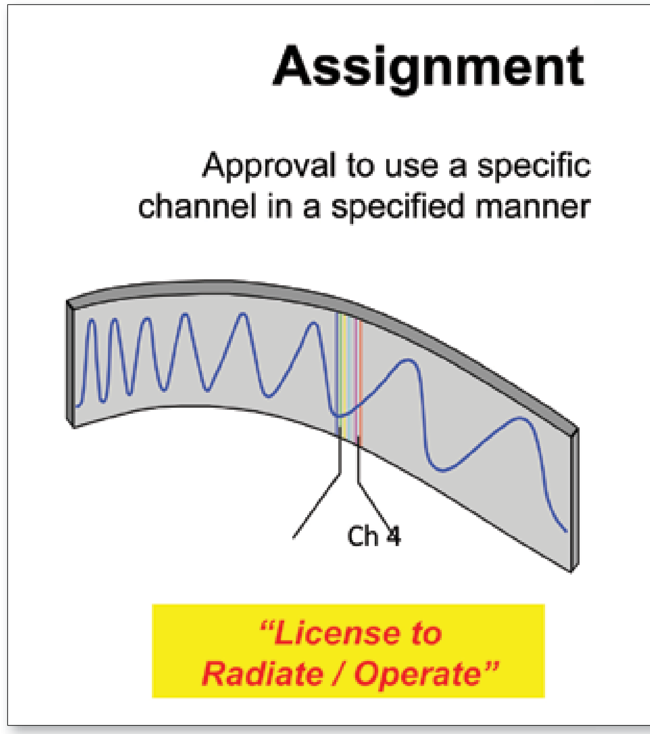
In the acquisition process, spectrum management usually begins with equipment spectrum certification, a process whereby a system is approved to operate in a particular spectral band. To actually operate the system, spectrum certification must be followed by obtaining a frequency assignment. Obtaining frequencies to operate equipment in the U.S. is a two-step process which is managed by the submittal of a properly filled out DD Form 1494. The first step is Equipment Spectrum Certification. The certification process assesses equipment transmit and receive characteristics to determine if it complies with existing RF spectrum regulations. The second step, Frequency Assignment, coordinates operational use of specific frequencies within specific bands among current users so that they do not interfere with each other. The Manual of Regulations and Procedures for Radio Frequency Management, issued by NTIA, is the standard for both steps. The NTIA is the regulatory authority over all federal equipment and spectrum in the US&P. The Federal Communications Commission (FCC) regulates non-federal spectrum in the US&P.

The DD Form 1494, a document that captures an exhaustive variety of technical data, serves two functions:

**1.** Provides a uniform method to capture the basic spectrum-dependent and operational parameters of military spectrum-dependent systems in a format that can be easily provided to US National and host nation spectrum authorities

**2.** Standardizes the format of the technical data required to be inserted into DoD and national databases to generate frequency assignment approvals enabling initial EMC analyses, and checks for compliance to military, US national, and host nation spectrum standards. System developers will complete and obtain approval for a DD Form 1494 during each phase of the acquisition process for each newly developed spectrum-dependent system.

In addition to the Frequency Allocation and Frequency Assignment processes, DoDI 4650.01 now requires the conduct of a Spectrum Supportability Risk Assessment for the


procurement of all spectrum dependent systems, including COTS. SSRAs will be required of programs at milestone reviews A, B and C as part of the overall balance of program success against future risks. A PM's failure to obtain spectrum supportability for components in its systems has direct consequences to the program in meeting performance, schedule and cost objectives established by its Acquisition Review Board and to the Combatant Commander in meeting Joint Mission Area requirements.

The Risk Management Guide (RMG) for DOD Acquisition defines ***Risk*** as a measure of the potential inability to achieve overall program objectives within defined cost, schedule, and performance/technical constraints and has two components: (1) the probability/likelihood of failing to achieve a particular outcome, and (2) the consequences/impacts of failing to achieve that outcome.

So just what is an SSRA?

It is an evaluation performed by DoD Components of all *S-D systems* to identify and assess *EM spectrum* and *Electromagnetic Environmental Effect (E3)* issues that can affect the required operational performance of the overall system based on the mission needs defined by the combat developer and/or Joint Staff in the ICD, CDD, and CPD.

The purpose of the spectrum supportability risk assessment is to identify and assess regulatory, technical, and operational spectrum issues with the potential to affect the required operational performance of the candidate system. For example, in addition to determining that a system's bandwidth requirement complies with an individual nation's frequency allocation scheme, a new or modified system must also be evaluated with respect to:

- The system's potential to cause interference to or suffer from other military and civilian RF systems currently in use or planned for operational environments.
- The effect of the system's proposed spectrum use on the ability of the extant force structure to access the RF spectrum without interference.
- How the system's spectrum use conforms to the tables of frequency allocation of intended host nations, ensuring regulatory protection from other national co-band spectrum users.
- If individual host-nation frequency allocations include enough bandwidth to fully support the system's operational mission, for example, required data rate.

A Spectrum Supportability Risk Assessment provides a formally documented SS risk assessment, with mitigation measure(s) identified, to achieve a SS Determination from the FMO, CIO, or OSD(NII) (depending on ACAT and/or level of Interest)

An SSRA should include the following components:

- **Regulatory component:** Addressing the compliance of the RF system with US national and international tables of frequency allocation as well as with regulatory agreements reached at the International Telecommunication Union.
- **Technical component:** Quantifying the mutual interactions between a candidate system and other co-band, adjacent band, and harmonically related RF systems, including the identification of suggested methods to mitigate the effects of possible mutual interference.
- **Operational component:** Identifying and quantifying

| DAS Phase | Materiel Solution Analysis | Technology Development | Engineering & Mfg Development | Production & Deployment | Operations & Support |
|---|---|---|---|---|---|
| SSRA | Prepare SSRA | Prepare/Update SSRA | Prepare/Update SSRA | Prepare/Update SSRA | Prepare/Update SSRA for specific missions, new HN deployments, system mods, etc |
| PMs/MATDEVs E3 Tasks<br><br>(See DoDD 3222.3 (Reference (d)), MIL-HDBK-237 (Reference (e)) and MIL-HDBK-235-1C (Reference (f)) and its supplemental parts for guidance) | Perform E3 Assessment for SSRA<br><br>Define EME<br><br>Budget for E3<br><br>E3 Rqmts Definition | Prepare/Update E3 Assessments for SSRA<br><br>Define/Update EME<br><br>Prepare E3 inputs to ISP<br><br>Address E3 in TEMP and Acquisition Documents | Prepare/Update E3 Assessments for SSRA<br><br>Update E3 inputs to TEMP and ISP<br><br>Establish E3 IPT<br><br>Perform E3 DT&E & Analyses<br><br>Define/Test Mitigation Measures<br><br>Define/Update EME | Prepare/Update E3 Assessments for SSRA<br><br>Finalize E3 Requirements for Production Spec and TEMP<br><br>Perform Full E3 Testing<br><br>E3 Assessment Report | Interference Resolution<br><br>Deployed Support |
| PMs/MATDEVs Additional Spectrum Responsibilities<br><br>(See References (a) and (c) and Service pubs for guidance.) | Stage 1 ESC (Conceptual)<br><br>Ensure that the Solution Analysis identifies op parameters for defining spectrum parameters.<br><br>Define initial spectrum requirements, frequency bands, and operational areas.<br><br>Initiate discussions with appropriate SMO. | Stage 2 ESC (Experimental)<br><br>Refine spectrum requirements.<br><br>Continue spectrum discussions with SMO to support ESC and HNC.<br><br>Consider obtaining HN comments through appropriate SMO. | Stage 3 ESC (Developmental)<br><br>Perform detailed spectrum emission, receiver degradation and antenna tests.<br><br>Request frequencies needed for US&P testing.<br><br>Continue spectrum discussions with SMO to support ESC and HNC and request processing. | Stage 4 ESC (Operational)<br><br>Request HNC through appropriate SMO | Stage 4 (Note to Holder)<br><br>Maintain awareness of impact of Nat'l and int'l spectrum access.<br><br>Request training frequency approvals.<br><br>Coordinate Homeland Defense spectrum requirements. |

**FIGURE 2:** E3 and Spectrum Supportability Tasks During the Acquisition Cycle.

the mutual interactions among the candidate system and other US military RF systems in the operational environment and identifying suggested methods to mitigate for possible instances of interference.

- **E3 Assessment for the SSRA:** DoD Components developing or acquiring S-D systems, including CI and NDI, are required to perform limited E3 assessments as part of the SSRA; as a minimum, EMC and EMI are to be addressed to determine the potential for interactions between the proposed system and its anticipated operational EME

When conducting an SSRA, operational restrictions, availability of frequencies, host nation approval (HNA), and known incidents of electromagnetic interference (EMI) must be considered. S-D systems and equipment cannot be operated legally until they have been granted equipment spectrum certification (ESC) by National and DoD authorities; in addition, a frequency assignment must be obtained from the appropriate area frequency manager. For systems that will operate outside the United States & Possessions, an HNA also is requested prior to operation in each foreign country designated for use.

Additionally, the program must be monitored to determine the EMC and EMI impact of any changes to such operational RF parameters such as tuning range, emission characteristics, antenna gain and height, bandwidth, or output power, etc. Changes to these parameters may require additional E3 analyses or tests. The E3 Assessment should:

- Identify and resolve co-site EMI issues during system acceptance testing.
- Demonstrate repeatable EMC utilizing appropriate development models.
- Maintain system E3 design integrity during operations.
- Implement procedures for EMI problem reporting.

The SSRA will include details of the following, for each piece of S-D system:

– Status of approved 1494s (or J/F 12's )
– Status of Host Nation Coordination via the COCOMs
– Provide/discuss known SS and E3 issues and assigns RISK
– Discuss potential operational impact of known SS and E3 deficiencies
– Provide program risk (R/Y/G) for each system, a risk summary, and mitigation plans to reduce or eliminate YELLOW and RED issues
– Provide an overall, Program assessment for upcoming acquisition Milestones

- Minimum E3 requirements:
  - Determine the potential for EMC and EMI interactions between the proposed system and other systems, and with the anticipated operational EME.
  - Include an EMV analysis to determine the possible effect on operational performance as a result of any EM interaction.

Available expertise and the existence of service E3/SS related organizations notwithstanding, it is widely known in the DoD Spectrum Management community that program offices, for a variety of reasons, including a lack of understanding of the requirements and their importance, frequently avoid spectrum supportability considerations early in program or take them on belatedly at the expense

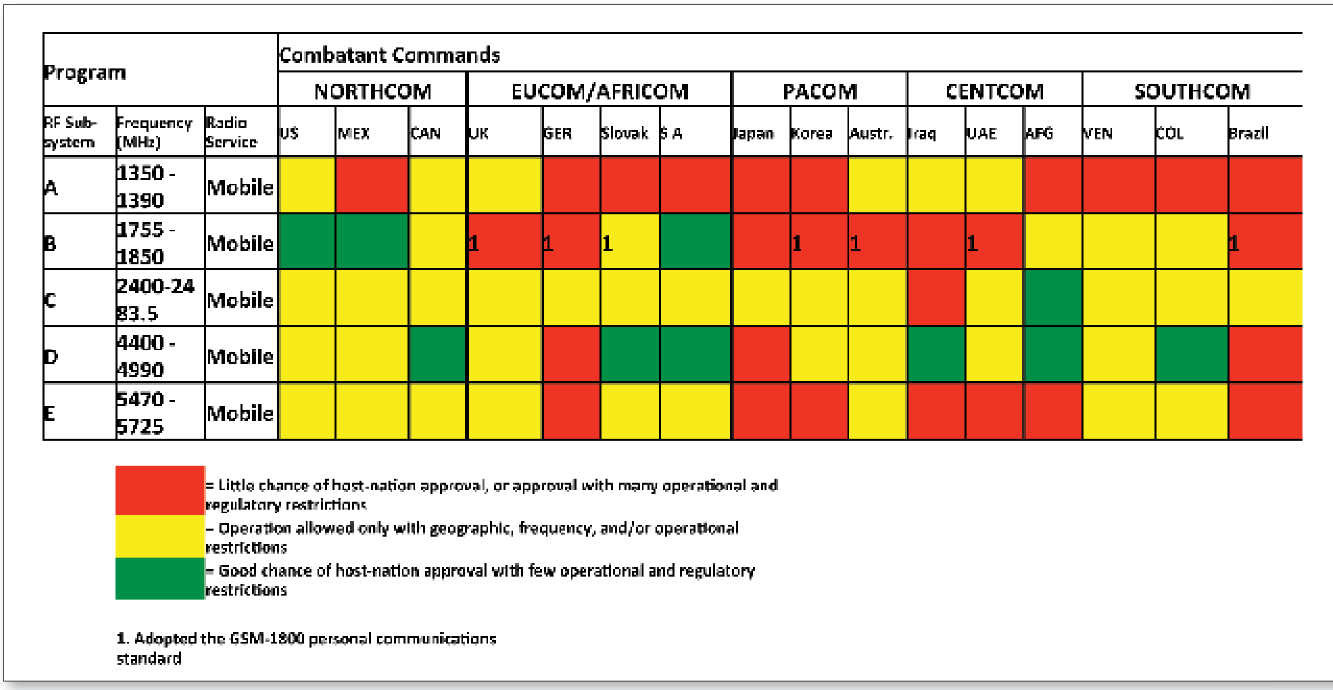



**FIGURE 3:** Example Regulatory Assessment Stoplight Chart.

of cost, schedule and operational capability. The General Accounting Office has documented a variety of issues related to the implementation of spectrum management issues in DoD acquisition systems over the years.

So what are the obstacles that keep program offices and acquisition personnel from complying with federal laws and DoD directives on RF spectrum use and instituting good engineering practices on control of electromagnetic environmental effects (E3)? Volumes have been written on the need to comply with the spectrum regulations but the list of infractions continues as does the list of radio interference issues, both during acquisition and operationally. Current requirements and methods for assuring that systems have spectrum access and electromagnetic compatibility are scattered among a variety of DoD Directives, Instructions, MIL-STDs and Handbooks; and they can be poorly defined with approval processes that are hard to understand, slow, subjective and inconsistent. These volumes of requirements documents, which currently define the processes for obtaining spectrum access, acquiring authorized frequencies and controlling E3, have created complexities that can inhibit successful implementation by program managers. Some of the requirements are technically daunting on the surface, yet technical experts are available within every military department to help as necessary.

## THE BASIC SOLUTION

- The good news is that there's lots of guidance
- The bad news is that there's lots of guidance

In addition to documenting the requirement for SSRAs, DoDI 4650.01 also provides a great deal of guidance, in the form of suggested tasks, for the program offices to follow. Unfortunately, it doesn't provide a specific approach to integrating the tasks into an overall SSRA product. However, subject matter experts from the three services have developed more detailed guidance and well as acceptable document format and content guidance. Some current suggested guidance for Program Offices, Acquisition Managers, and system developers to follow include:

**(1)** Determine the spectrum required to support the mission and define the intended EME in which the system will operate.
**(2)** Ensure E3 control and SS requirements are addressed in JCIDS and defense acquisition system documentation.
**(3)** Apply interface standards such as MIL-STD-461 and MIL-STD-464 to ensure that the system and its subsystems and equipment are built to operate compatibly in the mission EME.
**(4)** Define E3/SS test objectives in the Test and Evaluation Master Plan (TEMP) and allocate sufficient resources to conduct test objectives.
**(5)** Verify and document SS and E3 control issues during developmental and operational test and evaluation.
**(6)** Conduct early E3 and SS operational assessments that consider the intended mission including single Service, Joint, and international deployments.
**(7)** Provide E3 assessments during operational test readiness reviews. Report the operational impact, system limitations, and vulnerabilities from unresolved E3 and SS problems.

Ideally, an initial spectrum supportability assessment is generated in the first phase of the DoD acquisition process. Early identification of major regulatory and technical issues allows program management personnel to focus attention and resources on critical spectrum issues in the remaining acquisition phases. The SSRA's author uses inputs from several sources:

- Technical and regulatory information is obtained from DoD data bases, specifically the:
  - System Certification System (SCS) data base is used to generate lists of co-band and adjacent band DoD emitters, providing an overview of other systems sharing expected electromagnetic environments.
  - Host Nation Spectrum Worldwide Database Online (HNSWDO) data base is used to identify host nation comments on previous systems in the same frequency band and with similar technical parameters as the system being acquired.
  - US and non-US tables of allocation, which can be obtained in many cases directly from the internet.
- The latest pertinent Host Nation supportability comments are obtained by the Program Office from the Combatant Command (COCOM) spectrum managers. The COCOM spectrum managers will forward any resulting comments to the authors of the SSRA.
- The PMO defines the system's technical parameters and intended operational deployment required for spectrum support, e.g. the frequency bands of interest and the intended worldwide development, test and operational areas and host nations.

Coordination with the cognizant MILDEP FMO is a fundamental key to a successful SSRA. The MILDEP FMO should be made aware of initial activities and be kept informed of major SSA developments. The PMO should provide the SSRA's authors with copies of any DD Form 1494s sent to the MILDEP FMO. The national and host-nation comments resulting from previous J/F 12's submissions should be reviewed to see what comments may have been provided on earlier versions of the system.

The results from the regulatory portion of an SSA can be summarized for senior leadership as a "stoplight chart" where the colors of each box are an indication of the possibility of a system obtaining spectrum supportability in the US and selected host nations. In the example below, reading the rows indicates that the frequency band used by at least four of the program's sub-systems will have major spectrum issues in many of the intended host nations. Looking at the columns indicates the possibility of obtaining spectrum support for specific systems in specific host nations.

The colors result from a careful comparison of the radio service of each RF system with the technical and regulatory information contained in the databases and the host-nation tables of allocation.

Likewise, the results of the Technical and Operational analyses previously discussed, will constitute additional input into an overall risk assessment. The technical component would focus on the RF engineering related risks associated with possible mutual interference with other systems in the same band and the operational would focus on the risks of possible mutual interference within its intended operational environment.

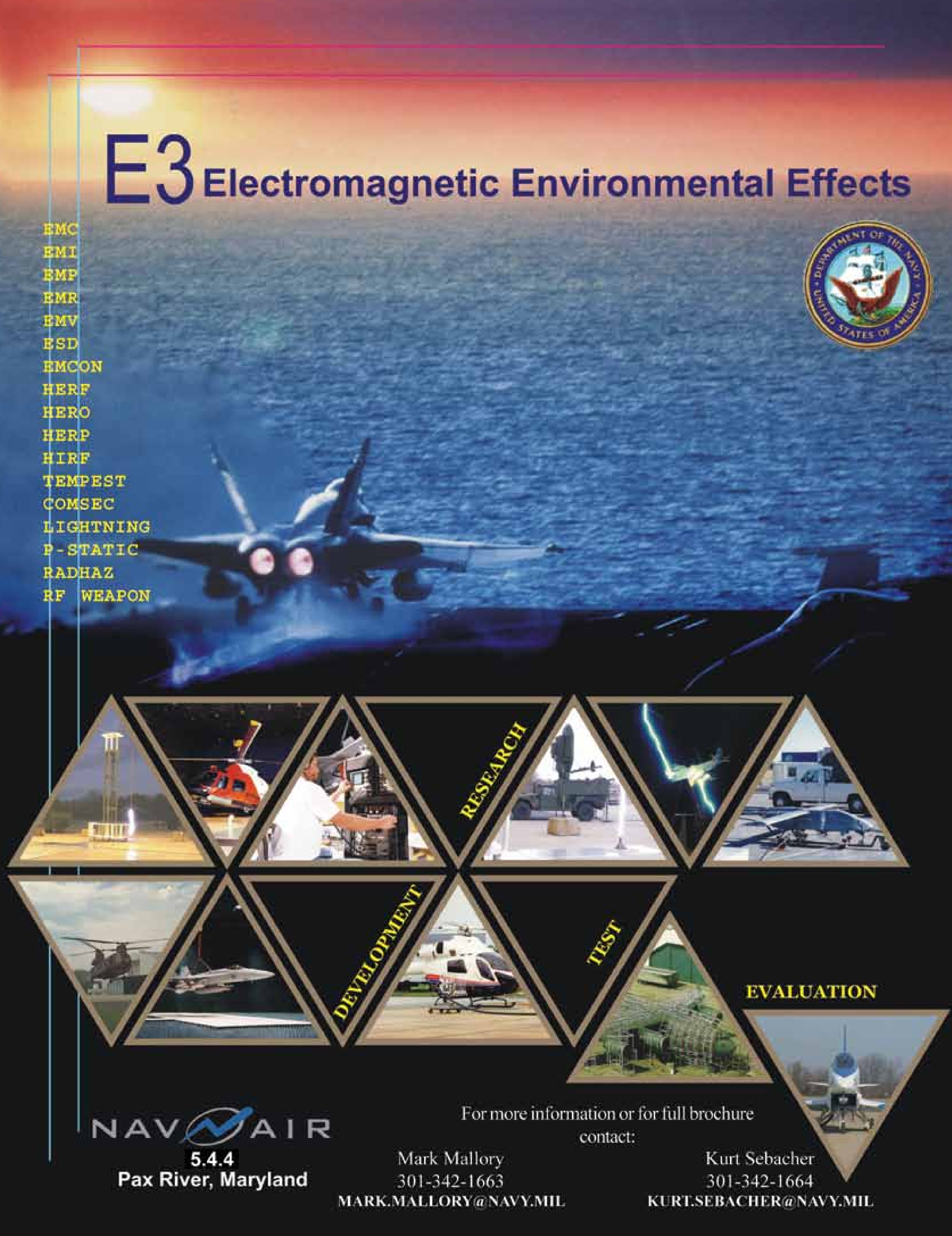
The major result of the SSRA may be that the PMO considers options such as: changing the system's spectrum use or other technical parameters or beginning consultations with the cognizant FMO regarding possible courses of action. Typical courses of action include coordinating bi-lateral negotiations with individual host-nations or briefing the spectrum requirements of the system to spectrum for a such as the NATO Frequency Management Sub-Committee (FMSC), the DoD spectrum Summit or various COCOM spectrum conferences. All PMO involvement with these groups must be closely coordinated with the cognizant MILDEP frequency management office and DoD representative.

***Now What?***

Hopefully, you realize that Spectrum Supportability is not something that can be assumed; spectrum demand is increasing and available spectrum is decreasing. The requirement to perform and submit SSRAs is part of the DoD effort to ensure that we don't continue to field systems with spectrum and/or interference problems. From the list of suggested tasks noted in DoDI 4650.01, you will also realize that producing a meaningful SSRA is a significant engineering undertaking, not a task for the faint of heart. An understanding of the entire gamut of required information, the sources and availability of that information and the technical ability to collate, analyze and present the data, requires a specialized expertise and particular experience. And as a relatively new requirement, knowledgeable, experienced help in producing and reviewing SSRAs can be hard to find.

You must – MUST – apply due diligence to Spectrum Supportability considerations

– It is a critical tenet for program success
– It requires application of resources and knowledgeable people
– You should apply Spectrum Supportability resources early and "Up-Front" in a program life cycle
– It will **save** you potentially **BIG $'s** in the end



E3 Electromagnetic Environmental Effects
EMC
EMI
EMP
EMR
EMV
ESD
EMCON
HERF
HERO
HERP
HIRF
TEMPEST
COMSEC
LIGHTNING
P-STATIC
RADHAZ
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301-342-1663
MARK.MALLORY@NAVY.MIL
Kurt Sebacher
301-342-1664
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# Filter Capacitor Selection Criteria for Linear Voltage Regulator Applications.

**STEVE WEIR**
MTS
X2Y ATTENUATORS, LLC

## ABSTRACT

**WHILE VOLTAGE** regulator vendors often suggest generic filter capacitors for use with their devices, these recommendations are often both vague and fail to take into account the effects of the larger PDN bypass network on VRM response.

## FILTER CAPACITOR NETWORKS

Figure 1 depicts a generic PDN conceptual model.

Moving from left to right we have: The the switching power stage for SMPS VRMs, the effective transfer function impedance of the VRM, bulk and bypass filter capacitor branches, series interconnect inductances, and finally a mounted IC load which may have its own internal capacitors.

PDN filter optimization consists of:

- Buying only the number of capacitors needed for high frequency performance.
- Buying only the number of Farads needed for low frequency performance.
- Inserting frequency compensation as needed for stable response.

PDN designs may be classified as tightly or loosely coupled through the effective frequency range of the VRM bulk capacitors. Tightly coupled designs are those where the interconnect impedance is small compared to the parallel equivalent impedance of the high frequency capacitors through the upper frequency response of the VRM. For most linear regulators the frequency limit is less than 1MHz. Most PCB PDNs particularly those with linear regulators are tightly coupled.

In tightly coupled designs, the distributed bypass network directly loads the VRM within the VRM's closed loop response. The distributed high frequency capacitors provide capacitance that need not be duplicated by bulk capacitors, but also must be accounted for in the VRM error response.

Because the high frequency performance of the PDN constrains the quantity and value of most of the capacitors, VRM filter design actually begins by designing the high frequency network first. This network is then fitted to the VRM requirements.

All VRMs are at their heart feedback control systems. The PCB PDN and ICs load the output amplifier altering the closed-loop transfer function. The primary concern is to realize an unconditionally stable response that accounts for the high frequency bypass network, and any large in-package IC capacitance.

An unfortunate reality is that most linear

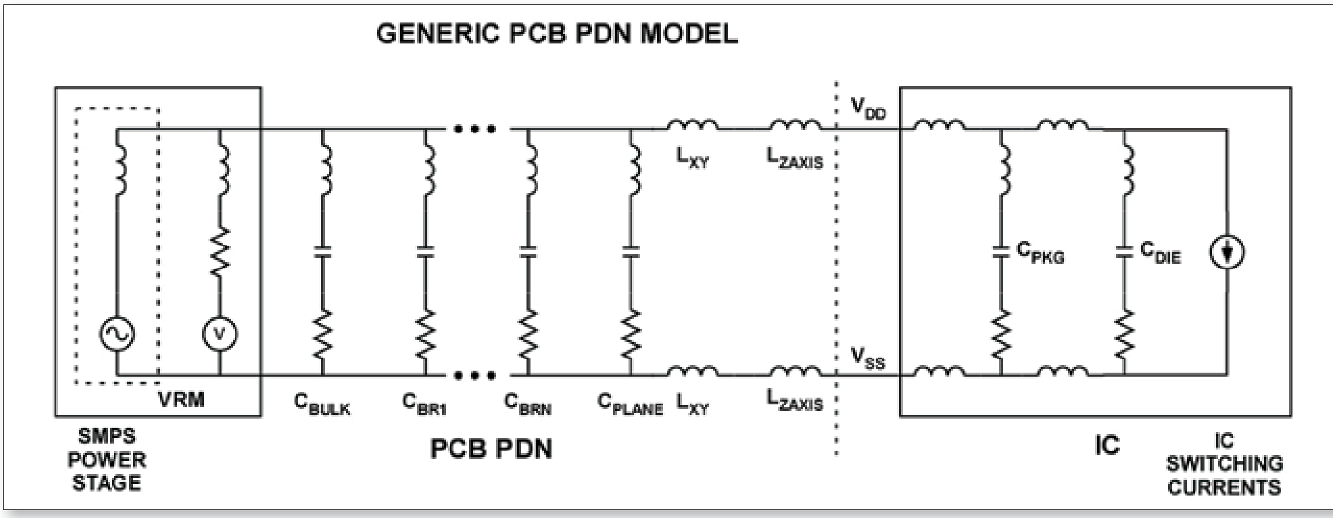


**FIGURE 1:** Generic PDN Model.

regulator data sheets and application notes fail to numerically specify acceptable filter capacitor parameters. In many cases vendors only vaguely recommend generic capacitor types such as tantalum or aluminum electrolytic capacitors. Other times, vendors may state that their products are tolerant of low-ESR MLCC capacitors without much further elaboration.

The following design procedure gets around this ambiguity by characterizing the VRM in simulation.

## DESIGN PROCEDURE

**1.** Add together the total PDN load capacitance as the parallel equivalent of all high frequency capacitors on the rail as well

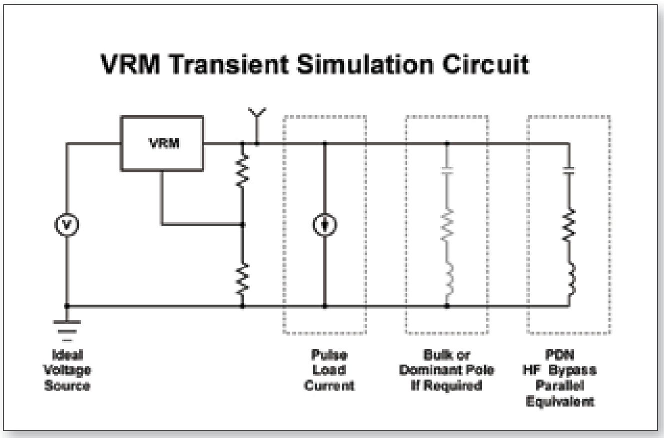


**FIGURE 2:** VRM Transient Simulation Set-up.

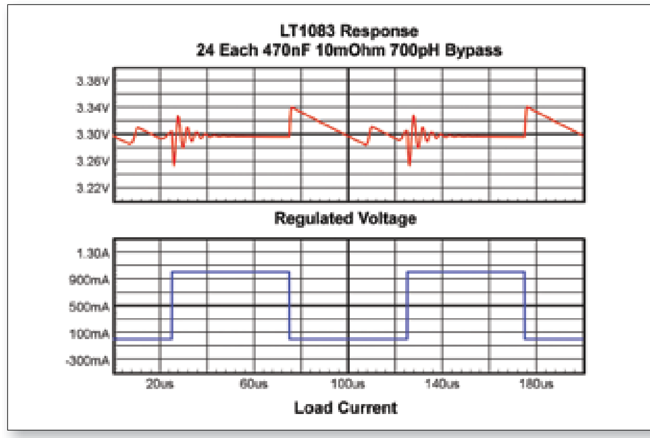


**FIGURE 3:** Initial PDN Transient Response.

as any large IC in-package capacitance on the rail as $C_{PDN}$.
**2.** Determine the initial bulk filter capacitance: $C_{BULK\_INITIAL}$ as the difference between the VRM manufacturer's recommended bulk capacitance and $C_{PDN}$.
**3.** Select an MLCC, or where necessary for capacitance parallel MLCC capacitors that together equal or exceed $C_{BULK\_INITIAL}$.
**4.** Perform transient simulation loading the VRM with the PDN network in parallel with $C_{BULK\_INITIAL}$.
**5.** If the transient simulations show less than 1.5 cycles ringing, the design is stable. In cases where $C_{BULK\_INITIAL}$ is costly as an MLCC, select a lower cost electrolytic capacitor as a substitute and resimulate. Otherwise, the MLCC form of $C_{BULK\_INITIAL}$ is the final design choice.

If the transient simulations show more than 1.5 cycles ringing a dominant pole with ESR is required. The next task is to


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determine the pole values, and on that basis select a final bulk filter capacitor value.

## DOMINANT POLE COMPENSATOR SYNTHESIS

**1.** Replace $C_{BULK\_INITIAL}$ with an ideal capacitor $C_{DP}$, and an ideal series resistor $R_{DP}$.
**2.** Set $C_{DP}$ to the smallest E3 value larger than 2*$C_{PDN}$.
**3.** Set $R_{DP}$ initially to 1mOhm.
**4.** Interatively, repeat the transient simulation increasing the value of $R_{DP}$ by 1.4x steps until the transient ringing settles within 1.5 cycles.
**5.** Select a suitable capacitor with a minimum ESR at least equal to $R_{DP}$ and no more than 4x $R_{DP}$. Alternatively, a discrete resistor in the same range can be inserted in series with MLCC capacitor(s).
**6.** Simulate the final selection.

## TRANSIENT SIMULATION SET-UP

The transient simulation can be performed in any SPICE variant, including the free LT SPICE Linear Technology, or WebBench offered by TI / National.

The simulation evaluates load transient stability. It supplies the VRM from an ideal voltage source. A pulsed current source loads the VRM. Pulse width should be set to approximately match the VRM manufacturer's data sheet test waveforms. However, pulse widths of 50us repeating at 100us are almost always adequate. Rise and fall times should be no more than: 1/(10 $F_{0dB}$ ), where $F_{0dB}$ is the 0dB intercept for VRM load response if specified, or VRM line rejection if load response is not specified. 100ns is generally adequate for all but the highest bandwidth linear regulators.

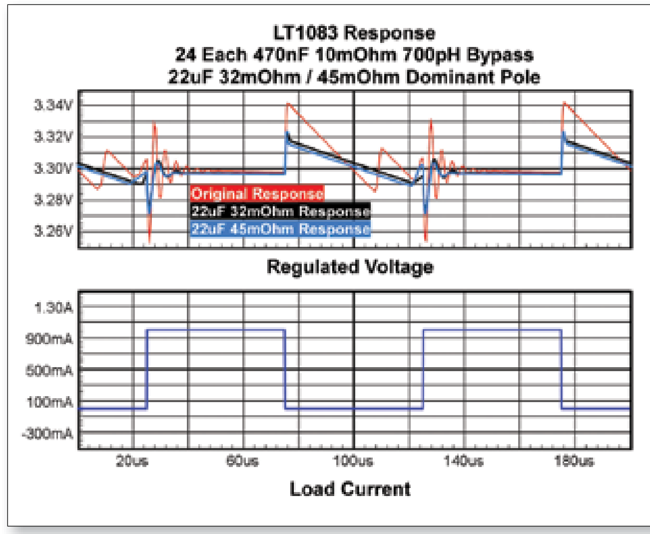


**FIGURE 4:** Compensated Responses.

## DESIGN EXAMPLE

For the design example we use a popular three terminal regulator: LT1083 from Linear Technology Inc. applied as a 3.3V regulator LTI recommends a 1uF frequency compensation capacitor and a 10uF unspecified tantalum capacitor for bulk filtering. Tantalum 10uF capacitors are available in different forms with ESRs from 25mOhms to 10 Ohms. The data sheet and application notes offer little further guidance. Insufficient ESR results in ringing and slow transient recovery. Excessive ESR results in excessive transient voltage excursions.

In our example the high frequency PDN is represented as 24 pieces of a major MLCC manufacturer's 470nF 0402 X5R capacitor attached with nominal attachment inductance to the power planes. The 24 470nF capacitors together: $\mathbf{C}_{\mathbf{PDN}}$ exceed the 10uF manufacturer recommendation. We start without any bulk capacitor. The resulting transient response as seen in Figure 3 exhibits substantial ringing. We will need to add dominant pole compensation.

Following our procedure we first select

an E3 capacitor value at least twice the parallel capacitance of the PDN. 22uF is adequate. Next we iterate transient simulation changing the ESR values until we adequately damp the transient ringing. We find that 32mOhms ESR is the minimum adequate ESR. As seen in Figure 4, the compensated response settles quickly with a nearly 50% reduction in peak excursion.

We can realize the dominant pole compensation network by several alternative capacitor choices:

A 22uF MLCC in series with a 35mOhm thick film resistor.
**Budgetary cost: $0.20**

An aluminum polymer SMT capacitor 22uF 40mOhms.
**Budgetary cost: $0.45**

A tantalum polymer SMT capacitor 22uF 40mOhms.
**Budgetary cost: $1.33**

## SUMMARY

VRMs are fundamentally feedback control systems. When the interconnect impedance is low throughout the frequency response of the VRM, the entire PDN is tightly coupled to and loads the VRM, reducing the required bulk capacitance, but also potentially destabilizing the response.

Through a simple simulation driven procedures, optimal VRM response can be obtained while allowing the use of compact, low cost solutions.


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# Spread Spectrum Clock Generation – Theory and Debate

**KENNETH WYATT**
Wyatt Technical Services LLC

## HISTORY OF SPREAD SPECTRUM

**DURING WW2,** the U.S. Navy was having problems with radio-controlled torpedoes that were being jammed by high-strength RF signals tuned to the same frequency as the transmitting link. In August 11, 1942, Austrian actress, Hedy (Lamarr) Keisler Markey [Ref 1] and pianist and composer, George Antheil, with the help of an electrical engineering professor at the California Institute of Technology, solved this problem and were granted U.S. Patent Number 2,292,387 for a "Secret Communication System" [Ref 2] diagramed in Figure 2. The device used a mechanism to rapidly switch between several frequencies on the transmitter (what is now called frequency hopping). A similar device on the receiver in the torpedo switched between the same frequencies and captured the transmitted signal. The signal controlling the torpedo never remained at any individual frequency long enough to be jammed by an external RF signal at a single frequency. The technology for this was based largely on the mechanism used for player pianos – a loop with coded holes. A special sync code was used to match up the initial hopping sequence.

As Hedy (Lamarr) Markey and George Antheil explain in their patent application:

*"This invention relates broadly to secret communication systems involving the lie of carrier waves of different frequencies and is especially useful in the remote control of dirigible craft, such as torpedoes. . Briefly, our system as adapted for radio control of a remote craft employs a pair of synchro-*

**FIGURE 1:** Actress, mathematician and inventor, Hedy Lamarr. Courtesy of http://www.hedylamarr.com.

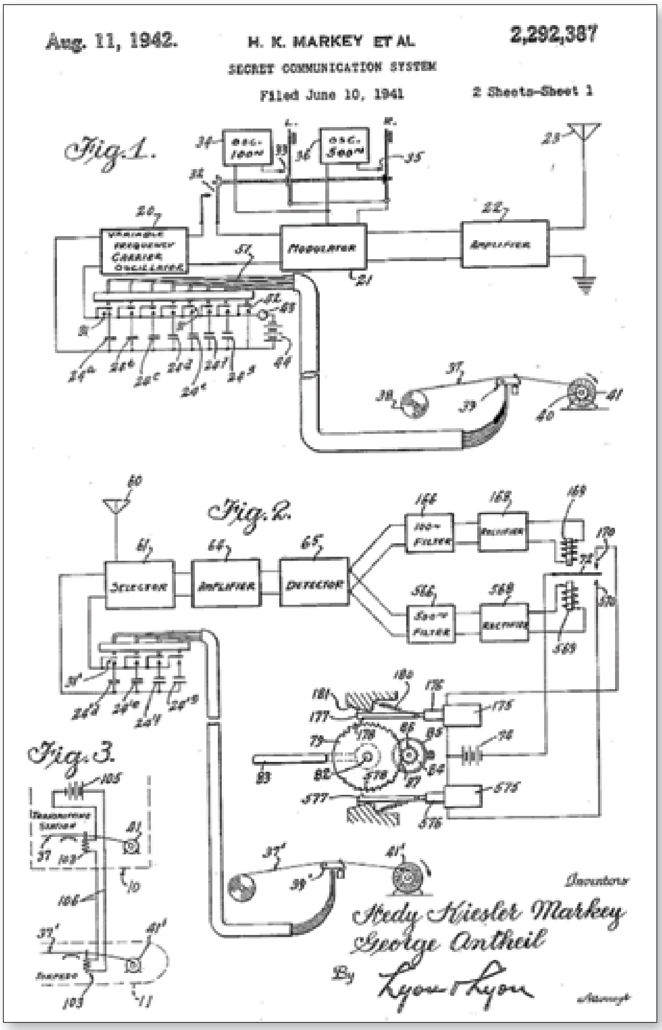


**FIGURE 2:** Original patent drawing for a "Secret Communication System". Note the two coded roller strips that switch in a bank of several capacitors, which cause the transmitted and received frequency to hop in sync.

*nous records, one at the transmitting station and one at the receiving station, which change the tuning of the transmitting and receiving apparatus from time to time . . . we contemplate employing records of the type used for many years in player pianos, and which consist of long rolls of paper having perforations variously positioned in a plurality of longitudinal rows along the records. In a conventional Player Piano record there may be 88 rows of perforations. And in our system such a record would permit the use of 88 different carrier frequencies, from one to another of which both the transmitting and receiving station would be changed at intervals. . ."*

While their prototype system used up to 50 perforations, or frequency hopping codes, it still formed the basis of the frequency hopping spread spectrum systems used today. Unfortunately, the U.S. NAVY never ended up using that system during WW2. However, once the patent lapsed, they did start using it during the Cuban missile crisis. Unfortunately, Lamarr was never credited until years later.

A more sophisticated version of this technique was used later to reduce jamming vulnerability in military communication systems and ultimately another jump in development was the use of direct sequence spread spectrum, which is used in today's cellular and cordless phones.

## SPREAD SPECTRUM CLOCK GENERATION FOR ITE PRODUCTS

Spread spectrum clock generation (SSCG) or "dithering" (modulating the clock frequency), has been around for a long while, even before the PC and printer manufacturers got on the bandwagon. There are also several ways to produce a dithered clock, using discrete logic or FPGAs.

In August 1994, Keith Hardin, John Fessler and Donald Bush, engineers from Lexmark International, Inc. (a spin-off from IBM), introduced the concept at the IEEE International Symposium on EMC that year. It was based on a chirp spread spectrum (CSS) method, where a square wave clock signal is modulated with a low-frequency signal to produce a series of fixed-frequency, lower-amplitude, harmonics. Their paper, "Spread Spectrum Clock Generation

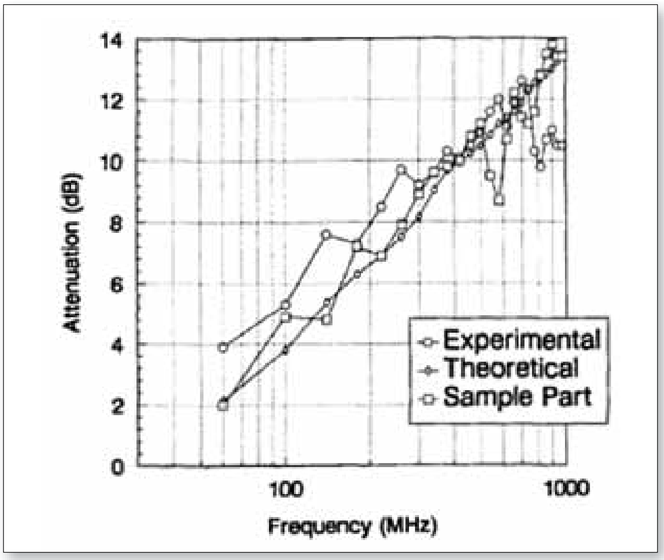


**FIGURE 3:** The experimental and theoretical improvement versus frequency at a 120 kHz bandwidth. Ref: Spread-Spectrum Clock Generation for the Reduction of Radiated Emissions, Hardin, Fessler, Bush, International Symposium on EMC, Aug. 1994.

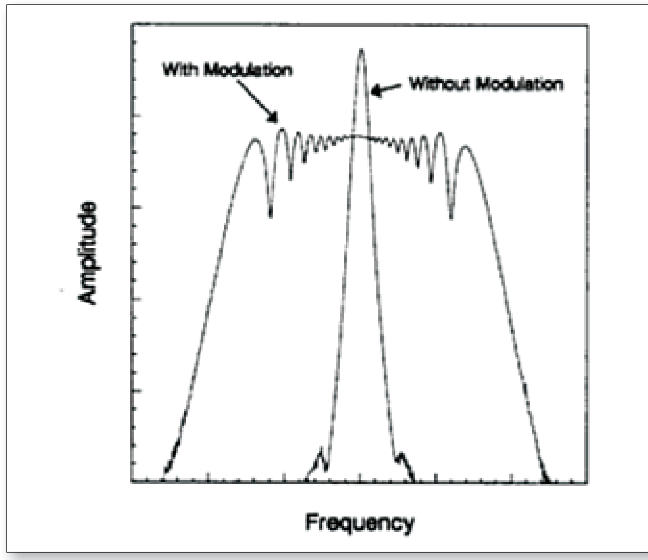


**FIGURE 4:** Comparison of a non-spread clock signal with the spread signal. Ref: Spread-Spectrum Clock Generation for the Reduction of Radiated Emissions, Hardin, Fessler, Bush, International Symposium on EMC, Aug. 1994.



for the Reduction of Radiated Emissions", was also voted a runner up for "best paper" [Ref 3]. They built the SSCG into a prototype printer and demonstrated it during that symposium. It created quite a stir among the attendees.

Following the presentation, Art Wall, one of the chief engineers from the FCC, stood up and questioned the legality. In a nutshell, he asked IBM to prove that the method reduced EMI to TVs and radios - but TVs, in particular. After publishing a study of the interference potential in 1995 [Ref 4], Hardin, Fessler and Bush presented convincing evidence to the FCC and were eventually able to license the patent out to a few chipmakers. The patent involved the modulation scheme - the so-called, exponential, or "Hershey Kiss," shape (Figure 5), which optimized the flatness of the spread clock [Ref 5, 6, 7, 8, 9]. The modulation frequency was generally designed just above the upper audio range, about 30 kHz, or so. Per EMC standards, the resolution bandwidth of the spectrum analyzer or EMI receiver for the range 30 to 1000 MHz is 120 kHz; so spreading the clock sufficiently beyond that bandwidth effectively reduced the average interference level by 8 to 12 dB, depending on frequency.

Fellow EMC engineer and consultant, Ken Javor, added the following comment in an ongoing debate on spread spectrum in the LinkedIn Group, "EMC Experts":

*"The FCC questioning the legality of spreading the spectrum is most interesting. The FCC bought off on the 120 kHz BW from 30 - 1000 MHz, which was based on FM receivers 88 - 108 MHz, and they rightly questioned the effect on TVI, where the spectrum is 6 MHz wide, but if they were considering a LEGAL challenge, then they should have considered that when they bought off on 120*

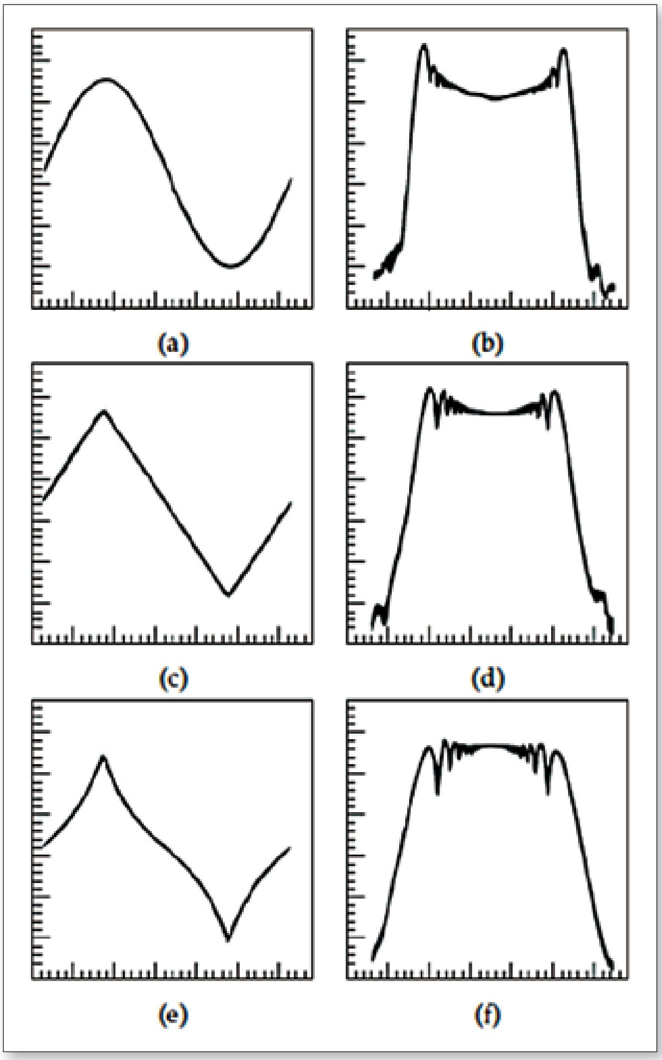

**FIGURE 5:** The key to maximizing the attenuation of a clock signal is the modulating signal. Ref: Spread-Spectrum Clock Generation for the Reduction of Radiated Emissions, Hardin, Fessler, Bush, International Symposium on EMC, Aug. 1994.

*kHz instead of using something approximating 1 MHz BW in TV bands 54 - 88 MHz, and above 108 MHz."*

The basis for a 120 kHz bandwidth (at 30 to 1000 MHz) was originally endorsed by CBEMA (Computer and Business Equipment Manufacturers Association) back in 1977 [Ref 10]. It was based on considerations of narrow band and broadband emissive sources and the current FM and TV broadcast receiver technology with some compromises on the TV bandwidth.

After considerable studies by Lexmark and Intel, experiments showed that SSCG technology did not appear to affect reception. In 1995, the FCC performed their own investigations on SSCG and concluded the following [Ref 11].

*"In our Laboratory investigations, we observed that the deliberate modulation of a clock could cause interference to be better or worse as compared to an unmodulated clock, depending on the conditions. However, given the variation that would occur under actual operating conditions, it does not appear that there would be any noticeable change in the overall interference risk from such equipment."*

*"More importantly, we have found that the frequency-synthesized clock used in many contemporary personal computers are often unstable. The spectrum signature of at least some existing computer equipment already on the market appears to be similar to that of SSCG equipment. Thus, we do not believe that the interference potential from SSCG equipment is any greater than for existing personal computer equipment."*

It took a couple more years for SSCG ICs to become incorporated into PC motherboards and other ITE peripherals due to system design issues and getting chipmakers to start supplying the clock generator ICs. PC manufacturers had started using microprocessors with higher and higher clock frequencies with internal PLLs to synthesize the higher frequencies. Most major microprocessor companies started making their processors compatible with the SSCG design. When SSCG ICs did finally become available,



SHIELDING

manufacturers eagerly implemented the technology just to stay below the FCC Class B limit on radiated emissions.

## SSCG THEORY

Spreading the clock frequency with a low frequency fixed or pseudo-random modulation (30 kHz, typically), such that the modulated signal is significantly wider than the resolution bandwidth of the measuring receiver or spectrum analyzer, effectively reduces the emissions from all signals synchronized with that clock oscillator. As can be observed in Figure 3, as the harmonic frequencies increase, the effective reduction in emission levels increases, as well.

Figure 4 shows an example of a clock oscillator with the spreading turned on versus turned off. This example demonstrates "center spreading", where the spread clock is equally spread above and below the non-spread clock signal. There can be timing issues with this method – especially, if the microprocessor or other digital devices are "overclocked" – that is, the non-spread clock frequency is already pushing past the manufacturers specified upper limit of the clocked devices.

For a sine wave modulation, the leading and trailing edges of the spread signal increase ("Batman" shape), due to the relative delay or time rate of change at the top and bottom of the sine wave. To improve the flatness of the spread signal, a triangle wave shape may be used, which includes much less delay at the top and bottom of the wave shape. Lexmark engineers improved that further by developing an exponential, or "Hershey Kiss" shaped waveform that provides best flatness in harmonic emissions. This wave shape, among other items, was what Lexmark ended up patenting. Many commercially available SSCG manufacturers license this modulation, but several also use triangular modulation.

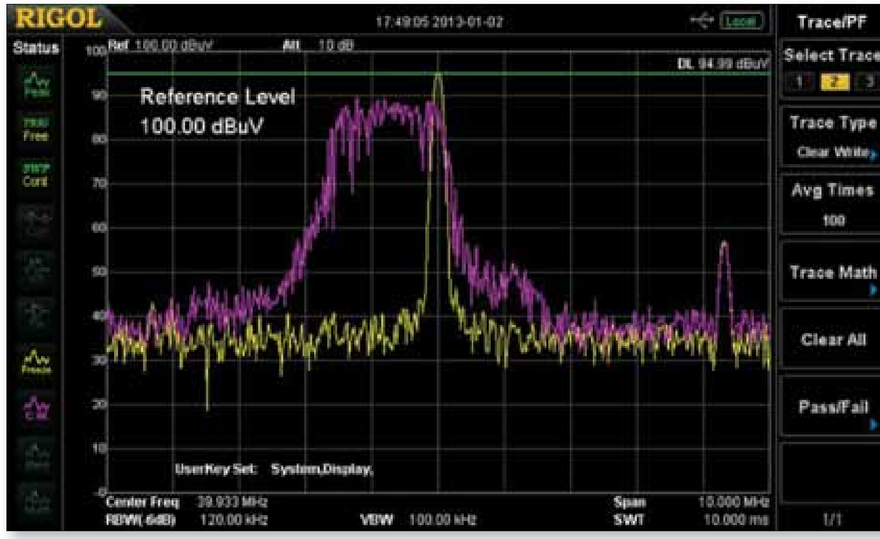


**FIGURE 6:** The fundamental frequency of 40 MHz before and after SSCG is turned on (measured at 120 kHz bandwidth). Note: This is an example of a "down-spread" clock, which is a lot safer technique to use if you're pushing the clocking limit of your digital devices (see Precautions section below).

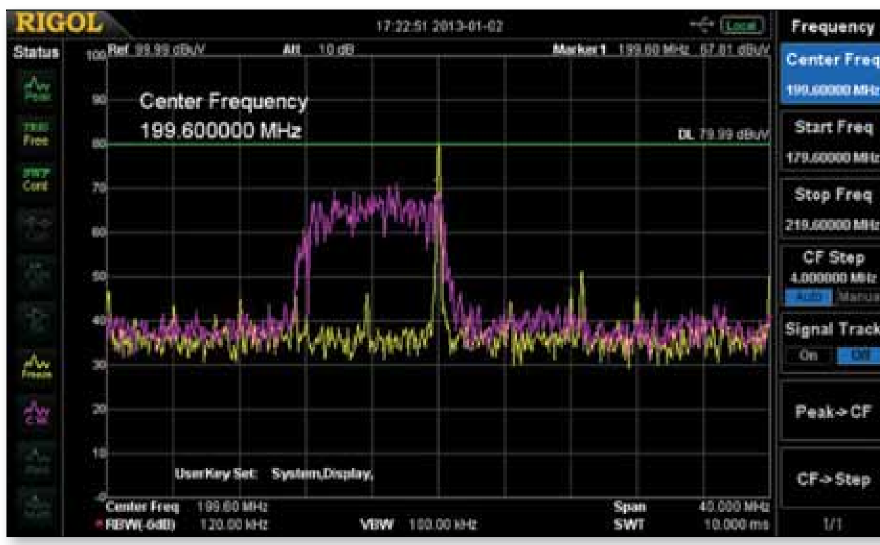


**FIGURE 7:** The harmonic at 200 MHz before and after SSCG is turned on (measured at 120 kHz bandwidth). Notice the effective EMI reduction has increased.

## MEASUREMENTS OF SPREAD SPECTRUM CLOCKING

I obtained an early spread spectrum clock demo board from IC Works several years ago, which I use as a demo of the technology during my EMC seminars. This board is nice in that the spread spectrum clocking may be easily turned on and off. For the purposes of this article, I measured the before and after spread clocking using the required EMI receiver bandwidth of 120 kHz versus frequency.

The sequence shows that as the harmonic order increases, so does the effective EMI reduction, because the higher order harmonics multiplies the spread. Starting with the fundamental clock frequency on this demo board of 40 MHz, we'll compare with the 200 and 440 MHz harmonics. As you can see, as the frequency increases, the effective EMI reduction also increases, with 6, 12 and 15 dB reductions, respectively. I adjusted the span so that the relative width of the spread clock occupied approximately

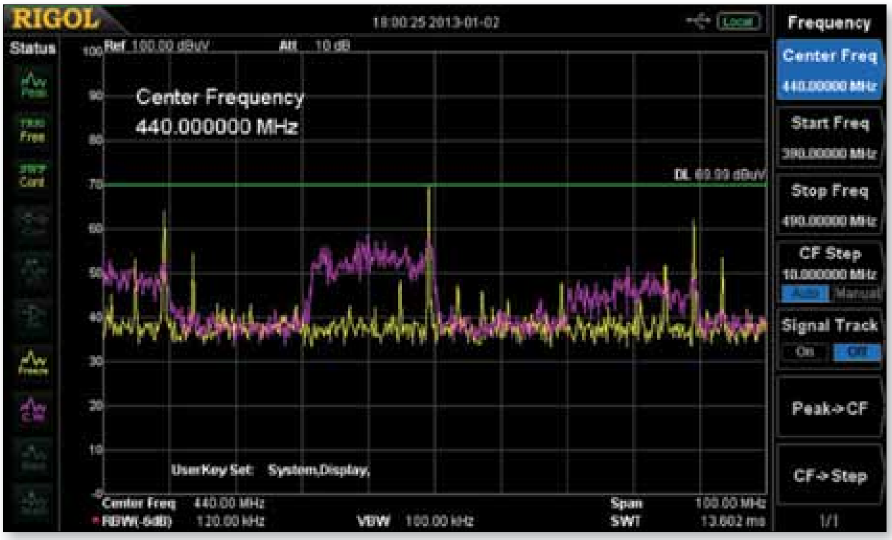


**FIGURE 8** The harmonic at 440 MHz before and after SSCG is turned on (measured at 120 kHz bandwidth). Notice the effective EMI reduction has increased even further.

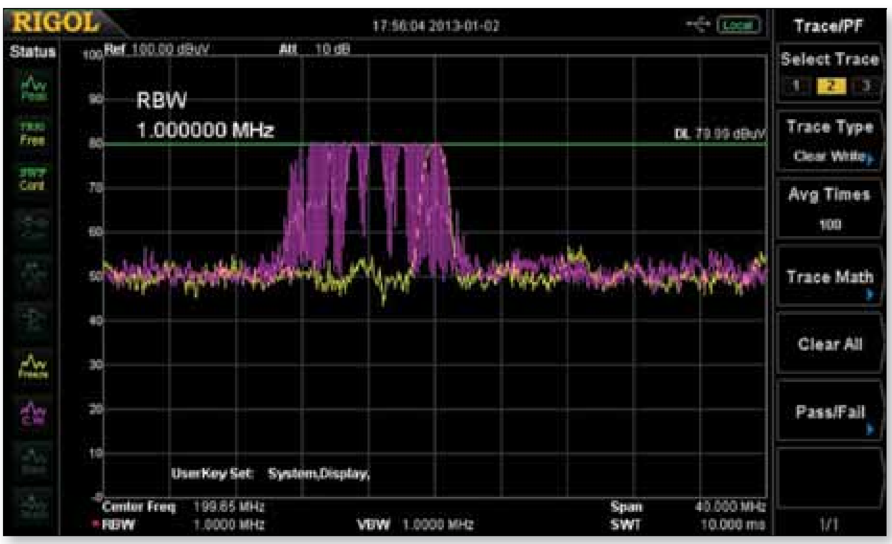


**FIGURE 9:** The same 200 MHz harmonic as in Figure 7, but now measured at a 1 MHz bandwidth. Note the apparent spread clock reduction is zero – fooling critics into thinking the modulated clock is simply "sweeping" back and forth and that there's no real reduction in EMI for wideband receiver technologies.

two divisions for ease of comparison. You can also observe the use of "down spreading" in frequency.

## PRECAUTIONS

One problem presented by SSCG is that it can introduce timing skew and corresponding jitter in the system.

One of the significant disadvantages in using SSCG is that it cannot be used in systems where clock accuracy is of major concern; for example, Ethernet, CAN bus or critical timing applications. You need to take special care in specifying SSCGs and the spreading amount (and direction), as it can introduce substantial jitter to the clock signal. This jitter may affect system performance, causing critical setup and hold violations, higher bit error rates and PLL unlock issues.

Another area where extra precautions need to be taken is where the design includes a PLL downstream driven by the SSCG. A PLL exhibits the characteristics of a low-pass filter, which allows low-speed variations in the input frequency. Since the SSCG purposely modulates the clock, the PLL may have trouble maintaining lock. If the PLL bandwidth is too low, the PLL will not reliably track the clock, resulting in tracking skew and even more system jitter.

One of the first manufacturers to produce SSCG ICs was IC Works (acquired by Cypress Semiconductor Corporation in 1999). They were among the first to license the exponential (optimized) wave shape from Lexmark. The demo board I have used the W42C31-09 SSCG chip with down-spread technology.

Today, there are multiple manufacturers of SSCG ICs, including Analog Devices, Maxim, Linear Technology, ON Semiconductor, Fujitsu, Silicon Labs, Cypress Semiconductor, Mercury Crystal, NEL Frequency Controls, Xilinx and others.

## SSCG – THE DEBATE

While the FCC has officially blessed the technique and most all ITE and peripheral manufacturers have been using the technique for years, there are still those who question the validity as to whether EMI is really effectively improved – especially for the wider-bandwidth communications and broadcast systems used today. As you can see from the actual measurements (below), it does appear that widening the receiver or spectrum analyzer resolution bandwidth (RBW) reduces the effective EMI reduction towards zero. In fact, there is the illusion that at these wider bandwidths, the fundamental clock is simply sweeping or hopping back and forth at the modulation rate, such that the spectrum analyzer is "fooled" into measuring a lower than actual spread amplitude at 120 kHz RBW. This is, in fact, not quite correct, as I'll explain further on.

In comparing the same measured harmonic frequency of 200 MHz (Figure 7 above) with Figure 9 measured using a wider resolution bandwidth of 1 MHz, it really does appear there is no effective reduction at all and that the clock is simply "sweeping" in the frequency domain.

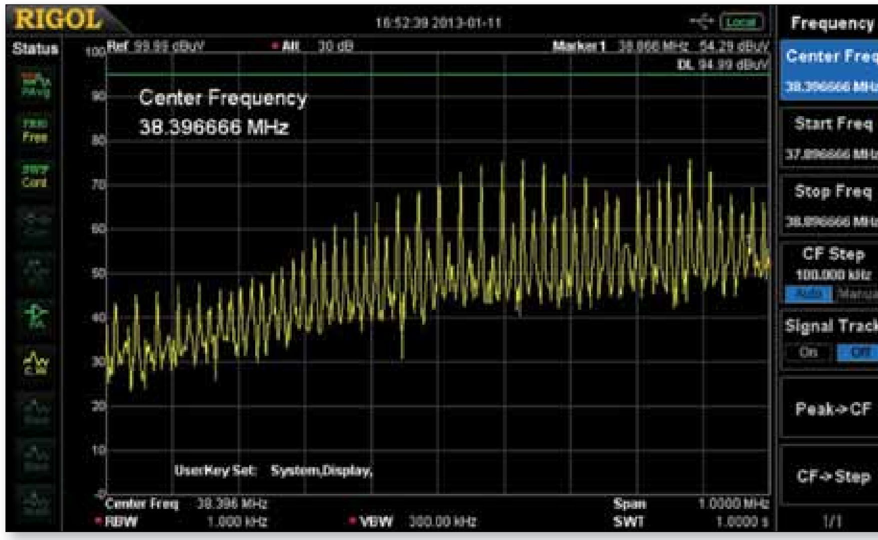


**FIGURE 10:** An expanded view of the 40 MHz spread spectrum signal tuned just below 40 MHz (38.4 MHz) so you can see the lower portion of the spread signal. In this case, the RBW is adjusted for 1 kHz. Notice the fixed – and reduced amplitude – series of 31.25 kHz harmonics. The fundamental 40 MHz fundamental signal is NOT being swept!

This seems to be the sticking point with most critics of the technology – that, in effect, for SSCG, the clock is really just "sweeping" or hopping back and forth in frequency according to the modulation applied and at the original amplitude so it seemingly allows product designers to exceed the radiated emissions limits by up to 20 dB, or so, worst case (assuming the spread signal is right at the limit and measured at 120 kHz bandwidth).

In April 2011, EE Times editor, Bill Schweber, published "Spread Spectrum Clock to reduce EMI: clever or cheat?" [Ref 12] where he brought up the general arguments on both sides. Excerpting from that article:

*"One argument against using spread-spectrum is that you are very likely actually making your design "problem" into someone else's. As you spread the energy, yes, you may meet a specification, but you also introduce the likelihood of unexpected problems when your spread energy mixes with as-yet unknown or undefined energy in other nearby or connected systems, each with their own frequencies and amplitudes. In short: "hey, I met the spec--after that, it's your problem, not mine!"*

Blogger, Michael Ossmann, echoes this sentiment in a blog posting August 18, 2011, "Spread Spectrum Clock Generation, Emissions, Security and You" [Ref 13].

*"SSCG became popular, first with PC manufacturers and more recently for other electronic devices. The technique is used for one and (as far as I know) only one reason: to make it easier to pass electromagnetic compatibility (EMC) testing required by the FCC and other regulatory bodies around the world. EMC regulations are intended to limit RF emissions of electronic devices in order to avoid harmful interference to radio systems and other neighboring electronics. SSCG doesn't do anything to reduce the radiated power of such emissions; it simply shifts their frequencies around so the EMC test equipment doesn't register too high a power level at any one frequency. The electronics manufacturers are playing a shell game with their clock frequencies in order to evade detection."*

In addition, a study published in 2000 by the University of Hertfordshire indicates that broadband SSCG harmonics can cause disruption of

DAB (Digital Audio Broadcasting) and DVB-T (Digital Video Broadcasting – Terrestrial) [Ref 14].

*"DAB (Digital Audio Broadcasting) and DVB-T (Digital Video Broadcasting – Terrestrial) use COFDM (Carrier Orthogonal Frequency Division Multiplex). COFDM exhibits a threshold effect whereby interference is tolerated until the bit error rate exceeds a certain critical level. Beyond this threshold there is a rapid degradation leading to complete loss of all programmes carried by the DAB or DVB-T multiplex. A narrow band interfering signal such as a harmonic from a non-dithered clock or co-channel interference from an analogue VSB television signal may interfere with one or a small number of sub-carriers. This is generally tolerated but if a broad band signal interferes with a significant number of sub-carriers, this is likely to result in complete loss of service."*

*"Tests have shown that an interfering source whose radiated emissions resemble broadband random noise has the greatest interference potential for DVB-T and DAB reception. The emissions from some types of DCO have an interference potential approaching that of random noise. If a radiated emission from such a DCO or one of its harmonics falls on a frequency that is being used for DVB-T reception, complete loss of service is likely."*

*"In the context of interference investigation, a broad band interfering signal 20 dB below a COFDM broadcast signal (when both are measured in the same bandwidth) could cause loss of service but it would be difficult to locate the source of such a signal or even to prove its existence."*

On the other hand, in August 2001, Harry Skinner and Kevin Slattery (Intel Corporation) published experimental results showing this technique does actually reduce the risks of interference in electronic systems [Ref 15]. In their words, "The question should be: Does clock dithering reduce the interference potential of unintended radiators or by spreading the noise does it introduce a new means of upset in services that the regulations are intended to protect?" and "since the interference potential of a signal is dependent on the presence of an aggressor in a services operational frequency band for a length of time significant [with respect to] the integration time of the receiver, the frequency/time relationship introduced as a result of a modulation actually lowers the interference potential."

Their experimental results measured the effect on an FM broadcast receiver (Sony Walkman) and indeed showed that spreading the energy over a 5 MHz bandwidth caused no apparent degradation in audio quality over a non-spread signal at the received frequency.

Later in 2003, Hardin, et al, published additional investigative results on interference to wideband digital systems [Ref 16]. The goal was to establish a method to measure interference potential using existing technologies as a reference level, and to determine the interference potential for digital television (DTV and DVB-T) receivers using both the modulated and unmodulated clock sources.

They defined a test procedure for evaluating the signal-to-interference margin for both DTV and DVB-T receivers. Because the COFDM transmission format used by DTV uses error-correction routines, it is much more tolerant of interfering signals than analog PAL TV receivers, to the tune of 16 dB better margins. Because interference problems in the field for PAL are being adequately managed under the current CISPR 22 and FCC Part 15 rules, Hardin concludes there is no need for further regulations for SSCG.

## THE PHYSICS OF SSCG

As I mentioned previously, SSCG is not simply sweeping or hopping the fundamental harmonic rapidly. If you were to examine the spread clock at a more reduced RBW, you would observe the spread signal is really comprised of an infinite series of fixed harmonics of the modulation frequency – in our example, 31.25 kHz (see Figure 10) with amplitudes gradually increasing as the fundamental frequency is approached. Most of these infinite harmonics will be hidden by the noise level of the analyzer until we start approaching the fundamental frequency and all its related higher-order harmonics.

You can see that what is actually happening is not a sweeping fundamental clock, but a series of fixed (discrete) harmonics of 31.25 kHz spacing at a reduced amplitude from the non-spread fundamental. In this case, the non-spread fundamental at 40 MHz was about 95 dBuV (green display line) and the 31.25 kHz harmonics are reduced by about 18 dB (at 1 kHz RBW). You won't be able to see this with the wider 120 kHz RBW, because at 120 kHz, there will be four to five discrete 31.25 kHz harmonics within the receiver pass band, which will add together and provide you an overall higher amplitude. As the RBW is increasingly widened (greater than the 31.25 kHz modulation), the discrete harmonics, when added together will approach the same amplitude as the non-spread fundamental because all of the discrete harmonics added together must give the same amplitude signal in the time domain as the non-modulated signal.

When assessing the actual physics of SSCG, it is important to keep the RBW (1 kHz, in this case) well below the modulation frequency of 31.25 kHz. The video BW should equal or exceed the RBW (300 kHz, used in this case). In general, spectrum analyzer plots with lower video bandwidths will give different amplitudes than a full compliance receiver because the filtering effect is different than in quasi-peak (QP) and Peak modes.

The harmonics we're seeing are actually the result of the Fourier series of the modulated square wave f(x). The argument of the integral form of the Fourier series is the product of the time domain clock multiplied times the cos(nx) or sin(nx) functions.

$$a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\,cos(nx)\,dx, \;\; n \geq 0$$

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\,sin(nx)\,dx, \;\; n \geq 1$$

In layman's terms the likeness of f(x) to the cos(nx) or sin(nx) gives a higher value for the $a_n$ and $b_n$ terms. The 40 MHz is the fundamental of the intended clock frequency with SSCG turned off, so one would expect the harmonics to only be at multiples of 40 MHz but we can also say that the 40 MHz non-spread clock is also periodic at 31.25 kHz as long as f(x) = f(x+1/31.25 kHz). This is saying the time shifted function by one period is the same as the original function. In this case all of the harmonics are zero from 31.25 kHz until you approach the 40 MHz fundamental (excluding some numerical errors). All of the amplitudes will be exactly the same at multiples of 40 MHz for calculating the harmonics with a period of 40 MHz. This is because the cos(2*pi*40 MHz*x) has a lot of likeness to the 40 MHz square wave and its harmonics.

Now let's turn SSCG on. As you look at the harmonics of 31.25 kHz at <<40 MHz, the $a_n$ and $b_n$ amplitudes are near zero since there is little likeness to a 40 MHz sine wave. As you approach n=1229 the Fourier series frequency is 31.25 kHz*1229 = 38.41 MHz (center frequency in Figure 10 above) then these frequencies are present part of the time in f(x), the modulated square wave. This gives rise to the harmonics you see on the spectrum analyzer. The harmonics will start to fall off again at frequencies higher than 40 MHz. If you were to add all the infinite harmonics in the time domain and with the correct phase (an inverse Fourier transform), you would reproduce the original modulated square wave clock.

## CONCLUSION

While many engineers have been fooled into thinking SSCG is really "cheating" the standard, this is really not the case. The spread spectrum clock is not really "sweeping" back and forth at the same amplitude as the non-spread clock, but is really comprised of the Fourier series of lower-amplitude fixed-frequency harmonics of the modulating frequency of 31.25 kHz (in the case of this demo clock generator). Because it's really the power density within the receiver pass band that causes interference, spreading the power through the use of SSCG tends to also reduce the risk of interference.

The fact there have been billions of products made with SSCG and that there have been few, if any, documented cases of SSCG being the root cause of interference problems, should provide a level of comfort to designers and those in standards enforcement.

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## OTHER CURRENT DISCUSSIONS

Scope Junction: http://www.scopejunction.com/author.asp?section_id=1835&doc_id=253355&

LinkedIn group "EMC Experts": http://www.linkedin.com/groupItem?view=&gid=1784463&type=member&item=181670231

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## AUTHOR BIO

*Kenneth Wyatt, Sr. EMC Engineer, Wyatt Technical Services, LLC, holds degrees in biology and electronic engineering and has worked as a product development engineer for 10 years at various aerospace firms on projects ranging from DC-DC power converters to RF and microwave systems for shipboard and space systems. For more than 20 years, he has worked as an EMC engineer for Hewlett-Packard and Agilent Technologies in Colorado Springs. He has been an independent EMC consultant since 2008. A prolific author and presenter, he has written or presented topics including RF amplifier design, RF network analysis software, EMC design of products and use of harmonic comb generators for predicting shielding effectiveness. He has been published in magazines such as, RF Design, EMC Design & Test, Electronic Design, Microwave Journal, HP Journal, Safety & EMC (China), Interference Technology (ITEM), InCompliance Magazine, Test & Measurement World and several others. He currently writes The EMC Blog for Test & Measurement World.*

*Wyatt is a senior member of the IEEE and a long time member of the EMC Society where he served as their official photographer. He is also a member of the dB Society and is a licensed amateur radio operator. He may be contacted at ken@emc-seminars.com.*

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# EMC = Grounding on Automation and Control Systems

## Applications to Eliminate Electromagnetic Interference in Industrial Plants

**ROBERTO MENNA BARRETO**
QEMC - Engenharia, Qualidade e Compatibilidade Eletromagnética Ltda.

## SUMMARY

**THE PRESERVATION** of signals and equipment are generally characterized by the term Electromagnetic Compatibility (EMC), whose essence will translate in its own grounding system. The proper EMC improvement in the installation of automation and control systems ensures a significant reduction of the risks and costs associated with failure of equipment, whose consequences can be disastrous, thus justifying a systematic approach for the grounding system, as it is not effective to elect a few "*rules of thumb*" to solve all would be scenarios.

## 1. THE ROLE OF THE GROUNDING SYSTEM AND ITS OBJECTIVES

Automation and control systems are dependent on electronics to meet their needs in the various processes. When the equipment associated with these processes is damaged or malfunctions due to electromagnetic disturbances, there will be risks related to safety and financial losses.

The proper operation of automation and control systems is thus directly related to the integrity of the equipment and signals—this integrity being generally characterized by the term Electromagnetic Compatibility (**EMC**), which can be defined as the ability of a device, unit of equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to that environment.

The best cost-effective approach to such a proper EMC configuration requires each item of equipment and its interconnections to comply with specific EMC standards that, however, may not be enough to answer for all needs in a particular installation when additional protective measures are so to be implemented.

Practically all protective measures to avoid electromagnetic interference (EMI) are directly related to the grounding system. Indeed, all different electrical-electronic technologies existing in an Industrial Plant will necessarily converge into the grounding system; therefore, it is in the grounding system where the noise coupling problems occur and thus it is in the grounding system where they must to be solved.

The essence of electromagnetic compatibility for automation and control systems will thus be translated into its own grounding system, which can be understood as an (single) electrical circuit that goes from the earth electrode subsystem to components in printed circuit boards, including all the installed protective measures, whose purpose aims to conciliate different commitments: safety for the power system, protection against lightning, and control of electromagnetic interference.

To meet these goals (safety, protection against lightning and interference control), the grounding system would be an ideal plan with zero impedance where different signal levels could be mixed without any interference. But the ideal is not real, and what is done is the simulation of this ideal behavior through a proper design of the grounding system for a specific installation, aiming at two complementary goals:

**First Safety Grounding** - to guarantee that dangerous voltages due to power fault or lightning discharge will not cause any harm to people or to the installation itself, being that its design is based mainly on industrial frequencies and supported by the electrode system;

**Second EMC Grounding** - to avoid electromagnetic interference external to the system (both from a third party into the installed electronic system or vice-versa) as well as internal to the system, being that its design is no more related to the electrode system but directed to the high frequency behavior of all system interconnections in order to:

**a.** prevent electromagnetic disturbances to be coupled into the circuitry under consideration;

**b.** prevent electromagnetic disturbances coupled into the circuitry to cause faults or operating errors.

The grounding system, as a way to assure the electromagnetic compatibility of automation and control systems, provides safety and ensures a significant reduction of risks and costs associated with interference problems and/or equipment damage—both direct costs, with replacement of damaged equipment, and indirect costs related to the shutdown or malfunction, whose consequences can be disastrous, thus justifying a systematic approach in this area.

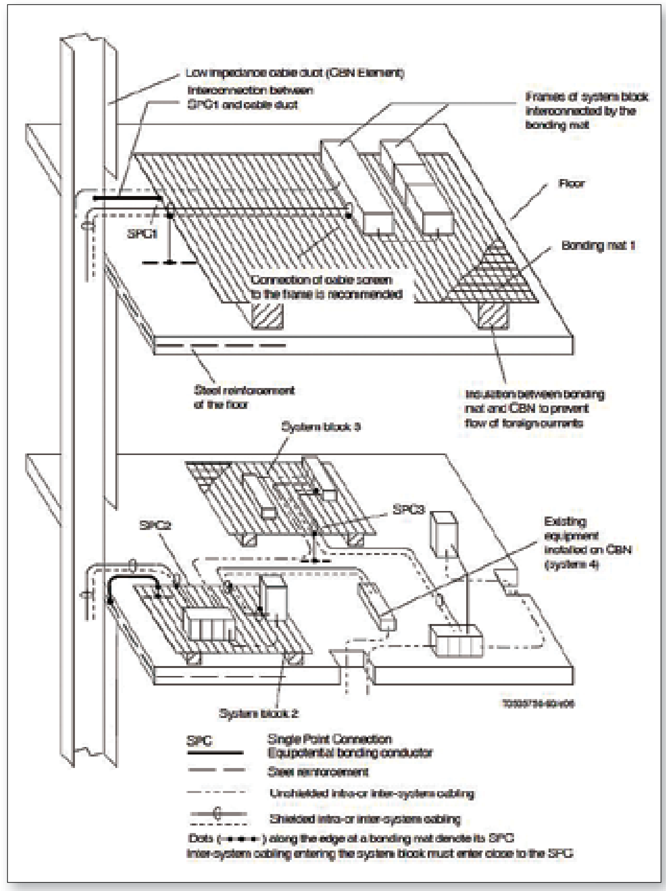


**FIGURE 1:** Mesh-IBN with bonding mat.

**Notes:**

**1** System blocks 1, 2 and 3 are new installations conforming to the mesh-IBN method. They may be connected to existing installations (system 4) that use any method of bonding.

**2** The SPC is the only metallic interface between the mesh-IBN and the CBN. It must be directly connected to the reinforcement of the floor. All cables leading to the system enter here. All conductors that are bonded to the mesh-IBN must be connected to the SPC (e.g. cable screens, battery return, etc.).

**Credit:** K-27 ITU Recommendation K.27, 1996, "Bonding configurations and earthing within a telecommunications building"

## 2. THE GROUNDING SYSTEM AND ITS RELATIONSHIP WITH THE POWER SYSTEM

The electrical potential of the power conductors relative to the Earth's conductive surface is defined by its earthing system, the Neutral earthing scheme, which is identified by three characters: XY-Z. The first character, X, refers to the connection of Neutral to Earth (T - directly connected to earth; I – isolated or connected by a high impedance) while the second character, Y, refers to the connection between the electrical device being supplied and Earth (T - directly connected to Earth; N – connected to Neutral at the origin of installation, which is connected to the Earth). The third character, Z, refers to the Neutral in relation to the Protective Earth (PE), the conductor that connects the exposed metallic parts of the consumer's electrical installation (S - Neutral and Protective Earth separated; C - Neutral and Protective Earth in a single/combined conductor - PEN)

This leads to the acronyms used for the different types of mains power distribution systems, each one fulfilling specific power requirements: TT, IT, TN-S, TN-C.

From the electromagnetic compatibility point of view, notably where lightning activity is high, the best configuration is the TN-C-S earthing system, where the combined neutral and earth occurs between the nearest transformer substation and the service cut out (the fuse before the meter) and, after this, separate earth and neutral cores are used in all the internal wiring. On the TN-C distribution section, the Neutral is earthed at many points, but at the consumer´s installation, the Neutral is connected to Earth only at the entrance of the facility (just one single connection of Neutral to Earth), where the cabling of a power circuit should form a compact group, including the Protective Earth conductor. Common mode voltages Neutral – PE that may exist from the power distribution system to local earthing system are so eliminated at the consumer´s entrance by the use of a TN-C-S power distribution system.

For some critical situations, it may be advisable to use a power transformer to create a new independent earthing system (TN-S) to overcome problems due to common mode voltage. A new independent earthed power system can also be created at panels in Industrial Plants to avoid such problems, where a shielded transformer is used to provide a better isolation for such common mode voltages (ground loops).

The value of the earth resistance for the electrode subsystem, which can be defined as the relationship between the resulting potential of the electrode and the current that is injected into the soil through it, is not critical for EMC. Although a low resistance should be the basic goal whenever possible (for Safety and Lightning protection reasons), it is not necessary to guarantee the proper EMC performance of electronic systems.

The way that the "Protective Earth" is distributed in the installation is the main factor to guarantee the correct performance of automation and control systems, what can be configured as the single point grounding or the multipoint grounding.

TThe single point grounding is characterized by a single Earth/Ground connection, from which it is distributed throughout the facility, in a concept of "tree or star," i.e. always opening without ever closing loops. This configuration is suitable for low frequencies, which means that the length of the wires is no longer than one-tenth of the wavelength of the signal, and is often used for panels in Industrial Plants and even for high frequency electronic systems installed in small areas, as is the case with telecommunication stations (shelters).

However, we must be quite careful when considering such a low frequency grounding system—the point to be considered is that even if the desired transmitted/processed signal of our system is under a low frequency category, the same certainly will not apply to the undesired ambient noise or to the conducted noise originating from items of electronic equipment, due to the high frequency content of digital processing and communication devices spread all around, as well as the increasingly widespread use of radio (i.e. wireless) communications for voice and data.

The multipoint grounding (meshed) is preferable for high frequencies, where it is implemented through a Signal Reference Grid whose mesh size should be less than one-tenth of the wavelength of the highest frequency that is required to be controlled by the ground structure (to better perform like an imaginary "equipontential ground plane" for those frequencies), favoring in this way lower noise communication between equipment (signal cables run along the mesh).

The use of such Signal Reference Grid for the equipment room is always recommended, notably for environments with high levels of radiated electromagnetic disturbances, though not always necessary due to its own circuitry, as new technologies provide a higher immunity level to noise (Ethernet or fiber optic, for example), eliminating that need for a more comprehensive treatment of the local grounding structure that was originally required to compensate for the poor susceptibility of RS-232 data connections.

Where very high intensity electromagnetic fields are to be present in the ambient, or even when intentional EM fields can constitute a security threat, a (architectural) shielded room may also be necessary in addition to the Signal Reference Grid for some Industrial Plants.

## 3 - THE GROUNDING SYSTEM AND ITS RELATIONSHIP WITH THE PROTECTION AGAINST LIGHTNING

Industrial Plants are often situated in remote locations and spread over a large area, which makes their instrumentation circuitry particularly exposed to any lightning strikes that may occur in the region.

Automation and control systems may be protected against lightning and its effects using two complementary approaches:

- The protection of structures against lightning; and
- The protection of electronics against lightning.

For the protection of structures against direct discharges, a lightning protection system (LPS) comprised of captors to intercept lightning strokes, down conductors to conduct the resulting lightning currents to the earthing system and an earth electrode system to spread the lightning currents into the soil should be implemented.

The Lightning Protection System should comply with international standard IEC 62305: Protection against Lightning, Edition 2: 2010, which includes risk assessment to define level of protection that takes into account the different structures to be protected (buildings, antenna towers, tanks, etc..) in a particular location (soil resistivity, keraunic level/lightning density, topography, etc.) and related issues that may exist, such as explosive atmosphere (ATEX) zoning. Technical studies to implement what has been specified by the risk assessment, the installation and its initial inspection, as well as further periodic inspections complete the protection of structures against lightning.

Here again the value of the earth resistance is not critical—a proper topology of the grounding system to spread the lightning currents into the soil through the earth electrode system without creating high differences in potential is far more important than a low value of the earth resistance, though a low value is addressed and should be the basic goal whenever possible.

For the protection of electronics and services against lightning, (which is also covered by the international standard IEC 62305: Protection against Lightning), a better understanding of the nature of the problem and the importance of grounding system is achieved by considering lightning protection within the scope of EMC, taking into account that lightning and its effects are indeed electromagnetic disturbances too.

Within the context of EMC, the protective measures to eliminate electromagnetic interference are defined upon the initial identification of the source of electromagnetic disturbance (what is generating the electromagnetic disturbances, which can be internal or external to the system); the coupling mechanism (how those generated electromagnetic disturbances are coupled to the circuit); and the receiver (the circuit that is being affected). Upon identification, it is then possible to solve the problem by working on one or more of these components to reduce the coupled noise and hence, the EMI.

Regarding the protection of automation and control systems against lightning, we may consider that it is not convenient, nor even possible, to work on the receiver (the equipment is already defined by manufacturers) or the source of electromagnetic disturbance (lightning). Therefore, we can only work on the coupling mechanism!

Returning to the context of EMC, electromagnetic disturbances are coupled into electronic circuits through three main basic mechanisms: capacitive coupling (electric fields), inductive coupling (magnetic fields) and common impedance coupling (ground).

Most of the techniques that can be applied to reduce these coupling mechanisms are directly related to the design of the grounding system. For example:

- The performance of a filter depends on how it is installed—that is, how it is grounded;
- A non-magnetic shield can be used to reduce magnetic field coupling into signal cable, where its use is oriented for the reduction of the "loop" area defined by the noise current flow—that is, how the shield is "grounded";
- And the same grounding situation is important for many other EMC techniques, too.

The grounding system is indeed the main factor to attenuate the noise coupling mechanisms within an EMC context and, in this same way, the grounding system assumes the leading role in protecting installations of automation and control systems against lightning and its effects, from which some guidelines can be derived.

For the protection of the instrumentation against EM fields generated by lightning currents (indirect lightning), all signal cables within an area (LPZ - Lightning Protection Zone) should run close to individual elements of the meshed grounding system to avoid the creation of large current "loop" areas. A metal tray that forms part of the mesh-grounding structure and/or a grounded cable (PEC - Parallel Earth Conductor) combined with the cables fulfills this need, which should be expanded throughout the area of the protected zone, with the metal tray providing better control of higher frequencies than a wire PEC.

The protection against high voltage/current surges on instrumentation cables connecting instruments located in buildings or areas far apart each other in the event of a lightning strike in one of the buildings or areas is another important situation to be addressed. Although each building or area can have its own earth electrode system, if they are connected through long cables (and they should be connected), it will not be possible to “equalize” them to higher frequencies in order to avoid such surges. The situation can be circumvented by the use of non-metallic media for galvanic isolation, which may include fiber optic or radio for signal transmission or, alternatively, if not using galvanic isolation, then it will be necessary to use surge protection devices (SPDs).

The use of SPDs for the protection against surges due to indirect (EM Field coupling) or direct lightning stroke requires a specific study regarding the grounding system, in addition to the SPDs’ own characteristics. The discharge current diverted by SPDs always goes somewhere in the circuit — it doesn´t disappear! The grounding system is the destination for these currents. A misunderstanding comes from the fact that though this type of device is called a SPD, it would be better to name it a TGD—a Transient Grounding Device, because this is its real function, while SPD—Surge Protection Device—is the purpose for which it is used. This leaves a margin to image that the fact of using a SPD in and of itself is enough, which is not true. The currents diverted by SPDs should flow to the very same (ground) reference of the protected circuit (not necessarily to the electrode earth system) and the discharge path must be as short and direct as possible to reduce its series inductance, in order to help insure that the transient voltages in the circuitry or the transient noises induced in nearby circuits are not too high.

## 4 - THE GROUNDING SYSTEM AND ITS RELATIONSHIP WITH THE TRANSMISSION OF SIGNALS

For the distribution of signals through the plant, what is sought is a compromise between different sources of electromagnetic disturbance, so that the total noise coupled into the circuitry does not cause interference—that is, the information is preserved although the signal may be distorted. To attain this proper configuration, the pertinent techniques should be applied to control radiated or conducted noise coupling on each signal path while preserving safety requirements regarding power distribution and lightning protection.

The control of common mode currents, generically called “ground loops,” is the most critical aspect for the grounding system regarding the instrumentation distributed in the plant. When considering the two conductors in a circuit (source, load, and the two conductors), we must distinguish between two forms of current circulation: differential mode, the desired signal, meaning that the current flows from the source to the load by one conductor and returns through the other; and common mode, the usually unexpected and unwanted signal (noise), meaning that the noise current flows in the same direction on both conductors of the circuit, returning by a third conductor, usually a "Ground Reference" (hence the term "ground loop").

The common mode current circulating circuit may have a "material existence," as in the case where both the signal source and the load are directly connected to a reference ("Ground") at different points. (Note that the concept of “potential equalization” does not apply for practical purposes at frequencies higher than a few kHz, because at these frequencies inductive reactance dominates the impedance of the ground structure, not resistance). In this case, the source of common mode current can be an electrical potential difference between these two reference points ("Ground"), which forces the current flow in both conductors in the same direction.

Under this scenario, it would be quite convenient to implement the signal circuits in a single point topology for the grounding system—that is, just the signal source or the load is grounded at one end of the circuit, thereby avoiding the circulation of currents in the common mode. The instrumentation circuits for the transmission of signals from sensors, which are mostly floating low frequency devices, have been using the single point topology for many years. As the voltages and currents in power frequency (50/60 Hz) in the plant were the main noise threat, the use of shielded (to avoid electric field coupling, the shield is grounded at one end only, normally at the equipment room where the circuit is grounded), twisted (to avoid the coupling of magnetic fields, by reducing the area of current loop) pair cables is largely present.

However, this traditional approach is increasingly ineffective due to the many high frequency devices which are increasingly used in industrial plants, such as microprocessors, digital/wireless data communications, switch-mode power conversion, etc. When higher frequencies are considered, the circuit where the common mode currents flows may not have a "material" connection to close their circulation "loop," which is usually to a reference (such as Ground). This can be understood by considering that, for high frequencies, stray capacitances at that ungrounded end of the circuit have a sufficiently low impedance to close the current loop. The high frequency CM current quite happily creates ground loops by flowing through the air at one or more points along its route, defeating the purpose of the single-point grounding topology.

As a consequence, sensors will almost always suffer from high frequency common mode noise from digital processing, digital/radio communications, switch-mode power converters (off-line as well as DC/DC), and the sampling circuits in their A/D converters. When equipment does not comply with an appropriate EMC specification, these high frequency noises can be very significant and will need to be controlled by (grounding related!) mitigation techniques, such as breaking the high-frequency CM loop (e.g. by the use of high-frequency isolating transformers, fiber optics, CM chokes, etc.); using shielded cables (properly grounded at both ends for radio frequencies); or using circuits more tolerant to common mode currents (e.g. balanced circuits) and others, which generally require a grounding system that is effective up to such high frequencies—that is, an “EMC grounding” as referred before in this article and better considered in the IEC 61000-5-2 and other references listed at the end of this article.

Instrumentation systems with floating power supply are sometimes used for signal transmission because they can help solve common mode current problems by adding high impedance in series with the common mode current loop, notably at low frequencies. However, there is some controversy in using this technique due to maintenance problems (an accidental short to ground can be difficult to identify because the system remains operative whilst its EMI problems might increase) and voltages induced in the signal conductors, which can take high values and make them unsafe.

Temperature measurements systems require special attention due to their noise susceptibility. For thermocouple circuits, it is advisable to use signal conditioning (e.g. 4 to 20 mA or 0 to 10 Vdc) for the signal transmission from the sensor to the control room, placing the signal conditioning circuit (often called a temperature transmitter) as close as possible to the sensor. The cable to connect the sensor to the conditioner should be a shielded twisted pair with a length as short as possible, and the shield should be grounded only at the transmitter (ungrounded sensor), at the sensor (grounded sensor), or at both ends. Sensors with grounded connections to the cable’s shield can be more vulnerable to noise than ungrounded ones. If the environment has a high potential for electromagnetic interference, the use of resistance temperature detectors (RTD) or, even better, infrared thermometers, provides a better immunity to noise than thermocouples.

However, care should always be put on considering EMC under a compromise of different parts and not restricted to a single unique element — if you have a sensor with built-in electronics to connect to a digital bus system (e.g. Profibus), it probably makes little difference whether it is a T/C or RTD sensing element. That is why grounding—interconnecting the whole system—is the key factor to EMC.

## 5. THE GROUNDING SYSTEM AND ITS RELATIONSHIP WITH ENGINEERING PROCEDURES

The primary purposes of the grounding system are to ensure electrical safety and to reduce the occurrence of interference problems. These two issues should be taken fully into account both in the design and installation phases, as well as in the maintenance phase in order to help ensure the correct and reliable operation of automation and control systems.

### 5.1 - Design and Installation: Interference Control Plan

Each facility has its own particularities regarding the specific electromagnetic environment and the characteristics of the automation and control systems, which makes it difficult to use such a simple low-cost “standard design" or “rules of thumb” for the grounding system to cope with all possible EMI scenarios.

The planning of EMC activities is the best cost-effective methodology to answer for both the inherent complexity of such systems and the sophisticated nature of electromagnetic interference problems and their solutions.

The “Interference Control Plan” aims to answer all situations for the occurrence of interference problems:

**a.** By requiring each item of equipment to comply with EMC standards, which cover both the aspect of emission (the equipment constituting a source of electromagnetic disturbance) as immunity (the equipment not being affected to an unacceptable degree by electromagnetic disturbances in the environment). The EMC standard IEC 61326-1 Ed. 2.0 :2012 – “Electrical equipment for measurement, control and laboratory use - EMC requirements” defines the necessary EMC qualification in order to guarantee that units of equipment are suitable to operate correctly in a wide range of installations.

**b.** By completing the EMC needs for that particular installation through a proper design of the grounding system. This work is carried out through an EMC Analysis, where a matrix for the EMI risk situations relating the various sources of EM disturbances (internal and external to the system) and the susceptible circuits is developed and all the would-be EMI situations are mitigated, supported by EMC-recommended practices and guidelines as published by IEEE and IEC, or others.

### 5.2 - Maintenance: EMC Procedures

Every Industrial Plant with a few years of existence undergoes changes in its initial design installation: data acquisition systems are modified, new equipment and its controls are changed, new technologies come into place, accidental and/or broken connections or loose contact occurs, to mention some usual facts.

As a consequence, there must be specific “EMC Maintenance Procedures” to guarantee the performance of the automation and control systems against the constant changes in their electromagnetic environment and the maintenance personnel needs to complete and adapt these electromagnetic interference control procedures according to the new technologies that come in use during the operational lifetimes.

The “EMC Maintenance Procedures” should include:

**a.** EMC Records – addressing the set of measurements to be made throughout the year, such as power quality, electromagnetic fields intensity, electrical continuities, surges, etc., as well as a detailed description of eventual occurrences in the Plant due to lightning, equipment failure, etc.

**b.** EMC Guidelines – addressing the methodologies, requirements and technologies related to EMC to be applied in the plant over time.

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# Cost-effective EMC Design by Working with the Laws of Physics

**KEITH ARMSTRONG**
Cherry Clough Consultants

*Note: The following are questions and answers related to Keith Armstrong's Interference Technology webinar, Cost-effective EMC Design by Working with the Laws of Physics, which took place Nov. 27, 2012. To view this webinar, visit www.interferencetechnology.com.*

## Q1. WHAT ARE THE SLEW RATES IN DIGITAL CIRCUITS THESE DAYS AND WHAT KINDS OF FREQUENCY SPECTRA ARE GENERATED?

**A1.** The slew rates of the digital signals generated by integrated circuits tend to increase as the silicon feature sizes used in their chips tend to decrease, according to Moore's Law.

For example, HC logic chips, when originally introduced in the 1980s, usually had output pins with rise and fall times measured in a few nanoseconds (ns). However, the exact same IC part numbers purchased in 2012 have rise and fall times under 0.5ns. When PCI Express was first introduced nearly 10 years ago, the typical rise and fall times of its IC's output pins were 100 picoseconds (ps); now they are significantly less.

The usual way of deriving the frequency spectrum associated with a square wave having a certain rise time (tr) is to understand that the spectrum of a square wave only contains odd harmonics of the fundamental, and their amplitude reduces at the rate of 20dB/decade of frequency. However, above a frequency that is calculated as 1/πtr, the harmonics reduce as frequency increases at the rate of 40dB/decade. Here is a figure, taken from one of my PCB EMC training courses, showing how the envelope of the frequency spectrum changes for a 100MHz clock with different rise/fall times.

Below are simulations corresponding to the above figure, frequency range 10MHz -10GHz.

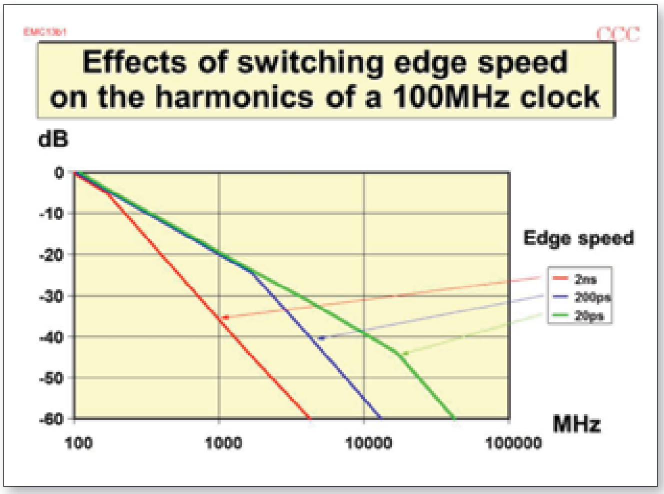
100MHz clock with 2ns rise/fall times
100MHz clock with 0.2ns rise/fall times
100MHz clock with 20ps rise/fall times

2ns is where we were in the 1990s; these days we are generally around 0.2ns, but the 22nm chips are probably faster than that. In a few years' time we will have to deal with 20ps rise/fall times.

The above is fine when we know what the value of tr is, but the data sheets for ICs only state the maximum value and the real values are always less than this, and will reduce as time goes on and the silicon chips inside them are replaced by die shrunk versions (according to Moore's Law).

It seems the only reliable way to determine the rise/fall times and/or frequency spectrum is to measure one and calculate the other based on the 20dB/40dB per decade frequency breakpoint being at 1/πtr.

To measure rise/fall times, it is easiest to equip our PCBs with some of its ICs' digital output pins connected directly to miniature coaxial connectors of a type that match our oscilloscope's probes, and use an oscilloscope and probe set that has a bandwidth




much greater than we expect. So, for example, if we want to be able to measure rise/fall times of 0.2ns, we must use a 'scope and probe bandwidth that is at least 3GHz.

However, generally, when I'm asked to help solve EMC problems, the PCBs aren't fitted with miniature coaxial connectors in the appropriate places, so I use a small close-field magnetic loop probe and hold it against the body of the ICs, measuring its output with a spectrum analyzer having more than enough bandwidth (e.g. 3GHz in the case of 0.2ns rise/fall time).

When we hold a close-field loop probe very close to an IC or PCB trace, we pick up some of the differential-mode (DM) fields that are the actual signals or power currents, so these measurements don't indicate an EMC problem. As I said in my webinar, it's when the probe picks up significant levels of noise far from the ICs, traces, etc., that we have problems because this shows that we have a poor EMC design that permits stray currents to flow in large loops – usually common-mode (CM) noise.

With a small enough probe, we can move around the body of an IC and see the spectrum of the signals used in its core logic in one area and the spectrum of the output driver signals in another.

The advantage of using the "small close-field loop probe held against the body of the IC" method is that we can see the frequency spectra of the IC's digital operations directly, which is what we need to know for our EMC design techniques. And, we don't need to worry about using coaxial probes. (Remember: any 'scope probe that has a flying ground lead is useless for measuring above a few 100MHz.)

Actually, we can also use a "pin probe", which has a small capacitor in series in its tip and no ground lead at all, to connect directly into a spectrum analyzer and determine the spectrum associated with each output pin.

Please note that the ever-continuing die shrinks (Moore's Law) have two implications:

1) EMC design is always changing, becoming more difficult as the noise emissions frequencies increase, so cost-effective design techniques are always changing, year to year.

2) Serially-manufactured products that comply when tested one year, might fail in two or more years' time, when all of its digital ICs are using new die-shrunk silicon chips. For this reason, many volume manufacturers have their own EMC test departments that test each and every one of their products that are in serial manufacture, at least once per year.

So, to design products that will pass their EMC tests in serial manufacturer at least 2 years from now, we should expect the rise/fall times we measure to get shorter and their frequency spectra to get higher, and design accordingly. Often, this means that our bosses complain that we have over-engineered when our new design passes its EMC tests with very good margins and we have to explain to them that this is to ensure that we don't have to re-design them when the chips suffer their next die-shrinks, as they will within the next two years.

The core logic of microprocessors and FPGAs has always switched much faster than their output drivers. For example , Xilinx Vertex 2 FPGAs used to have power supply transient currents on their core logic rails that had durations of 15ps (i.e. rise up and fall down in 15ps)! Since Vertex 2 was about 5 die-shrinks ago (current Xilinx FPGAs are Vertex 7) we should expect the core logic power supply noise currents to have much shorter rise/fall times, i.e. a bandwidth much greater than 20GHz. So, as well as signal rise and fall times, we need to design our power rails accordingly so as not to suffer excessive emissions from them.

## Q2. WHAT BOOKS DO YOU RECOMMEND FOR EMC DESIGN AND MITIGATION?

**A2.** Obviously, I'm going to recommend my own books (see below)!

But in all seriousness, I do think my books are very good for the practicing electronic design engineer because they are based on the material I have developed during nearly 20 years of training design engineers worldwide.

All my courses have received approval ratings of at least 80 percent from the attendees, so I know they find my courses practical and useful, and I have received a lot of very positive feedback from designers when they put my training material into practice.

*EMC Design Techniques for Electronic Engineers*

Nutwood UK November 2010, ISBN: 978-0-9555118-4-4, full colour graphics throughout.

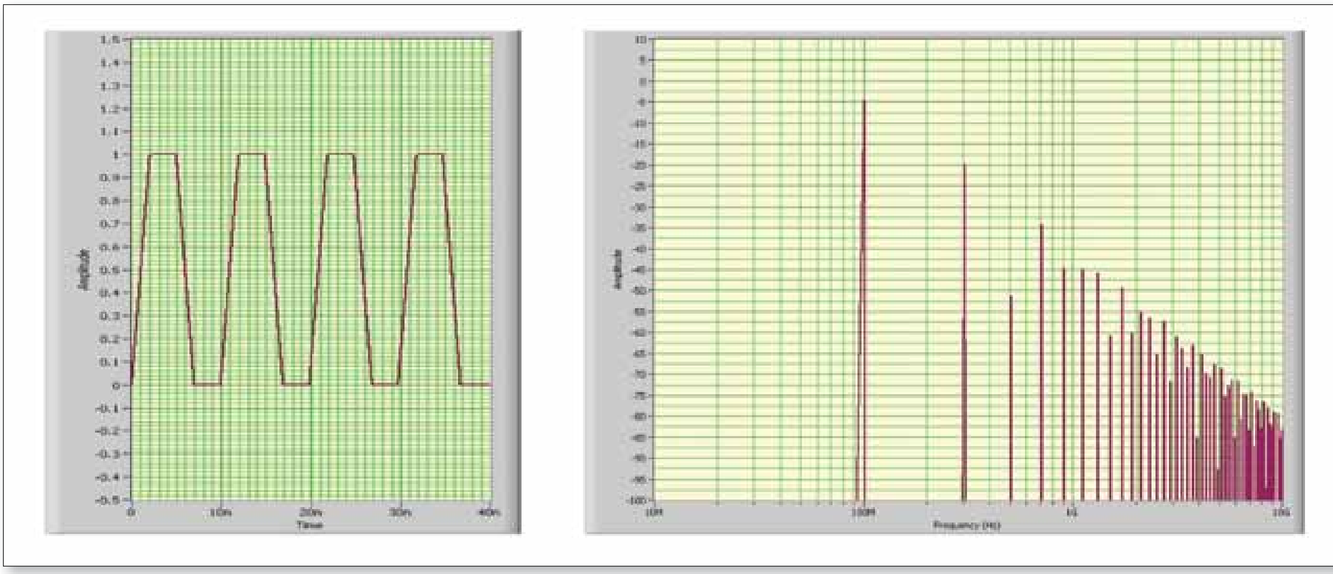
Order from www.emcacademy.org/books.asp

Covers all electronic applications, with a very practical approach to good design practices that will save time and cost, reduce time-to-market, and reduce warranty costs and financial risks.

(Chapter 2 of this book is the complete text of *The Physical Basis of EMC* (below), so don't purchase both of them!)

*EMC for Printed Circuit Boards – Basic and Advanced Design and Layout Techniques*

Nutwood UK December 2010, ISBN 978-0-9555118-5-1, full colour graphics throughout.



(2nd edition, identical to 1st edition except for the book's format)

Order from www.emcacademy.org/books.asp

Practical good-practice EMC design techniques for printed circuit board (PCB) design and layout for designers of electronic circuits and PCB designers themselves. All application areas are covered, from household appliances, commercial and industrial equipment, through automotive to aerospace and military. This book is used by some university courses.

*The Physical Basis of EMC*

Nutwood UK October 2010, ISBN: 978-0-9555118-3-7, full colour graphics throughout.

Order from www.emcacademy.org/books.asp

Provides an understanding of electromagnetic phenomena in a way that can be easily understood by practising electronic engineers.

(Chapter 2 of my book *EMC Design Techniques for Electronic Engineers* (above) is the complete text of this book, so don't purchase both of them!)

My good friend Tim Williams also writes very practical books, so I can recommend his book:

*EMC for Product Designers, 4th Edition*

Newnes, December 2006, ISBN: 0-750-68170-5.

Tim's book has received very good reviews and sold many copies worldwide since its first edition was published in (I think) 1992, and is used to teach EMC in many universities.

However, all books are always somewhat behind the times, and, given the fast pace of integrated circuit silicon die-shrinks (see Q1 above), if you want the latest good design practices, you need an up-to-date training course.

## Q3. SHOULD A GROUND MOAT BE USED ACROSS A SIGNAL TRANSFORMER?

**A3.** I'm assuming that we are discussing an isolating signal transformer with at least one side suffering from RF noise that we don't want to cross over to the other side.

Yes, if the primary and secondary circuits are rigorously segregated (separated from each other) on the PCB, having a ground moat in-between them can help reduce the crosstalk between the traces and so improve the RF isolation of the transformer. However;

a) If the transformer windings themselves don't achieve at least as much RF isolation (i.e. RF noise attenuation) as you need to achieve, a ground moat isn't going to magically improve it!

It may be necessary to add a CM choke and/or other CM-attenuating devices, such as shunt capacitors to the local RF Reference (see below), or reverse-connected CM chokes. Where balanced differential signals are used, additional CM attenuation can be achieved using center-tapped primary and/or secondary transformer windings, or center-tapped autotransformers.

b) The ground moat must have very low impedance at the highest noise frequency that we need to attenuate—let's call it fmax. Assuming this is higher than a few MHz, our moat must be "RF bonded" (see below) to its RF Reference Plane (see below) with via-holes all along its length if it is thin, and all over its area if it is wide.

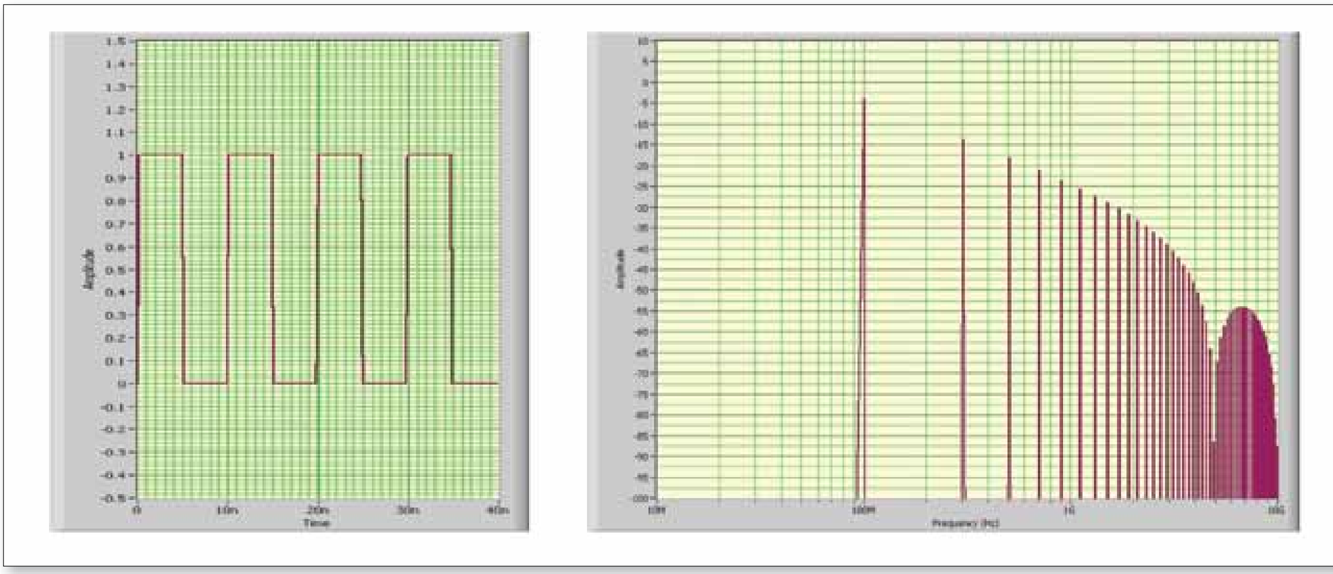
RF Bonding:

The general rule for RF bonding is that the bonds must be short and make multi-point connections to an RF Reference Plane (see below) that are effective at up to fmax.

To be at all effective for frequencies up to fmax, the length of each bond and the spacing between adjacent bonds must be no larger than one-tenth of the wavelength at fmax (preferably a lot less).

In air, "one-tenth of the wavelength at fmax" is the same as 30/fmax, where fmax given in MHz gives the bond spacing in meters and fmax in GHz gives bond spacing in millimeters.

But the dielectric constant, k (i.e. the relative permittivity) of the PCB material means that EM waves propagating inside the PCB have shorter wavelengths (actually $1/\sqrt{k}$)



than the same frequency propagating in the air.

Assuming a PCB dielectric constant of 4.0 (typical of FR4 above 1GHz and a good enough approximation above 100MHz), the via-holes that pin the moat to the solid ground plane must have a length and spacing no greater than 15/fmax (fmax in MHz gives via spacing in meters; fmax in GHz gives via spacing in millimeters).

However, "one-tenth of the wavelength at fmax" is simply the bond length and spacing to use to be sure that resonant effects aren't going to cause gain when you are hoping for attenuation. To get good attenuation, RF bond length and spacing must be much less than one-tenth of the wavelength at fmax. The more attenuation we want, the shorter the bond's lengths must be, and the closer their spacing.

For example, if we want the moat that is the topic of this question to just about function as a moat up to 1GHz, then it should be via'd to the RF Reference Plane on a different layer of the PCB with vias spaced no more than 15mm apart (the PCB's thickness is always going to be much less than 15mm, so the via length is adequately short).

However, I would always recommend less than one-fifth of that (3mm), and, why not, 1mm—after all, vias don't cost anything (well, not really).

There can even be an advantage in placing the RF Reference Plane one layer below (or above) the moat so that the via (RF bond) lengths are minimized. Where a moat trace is on an inner board layer, there can be advantages in using two RF planes in parallel—one on the layer above the moat and one on the layer below.

RF Reference Plane:

A solid (i.e. no gaps or splits) copper PCB layer that is as large as possible, often covering the entire board area and ideally extending beyond all of the components and traces on the board by as far as possible.

This is a much better term for a PCB plane that is used for EMC purposes, than "ground plane" or "0V plane," because it helps avoid confusing EMC design issues with safety grounding or circuit DC potentials – confusion that has delayed many design projects.

## Q4. IN THE CASE OF A PRODUCT WHICH HAS A METAL ENCLOSURE AND SHIELDED CABLES:

## 1. IS IT RECOMMENDED TO CONNECT THE METAL ENCLOSURE TO THE 0V REFERENCE PLANE?

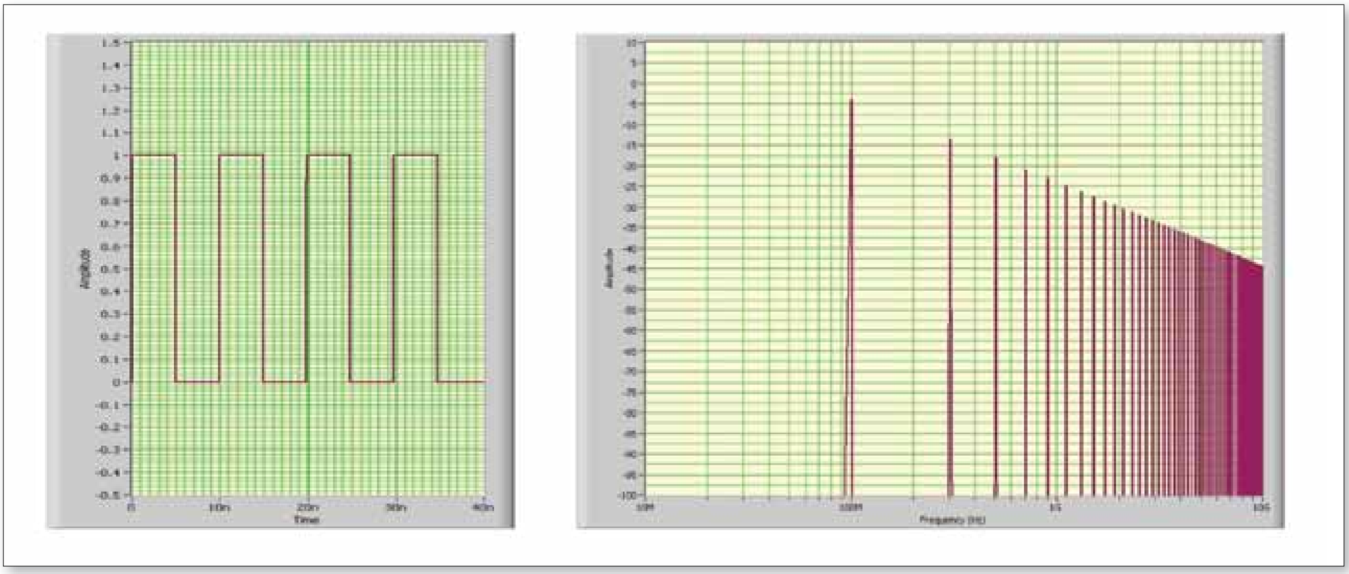
## 2. FOR SHIELDED CABLES, WHERE TO CONNECT THE SHIELD OF THE CABLE --> TO THE METAL ENCLOSURE, OR TO THE 0V REFERENCE PLANE?

**A4.** To answer both questions, we need to understand how best to use metal (or metallized) enclosures as shields and how to connect them to cable shields, filters, and PCB RF Reference Planes (I sometimes call them 0V Reference Planes too, because they are usually at the circuit's 0V DC potential. However, they don't have to be at 0V so we should always try to call them RF Reference Planes to avoid missing good opportunities for improving cost-effectiveness by thinking they ought to be at ground or 0V potential).

This requires that we understand the "Skin Effect" – the way that AC currents flow closer to the surface of a conductor as the frequency increases.

I presented 47 slides during my short webinar, but the whole presentation has 58 slides – the slides numbered 50-58 briefly describe the skin effect, and show how correct RF-bonding between metal enclosures, cable shields, shielded connectors and cable filters uses the skin effect to try to ensure that external surface currents (CM RF currents picked up by conductors from RF fields outside the metal box) flow only on the outside of the metal surfaces, giving the best RF immunity that is possible given the other aspects of the EMC design (e.g. the quality of the cable shield).

Also, these slides show how correct RF-bonding between metal enclosures, cable shields, shielded connectors, cable



filters and PCB RF Reference Planes, uses the skin effect to try to ensure that internal surface currents (CM RF currents generated by unbalanced signals and unbalanced stray couplings for circuits inside the box) flow only on the inside of the metal surfaces, giving good RF emissions.

Essentially, we provide short—low impedance—return paths for the CM currents, so they naturally 'prefer' to flow along them and improve our EMC. And, we use the skin effect to increase the impedances of the alternative current paths, that we don't want CM currents to flow in, increasing the percentage of CM current that flows in the short loops that we want them to.

The figures in my slides 50-58 imply that it is possible to get 100 percent of the CM current to flow where we want them to. If we want 100dB of shielding (or filtering), this means we must ensure that 99.999 percent of the external CM currents stay outside the box, and 99.999 percent of the internal CM currents stay inside. This is only achievable at significant cost and by paying great attention to every design detail. Most shielding and filtering in commercial and industrial products needs to achieve around 40dB or so, i.e. 99 percent diversion of CM currents.

I've used the terms "RF bonding" and "RF Reference Plane" in this answer, and they are briefly described in my answer to Q3 above.

It is important to note that the same EMC design techniques are effective when we don't have a metal enclosure, providing that we design our PCB's RF Reference Plane well-enough. We treat the edge of the RF Reference Plane as if it were the wall of a metal enclosure.

It isn't as good as having a well-shielded metal enclosure, but we have various PCB EMC design techniques that can make it almost as good, not least using board-level shielding using what are often called "tin cans" soldered to the PCB's RF Reference Plane (although there are modern board-level shielding techniques using plated plastics, which are not tin cans).

## Q5. HOW ARE DC SIGNALS PERCEIVED AS EM WAVES?

**A5.** They aren't EM waves, because by definition a DC signal (or power) is unchanging, so there can be no wave propagation going on.

It is important to understand that fluctuating DC cannot exist—anything that fluctuates is actually AC. We designers often use the term "DC" rather too loosely (rather like the way we use the term "ground" too loosely), leading to design confusion, delays and increased costs.

At the instant of connection of a DC voltage to a load, a transient current flows through the conductors (wires, PCB traces, etc.), charging up their capacitances. This transient current is AC, and is actually a propagating EM wave that generates fluctuating EM fields (magnetic and electric) as it travels along.

Afterwards, the current is DC and there is no more propagating EM wave. The EM fields are static instead of fluctuating.

If you want to think about electricity as electrons flowing along conductors, then continuous AC currents are associated with electrons jiggling back and forth and going nowhere overall. AC current (which includes transient currents) travel at the speed of light in the medium, which is about 300,000 kilometers per second for a bare wire in air, and about 210,000,000 km/s for a wire with a thick layer of PVC insulation.

Continuous DC currents, on the other hand, are associated with a continuous flow of electrons from the negative terminal to the positive terminal, travelling at a velocity of about 4 kilometers (about 3 miles) per hour (i.e. about walking speed)!

As I said at the start, a problem with understanding the above is caused by our electronic designer jargon. We often talk about a DC voltage or current when what we really mean is the few microseconds of unchanging (flat) voltage when a digital signal has settled down to a logic 1 or 0 after its transient overshoots and ripple have died away to acceptably low levels. Or, we talk about the "DC current" that an IC draws from its DC voltage rail, but what we really mean is a waveform with a frequency spectrum that includes lower frequencies, maybe even all the way down to 0Hz—but not true DC.

Designers often mislead themselves when they talk about a DC voltage rail—it tends to suggest that the currents that ICs draw from the DC rail are DC currents, when in fact with modern digital electronics, they are actually quite powerful RF currents plus a DC component, which is why we must be careful to decouple our DC rails properly at radio frequencies to control emissions.

### Q6. WHAT DO YOU THINK ABOUT USING A REDUCING EMI SPREAD SPECTRUM CLOCK OSCILLATOR, LIKE THE ONES MANUFACTURED BY MERCURY ELECTRONIC?

**A6.** This isn't really a question related to the subject of my webinar.

I am not familiar with the spread-spectrum clocks made by that company, but the technology has been around and commonly used to reduce the emissions—as measured by many of the standard EMC tests—for well over a decade.

Spread-spectrum clocking of synchronous digital circuits is a powerful technique that I generally recommend, when asynchronous processing devices are not used for whatever reason.

It is important to remember that it only works where the EMC emissions test standard that will be applied uses Quasi-Peak, Average, RMS, or other integrating-type detectors. Some military and telecommunication emissions test standards use Peak detectors, which have a 1μs response time and so are not "fooled" by spread-spectrum clocking.

Using asynchronous logic devices (sometimes called 'naturally clocked', or 'handshaked') is very much better than spread-spectrum for reducing emissions.

The total amount of radiated energy (all else remaining the same) is usually about one-tenth of the same amount of digital processing in a synchronous-switching (i.e. clocked) circuit, giving a 20dB reduction straight away. However, the most significant issue is that the emissions from an asynchronous logic circuit are spread all over the spectrum instead of being confined to the clock frequency and its harmonics, so the measured emissions levels are truly very low indeed, regardless of the type of detector used in the EMC receiver or spectrum analyzer.

(If you are not aware of asynchronous digital processors, they are used in hundreds of millions of smartcards, in most (if not all) cellphones, and are used for the core processing in powerful ICs from the Pentium IV on.

### Q7. IS THERE A SIMPLE METHOD TO CHOOSE A FILTER FOR A GIVEN PURPOSE?

**A7.** No. Sorry!

However, we can use appropriate design techniques based on the CM and DM impedances of both the source and load circuits, and the CM and DM attenuations we want our filters to achieve, to get into at least the right ballpark.

The problem is that the CM impedances and amounts of CM noise to be filtered are all caused by various kinds of tiny imbalances, and we generally don't know what they are with sufficient detail and/or accuracy to design our filters accurately. "Ball-park" (i.e. in the right order of magnitude) performance is actually pretty good!

We can use full-blown 3D Field Solvers to analyze all the imbalances in the various conductor structures in our designs (including inside the components) to accurately predict CM and DM levels, spectra and impedances and get filtering right first time—at significant cost per seat.

Or, we can aim to get in the right ballpark and leave ourselves with room to maneuver in our filters' PCB pad patterns or the panel space we provide for them, then do pre-compliance EMC testing at the earliest opportunity to determine what filters we actually need.

Most manufacturing companies are missing an important trick by not investing in costly 3D Field Solvers and training in how to use them. As a business investment, they can easily pay back their cost within one year, on the first project they are used on, by shortening the overall project timescale by the time that would otherwise have been spent in iterating the design to pass its functional and EMC specifications. (But of course, if design iteration isn't on the Critical Path because something else delays market introduction, then a field solver won't improve competitiveness by as much as it could.)

Note: A survey by a major international accountancy firm found that, since 2000, the greatest impact on the profitability of a new electronic product was its time-to-market.

Not its BOM (Bill Of Materials) cost, which was in second place!

### Q8. ARE X2Y CAPACITORS ARE AS EFFECTIVE AS ADVERTISED? ARE THEY EASY TO DESIGN AROUND?

**A8.** Like Questions 6 and 7 above, this question isn't related to the subject of my webinar.

X2Y capacitors are well-balanced internally, using three sets of plates and four sets of terminals, so they have a much lower equivalent series inductance (ESL) than ordinary capacitors (two plates, two terminals).

I understand they might even have lower ESL than three-terminal two-plate capacitors, but this is not a very helpful comparison because X2Ys cannot be used as feedthrough capacitors like three-terminal capacitors.

Being very well-balanced, an X2Y can be very much more effective at reducing CM noise or decoupling a PCB power plane, than several 'ordinary' components, especially at frequencies above about 300MHz.

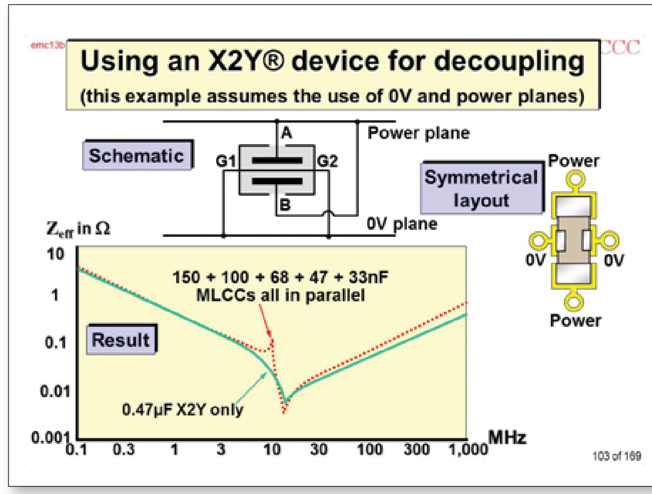
Sadly, I've not (yet!) had the opportunity to use X2Ys in a project, but the X2Y website (www.x2y.com) has many papers comparing their products with others in real applications using regular EMC measurements, and they seem genuine enough. I've had the opportunity to work with X2Y on a few occasions, and they seem to me to be a solid company with an excellent product. I understand that General Motors prefers X2Ys to be used to suppress windscreen wiper motors, where they replace a much larger and more costly assembly and give better suppression.

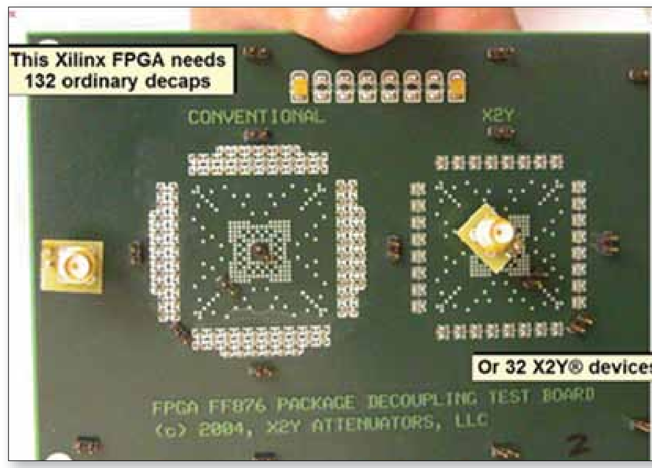
Because they are not (yet) purchased in high quantities, most X2Ys cost more than the equivalent ordinary capacitors, but because they can replace several ordinary components and save board space, their overall cost is often lower. If you can use the value(s) of X2Ys that GM's electronic suppliers purchase and source them from the same X2Y manufactures, their unit costs should compare quite well with ordinary capacitors of the same size and value!

When designing with them it is very important indeed that they are used in balanced, symmetrical arrangements of conductors (whether PCB traces or wires). They rely on splitting their 'ground' current equally between their two G terminals, so if the pad/trace/via hole/plane structure associated with G1 has a different impedance than the pad/trace/via hole/plane structure associated with G2, the part will not work as well.

What this means in practice is that the board layout for an X2Y must be symmetrical about an axis through the middle of the device passing through it's A and B terminals. Rotating the device and its pad patterns about its vertical axis must look no different.

Here are two relevant figures from one of my PCB EMC training courses:




I can't say what I have found by using X2Ys, because I haven't used any yet! As far as I can tell though, they really do what they claim to, as long as their design rules are followed correctly. And, I've never heard or read anywhere—ever—that X2Ys are not as good as their manufacturers claim they are.

## Q9. WHAT IS THE PURPOSE OF A BONDING TERMINAL ON A 19 INCH METAL CHASSIS IF UNWANTED SIGNALS DON'T FLOW TO GROUND?

**A9.** Bonding terminals are provided on racks, frames and cabinets so that wires or braid straps can be fitted—like those visible in the photograph on slide 31 of my presentation—to provide small, local, low-impedance return paths for the stray CM currents that have coupled into the external metalwork. The CM currents 'prefer' to flow in these local paths to return to the electronic components that created them, instead of spreading themselves around more widely by flowing in larger loops with higher impedances—this reduces their radiated emissions.

Most cabinet manufacturers assume that "single-point-bonding" is required, so if left to themselves they provide bonding terminals that are too few and in the wrong places. This has been a poor EMC design practice since before 1980.

Each electronic unit or cable is a source of CM currents into the cabinet they are contained within, so each needs at least one local strap to return CM currents. The principles of RF bonding I outlined above apply to this situation too, so we can see that—for example—using two cabinet straps each 150mm long, spaced apart by 150 millimeters, we can't expect to reduce the emissions of CM currents at wavelengths that are shorter than 1.5 meters (i.e. have frequencies above about 200MHz). At the frequency where the straps are either a quarter or a half of a wavelength long (either 500MHz or 1GHz, in this example), we can expect them to resonate and actually increase CM emissions.

Analyzing the frequency limitations of such cabinet-RF-bonding straps tells us that we had better design our electronic units and their cables to have low CM emissions above certain frequencies (200MHz in the above two-strap example), or else provide improved RF bonding between the units and their cabinets, e.g. by using conductive gaskets. Another way in which we deal with EMC design issues early in a project where design changes cost least and cause lest delay.

(Remember not to confuse RF bonding points on a cabinet with the bonding point (or points) that are provided for safety earthing/grounding. It may be possible to combine these two functions for some of them, with careful design.)

**Q10. GROUNDING STRATEGY OF CIRCUITS CAN IMPROVE EMC, I THINK. BUT, YOU MENTIONED THAT CONNECTING TO SAFETY GROUND HAS NO EFFECT ON EMI. COULD YOU EXPLAIN IT MORE?**

**A10.** I think I covered this well enough in my webinar when I said that all currents, including stray CM currents, always flow in closed loops. This is a Law of Nature (or Law of Physics, if you prefer) and one of Maxwell's famous equations.

Given that all currents flow in closed loops, there can never be any such thing as a "noise sink," so the common idea that noise can be "shunted away into the safety ground" is just plain wrong and always has been.

Any current that flows into a safety ground network, or even into a safety grounding rod stuck in the soil, must flow back out of that network or soil again at some point to complete its loop.

Because stray CM noise currents are ultimately generated by the electronic activities happening in semiconductors in our transistors and ICs, which cause our wanted signals and power, they have to flow 100 percent back in closed loops to those same semiconductors. They generally take multiple parallel paths (i.e. flow in multiple parallel loops), through air, PVC, fiberglass and along copper and other types of conductors—the current in each loop being inversely proportional to the impedance of that loop.

Good EMC design for stray noise currents thus consists of raising the impedances of the loops that we don't want them to take (e.g. by using skin-effect shielding, RF-bonding and CM choke filters) and lowering the impedance of the loops that we do want them to take (e.g. using skin-effect shielding, RF-bonding, and shunt capacitor filters).

In the PCB example I used in my webinar, the issue was the emissions from a PCB and its cables caused by poor EMC design. Good EMC design provided small, local, low-impedance paths for the RF CM currents to flow back to the circuits that emitted them, so they didn't flow along the cables and cause excessive conducted or radiated emissions.

The safety ground wire in the mains cable might play a part in providing local loops for some of the CM currents generated by the PCB's circuits, because it is a conductor like any other. However, my whole point was that because all currents always flow in closed loops, the path back through the ground conductor in the mains lead to a ground rod stuck in the soil under the building has nothing to do with reducing emissions.

There is no such thing as a sink for RF noise currents, and never has been. Neither the safety ground, nor anything else, has ever been somewhere that noisy unwanted currents could be dumped into and forgotten.

However, many designers who thought they were providing improved paths to 'dump the noise into the ground' were actually providing smaller, more local loops for CM currents to flow in, without realizing that this is what they were actually doing.

They saw some reductions in emissions and thought that this was because the noise was flowing into what they called "the ground" and being lost (they may even have thought that the noise was flowing into the safety ground rod that was stuck in the soil, and being lost in the mass of the planet)—but neither is possible, at least not in this universe.

In systems and installations, where there are two or more interconnected electronic units, because of poor EMC design there were often high levels of CM currents flowing along their signal interconnections (the signal cables themselves convert some of the wanted DM currents into unwanted CM noise, which is measured as their Longitudinal Conversion Loss, LCL, which varies with frequency). Adding CM chokes to the signal cables generally helped, but was not a universal solution, because:

- if the cables were not of high-enough quality we sometimes reached a point where the wanted signal became too degraded before the emissions had been reduced by enough
- there were sometimes weight, cost or accessibility issues associated with adding a sufficient number of CM chokes, especially in large installations with hundreds of long cables, which needed CM chokes adding every meter or two of their length.

The photograph below is an extreme example of CM-choking. I've included it as a sort of a joke, really, but nevertheless it is a real installation (although not one of mine!).


The safety ground wires in the unit's mains cables, and the metal structure of the building they were installed in, provided the return paths for the stray noise current loops, and so, when trying to reduce their noise emissions, we generally found that improving the RF bonding between all of the units' chassis (and/or their PCBs' ground/0V planes) and their local support metalwork would reduce emissions. This had the advantage of costing less than clipping dozens, sometimes hundreds, of split-core ferrite chokes to most/all of the cables.

What was really happening was that we were providing smaller, lower-impedance loops local to the units and their cables using existing support metalwork that just happened,

for safety reasons, to be connected to a ground rod that was stuck in the soil under the building. IEC 61000-5-2 calls this technique of RF-bonding support metalwork, "creating a Common Bonding Network (CBN)." This is the point of slide number 30 in my webinar.

Having got hold of the wrong idea—that the mass of the planet would somehow absorb the noise currents—this was often wrongly assumed to be the reason why improved RF-bonding to the metalwork reduced the noise emissions.

However, we also generally found that routing the interconnecting cables along the metal supports, once we had improved the units' RF-bonding to them, would reduce emissions by significantly more. This could not be happening if the noise currents were really being shunted into the mass of the planet via the ground rod that was stuck in the soil. It could only work if what we were really doing is making the stray noise current loops smaller in area. This, of course, is what was really going on, and is the reason why IEC 61000-5-2 (for example) strongly recommends using metal cable trays, trunking, ducts and conduits as the return current paths for the stray currents of the cables they carry.

Safety grounding only works because currents always flow in loops, too. One terminal of the AC mains supply to a building is connected to a ground rod stuck in the soil at the building's utility entrance. We call this grounded AC supply terminal the Neutral. All of the ground wires in all of the mains cords that have them are also connected back to this ground rod, and therefore so are all the chassis of the units powered by those cords. All of the building's metal structures are also connected back to that ground rod.

When an insulation fault occurs in a wire or cable carrying AC power, it either flows from the live wire to the neutral wire creating a closed current loop (that we call a short-circuit) that opens the line fuse, or it flows into the local metalwork. The safety-grounding of all of the metalwork then creates a closed current loop all the way back to the ground rod and the AC mains supply, creating a short-circuit that blows the line fuse, preventing electric shocks from being caused by live chassis.

The ground rod in the soil has nothing to do with the safety function I have just described. It is there so that if lightning strikes the building or near to it, the metalwork does not attain a voltage that is too high above the potential of the soil. This is to try to prevent serious electric shocks.

(Lightning currents also flow in loops, but although I am assured that this is so by lightning experts, they are not as obvious to electronic engineers like me, so I won't attempt to describe how they work.)

## Q11. HOW CAN WE SEPARATE CM AND DM NOISE BY OSCILLOSCOPE

**A11.** Another question that is not associated with the subject of my webinar!

The only two ways I know, whether using oscilloscopes or spectrum analyzers, are:

a) By using current monitoring clamps, such as those made by Fischer Communications Corp.

They aren't very costly, and by clipping them around a cable (or wire bundle) that contains all of the send and return conductors for wanted signals or power, we then connect the clamp's output into a spectrum analyzer or oscilloscope to see and measure the CM current on that cable (or wire bundle).

Clipping a current monitor clamp around just the send or return conductor for a given signal or power measures all of the DM signal current plus a proportion (half or less) of the CM noise current. Often, the CM noise is such a tiny fraction (0.1 percent or less) of the DM signal that it cannot even be seen in such a measurement.

Current clamps are available from various manufacturers in various diameters and frequency ranges to suit different sizes of cable and bundles. They are also variously limited in the amount of DM power they can handle when measuring CM noise (e.g. when measuring mains cords).

b) Some Line Impedance Simulation Networks (LISNs) for measuring EMC emissions on mains cords (which other EMC standards might call V-Networks or Artificial Mains Networks, AMNs), are available with additional internal transformers that create the sum and differences of their usual outputs to provide additional CM and DM outputs.

There used to be at least one supplier of a transformer that could be fitted external to a LISN, to convert its usual outputs into DM and CM signals.

Oscilloscopes can sometimes be preferable to spectrum analyzers for analyzing emissions, because they directly show the time relationships in the noise waveforms and so can make it easier to determine which circuit activities are creating them.

We can of course do the same type of analysis with spectrum analyzers, but it requires identifying the repetitious frequency spacing typical of a harmonic structure, then trying to determine its fundamental frequency and hence the circuit operation that is the cause of the emissions.

Both methods have their advantages and disadvantages, especially when there are multiple potential fundamental frequencies (e.g. several different digital clocks that are not spread-spectrum, see Q6 above) all contributing to a general mish-mash of noise.

In the case of a general noise mish-mash, it can help to observe using an oscilloscope, triggering the 'scope of each suspect clock frequency in turn. With the trigger settings adjusted correctly, if that clock is a source of noise, its contribution to the mish-mash will stabilize on the display, leaving all the other noises untriggered and so just a blur. Going around all the clocks, triggering one each in turn, can help establish which circuits and devices are causing the most emissions.

# Why Should we Consider EMC (and Safety) Early in the Design Stage?

**J M WOODGATE**
BSc(Eng) CEng MIET MIEEE FAES
J M Woodgate and Associates

## A SHORT HISTORY OF A HALF-MILLION DOLLAR LOSS

**April 2 2013**
**From:** Compliance (JH)
**To:** MJ54 Team Leader (BB)
**Subject:** MJ54 tests

*Not good news. Model for testing (MFT) failed several EMC tests, and there are safety issues as well. Details in a following message. Can we discuss?*

**May 30 2013**
**From:** BB
**To:** JH
**Subject:** MJ54 tests
**cc:** Manager, R&D

*I regret the delay in our discussion due to our incompatible schedules.*

*Your proposals for MJ54 are simply unacceptable; a $5 on-cost and a redesign of the PC board and enclosure to accommodate the larger EMI filter compromise both the costing and the time-scale already submitted to Marketing and approved. In addition, the bandwidth reserve of stage 1 has been reduced to such an extent that conformity with specification cannot be assured in production.*

**July 31 2013**
**From:** Manager, Compliance
**To:** Manager, R&D
**Subject:** MJ54

*After investigation, I confirm that the measures requested by JH are fully justified and essential. I also consider it most regrettable that both JH and BB are under suspension as a result of an altercation admittedly instigated by BB.*

**Sept. 29 2013**
**From:** VP Marketing
**To:** VP R&D
**cc:** President
**Subject:** MJ54

*The increased cost and revised time-scale that you have submitted make the product unviable. In addition, our original request to include BGQQ compatibility if possible, which you declined to fulfil, is no longer an option. Acme and two other competitors now have products with full BGQQ compatibility at prices 10% lower than your original costing indicated.*

Could this happen to you? It's happened many times in the past, and there are still organizations that haven't heeded the lesson.

## ELIMINATE CONFLICT

This is the principle which guides us to the way to avoid such disasters. There isn't just one conflict, there are many:

- conflict on design; changes necessary to attain EMC (and/or safety) compliance can easily compromise the achievement of specification compliance;
- conflict on costing; imposing changes at a late stage attracts development re-work costs and often a significant increase in product cost;
- conflict over delay; with ever-decreasing product life-times, even in the professional product field (consider oscilloscopes, for example), scheduled annual product portfolio reviews by large distributors and agents, increasing demands for interoperability (often achievable at very marginal cost by the use of newly-developed devices which integrate many functions in a single package), any significant delay threatens product viability;
- interpersonal conflict; doubt may easily grow, through frustration, and even be fuelled by managerial questioning or disapproval, that some part of the compliance-related critique is unjustified. This conflict can be between designer and compliance engineer or between design engineer and design management (you didn't give me enough training/time/test equipment/support, or all of them), and very often both occur.

## RESOLUTION WITHOUT (MUCH) REVOLUTION

The way to remove conflict is to reassign responsibilities, but that requires preliminary steps. First, design engineers need to be trained to take EMC (and safety) into account at the design stage. It isn't that difficult to apply good EMC (and safety) design principles, once you are trained to know what they are. Equally, it's clearly impossible to apply them, except by pure chance, if you don't know what they are.

It's not expected that designers should of necessity become highly expert (some will), but they can become sufficiently expert to function correctly, with support from the compliance engineers during development. The latter must know, and pass on to the designers as and when there is a 'need to know', the constantly-changing details of applicable standards and regulations and, where necessary, the intricacies of testing methods, whether carried out in-house or at a test laboratory.

In order to train the designers and keep them up to date, they must have ready access to the relevant EMC (and safety) standards, and the relevant legal regulations for the intended market as well. Permitting access to the standards only to Compliance personnel, or keeping the standards and regulations as hard copies in the R&D Manager's filing cabinets, is clearly unsatisfactory, even idiotic — what possible use are they in there? The designers who should know them are being kept as much in the dark as the standards are!

It would, of course, be better if all standards, as opposed to only some, were available free of charge, but we haven't evolved far enough for that yet. Even so, some standards (mainly European) are likely to be available at a very wide range of prices, so 'shop around' is the rule, and in some countries, national library services offer free access (but you may have to ask, and ask the right office).

When training and access are in place, the internal responsibility for compliance should rest with R&D. In other words, the MFT handed to Compliance shall not be expected to fail. Note 'shall', but 'shall be expected to pass' is a step too far: EMC would be an exact science only if we could, in general, handle functions of several hundred variables with precision. (A Model For Test, or MFT, however, may in some simple cases be expected with more confidence to pass safety tests.) Compliance, of course, retains external responsibility, i.e. responsibility for ensuring that the manufactured product continues to satisfy all regulatory requirements, standards related to regulations and non-mandatory standards which buyers nevertheless expect to be applied (such as for interoperability), in the markets in which it is exposed.

These changes are not going to happen, no matter how enlightened the engineers and their line managers become, until senior management is committed. Senior management must recognize the logic underlying the proposed system, abandoning traditional ideas, be convinced of its advantages and give it full support. Advantages that result from conflict resolution include:

- reduction of development costs by eliminating or reducing revisions;
- reduction of development time;
- increased confidence in design by eliminating 'fixes' introduced under pressure.

The revised system has profound effects; costs now include necessary EMC and safety measures, development time is not compromised by the need for complex re-working and the enclosure will be big enough to contain all the parts, even that over-sized EMI filter. Finally, interpersonal conflict has been overcome to such an extent that BB and JH are to be married. However, it has not been ruled out that future discussions, not about EMC, may include flying crockery rather than 50 ohm BNC terminations.

# Calendar

## FUNDAMENTALS OF APPLIED EMC ENGINEERING

**March 20-21, 2013, San Jose, CA**

This is a brief overview on concerns related to printed circuit board design and layout along with secondary methods to achieve EMC such as filtering, shielding and gasketing is examined. An overview on the international compliance arena is also presented along with the process one must take toward testing, troubleshooting and certification of a system. This course includes the following introductory topics, which covers most of the field of applied EMC engineering. Regardless how many years experience as an engineer, a fundamental seminar provides significant value since many have a tendency to over-think solutions and not identify the actual source or problem area. A senior engineer also tends to tackle simple problems using complex simulation analysis. A refresher in EMC basics will allow one to visualize problem differently and which will also provide guidance on new approaches toward achieving compliance quickly and at lowest cost.

**http://lms.ulknowledgeservices.com/catalog/display.resource.aspx?resourceid=354623**

## MIL-STD-461F TRAINING COURSE

**March 20-22, 2013, Baltimore, MD**

This 3-day course is limited to 14 students and will include an overview of MIL-STD-461F, a preview of MIL-STD-461G, how to prepare for testing, in-depth training on conducting the 7 most common test methods, and basic debug techniques. The training session is entirely hands-on – it will take place in one of MET's Military EMC chambers and on the floor area just outside of the chamber.

**http://mil-std-461f-training.eventbrite.com/#**

## EMC FOR WORKING ENGINEERS (BASIC COURSE)

**March 25-26, 2013, Stillwater, OK**

This seminar focuses on the basic causes of EMC problems, the latest research results for new design approaches, and how to overcome these problems. This seminar is not just a list of "rules or thumb" but rather it helps the student understand why EMC problems happen, and what can be done to eliminate them. This seminar's primary focus is to help working engineers understand the causes of EMC problems so this knowledge can be applied to real world product design immediately. Formulas and equations are not required and are minimized throughout the seminar. Understanding the causes of EMC problems will allow engineers to make difficult design trade-off decisions will be the main focus.

**http://emcdesign-course.okstate.edu/**

## ADVANCED EMC DESIGN USING SIMULATION TOOLS (ADVANCED

**March 27-28, 2013, Stillwater, OK**

This seminar focuses on causes of EMC problems, the latest research results for new design approaches, and how to overcome these problems. This seminar's focus is to help working engineers understand the causes of EMC problems so this knowledge can be applied to real world product design immediately.

**http://emcdesign-course.okstate.edu/**

## APEC 2013

**March 17-21, 2013, Long Beach, CA**

APEC 2013 continues the long-standing tradition of addressing issues of immediate and long-term interest to the practicing power electronics engineer. Outstanding technical content is provided at one of the lowest registration costs of any IEEE conference.

**http://www.apec-conf.org/**

## EMC ESSENTIALS

**April 2-3, 2013, Longmont, CO**

EMC Integrity will be offer its "EMC Essentials" short course once again this spring. The course has been expanded to include a module on magnetics. In addition, all participants will receive the Trilogy of Magnetics textbook as part of the course materials. Addressing problems seen in a variety of industries (commercial, military and aerospace), this is an introductory course to the field of electromagnetic compatibility. However, trouble-shooting tips presented will be valuable to even experienced engineers.

**http://www.emcintegrity.com/**

## EMI/EMC IN MILITARY SYSTEMS

**April 9-11, 2013, Columbia, MD**

This is a three day seminar addresses military EMI/EMC issues at the systems/interface levels. It is offered through the Applied Technology Institute as a public class. Also available as an in-house class. The seminar focus is systems design (outside the box) and does not address printed circuit board design issues.

**http://emiguru.com/index.php?option=com_registrationpro&view=event&Itemid=73&did=33**

## MICROWAVE & RF 2013

**April 10-11, 2013, Paris, France**

Launched in 2012 to meet the demands of professionals working in the fields of radio frequencies, microwaves, wireless and fiber optic, the second annual Microwave & RF trade show will feature over 90 exhibitors, manufacturers and distributors of instrumentation and testing, active and passive components, design and simulation software, sub-assemblies, systems and sub-contracting; and EMC products. As part of the trade show, attendees will have the opportunity to attend application conferences presented by the exhibitors. Conference topics will include EMC in new technologies, EMC in aeronautics, collaborative projects in EMC and EMC in radio communication.

**http://www.interferencetechnology.com/microwave-rf-2013/**

## CHINA CONSUMER ELECTRONICS FAIR 2013

**April 10-12, 2013, Shenzhen, China,**

China Consumer Electronics Fair (CCEF), China's largest electronics trade show is, an integrated marketing platform that provides media exposure chance, buyer invitation, brand promotion and other marketing services that up to half-year, besides exhibition booth.

**www.chinaexhibition.com/trade_events/2736-CCEF_2013_-_China_Consumer_Electronics_Fair_2013_%28Shenzhen%29.html**

## "EMC BY YOUR DESIGN" PRACTICAL APPLICATIONS SEMINAR & WORKSHOP

**April 23-35, 2013, Northbrook, IL**

D.L.S. Electronic Systems Inc is offering an "EMC by Your Design" practical applications seminar and workshop. The workshop will cover the fundamentals of electromagnetic compatibility, EMC regulatory requirements and how to minimize EMC problems. Attendees "will be lead step-by-step through simple calculations, be introduced to take-home proprietary software and be led through [how to troubleshoot] a product that does not meet the requirements." The newly updated curriculum was developed by Donald L. Sweeney and his associates.

**http://www.interferencetechnology.com/emc-by-your-design-practical-applications-seminar-workshop/**

## EMV 2013

**May 3- July 3, 2013, Stuttgart, Germany**

EMV is Europe's leading event on electromagnetic compatibility. Meet the industry's leading companies for EMC-equipment, components and EMC-services. The event offers a wide range of EMC-specific topics. It's a platform to get the latest information on newest trends and developments.

**www.e-emv.com**

## EMI/EMC DESIGN AND TROUBLESHOOTING

**May 7-9. 2013, Braintree, MA**

This course covers the methodology of designing an electronic product to minimize the possibilities of having problems of electromagnetic interferences (EMI) or Electromagnetic Compatibility (EMC). Useful techniques for troubleshooting an EMI/EMC problem are presented to help in products where problems exist. The basics of designing electronic products with EMI and EMC in mind are introduced in a very understandable and entertained style. The course presents the ways in which an electronic system can generate and/or receive EMI causing failure to meet EMC regulations. A practical approach with many real world examples, techniques, simulation and hardware tools for EMI design will be explained to minimize costs, production and marketing delays considering EMI in the design phase.

**http://www.besserassociates.com/outlinesOnly.asp?CTID=230**

## ADVANCED TECHNICAL SEMINAR OF ELECTRICAL SYSTEM GROUNDING/EARTHING AND ELECTROMAGNETIC INTERFERENCE ANALYSIS

**May 13-17, 2013, Montreal, Canada**

Hosted by Safe Engineering Services and Technologies Ltd. (SES), this five-day course will provide attendees with the opportunity to acquire practical and up-to-date engineering knowledge on how to study and design efficient and economical grounding/earthing and lightning mitigation systems. An emphasis will be placed on demonstrating scientific concepts using practical examples drawn from research projects and engineering studies conducted by SES researchers since 1978.

**http://www.interferencetechnology.com/advanced-technical-seminar-on-electrical-system-grounding-earthing-and-electromagnetic-interference-analysis/**

## ASIA PACIFIC EMC SYMPOSIUM

**May 20-23, 2013, Melbourne, Australia**

The Asia-Pacific International Symposium and Exhibition on EMC will cover the entire scope of electromagnetic compatibility, including emerging technologies, and will examine the EMC community of the Asian-Pacific region and its connection to the rest of the world. Members of both academia and industry are invited to attend.

**http://www.interferencetechnology.com/apemc-2013/**

## DESIGN FOR EMC

**May 22-24, 2013, Hampshire, UK**

This course will cover design to meet the compliance requirements of the European EMC Directive, as well as other commercial and military requirements. Good EMC design gives you a product that is more reliable and better fitted for its environment. The course is structured to achieve the maximum learning potential from a combination of tutorial and case study exercises. It emphasises the underlying physics of interference generation and coupling and how it affects design methods, without resorting to complex mathematics.

**http://www.tuv-sud.co.uk/uk-en/activity/training/design-for-emc**

## WEBINAR: NOISE REDUCTION IN SIGNAL & POWER CIRCUITS

**May 22, 2013**

Participants will learn about noise sources, methods to reduce signal noise, power noise sources (including harmonics), and techniques used both to reduce power line noise and maintain power quality.

**http://www.isa.org/Template.cfm?Section=Event_Calendar1&Template =/TaggedPage/DetailDisplay.cfm&ContentID=88304**

## MIL-STF 461F

**June 4-7, 2013, Gaithersburg, MD**

Approved on December 10, 2007, the newly released MIL-STD-461F supersedes MIL-STD-461E. MIL-STD-461F testing will be presented, including the new/modified test methods and test article configurations. This course offers critical information for military compliance professionals, testing industry professionals, and developers involved with electronics systems development. Hands-on instruction in MIL-STD-461 test and measurement methods along with analysis of the test results will be covered.

**http://wll.com/mil_std_461course.html**

## OVERVIEW OF RADIATED IMMUNITY/EMISSIONS TEST FACILITIES

**June 11-13, 2013, Cedar Park, TX**

The following topics will be discussed: review of regulatory standards - immunity and susceptibility; conducted immunity; radiated immunity; concept / description; application; applicable standards; facility description; nature of electromagnetic environment; fequency coverage; working volume; aspect angle / polarization issues; peak fields / power requirement; cost; advantages; disadvantages; summary; references.

**http://www.ets-lindgren.com/RadiativeEmissionImmunityTest**

## MODULE JAPAN

**June 5-7, 2013, Tokyo, Japan**

The main concern of Module Japan event will be the development of devices which must prove helpful in areas such as thermal management, high-speed/high-frequency resistance, power management, application driver control in different kinds of complex environments etc. The event will be attended by the technicians and application developers from both within Japan and abroad. The Module Japan event will led emphasis on design technologies such as pattern design, layout design, structure design, various design support tools (for the above listed technologies), signal integrity design support tools, power integrity design support tools, electromagnetic field analysis (measures for EMC/EMI/SI), electrical, mechanical, and thermal property simulators, CAE devices such as CAD, CAM, and CIM, etc.

**http://www.biztradeshows.com/trade-events/module-japan.html**

## 2013 IEEE EMC INTERNATIONAL SYMPOSIUM

**Aug. 5-9 2013, Denver, Colorado**

The Electromagnetic Compatibility Society is the world's largest organization dedicated to the development and distribution of information, tools and techniques for reducing electromagnetic interference. The society's field of interest includes standards, measurement techniques and test procedures, instrumentation, equipment and systems characteristics, interference control techniques and components, education, computational analysis, and spectrum management, along with scientific, technical, industrial, professional or other activities that contribute to this field. This is the largest event of the year.

**www.emcs.org**

## EMC EUROPE 2013

**Sept. 2-6 2013, Brugge, Belgium**

EMC Europe is the leading EMC Symposium in Europe and the 2013 edition will be held at the University College KHBO in Brugge, Belgium. They wish to invite and encourage all those working in the field of electromagnetic compatibility to participate in this prestigious event.

**www.emceurope2013.eu**

## MIL-STD 461F

**Sept. 10-13, 2013, Gaithersburg, MD**

Approved on December 10, 2007, the newly released MIL-STD-461F supersedes MIL-STD-461E. MIL-STD-461F testing will be presented, including the new/modified test methods and test article configurations. This course offers critical information for military compliance professionals, testing industry professionals, and developers involved with electronics systems development. Hands-on instruction in MIL-STD-461 test and measurement methods along with analysis of the test results will be covered.

**http://wll.com/mil_std_461course.html**

## ADVANCED TECHNICAL SEMINAR OF ELECTRICAL SYSTEM GROUNDING/EARTHING AND ELECTROMAGNETIC INTERFERENCE ANALYSIS

**Sept. 16-20, 2013, Montreal, Canada**

Hosted by Safe Engineering Services and Technologies Ltd. (SES), this five-day course will provide attendees with the opportunity to acquire practical and up-to-date engineering knowledge on how to study and design efficient and economical grounding/earthing and lightning mitigation systems. An emphasis will be placed on demonstrating scientific concepts using practical examples drawn from research projects and engineering studies conducted by SES researchers since 1978.

**http://www.interferencetechnology.com/advanced-technical-seminar-on-electrical-system-grounding-earthing-and-electromagnetic-interference-analysis-2/**



## INTERNATIONAL CONFERENCE ON ELECTROMAGNETIC FIELDS, HEALTH AND THE ENVIRONMENT

**Sept. 19-21, 2013, Porto, Portugal**

International Conference on Electromagnetic Fields, Health and Environment is going to be held at Porto, Portugal, for three consecutive days. It is going to hold its fifth edition and is also going to provide a world forum for a multi discipline audience with various backgrounds, as, researchers, physicians, engineers, ecologists, consultants, decision and opinion makers, public authorities and more. International Conference on Electromagnetic Fields, Health and Environment is going to help the invitees present, review and discuss the new developments and trends on electromagnetic field analysis, simulation and application with significance to the human health as well as increase the awareness of the public in this strategic area for the modern world.

**http://www.biztradeshows.com/conferences/ehe/**

## EUROPEAN MICROWAVE WEEK 2013

**Oct. 6-11, 2013, Nürnberg NCC, Germany**

European Microwave Week is the premier event of its kind in Europe and its conferences are set to be even more cutting edge and ground breaking in 2013 than in previous years. The European Microwave Week consists of three conferences: The European Microwave Conference (EuMC); The European Microwave Integrated Circuits Conference (EuMIC); The European Radar Conference (EuRAD). In addition, Exhibitor Workshops, Seminars and Round Table Forums will be an invaluable platform for leading manufacturers, institutes and industry bodies to stimulate dialogue and interaction with attendees on relevant Microwave, RF, Wireless, Defence/Security and Radar issues.

**www.eumw2013.com**

## 2013 IEEE INTERNATIONAL SYMPOSIUM ON PHASED ARRAY SYSTEMS AND TECHNOLOGY

**Oct. 15-18 2013, Waltham, Massachusetts**

Presentations include Advances in GAN Technology and Design for Active Arrays - Dr. Thomas Winslow, Hittite Microwave; Smart Antennas - Dr. Frank Gross, Boeing Technical Fellow, Argon ST; T/R Module Design & Calibration - Dr. William H. Weedon, Applied Radar, Inc., Dr. Leonard Johnson, MIT Lincoln Laboratory, Dr. Douglas J. Carlson, M/A-COM Tech; Phased Array Antenna Measurements - Dr. Alan J. Fenn, MIT Lincoln Laboratory, Mr. Dayel Garneski, Raytheon, Dr. Charles J. Kryzak, Lockheed Martin; Advances in SiGe BiCMOS Technology with Chip Scale Phased Array Applications - Dr. Gabriel Rebeiz, UCSD; Thermal Management of Active Electronically Scanned Arrays - Dr. Avram Bar-Cohen, DARPA; Microwave Array Beamforming: Analog, Digital, and Photonic - Dr. Hans Steyskal, Arcon, Dr. Paul Juodawlkis and Dr. Jeffery Herd, MIT Lincoln Laboratory; Phased-Arrays: Basics, Past Accomplishments, Amazing Breakthroughs and Future Trends - Dr. Eli Brookner, Raytheon.

**www.array2013.org**

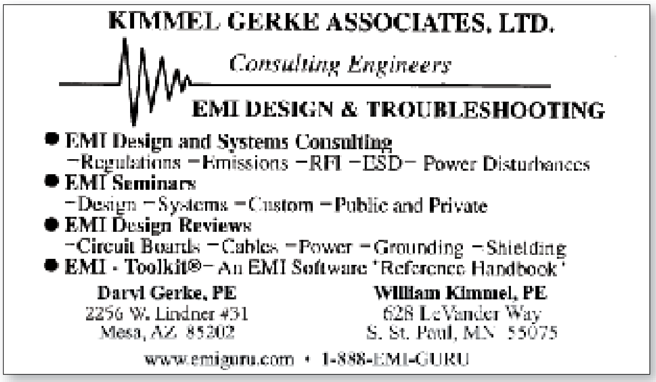
## DESIGN FOR EMC

**Oct. 23-25, 2013, Hampshire, UK**

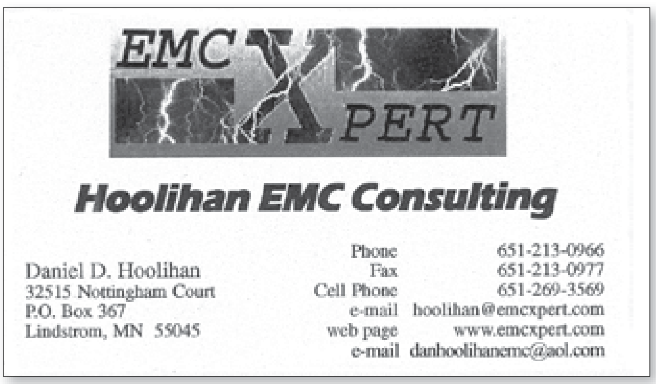
This course will cover design to meet the compliance requirements of the European EMC Directive, as well as other commercial and military requirements. Good EMC design gives you a product that is more reliable and better fitted for its environment. The course is structured to achieve the maximum learning potential from a combination of tutorial and case study exercises. It emphasises the underlying physics of interference generation and coupling and how it affects design methods, without resorting to complex mathematics.

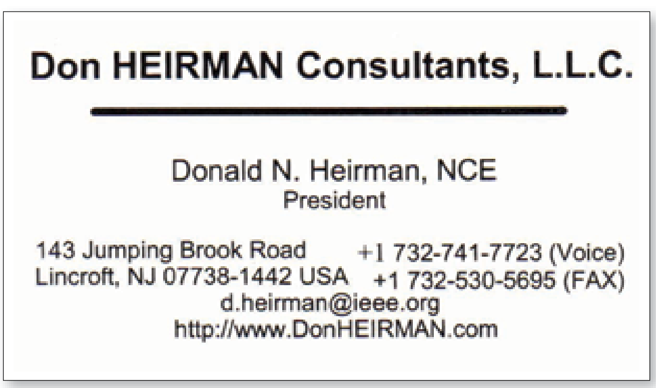
**http://www.tuv-sud.co.uk/uk-en/activity/training/design-for-emc**

# Consultant Services









# Standards

Compliance with standards makes or breaks the marketing of any new product. This section recaps new and revised national and international EMC standards. The information below has been featured in our weekly Interference Technology eNews. Just go to InterferenceTechnology.com, subscribe to the eNews, and you'll be updated on important changes in EMC standards weekly.

## INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

### MEASURING EARTH RESISTIVITY, GROUND IMPEDANCE, AND EARTH SURFACE POTENTIALS OF A GROUNDING SYSTEM

81-2012 presents practical test methods and techniques for measuring the electrical characteristics of grounding systems. Topics addressed include safety considerations; measuring earth resistivity; measuring the power system frequency resistance or impedance of the ground system to remote earth; measuring the transient or surge impedance of the ground system to remote earth; measuring step and touch voltages; verifying the integrity of the grounding system; reviewing common methods for performing ground testing; reviewing instrumentation characteristics and limitations; and reviewing various factors that can distort test measurements.

### STANDARD FOR TRIP SYSTEMS FOR LOW-VOLTAGE (1000 V AND BELOW) AC AND GENERAL PURPOSE (1500 V AND BELOW) DC POWER CIRCUIT BREAKERS

IEE Std C37.17-2012 describes requirements for direct acting current and voltage protective functions of direct-acting overcurrent electromechanical trip devices; direct-acting overcurrent electronic trip systems; reverse-current trip systems for dc circuit breakers; undervoltage trip devices that are integral with low-voltage ac (1000 V and below); and general purpose low-voltage dc (1500 V and below) power circuit breakers covered by IEEE Std C37.13(TM), IEEE Std C37.14(TM), and IEEE Std C37.16(TM). Additional information, communication and/or additional internal or external protective functions or devices are not covered (but also not restricted) by this standard.

### DIRECT LIGHTNING STROKE SHIELDING OF SUBSTATIONS

998-2012 provides information for the methods historically and typically applied by substation designers to minimize direct lightning strokes to equipment and buswork within substations. Two approaches, the classical empirical method and the electrogeometric model, are presented in detail. A third approach involving the use of active lightning terminals is also briefly reviewed.

### FIELD TESTING AND EVALUATION OF THE INSULATION OF SHIELDED POWER CABLE SYSTEMS RATES 5KV AND ABOVE

400-2012 covers shielded, insulated power cable systems rated 5 kV and above. The guide describes the tests and gives advantages and disadvantages, suggested applications, and typical results. Several field test methods that are currently available or under development are also listed in this guide.

### RECOMMENDED PRACTICE FOR NEAR-FIELD ANTENNA MEASUREMENTS

1720-2012 describes near-field test practices for the measurement of antenna properties and near-field measurement practices for the three principal geometries: cylindrical, planar, and spherical. Measurement practices for the calibration of probes used as reference antennas in near-field measurements are also recommended.

### METAL-OXIDE SURGE ARRESTERS FOR AC POWER CIRCUITS (>1 KV)

IEEE Std. C61.11-2012 addresses metal-oxide surge arresters (MOSAs) designed to repeatedly limit the voltage surges on 48 Hz to 62 Hz power circuits by passing surge discharge current and automatically limiting the flow of system power current. This standard applies to devices for separate mounting and to devices supplied integrally with other equipment. The tests demonstrate that an arrester is able to survive the rigors of reasonable environmental conditions and system phenomena while protecting equipment and/or the system from damaging overvoltages caused by lightning, switching and other undesirable surges.

### SURGE WITHSTAND CAPABILITY (SWC) TESTS FOR RELAYS AND RELAY SYSTEMS ASSOCIATED WITH ELECTRIC POWER APPARATUS

IEEE Std. C37.90.1-2012 describes two types of design tests for relays and relay systems that relate the immunity of this equipment to repetitive electrical transients are specified. Test generator characteristics, test waveforms, selection of equipment terminals on which tests are to be conducted, test procedures, criteria for acceptance and documentation of test results are described. This standard has been harmonized with IEC standards where consensus could be reached.

### APPLICATION OF NEUTRAL GROUNDING IN GENERAL AUXILIARY SYSTEMS

IEEE Std. C62.92.3-2012 describes basic factors in selecting the class and means of neutral grounding for electrical generating plant auxiliary power systems. Apparatus to be used to achieve the desired grounding are suggested, and methods to specify the grounding devices are given. Sensitivity and selectivity of equipment ground-fault protection as affected by selection of the neutral grounding device are also discussed, with examples.

## INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

### PROTECTIVE EQUIPMENT FOR SERIES CAPACITOR BANKS

IEC 60143-2:2012 covers protective equipment for series capacitor banks with a size larger than 10 Mvar per phase. Protective equipment is defined as the main circuit apparatus and ancillary equipment, which are part of a series capacitor installation, but which are external to the capacitor part itself. The recommendations for the capacitor part are given in IEC 60143-1:2004. The protective equipment is mentioned in Clause 3 and 10.6 of IEC 60143-1:2004.

This second edition cancels and replaces the first edition published in 1994. It constitutes a technical revision. The main changes with respect to the previous edition are:

- Updates with respect to new and revised component standards;
- Updates with respect to technology changes. Outdated technologies have been removed, such as series capacitors with dual self-triggered gaps. New technologies have been added, such as current sensors instead of current transformers;
- The testing of spark gaps has been updated to more clearly specify requirements and testing procedures. A new bypass making current test replaces the old discharge current test;
- Clause 5, Guide, has been expanded with more information about different damping circuits and series capacitor protections.

### REQUIREMENTS AND TEST METHODS FOR SOLDERLESS PRESS-IN CONNECTIONS

IEC 60352-5:2012 is applicable to solderless press-in connections for use in telecommunication equipment and in electronic devices employing similar techniques. The press-in connection consists of a termination having a suitable press-in zone which is inserted into a plated-through hole of a double-sided or multilayer printed board. Information on materials and data from industrial experience is included in addition to the test procedures to provide electrically stable connections under prescribed environmental conditions. The object of this part of IEC 60352 is to determine the suitability of press-in connections under mechanical, electrical and atmospheric conditions as specified by the manufacturer of the press-in termination and to provide a means of comparing test results when the tools used to make the connections are of different designs or manufacture.

This fourth edition cancels and replaces the third edition published in 2008. This edition constitutes a technical revision and includes a number of significant technical changes with respect to the previous edition. This edition includes the following significant technical changes with respect to the previous edition:

- Enhancement of Annex A and further application remarks are added;
- Editorial changes throughout the standard to prevent the document from being misunderstood as specification for establishing press-in connection in total;
- Deletion of all tables with hole dimensions. Historically the hole dimensions were constrained because of the dimensions of the wire wrap and clip connections posts. Since these connection technologies are no longer commonly used, the design requirements are no longer practical;
- Inclusion of additional figures and one table in 4.4.4 to define tolerance ranges for holes in test-boards and to illustrate them;
- Inclusion of a requirement for the thickness of the test-board in 4.4.

## SIGNAL INTEGRITY TESTS UP TO 1,000 MHZ ON IEC 60603-7 AND IEC 61076-3 SERIES CONNECTORS

IEC 60512-28-100:2013 specifies the test methods for transmission performance for IEC 60603-7 and IEC 61076-3 series connectors up to 1,000 MHz. It is also suitable for testing lower frequency connectors; however the test methodology specified in the detailed specification for any given connector remains the reference conformance test for that connector. The test methods provided here are:

- Insertion loss,
- Return loss,
- Near-end crosstalk (NEXT),
- Far-end crosstalk (FEXT),
- Transverse conversion loss (TCL) and
- Transverse conversion transfer loss (TCTL).

For the transfer impedance (ZT) test, see IEC 60512-26-100. For the coupling attenuation, see IEC 62153-4-12.

## METHODS OF MEASUREMENT OF NON-LINEARITY FOR FULL DIGITAL CHANNEL LOAD WITH DVB-C SIGNALS

IEC 60728-3-1:2012 is applicable to the methods of non-linearity measurement for cable networks that carry only digitally modulated television signals, sound signals and signals for interactive services. These methods take into account the specific signal form and behavior of digitally modulated signals, which differ from the analogue broadcast signals represented mainly by the existence of discrete carrier signals.

## METHOD FOR THE DETERMINATION OF THE SPACE REQUIRED BY CAPACITORS AND RESISTORS WITH UNIDIRECTIONAL TERMINATIONS

IEC 60717:2012 applies to capacitors and resistors with unidirectional wire terminations intended for use in electronic equipment. This standard provides a method for determination of the space required by capacitors and resistors with unidirectional wire terminations.

Instead of measuring the actual space, it may be sufficient to ensure that a component fits into the maximum space for which it is designed. This may be achieved by means of fixed gauges.

The main technical changes with respect to the first edition are the following:

- Employment of the millimeter-based grid, the preferred grid system given in IEC 60097;
- Employment of SI units only, causing deletion of the imperial dimensions from Table 1;
- Reduction of the tolerance on the chamfer depth in Figure 1; and
- Introduction of requirements on information to be given in a relevant specification.

## MECHANICAL AND CLIMATIC TEST METHODS FOR ELECTROSTATIC DISCHARGE (ESD) SENSITIVITY TESTING OF SEMICONDUCTOR DEVICES

IEC 60749-27:2006+A1:2012 establishes a standard procedure for testing and classifying semiconductor devices according to their susceptibility to damage or degradation by exposure to a defined machine model (MM) electrostatic discharge (ESD). It may be used as an alternative test method to the human body model ESD test method. The objective is to provide reliable, repeatable ESD test results so that accurate classifications can be performed. This test method is applicable to all semiconductor devices and is classified as destructive.

## GUIDELINES FOR USE OF SURFACE ACOUSTIC WAVE FILTERS

IEC 60862-2:2012 gives practical guidance on the use of SAW filters, which are used in telecommunications, measuring equipment, radar systems and consumer products. IEC 60862-1 should be referred to for general information, standard values and test conditions. This part of IEC 60862 includes various kinds of filter configuration, of which the operating frequency range is from approximately 10 MHz to 3 GHz and the relative bandwidth is about 0.02 percent to 50 percent of the center frequency. It is not the aim of this standard to explain theory, nor to attempt to cover all the eventualities that may arise in practical circumstances. This standard draws attention to some of the more fundamental questions, which should be considered by the user before he places an order for a SAW filter for a new application. Such a procedure will be the user's insurance against unsatisfactory performance.

This edition includes the following significant technical changes with respect to the previous edition:

- Clause 3, "Terms and definitions," has been deleted to be included in the next edition of IEC 60862-1;
- The tapered IDT filter and the RSPUDT filter have been added to the clause of SAW transversal filters. Also DART, DWSF and EWC have been added as variations of SPUDT;
- The balanced connection has been added to the sub-clause of coupled resonator filters;
- Recent substrate materials have been described;
- A sub-clause about the packaging of SAW filters has been added.

## GUIDE TO THE ASSESSMENT OF MEASUREMENT UNCERTAINTY

IEC/TR 61000-1-6:2012(E), which is a technical report, provides methods and background information for the assessment of measurement uncertainty. It gives guidance to cover general measurement uncertainty considerations within the IEC 61000 series. The objectives of this technical report are to give advice to technical committees, product committees and conformity assessment bodies on the development of measurement uncertainty budgets; to allow the comparison of these budgets between laboratories that have similar influence quantities; and to align the treatment of measurement uncertainty across the EMC committees of the IEC. It gives a description for:

- A method for the assessment of measurement uncertainty;
- Mathematical formulas for probability density functions;
- Analytical assessment of statistical evaluations;
- Correction of measured data; and
- Documentation.

This technical report is not intended to summarize all measurement uncertainty influence quantities nor is it intended to define how measurement uncertainty is to be taken into account in determining compliance with an EMC requirement.

## EMC TESTING AND MEASUREMENT TECHNIQUES FOR ELECTRICAL FAST TRANSIENT/BURST IMMUNITY TESTING

IEC 61000-4-4:2012 relates to the immunity of electrical and electronic equipment to repetitive electrical fast transients. It has the status of a basic EMC publication in accordance with IEC Guide 107. It gives immunity requirements and test procedures related to electrical fast transients/bursts. It additionally defines ranges of test levels and establishes test procedures. The object of this standard is to establish a common and reproducible reference in order to evaluate the immunity of electrical and electronic equipment when subjected to electrical fast transient/bursts on supply, signal, control and earth ports. The test method documented in this standard describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon. This third edition cancels and replaces the second edition published in 2004 and its amendment 1 (2010). It constitutes a technical revision which improves and clarifies simulator specifications, test criteria and test setups.

## HEMP IMMUNITY TEST METHODS FOR EQUIPMENT AND SYSTEMS

IEC 61000-4-25:2001+A1:2012 describe immunity test levels and related test methods for electrical and electronic equipment and systems exposed to high-altitude electromagnetic pulse (HEMP) environments. Specifications for test equipment and instrumentation test set-up, test procedures, pass/fail criteria and test documentation requirements are also defined by this standard. These tests are intended to demonstrate the immunity of electrical and electronic equipment when subjected to HEMP radiated and conducted electromagnetic disturbances.

The objective of this part of IEC 61000 is to establish a common and reproducible basis for evaluating the performance of electrical and electronic equipment when subjected to HEMP radiated environments and the associated conducted transients on power, antenna, and input/output (I/O) signal and control lines. The amendment 1 introduces the damped sinusoidal wave standard recently published IEC 61000-4-18.

## SAFETY REQUIREMENTS FOR HAND-HELD METERS CAPABLE OF MEASURING MAINS VOLTAGE

IEC 61010-2-033:2012 specifies safety requirements for meters. Meters that have a primary purpose of measuring voltage on a live mains circuit are within the scope of this standard. They have various names, but all of them have capability for measurements of voltages on a live mains circuit. Some of the names given to this equipment are as follows: multimeter, digital multimeter, voltmeter and clamp meter (see also Part 2-032). For the purpose of this standard, the term "meter" is used for these hand-held measuring instruments.

## SECTIONAL REQUIREMENTS FOR IMPLEMENTATION OF PRINTED BOARD FABRICATION DATA DESCRIPTION

IEC 61182-2-2:2012 provides the information on the manufacturing requirements used for fabricating printed boards. This standard determines the XML schema details, defined in the generic standard IEC 61182-2, and some of the sectional standards that are required to accomplish the focused tasks. When other standards are invoked, their requirements become a mandatory part of the fabrication details as defined in the IEC 61182-2.

## SECTIONAL SPECIFICATION FOR RADIO FREQUENCY COAXIAL CONNECTORS WITH CLAMP COUPLING

IEC 61169-47:2012(E) is part of the IEC 61169 series and provides information and rules for the preparation of detail specifications (DS) for RF coaxial connectors with clamp coupling typically used in 75 ohm cable networks (type F-Quick). This specification indicates the recommended performance characteristics to be considered when writing a DS and covers test schedules and inspection requirements.

## REQUIREMENTS FOR SEMI-FLEXIBLE RADIO FREQUENCY (RF) AND COAXIAL CABLES WITH PTFE DIELECTRIC

IEC 61196-8-1:2012 is part of the IEC 61196 series and applies to coaxial communications cables described in IEC 61196-8. It specifies the requirements for semi-flexible radio frequency and coaxial cables with polytetrafluoroethylene (PTFE) dielectric. These cables are for use in microwave and wireless equipment or other signal transmission equipment or units at frequencies from 500 MHz up to 18 GHz.

This blank detail specification is to be read in conjunction with IEC 61196-1 and IEC 61196-8. The blank detail specification determines the layout and style for detail. Detail specifications, based on the blank detail specification, may be prepared by a national organization, a manufacturer or a user.

## GENERIC SPECIFICATIONS OF OPTICAL AMPLIFIERS

IEC 61291-1:2012 applies to all commercially available optical amplifiers (OAs) and optically amplified assemblies. It applies to OAs using optically pumped fibers (OFAs based either on rare-earth doped fibers or on the Raman effect), semiconductors (SOAs) and waveguides (POWAs).

This third edition cancels and replaces the second edition published in 2006. It is a technical revision that includes the following significant changes: the definitions related to transient behavior have been extensively updated with terms from the 61290-4 series and the definition for gain ripple has been added.

## EMC REQUIREMENTS FOR ELECTRICAL EQUIPMENT FOR MEASUREMENT, CONTROL AND LABORATORY USE

IEC 61326-1:2012 specifies requirements for immunity and emissions regarding electromagnetic compatibility (EMC) for electrical equipment operating from a supply or battery of less than 1,000 V a.c. or 1,500 V d.c. or from the circuit being measured. Equipment intended for professional, industrial-process, industrial-manufacturing and educational use is covered by this part.

This second edition cancels and replaces the first edition, published in 2005. It constitutes a technical revision. The significant technical changes with respect to the previous edition are:

- The immunity test levels and performance criteria have been reviewed;
- Requirements for portable test and measurement equipment have been clarified and amended;
- The description of the electromagnetic environments has been improved.

## TEST REQUIREMENTS FOR EMC UNPROTECTED TEST AND MEASUREMENT EQUIPMENT

IEC 61326-2-1:2012 specifies more detailed test configurations, operational conditions and performance criteria for equipment with test and measurement circuits (both internal and/or external to the equipment) that are not EMC protected for operational and/or functional reasons as specified by the manufacturer. This second edition cancels and replaces the first edition published in 2005. This edition constitutes a technical revision. The main technical changes are: Update with respect to IEC 61326-1:2012.

## REQUIREMENTS AND TESTS FOR VARIABLE TRANSFORMERS AND POWER SUPPLY UNITS INCORPORATING VARIABLE TRANSFORMERS

IEC 61558-2-14:2012 deals with the safety of variable transformers for general applications and power supply units incorporating variable transformers for general applications. Transformers incorporating electronic circuits are also covered by this standard. This first edition cancels and replaces chapter IV of the IEC 60989 published in 1991. It is a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

- Update of the existing text;
- Complete editorial review.

This part has the status of a group safety publication in accordance with IEC Guide 104:2010.

## ELECTROMAGNETIC SHIELDING PERFORMANCE TESTS FOR CABINETS AND SUBRACKS

IEC 61587-3:2013 specifies the tests for empty cabinets and subracks concerning electromagnetic shielding performance in the frequency range of 30 MHz to 3,000 MHz. Stipulated attenuation values are chosen for the definition of the shielding performance level of cabinets and subracks for the IEC 60297 and IEC 60917 series. The shielding performance levels are chosen with respect to the requirements of the typical fields of industrial application. They will support the measures to achieve electromagnetic compatibility, but cannot replace the final testing of compliance of the equipped enclosure.

This second edition cancels and replaces the first edition issued in 2006. It constitutes a technical revision. This edition corrects the errors of EM code descriptions and extends the frequency range for the shielding performance up to 3,000 MHz.

## PERFORMANCE REQUIREMENTS AND TESTING METHODS FOR SURGE PROTECTIVE DEVICES CONNECTED TO TELECOMMUNICATIONS AND SIGNALING NETWORKS

IEC 61643-21:2000+A1:2008+A2:2012 is applicable to devices for surge protection of telecommunications and signaling networks against indirect and direct effects of lightning or other transient overvoltages. The purpose of these SPDs is to protect modern electronic equipment connected to telecommunications and signaling networks with nominal system voltags up to 1,000 V (r.m.s.) a.c. and 1 500 V d.c.

## POWER-DEPENDENT SURFACE RESISTANCE OF SUPERCONDUCTORS AT MICROWAVE FREQUENCIES

IEC 61788-16:2013 describes the standard measurement method of power-dependent surface resistance of superconductors at microwave frequencies by the sapphire resonator method. The measuring item is the power dependence of Rs at the resonant frequency. This method is the applicable for a frequency in the range of 10 GHz, for an input microwave power lower than 37 dBm (5 W). The aim is to report the surface resistance data at the measured frequency and then scaled to 10 GHz.

## APPLICATION OF STANDARD OUTLINES AND TERMINAL LEAD CONNECTIONS TO SMDS

IEC 61837-1:2012 deals with standard outlines and terminal lead connections as they apply to SMDs for frequency control and selection in plastic molded enclosures and is based on IEC 61240.

## CONFORMANCE TESTING FOR COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION

IEC 61850-10:2012 specifies standard techniques for testing the conformance of client, server and sampled value devices and engineering tools, as well as specific measurement techniques to be applied when declaring performance parameters. The use of these techniques will enhance the ability of the system integrator to integrate IEDs easily, operate IEDs correctly and support the applications as intended. The major technical changes with regard to the previous edition are as follows:

- Updates to server device conformance test procedures and
- Additions of certain test procedures (client device conformance, sampled values device conformance, (engineering) tool related conformance and GOOSE performance).

## MEASUREMENT OF PASSIVE INTERMODULATION IN COAXIAL CABLE ASSEMBLIES

IEC 62037-2:2012(E) defines a procedure to measure levels of passive intermodulation generated by a coaxial cable assembly. This test method is applicable to cable assemblies intended to provide interface flexibility between rigid devices, such as jumper cables.

## MEASUREMENT OF PASSIVE INTERMODULATION IN COAXIAL CONNECTORS

IEC 62037-3:2012(E) is part of the IEC 62037 series and defines the impact test on coaxial connectors to evaluate their robustness against weak connections and particles inside the connector as independently as possible from the effects of cable PIM (passive intermodulation).

## MEASUREMENT OF PASSIVE INTERMODULATION IN FILTERS

IEC 62037-5:2013(E) defines test fixtures and procedures recommended for measuring levels of passive intermodulation generated by filters typically used in wireless communication systems. The purpose is to define qualification and acceptance test methods for filters for use in low intermodulation (low IM) applications.

## MEASUREMENT OF PASSIVE INTERMODULATION IN ANTENNAS

IEC 62037-6:2013(E) defines test fixtures and procedures recommended for measuring levels of passive intermodulation generated by antennas typically used in wireless communication systems. The purpose is to define qualification and acceptance test methods for antennas for use in low intermodulation (low IM) applications.

## PERFORMANCE CHARACTERISTICS OF BULK ACOUSTIC WAVE (BAW) RESONATOR, FILTER, AND DUPLEXER DEVICES AS RADIO FREQUENCY (RF) CONTROL AND SELECTION DEVICES

IEC 62047-7:2011 describes terms, definition, symbols, configurations and test methods that can be used to evaluate and determine the performance characteristics of BAW resonator, filter, and duplexer devices as radio frequency control and selection devices. This standard specifies the methods of tests and general requirements for BAW resonator, filter and duplexer devices of assessed quality using either capability or qualification approval procedures.

## MEASUREMENT OF ELECTROMAGNETIC IMMUNITY IN INTEGRATED CIRCUITS

IEC 62132-8:2012 specifies a method for measuring the immunity of an integrated circuit (IC) to radio frequency (RF) radiated electromagnetic disturbances over the frequency range of 150 kHz to 3 GHz.

## STANDARD INDUCTANCE FACTORS AND TOLERANCES FOR GAPPED FERRITE CORES

IEC 62358:2012 provides standard AL values (inductance factors) and their tolerances of Pot, RM, ETD, E, EER, EP, PQ and low-profile gapped ferrite cores. This edition includes the following significant technical changes with respect to the previous editions:

- Addition of AL value (inductance factor) and its tolerance for PQ-cores;
- Addition of AL value (inductance factor) and its tolerance for EFD-cores;
- Addition of AL value (inductance factor) and its tolerance for Low-profile ER-I-cores;
- Addition of AL value (inductance factor) and its tolerance for Low-profile ER-cores (ER9,5 x 2,5 x 5, ER11 x 2,5 x 6, ER14,5 x 3 x 7 ferrite cores are same as the previous edition);
- Addition of AL value (inductance factor) and its tolerance for Low-profile PQ-I-cores.

## PERFORMANCE PARAMETERS OF ANALOG AND DIGITAL POWER LINE CARRIER SYSTEMS OPERATING OVER EHV/HV/MV ELECTRICITY GRIDS

IEC 62488-1:2012 applies to the planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids. The object of this standard is to establish the planning of the services and performance parameters for the operational requirements to transmit and receive data efficiently over power networks. The transmission media used by different electricity supply industries will include analogue and digital systems, together with more common communication services including national telecommunications authorities, radio links and fiber optic networks and satellite networks. With the developments in communication infrastructures over the last two decades and the ability of devices connected in the electricity communications network to internally and externally communicate, there is a variety of architectures to use in the electricity distribution network to provide efficient seamless communications.

## STANDARD FOR SIGNAL AND TEST DEFINITION

IEC 62529:2012(E) provides the means to define and describe signals used in testing. It also provides a set of common basic signals, built upon formal mathematical specifications so that signals can be combined to form complex signals usable across all test platforms. The standard provides support for structural textual languages and programming language interfaces for interoperability. This second edition cancels and replaces the first edition, published in 2007, and constitutes a technical revision.

### PERFORMANCE CHARACTERISTICS OF TERRESTRIAL DIGITAL MULTIMEDIA TRANSMISSION NETWORKS

IEC 62553:2012(E) is intended to establish measuring methods that enable the objective evaluation of the performance of transmission networks so as to make stable DTTB services a reality and establish a technical baseline, such as a definition of technical terms, to standardize measuring methods. The measurement methods described are intended for digital terrestrial television transmission network test and validation.

### GUIDELINES FOR THE USE OF RADIO FREQUENCY (RF) BULK ACOUSTIC WAVE (BAW) FILTERS

IEC 62575-2:2012 gives practical guidance on the use of RF BAW filters, which are used in telecommunications, measuring equipment, radar systems and consumer products. This part of IEC 62575 includes various kinds of filter configurations, of which the operating frequency range is from approximately 500 MHz to 10 GHz and the relative bandwidth is about one percent to five percent of the center frequency.

### FIXED SURFACE MOUNT INDUCTORS FOR USE IN ELECTRONIC AND TELECOMMUNICATIONS EQUIPMENT

IEC 62674-1:2012 applies to fixed surface mount inductors and ferrite beads. The object of this standard is to define the terms necessary to describe the inductors covered by this standard and provide recommendations for preferred characteristics, recommended performance, test methods and general guidance.

## INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO) / IEC

### TEST METHODS AND PROCEDURES FOR TESTING ELECTROMAGNETIC IMMUNITY TO PORTABLE TRANSMITTERS OF VEHICLE ELECTRONIC COMPONENTS

ISO 11452-9:2012 specifies test methods and procedures for testing electromagnetic immunity to portable transmitters of electronic components for passenger cars and commercial vehicles, regardless of the propulsion system (e.g. spark-ignition engine, diesel engine, electric motor). The device under test (DUT), together with the wiring harness (prototype or standard test harness), is subjected to an electromagnetic disturbance generated by portable transmitters inside an absorber-lined shielded enclosure, with peripheral devices either inside or outside the enclosure. The electromagnetic disturbances considered are limited to continuous narrowband electromagnetic fields.

### ELECTROMAGNETIC COMPATIBILITY TEST PROTOCOLS FOR IMPLANTABLE CARDIAC DEVICES

ISO 14117:2012 specifies test methodologies for the evaluation of the electromagnetic compatibility (EMC) of active implantable cardiovascular devices that provide one or more therapies for bradycardia, tachycardia and cardiac resynchronization. It specifies performance limits of these devices, which are subject to interactions with EM emitters operating across the EM spectrum in the 0 Hz to 450 MHz and 450 MHz to 3,000 MHz ranges.

ISO 14117:2012 also specifies requirements for the protection of these devices from EM fields encountered in a therapeutic environment and defines their required accompanying documentation, providing manufacturers of EM emitters with information about their expected level of immunity.

## INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE (CISPR)

### SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS

CISPR 16-1-5:2003+A1:2012 is designated as a basic standard that specifies the requirements for calibration test sites used to perform antenna calibrations as well as the test antenna characteristics, calibration site verification procedure and site compliance criteria. Further information on calibration site requirements, test antenna considerations and the theory of antennas and site attenuation is provided in informative annexes. Measurement instrumentation specifications are given in CISPR 16-1-1 and CISPR 16-1-4. Further information and background on uncertainties in general is given in CISPR 16-4-1, which may be helpful in establishing uncertainty estimates for the calibration processes of antennas. CISPR 16-1 has been reorganized into five parts to accommodate growth and easier maintenance. This first edition of CISPR 16-1-5, together with CISPR 16-1-1, CISPR 16-1-2, CISPR 16-1-3 and CISPR 16-1-4, cancels and replaces the second edition of CISPR 16-1 (1999), amendment 1 (2002) and amendment 2 (2003). It contains the relevant clauses of CISPR 16-1 without technical changes.

## EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE (ETSI)

### SHORT RANGE DEVICES (SRD) USING ULTRA WIDE BAND (UWB) MEASUREMENT TECHNIQUES

ETSI TS 102 883 summarizes the available information of possible measurement techniques and procedures for the conformance measurement of various UWB signal format, in order to comply with the given transmission limits given in the actual regulation. UWB radio technology opens new markets with a variety of innovative applications and enables a new generation of high-speed data devices for short range communication purposes as well as location tracking and sensor devices.

### ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS FOR TELECOMMUNICATIONS NETWORK EQUIPMENT

ETSI EN 300 386 covers the electromagnetic compatibility requirements for equipment the provides telecommunications between network termination points (NTPs) and that is intended to be used within a telecommunications network operating under a license granted by a national telecommunications authority. Examples of such equipment include switching equipment, non-radio transmission equipment and ancillary equipment, power supply equipment and supervisory equipment.

### SPECIFIC CONDITIONS FOR ELECTROMAGNETIC COMPATIBILITY OF FIXED RADIO LINKS, BROADBAND DATA TRANSMISSION SYSTEM BASE STATIONS, ANCILLARY EQUIPMENT AND SERVICES

ETSI EN 301 489-4, together with EN 301 489-1, covers the assessment of fixed radio links, broadband data transmission system base stations and ancillary equipment with respect to electromagnetic compatibility (EMC). Applicable test conditions, performance assessment and performance criteria for analog and digital fixed radio links operating as fixed point-to-point and point-to-multipoint systems as defined in annex B are included. The processing and protection switch, (de)modulator, transmitter, receiver, RF filters, branching networks, feeders are also covered. The multiplexing and/or de-multiplexing elements are only covered if they form part of the transmitter, receiver and/or transceiver. Technical specifications related to the antenna port of the radio equipment are not included.

### TECHNICAL CHARACTERISTICS AND TEST METHODS FOR LOW POWER ACTIVE MEDICAL IMPLANTS (MP-AMI) OPERATING IN FREQUENCY RANGE 2,484.5 MHZ TO 2,500 MHZ

EN 301 559-1 includes methods of measurement for low power active medical implants (LP-AMI) and peripherals (LP-AMI-P) fitted with antenna connectors and/or an integral antenna. Equipment designed for use with an integral antenna may be supplied with a temporary or permanent internal connector for the purpose of testing, providing the characteristics being measured are not expected to be affected. If equipment available on the market is required to be checked it should be tested in accordance with the methods of measurement specified in EN 301-599-1.

# Societies

## IEEE ELECTROMAGNETIC COMPATIBILITY SOCIETY (S-27)

**IEEE Operations Center**
**445 Hoes Lane, P.O. Box 6804**
**Piscataway, NJ 08855-1331**
**Phone: 732-981-0060**
**Website: www.emcs.org**
**President: Dr. Peter W. Staecker**

The Institute of Electrical & Electronics Engineers (IEEE), the world's largest professional engineering society, is a global organization of individuals dedicated to improving the understanding of electrical and electronics engineering and its applications to the needs of society. The parent organization has over 360,000 members, approximately 70 percent of whom belong to technical groups such as the EMC Society.

Membership in the IEEE is on a qualified basis, with a basic annual fee of between $140 and $180 depending on the region of the world. The U.S. fee is $183. The Institute offers major medical and life insurance at low group rates, and each member receives a copy of the monthly publication, Spectrum. Affiliate, associate, and student memberships are available for those who do not qualify for regular membership; and special arrangements are provided for those temporarily out of work. Members may join one or more of the 39 technical societies by paying the additional individual society fee(s). The EMC Society has an annual fee of $30. Student memberships are $15.

The EMC Society, which enjoys a membership of over 5000, functions through a Board of Directors elected by the Society membership. The Board includes 20 members-at-large who serve staggered 3-year terms. The Executive Board consists of the President, President-Elect, Immediate Past President, Secretary, Treasurer, and five Vice Presidents, who oversee the activities of standing and technical committees. The officers are elected by the Board of Directors. The annual IEEE International Symposium on Electromagnetic Compatibility is sponsored by the Board of Directors, which also coordinates activities of standing technical and ad hoc committees.

EMC Society publications include Transactions on EMC, a quarterly journal which features state-of-the-art papers on interference technology and EMC, and the EMC Society Newsletter, a quarterly newsletter of society activities, industry developments, practical papers, and notices of meetings, regulations, and new publications.

The EMC Society also has a group of distinguished lecturers who are available to present talks to IEEE and other organizations. The society subsidizes the lecturers' expenses, and organizations are encouraged to contact the society for further details.

Chairmen of these committees welcome assistance and indications of interest in committee activities from the EMC Society membership. EMC Society activities are provided by 54 chapters with members in 61 countries worldwide.

A committee directory, listing officer, board, committee, and chapter contacts' names, addresses, and telephone numbers, is available on the IEEE EMC Society website at www.emcs.org.

The EMC Society is also active in technical conferences and symposia through its sponsorship of the annual International Electromagnetic Compatibility Symposium and participation in other worldwide symposia. Symposia and conferences are announced in the EMC Society Newsletter.

The IEEE Symposium on Electromagnetic Compatibility will be held in Long Beach, Calif. USA from August 14-19, 2011. Visit the Symposium website at www.emc2011.org.

The EMC Society has published a number of standards. For information on EMC Society and other IEEE standards, contact the IEEE Operations Center.

**2013 EVENTS**

- **IEEE EMC Society Board of Directors Meetings**
  **March 7-9, 2013, Piscataway, New Jersey**
  **Aug. 4 and 8, 2013, Denver, Colorado**
  **Nov. 7-9, 2013, Rome, Italy**
- **IEEE EMC Chapter Colloquium and Exhibition "Table-Top Shows"**
  **March 19, 2013, Milwaukee, Wisconsin**
  **Kenneth Wyatt, Wyatt Technical Services LLC**
  **Topic to be announced**
  **Crown Plaza Hotel – Milwaukee Airport**
  **Jim Blaha, GE Healthcare**
  **Phone: 262.548.2978**
  **Email: jblaha@ieee.org**

## IEEE PRODUCT SAFETY ENGINEERING SOCIETY

While product safety had been addressed in various committees over the years, there was never a professional society or symposium solely devoted to product safety engineering as a discipline until recently. The IEEE Product Safety Engineering Society (PSES) began operation on 1 January 2004.

The field of interest of the Society is the theory, design, development and implementation of product safety engineering for electronic and electro-mechanical equipment and devices. This includes the theoretical study and practical application of analysis techniques, testing methodologies, conformity assessments, and hazard evaluations.

The society's mission is to strive for the advancement of the theory and practice of applied electrical and electronic engineering as applied to product safety and of the allied arts and sciences.

The society provides a focus for cooperative activities, both internal and external to IEEE, including the promotion and coordination of product safety engineering activities among IEEE entities. In addition, the Society will provide a forum for product safety engineering professionals and design engineers to discuss and disseminate technical information, to enhance personal product safety engineering skills, and to provide product safety engineering outreach to engineers, students and others with an interest in the field. The Society is accepting members at any time during the calendar year, both full IEEE members and affiliate members. Membership is available at www.ieee.org/services/join/.

The IEEE Product Safety Engineering Society works closely with various IEEE Societies and Councils that also include product safety engineering as a technical specialty.

Every year, the PSES hosts a Symposium on Product Compliance Engineering. The next conference will be in Portland, Oregon, USA on November 5-7, 2012. The Symposium will consist of Technical Sessions, Workshops, Tutorials and Demonstrations specifically targeted to the compliance engineering professional. Attendees will have the opportunity to discuss problems with vendors displaying the latest regulatory compliance products and services. For more information, visit http://www.ieee-pses.org/symposium/. Past papers from the Symposia are available in IEEE Xplore or on CD (for a fee).

In addition to hosting an annual conference, the PSES provides the opportunity for product safety engineers to publish technical papers in a newsletter. See http://www.ieee-pses.org/newsletters.html. **For further information visit www.ieee-pses.org.**

## dB SOCIETY

**22117 NE 10th Place**
**Sammamish, WA 98074**
**Fax: 425-868-0547**
**E-mail: j.n.oneil@ieee.org**

This unique, interesting, and exclusive fraternity of EMC engineers was founded in 1975 by 10 eminent EMC engineers. The purpose of the dB Society is to open doors within the EMC community. Its primary objectives are to greet and to welcome new engineers, suppliers, vendors, and manufacturers to the EMC community and to assist them in establishing contacts in the EMC field.

The following membership requirements are unique and rigidly enforced:

- Ten years of service to the EMC community,
- Five years of service to a recognized professional, EMC organization,
- Sponsorship by two Duo-Decade members,
- Favorable recommendations by three other recognized individuals in the EMC community, and
- Acceptance by the Admissions Board.

Business meetings and informal, relaxed get-togethers take place during major EMC functions. A formal evening social function is the highlight of each year and is usually conducted during the IEEE EMC Symposium. All meetings are for members only.

U.S. membership is limited to 100 EMC engineers. There are society affiliates in the United Kingdom, India, and Israel.

## ESD ASSOCIATION

**ESD Association**
**7900 Turin Road, Building 3**
**Rome, NY 13440-2069**
**Phone: 315-339-6937**
**Fax: 315-339-6793**
**Email: info@esda.org**
**Website: www.esda.org**

Founded in 1982, the ESD Association is a professional voluntary association dedicated to advancing the theory and practice of electrostatic discharge (ESD) avoidance. From fewer than 100 members, the Association has grown to more than 2,000 members throughout the world. From an initial emphasis on the effects of ESD on electronic components, the association has broadened its horizons to include areas such as textiles, plastics, web processing, cleanrooms, and graphic arts. To meet the needs of a continually changing environment, the Association is chartered to expand ESD awareness through standards development, educational programs, local chapters, publications, tutorials, certification, and symposia.

### ELECTROSTATIC DISCHARGE (ESD) TECHNOLOGY ROADMAP

In the late 1970s, electrostatic discharge, or ESD, became a problem in the electronics industry. Low-level ESD events from people were causing device failures and yield losses. As the industry learned about this phenomenon, both device design improvements and process changes were made to make the devices more robust and processes more capable of handling these devices. With devices becoming more sensitive through the year 2010, it is imperative that companies begin to determine the ESD capabilities of their handling processes. The ESD Technology Roadmap can be downloaded at: www.esda.org

### ANSI/ESD S20.20 CONTROL PROGRAM STANDARD AND CERTIFICATION

A primary direction for the association is the continued implementation of a facility certification program in conjunction with ISO registrars. With the association's ESD control program standard, ANSI/ESD S20.20: Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices), the Association offers a means of independently assessing a company's ESD control program and of issuing a formal ANSI/ESD S20.20 certification.

The ANSI/ESD S20.20 standard covers the requirements necessary to design, establish, implement, and maintain an ESD control program to protect electrical or electronic parts, assemblies and equipment susceptible to ESD damage from Human Body Model (HBM) discharges greater than or equal to 100 volts. Developed in response to the Military Standardization Reform Act, ANSI/ESD S20.20 has been formally adopted for use by the U.S. Department of Defense.

Although ESD programs have been part of some ISO 9000 audits in the past, the assessment frequently has been cursory and actual judgment of the program has been left to the individual auditor. ANSI/ESD S20.20 provides a formal, consistent process standard that can be audited. It provides a single, auditable ESD standard for OEM's, suppliers, and contractors. To date, there are approximately 132 facilities in 13 countries that have become ANSI/ESD S20.20 certified.

Accredited registrars conduct the actual assessments of the companies. The association has developed a training program for the registrars and supervises registrar witness audits. This independent assessment of a company's ESD control program could be performed as part of the company's ISO 9000 surveillance audit or as a separate audit. Currently, there are 161 trained auditors in 13 countries who have been certified to conduct ANSI/ESD S20.20 audits.

In addition, the ESD Association offers an ESD program documentation review service. For a fee of $1,500 (US), members of the ESD Association's Facility Certification committee will review your ESD program documentation and will compare it to the requirements listed in ANSI/ESD S20.20-2007. Facilities that choose to become certified will use the ANSI/ESD S20.20-2007 standard as the basis for their certification. A report will be provided that describes the areas that need to be improved for documentation to be compliant with ANSI/ESD S20.20-2007. This service should be considered a MUST for any company that is preparing for facility certification based on ANSI/ESD S20.20-2007.

### SYMPOSIA, TUTORIALS, AND PUBLICATIONS

As part of its commitment to education and technology, the association holds the annual EOS/ESD Symposium, which places major emphasis on providing the knowledge and tools needed to meet the challenges of ESD. Scheduled for September 9-14, 2012, at the Westin Tucson, La Poloma, Arizona, USA, the annual Symposium attracts attendees and contributors from around the world. Technical sessions, workshops, authors' corners, seminars, tutorials, and technical exhibits provide a myriad of opportunities for attendees to expand their knowledge of ESD.

In addition to tutorials and seminars, the association offers a number of publications and reference materials for sale. These range from proceedings of past EOS/ESD Symposia to textbooks written by experts in the field of ESD.

## TECHAMERICA ELECTROMAGNETIC COMPATIBILITY COMMITTEE

**1401 Wilson Blvd., Suite 1100**
**Arlington, VA 22209**
**Phone: 703-284-5344**
**Website: www.geia.org**

TechAmerica is the association that was created by the merger of AeA and ITAA. Earlier in 2008, ITAA and GEIA merged. The result of these mergers is an organization that is the leading voice for the U.S. technology industry, which is the driving force behind productivity growth and jobs creation in the United States. TechAmerica is the technology industry's only grassroots-to-global advocacy network. With nearly 1200 member companies, 20 regional councils and offices in Beijing and Brussels, the association represents the full spectrum of the technology industry.

TechAmerica is the technology industry's only grassroots-to-global advocacy network. The organization has expanded initiatives in areas such as information Assurance / Information Security, Identity Management, Cloud Computing, Global Sourcing / Globalization, Intelligence agencies, Department of Defense & NASA, and State & Local programs and public policy advocacy.

TechAmerica provides programs for business development, networking and market intelligence in the Federal arena, dealing with government entities such as Department of Defense, Homeland Security, Federal Communications Commission, Federal Trade Commission, Congress, as well as with state and local governments.

TechAmerica has a team of public policy professionals at state, federal and international levels that allow the organization to successfully influence legislative and regulatory issues that affect member companies.

In addition, TechAmerica offers an active standards development program to provide industry with proven solutions to business process challenges. The program is nationally and internationally recognized for its leadership and expertise in the development of standards. Configuration Management, Systems Engineering, Systems Safety, Earned Value Management, Logistics, Reliability and Electromagnetic Compatibility (EMC) area where TechAmerica is involved in standard.

The Electromagnetic Compatibility (EMC) Committee (formally known as G-46) deals with the system-oriented discipline that ensures electromagnetic compatibility in electronics design. The Committee develops technical criteria and procedures to guide the design engineer. Its work also includes spectrum management and conservation; secure communications; and electromagnetic emissions, susceptibility, control, and characterization.

The EMC Committee was established to provide an industry/user position on government specifications, regulations, and standards. Participation has expanded to include G-46 representation on the various committees drafting government specifications and standards. For example, G-46 participated on the working committees for MIL-STD-464A and MIL-STD-461E and provided update recommendations to MIL-STD-461F. The scope of G-46 activities has expanded to foster and facilitate the EMC discipline for the benefit of TechAmerica member companies.

Committee activities include spectrum management and conservation; personnel safety; and health care electronics design, usage and installation in terms of regulated and non-regulated electromagnetic (EM) emissions and immunity. Inter- and intra-environmental areas as they affect systems, subsystems and equipment, subassemblies, and components are also areas of concern. In addition to other activities, committees:

- Review, assess, advise and coordinate related activities of organizations/individuals in government, industry, and technical societies.
- Assure that EMC legislation, regulations, specifications, standards, requirements, and evaluation procedures are adequate for procurement and application.
- Assure that EMC legislation, regulations, specifications, standards, requirements, and evaluation procedures are harmonized with their commercial counterparts to the maximum extent practical for procurement and application.
- Propose and recommend action and provide support to other organizations, as deemed desirable.
- Coordinate and promulgate information to facilitate advancement of the state-of-the-art.

Additional information on TechAmerica and the EMC Committee (G-46) can be obtained at (703) 284-5315, phyllis.call@techamerica.org, or via the GEIA website at http://www.geia.org.

## SOCIETY OF AUTOMOTIVE ENGINEERS

**400 Commonwealth Drive**
**Warrendale, PA 15096-0001**
**Phone: 724-776-4841**

SAE International is a professional society of engineers dedicated to a broad spectrum of engineering disciplines within the aerospace and automotive fields. Under the SAE Aerospace Council, technical standards committees address disciplines ranging from electrical power to multiplex signal characteristics — and from fiber optic data transmission to electromagnetic compatibility. The many elements of EMC are handled by SAE Committee AE-4, Electromagnetic Compatibility, which was organized in 1942 under the Aerospace Council. The committee is composed of technically qualified members, liaison members, and consultants —all of whom are responsible for writing standards on electromagnetic compatibility.

Committee AE-4 provides assistance to the technical community through standardization, improved design and testing methodology, and technical forums for the resolution of mutual problems. Engineering standards, specifications, and technical reports are developed by the Committee and are issued by the Society for industry and governments worldwide. Objectives of Committee AE-4 are to advance the state of technology, to stabilize existing technology, to obtain a uniformity of EMC requirements among government agencies, and to further the interests of the EMC technical community. The theme of "design before the fact" for EMC is a guiding concept. Special attention is given to maintenance of EMI control requirements consistent with the rapidly advancing state-of-the-art.

The following is a partial list of documents that have been issued to assist in implementing SAE objectives. For a complete list, visit the SAE website at www.sae.org or call SAE Customer Service at 724-776-4841.

### AEROSPACE RECOMMENDED PRACTICES (ARPS)

| | | |
|---|---|---|
| ARP | 935A | Control Plan/Technical Construction File |
| ARP | 936A | Capacitor, 10 mF for EMI Measurements |
| ARP | 958C | Electromagnetic Interference Measurement Antennas, Standard Calibration Method |
| ARP | 958D | Electromagnetic Interference Measurement Antennas, Standard Calibration Method |
| ARP | 1172 | Filters, Conventional, EMI Reduction, Specifications for ???? |
| ARP | 1173 | Test Methods for EMI Gasketing |
| ARP | 1267 | EMI Measurement of Impulse Generators, Standard Calibration Requirements and Techniques |
| ARP | 1481A | Corrosion Control and Electrical Conductivity in Enclosure Design |
| ARP | 1705 | Coaxial Test Procedure to Measure the RF Shielding Characteristics of EMC Gasket Materials |
| ARP | 1870 | Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety |
| ARP | 1972 | Recommended Practices and Procedures for EMC Testing |
| ARP | 4043A | Flightline Bonding and Grounding of Aircraft |
| ARP | 4242 | Electromagnetic Compatibility Control Requirements, Systems |
| ARP | 4244 | Recommended Insertion Loss Test Methods for EMI Power Line Filters |
| ARP | 5416A | Aircraft Lightning Test Methods |

### AEROSPACE INFORMATION REPORTS (AIRS)

| | | |
|---|---|---|
| AIR | 1147 | EMI on Aircraft from Jet Engine Charging |
| AIR | 1209 | Construction and Calibration of Parallel-Plate Transmission Lines for EMI Susceptibility Testing |
| AIR | 1221 | EMC System Design Checklist |
| AIR | 1255 | Spectrum Analyzers for EMI Measurements |
| AIR | 1394A | Cabling Guidelines for Electromagnetic Compatibility |
| AIR | 1404 | DC Resistivity vs. RF Impedance of EMI Gaskets |
| AIR | 1423 | EMC on Gas Turbine Engines for Aircraft Propulsion |
| AIR | 1425A | Methods of Achieving EMC of Gas Turbine Engine Accessories, for Self-Propelled Vehicles |
| AIR | 1499 | Recommendations for Commercial EMC Susceptibility Requirements |
| AIR | 1662 | Minimization of Electrostatic Hazards in Aircraft Fuel Systems |
| AIR | 1700A | Upper Frequency Measurement Boundary for Evaluation of Shielding Effectiveness in Cylindrical Systems |
| AIR | 4079 | Procedure for Digitized Method of Spark Energy Measurement |

### SAE AE-4 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E3 OR EMC) COMMITTEE

The SAE AE-4 E3 Committee provides a technical, coordinating, and advisory function in the field of E3. The focus is on problem areas in which committee expertise can be effectively applied at the national and international levels. Electrical and electronic accessories are studied for compatibility within systems and with various communications media. Engineering standards, specifications, and technical reports are developed and are issued for the general information of industry and government.

In the past, subcommittees have included AE-4R, Aircraft Radiated Environments, and AE-4H, High Power RF Simulators and Effects. AE-4 E3 holds national meetings in conjunction with the IEEE EMC Society Symposium, usually held in August at various locations. Additional information about meetings or more specific information on the activities of the committee can be obtained by contacting the world headquarters at 1-724-776-4841. Visit the SAE's Technical Standards Committee Forum website at http://forums@sae.org.

## iNARTE

**Ste. 301, 600 N. Plankinton Ave.**
**Milwaukee, WI 53201**
**Phone: 888-722-2440**
**Fax 414-765-8661**
**Email: service@inarte.us**
**Website: www.inarte.org**

iNARTE, Inc. (The International Association for Radio, and Telecommunications and Electromagnetics, Inc.) was founded as a non-profit membership/certification organization in 1982. With the advent of deregulation and the Federal Communications Commission's "encouragement/urging" private industry to establish certification standards to fill the licensing void, iNARTE initiated and developed a comprehensive certification program for telecommunications engineers and technicians.

In 1988, a Command of the United States Navy, seeking a credible and respected certification entity, selected iNARTE as the administrative agent for the certification of engineers and technicians in the field of electromagnetic compatibility (EMC).

In 1993, iNARTE, certified by the Federal Communications Commission (FCC) as a Commercial Operators License Examination Manager (COLE Manager), was authorized to administer all examination elements for FCC licensure (formally an FCC responsibility).

In 1994, the ESD Association selected NARTE to implement and administer a certification program for Electrostatic Discharge Control Engineers and Technicians.

During 1997, two nations, China and Japan, requested iNARTE assistance in the establishment of specific in-country certification programs comparable to and able to meet iNARTE certification standards.

In 2000, iNARTE established the Unlicensed Wireless Systems Installer certification to identify fully qualified design and installation personnel. This certification accredits professionals who design and install wireless systems that do not require a license from the FCC —including information systems, security systems, and transportation systems.

In 2001, iNARTE developed an Agreement with the IEEE EMC Society for the co-promotion of awareness and education in EMC/EMI fields. Today the EMC Society is the keeper of the body of knowledge from which the iNARTE examinations are derived.

In 2003 iNARTE, together with specialist partners, developed the Product Safety certification program. The Product Safety program accredits professionals who use hazard-based analysis to identify and develop solutions to eliminate or minimize safety hazards. In 2004 iNARTE signed an Agreement with the IEEE Product Safety Engineering Society, PSES, to co-promote awareness and education in Product Safety. Today, technical experts within the PSES assist iNARTE in the development of the examination question pools.

In 2006 iNARTE executed Agreement with ANSI ASC 63, the Accredited Standards Committee on EMC, for the purposes of joint cooperation and promotion in education and technical achievement in EMC engineering.

By 2007, the global interest and participation in iNARTE Certification programs had resulted in almost one quarter of members being from overseas countries. In recognition of this, the iNARTE Board of Directors voted unanimously to change the association name to the, "International Association for Radio. Telecommunications and Electromagnetics, iNARTE."

As iNARTE, an agreement of mutual support and cooperation was signed with the ESD Association in 2007. The ESDA will assist iNARTE in formulating and maintaining the question pools from which certification examinations are derived

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## ACIL—THE AMERICAN COUNCIL OF INDEPENDENT LABORATORIES

**1875 I Street, NW, Suite 500**
**Washington, DC 20006**
**Phone: 202-887-5872**
**Fax: 202-887-0021**
**Email: Info@acil.org**
**Website: www.acil.org**

The American Council of Independent Laboratories (ACIL) is the trade association representing independent, commercial engineering, and scientific laboratory, testing, consulting, product certifying and R&D firms; manufacturers' laboratories; related non-profit organizations; and consultants and suppliers to the industry. The organization was founded in 1937. All ACIL activities focus on its mission: to enhance members' success by providing advocacy, education, services, and mutual support and by promoting ethics, objectivity, independence, and free enterprise.

ACIL is a voluntary, non-profit membership organization. Programs are determined by members, administered by an elected Board of Directors, and supported by a professional staff operating from headquarters in Washington, D.C.

### ACIL'S CONFORMITY ASSESSMENT SECTION

ACIL's Conformity Assessment Section consists of firms with wide and varied interests, all performing testing, listing, or labeling in accordance with applicable safety and performance standards, and/or materials testing and resolution of product and structural problems. Several committees have evolved within the Section to meet the needs of its diverse membership, including the EMC Committee, the U.S. Council of EMC Laboratories, and the Third-Party Product Certifiers Committee. In January 2005, the section sponsored a booth at the Consumer Electronics Show that advocated the advantages of independent third-party testing and the capabilities of ACIL member EMC laboratories.

### ACIL'S EMC COMMITTEE

ACIL's EMC Committee was established in 1996 to address the common concerns of the ACIL EMC community. The Committee sponsors educational sessions at ACIL meetings that include both technical and policy issues such as mutual recognition agreements (MRAs). The Committee updates members on the latest developments, upcoming requirements, and activities in the field—both domestic and international.

In January 2002, ACIL published a 143-page document, Technical Criteria for the Accreditation of Electromagnetic Compatibility (EMC) and Radio Testing Laboratories, a checklist to assist both assessors and laboratories.

The Committee also formed the U.S. Council of EMC Laboratories (USCEL) in an effort to aid U.S. laboratories in addressing technical issues arising from the U.S./EU MRA and other global concerns. As the USCEL Secretariat, ACIL provides staff and supports volunteers active in this important area.

Over the past several years, ACIL has administered round robin proficiency testing programs with two artifacts allowing laboratories to make both AC line conducted and radiated emissions measurements over the frequency range of 0.15–30 MHz and 30 MHz–1 GHz, respectively.

While continuing the round robins in the frequencies noted above, ACIL has launched another round robin with a new test artifact. This artifact will allow participating laboratories to demonstrate proficiency for radiated emissions measurements in the frequency range of 1–18 GHz. Emissions measurements above 1 GHz are becoming increasingly common with the advent of fast processors and wireless devices in the 2.4- and 5-GHz bands.

ACIL also was instrumental in the formation of the Telecommunication Certification Body Council (TCBC). New rules establishing TCBs were adopted by the FCC in December 1998, providing more options for manufacturers—they can now choose to have their product certified by either the FCC or a private certification body (TCB). A TCB may approve equipment subject to certification (e.g., transmitters, telecom terminal equipment, or scanning receivers). The TCB Council addresses the specific concerns of the TCB community and all constituent bodies are permitted to participate.

### U.S. PRODUCT CERTIFIERS

Key U.S. product certifiers are ACIL members and are reaping many benefits, such as participation in the ACIL Third-Party Product Certifiers Committee ($3P^2C^2$). This Committee provides a forum for members to discuss and to act upon various issues of common interest. This committee formed the American Council for Electrical Safety to serve as a forum among testing laboratories, regulators, and electrical inspectors.

# Government Directory

The following is a list of the principal government personnel involved in EMC/EMI. This list is based upon best available data at the time of publication. Additions, deletions and corrections for any facility may be updated at any time by e-mailing your changes to bstas@interferencetechnology.com.

## DEPARTMENT OF DEFENSE

### Defense Spectrum Organization
DSO Director: Ms. Paige R. Atkins........703-325-2567
Paige.Atkins@disa.mil
DSO Dep Dir: Mr. Ralph Puckett..........703-325-2874
Ralph.Puckett@disa.mil

### Strategic Planning Office (SPO)
SPO Director: Mr. Steven A. Molina ......703-325-0435
Steven.Molin@disa.mil
Internat'l Team Lead: Mr. Chris Hofer .....703-325-2876
EST Team Lead: Ms. Mary Lin ...........703-325-0136
National Team Lead: Mr. Dan O'Neill .....703-325-2606

### Joint Spectrum Center (JSC)
2004 Turbot Landing, Annapolis, MD 21402-5064
Tel: 410-293-4957, Fax: 410- 293-2631
Commander, JSC (J00):
COL John J. Hickey Jr., USA.............410- 293-2450
John.Hickey@jsc.mil
Commander's Group: commander@jsc.mil
Technical Director (J01):
Mr. Mike Williams .....................410- 293-2457
mike.williams@jsc.mil
Executive Officer (J02):
CDR Robert "Jeff" Lamont, USN .........410- 293-2452
Jeff.Lamont@jsc.mil

### Operations Division (J3)
Chief: LTC Kevin T. Laughlin ............. 410-293-9813
Kevin.Laughlin@jsc.mil
Senior Engineer: Mr. Robert Lynch ....... 410-293-9816
robert.lynch@jsc.mil
RD&A Division (J5):
Mr. Robert Schneider...................410-293-4958
robert.schneider@jsc.mil
Senior Engineer: Mr. Marcus Shellman....410-293-4959
marcus.shellman@jsc.mil
Team Lead: Mr. Matthew Grenis.........410-293-9264
matthew.grenis@jsc.mil
R&D Team Lead: Mr. Serey Thai .........410-293-9263
Serey.Thai@jsc.mil

### Spectrum Management InformationTechnology Division (J6)
Acting Chief: Mr. Joseph Whitworth .....410-293-9822
Plans and Resources Division (J7):
Chief: Mrs. Joanne F. Sykes .............410-293-2356
joanne.sykes@jsc.mil
Applied Engineering Division (J8):
Chief: Aaron Leong, Lt Col, USAF........ 410- 293-2682
Aaron.Leong@jsc.mil
Senior Engineer: Mr. Irving Mager........410- 293-2103
irving.mager@jsc.mil
Chief, DSRMA: Mr. Ted Grove .......... 410- 293-2222

### Joint Frequency Management and Spectrum Engineering Office, Atlantic (JFMO LANT)
Director JFMO LANT (USJFCOM/J63)
1562 Mitscher Ave., Ste. 200
Norfolk, VA 23551-2488
Tel.: 757-836-8006 Fax: 757-836-8022

## UNITED STATES AIR FORCE

### Aeronautical Systems Center (ASC) ASC / ENAC
2145 Monahan Way
Wright-Patterson Air Force Base, OH 45433-7101
Fax: 937-255-5305
E3 Technical Advisor
Mr. Manny Rodriguez...................937-255-6957
manuel.rodriguez@wpafb.af.mil
EMI/EMC Tech Expert
Mr. Joseph M. DeBoy, .................937-255-6995
joseph.deboy@wpafb.af.mil
EMI/EMC Engineer
Mr. Brian M. Lezanic ...................937-255-9051
brian.lezanic@wpafb.af.mil

### Aeronautical Systems Center (ASC) ASC / ENAC
2145 Monahan Way
Wright-Patterson Air Force Base, OH 45433-7017
Fax: 937-255-5305
Electromagnetic Environmental Effects (E3) Engineer
Mr. Jose Pabon Soto ...................937-255-7676
jose.pabon-soto@wpafb.af.mil

### Aeronautical Systems Center (ASC) ASC / WKE
2590 Loop Rd. West
Wright-Patterson Air Force base, OH 45433-7142
Fax: 937-255-7749
Electromagnetic Environmental Effects (E3) Engineer
Ms. Natalia Bartholomew...............937-255-3451
natalia.bartholomew@wpafb.af.mil

### Air Force Research Laboratory Headquarters
Bldg 15 Room 225
1864 Fourth Street
WPAFB, OH 45433-7132
Mr. Joe Harrington.....................937-656-4636
joseph.harrington@wpafb.af.mil
Aeronautical Systems Center (ASC)
312/326 AE SW (Fighter Bomber Wing)
702 AE SG (B-2)
2690 C St., B556
Wright-Patterson AFB, OH 45433-7424
Dr. Phil Beccue ........................937-255-6881
Philip.Beccue@wpafb.af.mil

### Aeronautical Systems Center (ASC)
312/326 AE SW (Fighter Bomber Wing)
651 AE SS (B-52)
2690 C St., B556
Wright-Patterson AFB, OH 45433-7424
FAX (937) 656-4621
Mr. Jeremy Burns.....................(937) 255-7025
jeremy.burns@wpafb.af.mil

### HQ Air Force Material Command (AFMC) AFMC / EN P
Bldg. 262/Rm N145/Post116D
Wright-Patterson AFB, Ohio 45433
Fax: 937-656-4183
Mr. John S. Welch .....................937-255-0651
john.welch@wpafb.af.mil

### Aeronautical Systems Center (ASC)
516 AE SW (Mobility)
836 AE SG (Tankers)
2530 Loop Road West,
Wright-Patterson AFB, Ohio 45433
Mr. Robert Rosengarten ...............(937) 255-3451
Robert.Rosengarten@wpafb.af.mil

### Air Force Research Laboratory, Sensors Directorate AFRL/RYWD
2241 Avionics Circle
Bldg 620, Rm 1DG106
Wright-Patterson Air Force Base, OH 45433
EMI Laboratory
Fax: 937-656-9047
Mr. Steven Coffman....................937-528-8673
steven.coffman.ctr@wpafb.af.mil
Mr. John Zentner ......................937-528-8677
john.zentner.ctr@wpafb.af.mil

### Aeronautical Systems Center Reconnaissance Systems Wing
303 AE SG (Global Hawk)
2640 Loop Road West
Wright-Patterson Air Force Base, OH 45433-7106
Mr. Dave Osborn....................... 937-255-7437
david.osborn@wpafb.af.mil

### Air Force Space Command (AFSPC)
85th Engineering Installation Squadron
85 EIS/SCYM
670 Maltby Hall Drive, Ste.234
Keesler AFB, MS 39534-2633
85.eis.scym@keesler.af.mil
Specialized Engineering Flight:
Mr. George R. McNeer, SCY............. 228-377-1037
Electromagnetics Section Chief:
Mr. Frederick G. Blache, SCYM ..........228-377-3926
frederick.blache@us.af.mil
E3 Engineers:
Mr. Randal Blanchard, SCYT............. 228-377-1068
randal.blanchard@us.af.mil
Captain Micah Coplan.................. 228-377-1035
micah.coplan@us.af.mil
Ms. Kristen M. Corrigan ................ 228-377-1073
kristen.corrigan@us.af.mil
Mr. Edward Crum, SCYM ............... 228-377-1096
edward.crum@us.af.mil
Mr. Stephen L. Dabney ................. 228-377-1074
stephen.dabney@us.af.mil
Mr. Tim O. Hillman ..................... 228-377-1278
timothy.hillman@us.af.mil
Mr. Justin L. Johnston..................228-377-3041
justin.johnston.4@us.af.mil
Mr. Carlton L. Jones.................... 228-377-1088
carlton.jones@us.af.mil
Mr. James W Laycock.................. 288-377-1035
james.laycock@us.af.mil
Mr. Tom Lipski......................... 228-377-1084
thomas.lipski@us.af.mil
Captain Arris Pineda ................... 228-377-1126
arris.pineda@us.af.mil
Mr. Alton J. Richards III................. 228-377-1079
alton.richards@us.af.mil
Captain Jason R. Seyba................. 228-377-1085
jason.seyba@us.af.mil
Mr. Gregory P. Smith ...................228- 377-1083
gregory.smith.7@us.af.mil
Mr. Jessie Thomas III.................. 228- 377-4601

jessie.thomas.2@us.af.mil
Mr. Phi D. Tran. . . . . . . . . . . . . . . . . . . . . . . . 228- 377-1062
phi.tran@us.af.mil
Mr. Truong X. Vu . . . . . . . . . . . . . . . . . . . . . . .228- 377-1866
truong.vu@us.af.mil
Mr. Brandon Walker. . . . . . . . . . . . . . . . . . . .228- 377-1048
brandon.walker.1@us.af.mil
Sr. Electronics Engineer:
Mr. Robert (Nick) Wilson . . . . . . . . . . . . . . .228- 377-1047
robert.wilson.6@us.af.mil

## UNITED STATES ARMY

**U. S. Army Research, Development and Engineering Command (RDECOM)**
Attn.: AMSRD-AAR-AEP-F
Bldg. 3208
Picatinny Arsenal, NJ 07806-5000
Fax: (73-724-3025
Mr. Tom Crowley, Supvr. . . . . . . . . . . . . . . . . 973-724-5678
thomas.m.crowley@us.army.mil
Mr. Daniel Gutierrez, Sr. Proj. Engr. . . . . . . . 973-724-4667
daniel.gutierrez@us.army.mil
Mr. Paul Lee, Proj. Engr.. . . . . . . . . . . . . . . . . 973-724-4584
paul.m.lee@us.army.mil

**Army Research, Development, and Engineering Command (RDECOM)**
Attn: RDMR-AES-E3
Building 4488
Redstone Arsenal, AL 35898-5000
Fax: 256-313-3194
E3 for Army Aircraft Airworthiness
E3 Branch Chief:
Mr. Dave Lewey. . . . . . . . . . . . . . . . . . . . . . .256-313-8464
dave.lewey@us.army.mil
E3 Team Lead, Attack/Recon/Cargo Team:
Ms. Karen Compton . . . . . . . . . . . . . . . . . . . .256-313-8437
karen.compton@us.army.mil
E3 Team Lead, Utility/Fixed Wing/SOA Team:
Mr. Duane Driver . . . . . . . . . . . . . . . . . . . . . .256-313-8447
duane.driver@us.army.mil
Mr. Dale Heber . . . . . . . . . . . . . . . . . . . . . . . .256-313-2229
dale.heber@us.army.mil
Mr. Bruce Hildebrandt . . . . . . . . . . . . . . . . . .256-313-8457
bruce.hildebrandt@us.army.mil
Mr. Elliot Croom . . . . . . . . . . . . . . . . . . . . . . .256-842-5387
Elliot.croom@amrdec.army.mil
Mr. Abner Merriweather. . . . . . . . . . . . . . . .256-313-8470
abner.merriweather@us.army.mil
Mr. Brian Smith,iNCE, iNCT . . . . . . . . . . . . 256- 313-8484
brian.smith42@us.army.mil
Mr. John Trp . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
256-313-3148
john.trp@us.army.mil
Mr. Mike Dreyer . . . . . . . . . . . . . . . . . . . . . . .256-313-6384
michael.dreyer@us.army.mil
Mr. Dan Hinton . . . . . . . . . . . . . . . . . . . . . . . .256-313-8497
daniel.w.hinton@us.army.mil
Mr. David Alan Landrith. . . . . . . . . . . . . . . . . 256-313-9102
david.landrith@amrdec.army.mil
Mr. Roy Lawson . . . . . . . . . . . . . . . . . . . . . . .256-313-8454
roy.lawson@us.army.mil
Mr. Chris Myers . . . . . . . . . . . . . . . . . . . . . . .256-842-3197
Christopher.myers@amrdec.army.mil
Mr. Thad Paone. . . . . . . . . . . . . . . . . . . . . . . . 256-842-1387
Thad.paone@us.army.mil
Attn.: AMSAM-RD-MG-SD
SC Functions
Mr. Dave Smith. . . . . . . . . . . . . . . . . . . . . . . 256- 876-1688
wayne.d.smith2@us.army.mil

**Army Test and Evaluation Command (ATEC) United States Army Aberdeen Test Center (ATC) Electromagnetic Interference Test Facility (EMITF)**
Attn.: TEDT-AT-C4
400 Colleran Road, Building 456
Aberdeen Proving Ground, MD 21005-5059
Fax: 410- 278-0579
EMITF Supervisor:
Mr. Michael C. Geiger . . . . . . . . . . . . . . . . . .410- 278-2598
michael.c.geiger.civ@mail.mil
Senior Electrical Engineer:
Mr. Clinton Sienkiewicz. . . . . . . . . . . . . . . . .410- 306-1334
clifton.j.sienkiewicz.civ@mail.mil
Electronic Technicians:
Mr. Duane Buono . . . . . . . . . . . . . . . . . . . . 410- 278-3005
duane.buono.ctr@mail.mil
Mr. Emmanuel Hammett. . . . . . . . . . . . . . . .410- 278-3161
Emmanual.hammett.ctr@mail.mil
Mr. Mark Connor. . . . . . . . . . . . . . . . . . . . . . .410- 278-3189
Mark.j.connor3.ctr@mail.mil
Christopher Dennison. . . . . . . . . . . . . . . . . 410- 278-3235
Christopher.r.dennison.ctr@mail.mil
JR Gildeleon . . . . . . . . . . . . . . . . . . . . . . . . 410- 278-3008
john.r.gildeleon.ctr@mail.mil
Mr. Todd Holman . . . . . . . . . . . . . . . . . . . . 410- 278-3022
richard.t.holman.ctr@mail.mil
Mr. Harry Giles . . . . . . . . . . . . . . . . . . . . . . 410- 278-3232
Harry.j.giles.ctr@mail.mil
Mr. Nate Reyerson. . . . . . . . . . . . . . . . . . . . . 410-278-3176
Nathan.p.reyerson.ctr@mail.mil
Mr. Brian Savage . . . . . . . . . . . . . . . . . . . . . .410- 278-2941
brian.c.savage.ctr@mail.mil

**Army Center for Health Promotion & Preventive Medicine (CDR USACHPPM)**
Radiofrequency/Ultrasound Program
Attn.: MCHB-TS-ORF
5158 Blackhawk Road
Aberdeen Proving Ground, MD 21010-5403
Mr. John J. DeFrank. . . . . . . . . . . . . . . . . . . .410-436-3353

**Bureau of Medicine and Surgery (M3F72)**
2300 E. St., N.W.
Washington, DC 20372-5300
Fax: 202-762-0931

**Army Engineer Research and Development Center - Construction Engineering Research Laboratory**
Attn.: CEERD-CF-F
P.O. Box 9005
Champaign, IL 61826-9005
Dr. William J. Croisant. . . . . . . . . . . . . . . . . .217-373-3496
william.j.croisant@erdc.usace.army.mil

**Army Electronic Proving Ground Test Engineering Directorate**
Laboratory Division
Attn.: TEDT-EP-TEL
Fort Huachuca, AZ 85613-7110
Div. Chief Mr. Rafael Anton. . . . . . . . . . . . .520- 538- 4916
rafael.anton@us.army.mil

**E3 Test Facility/Blacktail Canyon**
Mr. James Smith . . . . . . . . . . . . . . . . . . . . 520- 538-5188
james.a.smith4@us.army.mil
Ms. Rachel Blake . . . . . . . . . . . . . . . . . . . . 520- 538-2818
rachel.m.blake@us.army.mil
Mr. David Seitz . . . . . . . . . . . . . . . . . . . . . . 520- 533-5819
david.seitz3@us.army.mil

**Antenna Test Facility**
Technical Lead: Mr. Doug Kremer . . . . . . . .520-533-8170
douglas.kremer@us.army.mil

**Army Intelligence and Security Command G-4, Technical Support Division**
Attn.: IALO-T
8825 Beulah St.
Ft. Belvoir, VA 22060-5246
Tel.: 703-428-4479 (DSN: 328-4479)
Fax: 703-428-4911 (DSN: 328-4911)
Ms. Anne Bilgihan
anne.g.bilgihan.civ@mail.mil

**Army Nuclear and Chemical Agency (USANCA)**
7150 Heller Loop, Ste. 101
Springfield, VA 22150-3198
Mr. R. Pfeffer. . . . . . . . . . . . . . . . . . . . . . . . . .703-806-7862

**Army Research Laboratory (ARL)**
Survivability/Lethality Analysis Directorate (SLAD)
Bldg 1628, AMSRD-ARL-SL-ES WSMR, NM 88002
575-678-7650
jose.reza@us.army.mil

**White Sands Test Center**
Attn.: TEDT-WSV-E (S Jesson)
Building 21225
White Sands Missile Range, NM 88002-5158
Ms. Stephanie Jesson. . . . . . . . . . . . . . . . . .575-678-6107
Stephanie.s.jesson.civ@mail.mil
Ms. Janet Danneman . . . . . . . . . . . . . . . . . .575-678-6307
Janet.danneman.civ@mail.mil
Mr. Gustavo Sierra . . . . . . . . . . . . . . . . . . . . .575-678-2038
Gustavo.l.sierra.civ@mai . . . . . . . . . . . . . . . . . . . . . . . .l.mil
Mr. John Chavarria. . . . . . . . . . . . . . . . . . . . .575-678-1993
John.p.chavarria.civ@mail.mil

**Army Test and Evaluation Command (ATEC United States Army Electronic Proving Ground (EPG) Enterprise Test Services Directorate Electromagnetic Environmental Effects/TEMPEST and Antenna Division**
ATTN: TEDT-EP-SEA
2000 Arizona Street
Fort Huachuca, AZ 85613-7063
E3/TEMPEST
E3 Technical Lead
Mr. Johnny E. Douglas. . . . . . . . . . . . . . . . . .520-533-5819
Johnny.e.douglas2.civ@mail.mil
Test Officers
Mr. James A. Smith . . . . . . . . . . . . . . . . . . . .520-538-5188
james.a.smith4.civ@mail.mil
Mr. Thomas Q. Markham . . . . . . . . . . . . . . .520-538-1802
thomas.q.markham.civ@mail.mil
Mr. Fulton K. Woo. . . . . . . . . . . . . . . . . . . . . .520-533-8266
Fulton.k.woo.civ@mail.mil
Mr. David L. Seitz . . . . . . . . . . . . . . . . . . . . . .520-533-7529
david.l.seitz14.civ@mail.mil
Mr. Garrett V. Rude. . . . . . . . . . . . . . . . . . . . .520-538-5623
garrett.v.rude.civ@mail.mil
Antenna Technical Lead
Mr. Douglas P. Kremer . . . . . . . . . . . . . . . . .520-533-8170
douglas.p.kremer.civ@mail.mil
Test Officer
Mr. Anthony C. Sanchez . . . . . . . . . . . . . . . .520-533-9874
anthony.c.sanchez.civ@mail.mil
Ms. Rachel M. Blake . . . . . . . . . . . . . . . . . . .520-538-0726
rachel.m.blake.civ@mail.mil

## UNITED STATES MARINE CORPS

### Marine Corps Operational Test and Evaluation Activity (MCOTEA)

3035 Barnett Ave., Quantico, VA 22134, Chief of Test
(703) 432-0927, Marine Corps Systems Command (MCSC),
Attn.: Mr. Praful Bharucha (C4II/ACENG), 2000 Lester Street, Quantico, VA 22134-5010
E3 Control Program Sponsor
Mr. Praful Bharucha . . . . . . . . . . . . . . . . . . . 703-432-3806
praful.bharucha@usmc.mil

## UNITED STATES NAVY

### MID-LANT Area Frequency Coordination Office; Naval Air Warfare Center Aircraft Division

Code 5.2.2.2
23013 Cedar Point Road, Unit 4, Building 2118
Patuxent River, MD 20670-1183
Fax: 301- 342-1200
Mr. Mikel R. Ryan . . . . . . . . . . . . . . . . . . . . . 301-342-1532
mikel.ryan@navy.mil
E3 Aircraft Engineering Branch
AIR 4.1.13.1
Br. Head: Mr. Ted Rothman . . . . . . . . . . . . 301- 342- 9223
theodore.rothman@navy.mil
Ms. Carrol Basanez . . . . . . . . . . . . . . . . . . . 301-757-2451
carrol.basanez@navy.mil
Mr. Paul Belusko . . . . . . . . . . . . . . . . . . . . . . 301-757-2446
paul.belusko@navy.mil
Mr. Jon Bergmann . . . . . . . . . . . . . . . . . . . . 301-995-3832
jon.bergmann@navy.mil
Mr. John Besanceney . . . . . . . . . . . . . . . . . 301-757-2445
john.besanceney@navy.mil
Ms. Pamela Crispell . . . . . . . . . . . . . . . . . . . 301-342-8629
pamela.crispell@navy.mil
Mr. Ken Deans . . . . . . . . . . . . . . . . . . . . . . . 301-757-2447
kenneth.deans@navy.mil
Mr. William DePasquale . . . . . . . . . . . . . . . 301-757-6961
william.depasquale@navy.mil
Mr. Travis Flanagan . . . . . . . . . . . . . . . . . . . 301-342-7771
travis.flanagan@navy.mil
Mr. Frederick Heather . . . . . . . . . . . . . . . . . 301-342-6975
frederick.heather@navy.mil
Mr. Reggie Hope . . . . . . . . . . . . . . . . . . . . . . 301-342-6975
lionel.hope@navy.mil
Mr. DJ Jardine . . . . . . . . . . . . . . . . . . . . . . . 301-757-2451
david.jardine@navy.mil
Mr. Joe Kmetz . . . . . . . . . . . . . . . . . . . . . . . . 301-757-2361
joseph.kmetz@navy.mil
Mr. Gene Kuhn . . . . . . . . . . . . . . . . . . . . . . . 301-757-6545
gene.kuhn@navy.mil
Mr. Jay Lees . . . . . . . . . . . . . . . . . . . . . . . . . 301-342-0350
jay.lees@navy.mil
Mr. Jason Mackowiak . . . . . . . . . . . . . . . . . 301-342-8344
jason.mackowiak@navy.mil
Ms. Jennifer Nguyen . . . . . . . . . . . . . . . . . . 301-995-7671
jennifer.nguyen@navy.mil
Mr. Luke Onachila . . . . . . . . . . . . . . . . . . . . . 301- 757-2420
luke.onachila@navy.mil
Mr. Steve Salisbury . . . . . . . . . . . . . . . . . . . 301- 342-2255
steven.salisbury@navy.mil
Mr. John Schultz . . . . . . . . . . . . . . . . . . . . . . 301-757-2456
john.schultz@navy.mil
Mr. Craig Simmons . . . . . . . . . . . . . . . . . . . . 301-342-4907
craig.simmons@navy.mil
Mr. Michael Skrabacz . . . . . . . . . . . . . . . . 301- 342-5805
michael.skrabacz@navy.mil
Mr. Robert Tate . . . . . . . . . . . . . . . . . . . . . . . 301- 342-8632
robert.d.tate1@navy.mil
Mr. John Tonello . . . . . . . . . . . . . . . . . . . . . . 301- 342-2158
john.tonello@navy.mil
Mr. Thierry Wandji . . . . . . . . . . . . . . . . . . . . 301-342-3297
ketchiozo.wandji@navy.mil

### Naval Air Warfare Center Aircraft Division

Electromagnetic Interference Lab, 5.4.4.9
Patuxent River, MD, Fax: 301- 342-5390
EMI Lab
Branch Hd.: Mr. Lance Pearce . . . . . . . . . . . 301-342-0851
lance.pearce@navy.mil
Mr. Kenneth Brezinski . . . . . . . . . . . . . . . . . 301-342-0848
kenneth.brezinski@navy.mil
Mr. Tom Dennehey . . . . . . . . . . . . . . . . . . . . 301-342-0832
thomas.dennehey@navy.mil
Mr. Richard Harvan . . . . . . . . . . . . . . . . . . . 301-342-0847
richard.harvan@navy.mil
Ms. Diane Kempf . . . . . . . . . . . . . . . . . . . . . 301-342-0850
diane.kempf@navy.mil
Ms. Pam Lumsden . . . . . . . . . . . . . . . . . . . . 301-342-0852
pamela.lumsden@navy.mil
Mr. Patrick Mills . . . . . . . . . . . . . . . . . . . . . . 301-995-4148
patrick.n.mills@navy.mil

### Naval Air Warfare Center Training Systems Division (NAWCTSD)

Code 6.7.2.3
12350 Research Parkway, Orlando, FL 32826-3275

### Space and Naval Warfare Systems Center, Charleston (SPAWAR SYSCEN, Charleston)

P.O. Box 190022
North Charleston, SC 29419-9022
Fax: 843-218-4238
**Electromagnetic Environmental Effects (E3) Branch, Code 5610**
Branch Hd.: Mr. Wayne Lutzen. . . . . . . . . . . 843-218-5723
Wayne.lutzen@navy.mil
E3 Engineers
Reco Baker. . . . . . . . . . . . . . . . . . . . . . . . . . . 843-218-3988
Reco.baker@navy.mil
Mr. Frederic Duffy . . . . . . . . . . . . . . . . . . . . 843-218-4363
Frederic.duffy@navy.mil
Mr. Michael Hanna. . . . . . . . . . . . . . . . . . . . 843-218-4039
Michael.a.hanna@navy.mil
Mr. Guillermo Leiva . . . . . . . . . . . . . . . . . . . 843-218-7129
Guillermo.leiva@navy.mil
Mr. Thomas Sessions. . . . . . . . . . . . . . . . . . 843-218-6331
Thomas.sessions@navy.mil

### Space and Naval Warfare Systems Center Pacific, Pacific C4ISR Department

(SSC PAC, PAC C4ISR DEPT)
2293 Victor Wharf Access Road, Pearl City, HI 96782-3356
Fax: (808) 474-5511
Ms. Candice Saka. . . . . . . . . . . . . . . . . . . . . 808-471-4028
Candice.saka@navy.mil
Mr. Jack Munechika. . . . . . . . . . . . . . . . . . . 808-471-1976
Jack.munechika@navy.mil
Mr. Randy Yamada . . . . . . . . . . . . . . . . . . . . 808-474-6061
Randy.yamada@navy.mil
Mr. Lloyd Hayashida. . . . . . . . . . . . . . . . . . . 808-474-1967
Lloyd.hayashida@navy.mil
Mr. Laine Murakami. . . . . . . . . . . . . . . . . . . 808-471-0366
laine.murakami@navy.mil

### SPAWAR Systems Center - Pacific (SSC-Pacific)

53560 Hull St., San Diego, CA 92152-5001
Fax: 619- 553-3791
**Applied Electromagnetics Branch, Code 5541**
Branch Hd.: Dr. John Meloling . . . . . . . . . . 619-553-2134
john.meloling@navy.mil
Mr. Jeffrey C. Allen . . . . . . . . . . . . . . . . . . . 619-553-6566
jeffrey.allen@navy.mil
Ms. Carol Becker . . . . . . . . . . . . . . . . . . . . . 619-553-1033
carol.becker@navy.mil
Mr. David C. Dawson . . . . . . . . . . . . . . . . . . 619-553-4075
david.c.dawson@navy.mil
Mr. David Hurdsman . . . . . . . . . . . . . . . . . . 619-553-4261
david.hurdsman@navy.mil
Mr. Lance Koyama . . . . . . . . . . . . . . . . . . . . 619-553-3784
lance.koyama@navy.mil
Mr. Ahn Lee . . . . . . . . . . . . . . . . . . . . . . . . . . 619-553-3426
ahn.lee@navy.mil
Mr. P. Michael McGinnis . . . . . . . . . . . . . . . 619-553-5092
mike.mcginnis@navy.mil
Ms. Nazia Mozaffar . . . . . . . . . . . . . . . . . . . 619-553-2593
nazia.mozaffar@navy.mil
Mr. Rick Nielsen . . . . . . . . . . . . . . . . . . . . . . 619-553-6015
rick.nielsen@navy.mil
Ms. Jeanne Rockway . . . . . . . . . . . . . . . . . 619-553-3886
jeanne.rockway@navy.mil
Mr. Kianoush Rouzbehani . . . . . . . . . . . . . . 619- 553-3134
kian.rouzbehani@navy.mil
Raquel Sanchez-Karem . . . . . . . . . . . . . . . . 619-553-5876
raquel.sanchez-karem@navy.mil
Ricardo Santoyo-Mejia . . . . . . . . . . . . . . . . 619-553-6139
ricardo.santoyomejia@navy.mil
Anirudha Siripuram . . . . . . . . . . . . . . . . . . . 619-553-8749
anirudha.siripuram@navy.mil
Ron Thompson . . . . . . . . . . . . . . . . . . . . . . . 619-553-0457
ron.thompson@navy.mil
**Electromagnetics Technology Branch, Code 5542**
Branch Head: Matt Osburn . . . . . . . . . . . . . 619-553-5941
matthew.osburn@navy.mil
Dr. Rich Adams . . . . . . . . . . . . . . . . . . . . . . . 619-553-4313
rich.adams@navy.mil
Mr. Jim Birkett . . . . . . . . . . . . . . . . . . . . . . . 619-553-3586
jim.birkett@navy.mil
Mr. Jose L. Chavez . . . . . . . . . . . . . . . . . . . . 619-553-5075
jose.chavez@navy.mil
Dr. Will Cronyn . . . . . . . . . . . . . . . . . . . . . . . 619-553-5084
will.cronyn@navy.mil
Mr. Chris Dilay. . . . . . . . . . . . . . . . . . . . . . . . 619-553-3794
chris.dilay@navy.mil
Mr. Vincent V. Dinh . . . . . . . . . . . . . . . . . . . 619-553-7255
vincent.v.dinh@navy.mil
Ms. Silvia Goodman, Secretary . . . . . . . . . 619-226-5953
silvia.goodman@navy.mil
Mr. David Hilton . . . . . . . . . . . . . . . . . . . . . . 619-553-2666
david.r.hilton@navy.mil
Mr. Carl P. Kugel . . . . . . . . . . . . . . . . . . . . . . 619-553-3066
carl.kugel@navy.mil
Ms. Wendy Massey. . . . . . . . . . . . . . . . . . . . 619-553-9711
wendy.massey@navy.mil
Mr. Daniel Meeks. . . . . . . . . . . . . . . . . . . . . 619-553-6753
daniel.meeks@navy.mil
Dr. John D. Rockway . . . . . . . . . . . . . . . . . . 619-553-5438
john.rockway@navy.mil
Mr. Alberto Rodriguez . . . . . . . . . . . . . . . . . 619-553-5697
alberto.rodriguez2@navy.mil
**Advanced Electromagnetic Technology Branch, Code 5546**
Branch Hd.: Jodi McGee . . . . . . . . . . . . . . . 619-553-3778
jodi.mcgee@navy.mil
Diana Arceo. . . . . . . . . . . . . . . . . . . . . . . . . 619-553-6344
diana.arceo@navy.mil
Lam T. Bui. . . . . . . . . . . . . . . . . . . . . . . . . . . 619-553-6038
lam.bui@navy.mil

Jennifer Edwards . . . . . . . . . . . . . . . . . . . . . . 619-553-5428
jennifer.edwards@navy.mil
Daniel R. Gaytan. . . . . . . . . . . . . . . . . . . . . . . 619-553-7461
daniel.gaytan@navy.mil
John L. Hunter. . . . . . . . . . . . . . . . . . . . . . . . .619-553-5086
john.hunter@navy.mil
Lillie Jackson, Secretary . . . . . . . . . . . . . . . .619-553-5076
lillie.jackson@navy.mil
Dr. Burt Markham. . . . . . . . . . . . . . . . . . . . . .619-553-6082
burt.markham@navy.mil
Mr. Marcus Maurer . . . . . . . . . . . . . . . . . . . .619-553-3797
marcus.maurer@navy.mil
Mr. Aldo Monges . . . . . . . . . . . . . . . . . . . . . .619- 553-6129
aldo.monges@navy.mil
Mr. Filemon Peralta . . . . . . . . . . . . . . . . . . . .619-553-3043
filemon.peralta@navy.mil
Mr. Hoa Phan. . . . . . . . . . . . . . . . . . . . . . . . . .619-553-0148
hoa.phan@navy.mil
Mr. Randall Reeves . . . . . . . . . . . . . . . . . . . . 619-553-1032
randall.reeves@navy.mil
Mr. Anthony Ton . . . . . . . . . . . . . . . . . . . . . . .619-553-5428
anthony.ton@navy.mil
Mr. Daryl W. Von Mueller . . . . . . . . . . . . . . 619- 553-6527
daryl.vonmueller@navy.mil
Mr. Benton Wong . . . . . . . . . . . . . . . . . . . . . .619-553-3043
benton.wong@navy.mil
Chief of Naval Operations
Code NC-1, PT-5451, N6F13
2000-Navy Pentagon, Washington, DC 20350-2000
Fax: (703) 601-1323
Spectrum Electromagnetic Environmental Effects (E3) & EMP Policy & Programs
Head: Mr. Dave D. Harris. . . . . . . . . . . . . . . (703) 601-3968
dave.harris@navy.mil
Naval Ordnance Safety and Security Activity (NOSSA)
NAVORDSAFSECACT INDIAN HEAD
Electrical Explosives Safety
Code N84
Farragut Hall, Bldg. D323, 23 Strauss Ave.
Indian Head, MD 20640-5035, Fax: 301- 744-6088
Weapons Assessment (N8)
Director: Charles Denham. . . . . . . . . . . . . . 301- 744-4447
charles.denham@navy.mil

### Naval Research Laboratory

Code 5348
4555 Overlook Ave., S.W., Washington, D.C. 20375-5320
Tel.: 202-404-7726, Mr. Larry Cohen
Lawrence.Cohen@nrl.navy.mil
Naval SeaSystems Command (NAVSEA)

### Force Electromagnetic Environmental Effects (E3) and Spectrum Management Warfare Systems

Engineering Directorate (SEA 06)
1333 Isaac Hull Ave., S.E., Stop 5011, Washington Navy Yard, DC 20376-5011, Fax: (202) 781-4568
**Force E3 and Spectrum Management Branch**
Branch Head: Mr. J. Don Pierce . . . . . . . . . . 202-781-4214
james.d.pierce@navy.mil

### Naval Surface Warfare Center, Crane Division (NSWC Crane)

Code GXS
300 Highway 361, Bldg. 3287E, Crane, IN 47522
Fax: 812-854-3589
Mr. Larry McKibben . . . . . . . . . . . . . . . . . . . . 812-854-5107
Lawrence.McKibben@navy.mil
Naval Surface Warfare Center
Dahlgren Division
5493 Marple Road, Suite 156, Dahlgren, VA 22448-5153
**Electromagnetic Effects Division, Code Q50**
Electromagnetic Effects Division
Chief Engineer:
Mr. Jason Bardine . . . . . . . . . . . . . . . . . . . . .540-653-7450
Jason.bardine@navy.mil
NAVSEA E3 Technical Warrant Holder:
Mr. Kurt Mikoleit. . . . . . . . . . . . . . . . . . . . . . .540-653-3425
Kurt.mikoleit@navy.mil
**E3 Spectrum Supportability Branch, Code Q51**
Branch Head:
Mrs. Amy Sunshine Smith-Carroll . . . . . . . .540-653-1694
amy.smith-carroll@navy.mil
**E3 Spectrum Supportability Branch, Code Q51**
Operations and Spectrum Support Group Lead:
Mr. Mark Flenner . . . . . . . . . . . . . . . . . . . . . .540-653-7892
Mark.l.fleener@navy.mil
**E3 Spectrum Supportability Branch, Code Q51**
Spectrum Engineering Group Lead:
Ms. Margaret Neel. . . . . . . . . . . . . . . . . . . . 540-653-8021
Margaret.neel@navy.mil
**E3 Spectrum Supportability Branch, Code Q51**
Electromagnetic Pulse Group Lead:
Mr. Blaise Corbett . . . . . . . . . . . . . . . . . . . . .540-653-2104
Blaise.corbett@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
Branch Head:
Mr. William T. Lenzi . . . . . . . . . . . . . . . . . . . 540-653-3444
william.lenzi@navy.mil
E**3 Assessment & Evaluation Branch (Q52)**
EMC/EMV Evaluation Group Lead:
Mr. James McGinniss . . . . . . . . . . . . . . . . . 540-653-0489
james.mcginniss@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
RADHAZ Program Manager:
Mr. Richard Magrogan. . . . . . . . . . . . . . . . . 540-653-3445
richard.magrogan@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
Weapons System E3 Group Lead:
Mr. Michael Miller . . . . . . . . . . . . . . . . . . . . 540-653-3460
michael.d.miller4@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
HERO Systems Certification Group Lead:
Mr. Andrew Rash . . . . . . . . . . . . . . . . . . . . . .540-653-1368
andrew.a.rash@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
EMI/461 Lab Group Lead:
Mr. Carl Hager. . . . . . . . . . . . . . . . . . . . . . . . .540-653-9501
carl.hager@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
Test Operations Group Lead:
Mr. Matthew Curtis . . . . . . . . . . . . . . . . . . . 540-653-3439
matthew.a.curtis@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
Science & Technology Applications Group Lead:
Mr. Michael Slocum . . . . . . . . . . . . . . . . . . . .540-653-2212
michael.slocum@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
RADHAZ Environment Characterization Group Lead:
Ms. Tamera Hay . . . . . . . . . . . . . . . . . . . . . . . 540-653-1419
tamera.hay@navy.mil
**E3 Assessment & Evaluation Branch (Q52)**
Surface Maritime Sensors Group Lead:
Mr. Michael Workman. . . . . . . . . . . . . . . . . 540-653-4646
michael.l.workman@navy.mil
**E3 Platform Integration Branch (Q53)**
Branch Head:
Mr. Kenneth D. Larsen . . . . . . . . . . . . . . . . . .540-653-3476
kenneth.d.larsen@navy.mil
**E3 Platform Integration Branch (Q53)**
Senior Scientist:
Dr. Greg Balchin . . . . . . . . . . . . . . . . . . . . . 540-653-6037
gregory.a.balchin@navy.mil
E**3 Platform Integration Branch (Q53)**
MAAC Group Lead:
Mr. Greg Brobjorg. . . . . . . . . . . . . . . . . . . . . .540-653-7075
greg.brobjorg@navy.mil
**E3 Platform Integration Branch (Q53)**
Combatant Group Lead:
Mr. Reza Biazaran. . . . . . . . . . . . . . . . . . . . . .540-284-0595
reza.biazaran1@navy.mil
**E3 Platform Integration Branch (Q53)**
CVN Group Lead:
Mr. Tim Baseler. . . . . . . . . . . . . . . . . . . . . . . 540- 653-0741
timothy.baseler@navy.mil
**E3 Platform Integration Branch (Q53)**
Computational Electromagnetics Group Lead:
Mr. Bryan Wagaman . . . . . . . . . . . . . . . . . . 540- 653-3430
bryan.wagaman@navy.mil
**E3 Systems Interoperability Branch, Code Q54**
Branch Head:
Mr. Rich Link . . . . . . . . . . . . . . . . . . . . . . . . . 540- 653-8907
rich.link@navy.mil
**E3 Systems Interoperability Branch, Code Q54**
Shipboard EMC Improvement Program Lead:
Mr. Mark Hamer . . . . . . . . . . . . . . . . . . . . . . 540- 284-0711
mark.hamer@navy.mil
**E3 Systems Interoperability Branch, Code Q54**
Force E3 Interoperability Group Lead:
Mr. John "Bart" Barbee . . . . . . . . . . . . . . . . 540- 653-3483
john.s.barbee@navy.mil
**E3 Systems Interoperability Branch, Code Q54**
Communication Systems E3 Interoperability Group Lead:
Mr. Cris Lake . . . . . . . . . . . . . . . . . . . . . . . . . 540- 653-5087
cristopher.lake@navy.mil
**E3 Systems Interoperability Branch, Code Q54**
Radar Systems E3 Interoperability Group Lead:
Mr. Al Pitts. . . . . . . . . . . . . . . . . . . . . . . . . . . 540- 653-6268
albert.pitts@navy.mil
**E3 Systems Interoperability Branch, Code Q54**
Electronic Warfare Systems E3 Interoperability Group Lead:
Mr. Brad Conner . . . . . . . . . . . . . . . . . . . . . . 540- 653-0610
bradley.conner@navy.mil

### Naval Undersea Warfare Center (NUWC)

1176 Howell St.
Newport, RI 02841-1708
Submarine Electromagnetic Environmental Effects (E3) Branch, Code 3431
Branch Head, 401- 832-5542
Branch Head: Mr. Craig F. Derewiany . . . . .401-832-5542
craig.derewiany@navy.mil
Mr. Scott Albert . . . . . . . . . . . . . . . . . . . . . . . 401-832-4122
scott.albert@navy.mil
Mr. Jon Bond. . . . . . . . . . . . . . . . . . . . . . . . . .401-832-6480
jon.bond@navy.mil
Mr. Michael J. Carpenter . . . . . . . . . . . . . . .401-832-5540
michael.j.carpenter@navy.mil
Mr. Douglas L. DeAngelis . . . . . . . . . . . . . 401- 832-5872
douglas.deangelis@navy.mil
Mr. Jamie A. Donais. . . . . . . . . . . . . . . . . . . .401-832-3603
jamie.donais@navy.mil
Mr. Anthony Francis. . . . . . . . . . . . . . . . . . . .401-832-5493
anthony.francis1@navy.mil
Mr. Edward R. Javor. . . . . . . . . . . . . . . . . . . .401-832-5546
edward.javor@navy.mil
Mr. Alan T. McHale. . . . . . . . . . . . . . . . . . . . .401-832-5635
alan.mchale@navy.mil
Mr. Michael P. Martin . . . . . . . . . . . . . . . . . .401-832-5630
michael.p.martin@navy.mil
Mr. Paul D. Opperman . . . . . . . . . . . . . . . . . .401-832-4092
paul.opperman@navy.mil
Mr. Fredric A. Stawarz. . . . . . . . . . . . . . . . . .401-832-5550


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fredric.stawarz@navy.mil
Mr. John L. Thibeault . . . . . . . . . . . . . . . . . . . 401-832-5551
john.thibeault@navy.mil
Mr. Richard L. Thibeault. . . . . . . . . . . . . . . . . 401-832-5552
richard.thibeault@navy.mil
Mr. Oleg Volchansky . . . . . . . . . . . . . . . . . . 401-832-5399
oleg.volchansky@navy.mil
Mr. Oscar R. Zelaya . . . . . . . . . . . . . . . . . . . 401-832-5597
oscar.zelaya@navy.mil
EMC Laboratory . . . . . . . . . . . . . . . . . . . . . . 401-832-5554
OPNAV N2N6F1221

### Spectrum Management and Electromagnetic Environmental Effects Office Net-Centric Capabilities/Strategic and Tactical Communications Branch Information Dominance Directorate

2511 Jefferson Davis Highway, Arlington, VA 22244-0001, Tel: 703-601-1414; Fax: 703-601-1323
Director: Mr. D. Mark Johnson . . . . . . . . . . . 703-601-1414
david.m.johnson4@navy.mil

## OTHER UNITED STATES AGENCIES

### Dept. of Health & Human Services - Food and Drug Administration

Center for Devices and Radiological Health
12725 Twinbrook Pkwy. (HFZ 133), Rockville, MD 20852
Tel.: 301- 827-4944
Electrophysics Branch, Div. Physical Sciences
Mr. Howard I. Bassen, Chief
Mr. Paul S. Ruggera
Mr. Donald Witters

### U.S. Environmental Protection Agency (EPA)

Office of Radiation and Indoor Air (ORIA)
Radiation Protection Division (6608J)
1200 Pennsylvania Ave., N.W., Washington, DC 20460
Fax: 202-343-3204
Director: Mr. Jonathan Edwards . . . . . . . . .202-343-9437
edwards.jonathan@epa.gov
Mr. Norbert Hankin . . . . . . . . . . . . . . . . . . . .202-343-9235
hankin.norbert@epa.gov

### Federal Aviation Administration

**Headquarters- ATC Spectrum Engineering Services, AJW-6**
800 Independence Avenue, S.W.
Washington, DC 20591, Dir.: VACANT
Spectrum Assignment & Engineering Office, AJW-932
Manager: Mr. Jerrold B. Sandors. . . . . . . . . 202-267-9720
Jerrold.Sandors@faa.gov
Spectrum Planning & International Office, AJW-933
Manager: Mr. Robert A. Frazier . . . . . . . . . . 202-267-9722
Robert.Frazier@faa.gov
**Federal Aviation Administration**
**FAA Aviation Safety (AMN-110N)**
1601 Lind Ave. S.W., Renton, WA 98057
Fax: 425-917-6590
Chief Scientific & Technical Advisor - Aircraft EMC:
Mr. David Walen. . . . . . . . . . . . . . . . . . . . . . . 425-917-6586
dave.walen@faa.gov

### Federal Communications Commission

445 12th Street, SW, Washington, DC 20554, Office of Engineering & Technology, Tel.: 202-418-2470
Chief: Julius P. Knapp
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**Policy & Rules Division**
Tel.: 202-418-2472
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### Federal Communications Commission Laboratory

7435 Oakland Mills Rd., Columbia, MD 21046
FCC Laboratory Division
Dr. Rashmi Doshi, Chief . . . . . . . . . . . . . . . . . 301-362-3011
Mr. Jim Szeliga . . . . . . . . . . . . . . . . . . . . . . . . 301-362-3051
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### Goddard Space Flight Center

Greenbelt, MD 20771
Code 565 Electrical Systems Branch
Code 549.0, Electromagnetic Systems Engineering
Mr. Todd Bonalsky, PhD, lead engineer. . . . 301-286-1008
Todd.M.Bonalsky@nasa.gov

### National Aeronautics and Space Administration - Kennedy Space Center

Kennedy Space Center, FL 32899
EMC Engineers
Team Lead: Ms. Dawn Trout (VA-F3), . . . . .321-867-5366
dawn.h.trout@nasa.gov
Mr. Ron Brewer (Analex) . . . . . . . . . . . . . . . .321-867-5329
ronald.w.brewer-1@nasa.gov
Ms. Janessa Burford (VA-H3). . . . . . . . . . . .321-867-5333
janessa.l.burford@nasa.gov
Mr. Tung Doan. . . . . . . . . . . . . . . . . . . . . . . . .321-867-5330
tung.m.doan@nasa.gov
Mr. Paul Edwards . . . . . . . . . . . . . . . . . . . . . .321-867-8927
paul.edwards@nasa.gov
Mr. Gabriel Vazquez Ramos, (VAH3) . . . . . . 321-867-3374
gabriel.vazquezramos-1@nasa.gov
Mr. Noel Sargent (Analex). . . . . . . . . . . . . . .216-433-3395
noel.b.sargent@nasa.gov
Mr. James Stanley . . . . . . . . . . . . . . . . . . . . . 321-867-1991
james.e.stanley@nasa.gov
Mr. Jarek Tracz . . . . . . . . . . . . . . . . . . . . . . . .321-867-2780
jarek.a.tracz@nasa.gov
EMC Test Engineer Manager:
Pete Aragona (NEE10) . . . . . . . . . . . . . . . . . 321-867-1027
peter.s.aragona@nasa.gov

### National Aeronautics and Space Administration - Langley Research Center

5 North Dryden St., Bldg. 1202, Hampton, VA 23665
Fax: 757-864-9884
**EMC Test Facility (MS 130)**
Ms. Courtney Rollins . . . . . . . . . . . . . . . . . . . 757-864-7814
c.h.rollins@larc.nasa.gov
**HIRF Laboratory (MS 130)**
Mr. Jay J. Ely. . . . . . . . . . . . . . . . . . . . . . . . . .757-864-1868
j.j.ely@nasa.gov
Mr. Truong X. Nguyen . . . . . . . . . . . . . . . . . .757-864-7528
t.x.nguyen@larc.nasa.gov
**EMI/EMC Analysis and Troubleshooting (MS 488)**
Dr. Arthur T. Bradley. . . . . . . . . . . . . . . . . . . .757-864-7343
arthur.t.bradley@nasa.gov

### National Aeronautics and Space Administration - John H. Glenn Research Center

21000 Brookpark Road, Cleveland, OH 44135

### National Aeronautics and Space Administration - Lyndon B. Johnson Space Center

2101 NASA Rd., Houston, TX 77058-3696
**Avionics Systems Test Branch (EV4)**
Branch Chf.: Ms. Linda Bromley . . . . . . . . . .281-483-0129
Analysis Grp. Ldr.: Ms. C. Sham . . . . . . . . . .281- 483-0124
EMC Grp. Ldr.: Mr. Robert Scully . . . . . . . . . 281-483-1499
robert.c.scully@nasa.gov
**EMC Test Laboratory**
Facility Mgr: Mr. Rod Robinson . . . . . . . . . . 281-483-1465
Electronic Systems Test Laboratory
Facility Mgr: Mr. Ned Robinson . . . . . . . . . .281-483-0130

### National Aeronautics and Space Administration - George C. Marshall Space Flight Center

Marshall Space Flight Center, AL 35812
Spectrum Manager: Terry Luttrell . . . . . . . .256-544-0130
Terry.Luttrell@nasa.gov
EMC Engineers (M/S ES42/4708)
Division Chief: Mr. Tony Clark. . . . . . . . . . . 256- 544-2394
Tony.Clark@nasa.gov
Branch Chief: Mr. Jeff Wesley . . . . . . . . . . 256- 544-3393
Jeff.Wesley@nasa.gov
Team Lead: Mr. Mark Krome . . . . . . . . . . . 256- 544-5635
Mark.Krome@nasa.gov
Mr. Michael Crane (ERC) . . . . . . . . . . . . . . . 256- 544-7259
Michael.G.Crane@nasa.gov
Mr. Tim Dew (ERC) . . . . . . . . . . . . . . . . . . . . 256- 544-3718
Timothy.M.Dew@nasa.gov
Mr. Ross Evans (Dynetics). . . . . . . . . . . . . . 256- 961-2305
Ross.W.Evans@nasa.gov
Ms. Tammy Flowers . . . . . . . . . . . . . . . . . . . .256-961-0508

Tammy.D.Flowers@nasa.gov
Mr. Truman Glasscock (Triumph) . . . . . . . . .256-544-5318
Truman.G.Glasscock@nasa.gov
Mr. Kenneth Gonzalez (Qualis) . . . . . . . . . . 256- 544-1658
Kenneth.P.Gonzalez@nasa.gov
Mr. Steve R Jones . . . . . . . . . . . . . . . . . . . . 256-544-4373
Steve.Jones@nasa.gov
Mr. Steve Linthicum (Dynetics). . . . . . . . . . .256-544-5312
Steven.E.Linthicum@nasa.gov
Mr. Jonathan Mack . . . . . . . . . . . . . . . . . . .256-544-3599
Jonathan.D.Mack@nasa.gov
Mr. Matthew McCollum . . . . . . . . . . . . . . . .256-544-2351
Matt.Mccollum@nasa.gov
Mr. Matthew McGrath (Dynetics) . . . . . . . 256- 544-3051
Matthew.M.McGrath@nasa.gov
Mr. Tom Perry (Jacobs) . . . . . . . . . . . . . . . .256-544-0744
Thomas.A.Perry@nasa.gov
Mr. Glenn Shelby . . . . . . . . . . . . . . . . . . . . . 256-544-0694
Glenn.Shelby@nasa.gov
EMI Test Facility . . . . . . . . . . . . . . . . . . . . . .256-544-8121

### National Institute of Standards and Technology

Electromagnetics Division, 687, Boulder, CO 80305
Div. Chief: Dr. Michael H. Kelley. . . . . . . . . .303-497-4736
michael.kelley@boulder.nist.gov
Secretary: Ms. Mary Filla . . . . . . . . . . . . . . (303) 497-3132
mary.filla@boulder.nist.gov

**RF Fields Group 687.02**

Group Leader: Dr. Perry F. Wilson . . . . . . . .303-497-3406
pfw@boulder.nist.gov
Secretary: Mr. Gian Aparicio . . . . . . . . . . . .303-497-3321
aparicio@boulder.nist.gov

**Antenna Parameters (687.02 Project)**

Mr. Jeffrey Guerrieri . . . . . . . . . . . . . . . . . .303-497-3863
guerrieri@boulder.nist.gov

**Wireless Systems (687.02 Project)**

Dr. Kate Remley . . . . . . . . . . . . . . . . . . . . . .303-497-3652
kate.remley@boulder.nist.gov

**Field Parameters and EMC Applications (687.02 Project)**

Galen Koepke . . . . . . . . . . . . . . . . . . . . . . . .303-497-5766
koepke@boulder.nist.gov

**Quantum Measurement Division, 684**

Gaithersburg, MD 20899
Div. Chief: Dr. Carl Williams . . . . . . . . . . . . 301- 975-3531
carl.williams@nist.gov

### National Telecommunications and Information Administration (NTIA)

U.S. Department of Commerce
1401 Constitution Ave., N.W., Washington, DC 20230
202-482-1850
Emergency Planning Subcommittee Chairman
Chief: Mr. Stephen R. Veader . . . . . . . . . . . .202-482-4417
sveader@ntia.doc.gov
Spectrum Planning Subcommittee Chairman
Chief: Mr. Stephen Butcher. . . . . . . . . . . . . .202-482-4163
sbutcher@ntia.doc.gov

**Institute for Telecommunications Sciences (ITS)**

325 Broadway, Boulder, CO 80305-3328
Exec. Officer: Mr. Brian Lane . . . . . . . . . . . .303-497-3484
blane@its.bldrdoc.gov
Director: Mr. Al Vincent. . . . . . . . . . . . . . . . .303-497-3500
avincent@its.bldrdoc.gov

**Spectrum & Propagation Measurements Division**

Mr. Eric D. Nelson. . . . . . . . . . . . . . . . . . . . . 303-497-7410
enelson@its.bldrdoc.gov

**Telecommunications & Information Technology Planning Division**

Mr. Jeffrey R. Bratcher . . . . . . . . . . . . . . . . .303-497-5132
jbratcher@its.bldrdoc.gov

**Telecommunications Engineering, Analysis & Modeling Division**

Ms. Patricia Raush . . . . . . . . . . . . . . . . . . . . .303-497-3568
praush@its.bldrdoc.gov

**Telecommunications Theory Division**

Mr. Frank Sanders . . . . . . . . . . . . . . . . . . . . .303-497-7600
fsanders@its.bldrdoc.gov

## TEMPEST CONTACTS

### Army Electronic Proving Ground Enterprise Test Services Directorate

Mr. Alan Morris, Driector
Attn.: TEDT-EP-SE
2000 Arizona Street, Fort Huachuca, AZ 85613-7110
520- 533-8275
Floyd.a.morris10.civ@mail.mil

### Electromagnetic Environmental Effects/ TEMPEST & Antenna Division

Attn.: TEDT-EP-SEA
2000 Arizona Street, Fort Huachuca, AZ 85613-7110
E3 Test Facility/Blacktail Canyon
Mr. James A. Smith . . . . . . . . . . . . . . . . . . . .520-538-5188
james.a.smith4.civ@mail.mil
Mr. David Seitz. . . . . . . . . . . . . . . . . . . . . . . .520-533-5819
david.l.seitz14.civ@mail.mil
Mr. Garrett Rude . . . . . . . . . . . . . . . . . . . . . .520-533-2818
garrett.v.rude.civ@mail.mil
Mr. Fulton Woo . . . . . . . . . . . . . . . . . . . . . . . .520-533-5819
fulton.k.woo.civ@mail.mil

**Antenna Test Facility**

Technical Lead: Mr. Doug Kremer . . . . . . . .520-533-8170
douglas.p.kremer.civ@mail.mil
Mr Anthony Sanchez . . . . . . . . . . . . . . . . . . .520-533-9874
anthony.c.sanchez.civ@mail.mil
Ms. Rachel Blke . . . . . . . . . . . . . . . . . . . . . . .520-538-0726
rachel.m.blake.civ.mail.mil

## BELGIUM

### Belgian Naval Headquarters

Project Office, Kwartier Koningin Elisabeth
1 Everestraat, 1140 Brussels, Belgium
Tel.: +32-2-7013334, Fax: +32-2-7014786

## CANADA

### Aerospace Engineering Test Establishment (DND)

PO Box 6550, Cold Lake, AB T9M 2C6, Canada
Tel.: 780-840-8000
Mr. Serge Couture ext. 7511
serge.couture@forces.gc.ca

## DENMARK

### Naval Materiel Command Denmark

Danneskiold-Sasoees Alle 1 Copenhagen K 1434
Denmark
Tel.: +45-32-663266
FAX: +45-32-663299
http://smk.svn.dk

## GERMANY

### Bundesministerium der Verteidigung

Arbeitsbereich 2
Stauffenbergstr. 18
10785 Berlin
Tel: +49 (0) 18 88 -242424
Fax: 49 (0) 18 88-248520
bmvgprinfoab2@bmvg.bund.de

### Wehrtechnische Dienststelle für Fernmeldewesen und Elektronik (WTD 81)

Center of Competence EMC
91171 Greding
Germany
Tel: +49-8463-652-0
Fax: +49-8463-652-607
www.bwb.org/wtd81

## GREECE

### Ministry of National Defence

Hellenic Navy Research Center (GETEN)
229 Messogion Ave.
Hollargos 155-60
Greece
Tel.: +30-210-6598100-200

## ITALY

### Ministry of Defense

Centro Interforze Studi per le Applicazioni Militari (CISAM)
Via della Bigattiera 10, San Piero a Grado, 56010 San Piero a Grado (Pisa), Italy
Fax: +39 050-961001
Director:
Amm. Isp. Giordano Cottini . . . . . . . . . . . .+39 050-964200

### MARITELERADAR - Instituto per le Telecomunicazioni e l'Elettronica della Marina Militare

"Giancarlo Vallauri", Viale Italia, 72-57126 Livorno, Italy
E-mail: mariteleradar@marina.difesa.it
EMC Dept.
Ric. Ing. Giancarlo Misuri. . . . . . . . . +00-39-0586-238208
EMC Section/Laboratory
Cdr. Roberto Desideri. . . . . . . . . . . . +00-39-0586-238153
C.T.E.R. Salvatore Trovato . . . . . . . . +00-39-0586-238153

## NETHERLANDS

### Royal Netherlands Navy

Naval Establishment
Division Special Product/Consultancy
P.O. Box 1000
1780 CA Den Helder
The Netherlands
Tel.: +31-223-656124
Fax: +31-223-656467

### Ministry of Defense - Directorate of Materials RNI Navy, Department of Naval Architecture & Marine Engineering

P.O. Box 20702
2500 ES The Hague
The Netherlands
Tel.: +31 70 3162335
Fax: +31 70 3163131

## UNITED KINGDOM

### Defence Science & Technology Laboratory

Headquarters
Porton Down
Salisbury, Wiltshire
SP4 0JQ
Tel.: +44 (0) 1980 613000

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Teseq

### LOG PERIODIC ANTENNAS

Aaronia AG
A.H. Systems, Inc.
Advanced Test Equipment Rentals
AR RF/Microwave Instrumentation
ETS-Lindgren
Instruments for Industry (IFI)
Liberty Labs, Inc.

### MONOPOLE ANTENNAS

ETS-Lindgren
Instruments for Industry (IFI)
Noise Laboratory Co., Ltd.

### TEST ANTENNAS

Advanced Test Equipment Rentals
A.H. Systems, Inc.
AR RF/Microwave Instrumentation
Electro-Metrics Corp.
germania elektronik GmbH
Instruments for Industry (IFI)
R A Mayes Company, Inc.
Teseq

## CABLES AND CONNECTORS

### CABLES & CONNECTORS

AEF Solutions
Americor Electronics, Ltd.
Amphenol Industrial Operations
Brim Electronics, Inc.
Calbrooke Marketing Inc.
Captor Corp.
Carlisle Interconnect Technologies
CONEC Corp. - USA
Electri-Flex Company
ETS-Lindgren
Federal-Mogul Corporation Systems Protection
EMI Solutions Inc.
Fischer Connectors Inc.
Fotofab
Harwin
Heilind Electronics
Hi-Tech Controls
Hi-Voltage & EMI Corp.
ITT Interconnect Solutions
Ja-bar Silicone Corporation
Lutze Inc.
Megaphase
Onanon Connectors
PennEngineering
Positronic Industries
Potters Industries, Inc.
PSC Electronics
Qualtek Electronics Corp.
Quell Corp.
RIA CONNECT
Schaffner EMC, Inc.
Schurter Inc.
Sealcon
Spectrum Advanced Specialty Products
Swift Textile Metalizing LLC
Teledyne Reynolds
Wilcoxon Research
Wurth Electronics Midcom Inc.

### FIBER OPTIC CABLES

Carlisle Interconnect Technologies
ETS-Lindgren
FiberPlex Technologies, LLC

### FILTER CONNECTORS

AEF Solutions
API Technologies - Spectrum Control
Carlisle Interconnect Technologies
Captor Corp.
Curtis Industries / Filter Networks
EMCCons Dr. Rasek GmbH & Co
Glenair Inc.
Heilind Electronics
Kensington Electronics Inc.
Marcom Coordinator
RF Immunity
Spectrum Advanced Specialty Products
Spectrum Control
Schurter Inc.

### FILTER PIN CONNECTORS

Captor Corp.
Carlisle Interconnect Technologies
EMI Solutions Inc.
Fischer Connectors Inc.
Kensington Electronics Inc.
Onanon Connectors
Spectrum Advanced Specialty Products

### RETROFIT FILTERS & CONNECTORS

EMI Solutions Inc.
Quell Corporation
Schaffner EMC, Inc.
Schurter Inc.

## CONDUCTIVE MATERIALS

### CONDUCTIVE ADHESIVES, CAULKS, EPOXIES & ELASTOMERS

ARC Technologies, Inc.
Creative Materials, Inc.
Dontech, Inc.
EEMCCOIMEX
Feuerherdt GmbH
germania elektronik GmbH
HITEK Electronic Materials Ltd
Ja-bar Silicone Corporation
Leader Tech, Inc.
Master Bond
Metal Textiles Corp.
P&P Technology Ltd.
Silicone Solutions
Sunkyoung S.T.
VTI Vacuum Technologies, Inc.
Sealing Devices Inc.
Seal Science West
Tech-Etch, Inc.

### CONDUCTIVE CLOTH

ARC Technologies, Inc.
Dontech, Inc.
Eeonyx Corporation
Intermark (USA) Inc.
Ja-bar Silicone Corporation
JEMIC Shielding Technolgy
Jinan EMI Shielding Technology Co., Ltd.
Less EMF Inc.
Marktek Inc.
Sealing Devices Inc.
Swift Textile Metalizing LLC

### CONDUCTIVE COATINGS

ALX Technical
Amstat Industries, Inc.
Conductive Compounds Inc.
Dontech, Inc.
Ja-bar Silicone Corporation
Master Bond
Nolato Silikonteknik AB
Plastic-Metals Technologies, Inc.
Sealing Devices Inc.
Sulzer Metco (Canada) Inc.
Swift Textile Metalizing LLC
VTI Vacuum Technologies, Inc.

### CONDUCTIVE CONTAINERS

MμShield Company, Inc.
Swift Textile Metalizing LLC
VTI Vacuum Technologies, Inc.

### CONDUCTIVE LAMINATES

Dontech, Inc.
Insul-Fab, a Div. of Concote Corporation
Ja-bar Silicone Corporation
Sealing Devices Inc.
Sulzer Metco (Canada) Inc.
Swift Textile Metalizing LLC

### CONDUCTIVE MATERIALS

3M Electronics Markets
Adhesives Research, Inc.
Alchemetal
Antistatic Industries of Delaware
ARC Technologies, Inc.
Caprock Mfg.
Cool Polymers, Inc.
Creative Materials, Inc.
Desco Industries Inc.
Device Technologies, Inc.
Dontech, Inc.
EEMCCOIMEX
Eeonyx Corporation
ElectriPlast Corporation
Federal-Mogul Corporation
HITEK Electronic Materials Ltd
Intermark (USA) Inc.
Ja-bar Silicone Corporation
Less EMF Inc.
LGS Technologies
M&C Specialties
Marktek Inc.
Master Bond
Metal Textiles Corp.
MTI - Microsorb Technologies, Inc.
Mueller Corp.
Nolato Silikonteknik AB
Oak-Mitsui Technologies
Optical Filters Ltd
P&P Technology Ltd.
Premix Oy
Progressive Fillers International
Sealing Devices Inc.
Sulzer Metco (Canada) Inc.
Swift Textile Metalizing LLC
Tech-Etch, Inc.
THEMIX Plastics, Inc.
Venture Tape Corp.
VTI Vacuum Technologies, Inc.

### CONDUCTIVE PAINT

Dontech, Inc.
Sealing Devices Inc.
Sulzer Metco (Canada) Inc.
Swift Textile Metalizing LLC

### CONDUCTIVE PARTICLES

Ja-bar Silicone Corporation
Sulzer Metco (Canada) Inc.

### CONDUCTIVE PLASTICS

CAPLINQ Corp.
Cool Polymers, Inc.
Dexmet Corporation
Dontech, Inc.
ElectriPlast Corporation
Optical Filters Ltd
Premix Oy
Sealing Devices Inc.
THEMIX Plastics
VTI Vacuum Technologies, Inc.

### CONDUCTIVE PLATING

Dontech, Inc.
ElectriPlast Corporation
Ja-bar Silicone Corporation
Sealing Devices Inc.
Sulzer Metco (Canada) Inc.
Swift Textile Metalizing LLC
VTI Vacuum Technologies, Inc.

### CONDUCTIVE TAPES

Bystat International Inc.
Dontech, Inc.
HITEK Electronic Materials Ltd
Intermark (USA) Inc.
ITW/Pressure Sensitive Adhesives & Components
Ja-bar Silicone Corporation
M&C Specialties
P&P Technology Ltd.
Swift Textile Metalizing LLC

## FILTERS AND FERRITES

### ABSORPTIVE FILTERS

Dontech, Inc.
Instruments for Industry (IFI)
Intermark (USA) Inc.
TDK-EPC Corp

### ACTIVE FILTERS

LCR Electronics, Inc.
Richardson RFPD
Schaffner EMC, Inc.

### COAXIAL FILTER CONNECTORS

Captor Corp.
EMC Eupen, A Div. of I2R Corp.
Kensington Electronics Inc.
NexTek, Inc.
Soshin Electronics Europe GmbH
Spectrum Advanced Specialty Products

### DISCOIDAL CAPACITORS

Pacific Aerospace and Electronics
Union Technology Corp.

### FEED-THROUGH FILTERS

Captor Corp.
Genisco Filter Corp.
Instec Filters
LCR Electronics
NexTek, Inc.
Radius Power, Inc.
Pacific Aerospace and Electronics
Radius Power
RF Immunity Ltd.
Schaffner EMC, Inc.
Spectrum Advanced Specialty Products
Syfer Technology Limited
TDK-EPC Corp.
Tri-Mag, Inc.

### FERRITE BEADS & CORES

AEM, Inc.
Allied Components International
Cosmo Ferrites Limited
Dexter Magnetic Technologies
Fair-Rite Products Corp.

## FIELD INTENSITY METERS

EMC Test Design
ETS-Lindgren
Instruments for Industry (IFI)
Narda Safety Test Solutions S.r.l.
Potomac Instruments Inc.
SRICO, Inc.
TREK, INC.

## GROUND RESISTANCE TESTERS

AEMC Instruments, Inc.

## HELMHOLTZ COILS

ETS-Lindgren

## HIGH VOLTAGE PULSE TRANSFORMERS

Pearson Electronics, Inc.

## IMPULSE GENERATORS

AR RF/Microwave Instrumentation
ASIA & EMC CONSULTANCY, Rudolfstetten/Switzerland
Compliance West, USA
EMC Partner AG
EM TEST USA
HV Technologies, Inc.
Ion Physics Corp.
Montena Technology SA

## INDUCED CURRENT METERS & PROBES

AR RF/Microwave Instrumentation
ETS-Lindgren

## INSERTION LOSS TEST NETWORKS

Captor Corp.

## INTERFERENCE GENERATORS

EMC Partner AG
HV Technologies, Inc.

## ISOTROPIC FIELD SENSORS

D.A.R.E!! Consultancy
ETS-Lindgren
Instruments for Industry (IFI)
Narda Safety Test Solutions S.r.l.

## LIGHTNING GENERATORS

Advanced Test Equipment Rentals
Avalon Test Equipment Corp.
EM Test USA
EMC Partner AG
HV Technologies, Inc.
Lightning Technologies, Inc.

## LIGHTNING SIMULATORS

Advanced Test Equipment Rentals
EM Test USA
EMC Partner AG
HV Technologies, Inc.

## LISNS

AFJ Instruments srl
ETS-Lindgren
Fischer Custom Communications
Laplace Instruments Ltd

## MAGNETIC FIELD METERS

Combinova AB
Ergonomics, Inc.
Less EMF Inc.

## MAGNETIC FIELD PROBES

Agilent Technologies, Inc.
AR RF/Microwave Instrumentation
ETS-Lindgren
Langer EMV-Technik GmbH

## NETWORK ANALYZERS

Agilent Technologies, Inc.

## PARALLEL PLATE LINE TEST SET

ETS-Lindgren

## PORTABLE TEST EQUIPMENT

A.H. Systems, Inc.
ETS-Lindgren
HV Technologies, Inc.
Instruments for Industry (IFI)
MPB Srl
Prostat Corp.
Rigol Technologies

## RADIATION HAZARD METERS

ETS-Lindgren
Narda Safety Test Solutions S.r.l.

## RADIATION HAZARD PROBES

ETS-Lindgren
Instruments For Industry (IFI)

## RF POWER COMPONENTS

Cree, Inc.
EM Test USA
MCL Inc. TWT Amplifiers
MKS Instruments
Richardson RFPD

## RF POWER METERS

Agilent Technologies, Inc.
AR RF/Microwave Instrumentation
D.A.R.E!! Consultancy
ETS-Lindgren
Test Equipment Connection

## SIGNAL GENERATORS

Agilent Technologies, Inc.
AR RF/Microwave Instrumentation
D.A.R.E!! Consultancy
Laplace Instruments Ltd
Praxsym, Inc.
Rigol Technologies
York EMC Services Ltd.

## SIMULATION SOFTWARE

CST of America Inc.
Delcross Technologies
EM Software & Systems
EMS-Plus
Integrated Engineering Software
Remcom Inc.

## SPECTRUM ANALYZERS

Aaronia AG
Agilent Technologies, Inc.
Rigol Technologies
ValueTronics International, Inc.

## TELECOMMUNICATIONS TEST NETWORKS

Agilent Technologies, Inc.
HV Technologies, Inc.

## TEMPEST TEST EQUIPMENT

A.H. Systems, Inc.
Fischer Custom Communications

## TEST ACCESSORIES

AR RF/Microwave Instrumentation
Audivo GmbH
CST of America, Inc.
EM Test USA
EMC Partner AG
EMCO Elektronik GmbH
ETS-Lindgren
Fischer Custom Communications
Innco Systems GmbH
Instruments for Industry (IFI)
TDK-Lambda Americas

## TEST CAPACITORS

Captor Corp.

## TEST EQUIPMENT, LEASING & RENTAL

A.H. Systems, Inc.
Advanced Test Equipment Rentals
AR RF/Microwave Instrumentation
Instruments for Industry (IFI)

## TEST EQUIPMENT, REPAIR & CALIBRATION

A.H. Systems, Inc.
Adler Instrumentos SL
Agilent Technologies, Inc.
D.A.R.E!! Consultancy
Electronic Instrument Associates
Embassy Global, LLC
EMC Partner AG
EMSCAN
ETS-Lindgren
Fischer Custom Communications
Instruments for Industry (IFI)
Restor Metrology
Seibersdorf Labor GmbH

## TEST INSTRUMENTATION

A.H. Systems, Inc.
Aaronia AG
Accurate Controls Ltd.
Adler Instrumentos SL
Advanced Test Equipment Rentals
Aeroflex
Agilent Technologies, Inc.
All-Spec Industries
Alltest Instrument, Inc.
Amstat Industries, Inc.
Anritsu Company
Apogee Labs Inc.
APREL Laboratories
AR RF/Microwave Instrumentation
ASR Technologies Inc.
Audivo GmbH
AWR Corporation
Barth Electronics, Inc.
Bird Technologies Group / TX RX Systems
Circuit Insights LLC
Combinova AB
Compliance West, USA
CST of America, Inc.
D.A.R.E!! Consultancy
D.A.R.E!! Instruments
Ecliptek Corp.
EM Software & Systems
EM Test USA
Embassy Global, LLC
EMC Partner AG
EMSCAN
emscreen GmbH
EMSS Consulting Pty (Ltd.)
EM TEST USA
emv - Elektronische Meßgeräte Vertriebs GmbH
Ergonomics, Inc.
ETS-Lindgren
Fischer Custom Communications
Fotofab
GAUSS Instruments
Haefely EMC
HV Technologies, Inc.
Inceleris
Innco Systems GmbH
Instruments for Industry (IFI)
Ion Physics Corp
Langer EMV-Technik GmbH
Laplace Instruments Ltd.
Liberty Labs, Inc.
Macton
Michigan Scientific Corp.
Micronor Inc.
Mihajlo Pupin Institute-EMC Lab
Montena Technology sa
MPB Srl
Narda Safety Test Solutions S.r.l.
NEDC Fabricating Solutions
Noise Laboratory Co., Ltd.
Pearson Electronics, Inc.
Potomac Instruments Inc.
PPM (Pulse Power & Measurement) Ltd.
Praxsym, Inc.
Protek Test and Measurement
Ramsey Electronics
Rigol Technologies
Rohde & Schwarz USA, Inc.
Saelig Company
Safe Engineering Services & Technologies, Ltd.
Safety Test Technology Co., Ltd
Seibersdorf Labor GmbH
Sensor Products Inc.
Shanghai Empek Electromagnetic Technology Ltd.
SILENT Solutions
SimLab Software GmbH
Solar Electronics Co.
Suzhou 3CTEST Electronic Co.
TE Connection Asia
TESEO
Teseq
Thermo Fisher Scientific
TREK, INC.
ValueTronics International, Inc.
Wavecontrol

## TEST SOFTWARE

Averna
CST of America, Inc.
D.A.R.E!! Consultancy
NEXIO

Global Testing
Montrose Compliance Service
Nemko USA - Tampa
Professional Testing (EMI), Inc.
Retlif Testing Laboratories
Timco Engineering, Inc.
TUV SUD America Inc.
Washington Laboratories

## RADHAZ TESTING

DNB Engineering, Inc.
Electronics Test Centre (Kanata)
Retlif Testing Laboratories

## RS03 > 200 V / METER TESTING

CKC Laboratories, Inc.
D.L.S. Electronic Systems, Inc.
DNB Engineering, Inc.
Electronics Test Centre (Kanata)
Elite Electronic Engineering Co.
Radiometrics Midwest Corp.
Retlif Testing Laboratories
TUV SUD America Inc.

## RTCA DO-160 TESTING

AE Techron
Cascade TEK
CKC Laboratories, Inc.
D.L.S. Electronic Systems, Inc.
DNB Engineering, Inc.
Electronics Test Centre (Kanata)
Elite Electronic Engineering Co.
EMC Partner AG
Environ Laboratories
Little Mountain Test Facility
National Institute for Aviation Research
Pacific Power Source, Inc.
Radiometrics Midwest Corp.
Retlif Testing Laboratories
TUV SUD America Inc.

## SHIELDING EFFECTIVENESS TESTING

D.A.R.E!! Calibrations
D.L.S. Electronic Systems, Inc.
Dontech, Inc.
Electronics Test Centre (Kanata)
Elite Electronic Engineering Co.
EMC Integrity, Inc.
ETS-Lindgren
Federal-Mogul Corporation Systems Protection
National Institute for Aviation Research
Radiometrics Midwest Corp.
Retlif Testing Laboratories
TUV SUD America Inc.

## SITE ATTENUATION TESTING

D.A.R.E!! Calibrations
D.L.S. Electronic Systems, Inc.
Electronics Test Centre (Kanata)
ETS-Lindgren
Radiometrics Midwest Corp.
Retlif Testing Laboratories
Wave Scientific Ltd

## SITE SURVEY SERVICES

D.A.R.E!! Calibrations
D.L.S. Electronic Systems, Inc.
Electronics Test Centre (Kanata)
Elite Electronic Engineering Co.
ETS-Lindgren
Kimmel Gerke Associates, Ltd.
Radiometrics Midwest Corp.
Retlif Testing Laboratories
Wave Scientific Ltd.

## TELCORDIA TESTING

D.L.S. Electronic Systems, Inc.
Electronics Test Centre (Kanata)
Radiometrics Midwest Corp.

## TEMPEST TESTING

National Technical Systems
Storm EMC Services Ltd

## TESTING

3C Test Ltd. - EMC Testing
A.H. Systems, Inc.
A2LA
Acme Testing Company
Advanced Compliance Solutions, Inc.
Advanced Testing Services
AERO NAV Laboratories
AE Techron, Inc.
AHD EMC Lab / Amber Helm Development L.C.
Alion Science and Technology
American Environments Co., Inc.
Apache Design Solutions, Inc.
Applied Physical Electronics, L.C.
ATLAS Compliance & Engineering
BEC Inc.
Blackwood Labs
Blue Guide EMC Lab
Braco Compliance Ltd.
Bureau Veritas (formerly Curtis-Straus)
Cascade TEK
CertifiGroup
CETECOM Inc.
CKC Laboratories, Inc.
Communication Certification Laboratory
Compatible Electronics, Inc.
Compliance Certification Services
Compliance Engineering Ireland Ltd.
Compliance Management Group
Compliance Testing LLC
Compliance Worldwide
Core Compliance Testing Services
Cranage EMC Testing Ltd.
Criterion Technology, Inc.
CSA International
Custom Assembly LLC
D.A.R.E!! Calibrations
D.L.S. Electronic Systems, Inc.
Dayton T. Brown, Inc.
dBi Corp.
Diversified T.E.S.T. Technologies
DNB Engineering, Inc.
Don HEIRMAN Consultants
E.F. Electronics Co.
E-Labs Inc.
ElectroMagnetic Investigations, LLC
Electro Magnetic Test, Inc.
Electro Rent Corporation
Electronics Test Centre
Elite Electronic Engineering Co.
EM Software & Systems
EMC Compliance
EMC Cons Dr. Rasek GmbH
EMC Integrity, Inc.
EMC Technologies Pty Ltd.
EMC Tempest Engineering
EMC Testing Laboratories. Inc.
EMCMCC
EMF Testing USA
EMField
EMITECH
Enerdoor Inc.
Engineered Testing Systems
Environ Laboratories, LLC
ETS-Lindgren
Eurofins Product Service GmbH
Fabreeka International, Inc.
Federal-Mogul Corporation Systems Protection
Global Advantage
Global Certification Laboratories, Ltd.
Global Testing
Green Mountain Electromagnetics, Inc.
GTN GmbH & Co. KG
H.B. Compliance Solutions
Harris Corp (GCSD)
Hermon Laboratories
iNARTE, Inc.
Ingenium Testing, LLC
International Certification Services, Inc.
International Compliance Laboratories, LLC
Intertek Testing Services
IQS, a Div. of The Compliance Management Group
ITC Engineering Services, Inc.
Jacobs Technology Inc.
JS TOYO Corporation (Shenzhen) Ltd.
Keystone Compliance
Kimmel Gerke Associates, Ltd.
L.S. Research
L-3 Communications Cincinnati Electronics
Laboratory Testing Inc.
Langer EMV-Technik GmbH
L F Research EMC
Liberty Labs, Inc.
Little Mountain Test Facility
Mesago Messe Frankfurt GmbH
MIRA Ltd.
National Technical Systems
Naval Air Systems Command
Naval Air Warfare Center
NCEE Labs
Nemko USA
Northwest EMC, Inc.
NU Laboratories
Pacific Power Source, Inc.
Paladin EMC
Parker EMC Engineering
Peak Electromagnetics Ltd.
Pearson Electronics, Inc.
Percept Technology Labs, Inc.
Philips Applied Technologies - EMC Center
Philips Innovation Services-EMC Center
Pioneer Automotive Technologies, Inc. - EMC Lab
Power-Electronics Consulting
Product Safety Engineering Inc.
Protocol Data Systems Inc.
Pulver Laboratories Inc.
QinetiQ
Qualtest Inc.
Radiometrics Midwest Corp.
Radiotechnika Marketing Sp. z o.o.
Remcom Inc.
Restor Metrology
Reliant EMC LLC
Retlif Testing Laboratories
RF Exposure Lab, LLC
RFI Global Services Ltd.
RFTEK
Rhein Tech Laboratories, Inc.
Richardson RFPD
Rogers Labs, Inc.
Rubicom Systems, A division of ACS
SAE Power
Seven Mountains Scientific, Inc. (ENR)
SGS
SIEMIC
Southwest Research Institute
SPAWAR Systems Center Atlantic
Swift Textile Metalizing LLC
Sypris Test and Measurement
TEMPEST Inc.
Teseq
Test Site Services Inc.
The Compliance Management Group
Timco Engineering, Inc.
TRaC Global
Trialon Corp.
TUV Rheinland Of North America
TUV SUD America Inc.
TÜV SÜD Product Service Ltd.
TÜV SÜD SENTON GmbH
Ultratech Group of Labs
Underwriter's Laboratories Inc.
Walshire Labs, LLC
Washington Laboratories, Ltd.
White Sands Missile Range
Willow Run Test Labs, LLC
Wyle
Yazaki Testing Center
D.A.R.E!! Instruments

## TESTING LABORATORIES

Alion Science and Technology
AT4 Wireless
Blue Guide EMC Lab
CKC Laboratories, Inc.
Compliance Testing LLC
Compliance Worldwide
D.A.R.E!! Instruments
D.L.S. Electronic Systems, Inc.
Diversified T.E.S.T. Technologies
DNB Engineering, Inc.
Don HEIRMAN Consultants
Electro Magnetic Test, Inc.
Electronics Test Centre (Kanata)
Elite Electronic Engineering Co.
EMC Integrity, Inc.
EMC Technologies Pty Ltd.
H.B. Compliance Solutions
International Compliance Laboratories, LLC
Jakob Mooser GmbH
Keystone Compliance
Langer EMV-Technik GmbH
Liberty Labs, Inc.
Little Mountain Test Facility
National Technical Systems
Northwest EMC Inc.
Partnership for Defense Innovation
Percept Technology Labs
Professional Testing (EMI), Inc.
Qualtest Inc.
Radiometrics Midwest Corp.
Retlif Testing Laboratories

Richardson RFPD
RMV Technology Group, LLC
SDP Engineering Inc.
SIEMIC
Sprinkler Innovations
Stork Garwood Laboratories Inc.
Test Site Services Inc.
Timco Engineering, Inc.
Tranzeo EMC Labs Inc.
TÜV SÜD America Inc.
TÜV SÜD Product Service Ltd.
TÜV SÜD SENTON GmbH
Wave Scientific Ltd.
World Cal, Inc.

## OTHER PRODUCTS AND SERVICES

### BOOKS

Cherry Clough Consultants Ltd
Henry Ott Consultants
ITEM Media
Montrose Compliance Service

### CHAMBERS REVERB

ETS-Lindgren

### CONSULTANTS

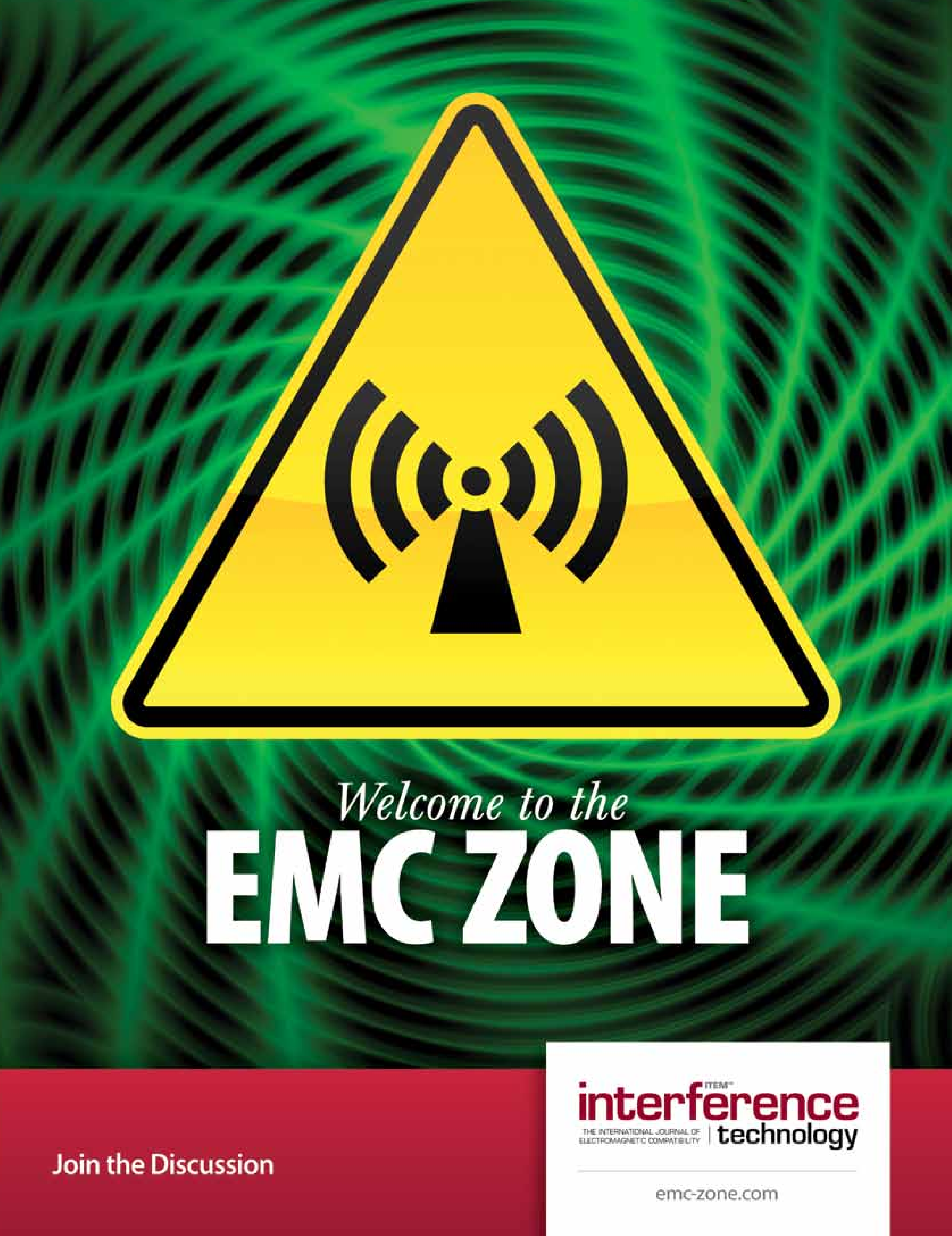
Captor Corp.
Cherry Clough Consultants Ltd
D.A.R.E!! Instruments
D.L.S. Electronic Systems, Inc.
DNB Engineering, Inc.
Don HEIRMAN Consultants
Elite Electronic Engineering Co.
EM Software & Systems
EMC Cons Dr. Rasek GmbH
EMC Management Concepts
EMCMCC
EMITEMC
Equipment Reliability Institute
ERA Technology Ltd. Trading as Cobham Technical Services
ETS-Lindgren
Henry Ott Consultants
Hoolihan EMC Consulting
ITEM Media
Jakob Mooser GmbH
Kimmel Gerke Associates, Ltd.
Montrose Compliance Service, Inc.
MOOSER Consulting GmbH
NewPath Research L.L.C.
Paladin EMC
Power & Controls Engineering Ltd.
Power Standards Lab (PSL)
Radiometrics Midwest Corp.
Retlif Testing Laboratories
Storm EMC Services Ltd
TUV SUD America Inc.
Wyatt Technical Services LLC

### STANDARDS TRANSLATIONS

Advanced Programs, Inc.
ANDRO Computational Solutions
Electronics Test Centre (Kanata)
PGMC Ltd
TUV SUD America Inc.

### TRAINING, SEMINARS & WORKSHOPS

A2LA
Andre Consulting, Inc.
Cherry Clough Consultants Ltd.
CST of America, Inc.
Delcross Technologies
D.L.S. Electronic Systems, Inc.
Don HEIRMAN Consultants
EM Software & Systems
EMC Engineering and Safety
EMC Goggles Ltd.
Euro EMC Service (EES)
Fotofab
Gaddon Consultants
Henry Ott Consultants
Hoolihan EMC Consulting
Integrated Engineering Software
Jastech EMC Consulting, LLC
Langer EMV-Technik GmbH
M.MARDIGUIAN, EMC Consulting
Montrose Compliance Service
QEMC - Engenharia, Qualidade e Compatibilidade Eletromagnética Ltda.
Retlif Testing Laboratories
SIEMIC
Simberian Inc.
Spec-Hardened Systems
Stephen Halperin & Associates
Storm EMC Services Ltd
Teseq
TUV SUD America Inc.


Welcome to the
EMC ZONE
Join the Discussion
ITEM
interference
THE INTERNATIONAL JOURNAL OF ELECTROMAGNETIC COMPATIBILITY
technology
emc-zone.com

# Company Directory

Manufacturers, consultants, and service organizations active in the electromagnetic interference field are listed in this directory. To learn how to be included in this directory, or for any corrections. e-mail info@interferencetechnology.com.

## 0-9

**3C Test Ltd. - EMC Testing**
Silverstone Technology Park, Silverstone Circuit, Towcester, Northampton NN12 8GX, United Kingdom; 44- 1327-857500; Fax: 44-1327-857747; sales@3ctest.co.uk; www.3ctest.co.uk

**3Gmetalworx World**
2 - 90 Snow Boulevard, Concord, Ontario L4K 4A2, Canada; 888-965-3634; sales@3gmetalworx.com; www.3gmetalworx.com

**3M Electronics Markets Materials Division**
6801 River Place Boulevard, Austin, TX 78726-9000, USA; 800-245-0329; Alex.Gwin@kolarmail.com; www.3M.com/electrical

**7Layers AG**
Borsigstrasse 11, Ratingen 40880, Germany; 49-210-27490; www.7layers.com

## A

**A&R Tarpaulins, Inc.**
16246 Valley Boulevard, Fontana, CA 92335 USA; 909-829-4444; mail@artech2000.com; www.artarps.com

**A.H. Systems, Inc.**
9710 Cozycroft Avenue, Chatsworth, CA 91311 USA; 818-998-0223; Fax: 818-998-6892; sales@ahsystems.com; www.AHSystems.com

| | | |
|---|---|---|
| AL | T & M Solutions | 770-973-7492 |
| AR | Southwest Electronic Industries, Inc. | 972-523-0017 |
| GA | T & M Solutions | 770-973-7492 |
| LA | Southwest Electronic Industries, Inc. | 972-523-0017 |
| OK | Southwest Electronic Industries, Inc. | 972-523-0017 |
| TN | T & M Solutions | 770-973-7492 |
| TX | Richardson, Southwest Electronics Industries | 972-523-0017 |

INTERNATIONAL

| | | |
|---|---|---|
| AUS | Test & Measurement Australia PTY Limited | 61-2-4739-9523 |
| AUT | Pro Nova Elektronik GmbH | 49-7141-2858-20 |
| BEL | EEMCCOIMEX | 31-320-295-395 |
| BOL | Rentametric International, Inc. | 305-767-4000 |
| BUL | Test Solutions | 359-2-970-1990 |
| CHN | Beijing Twenty First Century Co., Ltd., Beijing | 86-10-8267-5757 |
| CHN | Compliance Direction Systems, Beijing | 86-10-6846-0592 |
| COL | Rentametric International, Inc. | 305-767-4000 |
| CRC | Rentametric International, Inc. | 305-767-4000 |
| ECU | Rentametric International. Inc. | 305-767-4000 |
| ESA | Rentametric International, Inc. | 305-767-4000 |
| ESP | Wavecontrol | 34-93-320-8055 |
| FRA | AR France | 33-147-91-7530 |
| GER | Pro Nova Elektronik GmbH | 49-7141-2858-20 |
| GRB | SystemWare Europe | 44-1462-734777 |
| GRE | Vector Technologies | 30-210-68-58008 |
| GUA | Rentametric International, Inc. | 305-767-4000 |
| HON | Rentametric International, Inc. | 305-767-4000 |
| INA | Singapore Technologies Ltd. | 65-6413-3119 |
| IND | Technocomm Instruments Private Ltd. | 91-80-25731009 |
| ISR | WAVE Components Ltd. | 972-9-764-4878 |
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| MAS | Singapore Technologies Ltd. | 65-6413-3119 |
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**AFJ Instruments Srl**
Via Corno di Cavento 5, Milan 20148, Italy; 39-02-91434850; info@afj-instruments; afj-instruments.com

**Agilent Technologies, Inc.**
5301 Stevens Creek Boulevard, Santa Clara, CA 95051 USA; 800-829-4444; www.agilent.com

**AHD EMC Lab /Amber Helm Development L.C.**
92723 Michigan Highway 152, Sister Lakes, MI 49047 USA; 269-429-8352; 888-847-8027; Fax: 269-429-9016; ghelm@ahde.com; www.ahde.com

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Daimlerstraße 17, 89564 Nattheim, Germany; 49-7321-730510; Fax: 49-7321-730590; info@albatross-projects.com; www.albatross-projects.com

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9 Packard Avenue, Unit 2, Castle Hill NSW 2154, Australia; 61-2-9680-9990; Fax: +61 (0)2 9882 6600; martin@austest.com.au; www.austest.com.au

**Autosplice, Inc.**
10121 Barnes Canyon Road, San Diego, CA 92121 USA; 858-678-3119; Fax: 858-535-0130; Ken Kozicki, kkozicki@autosplice.com; www.autosplice.com

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1960 East Grand Avenue, Suite 430, El Segundo, CA 90245 USA; 310-726-3000; Fax: 310-726-3005; info@awrcorp.com; www.awrcorp.com

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20 Post Lane North, Suffern, NY 10901 USA; 845-228-8924; Fax: 914-652-2489; info@axonics.net; www.axonics.net

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**Bird Technologies**
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**Blackwood Labs**
Unit 8 Woodfieldside Business Park, Pontllanfraith, Blackwood, NP12 2DG, United Kingdom; +44 (0) 1495-229-219; Fax: +44 (0) 1495-228-331; blackwoodenquiries@kiwa.co.uk; www.blackwood-labs.co.uk

**Blue Guide EMC Laboratory**
Joseph Cardijnstraat 21, B-9420 Erpe-Mere, Belgium; 32 (0) 53-60-16-01; Fax: 32 (0) 53-70-78-99; info@bgemc.com; www.bgemc.com

**BONN Elektronik GmbH**
Ohmstr. 11, DE-83607 Holzkirchen, Germany; 49-8024-608830; Fax: 49-8024-6088310; info@bonn-elektronik.com; www.bonn-elektronik.com

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420 East Alton Avenue, Santa Ana, CA 92707; 800-905-7161; Fax: 714-549-4028; calsales@calmont.com; www.calmont.com

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950 Lawrence Drive, Newbury Park, CA 91320 USA; 805-499-1818; Fax: 805-499-6649; info@capwireless.com; www.capwireless.com

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120 Craft Avenue, Inwood, NY 11096 USA; 516-371-5600; Fax: 516-239-5481; info@capconemi.com; www.capconemi.com

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957 Snowshoe Crescent, Orléans, Ontario K1C 2Y3, Canada; 613-482-2215; Fax: 702-995-1235; info@caplinq.com; www.caplinq.com

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1801 West Parkside Lane, Phoenix, AZ 85027 USA; 623-869-0600; Fax: 623-582-4813; info@cgstech.com; www.cgstech.com

**Cherry Clough Consultants Ltd.**
9 Bracken View, Brocton, Stafford, Staffs ST17 0TF, United Kingdom; 44-1785-660-247; Fax: 44-1785-660-247; Keith Armstrong, keith.armstrong@cherryclough.com; www.cherryclough.com

**Chomerics**
77 Dragon Court, Woburn, MA 01888 USA; 781-935-4850; Fax: 781-933-4318; chomailbox@parker.com; www.chomerics.com; www.chomericstest.com

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5046 Sierra Pines Drive, Mariposa, CA 95338 USA; 209-966-5240; Fax: 866-779-9776; www.ckc.com

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2900 Westinghouse Boulevard, Suite 118, Charlotte, NC 28273 USA; 866-649-8665; info@clickfold.com; www.clickfoldplastics.com

**Cobham PLC**
Brook Road, Wimborne, Dorset BH21 2BJ, Kingdom; www.cobham.com

**Combinova AB**
Domkraftsvägen 1, S-197 40 Bro, Sweden; 46-8-627-93-10; Fax: 46-8-29-59-85; sales@combinova.se; www.combinova.se

**Communication Coil, Inc.**
9601 Soreng Avenue, Schiller Park, IL 60176 USA; 847-671-1333; Fax: 847-671-9191; info@communicationcoil.com; www.communicationcoil.com

**Compac Development Corp.**
1460 North Clinton Avenue, Suite O, Bay Shore, NY 11706 USA; 631-585-3400; Fax: 631-585-3534; sales@compac-rf.com; www.compac-rf.com

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102 Olinda Drive, Brea, CA 92823 USA; 714-579-0500; Fax: 714-528-1992; www.celectronics.com

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47173 Benicia Street, Fremont, CA 94538 USA; 510-771-1000; Fax: 510-661-0888; www.ccsemc.com

**Compliance Engineering Ireland Ltd.**
Clonross, Dunshaughlin, Co. Meath, Ireland; 353-1-8017000; Fax: 353-1-8256733; www.cei.ie

**Compliance Management Group**
257 Simarano Drive, Marlborough, MA 01752 USA; 508-460-1400; www.cmgcorp.net

**Compliance Testing, LLC**
3356 North San Marcos Place, Suite 107, Chandler, AZ 85225 USA; 480-926-3100; 866-311-3268; Fax: 480-926-3598; info@compliancetesting.com; www.compliancetesting.com

**Compliance West, USA**
650 Gateway Center Drive, Suite D, San Diego, CA 92012 USA; 619-878-9696; 858-481-6454; Fax: 858-481-8527; sales@compwest.com; www.compwest.com

**Compliance Worldwide**
357 Main Street, Sandown, NH 03873 USA; 603-998-3903; Fax: 603-887-6445; www.complianceworldwide.com

**Com-Power Corp.**
114 Olinda Drive, Brea, CA 92823 USA; 714-528-8800; Fax: 714-528-1992; sales@com-power.com; www.com-power.com

**Comtech PST Corp.**
105 Baylis Road, Melville, NY 11757 USA; 631-777-8900; Fax: 631-777-8877; info@comtechtel.com; www.comtechpst.com

**Comtest Engineering BV**
Industrieweg 12, 2382NV Zoeterwoude, The Netherlands; 31-71-5417531; Fax: 31-71-5420375; info@comtest.eu; www.comtest.eu

**Conductive Compounds Inc.**
17 Hampshire Drive, Unit 8, Hudson, NH 03051 USA; 603-595-6221; Fax: 603-595-6228; sales@conductivecompounds.com; www.conductivecompounds.com

**CONEC Corp. - USA**
343 Technology Drive, Garner, NC 27529 USA; 919-460-8800; Fax: 919-460-0141; info@conec.com; www.conec.com

**Connors Company**
P.O. Box 807, Carver, MA 02330 USA; 508-272-1500; Fax: 508-866-5393; Brian Connors, brian@connorsrep.com; connorsrep.com

**Cool Polymers, Inc.**
51 Circuit Drive, North Kingstown, RI 02852 USA; 401-667-7830; 888-811-3787; sales@coolpolymers.com; www.coolpolymers.com

**Core Compliance Testing Services**
79 River Road, Hudson, NH 03051 USA; 603-892-0620; Kenneth L. MacGrath, khcmacgrath@aol.com; www.corecompliancetesting.com

**Cosmo Ferrites Limited**
Jabli, Solan, Himachal Pradesh 173209, India; 91-1792-277231; Fax: 91-1792-277234; sales@cosmoferrites.com; www.cosmoferrites.com

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**Cranage EMC Testing Ltd.**
Stable Court, Oakley, Market Drayton, Shropshire TF9 4AG, United Kingdom; 44-1630-658568; Fax: 44-1630-658921; info@cranage.co.uk; www.cranage.co.uk

**Cree, Inc.**
4600 Silicon Drive, Durham, NC 27703 USA; 866-924-3645; media@cree.com; www.cree.com

**Cre8 Associates Ltd.**
Bruntingthorpe Proving Ground, Bath Lane, Lutterworth, Leicestershire LE17 5QS, United Kingdom; 44-1162-479787; enquires@cre8-associates.com; www.cre8-associates.com

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12 Willow Road, Ayer, MA 01432 USA; 978-391-4700; 800-560-5667; Fax: 978-391-4705; info@creativematerials.com; www.creativematerials.com

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1350 Tolland Road, P.O. Box 489, Rollinsville, CO 80474 USA; 303-258-0100; Fax: 303-258-0775; critech@criteriontech.com; www.criteriontech.com

**CSA International**
178 Rexdale Boulevard, Toronto, Ontario M9W 1R3, Canada; 416-747-400; 800-463-6727; www.csa-international.org

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600 Wheat Lane, Wood Dale, IL 60191 USA; 630-595-2300; 800-323-9562; Fax: 630-595-6579; sales@phoenix-ofchicago.com; phoenixofchicago.com

**Cybershield**
308 Ellen Trout Drive, Lufkin, TX 75904 USA; 936-633-6387; Fax: 936-633-6398; sales@cybershieldinc.com; www.cybershieldinc.com

## D

**D.A.R.E!! Consultancy**
Vijzelmolenlaan 7, Woerden, Utrecht NL-3447GX, The Netherlands; 31-348-430-979; Fax: 31-348-430-645; René Dijkstra, consultancy@dare.nl; consultancy.dare.nl



**D.L.S. Electronic Systems, Inc.**
1250 Peterson Dr., Wheeling, IL 60090 USA; 847-537-6400; Fax 847-537-6488; jblack@dlsemc.com; www.dlsemc.com

**Datatronics**
28151 Highway 74, Menifee, CA 92585 USA; 951-928-7700; Fax: 951-928-7701; ddisles@datatronics.com; www.datatronics.com

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1175 Church Street, Bohemia, NY 11716-5031 USA; 631-589-6300; Fax: 631-589-3648; test@dtbtest.com; www.dtbtest.com

**dB Control**
1120 Auburn Street, Fremont, CA 94538 USA; 510-656-2325; Fax: 510-656-3214; marketing@dbcontrol.com; www.dBControl.com

**dBi Corp.**
216 Hillsboro Avenue, Lexington, KY 40511 USA; 859-253-1178; Fax: 859-252-6128; jrbarnes@iglou.com; www.dbicorporation.com

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3015 Village Office Place, Champaign, IL 61822 USA; 217-363-3396; contact@delcross.com; www.delcross.com

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22 Barnes Industrial Road South, Wallingford, CT 06492 USA; 203-294-7867; Fax: 203-294-7898; k.mull@dexmet.com; www.dexmet.com

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1050 Morse Avenue, Elk Grove Village, IL 60007 USA; 847-956-1140; info@dextermag.com; www.dextermag.com

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3535 W. Commonwealth Avenue, Fullerton, CA 92833 USA; 800-282-1462; 714-870-7781; Fax: 714-870-5081; Tony Piraino, tonyp@dnbenginc.com; www.dnbenginc.com

**Don Heirman Consultants**
143 Jumping Brook Road, Lincroft, NJ 07738 USA; 732-741-7723; Fax: 732-530-5695; Don Heirman, d.heirman@ieee.org; www.DonHeirman.com

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700 Airport Boulevard, Doylestown, PA 18902 USA; 215-348-5010; Fax: 215-348-9959; Jeff Blake, info@dontech.com;
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**Dutch Microwave Absorber Solutions**
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222 W. Central Avenue, Roselle, IL 60172 USA; 800-323-6174; 630-529-0482; mktg@electriflex.com; www.electriflex.com

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3366 Pomona Boulevard, Pomona, CA 91768 USA; 909-595-4037; 800-515-1112; Fax: 909-595-0186; ecubesales@electrocube.com; www.electrocube.com

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20811 NW Cornell Road, Suite 600, Hillsboro, OR 97124 USA; 503-466-1160; 888-466-1160; Fax: 503-466-1170; www.emicomply.com

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**Electro-Metrics Corp.**
231 Enterprise Road, Johnstown, NY 12095 USA; 518-762-2600; Fax: 518-762-2812; sales@emihq.com; www.electro-metrics.com

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6060 Sepulveda Boulevard, Van Nuys, CA 91411 USA; 877-581-3384; 818- 787-2100; sales@electrorent.com; www.ElectroRent.com

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P.O. Box 6487, Bloomingdale, IL 60108-6487 USA; 630-924-1600; Fax: 630-477-0321; frank@electronicinstrument.com; www.electronicinstrument.com



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302 Legget Drive, Suite 100, Kanata K2K 1Y5, Canada; 613-599-6800; Fax: 613-599-7614; Lynn Diggins, sales@etc-mpb.com;

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27 East Lake Hill, Airdrie, Alberta T4A 2K3, Canada; 403-912-0037; Fax: 403-912-0083; www.etc-mpb.com

**Electrorack Enclosure Products**
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**Element Materials Technology**
15062 Bolsa Chica St, Huntington Beach, CA 90660 USA; 714-892-1961; 888-786-7555; Fax: 714-892-8159; info.hb@element.com; www.element.com

**Elite Electronic Engineering Inc.**
1516 Centre Circle; Downers Grove, IL 60515-1082 USA; 800-ELITE-11, 630-495-9770, ext. 119; Fax: 630-495-9785; sglaya@elitetest.com; www.elitetest.com

**Elite EMC Ltd.**
12 Station Road, Marston Green, Birmingham, West Midlands B37 7AS, United Kingdom; 44 121 288 0543; Fax: 44 121 288 0543; David Hobbs, sales@eliteemc.com; www.eliteemc.com

**EM Software & Systems-SA Pty Ltd.**
P.O. Box 1354, Stellenbosch, 7599, South Africa; 27 21 880 1880; Fax: 27 21 880 1936; Celeste Mockey, info@emss.co.za; www.feko.info

**EM Software & Systems USA Inc.**
100 Exploration Drive, Suite 310-B, Hampton, VA 23666 USA; 866-419-FEKO; www.emssusa.com
INTERNATIONAL
CHN EM Software & Systems China, Shanghai.... 21-50116635
DEU EM Software & Systems GmbH, Böblingen........................ 49-07031-714-5200

**EM Test USA**
9250 Brown Deer Road,San Diego, CA 92121 USA; 603-396-2680; ron.ahlquist@ametek.com; www.emtest.com

**Embassy Global, LLC**
PO Box 105, Orchard Park, NY 14127-0105 USA; 800-309-6150; Fax: 716-706-1248; inquiries@embassyglobalpr.com; www.embassyglobalpr.com

**EMC Compliance**
P.O. Box 14161, Huntsville, AL 35815-0161 USA; 256-650-5261; Ken Javor, ken.javor@emccompliance.com; www.emccompliance.com

**EMC Component Group, Inc.**
2901 Tasman Drive, Suite 211, Santa Clara, CA 95054 USA; 408-330-9216; Fax: 408-330-0012; sales@emccomponent.com; www.emccomponent.com

**EMC Engineering and Safety**
Haifa, Israel; 972-528396080

**EMC Eupen, A Div. of I2R Corp.**
5033 Industrial Road, Bldg. 6, Farmingdale, NJ 07727 USA; 732-919-1100; Fax: 732-919-7196; sales@emceupen.com; www.emceupen.com

**EMC Goggles Ltd.**
P.O. Box 130, Cwmbran, Torfaen NP44 9BT, United Kingdom; 44 0 7506015791; John Davies, info@emcgoggles.com; www.emcgoggles.com

**EMC Integrity, Inc.**
1736 Vista View Drive, Longmont CO 80504 USA; 888-423-6275; Fax: 303 776-7314; guyd@emcintegrity.com; www.emcintegrity.com

**EMC Management Concepts**
46603 Kingschase Court, Sterling, VA; 703-864-7023; Fax: 801-849-3516; bfarmer@emcmanagement.com; www.emcmanagement.com

**EMC Partner AG** ..................................................................
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**EMC Technologies Pty Ltd.**
176 Harrick Road, Keilor Park Victoria 3042 Australia; 61393651000; Fax: 61393317455; Chris Zombolas, chris@emctech.com.au; www.emctech.com.au

**EMC Tempest Engineering**
2190 East Winston Road, Anaheim, CA 92806 USA; 714-778-1726; rbc@emctempest.com; www.emctempest.com

**EMC Test Design**
PO Box 600532, Newton, MA; 508-292-1833; exid@emctd.com; www.emctd.com

**EMC Testing Laboratories, Inc.**
2100 Brandon Trail, Suite 101, Alpharetta, GA 30004 USA; 770-475-8819; Fax: 770-475-2011; Gene Bailey, gbailey@emctesting.com; emctesting.com

**EMCC Dr. Rasek**
Moggast, Boelwiese 8, Ebermannstadt 91320 Germany; 1 49 9194-9016; Fax: 1 49 9194-8125; Irmhild Helldoerfer, emc.cons@emcc.de; www.emcc.de

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Wallbergstraße 7, Taufkirchen , Bavaria 82024, Germany; 49 89 614171 -0; Fax: 49 89 61471-71; info@emscreen.de; www.emscreen.de

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**emv - Elektronische Meßgeräte Vertriebs GmbH**
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**Equipment Reliability Institute**
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**EU Compliance Services, Inc.**
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**Eurofins Product Service GmbH**
Storkower Str. 38C Reichenwalde 15526 Germany; 49 33631 8880; Fax: 49 33631 888 660; jenszimmermann@eurofins.com; http://pt.eurofins.com

## F

**F-Squared Laboratories**
26501 Ridge Road, Damascus, MD 20872 USA; 301-253-4500; 877-405-1580; Fax: 301-253-5179; Ken DeVore, kdevore@f2labs.com; www.f2labs.com

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**F-Squared Laboratories**
26501 Ridge Road, Damascus, MD 20872 USA; 301-253-4500; Fax 301-253-5179; kdevore@f2labs.com; www.f2labs.com

**Fuss-EMV**
Johann-Hittorf-Strasse 6, 12489 Berlin, Germany; 49 30 - 6331319100; info@fuss-emv.de; www.fuss-emv.de

## G

**Gaddon Consultants**
18 New Royd, Millhouse Green, Sheffield, South Yorkshire S36 9NW, United Kingdom; 01226-766999; info@gaddon.co.uk; www.gaddon.co.uk

**GAUSS Instruments**
Agnes-Pockels-Bogen 1, Munich 80992, Germany; 49-89-54-04-699-0; Fax: 49-89-54-04-699-29; info@tdemi.com; www.gauss-instruments.com

**Gaven Industries Inc.**
6655 North Noah Drive, Saxonburg, PA 16056, USA; 724-352-8100; Fax: 724-352-8121; www.gavenindustries.com

**Genisco Filter Corp.**
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**Germania Elektronik GmbH**
Gutenbergring 41, 22848 Nordenstedt, Germany; 49-40-593-558-0; 49-40-593 558-29; http://www.germania-elektronik.com

**GETELEC**
375, rue Morane Saulnier, 78530 BUC, France; 33-01-39-20-42-49; Fax: 33-01-39-20-42-43; info@getelec.com; www.getelec.com

**Giga-tronics Inc.**
4650 Norris Canyon Road, San Ramon, CA 94583 USA; 925-328-4650; Fax: 925-328-4700; info@gigatronics.com; www.gigatronics.com

**Glenair Inc.**
1211 Air Way, Glendale, CA 91201 USA; 818-247-6000; Fax: 818-500-9912; sales@glenair.com; www.glenair.com

**Global EMC Ltd.**
Prospect Close, Lowmoor Road Industrial Estate, Kirkby-in-Ashfield, Nottinghamshire NG17 7LF, United Kingdom; 44-1623-755539; Fax: 44-1623-755719; info@globalemc.co.uk; www.globalemc.co.uk

**Global Testing**
4183 Riverview Drive, Riverside, CA 92509 USA; 951-781-4540; Fax: 951-781-4544; kumar@global-testing.com; www.global-testing.com

**Gowanda Electronics Corp.**
One Magnetics Parkway, P.O. Box 11, Gowanda, NY 14070 USA; 716-532-2234; Fax: 716-532-2702; sales@gowanda.com; www.gowanda.com

**Green Mountain Electromagnetics, Inc.**
219 Blake Roy Road, Middlebury, VT 05753 USA; 802-388-3390; Fax: 802-388-6279; gme@gmelectro.com; www.gmelectro.com

**GTN Kommunikations**
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## H

**H.B. Compliance Solutions, LLC**
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1650 Route 22, Brewster, NY 10509 USA; 845-279-3644; Fax: 845-279-2467; emcsales@hubbell-haefely.com; http://www.haefelyemc.com

**Harris Corp.**
1025 West NASA Boulevard, Melbourne, FL 32919 USA; 321-727-9100; webmaster@harris.com; harris.com

**Harwin Inc.**
7B Raymond Avenue, Unit 11, Salem, NH 03079 USA; 603-893-5376; mis@harwin.com; www.harwin.com

**Heilind Electronics, Inc.**
58 Jonspin Road, Wilmington, MA 01887 USA; 800-400-7041; Fax: 978-658-0278; www.heilind.com

**Henry Ott Consultants**
48 Baker Road, Livingston, NJ 07039 USA; 973-992-1793; Fax: 973-533-1442; Henry Ott, hott@ieee.org; www.hottconsultants.com

**Hermon Laboratories**
Hatachana Street, P.O. Box 23, Binyamina 30500, Israel; 972-4-626-8450; Fax: 972-4-626-8498; sales-tca@hermonlabs.com; www.hermonlabs.com

**HFC Shielding Prod. Co. Ltd.**
C Bldg, 3rd Industrial Park, Feng Huang Fuyong Town, Bao'an District, Shenzhen 518103 China; 86-755-27327247-49; Fax: 86-755-27306260; emi@emigasket.com; www.emigasket.com

**High & Low Corp.**
7F, No. 118, Lane 235,Baoqiao Road, Xindian District, New Taipei City 231, Taiwan; 886-2-8978-1800; Fax: 886-2-8912-1900; service@hal.com.tw; www.hal.com.tw

**HITEK Electronic Materials Ltd.**
15 Wentworth Road, South Park Industrial Estate; Scunthorpe, LINCS DN17 2AX, United Kingdom; 01724-851678; Fax: 01724-280586; sales@hitek-ltd.co.uk; www.hitek-ltd.co.uk

**Hi-Tech Controls**
14853 East Hinsdale Avenue, Centennial, CO 80112 USA; 303-680-5159; Fax: 303-680-5344; info@hitechcontrols.com; www.hitechcontrols.com

**Hi-Voltage & EMI Corp.**
93 Stone Lane, Levittown, NY 11756 USA; 516-644-5486; Fax: 516-735-3585; www.hivoltage.li

**Holland Shielding Systems BV**
Jacobus Lipsweg 124, 3316BP Dordrecht, The Netherlands; 31-78-613-1366; Fax: 31-78-614-9585; info@hollandshielding.com; www.hollandshielding.com

**Hoolihan EMC Consulting**
32515 Nottingham Court, P.O. Box 367, Lindstrom, Minnesota 55045, USA; 651-213-0966; Daniel Hoolihan; danhoolihanemc@aol.com; www.emcxpert.com

**HV TECHNOLOGIES, Inc.**
8526 Virginia Meadows Drive, Manassas, VA 20109 USA; 703-365-2330; Fax: 703-365-2331; emcsales@hvtechnologies.com; www.hvtechnologies.com

## I

**I. Thomas GmbH**
An der B73 - 200a, D-21684 Stade, Germany; 49-04141-82920; Fax: 49-04141-84461; info@i-thomas-gmbh.de; www.schirmkabinen.com

**Identification Products Corp.**
104 Silliman Avenue, Bridgeport, CT 06605 USA; 800-243-9888; Fax: 203-334-5038; info@idproducts.com; www.idproducts.com

**IMS Engineered Products**
One Innovation Drive, Des Plaines, IL 60016 USA; 847-391-8100; www.imsep.com

**iNARTE, Inc.**
600 North Plankinton Avenue, Suite 301, Milwaukee, WI 53201 USA; 888-722-2440; Fax: 414-765-8661; service@inarte.us; www.narte.org

**Inceleris**
Latinos 149, Col. Moderna Mexico, D.F. 3510, Mexico; 52-55-9180-3655; Guillermo Dominguez, guillermo.dominguez@inceleris.com; www.inceleris.com

**Ingenium Testing, LLC**
3761 South Central Avenue, Rockford, IL 61102 USA; 815-315-9250

**Innco Systems GmbH**
Erlenweg 12, Schwarzenfeld D-92521, Germany; 49-9435-3016590; Fax: 49-9435-301659-99; info@inncosystems.com; innco-systems.de/en/

**Instec LLC**
7426A Tanner Parkway, Arcade, NY 14009 USA; 716-532-2234; Fax: 716-532-2702; sales@instec-filters.com; www.instec-filters.com

**Instrument Rental Labs**
2100 West 6th Avenue, Suite C, Broomfield, CO 80020, USA; 303-469-5335: Fax: 303-469-5336; sales@testequip.com; www.testequip.com

**Instrument Plastics Ltd.**
35 Kings Grove Industrial Estate, Maidenhead, Berkshire SL6 4DP, United Kingdom; 44-1628-770018; Fax: 44-01628-773299; www.instrumentplastics.co.uk

**Instruments For Industry (IFI)**
903 South Second Street, Ronkonkoma, NY 11779 USA; 631-467-8400; Fax: 631-467-8558; www.ifi.com

**Insul-Fab, a Division of Concote Corp.**
600 Freeport Parkway., Suite 150, Coppell, TX 75019 USA; 214-956-0055; 800-442-1338; Fax: 214-956-0848; www.insulfab.net

**Integran**
6300 Northam Drive, Mississauga, Ontario L4V 1H7, Canada; 416-675-6266; Fax: 905-672-4984; www.integran.com

**Integrated Engineering Software**
220-1821 Wellington Avenue, Winnipeg, Manitoba, R3H 0G4 Canada; 204-632-5636; Fax: 204-633-7780; info@integratedsoft.com; www.integratedsoft.com

**Integrated Microwave Corp.**
11353 Sorrento Valley Road, San Diego, CA 92121 USA; 858-259-2600; www.imcsd.com

**Intermark USA Inc.**
1310 Tully Road, Suite117, San Jose, CA 95122 USA; 1-855-362-7278; Fax: 408-971-6033; www.intermark-usa.com
CA TechDream Inc; Cupertino.................................408-483-5413
CA Z-Tech Sales, Inc.; Saratoga..............................408-257-5371
GA dBm Marketing..................................................770-402-2560
IL Technology Sales, Inc. ........................................847-991-6600
MA Connors Company ...............................................508-272-1500
NJ EMC Technologies.............................................. 732-919-1100
INTERNATIONAL
CAN Neutronics...........................................................613-599-1263

**International Certification Services, Inc.**
1100 Falcon Avenue, Glencoe, MN 55336 USA; 320-864-4444; 888-286-6888; Fax: 320-864-6611; www.icsi-us.com

**International Compliance Laboratories**
1057 Tullar Court, Neenah, WI 54956 USA; 920-720-5555; Fax: 920-720-5556; Ron Zimmerman, rzimmerman@icl-us.com; www.icl-us.com

**Interpower Corp.**
100 Interpower Avenue, P.O. Box 115, Oskaloosa, IA 52577, USA; 641-673-5000; Fax: 641-673-5100; info@interpower.com; www.interpower.com

**Intertek Testing Services**
70 Codman Hill Road, Boxborough, MA 01719 USA; 978-263-2662; Fax: 978-263- 7086; www.intertek.com

**INTERTest Systems, Inc.**
303 Route 94, Colorado Springs, CO; 719-522-9667; Fax: 908-496-8004; info@intertestinc.com; www.intertest.com

**Ion Physics Corp.**
373 Main Street, P.O. Box 165, Fremont, NH 03044 USA; 603-895-5100; 800-223-0466; Fax: 603-895-5101; sales@ionphysics.com; www.ionphysics.com;

**IQS, a Division of the Compliance Management Group**
257 Simarano Drive, Marlboro, MA 01752 USA; 508-460-1400; Fax: 508-460-7979; rdunne@cmgcorp.net; www.iqscorp.com

**ITC Engineering Services, Inc.**
9959 Calaveras Road, Sunol. CA 94586 USA; 925-862-2944; Fax: 925-862-9013; sales@itcemc.com; www.itcemc.com

**ITEM Media - Interference Technology**
1000 Germantown Pike, Suite F-2, Plymouth Meeting, PA 19462 USA; 484-688-0300; Fax: 484-688-0303; info@interferencetechnology.com; www.interferencetechnology.com
INTERNATIONAL
CHN Beijing Hesicom Consulting Co. ............86-010-65250537
JPN TUV SUD Ohtama, Ltd. ..............................81-44-980-2092

**ITL Israel**
Bat-Sheva Street 1, P.O. Box 87, Lod, Israel; 972 8 9153100; Fax: 972-8-9153101; standard@itl.co.il; www.itl.co.il

**ITT Interconnect Solutions**
666 East Dyer Road, Santa Ana, CA 92705 USA; 714-628-8277; Fax: 714-628-8470; www.ittcannon.com

**ITW/Pressure Sensitive Adhesives & Components**
90 James Way, Southampton, PA 18966; 215-322-1600; Fax: 215-322-1620; info@mcspecialties.com; www.mcspecialties.com

## J

**Ja-Bar Silicone Corp.**
252 Brighton Road, P.O. Box 1249, Andover, NJ 07821 USA; 973-786-5000; Fax: 973-786-5546; info@ja-bar.com; www.jabar.com

**Jacobs Technology Inc.**
3300 General Motors Road, Milford, MI 48380 USA; 248-676-1123; www.jacobstechnology.com

**Jakob Mooser GmbH**
Osterholzallee 140.3, 71636 Ludwigsburg, Germany; 49-7141-64826-0; Fax: 49-7-141-64826-11; www.mooser-consulting.de

**Jastech EMC Consulting, LLC**
P.O. Box 3332, Farmington Hills, MI; 248-876-4810; info@jastech-emc.com; www.Jastech-EMC.com

**JEMIC Shielding Technology**
1160 South Cameron Street, Harrisburg, PA 17104 USA; 717-232-1030; dietrich@jemic.com; www.jemic.com

**JiangSu WEMC Technology Co., Ltd.**
No. 8, JianYe Road, TianMu Lake, Industrial Park LiYang Jiangsu 213300 China; 86-519-8796-1998; Fax: 86-519-8746-5666; weiyl@wemctech.com; www.wemctech.com

**Jinan EMI Shielding Technology Co., Ltd.**
509, No.792 Hualong Road, Jinan Shandong 250100 China; 8.65318E12; Fax: 8.65318E12; Sunny Li, info@emishielding.com.cn; www.emishielding.com.cn

**JINAN Filtemc Electronic Equipment Co., Ltd.**
# 9 Lanxiang Road, Jinan ID 250032, China; 86 531 85738859; Fax: 86 531 85717366; lwl@filtemc.com; www.filtemc.com

**Johanson Dielectrics, Inc.**
15191 Bledsoe Street, Sylmay, CA 91342 USA; 818-364-9800; scole@johansondielectrics.com; www.johansondielectrics.com

**JRE Test, LLC.**
1350 Pittsford-Mendon Road, Mendon, NY 14506 USA; 585-298-9736; 888-430-3332; Fax: 585-919-6586; brian@jretest.com; www.jretest.com

**JS TOYO Corp. (Shenzhen) Ltd.**
2-25G, China Phoenix Building Futian CBD, Shenzhen,, 518026 China; www.jstoyo.cn

## K

**K-Form, Inc.**
9A Acacia Lane, Sterling, VA 20166 USA; 703-450-4401; Fax: 703-894-4914; kform@kform.com; www.kform.com

**KEMET Corp.**
P.O. Box 5928, Greenville, SC 29606 USA; 864-963-6300; www.kemet.com

**Kemtron Ltd.**
19-21 Finch Drive, Springwood Industrial Estate, Braintree, Essex CM7 2SF, United Kingdom; 44-1376-348115; Fax: 44-1376-345885; info@kemtron.co.uk; www.kemtron.co.uk

**Kensington Electronics, Inc.**
11801 Stonehollow Drive, Suite 150, Austin, TX 78758 USA; 512-339-3300; Fax: 512-833-8034; www.keiconn.com

**Keystone Compliance**
2861 West State Street, New Castle, PA 16101 USA; 724-657-9940; Fax: 724-657-9920; tony@keystonecompliance.com; www.keystonecompliance.com

**Kikusui America Inc.**
1633 Bayshore Highway., Suite 331, Burlingame, CA 94010 USA; 650-259-5900; Fax: 650-259-5904; itoko@kikusuiamerica.us; www.kikusuiamerica.us

**Kimmel Gerke Associates, Ltd.**
2538 West Monterey Avenue, Mesa, AZ 85202 USA; 888-EMI-GURU; Daryl Gerke, dgerke@emiguru.com;; 628 LeVander Way, South Saint Paul, MN 55075 USA; Bill Kimmel, bkimmel@emiguru.com; www.emiguru.com

**KOA Speer Electronics**
199 Bolivar Drive, Bradford, PA 16701 USA; 814-362-5536; Fax: 814-362-8883; www.koaspeer.com

**Krieger Specialty Products**
4880 Gregg Road, Pico Rivera, CA 90660 USA; 562-695-0645; Fax: 562-692-0146; Bob McCluney, bmccluney@kriegerproducts.com; www.kriegerproducts.com

**Kycon**
11810 Little Orchard Street, San Jose, CA 95125 USA; 408-494-0330; jill_scarnecchia@kycon.com; www.kycon.com

## L

**L. Gordon Packaging**
22 West Padonia Road, Suite 304A, Timonium, MD 21093 USA; 410-308-2202; Fax: 410-308-2207; lgordonpkg@verizon.net; www.lgordonpackaging.com

**L.S. Research**
W66 N220 Commerce Court, Cedarburg, WI 53012 USA; 262-375-4400; Fax: 262-375-4248; www.lsr.com

**L-3 Communications Cincinnati Electronic**
7500 Innovation Way, Mason, OH 45040-9699 USA; 513-573-6100; Steven Davis, Steven.Davis@L-3Com.com; www.L-3Com.com/ce

**Laboratory Testing Inc.**
2331 Topaz Drive, Hatfield, PA 19440 USA; 800-219-9095; Fax: 800-219-9096; sales@labtesting.com; www.labtesting.com

**Laird Technologies**
3481 Rider Trail South, Earth City, MO 63045 USA; 636-898-6000; Fax: 636-898-6100; www.lairdtech.com

**Lamart Corp.**
16 Richmond Street, Clifton, NJ 07011 USA; 973-772-6262; Fax: 973-772-3673; www.lamartcorp.com

**Langer EMV-Technik GmbH**
Noethnitzer Hang 31, DE-01728, Bannewitz, Germany, 49-351-430-093-23; Fax: 49-351-430-093-22; mail@langer-emv.de; www.langer-emv.de

**Laplace Instruments Ltd.**
3B, Middlebrook Way, Holt Road, Cromer, Norfolk, NR27 9JR, UK; 44-12-63-51-51-60; Fax: 44-12-63-51-25-32; tech@laplace.co.uk; www.laplaceinstruments.com

**Lapp USA**
29 Hanover Road, Florham Park, NJ 07932 USA; 973-660-9700; 800-774-3539; Fax: 973-660-9330; mbroe@lappusa.com; www.lappusa.com

**LCR Electronics, Inc.**
9 South Forest Avenue, Norristown, PA 19401 USA; 800-527-4362; 610-278-0840; Fax: 610-278-0935; sales@lcr-inc.com; www.lcr-inc.com

**Leader Tech, Inc.**
12420 Race Track Road, Tampa, FL 33626 USA; 813-855-6921; 866-832-4364; Fax: 813-855-3291; sales@leadertechinc.com; www.leadertechinc.com

**LEDE-SIECIT**
48 & 116 Street, La Plata, Buenos Aires 1900, Argentina; 54 11 221 4250877; lede@ing.unlp.edu.ar

**Less EMF Inc.**
776B Watervliet Shaker Road, Latham NY 12110 USA; 888-537-7363; Fax: 309-422-4355; lessemf@lessemf.com; www.lessemf.com

**L F Research EMC**
12790 Route 76, Poplar Grove, IL 61065; 815-566-5655; FAX: 815-547-3467; info@lfresearch.com; www.lfresearch.com;

**LGS Technologies**
2950 West Wintergreen, P.O Box 763039, Lancaster, TX 75134 USA; 972-224-9201; 1-800-441-5470; Fax: 972-228-0652; crobles@lgsco.com; www.lgstechnologies.com

**Liberty Labs, Inc.**
3245 University Avenue, Suite 1122, San Diego, CA 92104 USA; 619-284-8013; sales@libertylabs.com; www.libertylabs.com

**Lightning Eliminators & Consultants, Inc.**
6687 Arapahoe Road, Boulder, CO 80303; 303-447-2828; Fax: 303-447-8122; www.lecglobal.com

**Lightning Technologies, Inc.**
10 Downing Industrial Parkway, Pittsfield, MA 01201-3890 USA; 413-499-2135; Fax: 413-499-2503; Mary Cancilla, cancilla@lightningtech.com; www.lightningtech.com

**Little Mountain Test Facility**
12000 West 12th Street, Ogden, UT 84404 USA; 801-315-2398

**Littlefuse Inc.**
8755 West Higgins Road, Suite 500, Chicago, IL; 773-628-1000; Fax: 847 759 0272; www.littlefuse.com

**Loos & Co., Inc.**
P.O. Box 98, Pomfret Center, CT 06258, USA; 800-533-5667; Fax: 860-928-6681; sales@loosco.com; www.loosco.com

**LTI Metrology**
2331 Topaz Drive, Hatfield, PA 19440; 800-784-2882; Fax: 800.219.9096; sales@labtesting.com; www.labtesting.com

**Lubrizol Conductive Polymers**
29400 Lakeland Boulevard, Wickliffe, OH 44092 USA; 440-943-4200; www.statrite.com

**Lutze Inc.**
13330 South Ridge Drive, Charlotte, NC 28273 USA; 704-504-0222; Fax: 704-504-0223; www.lutze.com

## M

**M&C Specialties**
90 James Way, Southampton, PA 18966 USA; 215-322-7441 x 124; Fax: 215-322-1620; Dave Cornelison, dcornelison@mcspecialties.com; www.mcspecialties.com

**M.MARDIGUIAN, EMC Consulting**
2 Allee des Chataigniers, St Remy les Chevreuse 78470, France; 33-1-30-52-97-25; Fax: 33-1-30-52-97-25; Michel Mardiguian, m.mardiguian@orange.fr

**Macton Corp**.
116 Willenbrock Road, Oxford, CT 06478 USA; 203-267-1500; Fax: 203-267-1555; www.macton.com

**Magnetic Radiation Laboratories**
690 Hilltop Drive, Itasca, IL 60143 USA; 630-285-0800; 888-251-5942; Fax: 630-285-0807; admin@magrad.com; www.magrad.com

**Magnet Industry Ltd.**
No.6,Chung-Hsin Road,Chung-Hsin Industrial Park, Maio-Li Taiwan 366 Taiwan; 886-2-25149690; Fax: 886-2-25149145; Simon Hsu, simon@ferrite.com.tw; www.ferrite.com.t

**Magnetic Shield Corp.**
740 Thomas Drive, Bensenville, IL 60106 USA; 630-766-7800; Fax: 630-766-2813; Brad Friestedt, shields@magnetic-shield.com; www.magnetic-shield.com

**MAJR Products Corp.**
17540 State Highway 198, Saegertown, PA 16433 USA; 814-763-3211; 877-625-7776; Fax: 814-763-2952; terry@majr.com; www.majr.com

**Marcom Coordinator**
447 Aviation Boulevard, Santa Rosa, CA 95403 USA; 707-636-3000; www.schurterinc.com

**Marktek Inc.**
13621 Riverway Drive, Suite H, Chesterfield, MO 63017 USA; 314-878-9190; 866-364-6285; Fax: 314-878-9558; www.marktek-inc.com

**Master Bond Inc.**
154 Hobart Street, Hackensack, NJ 7601 USA; 201-343-8983; Fax: 201-343-2132; www.masterbond.com

**Materion Brush Performance Alloys**
6070 Parkland Boulevard, Mayfield Heights, OH 44124 USA; 800-321-2076; 216-383-4005; Jimmy Johnson, BrushAlloys-Info@materion.com; http://materion.com/brushalloys

**maturo GmbH**
Bahnhofstr. 26,92536 Pfreimd, Germany; 49 9606 9239130; Fax: 49-9606-923913-29; info@maturo-gmbh.de; www.maturo-gmbh.de

**MCG Surge Protection**
12 Burt Drive, Deer Park, NY 11729 USA; 800-851-1508; 631-586-5125; Fax: 631-586-5120; info1@mcgsurge.com; www.mcgsurge.com

**MCL, Inc.**
501 South Woodcreek Drive, Bolingbrook, IL 60440 USA; 630-759-9500; Fax: 630-759-5018; sales@mcl.com; www.mcl.com

**MEC Kitagawa**
Marcom House, 1 Steam Mill Lane, Great Yarmouth, Norfolk NR31 0HP, United Kingdom; 4.41494E11; Fax: 01493 668623; Michael Baker, michael@marcomuk.co.uk; www.meckitagawa.co.uk

**Mech-Tronics**
1635 North 25th Avenue, Melrose Park, IL 60160 USA; 708-344-9823 ext.638; 1-800-989-9823; Fax: 708-344-0067; bob.feiler@mech-tronics.com; www.mech-tronics.com

**MegaPhase LLC**
122 Banner Road, Stroudsburg, PA 18360 USA; 570-424-8400; www.megaphase.com

**Mekoprint A/S Chemigraphics**
Mercurvej 1, DK-9530 Støvring, Denmark; 45 9936 5618; Fax: 45 9936 5603; sk@mekoprint.dk; www.mekoprint.dk

**Mercury United Electronics Inc.**
9299 9th Street, Rancho Cucamonga, CA 91730 USA; 909-466-0427; Fax: 909-466-0762; Art Trejo, art-trejo@mercury-crystal.com; www.MercuryUnited.com

**Mesago Messe Frankfurt GmbH**
Rotebuehlstrasse 83-85, Stuttgart, D-70178, Germany; www.mesago-online.de/en; 49 711 61946 26

**MET Laboratories, Inc.**
914 West Patapsco Avenue, Baltimore, MD 21230 USA; 410-354-3300;Fax: 410-354-3313; info@metlabs.com; www.metlabs.com

**Metal Textiles Corp.**
970 New Durham Road, Edison, NJ 08818 USA; 732-287-0800; Fax: 732-287-8546; www.metexcorp.com

**Metatech Corp.**
358 South Fairview Avenue Suite E, Goleta, CA; 805-683-5681; Fax: 805-683-3023; info@metatechcorp.com; www.metatechcorp.com

**METZ Connect**
200 Tornillo Way, Tinton Falls, NJ 07712 USA; 732-389-1300; 888-722-5625; Fax: 732-389-9066; info@metzconnectusa.com; www.metz-connect.com/us

**MH&W International Corp.**
14 Leighton Place, Mahwah, NJ 07430 USA; 201-891-8800; 866-MHW-CORE; Fax: 201-891-0625; garyv@mhw-intl.com; www.mhw-intl.com

**Micrometals, Inc.**
5615 East La Palma Avenue, Anaheim, CA 92807; 714-970-9400; Fax: 714-970-0400; sales@micrometals.com; www.micrometals.com

**Michigan Scientific Corp.**
321 East Huron Street, Milford Michigan 48383 USA; 248-685-3939; Fax: 248 684-5406; Paul Morand, fiber@michscimfd.com; www.michsci.com

**Micronor, Inc.**
750 Mitchell Road, Newbury Park, CA 91320-2213 USA; 805-499-0114; Fax: 805-499-6585; Dennis Horwitz, sales@micronor.com; www.micronor.com

**Mihajlo Pupin Institute – EMC Laboratory**
Volina 15 Street, Belgrade, Serbia 11000 Serbia; 38162369796; Fax: 3.81113E11; Nikola Nenadic, nikola.nenadic@pupin.rs; www.pupin.rs

**MILMEGA Ltd.**
Park Road, Ryde, Isle of Wight PO33 2BE, United Kingdom; 44-1983-618004; Fax: 44-1983-811521; sales@milmega.co.uk; www.milmega.com

**MIRA Ltd.**
Watling Street, Nuneaton, Warwickshire CV10 0TU, United Kingdom; 44-24-6-355-5000; Fax: 44-2476-355-8000; matthew.farmer@mira.co.uk; www.mira.co.uk

**Mitsubishi Digital Electronics America Inc.**
9351 Jeronimo Road, Irvine, CA 92618-1904 USA; 949-465-6206

**MKS Instruments**
2 Tech Drive, Suite 201, Andover, MA 01810 USA; 978-645-5500; mks@mksinst.com; www.mksinst.com

**Modpak, Inc.**
97 Mudgett Road, Kenduskeag ME 4450 USA; 207-884-8285; Fax: 207-884-8712; Jeff Billington, modpak@roadrunner.com; www.modpak.com

**Montena Technology SA**
Route de Montena 89, Rossens 1728, Switzerland; 41-26-411-84-84; Fax: 41-26-411-17-79; products@montena.com; www.montena.com

**Montrose Compliance Service, Inc.**
2353 Mission Glen Drive, Santa Clara, CA 95051 USA; 408-247-5715; mark@montrosecompliance.com; www.montrosecompliance.com

**Moss Bay EDA**
23889 NE 112th Circle #2, Redmond ,WA 98053 USA; 206-779-5345; Fax: 484-730-5345; gene@mossbayeda.com; www.mossbayeda.com

**MPB Srl**
Via Giacomo Peroni 400/402, Rome, RM 131, Italy; 0039-06-41200744; Fax: 0039-06-41200653; Silvia Petrelli, marketing@gruppompb.com; www.gruppompb.co.uk

**MPE Ltd.**
Hammond Road, Knowsley Industrial Estate, Liverpool, England L33 7UL United Kingdom; 44-151-632-9100; Fax: 44-151-632-9112; sales@mpe.co.uk; www.mpe.co.uk

**MTI - Microsorb Technologies, Inc.**
32 Mechanic Avenue, Unit 211, Woonsocket, RI 02895-0089 USA; 401-767-2269; 401-767-2255; www.microsorbtech.com

**Mueller Corp.**
530 Spring Street, East Bridgewater, MA 02333 USA; 508-583-2800; Fax: 508-378-4744; glenn@muellercorp.com; www.muellercorp.com

**Murata Electronics North America**
2200 Lake Park Drive, Smyrna, GA 30080 USA; 770-436-1300; 800-241-6574; Fax: 770-805-3192; nrosenfeld@murata.com; www.murata.com

**MµShield Company, Inc.**
9 Ricker Avenue, Londonderry, NH 03053 USA; 603-666-4433; 888-669-3539; Fax: 603-666-4013; info@mushield.com; www.mushield.com

## N

**Narda Safety Test Solutions, S.r.l.**
Via Leonardo da Vinci, 21/23 20090 Segrate, Milano, Italy; 39-02-2699871; support@narda-sts.it;

**National Institute for Aviation Research**
Wichita State University, 1845 Fairmount Street, Wichita, KS 67260 USA; 316-978-5727; www.niar.wichita.edu

**National Magnetics Group, Inc.**
1210 Win Drive, Bethlehem, PA; 610-761-7600; Fax: 610-867-0200; sales@magneticsgroup.com; www.magneticsgroup.com

**National Technical Systems**
24007 Ventura Boulevard, Suite 200, Calabasas, CA 91302 USA; 800-270-2516; Fax: 818-591-0899; sales@nts.com; www.nts.com

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**NAVAIR 5.4.4.5**
Aircraft Division - E3 Branch Code 5.4.4.5 Hangar 144, Suite 3B, Unit 5, 48202 Standley Road, Patuxent River, MD 20670-1910 USA; 301-342-1663; Fax: 301-342-6982; www.navair.navy.mil

**NCEE Labs**
4740 Discovery Drive, Lincoln, NE 68521 USA; 402-472-5880; 888-567-6860; Fax: 402-472-5881; dkramer@nceelabs.com; www.nceelabs.com

**NEDC Fabricating Solutions**
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**Nemko-CCL, Inc**
1940 West Alexander Street, Salt Lake City, UT 84119 USA; 801-972-6146; Fax: 801-972-8432; Tom Jackson, tom.jackson@nemko.com; www.cclab.com

**Nemko USA**
2004 Chelam Way, Brandon, FL 33511 USA: 813-528-1261; Andrew Robbins, Andrew.robbins@nemko.com; www.nemco.com

**NewPath Research L.L.C.**
2880 South Main Street, Salt Lake City, UT 84115 USA; 801-573-9853; mahagmann@newpathresearch.com; www.newpathresearch.com

**NEXIO**
46 Avenue du General de Croutte, Toulouse 31300, France; 33-5-61-44-02-47; Fax: 33-)5-61-44-05-67; sales@nexio.fr; www.nexio.fr

**Next Generation Power Amplifiers**
316 West Florence Avenue, Inglewood, CA 90301 USA; 310-412-8100; Fax: 310-412-9232; www.empowerrf.com

**Nextek**
2 Park Drive, Building 1, P.O. Box 385, Westford, MA 01886 USA; 978-486-0582; Fax: 978-486-0583;sales@nexteklightning.com; www.nexteklightning.com

**Noise Laboratory Co., Ltd.**
1-4-4, Chiyoda, Chuo-ku, Sagamihara City, Kanagawa Pref 252-0237, Japan; sales@noiseken.com; www.noiseken.com
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KOR Seoul, Noise Technology Co. Ltd. .....................82-31-781-7816
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MAS AMPTRONIC (M) SDN.BHD.; Selangor Daurl Ehsan................ 60-3-5632-8411
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THA Industrial Electrical Co., Ltd.; Bangkok .............66-2-642-6700
TPE Precision International Corp............................886-2-8512-4888
VIE Nihon Denkei Co., Ltd............................................84-4-951-6505

**Nolato Silikonteknik AB**
Bergmansv 4, Hallsberg 69491, Sweden; 46-582-88900; www.nolato.se/silikonteknik

**Northern Technologies Corp.**
95 Konrad Crescent, Markham, Ontario L3R 8T8, Canada; 905-475-9320; 800-456-1875; Fax: 905-475-5719; chrismarshall@northerntech.com; www.northerntech.com

**Northwest EMC, Inc.**
22975 Northwest Evergreen Parkway, Suite 400, Hillsboro, OR 97124 USA: 503-943-3122; www.nwemc.com

**NP Technologies, Inc.**
2393 Teller Road #108, Newbury Park, CA 91320 USA; 805 376-9299; Fax: 805 376-9288; sales@nptrf.com; www.nptrf.com

**Nu Laboratories, Inc.**
312 Old Allerton Road, Annandale, NJ; 908-713-9300; Fax: 908-713-9001; webmaster@nulabs.com; www.nulabs.com

## O

**Oak-Mitsui Technologies**
80 1st Street, Hoosick Falls, NY 12090 USA; 518-686-8088; Fax: 518-686-8080; john.andresakis@oakmitsui.com; www.oakmitsui.com

**Okaya Electric America, Inc.**
52 Marks Road, Suite 1, Valparaiso, IN 46383 USA; 800-852-0122; Fax: 219-477-4856; ross@okaya.com; www.okaya.com

**Omicron Electronics GmbH**
Oberes Ried 1, Klaus 6833, Austria; 43- 5523-507; Fax: 43-5523-507 -999; info@omicron.at; www.omicron.at

**Onanon Connectors**
720 South Milpitas Boulevard, Milpitas, CA 95035 USA: 408-262-8990; Fax: 408-262-2901; www.onanon.com

**OPHIR RF**
5300 Beethoven Street, Los Angeles, CA 90066 USA; 310-306-5556; Fax: 310-821-7413; info@ophirrf.com; www.ophirrf.com

**Optical Filters Ltd.**
13447 South Mosiertown Road, Meadville, PA 16335 USA: 814-333-2222; Fax: 814-333-4338; www.opticalfiltersusa.com

**Orbel Corp.**
2 Danforth Drive, Easton, PA 18045 USA; 610-829-5000; Fax: 610-829-5050; lgiralico@orbel.com; www.orbel.com

**ORBIT Advanced Electromagnetics, Inc.**
P. O. Box 711719, Santee, CA 92072-1719 USA; 619-449-9492; Fax: 619-449-1553; www.aemi-inc.com

**Orion Industries Inc.**
One Orion Park Drive, Ayer, MA; 978-772-6000; Fax: 978-772-0021; www.orionindustries.com

**Oxley Developments Company Ltd.**
Priory Park, Cumbria, Ulverston LA12 9QG, United Kingdom; 44 0 1229 840519; Fax: 44 0 1229 870451; m.blows@oxley.co.uk; www.oxleygroup.com

## P

**P & P Technology Ltd.**
Finch Drive, Springwood Industrial Estate, Braintree, Essex, CM7 2SF, United Kingdom; 44-1376-550525; Fax: 44-1376-552389; info@p-p-t.co.uk; www.p-p-t.co.uk

**Pacific Aerospace & Electronics, Inc.**
434 Olds Station Road, Wenatchee, WA 98801 USA; 509-285-5299; Fax: 509-663-5039; sales@pacaero.com; www.pacaero.com

**Pacific Power Source, Inc.**
17692 Fitch, Irvine, CA 92614; 800-854-2433: 949-251-1800; Fax: 949-756-0756; sales@pacificpower.com; www.pacificpower.com

**Paladin EMC**
65 Buckwheat Avenue, Portsmouth, RI 02871 USA; 401-924-3700; spence@paladinemc.com; www.paladinemc.com

**Panashield, Inc.**
185R West Norwalk Road #R, Norwalk, CT 06850-4312 USA; 203-866-5888; Fax: 203-866-6162; help@panashield.com; www.panashield.com

**Panasonic Electronic Components**
Three Panasonic Way, 7H-2, Secaucus, NJ 07094 USA; 1-800-344-2112; Fax: 201-348-7393; industrial@us.panasonic.com; www.panasonic.com/industrial/electronic-components/

**Parker EMC Engineering**
15246 Daphne Avenue, Gardena, CA 90249-4122 USA; 310-323-4188; Fax: 310-323-4188; parkeremc@worldnet.att.net; parkeremc.mustbehere.com

**Partnership for Defense Innovation**
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**Pasternack Enterprises**
17802 Fitch, Irvine, CA 92614 USA; 1-866-727-8376; Fax: 949-261-7451; sales@pasternack.com; www.pasternack.com

**Peak Electromagnetics Ltd.**
139 Bank Street, Macclesfield, Cheshire SK11 7AY, United Kingdom; 44-0162-5269808; sales@peak-em.co.uk; www.peak-em.co.uk

**Pearson Electronics, Inc.**
4009 Transport Street, Palo Alto, CA 94303 USA; 650-494-6444; Fax: 650-494-6716; sales@pearsonelectronics.com; www.pearsonelectronics.com
INTERNATIONAL
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**PennEngineering**
5190 Old Easton Road, Danboro, PA 18916 USA; 215-766-8853; Fax: 215-766-3633; info@pemnet.com; www.pemnet.com

**Percept Technology Labs, Inc.**
4888 Central Ave Suite #110, Boulder, CO 80301 USA; 303-444-7480; martyb@percept.com; www.percept.com

**PGMC Ltd.**
4 Pondholton Drive, Witham, Essex , CM8 1QG, United Kingdom; Tel: 44-2071-93 1730; Pablo Garcia, pablog@o2.co.uk

**Philips Innovation Services - EMC center**
High Tech Campus 7, 5656 AE Eindhoven, The Netherlands; 31-40-27-48060; emc.testlab@philips.com; www.emc.philips.com

**Phoenix Company of Chicago Inc.**
600 Wheat Lane, Wood Dale, IL 60191 USA; 630-595-2300; 800-323-9562; Fax: 630-595-6579; sales@phoenixofchicago.com; phoenixofchicago.com

**Phoenix Contact**
586 Fulling Mill Road, Middletown, PA 17057 USA; 717-944-1300; Fax: 717-944-1625; info@phoenixcon.com; www.phoenixcontact.com/usa_home

**Photofabrication Engineering Inc.**
500 Fortune Boulevard, Milford, MA 01757 USA; 508-478-2025; Fax: 508-478-3582; pei@photofabrication.com; www.photofabrication.com

**Plastic-Metals Technology Inc.**
7051 SW Sandburg Road, Suite 400, Tigard, OR 97223 USA; 503-684-0725; Fax: 503-684-0735; info@p-mtinc.com; www.p-mtinc.com

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423 North Campbell Avenue, Springfield, MO 65806 USA; 800-641-4054; Fax: 417-866-4115; info@connnectpositronic.com; www.connectpositronic.com

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4 Foothills Drive, Ottawa, Ontario K2H 6K3, Canada; 613-829-0820; Fax: 613-829-8127; mail@pcel.ca; www.pcel.ca

**Power Products International Ltd.**
Commerce Way, Edenbridge, Kent TN8 6ED, United Kingdom; 44-1732-866424; Fax: +44-1732-866399; info@ppi-uk.com; www.ppi-uk.com

**Power Standards Lab (PSL)**
2020 Challenger Drive #100, Alameda, CA; 510-522-4400; Fax: 510-522-4455; sales@powerstandards.com; www.powerstandards.com

**PPM (Pulse Power & Measurement) Ltd.**
65 Shrivenham, Hundred Business Park, Watchfield, Swindon, Wiltshire, SN6 8TY, United Kingdom; 44-1793-784389; Fax: 44-1793-784391; sales@ppm.co.uk; www.point2point.co.uk

**Praxsym, Inc.**
120 S. Third Street, P.O. Box 369, Fisher, IL 61843 USA; 217-897-1744; sales@praxsym.com; www.praxsym.com

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**Prismier**
10216 Werch Drive, Suite 118, Woodridge, IL 60517 USA; 630-592-4515; Fax: 630-214-4099; websales@prismier.com; prismier.com

**Product Safety Engineering Inc.**
12955 Bellamy Brothers Boulevard, Dade City, FL 33525 USA; 352-588-2209; Fax: 352-588-2544; hwatkins@pseinc.com; www.pseinc.com

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1601 N. A.W. Grimes Boulevard, Suite B, Round Rock, TX 78665 USA; 512-244-3371; Fax: 512-244-1846; info@ptitest.com; www.ptitest.com

**Progressive Fillers International**
2404 East 28th Street, P.O. Box 72709, Chattanooga, TN 37407 USA; 423-629-0007; 888-988-0007; Fax: 423-629-0444; support@pfillers.com; www.progressivefillers.com

**Prostat Corp.**
1072 Tower Lane, Bensenville, IL 60106 USA; 630-238-8883; Fax: 630-238-9717; www.prostatcorp.com

**Protection Technology Group**
10701 North Airport Road, Hayden, ID 83835 USA; 208-772-8515; 800-882-9110; Fax: 208-762-6133; www.protection-group.com/Home

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40 Boroline Road, Allendale, NJ 07401 USA; 201-818-9300

**Protocol Data Systems Inc.**
4741 Olund Road, Abbotsford, British Columbia V4X 2A1, Canada; 604-218-1762; info@protocol-emc.com; www.protocol-emc.com

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**Pulver Laboratories Inc.**
320 North Santa Cruz Avenue, Los Gatos, CA 95030-7243 USA; 408-399-7000; 800-635-3050; Fax: 408-399-7001; Lee.Pulver@PulverLabs.com; www.PulverLabs.com

## Q

**QAI Laboratories**
211 Schoolhouse Street, Unit 16, Coquitlam, British Columbia V3K 4X9, Canada; 877-461-8378; 604-527-8378; Fax: 604-527-8368; qai.org

**QEMC**
Rio de Janeiro, Brazil; 5521-8111-6661; menna@qemc.com.br; www.qemc.com.br

**QinetiQ**
Cody Technology Park, Ively Road, Farnborough, Hampshire GU14 0LX, United Kingdom; 44-843-658-4668; www.QinetiQ.com/emc

**Q-par Angus Ltd.**
Barons Cross Laboratories, Leominster, Herefordshire HR6 8RS, United Kingdom; 44-1568-612138; Fax: 44-1568-616373; info@q-par.com; www.q-par.com

**Qualtek Electronics Corp.**
7675 Jenther Drive, Mentor, OH 44060 USA; 440-951-3300; Fax: 440-951-7252; mailbox@qualtekusa.com; www.qualtekusa.com

**Qualtest Inc.**
5325 Old Winter Garden Road, Orlando, FL 32811 USA; 407-293-5844; Fax: 407-297-7376; info@qualtest.com; www.qualtest.com

**Quarterwave Corp.**
1300 Valley House Drive, Suite 130, Rohnert Park, CA 94928 USA; 707-793-9105; Fax: 707-793-9245; engineering@quarterwave.com; www.quarterwave.com

**Quell Corp.**
5639-B Jefferson NE, Albuquerque, NM 87109 USA; 877-730-1669; 505-243-1423; Fax: 505-243-9772; eeseal@quell.us; www.eeseal.com

## R

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10064 Deerfield Road, Franktown, CO 80116 USA; 800-761-9447; 303-761-5067; Eric Evans; sales@ramayes.com; www.ramayes.com

**R & K Company Ltd.**
721-1 Maeda, Fuji, Shizuoka 416-8577, Japan; 81-545-31-2600; Fax: 81-545-31-1600; info@rkco.jp; www.rk-microwave.com

**Radiometrics Midwest Corp.**
12 East Devonwood Drive, Romeoville, IL 60446 USA; 815-293-0772; Fax: 815-293-0820; Dennis Rollinger, CEO; sales@radiomet.com; www.radiomet.com

**Radiotecknika Marketing Sp. Z o.o.**
20 Fabryczna Street, Pietrzykowice 55-080, Poland; 48-71-327-0700; www.radiotechnika.com.pl

**Radius Power, Inc.**
22895 Eastpark Drive, Yorba Linda, CA 92865 USA; 714-289-0055; Fax: 714-289-2149; sales@radiuspower.com; www.radiuspower.com

**Rainford EMC Systems Ltd.**
Haydock Lane, St. Helens, Merseyside WA11 9TN, United Kingdom; 44-1942-296190; sales@rainfordemc.com; www.rainfordemc.com

**Ramsey Electronics**
590 Fishers Station Drive, Victor, NY 14564 USA; 585-924-4560; Fax: 585-924-4886; www.ramseytest.com

**REMCOM, Inc.**
315 S. Allen Street, Suite 416, State College, PA 1680 USA; 814-861-1299; 888-773-6266; Fax: 814-861-1308; sales@remcom.com; www.remcom.com

**Restor Metrology**
921 Venture Avenue, Leesburg, FL 34748 USA; 877-220-5554; 888-886-0585; www.restormetrology.com

**Reliant EMC LLC**
6501 Crown Boulevard, Suite 106A9, San Jose, CA 95120 USA; 408-600-1472; contact@reliantemc.com; www.reliantemc.com

**Retlif Testing Laboratories**
795 Marconi Avenue, Ronkonkoma, NY 11779 USA; 631-737-1500; Fax: 631-737-1497; sales@retlif.com; www.retlif.com

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| CT | Mantec, Inc./Peter Mann | 860-774-1551 |
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| NC | Retlif Testing Laboratories | 704-909-2840 |
| NH | Retlif Testing Laboratories | 603-497-4600 |
| PA | Retlif Testing Laboratories | 215-256-4133 |

**RF Exposure Lab, LLC**
802 North Twin Oaks Valley Road, Suite 105, San Marcos, CA 92029 USA; 760-471-2100; Fax: 760-471-2121; www.rfexposurelab.com

COMPANY DIRECTORY

**RF Immunity Ltd.**
36 Hayarkon Street, Yavne 81227, Israel; 972-73-2331300; Fax: 972-73-2332325; sales@rfimmunity.co.il; www.rfimmunity.com

**RFI Controls Company**
341 Village Lane, Los Gatos, CA 95030 USA; 408-399-7007; Fax: 408-399-7011; info@rficontrols.com; www.rficontrols.com

**RFI Corp.**
100 Pine Aire Drive, Bay Shore, NY 11706-1107 USA; 631-231-6400; Fax: 631-231-6465; rfisales@rficorp.com; www.rficorp.com

**RFTEK**
5103 Duntrune Court, Raleigh, NC 27606 USA; 919-622-4088; info@rftek.net; www.rftek.net

**Rhein Tech Laboratories, Inc.**
360 Herndon Parkway, Suite 1400, Herndon, VA 20170 USA; 703-689-0368; Fax: 703-689-2056; www.rheintech.com

**Richard Wöhr GmbH**
Gräfenau 58-60, D-75339 Höfen/Enz, Germany; 49-7081-9540-0; 49-7081-9540-90; info@engl@woehrgmbh.com; www.woehrgmbh.com

**Richardson RFPD, Inc.**
40W267 Keslinger Road, P.O. Box 307, LaFox, IL 60147, USA; 630-208-2700; Fax: 630-208-2662; sales@richardsonrfpd.com; www.richardsonrfpd.com/Pages/home.aspx

**Rigol Technologies**
7401 First Place, Suite N, Oakwood Village, OH 44146 USA; 440-232-4488; info@rigol.com; www.rigolna.com

**Rittal Corp.**
1 Rittal Place, Urbana, OH 43078 USA; 937-399-0500; 800-477-4000; Fax: 937-390-5599; customerservicefax@rittal.us; www.rittal-corp.com

**RMV Technology Group, LLC**
NASA-Ames Research Center, Bldg. 19, Suite 1073, MS 19-46C, P.O. Box 1, Moffett Field, CA 94035 USA; 650-964-4792; Fax: 650-964-1268; Renee Mitchell, renee@esdrmv.com; www.esdrmv.com

**Rogers Labs, Inc.**
4405 West 259th Terrace, Louisburg, KS 66053 USA; 913-837-3214; Fax: 913-837-3214; info@rogerslabs.com; www.rogerslabs.com

**Rohde & Schwarz GmbH**
4 Kamp 6, 22453 Hamburg, Germany; 49-40-38-61-83-00; Fax: 49-38-61-83-20; Vertrieb.Hamburg@rohde-schwarz.com; www rohde-schwarz.com.de

**Rohde & Schwarz, Inc.**
8661A Robert Fulton Drive, Columbia, MD 21046 USA; 888-837-8772; 410-910-7800; Fax: 410-910-7801; info@rsa.rohde-schwarz.com; www.rohde-schwarz.us

**Roxburgh EMC**
Deltron Emcon House, Hargreaves Way, Sawcliffe Industrial Park, Scunthorpe, North Lincolnshire, DN15 8RF, United Kingdom; 44-1724-273200; Fax: 44-1724-280353; sales@dem-uk.com; www.dem-uk.com/roxburgh

**Roxtec**
10127 East Admiral Place, Tulsa, OK 74116 USA; 918-254-9872; 800-520-4769; Fax: 918-254-2544; info@us.roxtec.com; www.roxtec.com

**RTP Company**
580 East Front Street, P.O. Box 5439, Winona, MN 55987 USA; 507-454-6900; 800-433-4787; Fax: 507-454-2041; rtp@rtpcompany.com; www.rtpcompany.com

**Rubbercraft**
3701 Conant Street, Long Beach, CA 90808 USA; 562-354-2800; Fax: 562-354-2900; info@rubbercraft.com; www.rubbercraft.com

## S

**Sabritec**
17550 Gillette Avenue, Irvine, CA 92614 USA; 949-250-1244; Fax: 949-250-1009; www.sabritec.com

**SAE Power**
950 S Bascom Avenue, San Jose, CA 95128 USA; 408-808-6496; sales@saepower.com; www.saepower.com

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71 Perinton Parkway, Fairport, NY 14450 USA; 888-772-3544; Fax: 585-385-1768; info@saelig.com; www.saelig.com

**Safe Engineering Services & Technologies**
3055 Boulevard Des Oiseaux, Laval, Quebec H7L 6E8, Canada; 800-668-3737; 450-622-5000; Fax: 450-622-5053; info@sestech.com; www.sestech.com

**Safety Test Technology Co., Ltd**
Pu Tian Science Park B415, 28 Xin Jie Kou Wai Da Jie, Xicheng District, Beijing, 100088 P.R. China; 86-10-51654077; www.instrument.com.cn

**Saint-Gobain Performance Plastics**
7301 Orangewood Avenue, Garden Grove, CA 92841 USA; 1-800-833-5661; Fax: 1-714-688-2701; http://www.plastics.saint-gobain.com/Default.aspx

**SAS Industries, Inc.**
939 Wading River Manor Road, Manorville, NY 11949 USA; 631-727-1441; Fax: 631-727-1387; info@sasindustries.com; www.sasindustries.com

**Schaffner EMC, Inc.**
52 Mayfield Avenue, Edison, NJ 08837 USA; 800-367-5566; 732-225-9533; Fax: 732-225-4789; usasales@schaffner.com; www.schaffnerusa.com

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| AZ Southwest Systems Technology | 602-437-5030 |
| CA Admor Technical Sales | 760-522-4140 |
| CA Automation Industrial Sales | 909-864-8251 |
| CA Brill Electronics | 510-834-5888 |
| CA Conquest Technical Sales | 805-241-5118 |
| CA Master Distributors | 502-568-8888 |
| CA O'Donnell Associates North | 408-456-2950 |
| CA Online Components | 310-452-8516 |
| CO Arrow Electronics | 800-833-3557 |
| CO Walker Components | 800-825-8585 |
| FL Electronic Components and Equipment | 305-638-2000 |
| FL Sunland Associates | 407-365-9533 |
| IL Brainard-Nielsen Marketing | 847-734-8400 |
| IL Newark | 800-463-9275 |
| IL Revere Electric | 312-738-3636 |
| MA Sager Electronics | 800-724-3780 |
| MA Norris Associates Inc | 781-749-5088 |
| MD Phoenix Sales and Marketing, Inc | 410-247-8505 |
| MN Digi-Key | 218-681-6674 |
| MN, Grissinger-Johnson Sales | 763-544-5451 |
| MN Rockford Controls of Minnesota | 763-557-2801 |
| MN Werner Electric | 651-458-3701 |
| MO Connector Technology LLC | 636-561-3543 |
| NC Aurora-Tech Marketing | 800-995-1970 |
| NJ Industrial Components & Engineering, LLC | 609-371-5950 |
| NJ State Electronics | 800-631-8083 |
| NJ Synergy Sales | 732-751-1700 |
| NY Equiptex Industrial Products Corp. | 800-352-5090 |
| NY Masline Electronics | 585-546-5373 |
| NY Net Sales Inc. | 585-924-1844 |
| NY Powertech Controls | 631-368-6678 |
| OH Allied Enterprises, Inc | 440-808-8760 |
| OR Globale, Inc | 503-590-2325 |
| PA Rumsey Electric Supply Co. | 610-832-9000 |
| PA Colrud Lowery | 610-338-0606 |
| PA, Cusick Electrical Sales, Inc. | 215-659-6666 |
| TX Allied Electronics | 800-433-5700 |
| TX Kruvand | 972-437-3355 |
| TX Mouser Electronics | 817-804-3888 |
| TX Smith Power Systems, Inc. | 972-690-1500 |
| WA WESCO Sales Group, Inc | 425-941-6681 |
| WI, Bunell and Associates | 262-784-0994 |
| WI Revere Electric | 262-369-7100 |
| WI Taylor Industrial Electronics | 262-241-4321 |
| WI Werner Electric | 920-729-4500 |
| INTERNATIONAL | |
| BRA Arrow Brazil | 55-11-3613-9300 |
| BRA Farnell-Newark | 55-11-4066-9400 |
| BRA LC Overdata Representação e Comércio Exterior Ltda. | 55-11-2842-6842 |
| CAN E-Cubed Components Inc | 905-791-0812 |
| CAN Powerco Canada, Inc | 403-252-2444 |
| CHI Conecta S.A. | 56-2-669-79-13 |
| MEX Kuvand de Mexico | 01152-33-3671-4159 |

**Schlegel Electronic Materials**
1600 Lexington Avenue, Rochester, NY 14606 USA; 1-585-643-2000; Fax: 1-585-427-7216; schlegelemi.na@schlegelemi.com; www.schlegelemi.com

SCHURTER
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**Schurter, Inc.**
447 Aviation Boulevard, Santa Rosa, CA 95403 USA; 707-636-3000; Fax: 707-636-3033; info@schurterinc.com; www.schurterinc.com

**SDP Engineering Inc.**
17 Spectrum Pointe #508, Lake Forest, CA 92630 USA; 949-588-7568; Fax: 949-588-8871; www.sdpengineering.com

**Seal Science**
Seal Science West: 17131 Daimler Street, Irvine, CA 92614 USA; 949-253-3130; Fax: 949-253-3141; westernsales@sealscience.com; Seal Science East: 1160 Win Drive, Bethlehem, PA 18017; 610-868-2800; Fax: 610-868-2144; easternsales@sealscience.com; www.sealscience.com

**Sealcon**
14853 East Hinsdale Avenue, Centennial, CO 80112 USA; 800-456-9012; 303-699-1135; Fax: 303-680-5344; info@sealconusa.com; www.sealconusa.com

**Sealing Devices Inc.**
4400 Walden Avenue, Lancaster, NY 14228 USA; 716-684-7600; 800-727-3257; Fax: 716-684-0760; www.sealingdevices.com

**Seibersdorf Laboratories**
Forschungszentrum, 244 Seibersdorf, Austria; -43-50550-2500; Fax: 43-50550-2502; office@seibersdorf-laboratories.at; www.seibersdorf-laboratories.at

**Select Fabricators Inc.**
5310 North Street Bldg. 5, P.O. Box 119, Canandaigua, NY 14424 USA; 585-393-0650; 888-599-6113; Fax: 585-393-1378; www.select-fabricators.com

**Sensor Products Inc.**
300 Madison Avenue, Madison, NJ 07940 USA; 973-884-1755; 800-755-2201; Fax: 973-884-1699; sales@sensorprod.com; www.sensorprod.com

**Seven Mountains Scientific, Inc. (ENR)**
913 Tressler Street, P.O. Box 650, Boalsburg, PA 16827 USA; 814-466-6559; Fax: 814-466-2777; www.7ms.com

**SGS**
1 Place des Alpes, P.O. Box 2152, Geneva 1211, Switzerland; 41-22-739-91-11; Fax: 41-22-739-98-86; www.ee.sgs.com

**Shieldex Trading**
4502 Route31, Palmyra, NY 14522 USA; 315-597-1674; Fax: 315-597-6687;whoge@rochester.rr.com; www.shieldextrading.net

**Shielding Resources Group, Inc.**
9512 East 55th Street, Tulsa, OK 74145; 918-663-1985; 888-895-3435; Fax: 918-663-1986; www.shieldingresources.com

**Siemic Laboratories**
775 Montague Expressway, Milpitas, CA 95035 USA; 408-526-1188; Fax: 408-526-1088; www.SIEMIC.com

**Silicon Labs**
400 West Cesar Chavez Street, Austin, TX 78701 USA; 512-416-8500; 877-44-3032; Fax: 512-416-9669; susan.nayak@silabs.com; www.silabs.com

**Silicone Solutions**
1670-C Enterprise Parkway, Twinsburg, OH 44087 USA; 330-920-3125; Fax: 330-920-3126; www.siliconesolutions.com

**SILENT Solutions**
10 Northern Boulevard, Suite 1, Amherst, NH 03031 USA; 603-578-1842; Fax: 603-578-1843; Lee Hill, LHill@silent-solutions.com; www.silent-solutions.com

**Simberian Inc.**
3030 S. Torrey Pines Drive, Las Vegas, NV 89146 USA; 401-627-7706; Fax: 702-482-7903; info@simberian.com; www.simberian.com

**SiTime Corp.**
990 Almanor Avenue, Sunnyvale, CA 94085 USA; 408-328-4400; Fax: 408-328-4439; info@sitime.com; www.sitime.com

**Solar Electronics Co.**
10866 Chandler Boulevard, North Hollywood, CA 91601 USA; 818-755-1700; 800-952-5302; Fax: 818-755-0078; sales@solar-emc.com; www.solar-emc.com

**Soliani EMC SRL**
Via Varesina 122, 22100 Como, Italy; 39-031-5001112; Fax: 39-031-505467; info@solianiemc.com; www.solianiemc.com

**Sonnet Software, Inc.**
100 Elwood Davis Road, North Syracuse, NY 13212 USA; 315-453-3096; Fax: 315-451-1694; info@sonnetsoftware.com; www.sonnetsoftware.com

**Soshin Electric Co., Ltd.**
No. 3-13-16 Mita, Minato-ku, Tokyo 108-8322, Japan; 81-3-5730-4500; Fax: 81-3-5730-4504; oversea@soshin.co.jp; www.soshin-ele.com

**Southwest Microwave, Inc.**
9055 S. McKemy Street, Tempe, AZ 85284 USA; 480-783-0201; Fax: 480-783-0360; www.southwestmicrowave.com

**Southwest Research Institute**
6220 Culebra Road, P.O. Drawer 28510, San Antonio, TX 78228 USA; 210-684-5111; www.swri.com

**Source1 Solutions**
4675 Burr Drive, Liverpool, NY 13088 USA; 315-730-5667; Fax: 315-457-0428; Steve Frierson, sf@source1compliance.com; www.source1compliance.com

**Souriau PA&E**
434 Old Station Road, Wenatchee, WA 98801 USA; 855-285-5200; Fax: 509-663-5039; sales@pacaero.com; www.pacaero.com

**SPAWAR Systems Center Atlantic**
P.O. Box 190022, North Charleston, SC 29419 USA; 843-218-4000; 843-218-3390; www.public.navy.mil/spawar/Atlantic/Pages/AboutUs.aspx

**Spec-Hardened Systems**
119 Larkwood Drive, Rochester, NY 14626 USA; 585-225-2857; Fax: 585-225-2857; Anthony A. DiBiase, shsesc@aol.com

**Specialty Silicone Products**
Corporate Technology Park, 3 McCrea Hill Road, Ballston Spa, NY 12020 USA; 518-885-8826; 800-437-1442; Fax: 518-885-4682; www.sspinc.com

**Spira Manufacturing Corp.**
12721 Saticoy Street South, North Hollywood, CA 91605 USA; 818-764-8222; Fax: 818-764-9880; sales@spira-emi.com; www.spira-emi.com
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Electronic Marketing Associates, Inc. ....................888-942-1555
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JPN Kitigawa Industries Co., Ltd. .............011-81-587-34-3761

**Sprinkler Innovations**
95 Ledge Road, Suite 4, Seabrook, NH 03874 USA; 800-850-6692; Fax: 603-468-1031; Jim Beers, jbeers@sprinklerinnovations.com; www.sprinklerinnovations.com

**Spitzenberger & Spies GmbH & Co. KG**
Schmidstraße 32, 94234 Viechtach, Germany; 49-9942-956-0; info@spitzenberger.de; www.spitzenberger.de

**SRICO, Inc.**
2724 Sawbury Boulevard, Columbus, OH 43235 USA; 614-799-0664; Fax: 614-799-2116; sri@srico.com; www.srico.com

**Stahlin Enclosures**
500 Maple Street, Belding, MI 48809 USA; 616-794-0700; Fax: 616-764-3378; www.stahlin.com

**Stephen Halperin & Associates, Ltd.**
1072 Tower Lane, Bensenville, IL 60106 USA; 630-238-8883; Fax: 630-238-9717; info@halperinassoc.com; www.halperinassoc.com

**Stockwell Elastomerics, Inc.**
4749 Tolbut Street, Philadelphia, PA 19136 USA; 215-335-3005; Fax: 215-335-9433; service@stockwell.com; www.stockwell.com

**Storm EMC Services Ltd.**
14 Willersey Road, Cheltenham, Gloucestershire GL51 6NN, United Kingdom; 0117-230-3627; enquiry@stormemc.co.uk; www.stormemc.co.uk

**Sulzer Metco Inc.**
Zürcherstrasse 12, 8401 Winterthur, Switzerland; 41-52-262-11-22; Fax: 41-52-262-01-01; www.sulzer.com/en/About-us/Our-Businesses/Sulzer-Metco

**Sunkyoung S.T.**
Hwaseong-Si Gyeonggi-Do, Jangan-myeon Suchon-ri, Korea; 031-351-8171; Fax: 031-351-8174; www.sunkyoungst.com

**Sunol Sciences Corp.**
6780 Sierra Court, Suite R, Dublin, CA 94568 USA; 925-833-9936; Fax: 925-833-9059; emc@sunolsciemces.com; www.sunolsciences.com

**Suppression Devices**
Unit 8, York Street Business Centre, Clitheroe, Lancashire BB7 2DL, UK; 44-1200-444497; Fax: 44-1200-444330; sales@suppression-devices.com; www.suppression-devices.com

**Suzhou 3CTEST Electronic Co., Ltd.**
Unit 2, Anda Industrial Park, No.198 Jinshan Rd, SND, Suzhou 215011, China; 86-512- 66389987; 86-512-68077661; Fax: 86-512- 66384886; emitest@188.com; www.3ctest.cn

**Swift Textile Metalizing LLC**
23 Britton Drive, P.O. Box 66, Bloomfield, CT 06002 USA; 860-243-1122; Fax: 860-243-0848; sales@swift-textile.com; www.swift-textile.com

**Syfer Technology Ltd.**
Old Stoke Road, Arminghall, Norwich, Norfolk, NR14 8SQ, United Kingdom; 44-1603-723300; 44-1603-723310; Fax: -44-1603-723301; sales@syfer.co.uk; www.syfer.com

**Synergistic Technology Group, Inc.**
2490 North Buttercup Drive Tucson, AZ 85749 USA; 520-760-0291

**Syscom Advanced Materials**
1275 Kinnear Road Columbus OH 43212 USA; 614-487-3626; Fax: 614-487-3631; www.metalcladfibers.com

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**Tapecon, Inc.**
701 Seneca Street, Suite 255, Buffalo, NY 14210 USA; 716-854-1322; 800-333-2407; Fax: 716-854-1320; www.tapecon.com

**Taiyo Yuden (U.S.A.) Inc.**
10 North Martingale Road, Suite 575, Schaumburg, IL 60173 USA; 800-348-2496; 630-237-2405; Fax: 847-240-1715; www.t-yuden.com

**TDK Corp.**
475 Half Day Road, Lincolnshire, IL 60069 USA; 847-699-2299; Fax: 847-803-6296; www.tdk.com

**TDK-EPC Corp.**
485B Route 1 South, Suite 200, Iselin, NJ 08830 USA; 732-906-4300; Fax: 732-906-4395; sales.usa@epcos.com; www.epcos.com

**TDK-Lambda Americas**
3055 Del Sol Boulevard, San Diego, CA 92154 USA; 619-575-4400; 800-526-2324; Fax: 619-429-1011; us.tdk-lambda.com/lp/

**TDK RF Solutions, Inc.**
1101 Cypress Creek Road, Cedar Park, TX 78613 USA; 512-258-9478; 800-254-9478; Fax: 512-258-0740; info@tdkrf.com; www.tdkrfsolutions.com

**Tech-Etch, Inc.**
45 Aldrin Road, Plymouth, MA 02360 USA; 508-747-0300; Fax: 508-746-9639; websales@tech-etch.com; www.tech-etch.com
AK Tech-Etch, Inc. ...........................................................508-747-0300
AL Cornerstone Sales, LLC..........................................256-430-8000
AR Centramark...............................................................972-414-8188
AZ Moss Marketing .............. ....................................602-828-1461
CA Motion Components ..........................................714-255-1080
CA Ross Marketing ..................................................650-691-0119
CO Moss Marketing ................................................800-980-8812
CT Brandon Associates, Inc.................................... 610-738-8500
DE Brandon Associates, Inc.................................... 610-738-8500
DC Eastern Tech Corp. ............................................. 410-715-2100
FL Cornerstone Sales, LLC ...................... ................ 321-765-4862
FL Cornerstone Sales, LLC ...................................... 727-789-4802
GA Cornerstone Sales, LLC ................ ...................770-638-8998

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| HI | Tech-Etch, Inc. | 508-747-0300 |
| ID | Technical Marketing Inc. | 509-991-5664 |
| IL | EMT Engineering Sales | 847-481-7403 |
| IN | Frederic Ohmer & Associates | 937-434-1454 |
| IN | Midtec Associates, Inc. | 913-541-0505 |
| KS | Midtec Associates, Inc. | 913-541-0505 |
| KY | Frederic Ohmer & Associates | 937-434-1454 |
| LA | Centramark | 713-771-1500 |
| MA | Connors Co., Inc. | 508-866-5392 |
| MD | Eastern Tech Corp. | 410-715-2100 |
| ME | Connors Co.. Inc. | 508-747-0300 |
| MI | Frederic Ohmer & Associates | 937-434-1454 |
| MN | EMT Engineering Sales. | 952-888-1020 |
| MO | Midtec Associates, Inc. | 314 839-3600 |
| MS | Tech-Etch, Inc. | 508-747-0300 |
| MT | Technical Marketing Inc | 509-991-5664 |
| NE | Midtec Associates, Inc | 913-541-0505 |
| NC | Cornerstone Sales, LLC | 919-834-2677 |
| ND | EMT Engineering Sales | 952-888-1020 |
| NH | Connors Co., Inc. | 508-866-5392 |
| NJ | Brandon Associates, Inc. | 610-738-8500 |
| NM | Moss Marketing | 800-980-8812 |
| NV | Ross Marketing Associates | 650-691-0119 |
| NY | Brandon Associates, Inc. | 610-738-8500 |
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| NY | Brandon Associates, Inc. | 610-738-8500 |
| OH | Frederic Ohmer & Assoc | 937-434-1454 |
| OK | Centramark | 972-414-8188 |
| OR | Technical Marketing, Inc. | 503-627-9000 |
| PA | Brandon Associates, Inc. | 610-738-8500 |
| RI | Connors Co, Inc. | 508-866-5392 |
| SC | Cornerstone Sales, LLC | 919-834-2677 |
| SD | EMT Engineering Sales | 952-888-1020 |
| TN | Cornerstone Sales, LLC. | 770-638-8998 |
| TN | AL Cornerstone Sales, LLC | 256-430-8000 |
| TX | Centramark | 817-498-5818 |
| TX | Centramark | 972-414-8188 |
| TX | Centramark | 512-795-0966 |
| TX | Centramark | 713-771-1500 |
| UT | Moss Marketing | 801-947-0169 |
| VA | Eastern Tech Corp | 410-715-2100 |
| VT | Connors Co., Inc. | 508-866-5392 |
| WA | Technical Marketing, Inc. . | 425-739-4600 |
| WA | Technical Marketing, Inc. | 509-481-5715 |
| WI | Mequon, EMT Engineering Sales. | 262-236-4001 |
| WV | Tech-Etch, Inc. | 508-747-0300 |
| WY | Moss Marketing | 800-980-8812 |
| INTERNATIONAL | | |
| BEL | HF Technology | 3175-6283717 |
| CAN | The ID Group Inc. | 514-575-8044 |
| CHN | Mindar China Co. Ltd. | 8610-64680338 |
| DNK | Bomberg EMC Products | 454-814-0155 |
| FRA | Yelloz Components | 330164466968 |
| GBR | TBA Electro Conductive Products | 441706-647718 |
| GER | Feuerherdt GmbH | 49-30-710-96-45-53 |
| ISR | Maham Fasteners | 972 3 9626516 |
| ITA | Sirces SRL Italy | 390-255-231395 |
| JPN | Taiyo Wire Cloth Co. | 81-334-937051 |
| NOR | EG Components | 472-325-4600 |
| KOR | Eretec Inc | 82-31-436-1100 |
| SGP | Glocom Marketing PTE, Ltd. | 65-6873-0933 |
| TPE | TennMax, Inc. | 886-2269-54137 |
| RSA | Actum Electronics | 27-11-608-3001 |

**Telcron LLC**
Harleysville, PA 19438 USA; 310-492-5035: info@telcron.net; www.telcron.net

**Teledyne Reynolds**
Navigation House, Canal View Road, Newbury, Berkshire, RG14 5UR, United Kingdom; 44-1635-262-262; Fax: 44-1635-521936; trlsales@teledyne.com; www.teledynereynolds.co.uk

**Temas Engineering**
Via Milano 72, 22070 Bregano CO, Italy; 39-031-772348; Fax: 39-031-773897; info@temas.it; www.temas.it

**TEMPEST Inc.**
11654 Plaza America Drive, P.O. Box #134, Reston, VA 20190 USA; 703-836-7378; info-2013@tempest-inc.com; www.tempest-inc.com

**Tempest Security Systems Inc.**
2855 Kensington Court, Troy, OH 45373 USA; 937-335-5600; Fax: 937-335-0018; info@tempestusa.com; www.tempestusa.com

**TESEO**
Corso Alexander Fleming, 25/27/29, 10040 Druento, Torino, Italia; 39-011-9941-911; Fax: 39-011-9941-900; info@teseo.net; www.teseo.net



**Teseq**
52 Mayfield Avenue, Edison, NJ 08837 USA; 732-417-0501; 888-417-0501; Fax: 732-417-0511; www.teseq.com

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| AL | Testrack | 239-691-6117 |
| AK | TESEQ | 888-417-0501 x239 |
| AR | Kemp Instrument | 469-233-7288 |
| AZ | Aztec Enterprizes | 480-858-9511 |
| CA | Comply Tek | 858-674-6155 |
| | TechDream | 408-800-7362 |
| CT | Scientific Devices | 508-528-2458 |
| CO | Azetec Enterprizes | 800-304-3565 |
| DC T | Technical Representatives, Inc. | 703-675-6723 |
| DE | Technical Representatives, Inc. | 609-313-3045 |
| FL T | Testrack | 941-720-0673 |
| GA | Testrack | 704-905-8628 |
| HI | TESEQ | 978-764-7358 |
| IA | Test Midwest East | 314-246-0360 |
| | Test Midwest West | 816-866-0360 |
| ID | PSI Solutions | 503-233-8100 |
| IL | Test Midwest North | 262-521-3056 |
| | Test Midwest Central | 847-282-0360 |
| | Test Midwest South | 314-246-0360 |
| IN | Micro Sales | 614-792-9117 |
| KS | Test Midwest | 816-866-0360 |
| KY | Micro Sales | 614-792-9117 |
| LA | Kemp Instruments | 469-233-7288 |
| MA | Scientific Devices | 508-528-2458 |
| MD | Technical Representatives, Inc. | 703-675-6723 |
| ME | Scientific Devices | 603-672-1198 |
| MI | Micro Sales | 614-792-9117 |
| MN | Test Midwest | 612-460-0360 |
| MO | Test Midwest East | 314-246-0360 |
| | Test Midwest West | 816-866-0360 |
| MS | Testrack | 239-691-6117 |
| MT | PSI Solutions | 253-838-9263 |
| NC | Testrack | 704-905-8628 |
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| NE | Test Midwest | 816-866-0360 |
| NH | Scientific Devices | 508-528-2458 |
| NJ | Contech Marketing | 732-634-5501 |
| NM | Aztec Enterprizes | 800-304-3565 |
| NV | TechDream | 408-800-7362 |
| | Comply Tek | 858-674-6155 |
| NY | Contech Marketing | 732-634-5501 |
| | L-MAR Associates | 585- 899-3920 |
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| OR | PSI Solutions | 503-233-8100 |
| PA | Micro Sales | 614-792-9117 |
| | Contech Marketing | 732-634-5501 |
| RI | Scientific Devices | 508-528-2458 |
| SC | Testrack | 704-905-8628 |
| SD | Test Midwest | 612-460-0360 |
| TN | Testrack | 704-905-8628 |
| TX | Kemp Instruments | 469-233-7288 |
| UT | Aztec Enterprizes | 435-649-1510 |
| VT | Scientific Devices | 508-528-2458 |
| VA | Technical Representatives, Inc. | 703-965-4150 |
| WA | PSI Solutions | 253-838-9263 |
| WV | Technical Representatives, Inc. | 703-965-4150 |
| WI | Test Midwest | 262-521-3056 |
| WY | Atzec Enterprizes | 801-546-9570 |
| INTERNATIONAL | | |
| AUS | Westek Electronics Pty. Ltd | 61-3-9369-8802 |
| BRA | Campinas; EMCert Consultoria | 19-3243-9371 |
| CAN | Montreal; Testforce | 514-856-0970 |
| IND | Rohde & Schwarz India Pvt. Ltd. | 91-11-4254-5422 |
| MEX | TESEQ | 888-417-0501 x239 |
| POL | Astat Sp. Z o.o. | 48-61-849-80-61 |
| RUS | St. Petersburg; ZAO NFP Dipaul Ltd. | 7-812-325-1478 |

**Test & Measurement Australia Pty Ltd.**
P.O. Box 197, Blaxland, NSW 2774 Australia; 612-47399523; Fax: 612-47399524; sjb@TandM.com.au; www.TandM.com.au

**Test Equipment Connection**
30 Skyline Drive, Lake Mary, FL 32746 USA; 407-804-1299; 800-615-8378; Fax: 800-819-8378; sales@testequipment-connection.com; www.testequipmentconnection.com

**Test Site Services**
30 Birch Street, Milford, MA 01757 USA; 508-634-3444; Fax: 508-634-0388; lab@testsiteservices.com; testsite-services.com

**Texas Spectrum Electronics**
120 Regency Drive, Wylie, TX 75098 USA; 972-296-3699; Fax: 972-296-7881; sales@texasspectrum.com; www.texasspectrum.com

**The Compliance Management Group**
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