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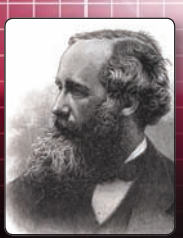
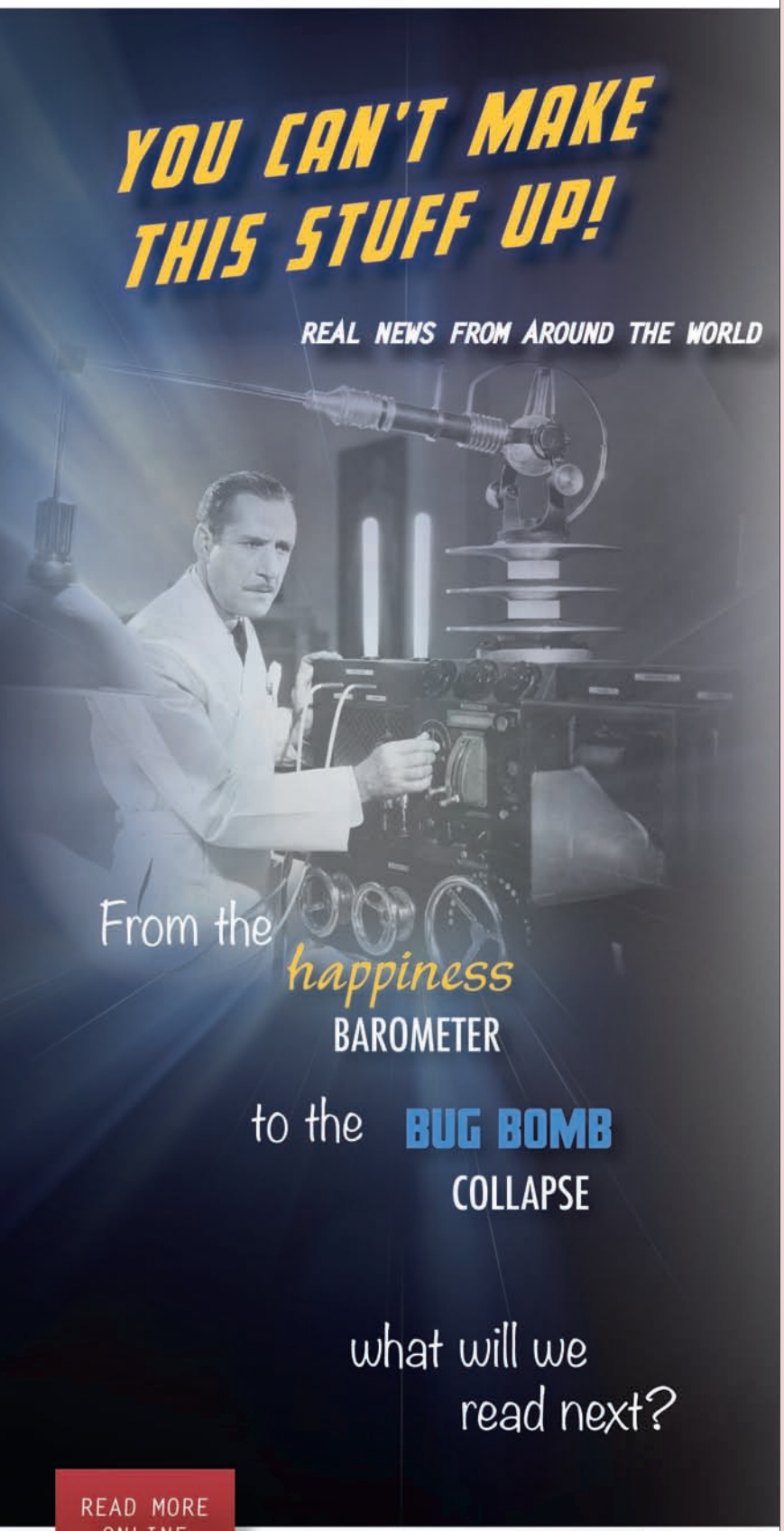


Celebrating the 150th Anniversary of Maxwell's Equations

Reality Engineering: On Maxwell, The Natural Philosopher

Maxwell's Theory of the Electromagnetic Field



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IN COMPLIANCE

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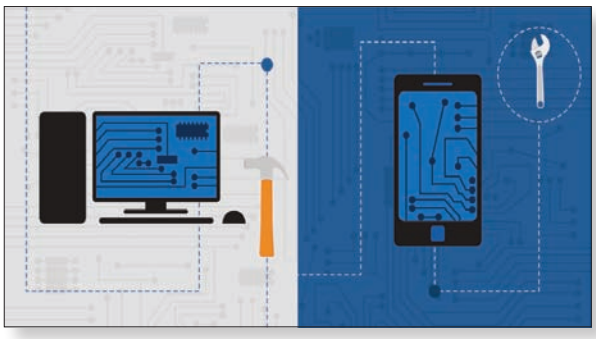

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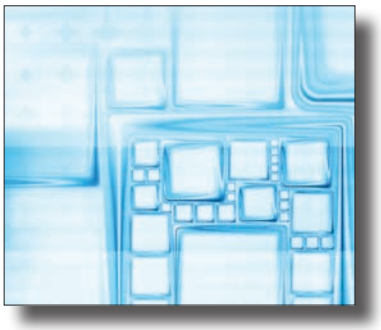

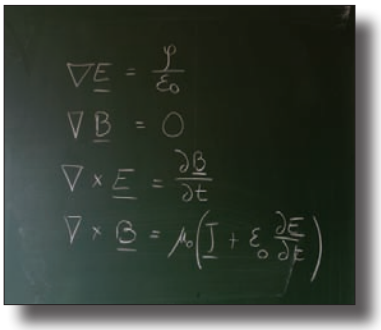

Join us for this 3-Day Intensive Course

presented by renowned EMC expert Henry Ott

Electromagnetic Compatibility Engineering

a course in noise and interference control in electronic systems

September 23-25, 2014 | Sheraton Baltimore North | Baltimore, M

In this 3-day intensive course we'll cover practical aspects of noise and interference control in electronic systems and provide a working knowledge of EMC principles. Ideas are illustrated with examples of actual case histories and mathematic complexity is kept to a minimum. Participants will gain knowledge needed to design electronic equipment compatible with the electromagnetic environment and in compliance with national and international EMC regulations.

COURSE CONTENT

CABLING
Electric and magnetic field coupling, crosstalk. Cable types: coax, twisted pair and ribbon cables. Cable shielding and terminations.

GROUNDING PRINCIPLES
Why do we ground? Ground systems: single point, multipoint, hybrid. Ground loops. Return current paths, split reference planes. EMC grounding philosophy. AC power grounds.

DIGITAL LAYOUT & GROUNDING
Noise sources, PCB layout, power distribution, ground grids, characteristics of ground planes. Decoupling capacitors: value, placement, resonance and limitations.

HIGH SPEED DIGITAL DECOUPLING
Alternative decoupling methods, use of distributed decoupling capacitance, power supply isolation, effect of paralleling capacitors. Embedded PCB capacitance.

DIFFERENTIAL-MODE EMISSION
Radiated emission mechanisms. Fourier spectrum. Methods of controlling differential-mode emission. Clock dithering. Cancellation techniques.

COMMON-MODE FILTERING
Basic C-M filter theory. Filter source and load impedances. Single and multi-stage filters. Ferrite chokes versus shunt capacitors. Effectiveness of various filter configurations. Filter mounting and layout.

TRANSMISSION LINES
What is a transmission line? Transmission-line effects, transmission-line radiation, and matching. How currents flow on transmission lines. Series, shunt and AC terminations. Simulation.

MIXED SIGNAL PCBs
Defining the problem, A/D converter requirements, return current paths, split ground planes, PCB partitioning, bridges & moats, routing discipline.

RF & TRANSIENT IMMUNITY
RF immunity: circuits affected, PCB layout, audio rectification, RFI filters. Transient immunity: circuits affected, the three-prong approach, keeping transient energy out, protecting the sensitive devices, designing software/firmware for transient immunity.

CONDUCTED EMISSION
AC power line conducted emission models, switching power supplies, parasitic capacitance, layout. Common-mode and differential-mode conducted emission, common-mode chokes, saturation. Power line filters.

SHIELDING
Absorption and reflection loss. Seams, joints, gaskets, slot antennas, and multiple apertures. Waveguides below cutoff, conductive coatings. Cabinet and enclosure design.

Presented by Henry Ott Consultants
in partnership with
IN COMPLIANCE

Who Should Attend

This course is directed toward electrical engineers. However, mechanical engineers, reliability and standards engineers, technical managers, systems engineers, regulatory compliance engineers, technicians and others who need a working knowledge of electromagnetic compatibility engineering principles will also benefit from the course.

EMC EXHIBITS AND EVENING RECEPTION: WEDNESDAY, SEPTEMBER 24, 2014

Exhibitors:for information contact Sharon Smith
e-mail: sharon.smith@incompliancemag.com or call (978) 873-7722

Henry W. Ott is President and Principal Consultant of Henry Ott Consultants, an EMC training and consulting organization. He has literally "written the book" on the subject of EMC and is considered by many to be the nation's leading EMC educator. He is the author of the popular EMC book Noise Reduction Techniques in Electronic Systems (1976, 1988).

The book has sold over 65,000 copies and has been translated into six other languages. In addition to knowing his subject, Mr. Ott has the rare ability to communicate that knowledge to others. Mr. Ott's newly published (Aug. 2009) 872-page book, Electromagnetic Compatibility Engineering, is the most comprehensive book available on EMC. While still retaining the core information that made Noise Reduction Techniques an international success, this new book contains over 600 pages of new and revised material.

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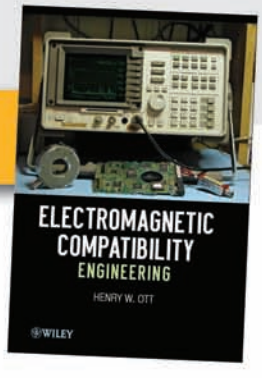


*Electromagnetic Compatibility Engineering, by Henry W. Ott

REGISTRATION

COURSE DATES/TIME: September 23-25, 2014
Tuesday and Thursday 8:30 a.m. to 4:30 p.m.
Wednesday 8:30 a.m. to 5:00 p.m.

COURSE LOCATION: Sheraton Baltimore North
903 Dulaney Valley Road | Towson, Maryland 21204

COURSE FEE: $1,495 ($1,295 until 8/15/2014). Fee includes notes, textbook*, breakfast, luncheon and beverage breaks. Payment required prior to course. Hotel accommodations are NOT included.

CANCELLATION POLICY: You may cancel your registration up to two weeks prior to the course and receive a full refund. For cancellations received after this time there will be a $100 cancellation fee, or you can send a substitute, or use the registration for a future course. No-shows will not receive a refund; however the seminar fee may be applied to a future course.

TO REGISTER: Call 973-992-1793, fax 973-533-1442

HOTEL RESERVATIONS: Call the Sheraton Baltimore North at 1-888-627-7147 or 1-410-321-7400. Room rates start at $139 per night (tax not included). Book by August 29th to receive this rate. Rate is based on availability. You must mention HOC EMC Seminar when making reservations to get this special rate. The hotel is holding a limited block of rooms.

News in Compliance

FCC News

Online Retailer Assessed $35 Million for Selling Signal Jammers

The U.S. Federal Communications Commission (FCC) has proposed a monetary forfeiture of $34.9 million against a Chinese online retailer for allegedly marketing signal jamming devices to U.S. consumers.

In a Notice of Apparent Liability for Forfeiture issued in June 2014, the FCC has charged C.T.S. Technology Company, Limited for marketing and selling 285 different models of signal jammers through its online retail portal for more than two years. The marketing of such devices in the U.S. is illegal under FCC regulations, since they can interfere with emergency communications. However, C.T.S. allegedly informed consumers on its website that certain signal jammer models were approved by the FCC. The FCC says that C.T.S. also sold 10 high-powered signal jammers to undercover FCC personnel. The nearly $35 million fine is the largest ever proposed by the FCC.

In addition to the proposed fine, the FCC has ordered C.T.S. to cease marketing signal jammers to U.S. consumers, and to provide the FCC with information about persons or entities in the U.S. that may have purchased the illegal devices.

The complete text of the Commission's Notice of Apparent Liability in connection with C.T.S. Technology is available at incompliancemag.com/news/1408_01.

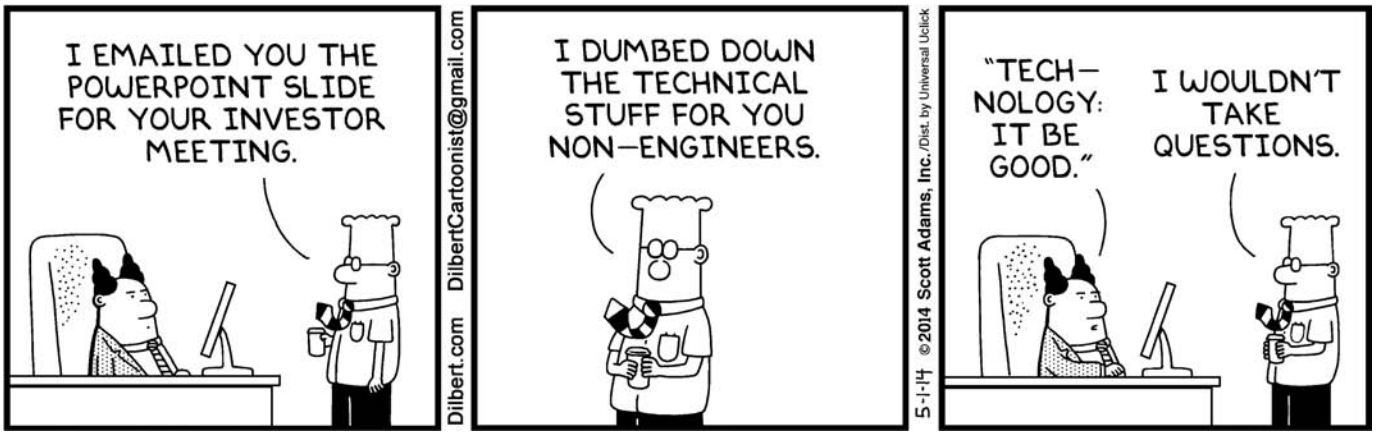
Sony Pays $400k for HAC Violations

The U.S. Federal Communications Commission (FCC) has entered into a settlement agreement with Sony Mobile Corporation in connection with the company's failure to offer consumers the required number of hearing aid-compatible (HAC) digital wireless handset models.

In a Consent Decree issued in June 2014, Sony agreed to make a voluntary contribution to the U.S. Treasury in the amount of $400,000 for its failure to consistently offer a sufficient number of HAC handsets during the 2011-2012 mandated reporting period. According to Sony, the company erroneously assumed that compliance with the FCC's HAC handset requirements was measured on an annual basis, and not on a month-to-month basis as required by the FCC, and that it failed to offer a sufficient number of HAC handsets for 11 of the 12 months of the reporting period.

In addition to the voluntary contribution, Sony also agreed to appoint a senior corporate officer to oversee compliance with the FCC's HAC requirements, and to develop and implement a company-wide compliance plan, including a compliance manual and compliance training for employees.

The complete text of the FCC's Consent Decree with Sony is available at incompliancemag.com/news/1408_02.



u • nique [yōō-nēk′]

adjective
being the only one of its kind; unlike anything else:

[predic] (unique to) belonging or connected to (one particular person, group, place or thing)

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News in Compliance

FCC News

Commission Proposes Fines for Unlicensed Radio Transmissions

The U.S. Federal Communications Commission (FCC) continues to enforce its regulations against the operations of unlicensed radio transmitters that can potentially interfere with licensed radio operations and public safety communications.

In June 2014, the FCC issued Forfeiture Orders in two separate cases involving unlicensed radio operations. In the first instance, the Commission fined Damian Anthony Ojouku Allen of Ft. Lauderdale, FL $25,000 for operating a pirate radio station, self-identified as "NGR Online Radio." Allen failed to respond to a Notice of Apparent Liability issued by the FCC in March 2014.

In the second instance, Walter Olenick and M. Rae Nadler-Olenick were fined $15,000 by the Commission for operating an unlicensed FM radio station in Austin, TX. The Olenicks did not deny operating an unlicensed radio station but claimed that their operation was not subject to the jurisdiction of the Commission, a claim denied by the Commission.

In a separate matter, the Commission has issued a Notice of Apparent Liability against Marc-Nus Charles for allegedly operating an unlicensed radio station in Pompano Beach, FL. The unlicensed operation was identified by agents based in the Miami Office of the Commission's Enforcement Bureau, who took field strength signals of the station transmission on multiple days in June 2013.

Charles has had previous run-ins with the FCC over unlicensed radio operations. He was issued a written warning from the FCC in 2009 connected with a separate unlicensed operation in Pompano Beach, which ultimately resulted in the confiscation of his radio equipment.

Company To Pay $80k for Selling Unauthorized Electronic Equipment

The U.S. Federal Communications Commission (FCC) has entered into a settlement agreement with a German-based retailer of digital devices for failing to obtain FCC authorization for various cameras and wireless accessories prior to marketing them in the U.S.

In a Consent Decree issued in June 2014, the company, ARRI, based in Munich, Germany, agreed to make a voluntary contribution of $80,000 to the U.S. Treasury for the marketing of radio frequency devices without FCC authorization. A 2013 investigation by the Commission's Spectrum Enforcement Division determined that certain wireless accessories marketed by ARRI to consumers in the U.S. had not been properly tested prior to marketing.

In addition to the voluntary contribution, ARRI also agreed to appoint a senior corporate officer to oversee compliance with FCC regulations, and to develop and implement a compliance plan, including a compliance manual and compliance training for employees.

The complete text of the Commission's Consent Decree with ARRI is available at incompliancemag.com/news/1408_03.

Commission Investigates T-Mobile for Cramming Complaints

The U.S. Federal Communications Commission (FCC) has announced plans to investigate consumer complaints of widespread cramming practices by mobile phone carrier T-Mobile.

In a press release issued in early July 2014, the Commission notes that T-Mobile may have illegally billed customers millions of dollars for unauthorized third-party subscriptions and premium text messaging services, a practice known as cramming. The FCC is reportedly coordinating its investigation with the U.S. Federal Trade Commission (FTC), which has separately initiated its own legal action against T-Mobile from placing unauthorized charges on the mobile phone bills of consumers.

The federal Communications Act prohibits carriers for billing subscribers for services without authorization, or for changing a subscriber's selection of

telephone service providers without permission (referred to as slamming). In the past few months alone, the Commission has proposed fines of $5.2 million and $3.5 million for slamming and cramming activities in separate cases involving two Nevada telephone companies.

FCC Releases Report on Internet Access Services

The U.S. Federal Communications Commission (FCC) has released its most recent report on access in the United States to fixed and mobile Internet connections, including information on the gap between current service levels and the benchmark Internet connection speeds recommended under the Commission's National Broadband Plan.

According to the Commission's report, entitled *Internet Access Services: Status as of June 30, 2013*, nearly 75% of fixed Internet connections to households meet or exceed the speed tier that most closely approximates the target set in the National Broadband Plan of 3 megabits per second (Mbps) downstream and 768 kilobits per second (kbps) upstream. This penetration rate for fixed high-speed service compares with 70% at the end of 2012, and just 49% in 2009.

At the same time, high-speed Internet access (defined at 3 Mbps downstream or greater) for subscribers of mobile wireless service continues to grow. As of June 2013, more than 51% of mobile subscribers had access to high-speed service, compared with just 38% as of December 2012.

Without accounting for speed, Internet connections overall are growing. By the end of June 2013, there were 276 million Internet connections offering access at speeds of at least 200 kpbs, a 5% increase in just 6 months. Overall growth continues to be driven by dramatic increases in mobile connections. At the end of June 2013, there were 181 million mobile Internet connections, more than double the number of connections at the end of June 2012, and representing more than half of the total number of Internet connections.

The complete text of the Commission's latest report on Internet access is available at incompliancemag.com/news/1408_04.

News in Compliance

European Union News

EU Commission Updates Standards List for Toy Safety Directive

The Commission of the European Union (EU) has published an updated list of standards that can be used to demonstrate conformity with the essential requirements of its directive relating to the safety of toys (88/378/EEC).

According to the Directive, a toy is defined as "any product or material designed or clearly intended for use in play by children of less than 14 years of age." The scope of the Directive includes electric toys that are powered by a nominal voltage up to and including 24 V, and requires sufficient protections for such devices to prevent the risk of electric shock and/or burns.

The most recently updated list of CEN standards for the Directive was published in June 2014 in the *Official Journal of the European Union*, and replaces all previously published standards lists for the Directive.

The revised list of standards can be viewed at incompliancemag.com/news/1408_05.

EU's New Radio Equipment Directive to Replace R&TTE Directive

In an effort to update and consolidate requirements for radio equipment and to eliminate overlap with other directives, the EU Commission has released a new directive intended to cover all products that utilize the radio frequency spectrum.

In an effort to update and consolidate requirements for radio equipment and to eliminate overlap with other directives, the EU Commission has released a new directive intended to replace the EU's Directive 1999/5/EC covering radio equipment and telecommunications terminal equipment (the so-called R&TTE Directive).

Published in May 2014 in the *Official Journal of the European Union*, the new Radio Equipment Directive (2014/53/EU) is intended to replace the EU's Directive 1999/5/EC covering radio equipment and telecommunications terminal equipment (the so-called R&TTE Directive).

According to the EU Commission, the new Directive has been aligned with the EU's new legislative framework for products in an effort to provide a more consistent application of requirements. New requirements include:

- More specific requirements regarding the efficient use of the radio spectrum
- More clearly defined obligations for manufacturers, importers and distributors
- More stringent traceability requirements to improve market surveillance
- In some cases, prior notification requirements for radio equipment categories characterized by low levels of compliance

The requirements under the new Radio Equipment Directive will come into full effect in June 2016. In the interim, EU member states will be required to take the necessary steps to transpose the Directive's essential requirements into their respective national laws.

The complete text of the EU's new Radio Equipment Directive is available at incompliancemag.com/news/1408_06.

FDA News

Infusion Pump Manufacturer Announces Corrective Action

Hospira, Inc. of Lake Forest, IL has issued an urgent correction notice in connection with a docking station used with the company's GemStar infusion pumps.

In a press release issued by the company and posted on the website of the U.S. Food and Drug Administration (FDA), attaching the docking station to the GemStar infusion pump may result in the failure of the infusion pump to properly power up, or cause the pump to display an error code indicating excessive input voltage from external sources, thereby halting pump infusion activity.

According to Hospira, users should turn on the pump before connecting it with the docking station, and remove the external battery pack accessory from the docking station and pump prior to installing the pump into the docking station. The company is not issuing a product recall at this time.

Hospira says that it released its correction notice following customer reports regarding the pump failures.

The full text of the Hospira notice in connection with its GemStar Docking Station is available at incompliancemag.com/news/1408_07.

News in Compliance

CPSC News

Emergency Lights Recalled Due to Fire Hazard

Lithonia Lighting has announced the recall of approximately 1.7 million units of its Quantum-brand two-light emergency light fixtures. The fixtures were manufactured in Mexico and imported into the U.S. by Acuity Brands Lighting of Conyers, GA.

According to a recall notice issued by Lithonia and posted on the website of the U.S. Consumer Product Safety Commission (CPSC), the circuit board in the light fixture can overheat and cause the fixture to melt, catch fire and ignited nearby items, thereby posing fire and burn hazards to consumers. Lithonia says that it has received 29 separate reports of circuit boards overheating and fixtures melting or catching fire. In one incident, a resulting fire caused more than $100,000 in property damage. However, there have been no reports of injuries.

The recalled emergency light fixtures were sold through electrical distributors, and at The Home Depot, W.W. Granger stores and other retailers nationwide, as well as online at grainger.com and amazon.com from March 2010 through February 2014 for between $35 and $55.

Further details about this recall are available at incompliancemag.com/news/1408_08.

Nokia Recalls Travel Chargers

Nokia, Inc. of Sunnyvale, CA is recalling about 500 travel charger kits manufactured in China and designed for use with its Nokia Lumia 2520 tablet computers.

According to a recall notices issued by the company and posted on the website of the U.S. Consumer Product Safety Commission (CPSC), the plastic cover on the charger's exchangeable plugs can come loose and separate, thereby exposing internal electrical components that could pose an electrocution hazard to consumers when the plug in placed in a live electrical outlet. Nokia reports that it has not received any reports of incidents or injuries related to the recalled charger kits, but has initiated the recall to prevent such incidents in the future.

The recalled travel charger kits were sold at AT&T and Verizon Wireless-authorized dealers and retailers nationwide, as well as online at att.com and verizaon.com, from January 2014 through May 2014 for about $50.

More information about this recall is available at incompliancemag.com/news/1408_09.

You Can't Make This Stuff Up

Burglar Traced with Facebook Account

A preoccupation with Facebook has apparently led to the arrest of Minnesota man on charges of second degree burglary.

According to the Reuters News Service, the man, 26 year-old Nicholas Wig, allegedly broke into a home in a South Saint Paul neighborhood, taking with him an iPod Shuffle and a watch, along with cash, credit cards and a checkbook. However, the alleged thief was not in too much of a rush, since he apparently had enough time to log into his Facebook account on a computer located in the home.

Returning after the thief departed, the home's resident found his front door unlocked and a screen removed from a side window, and his home in disarray. He also found the thief's Facebook profile open on his computer. The resident later recognized the thief on a nearby street based on his Facebook picture, and alerted the police.

Wig faces felony charges in connection with the burglary, which carries up to a $20,000 fine and up to 10 years in prison.

CPSC News

Company Expands Recall of PERS Transmitters

Linear LLC of Carlsbad, CA has expanded the recall of its personal emergency reporting system (PERS) transmitters manufactured in China to include an additional 175,000 units.

According to the company, the battery clips in the transmitters can corrode, causing the transmitters to operate intermittently or not at all, thereby failing to generate a warning when appropriate. Linear says that it has received one report of a transmitter that failed to operate, but has not received any reports of injuries.

The recalled transmitters were sold through independent PERS distributors and dealers nationwide from June 2008 through July 2011 for about $45.

This is the second recall issued by Linear in connection with its PERS transmitters. The company previously recalled about 48,000 units in December 2013.

Additional information about this recall is available at incompliancemag.com/news/1408_10.

Power Production Routers Recalled

Black & Decker U.S., Inc. of Towson, MD, doing business as Porter-Cable, is recalling about 100,000 fixed based power routers and router bases manufactured in Mexico.

According to the company, the router base handles attached to the unit are not insulated, thereby posing a risk of electric shock to users. In a recall notice issued Porter-Cable and posted on the website of the U.S. Consumer Product Safety Commission (CPSC), there have been no reports of incidents or injuries related to the routers.

The recalled routers were sold through major industrial equipment suppliers and woodworker suppliers nationwide from 1990 until April 2014 for about $85 to $690, depending on the specific model.

This recall also includes approximately 7800 router units sold in Canada.

More details about this recall are available at incompliancemag.com/news/1408_11.

REALITY Engineering

On Maxwell, The Natural Philosopher

The 150th Anniversary of Maxwell's Equations

BY MIKE VIOLETTE

James Clerk Maxwell was a man of prodigious and singular gifts, of insight, curiosity and determination. The equations, developed one hundred and fifty years ago, describe the link between the classical and quantum worlds of physics.

We gather in Raleigh this month to speak grounding, waves, signals, crosstalk, electrical burps, hiccoughs, and groans. As a tribute to the man whose equations have both inspired innovations and struck great fear in the hearts of undergrads around the world, we present this tribute to one of the greatest of Natural Philosphers, James Clerk Maxwell.

James, or "Jamsie" as he was known to his family, was born in 1831 in Edinburgh Scotland. He was a precocious young man, and, after the death of his mother, he was sent to study at the Edinburgh Academy where his gifts were soon to blossom.

James was a country kid, observant and curious, and pursued many activities that were spurred by his natural inquisitiveness. Although he was brutally teased when he entered Edinburgh Academy for his odd vestments, square peasant-like shoes, and funny Galloway accent (he was christened "Dafty" by his schoolmates) he dove intensely into his studies, a broad mix of mathematics and philosophy. He mastered Greek and received the epitome of a classical education.

One of his friend's mother summed him up thus: "His manners are very peculiar; but having good sense, sterling worth, and good humour, the intercourse with a college will rub off his oddities."

John Maxwell, James' father, who remained close to him for his entire life, realized that he had a boy with a particular way to see the world. He advocated for him and James' first paper was published at the young age of fourteen, a treatise on the mathematics of curves and lines, ellipsoids and multi-foci shapes. His work improved on the work of the great French philosopher and mathematician from the seventeenth century, Rene Descartes, generalizing the behavior of lines.

No lesser man than William Thompson, who would later become Lord Kelvin, recognized James' gifts as well.

James' natural inquisitiveness gave him an intense desire to explore, create and discover. A pivotal part of his genius was to visualize the phenomena he was investigating, using geometric models which gave rise to the equations that described the behavior of heat, gasses, optics and, his ultimate contribution, the theory of electromagnetic fields.

At Edinburgh, James developed fast friendships with two great minds, P.G. Tait and Lewis Campbell, both of whom would rise in academia and remain life-long friends.

James was an inveterate tinkerer and experimenter and once wrote: "I never try to dissuade a man from trying an experiment, if he does not find what he wants he may find out something else." That is a value that every great discoverer holds. Truly grounded in

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REALITY Engineering

Reality, his theoretical mastery of mathematics and ability to visualize physical phenomena were singularly prescient.

"In the mid-nineteenth century, the word 'scientist' had not yet come into common use. Physicists and chemists called themselves 'natural philosophers' and biologists called themselves 'natural historians'… science was a splendid hobby for a gentleman but a poor profession." (Mahon, p31).

A man who touched nearly every corner of natural philosophy (the study of nature), James reconciled the properties of light, heat and radiation was a link in the chain that brought Sir Isaac Newton to Albert Einstein who noted that "One scientific epoch ended and another began with James Clerk Maxwell."

What was remarkable about discovery in the 1800s was the capability of the innovators of the day to link disparate physical phenomena. James both solved the equations that dictate the movement of the rings of Saturn (validated by spacecraft 100 years later) as well as made discoveries about the nature or color (making the first color photograph in the process).

For electromagnetics, James' approach was one of the first to employ the concept of a 'field' of energy. This notion ran counter to ideas of Weber and Reimann that preferred to describe the effects of 'action at a distance.' In James' view, the reductio ad absurdum conclusion of that line of reasoning would lead to the development of perpetual motion machines and the violation of the conservation of energy.

In 1864, James published A Dynamical Theory of the Electromagnetic Field and presented it to the Royal Society in December of that year. "Most of his contemporaries were bemused. It was almost as if Einstein had opposed out of a time machine to tell them about general relativity; they simply did not know what to make of it." (Mahon, p. 100) James' approach was so novel, many of his colleagues at the time never understood this new way to describe a fundamental behavior of nature.

In addition, James was a man of moral conscience. He advocated for, and provided teaching to various "Working Men's Colleges" bringing education to the common man, supporting these institutions in Cambridge Aberdeen.

James died in Edinburgh at the age of 48 on November 5, 1879 of stomach cancer, cutting short what would have been years of further exploration of the natural world and support for education and the conquest of the unknown.

It would be a scant 8 years until Heinrich Hertz proved that radio waves followed the behavior predicted by Maxwell.

The rise of age of Wireless thus began. IN

REFERENCE

Mahon, Basil. 2003. *The Man Who Changed Everything.* West Sussex, England: John Wiley & Sons.

(the author)

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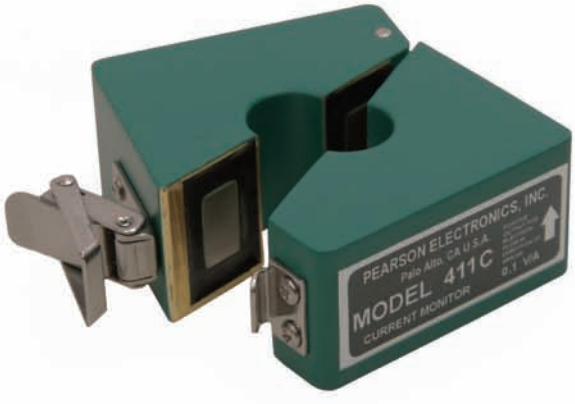

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TECHNICALLY Speaking

Thermocouples and Temperature Measurement

Product Safety Newsletter - January/February 1989

BY RICHARD NUTE

Dear Readers,
Over the past couple of years many of you have requested that we include more product safety related information in our issues. Of particular interest has been Rich Nute's series of "Technically Speaking" articles. And so… Mr. Nute has graciously agreed to work with us to bring you that series! Look for his column each month. We hope you enjoy the addition of "Technically Speaking" to the pages of In Compliance.

One of our members suggested I write about thermocouples and temperature measurement. Textbooks have been written on this subject; I can only give a broad overview of the subject. Since temperature meaurement is indigenous to every safety evaluation, perhaps I can demystify some of the rules applied by the various certification houses.

Disregarding accessible hot parts, why do we measure temperatures, and how do we decide what parts should be measured? What is the hazard that is prevented, controlled or limited as a result of measuring temperatures within electronic equipment? Why do we measure temperature rise rather than absolute temperature?

Why do we use thermocouples rather than other temperature measuring devices? And, how do thermocouples work?

THERMOCOUPLE THEORY

Let's tackle this last question first. According to ANSI MC96-1, a thermocouple is "two dissimilar thermoelements so joined as to produce a thermal emf when the measuring and reference junctions are at different temperatures."

This definition has three critical concepts in it: "thermoelements," "thermal emf," and "junction." The most critical concept is that of "thermal emf."

In 1821, Thomas Johann Seebeck discovered that, in a closed circuit made up of two dissimilar metals (thermoelements), electric current will flow if the temperature of one junction is elevated above that of the other. This phenomenon is known as the "Seebeck effect." See Figure 1. The "circuit" comprises a thermocouple. All dissimilar metals exhibit this effect.

Note that every wire has two ends. When connected into a circuit, every wire has two junctions, one at each end of the wire. Where a junction involves dissimilar metals, the wires become thermoelements. Where both junctions involve dissimilar metals, the system becomes a thermocouple where one junction is the "measuring junction," and the other end is the "reference junction."

Each thermoelement junction generates a voltage (thermal emf), proportional to temperature. When the two thermoelement junctions are at the same temperature, the thermal emf's are equal, and there is no current in the circuit. When the temperature of one junction is higher or lower than the other junction, the ammeter will indicate a current which is proportional to the temperature difference between the two junctions and to the areas of the junctions.

(The tricky part of the system is to connect the meter in such a fashion as to neutralize the effect of nonmeasuring junctions of dissimilar metals. More about this later.)

Figure 2 is an equivalent circuit to Figure 1. Each junction can be represented by a battery and resistor in series. In Figure 2, thermal emf's Eland E2 are a function of the combination of different metals and proportional to the temperatures of the junctions. Resistances R1 and R2 are proportional to the area of the respective junctions.

In Figure 2, I is proportional to the temperature difference between Junction 1 and Junction 2. But I is also proportional to the values of R1 and R2. The values of R1 and R2 are proportional to the areas of the junctions, which are neither predictable nor repeatable. Therefore, while I is proportional to the temperature difference, it cannot be used to determine temperature difference unless the values of R1 and R2 are determined and accounted for.

We can eliminate the effects of R1 and R2 by replacing the ammeter with a voltmeter. See Figure 3. The voltmeter measures the voltage difference E + E1 - E2, between the two junctions. If we know the temperature of the ref-erence junction, then we can deter-mine the voltage E2 by looking up, in tables, the voltage that corresponds to the reference junc-tion temperature. Now, we can solve the equation E1 = E + E2. We now go back to the tables and look up E1 and its temperature, which is the measuring junction temperature.

If the reference junction temperature is at 0° C (in an ice bath), then, since the voltages in the tables are referenced to 0° C, E2 = 0, and E = E 1. Now, we can eliminate the summing step, and just read the temperature directly from the tables.

VOLTMETER JUNCTIONS

Now the question: How do we deal with the connection (junctions) of the iron wire to the copper wires of the meter? Recall two statements: First, all dissimilar metals exhibit the Seebeck effect. Thus, the connection from the iron wire to the two copper wires constitutes another thermocouple. Second, when two junctions are at the same temperature, the thermal emf s are equal, and there is no current in the circuit. So, we put the two iron-copper junctions on an isothermal block so that the temperature of one junction is the same as the temperature of the other junction. (See Figure 3.) Thus, the two additional junctions cancel out, and do not contribute to the measurement.

REFERENCE JUNCTION TEMPERATURE

The temperature of the reference junction needs to be determined. There are several ways to do this.

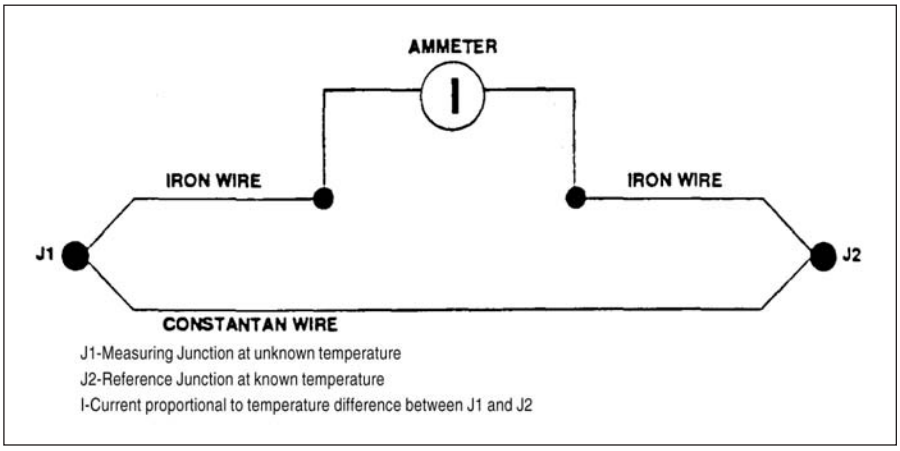

Figure 1: Seebeck effect

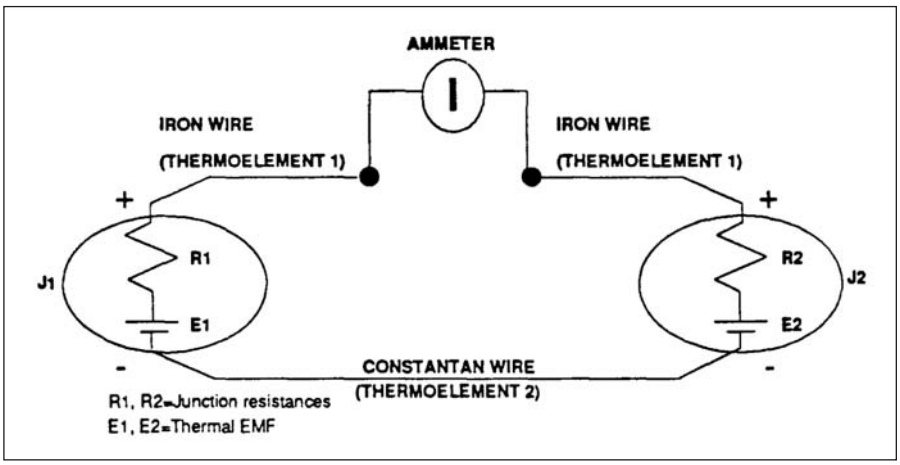

Figure 2: Equivalent circuit

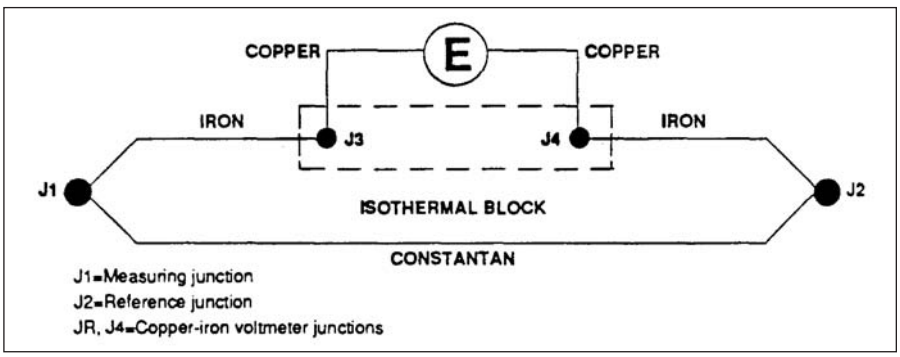

Figure 3: A practical thermocouple thermometer

TECHNICALLY Speaking

First, we can force the junction to a particular temperature. The most obvious is the ice bath. But this is cumbersome.

Or, second, we can put the refer-ence junction onto an isothermal block and measure the temperature of the block by some other means. This is commonly done with a thermistor.

Or, third, we can use a battery and thermistor circuit to generate the same voltage as if the reference thermocouple was at 0° C. This is the "electronic ice point."

In each case, and possible after some intermediary steps, the result is the voltage (proportional to the temperature) of the measuring junction. The next step is to convert the voltage to a temperature.

VOLTAGE-TO-TEMPERATURE CONVERSION

First, we can simply look up the voltage in a table, and read the corresponding temperature. This could be done either manually or with an electronic memory.

Or, we can calculate the temperature from an equation of the relationship between voltage and temperature.

Or, we can assume the voltage- to-temperature relationship is linear, measure voltage, employ a scale factor, and read out tempera-ture (with some inaccuracy).

(The voltage-to-temperature relationship of a thermocouple is not linear. The Type K thermocouple approaches linearity over a temperature range of 0 to 1000° C and is the thermocouple of choice for use with a scaling voltmeter.)

Fortunately, most modern-day thermocouple measuring equipment addresses all of these parameters so that we need not concern ourselves with meter junctions, isothermal blocks, reference junctions, reference junction tem-perature, voltage-to-temperature relationship, or nonlinearity. We need only apply the thermocouple or probe to the object and read temperature.

THERMOCOUPLE TYPES

There are many different thermocouple types, and the more common types have been standardized by letter designation and color coding of wires, connectors, and isothermal junction blocks. Certification houses have standardized on the Type J thermocouple because it is inexpensive and, therefore, popular and readily available, and it has a suitable temperature range.

Despite this standardization, mixups occur. A cup of ice water will not show a mixup of thermocouple types since, by convention, 0° C corresponds to 0 V for all thermocouple types. Instead, a cup of boiling water confirms whether the system is homogeneous and calibrated.

THERMOCOUPLES VS. OTHER THERMOMETERS

Why do we use thermocouples rather than other temperature-measuring devices? Certainly one of the reasons is that thermocouples have been around for a long time and are well-characterized in their performance. By standardizing on one particular system, thermocouples, one of the variables in temperature measurement is eliminated.

Thermocouples, in general for safety evaluation, have relatively low thermal mass compared to the part being measured. This is necessary because a thermocouple *always* takes heat away from the object being measured, and lowers the temperature by some amount. To minimize this error, we use the smallest thermocouple practicable for the particular measurement. CSA, for example, specifies No. 30 A WG thermocouple wire with a welded junction.

THERMOCOUPLE ATTACHMENT

The attachment of the thermocouple to the part to be measured is also critical to an accurate temperature measurement. The thermocouple junction must be in direct contact with the pan or material being measured. This means that, if epoxy cement is used to attach the thermocouple, there must be no cement between the thermocouple and the pan. Otherwise, there is a temperature gradient through the cement. The thermocouple will measure the temperature at its location within the epoxy which will, necessarily, be less than that of the pan being measured.

In some cases, the epoxy or other attachment means may act as a thermal insulator for the pan such that the temperature measured by the thermocouple is actually higher than the temperature without the epoxy or other attachment means.

The general rule is: use the least amount of material practicable for attaching the thermocouple to the pan.

HAZARDS

What is the hazard that is prevented, controlled, or limited as a result of measuring temperatures within electronic equipment? This is not at all intuitively obvious, nor is it obvious from a study of the various certification-house standards. We begin to get an idea of the hazard from the title of Clause 7.2 of IEC 348, "Safety Requiremerments for Electronic Measuring Apparatus." The title: Preservation of Insulation.

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TECHNICALLY Speaking

The principal objective of temperature measurement is to determine that all safety-related insulations are used within their temperature ratings. When this is accomplished, we can be assured that the insulation is not unduly stressed by the temperature imposed upon it, and that, therefore, it will be "preserved." A fundamental assumption is that if the insulation is used within its temperature rating, it is not likely to fail--- that is, it is preserved --- for its lifetime.

The hazard that is prevented is that hazard that would result from the failure of the particular insulation. Often, insulation failure results in conditions for electric shock. Insulation failure in electronic equipment may also result in electrically-caused fire.

MEASUREMENTS

Now we can begin to decide what pans should be measured. Obviously, we measure all safety-related insulations. This would include transformers, inductors in mains circuits, printed wiring boards, switch bodies, thermoplastic-insulated wires, etc.

But, in a transformer, we measure the wire temperature, not the insulation temperature. Why? The wire temperature heats the insulation, and since the wire is in intimate contact with the insulation, the wire temperature is the worst-case insulation temperature. And, most electrical insulators are also thermal insulators, so measuring the hottest spot on the insulation is difficult, if not impossible.

In some standards, we are required to measure semiconductor devices and resistors. Why do we measure these components since they are not a safety insulation? We do so because wire insulation could come in contact with the devices and be burned.

We also measure polymeric materials and capacitors. Polymeric materials are used as enclosures and structures. Here, too, the material must be "preserved" to retain its enclosing and structural functions; preservation is accomplished by using the material within its ratings.

Electrolytic capacitors are subject to explosion if the temperature is too high, so we measure their temperature. However, most of today's modem capacitors are provided with pressure relief mechanisms, but the requirement hangs on. X and Y capacitors are essentially across-the-line and line-to-ground insulations which must be used within their temperature ratings if the insulation is to be preserved.

TEMPERATURE RISE

Why do we measure temperature rise rather than absolute temperature? This is a difficult question based on the preceding discussion. In the preceding discussion I implied that each material, whether insulation, polymeric material, or electrolytic capacitor, will fail to perform its function at some absolute temperature. If our objective is to obviate failure by operating insulations, polymeric materials, electrolytic capacitors, etc., within their ratings, then we should be concerned with absolute temperatures.

The problem with absolute temperature is that if we should measure temperature in a 20° C environment, and someone else should measure temperature in a 25° C environment, then our measurements may show acceptable performance, while their measurements may show unacceptable performance. But, if we subtract the ambient temperature, we both will get very nearly the same number.

The temperature-rise limits specified in standards are conservative when compared to rated temperatures of insulations, etc. And, they assume that the ambient temperature will be in the neighborhood of 20 to 25° C. For example, a typical Class 105 insulation is allowed to rise 65° C. So, if ambient is 25° C, the absolute temperature is 90° C, comfortably below the 105° C rating.

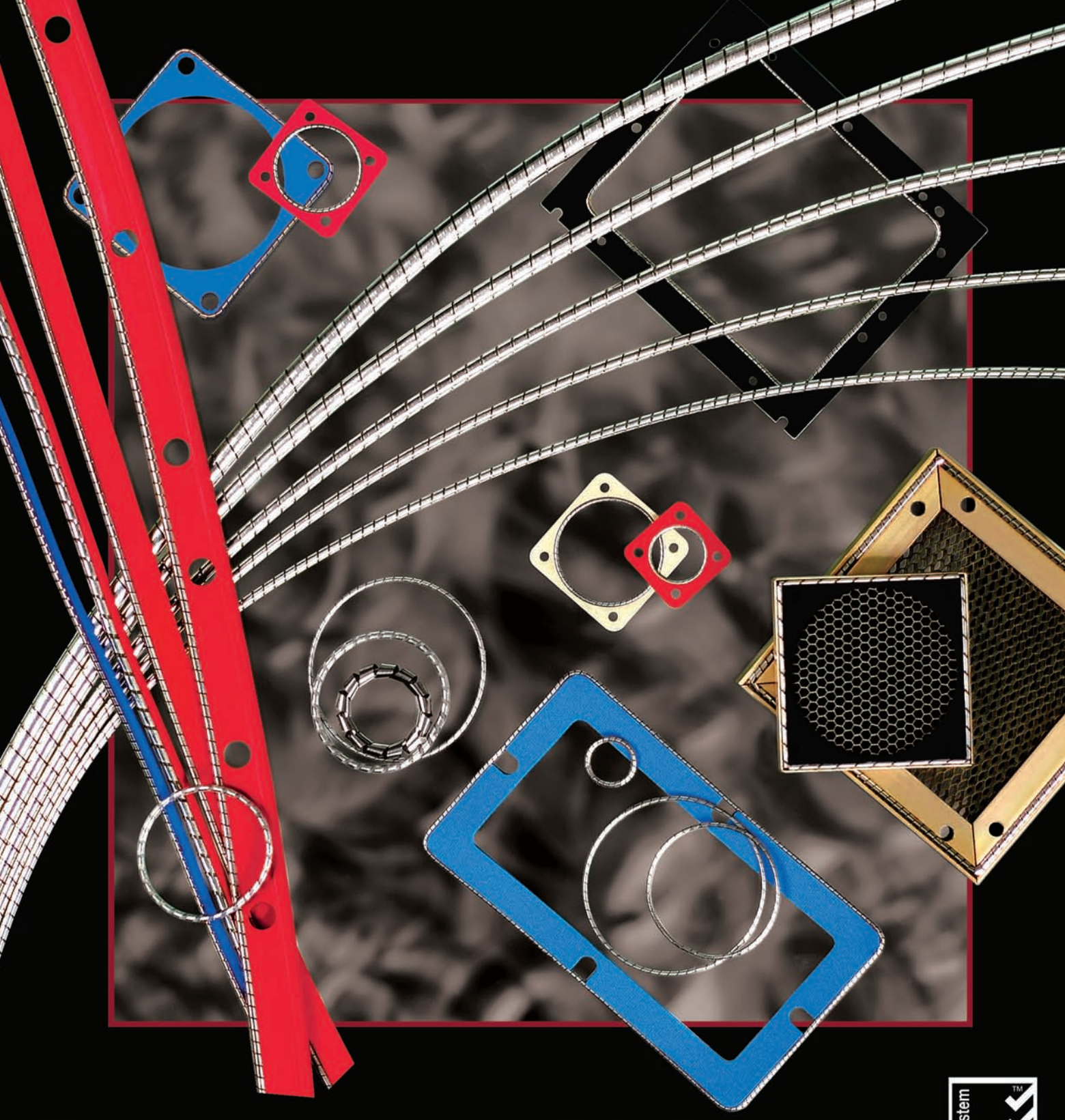
Temperature-rise measurements and limits are used for the purpose of standardizing measurements between parties when the ambient is not closely controlled.

Due to space limitations, I have covered only a limited number of details within this subject. My selection of subjects is based on my personal experiences (or, rather, problems) encountered in temperature measurement and the use of thermocouples. IN

(the author)

RICHARD NUTE
is a product safety consultant engaged in safety design, safety manufacturing, safety certification, safety standards, and forensic investigations. Mr. Nute holds a B.S. in Physical Science from California State Polytechnic University in San Luis Obispo, California. He studied in the MBA curriculum at University of Oregon. He is a former Certified Fire and Explosions Investigator.

Mr. Nute is a Life Senior Member of the IEEE, a charter member of the Product Safety Engineering Society (PSES), and a Director of the IEEE PSES Board of Directors. He was technical program chairman of the first 5 PSES annual Symposia and has been a technical presenter at every Symposium. Mr. Nute's goal as an IEEE PSES Director is to change the product safety environment from being standards-driven to being engineering-driven; to enable the engineering community to design and manufacture a safe product without having to use a product safety standard; to establish safety engineering as a required course within the electrical engineering curricula.



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MR. Static

Polarization

For Better or Worse

BY NIELS JONASSEN, sponsored by the ESD Association

In a previous article we discussed the phenomenon of induction, that is, the effect of an electric field on a conductor (see Mr. Static in the December 2013 issue). If a conductor is placed in an electric field, charges will move within the conductor until the interior field is zero. If the conductor is grounded, the free induced charge disappears. If the ground connection is broken and the conductor is removed from the field, the conductor will retain a net charge. It has been charged by induction.

INTRODUCTION

Associate Professor Neils Jonassen authored a bi-monthly static column that appeared in *Compliance Engineering Magazine*. The series explored charging, ionization, explosions, and other ESD related topics. The ESD Association, working with *In Compliance Magazine* is re-publishing this series as the articles offer timeless insight into the field of electrostatics.

Professor Jonassen was a member of the ESD Association from 1983-2006. He received the ESD Association *Outstanding Contribution Award* in 1989 and authored technical papers, books and technical reports. He is remembered for his contributions to the understanding of Electrostatic control, and in his memory we reprise "Mr. Static".

~ The ESD Association

Now suppose that the material placed in the electric field is an insulator. This being the case, the above processes cannot take place because of the absence of mobile charge carriers. But the field may disturb the otherwise symmetrical distribution of positive and negative charges in the molecular structure of the insulator. Where this slight relative shift of electrons and nuclei is created in an electric field we have an effect called polarization.

But before we begin explaining what polarization is, we should touch briefly upon what it means to compliance engineers and other electronics industry professionals. And its meaning is twofold. For polarization can be not only beneficial, making it possible to increase the capacitance of capacitors, but also detrimental, causing plateout to occur on all types of surfaces in an electric field, for instance on wafers in cleanrooms.

EXAMPLES

Figure 1 shows an atom in a field-free region. The time-mean distribution of the atom's charges is symmetrical, so that there is no external field. The atom is neutral. If an electric field E is applied (Figure 2), the symmetry

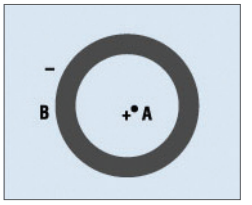


Figure 1: Atom in field-free region with nucleus (A) and symmetrical electron cloud (B).

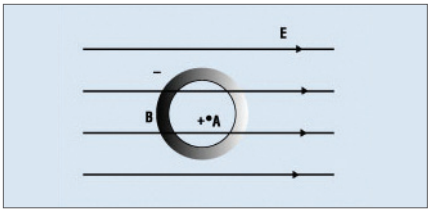


Figure 2: Atom in electric field (E) with nucleus (A) and asymmetrical electron cloud (B).

will be disturbed. The electrons, or rather the center of distribution of the electrons, will be displaced in the opposite direction of the field. For some materials, the nucleus may shift its position in the direction of the field.

The situation shown in Figure 2 may be represented by a negative charge and a positive charge separated by a distance dependent on the field strength Figure 3). This is called an electrical dipole, and such dipoles are formed throughout the insulator, hence the name polarization.

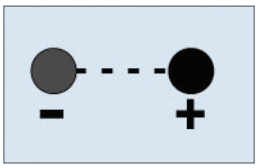


Figure 3: Electrical dipole.

An insulator in which dipoles may be formed is often called a dielectric. The dipoles line up end to end along the field lines. If the field is rectilinear, we can imagine a situation like the one shown in Figure 4. The internal positive and negative charges cancel each other, and the dipole string acts like one long dipole (Figure 5). So what will these polarization dipoles do to the field inside the dielectric? Let's answer this question in two steps.

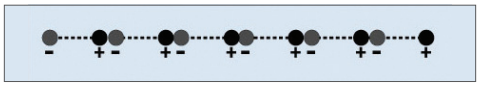


Figure 4: Dipole string.

Figure 5: Simplified dipole string.

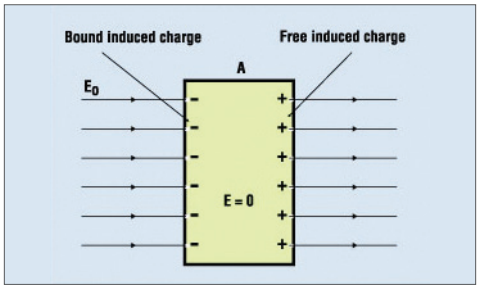


Figure 6: Conductor in electric field (induction).

A conductor "A" placed in an electric field with the strength E_0 is shown in Figure 6. The field binds (in this case) a negative charge on the left side (i.e., the bound induced charge) and frees an equally large positive charge on the right side (i.e., the free induced charge). Thus, the total field inside the conductor is zero. The free charge may be removed if the conductor is grounded. (An explanation of this situation was given in the article on induction in the December 2013 issue).

If, however, the body A is a dielectric, the situation is different (see Figure 7). The external field E_0 causes polarization, that is, it forms dipole strings. These strings will be stacked on top of each other, creating a dipole field E_p in the opposite direction of and superimposed on E_0.

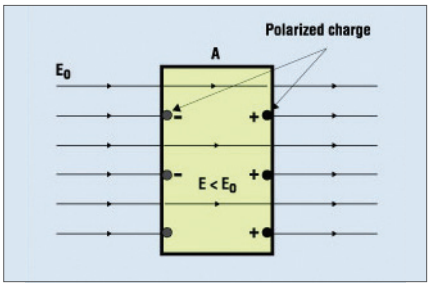


Figure 7: Dielectric in electric field (polarization).

MR. Static

The charges of the dipoles are called polarized charges. In contrast to induced charges, polarized charges cannot be removed from the dielectric.

The resulting field

$E = E_0 - E_p$

is smaller than E_0, and it turns out that

$$\frac{E_0}{E} = \varepsilon_r$$

is a constant characteristic for the dielectric in question. The value ε_r is called the relative permittivity or dielectric constant. Many commonly used dielectrics have ε_r values from 2 to 7. The charges of the dipoles are called polarized charges. In contrast to induced charges, polarized charges cannot be removed from the dielectric. The situation shown in Figure 7 is the simplest possible, with the external field being homogeneous and the field lines being perpendicular to the sides of the dielectric. If the field lines are not perpendicular to the sides of the dielectric, E_0 and E will not be parallel. In such a case, a "refraction" happens at the interface, and we have a parallel to Snell's law of optical refraction, where the optical refractive indices are substituted by the relative permittivities.

Let's consider two practical effects of polarization.

Effect on Capacitance. Figure 8a shows a parallel-plate capacitor connected to an electrometer. The assumption is that the capacitance of the electrometer is negligible compared with that of the parallel-plate capacitor. There is air (or vacuum) between the capacitor plates. The system is charged with a charge *q*, and a voltage V_v is displayed on the electrometer. When the space between the capacitor plates is filled with a dielectric (Figure 8b) the voltage drops to V_d. As previously explained, the field strength in the dielectric will be $\boldsymbol{\varepsilon}_r$ times smaller than it was in air, and because the voltage difference across the capacitor is the field strength times the plate spacing, *s*, we have the following:

$$\varepsilon_r = \frac{E_v}{E_d} = \frac{E_v \cdot s}{E_d \cdot s} = \frac{V_v}{V_d} .$$

And, since the charge *q* is the same in the two situations,

$C_d = \varepsilon_r \cdot C_v$.

The capacitance thus increased by the factor $\boldsymbol{\varepsilon}_r$ when the interspace was filled by the dielectric. Using a dielectric in a capacitor has another advantage—an increase in the breakdown voltage. This occurs because the breakdown field strength of a dielectric is usually considerably higher than that of air.

Polarization Plateout. Figure 9 shows an airborne, insulative (dielectric) particle P in an inhomogeneous field E. The field polarizes the particle. The positive and negative polarized charges have the same numerical value, but because the field strength is higher at the positive end than at the negative one, the positive force F_+ will be stronger than the negative force F_-. The result is a net force

$F = F_+ - F_-$

in the direction of increasing field strength. The uncharged particle tends to move in an inhomogeneous field and eventually lands or plates out on the first solid or liquid surface intersecting the field lines. (It should be noted that if the particle P is conductive, induction will make it behave in a similar way.)

Suppose we have a positively charged surface, for instance, a sheet of plastic. The sheet will obviously attract negatively charged, airborne particles and reject the positive ones, but what may be just as relevant is that it definitely will also make the neutral particles move, not necessarily toward the charged surface, but always in the direction of increasing field strength. An important example of this is the occurrence of static charges in cleanrooms. Although the air is clean, there are always some airborne particles around. For example, if a wafer carrier has a charge, it may cause, by polarization plateout, some of the particles to land on the wafer surface with very unwanted results, at worst a ruined wafer.

Let's finish this by looking at another well-known example of polarization plateout—the field in front of a monitor or TV screen. The field (created by the electrodes in the tube) is strongest

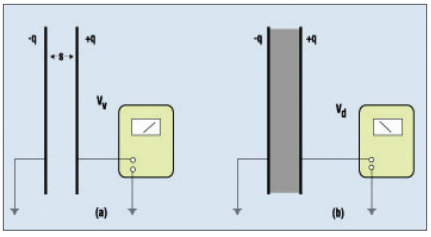


Figure 8: A parallel-plate capacitor connected to an electrometer.

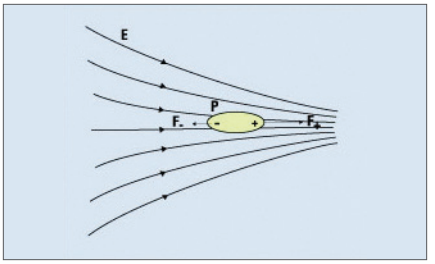


Figure 9: Polarization plateout.

Let's finish this by looking at another well-known example of polarization plateout—the field in front of a monitor or TV screen.

at the surface of the screen, so the particles plate out there.

Now if a viewer faces the front of the screen, he or she will be virtually at ground potential, so the field lines will converge toward his or her face, especially around the nose and chin, and possibly around the ears. These areas are now the primary sites of plateout. It has been demonstrated that the plateout rate of airborne particles to the viewer's face is much higher in the situation just discussed than when the viewer is in a field-free region. It has also been suggested that this effect could be the cause of skin diseases and other ailments contracted in the presence of airborne allergens. This claim, however, does not seem to have been scientifically proven.

CONCLUSION

The purpose of this article has been to give an idea of some of the basic features of the phenomenon of polarization. It should be stressed, however, that the presentation is far from complete. A thorough treatment would have resulted in a much longer paper with an exercise in atomic physics and higher mathematics that probably would have scared some readers away. IN

(the author)

NIELS JONASSEN, MSC, DSC, worked for 40 years at the Technical University of Denmark, where he conducted classes in electromagnetism, static and atmospheric electricity, airborne radioactivity, and indoor climate. After retiring, he divided his time among the laboratory, his home, and Thailand, writing on static electricity topics and pursuing cooking classes. Mr. Jonassen passed away in 2006.

EMC Education

The View from the Chalkboard

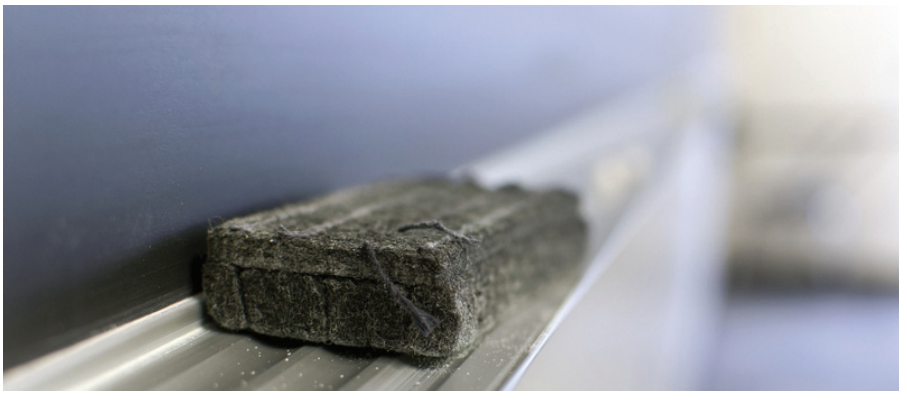
BY MARK STEFFKA

This month's "theme" I think can best be summarized as "Learning it by DOING it – a key aspect in EMC understanding."

Many times comments are heard that the "young people of today aren't willing to work". I can report that this is not always the case. For this installment of *The View from the Chalkboard*, we will hear from a young person that was willing to work and learn, and to make things better for students that follow her.

That person is Lisa Linna, who actually wanted to work and find out about this stuff called EMC.

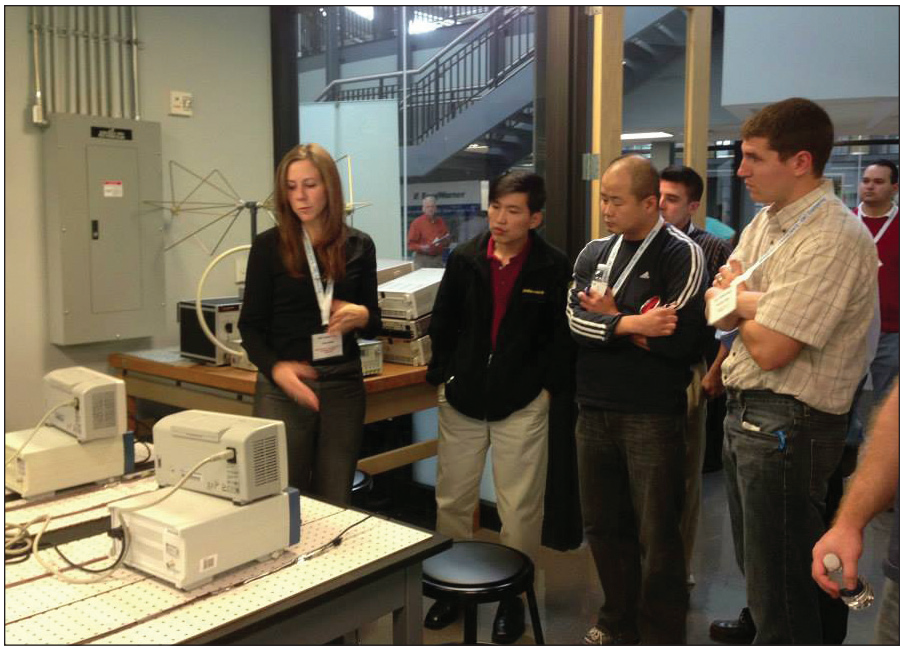
Lisa is a recent graduate with both her B.S. and M.S. degrees in electrical engineering. As a young person, she decided to go into engineering due to her interest in mathematics and physics, and then decided to take a graduate level EMC course after her father (who was a product design engineer) told her about the importance of EMC. She said this was intriguing to her that even though almost every electrical and/or electronic component or system has to at some point pass EMC requirements – there is actually very little knowledge about those requirements in the engineering discipline. Rather than just accepting that situation, Lisa decided to address this head-on, by not only learning herself, she also developed a *learning by doing* lab project to help others. Along the way – she discovered that this has opened new doors in her professional career (which is always a nice benefit). So with that – I am pleased to introduce Lisa's thoughts to you about what makes a valuable educational experience and how she helped design one.



BEYOND THE CLASSROOM

Lisa Linna

Structured education generally comes in two forms, traditional classroom learning, and then the hands on approach. In my personal experience, in order to fully grasp a subject, this combination is necessary. The difference between the two methods of education is highlighted in technical fields where topics can be quite complex and difficult for one to fully absorb based on a semester's worth of lectures, practice problems and exams. This is what led me to expand my education beyond the EMC course I completed at the University of Michigan, Dearborn, with Professor Mark Steffka. My goal was two-fold,

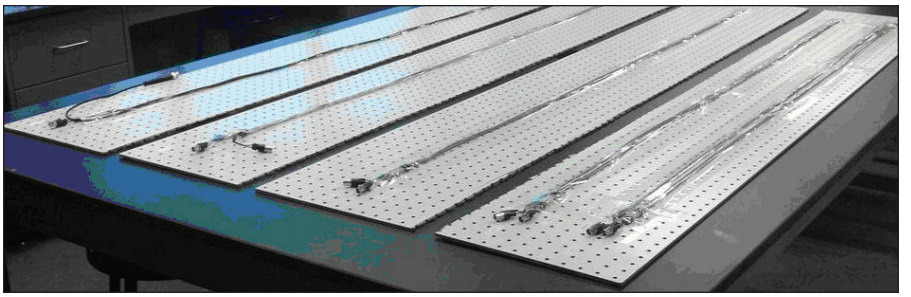


Lab demonstration

EMC Education

improve my understanding of EMC concepts, and also contribute to education of others by creating a lab which could demonstrate a complex topic on a basic level. Often times when we learn a subject only a portion is carried over into our professional life. In electrical engineering, EMC is one area that is of high priority for everyone in the field to have a basic understanding of. Therefore, we want to use labs as a way to impress core topics into the minds of students, so that it's not left at the end of the semester and tucked away in the back of their mind.

Following my graduate course in EMC, I wanted to continue my studies and was given the opportunity to contribute to the existing undergraduate laboratory run by another former student, Christopher Semanson. Crosstalk was chosen as my primary focus. This is a subject that affects all areas of electrical engineering from power communications and industrial controls, to electronic control unit PCB designs and integrated circuits. Cables and PCB traces have different aspects due to conductor dimensions and insulation, but essentially crosstalk affects these in the same manner. The lab was developed based on an experiment by Clayton R. Paul which was published in the IEEE EMC Educational Manual (revised July 1992). It explores the concepts of electro-magnetic fields and how they can create capacitive and inductive coupling between neighboring conductors. The concept of common mode (conductive) crosstalk is also included. A pre-lab lecture is given in order to reiterate the concept reviewed in class, which is then expected to be used by the students to explain their findings. Students rotate between 4 lab stations which show examples crosstalk with non-shielded pairs, twisted pair, coaxial cable and common mode wires with a shared ground. Measurements are taken at each station, across a range of frequencies. These measurements are then plotted and compared. As a result, students are able to see the affects that distance, twisting wires and shielding has on radiated crosstalk, as well as the interesting fact that shared "grounds" or supply lines can cause interference at any frequency!



Crosstalk configurations

In closing, I am also pleased to report that Lisa has discovered that this work has greatly enhanced her knowledge AND has opened new doors in her professional career (which is always a nice benefit). Hopefully Lisa's thoughts have helped in understating what makes a valuable educational experience and how she helped design one.

(the authors)

MARK STEFFKA, B.S.E., M.S.

is a Lecturer (at the University of Michigan – Dearborn), an Adjunct Professor (at the University of Detroit – Mercy) and an automotive company Electromagnetic Compatibility (EMC) Technical Specialist. His university experience includes teaching undergraduate, graduate, and professional development courses on EMC, antennas, and electronic communications. His extensive industry background consists of over 30 years' experience with military and aerospace communications, industrial electronics, and automotive systems.

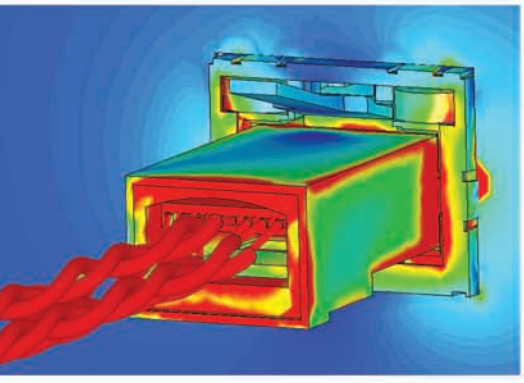
Mr. Steffka is the author and/or co-author of numerous technical papers and publications on EMC presented at various Institute of Electrical and Electronics Engineers (IEEE) and Society of Automotive Engineers (SAE) conferences. He has also written about and has been an invited conference speaker on topics related to effective methods in university engineering education. He is an IEEE member, has served as a technical session chair for SAE and IEEE conferences and has served as an IEEE EMC Society Distinguished Lecturer. He holds a radio communications license issued by the United States' Federal Communication Commission (FCC) and holds the call sign WW8MS. He may be reached at msteffka@umich.edu.

LISA LINNA

started her career as a controls engineer where she worked in automotive paint finishing industry at Durr Systems, Inc. Following this, she began her current position at Robert Bosch LLC in Plymouth, MI, where she works as a hardware engineer in the chassis controls division. She recently completed her M.S.E. in Electrical Engineering from the University of Michigan-Dearborn. As a result of this achievement, she is expanding her career to include training in EMC design and testing. She may be reached at lisa.linna@gmail.com.

Make the Connection

Find the simple way through complex EM systems with CST STUDIO SUITE



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2014 IEEE International Symposium on Electromagnetic Compatibility

Raleigh, North Carolina
August 4-8, 2014

Bruce Archambeault
EMC 2014 General Chair

Friends and Colleagues,

Are y'all ready for something a little different? This year we have a number of exciting new events planned! The embedded Signal and Power Integrity Conference has brought in a record number of technical papers in this very timely subject area. The renowned, Henry Ott will be presenting the Keynote Speech to discuss the evolution of EMC Engineering. We'll have a Special Event to honor those famous (infamous?) Maxwell's Equations. And of course, we'll have the high quality technical papers, workshops/tutorials and special sessions that you have come to expect over the years!

I would like to welcome you to the 2014 IEEE International Symposium on Electromagnetic Compatibility in Raleigh, North Carolina. I would also like to extend a welcome to the Eastern NC Section of the IEEE and to our local Electromagnetic Compatibility Society Chapter.

The Symposium Organizing Committee has planned and designed the 2014 EMC Symposium with the goal of ensuring the most enriching technical and professional networking opportunities possible through multiple exhibits, technical programs, companion programs, and social events. We have prepared three days of top-rated, peer-reviewed technical papers presented by experts in multi-track sessions and two days of practical workshops and tutorials, experiments and demonstrations presented by industry professionals. In addition to the number of regular sessions, special sessions and workshop/tutorial sessions on 'standard EMC' and Signal/Power Integrity, there will be papers on emerging wireless technology, nanotechnology, information security and many more topics! Also included are collateral industry meetings and a full exhibit hall to learn about the latest offerings in EMC products and services. Make sure to visit the booths of our new exhibitors.

You will have the opportunity to experience the cultural element of North Carolina at our Welcome Reception at the Duke Energy Center for the Performing Arts. This stunning venue is a short walk from the host hotels and convention center. Our evening will feature live entertainment, and a distinct 'taste' of the South while you mingle and chat with friends and colleagues. If you are musically inclined, you might want to show off your talent in the Engineer Talent Showcase. Or, if you enjoy biking, don't miss the second annual Team EMC Bike ride. In addition, in the evening of August 7th, we have organized a tour of IBM's largest 10 meter EMC Test chamber with unique power, cooling and weight requirements for large main frame servers. There is certainly something new for everyone, regardless of your interests within the broad EMC world.

We are very pleased you decided to join us for EMC 2014 in Raleigh to enjoy the networking, education, special events, and hospitality of North Carolina at its finest!

Welcome!

Bruce Archambeault

www.emc2014.org

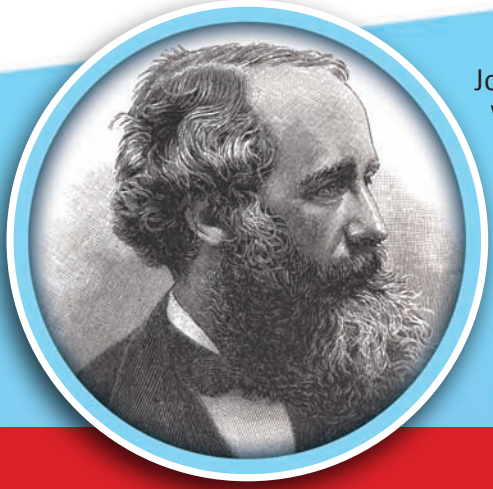
WHAT'S HAPPENING AT EMC 2014?

2014 IEEE International Symposium on Electromagnetic Compatibility

AUGUST 3-8 • RALEIGH • NORTH CAROLINA

150th Anniversary of Maxwell's Equations

A Special Session to Recognize the Scientific Contributions of James Clerk Maxwell



Join us for a special session on Wednesday, August 6 at 1:30pm in Room 305AB. Speakers include former IEEE MTT Society Distinguished Lecturer, James Rautio, on the life and times of Maxwell and IEEE EMC Society President Dr. Robert Scully who will provide insight on how these equations continue to impact the work of today's EMC engineers.

EMC Band

Engineer Talent Showcase

Our gifted colleagues share their musical talents at the Engineer Talent Showcase!

Veteran EMC Society Band members and newcomers alike are welcome to participate. Shows will take place in the Mezzanine (outside the Exhibit Hall) on Tuesday, Aug 5 and Wednesday, Aug 6 from noon to 1:30pm.

Team EMC*

Interested in exploring some of Raleigh on bike with your fellow EMCS members?

Join us on Thursday morning for a leisurely ride to get some exercise and to experience part of the city in a refreshing way. This year we will host two levels of escorted riding: leisure and performance. Meet us on Thursday, August 7 at 7:00am outside the Registration Area on the Salisbury Street side. The ride will depart from the Convention Center and proceed to the bike trails. To sign up or learn more about bike rental information, contact Ray Adams at r.k.adams@ieee.org or (310) 387-7201.

Welcome Reception*

Come join us for a Southern Hospitality Culinary experience at the Duke Energy Center for the Performing Arts on Tuesday, August 5 at 6:00pm. We will have food and beverage that represents North Carolina and the different styles of barbeque and other culinary items that have made the state of North Carolina so unique. Entertainment will be a Blue Grass Band and a Barbershop Quartet.

Awards Luncheon*

Help us recognize the winners for the Best Symposium Paper Awards and Best Student Paper Awards for both EMC 2014 and SI/PI 2014! Join us for the Awards Luncheon on Thursday, August 7 at 12:30pm in Ballroom B.

The luncheon will include a catered sit-down meal and will be the last formal opportunity to gather and network with families and EMC professionals.

Evening Gala*

We have great food and entertainment planned for our Gala on Wednesday, August 6 at 6:30pm in the Raleigh Convention Center Ballroom ABC. The magician and the comedian will be sure to leave you with a smile!

Learn more about these and other EMC 2014 and SI/PI 2014 happenings at **www.emc2014.org**

**Extra fees may apply, depending on factors such as registration status and whether cycling equipment is needed. Check at the registration desk if you have any questions.*

Jun Fan
SI/PI 2014 General Chair

SI/PI 2014

Welcome to the 2014 IEEE International Conference on Signal and Power Integrity (SI/PI 2014), embedded within the 2014 IEEE International Symposium on Electromagnetic Compatibility. Signal and Power Integrity is not new to the EMC Society at all! As a matter of fact, a technical committee (TC10) fully dedicated to this field has been around for over 10 years within the IEEE EMC Society. However, with the recent development in high speed circuits and their applications in electronic, computer, communication systems and more, Signal and Power Integrity is emerging as a critical area that has its unique focuses while being tightly connected with EMC. This special setting of the embedded conference not only provides an effective venue for the Signal and Power Integrity community to discuss their unique challenges and issues, but also encourages and fosters the exchanges and collaborations with the general EMC community. Attendees of SI/PI 2014 will have free access to the entire technical program of the 2014 IEEE International Symposium on Electromagnetic Compatibility.

I would like to take this opportunity to thank Dr. Xiaoning Ye and Dr. Dale Becker for their leadership in putting together an impressive technical program for SI/PI 2014. My thanks also go to the conference International Committee members and the TPC Coordinators. I am sure you will enjoy the technical program and the social activities provided by the embedded conference and the general symposium!

Again, welcome to SI/PI 2014, where academia meets industry!

Jun Fan

Keynote Presentation

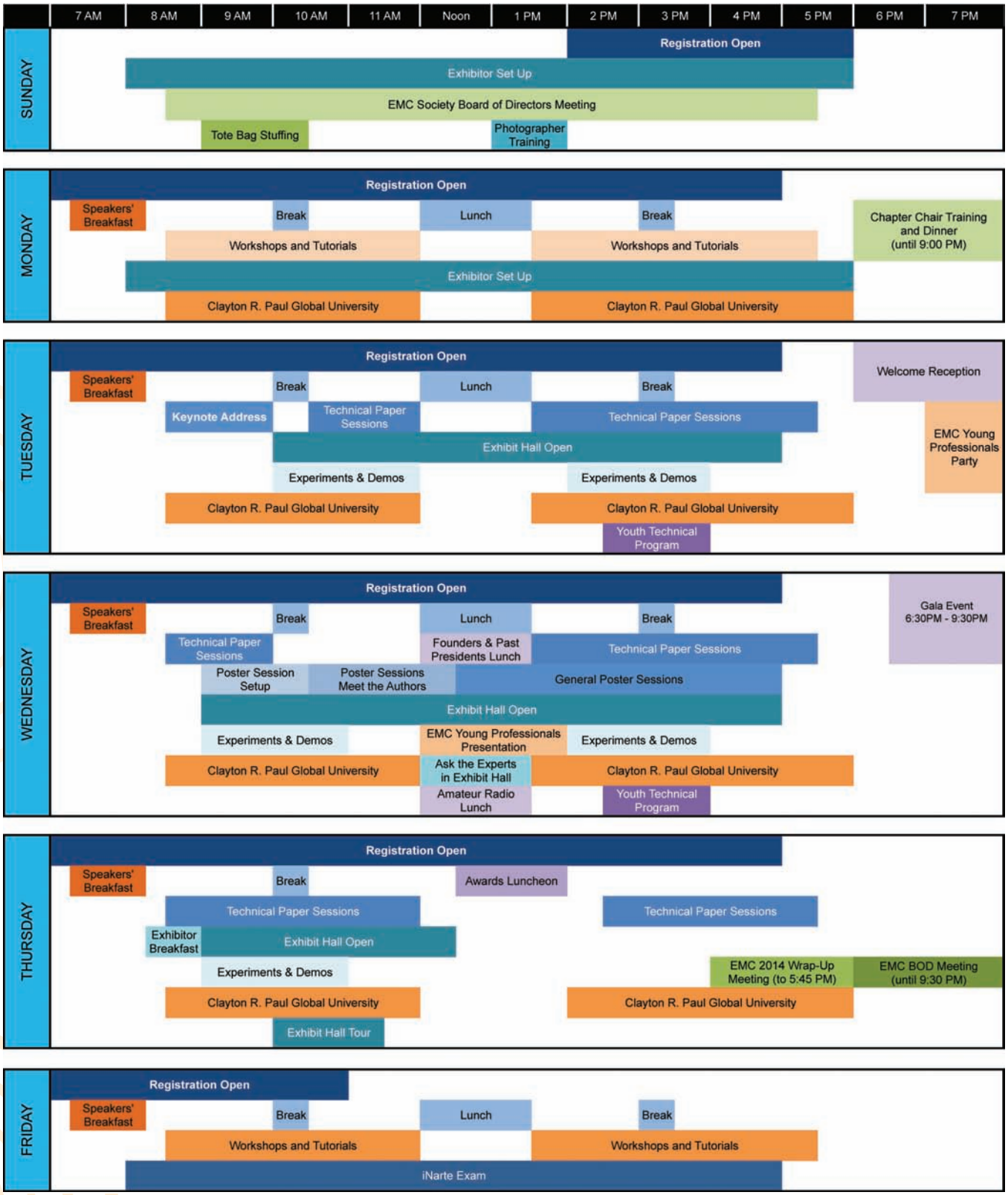
EMC Past, Present, and Future

Tuesday, August 5
8:30 AM - 10:00 AM
Ballroom B

This keynote presentation traces the evolution of EMC engineering, starting with the EMC concerns of the military during WW II, progressing through present day commercial and military EMC issues, and then looking forward into the future. The development of EMC standards, military and commercial, is traced along with the formation of the IEEE EMC Society and the emergence of various EMC educational options. The presentation discusses the driving forces behind present day EMC technology and concludes with my gazing into a hazy crystal ball and speculating on the future trends in EMC.

Henry Ott
2014 Keynote Speaker

Symposium-at-a-Glance



Daily Schedule

Monday

8:30 AM - Noon

Fundamentals of EMC
MO-AM-1
Room 305 AB

Understanding the Importance of Bore Sight Antenna Measurements
MO-AM-2
Room 306 AB

Smart Grid EMC Update
MO-AM-3
Room 303

EMC Issues for Unmanned Aircraft Systems
Room 306C
MO-AM-4

Nanotechnology Applied to EMC
MO-AM-5
Room 302C

Introduction to SI/PI Modeling and Design
MO-AM-6-SIPI
Room 302B

1:30 PM - 5:30 PM

Fundamentals of EMC
MO-PM-1
Room 305 AB

Application of Reverberation Chambers
MO-PM-2
Room 303

Introduction to Medical EMC
MO-PM-3
Room 306C

Recent Developments in EMC for Emerging Wireless Technologies
MO-PM-4
Room 306 AB

Using CEM Modeling to Understand the Underlying Physics in EMC Problems
MO-PM-5
Room 302C

Advanced Topics in Signal and Power Integrity - Achieving 25 Gb/s to 100 Gb/s
MO-PM-6-SIPI
Room 302B

Tuesday

8:30 AM - 10:00 AM

KEYNOTE ADDRESS
Henry Ott: EMC Past, Present and Future
Ballroom B

10:30 AM - Noon

EMC Measurements
TU-AM-1
Room 305AB

Spectrum Management
TU-AM-2
Room 306AB

Nanotechnology and Advanced Materials
TU-AM-3
Room 306C

SI/PI Design and Modeling for 3D Integration
TU-AM-5-SIPI
Room 302B

SI/PI Advanced Noise/Jitter Modeling and Analysis
TU-AM-6-SIPI
Room 302C

1:30 PM - 5:30 PM

Applications of Numerical Modeling
TU-PM-1
Room 305AB

EMI Systems
TU-PM-2
Room 306AB

Special Session: Radio-Frequency Interference and Wireless EMC
TU-PM-3
Room 306C

Special Session: Nanotechnology in EMC
TU-PM-4
Room 303

Special Session: Numerical Methods for Signal and Power Integrity
TU-PM-5-SIPI
Room 302B

SI/PI High Speed Interconnect Design and Analysis I
TU-PM-6-SIPI
Room 302C

Wednesday

8:30 AM - Noon

Cables and Connectors
WED-AM-1
Room 305AB

Measurement - Immunity
WED-AM-2
Room 306AB

Statistical Analysis and Model Validation
WED-AM-3
Room 306C

Low Frequency EMC
WED-AM-4
Room 303

SI/PI GHz Power Integrity Design
WED-AM-5-SIPI
Room 302B

SI/PI Co-Design and Co-Simulations
WED-AM-6-SIPI
Room 302C

Technical Program

Poster Session
WED-AM-7
Convention Center Foyer

1:30 PM - 5:30 PM

Special Event
Celebrating the 150th Anniversary of Maxwell's Equations
WED-PM-1
Room 305AB

PCB EMC
WED-PM-2
Room 306AB

High Power EM Including Intentional EMI, ESD and Lightning
WED-PM-3
Room 306C

Wireless EMC
WED-PM-4
Room 303

SI/PI Full Link Modeling and Design Optimization
WED-PM-5-SIPI
Room 302B

SI/PI High Speed Interconnect Design and Analysis II
WED-PM-6-SIPI
Room 302C

Thursday

8:30 AM - Noon

Antennas
TH-AM-1
Room 305AB

Special Session: Large Scale Modeling for Signal and Power Integrity
TH-AM-2
Room 306AB

Special Session: Recent Research and Education in EM Information Security
TH-AM-3
Room 306C

Reverb Chambers and Complex Cavities
TH-AM-4
Room 303

SI/PI Package/PCB Material Characterization
TH-AM-5A-SIPI
Room 302B

SI/PI High Speed Interconnect Design and Analysis III
TH-AM-5B-SIPI
Room 302B

SI/PI On-Chip and Off-Chip Power Integrity Issues and Design
TH-AM-6-SIPI
Room 302C

2:30 PM - 5:30 PM

Numerical Modeling Approaches
TH-PM-1
Room 305AB

TEM and Reverb Measurements
TH-PM-2
Room 306AB

Business and Management Concerns in EMC
TH-PM-3
Room 306C

SI/PI Channel Emulation
TH-PM-5-SIPI
Room 302B

SI/PI High Speed Interconnect Design and Analysis IV
TH-PM-6-SIPI
Room 302C

Friday

8:30 AM - Noon

Basic EMC Measurements
FR-AM-1
Room 306C

EMC for Space Applications
FR-AM-2
Room 306 AB

EMC Consultant's Toolkit
FR-AM-3
Room 302C

Time Domain Site VSWR (sVSWR) Method above 1 GHz and Correlations to CISPR sVSWR
FR-AM-4
Room 305 A&B

Introduction to Spectrum Engineering
FR-AM-5 and FR-PM-5
Room 303

Essential Principles of Jitter
FR-AM-6-SIPI
Room 302B

1:30 PM - 5:30 PM

Electromagnetic Time Reversal with Emphasis on Lightning and Fault Detection
FR-PM-1
Room 306C

Details of the First Practical Method for Risk-Managing EMC (i.e. Achieving EMC for Functional Safety)
FR-PM-2
Room 306 AB

Understanding Recent EMC Standards from the IEEE
FR-PM-3
Room 302C

System Level Approaches to Design and Test for EMI Control
FR-PM-4
Room 305 A&B

Introduction to Spectrum Engineering
FR-AM-5 and FR-PM-5
Room 303

SAVE THE DATE

KEEPING INTERFERENCE AT BAY

EMC&SI 2015

Silicon Valley • March 15-21, 2015

EMC & SI 2015 Symposium will be striving to "Keep Interference at Bay" by providing the most current information, tools and techniques on EMC testing and signal and power integrity.

Plan ahead to join your colleagues and experts/innovators in Santa Clara, California for a full week of learning, collaboration and networking with fellow industry peers.

The Symposium appeals to a vast audience, from novice to veteran, across all industries and academia.

- Attend concurrent **workshops, tutorials and demonstrations** to learn the latest innovations in EMC & Signal Integrity.
- Participate in some of the many **industry and professional meetings** to take your participation to the next level.
- Visit the **Exhibit Hall** with hundreds of booths filled with the latest products, equipment and services.
- Greet old friends, meet new friends, experts, and colleagues at numerous formal and informal **networking functions.**
- **Interns and newly graduated EE/EMC engineers** will have the chance to learn from the more experienced and participate in Young Professionals activities.




IEEE

EMC SOCIETY®

For Event Details Visit:
emc2015usa.emcss.org

Meet the Candidates

for Election to the 2015-2017 IEEE EMC Society Board of Directors

Tuesday, August 5
10:30 AM – Noon
Room 303

Ghery Pettit
Nominations and Appointments Committee Chair

At the 2014 IEEE International Symposium on EMC this August in Raleigh, North Carolina, we will be providing special ribbons to all election candidates to the Board of Directors who are in attendance, identifying them as candidates for the Board of Directors. Also, we will be giving all candidates an opportunity to speak directly to the attendees in a public forum, and answer questions regarding their candidacy. In this fashion, candidates will be able to tell the membership why they should be elected to the Board, and the membership in turn will be able to see and speak directly with candidates just prior to the election.

Candidates who are unable to attend the symposium will be given the opportunity to pre-record a short speech detailing their candidacy and why they should be elected to the Board. We will play these pre-recorded sessions in the same forum as the candidates who are present, so that all have an opportunity to convey their own message.

Bruce Archambeault

Irina Kasperovich

Mark Montrose

Vince Rodriguez

Robert Davis

Dennis Lewis

Vignesh Rajamani

Frank Sabath

2014 Social Events

Welcome Reception

Tuesday, August 5, 6:00 PM – 8:00 PM

Come join us for a Southern Hospitality Culinary experience at the Duke Energy Center for the Performing Arts. We will have food and beverage that represents North Carolina and the different styles of barbeque and other culinary items that have made the state of North Carolina so unique. Enjoy the open foyer both inside and outside of the Duke Energy Center for the Performing Arts; the Center is within walking distance to our host hotels (Marriott City Center and the Sheraton).

One ticket to this event is included in all 5-Day technical registrations and the Companion Program registration. All others may purchase a ticket to the Welcome Reception as an add-on to your registration.

An Adult Reception Ticket price: $75
A Junior (Age 8 to 17, inclusive) Reception Ticket is: $35
Children under age 8 are free, but must be accompanied by a registered adult.

Gala Event

Wednesday, August 6, 6:30 PM – 9:30 PM Ballroom ABC

The Raleigh Convention Center will be the location of the Gala Event. We will have entertainment and southern hospitality cuisine for all to enjoy. The Raleigh Convention Center is located across the street from our host hotels (Marriott City Center and the Sheraton).

One ticket to this event is included in all 5-Day technical registrations EXCEPT student registrations. This is a change from last year, made to keep student registration costs down. Extra tickets to the Gala may be purchased as an add-on to your registration.

An Adult Gala Ticket is: $90
A Junior (Age 8 to 17, inclusive) Gala Ticket is: $45
Children under age 8 are free, but must be accompanied by a registered adult.

Awards Luncheon

Thursday, August 7, 12:30 PM – 2:00 PM Ballroon B

The Awards Luncheon will be held at The Raleigh Convention Center. The Awards Luncheon will be the last formal opportunity to gather and network with families and EMC professionals from academia, industry, government, military, and retired sectors. The event will start off with a catered sit-down meal. Afterwards, the EMC Society will take time to recognize members and non-members for their contribution to the Society and for professional excellence.

One ticket to this event is included in all 5-Day technical registrations. All others may purchase a ticket to the Awards Luncheon as an add-on to their registration.

An Adult Awards Luncheon ticket is: $45
A Junior (Age 8 to 17, inclusive) Awards Luncheon ticket is: $20
Children under age 8 are free, but must be accompanied by a registered adult.

Anticipated Awards

Best EMC 2014 Symposium Paper

Best SI/PI 2014 Symposium Paper

Best EMC 2014 Student Paper

Best SI/PI 2014 Student Paper

Special Service

Richard R. Stoddart Award for Outstanding Performance

Lawrence G. Cumming Award for Outstanding Service

President's Memorial Award

2nd Year Extension

President's Memorial Award

Technical Achievement Award

Honorary Life Member Award

Certificate of Appreciation

Certificate of Acknowledgement

Certificate of Recognition

Hall of Fame

Sustained Service

Symposium Chair Award

Social Events

Chapter Chair Training Session and Dinner

Monday, August 4, 5:30 PM – 9:00 PM Room 206

The Chapter Chair Training Session provides a forum for providing focused training to the Chapter Chairs, provides the Chapter Chairs with the opportunity to discuss their chapter issues and get group feedback, gives the Chapter Chairs the opportunity to meet other Chapter Chairs from around the world and for the Chapter Coordinator to disseminate important information from IEEE headquarters and the EMC Society Board of Directors.

A Social Session will precede the Dinner, to give the Chapter Chairs the opportunity to socialize with the other Chapter Chairs and their Angels. The Dinner will be served at the end of the Social Session. Besides a great meal, each Chapter Chair or their representatives will have the opportunity to share what their chapter has been doing for the past year. After the Dinner, an interactive brainstorming session will conclude the meeting. This session is intended to exchange information and new ideas for effective chapter management, as well as to discuss best practices and suggestions for future development and growth of the EMC chapters.

This is a free event open to Chapter Chairs or their representatives. Please check with your Chapter Chair, as you can be that representative for your chapter if your Chapter Chair cannot attend this event.

EMC Young Professionals Party

Tuesday, August 5, 8:30 PM – 10:00 PM
(after the Tuesday Welcome Reception)

Join us at Coglin's for a social gathering, karaoke and corn hole games. 226 Fayetteville Street (919) 410-6427

EMC YP members or eligible members only. Party Tickets are $10 with registration. Raffle tickets may be picked up at the EMC YP table by the registration desk.

Engineer Talent Showcase

Tuesday, August 5 ,Noon – 1:30 PM Mezzanine
Wednesday, August 6, Noon – 1:30 PM Mezzanine

Come see our gifted colleagues share their musical talents at the Engineer Talent Showcase!

Shows will take place in the Mezzanine (outside the Exhibit Hall) on Tuesday, August 5 and Wednesday, August 6 from noon to 1:30 PM. This is a comeback event that was first featured in Austin at EMC 2009. Veteran EMC Society Band members and newcomers alike are welcome to participate. If you would like to perform, please contact our Showcase Host Jeff Silberberg at jeffrey.silberberg@verizon.net.

Photo courtesy of Ken Wyatt

Founders and Past-Presidents Luncheon

Wednesday, August 6, 11:30 AM – 1:30 PM Room 203

The Founders and Past-Presidents Luncheon will be held at the convention center. The Luncheon is open to the Founders of the EMC Society, Past-Presidents of the EMC Society, current members of the Board of Directors, and students. The luncheon is a chance for the old and the new to mix, exchanging experiences of the past, challenges of the future, and learning about the EMC profession. A sit down lunch is provided. When making your reservation, please indicate that you plan to attend so there will be seating and food for you.

Exhibitors List (alphabetically)

Exhibits

Exhibitor Map

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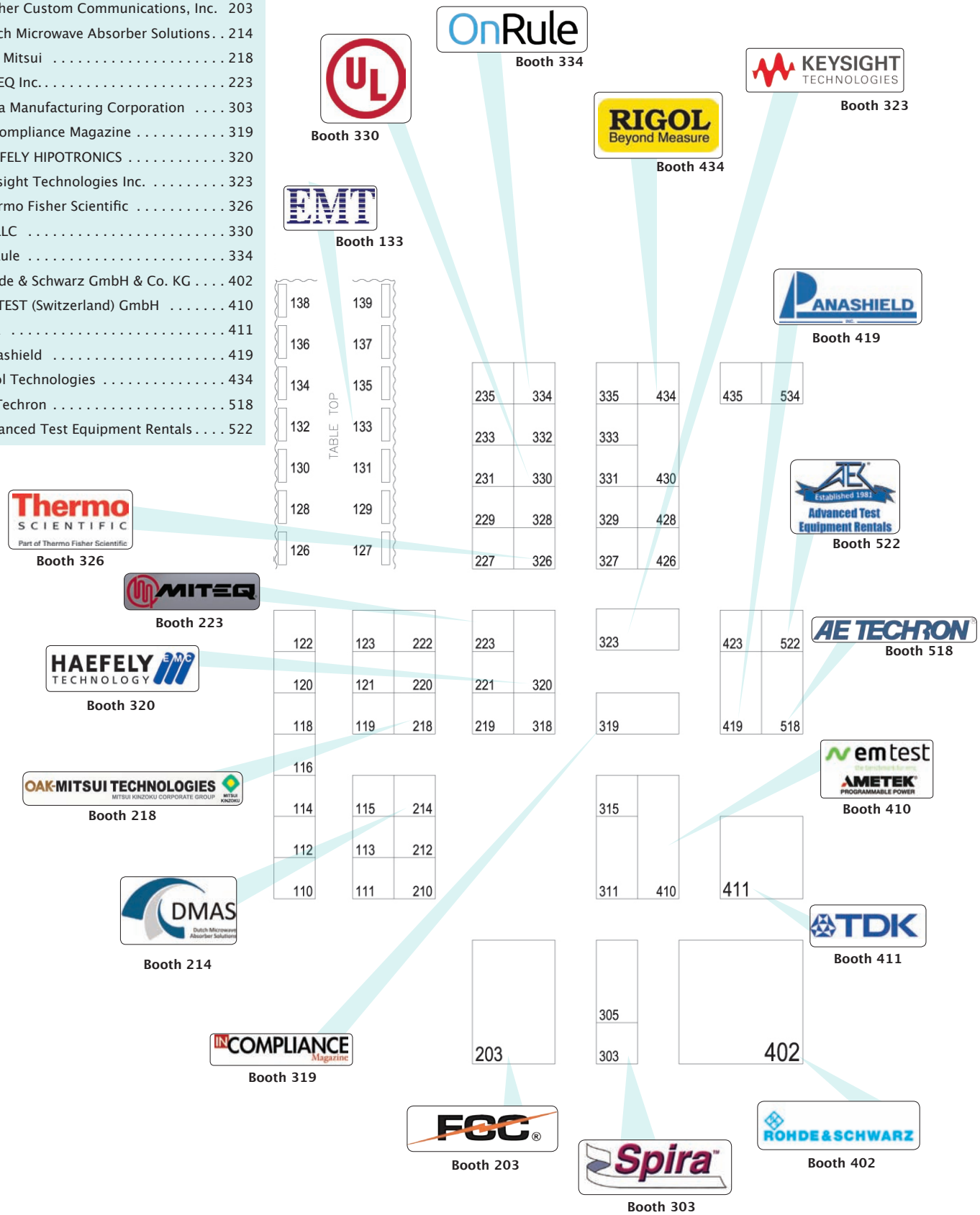

www.emc2014.org

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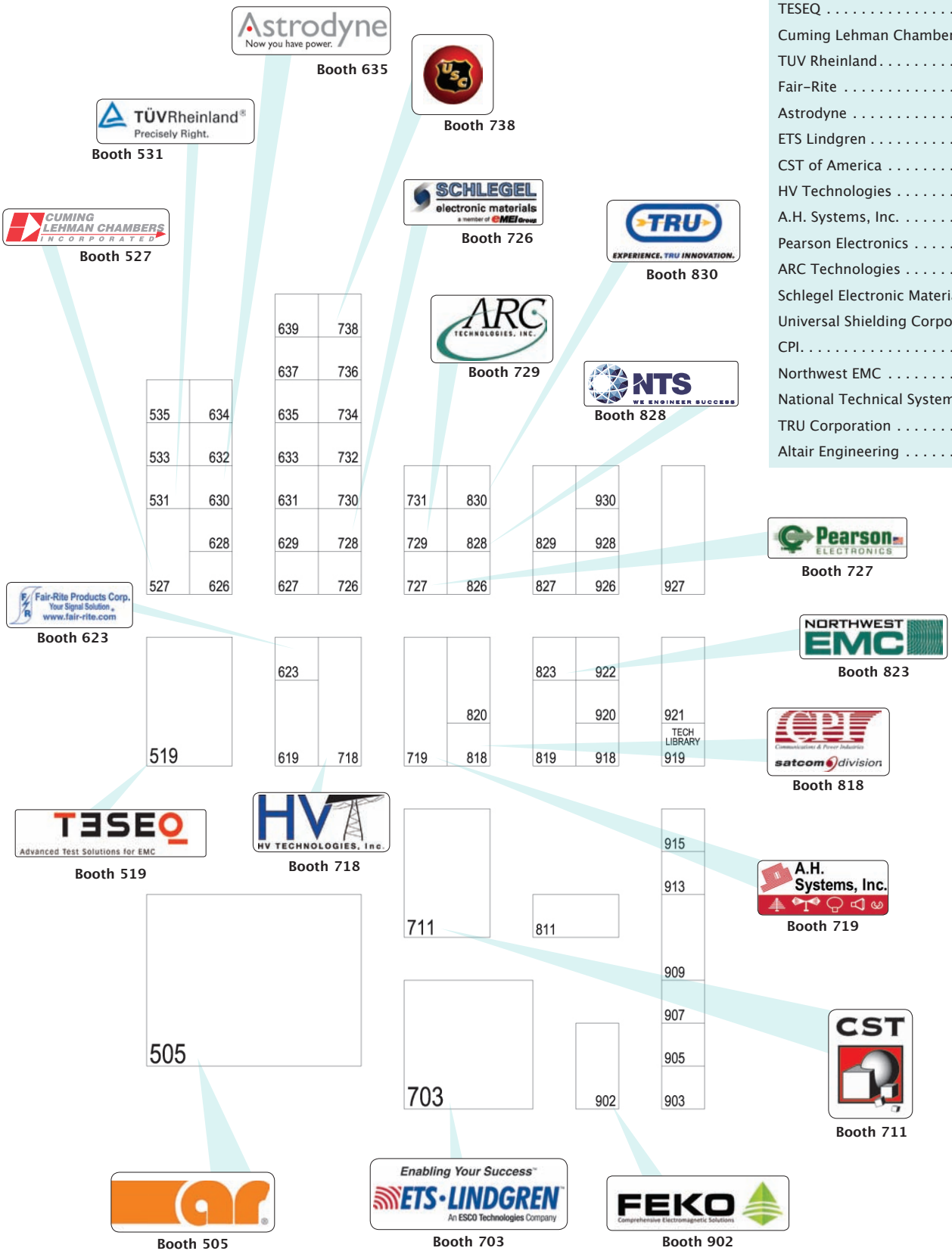

2014 Exhibitor Profiles

A.H. Systems, Inc.

Booth 719

Manufacturer
Antennas and Antenna Products

A.H. Systems, Inc. - manufactures a complete line of affordable, reliable, individually calibrated EMC Test Antennas and Current Probes that satisfy FCC, MIL-STD, VDE, IEC and SAE testing standards. Delivering high quality products at competitive prices with immediate shipment plus prompt technical support for the entire product line are goals we strive to achieve at A.H. Systems. We provide rental programs for our equipment and offer Recalibration Services for all our antennas and probes, including others manufactured worldwide. We take pride in providing a fast turn around schedule to help minimize any down time the customer may experience during testing. 100% inventory, NEXT-DAY ON-TIME DELIVERY.

Website: www.ahsystems.com

Advanced Test Equipment Rentals

Booth 522

Equipment Resellers/Rentals

Advanced Test Equipment Rentals (ATEC), A2LA ISO 17025 certified for calibration, supplies complete testing solutions for EMC, Electrical, Power Quality, Environmental and similar testing applications for the Aerospace, Defense, Medical, Telecom and many other industries. ATEC takes pride in serving our customers for over 30 years with invaluable expertise and technical support.

Website: www.atecorp.com

AE TECHRON

Booth 518

Manufacturer
Test & Measurement Equipment

AE Techron, Inc. - The audio-bandwidth EMC experts. AE Techron amplifiers and tests systems are designed to meet the rigorous requirements of EMC testing. Their popular 7224 linear amplifier has been recognized by Ford for use in EMC-CS-2009 testing and features a DC to 300 kHz bandwidth. The Electronic Smart Test (EST) system , the newest addition to their line-up, offers solutions for Aviation (DO-160, MIL-STD-461),and Automotive testing (SAE J1113-22, ISO 16750-2, MILSTD1275, GMW3172), with additional testing modules to be available soon. Other products offer solutions for power susceptibility and conducted immunity testing found in Telecom (GR 1089 Section 10/ATIS-0600315.2007).

Website: www.aetechron.com

FEKO

Comprehensive Electromagnetic Solutions

Booth 902

Distributors

Altair Engineering - FEKO
(Formerly EM Software & Systems) is a comprehensive electromagnetic simulation software tool, based on state of the art computational electromagnetics (CEM) techniques enabling users to solve a wide range of electromagnetic problems. The multiple solution techniques available within FEKO make it applicable to a wide range of problems for a large section of industries. Typical applications include:

- EMC/EMI
- Antennas
- Antenna placement
- Bio-electromagnetics
- RF components
- 3D EM circuits
- Radomes
- Scattering problems

Please visit our booth for more information, articles & interesting demonstrations.

Website: www.feko.info

ar rf/microwave instrumentation

Booth 505

Manufacturer
Antennas and Antenna Products
Test and Measurement Equipment

AR RF/Microwave Instrumentation is a manufacturer and distributor of high power broadband amplifiers from DC – 45 50 GHz, 1 – 50,000 watts and beyond. Our amplifiers are well suited for radiated and conducted immunity testing and equally suitable for general laboratory testing. In addition to our world class line of amplifier products we have a full line of other instruments and test accessories including antennas, directional couplers, field monitoring equipment, power meters and EMC test software. We also offer EMI receivers, RF conducted immunity test generators and EMC/RF test systems.

Website: www.arworld.us

ARC Technologies, Inc.

Booth 729

Manufacturer
Anechoic Chambers/Materials
Antennas & Antenna Products
Conductive Materials
Ferrite/Suppression Products
Shielding Products & Materials
Test & Measurement Equipment

ARC Technologies, Inc. offers a complete range of absorber products that provide solutions to the diverse RF and EMI problems facing today's military, aerospace, and commercial electronics design engineers. Whether a customer is facing these problems at 50 MHz or 100 GHz, nearfield or farfield, narrowband or broadband, the company has an absorber product or will develop an application-specific product to meet its requirements.

Website: www.arc-tech.com

Astrodyne
Now you have power.

Booth 635

Manufacturer
Ferrite/Suppression Products
Filters
Passive Electronic Components
Power Supplies

Astrodyne Corporation is a global developer & manufacturer of specialized power solutions that protect and enhance peoples' lives. We specialize in Power Conversion and EMI Solution for demanding applications worldwide.

Website: www.astrodyne.com

CPI
Communications & Power Industries
satcom division

Booth 818

Communications & Power Industries/CPI is the world's leading producer of high power TWT amplifiers, with a proven track record of consistent performance, service and support. For EMC testing, CPI is the only manufacturer of both TWTs and amplifiers. CW and pulsed amplifiers are available from 1 to 95GHz, with power levels exceeding 2 kW. Meet the latest EMC standards with CPI TWT Amplifiers

Website: www.cpii.com

CST

Booth 711

Software Development/Products

CST of America, Inc. is a world leader in computer simulation of radiated emissions and susceptibly. CST STUDIO SUITE® provides dedicated solvers and powerful features for complex EMC analysis including coupled simulations which allow for large system analysis and installed performance studies. Many years of in house expertise support the tools and give customers confidence in simulation results.

Website: https://www.cst.com

CUMING LEHMAN CHAMBERS INCORPORATED

Booth 527

Manufacturer
Anechoic Chambers/Materials
Shielding Products & Materials

Cuming-Lehman Chambers, Inc. (CLCI) is a wholly owned subsidiary of Cuming Microwave, Inc. specializing in the design and construction of anechoic chambers and host facilities "tailor made" to fit your performance needs and personal preferences. Our highly skilled project managers provide CLCI with the capacity to be the total turnkey solution for all of your testing needs.

Products and Services: EMC as well as High Frequency anechoic chambers, host facilities, shielded rooms, doors and door repairs, filters, and Microwave Absorbers, dielectric materials, artificial dielectrics and radomes.

Website: www.cuminglehman.com

DMAS
Dutch Microwave Absorber Solutions

Booth 214

Manufacturer
Anechoic Chambers/Materials

Dutch Microwave Absorber Solutions (DMAS) is an independent supplier of high performance polystyrene microwave absorbers suited for (semi) anechoic chambers enabling our customers to make the difference. Our product range consists of both hybrid (EMC) and broadband (microwave) absorbers. DMAS polystyrene absorbers are sustainable, environmentally friendly and fully compliant with REACH and ROHS.

For any EMC test engineer who has a need for a high performance, sustainable and environmental friendly anechoic chamber.

Website: www.dmas.eu

EMT

Booth 133

Testing/Certification

Electro Magnetic Test, Inc. is a one stop solution for EMI/EMC testing and International approval for ITE, wireless, and medical products. We also do the OTA/LTE/A-GPS, and converged devices testing. EMT labs is an India specialist and we have BIS safety approval problem solved! EMT labs has a one stop solution for India BIS registration approval.

Website: www.emtlabs.com

AMETEK PROGRAMMABLE POWER
emtest
the benchmark for emc

Booth 410

Manufacturer
Power Supplies
Test & Measurement Equipment
Testing/Certification
Training & Seminars

EM Test, a unit of AMETEK Compliance Test Solutions is the leading supplier of innovative Conducted Transient & RF Immunity, Power Anomaly, and Harmonics & Flicker test and measurement solutions worldwide.

Founded in 1987, we are the gold-label supplier of choice serving customers in the Automotive, IEC, Military, Aerospace, Medical, Telecom, and Component testing industries.

Website: www.emtest.com

2014 Exhibitor Profiles

ETS-LINDGREN
An ESCO Technologies Company

Booth 703

Manufacturer
- Anechoic Chambers/Materials
- Antennas & Antenna Products
- Filters
- Shielding Products & Materials
- Test & Measurement Equipment

Software Development/Products
Testing/Certification
Training & Seminars

ETS-Lindgren is a world leading provider of turn-key solutions and components for EMC, RF microwave, wireless OTA, and acoustic test. Services include classroom and lab training for EMC test, calibration services in our A2LA accredited lab, wireless OTA testing in our CTIA CATL lab, and acoustic testing in our NVLAP accredited lab. Based in Cedar Park, TX, ETS_Lindgren has ISO 9001:2000 certified facilities in North America, Europe, and Asia.

Website: www.ets-lindgren.com

Fair-Rite Products Corp.
Your Signal Solution
www.fair-rite.com

Booth 623

Manufacturer
- Antennas & Antenna Products
- Ferrite/Suppression Products
- Shielding Products & Materials

Fair-Rite Products Corporation . manufactures a comprehensive line of ferrite components in a wide range of materials and geometries for EMI Suppression, Power Applications, and Antenna/RFID Applications. Fair-Rite is the first U.S. soft ferrite manufacturer to receive ISO/TS 16949:2002 certification. We place the highest value on quality, engineering, and service and are dedicated to continual improvement. In addition to our standard product offering, Fair-Rite can provide custom designs and shapes to meet your specific requirements. We have an experienced team of engineers to assist you with new design and technical support. Please visit fair-rite.com to view our new online catalog and find contact information for customer service, applications engineers, local sales representatives, and local distributors.

Website: www.fair-rite.com

FCC®

Booth 203

Manufacturer

Fischer Custom Communications, Inc. is the leading designer and manufacturer of
- Current Monitor Probes
- Bulk Current Injection Probes
- LISNs
- CDNs
- EM Injection Clamps
- TLISNs
- TEM Cells
- CMAD's
- Telecom Surge CDNs

Our calibration laboratory is accredited to ISO/IEC 17025:2005 by A2LA

Web site: www.fischercc.com

HAEFELY TECHNOLOGY EMC

Booth 320

Manufacturer
Test & Measurement Equipment

As a leader in the field of EMC, **HAEFELY HIPOTRONICS** has a full range of conducted immunity test equipment designed to simulate the effects of interference sources on electronic, electrical and telecommunications products. Most prevalent and included in both IEC and EN product standards are the "classic" EMC tests for electrostatic discharge (ESD), electric fast transient/ burst (EFT), lightning surge, magnetic fields (MF), and power line quality. Our objective is to provide the best-in-class range of instruments that are flexible enough to be used in many applications including CE Marking, product development, type verification, product safety, component and production testing for IEC, EN, IEEE, ANSI, UL, and other standards.

Website: www.hipotronics.com

HV TECHNOLOGIES, Inc.

Booth 718

Manufacturer
Test & Measurement Equipment

HV TECHNOLOGIES, Inc. (HVT), with our partners: EMC Partner, Prana, Gauss, Montena, Innco Systems, and Pontis EMC are focused on providing our clients with top quality, full compliant EMC test instruments. Our staff has been supporting the EMC testing community by designing, producing, and distributing the best in EMC test instruments for over two decades. We cover all aspects of EMC testing for immunity and emissions. When using our products, customers experience the most reliable test instruments with the cleanest most repeatable measurements. This has been possible through innovative product design and the deployment of unique leading-edge technologies. The highest level of support is our main focus and part of every product. Offering Equipment: ESD, Surge, EFT, Lightning, EMI Receivers, Class A amplifiers, Reverberation and Anechoic Chambers, Turntables, Antenna Masts, Hardened Camera EMC Systems, Antennas, EMP Systems… We have the products, delivery, and support you need today and for years to come.

Website: www.hvtechnologies.com

IN COMPLIANCE Magazine

Publishers
Training & Seminars

Booth 319

In Compliance Magazine features in-depth coverage of worldwide regulatory compliance issues for the electronics industry. Each month you'll find technical articles from industry leading authors on topics related to test and design, standards updates and changes, products, services, and more!

Available in print or digitally, we offer a variety of informational resources for the electrical engineering professional. Visit our website, activate your free subscription, and join one of our many eNewsletters for regular updates.

Website: www.incompliancemag.com

KEYSIGHT TECHNOLOGIES

Booth 323

Manufacturers
Test & Measurement Equipment

Keysight Technologies (formerly Agilent Technologies EMG) is advancing at a rapid pace and EMC testing is necessary to the success of this progress. No longer are the boundaries of EMC testing relegated to open area test sites, C30 laboratories and text books; they are becoming part of our daily lives. Join us in booth 323 along with industry peers to understand how Keysight's design and test solutions contribute to the progress.

Agilent's Electronics Measurement Group is now known as Keysight Technologies, Inc. Currently a wholly owned subsidiary of Agilent Technologies, Keysight will become a fully independent company in early November 2014.

Website: www.keysight.com

MITEQ

Booth 223

Manufacturer
Passive Electronic Components
Test & Measurement Equipment

Established in 1969, **MITEQ Inc.** is a leading designer and manufacturer of microwave components and subsystems. MITEQ offers for the Compliance Testing Market a unique product line of broadband Low Noise Amplifiers and Broadband Block Converters (up to 40 GHz) as well as RF over Fiber Optical Links up to 18 GHz. MITEQ is registered to AS9100:2009 (Rev. C) as well as ISO9001:2008.

Website: www.miteq.com

NTS
WE ENGINEER SUCCESS

Booth 828

Software Development/Products
Testing/Certification
Training and Seminars

National Technical Systems (NTS) is the largest independent provider of EMC services in North America with 8 locations to provide you with world-class product compliance services.

Our state-of-the-art labs offer EMC, Product Safety, Wireless and Telecommunications engineering and compliance testing.

Our expert engineers and test technicians take the time and put forth the effort to understand your business, your needs and your goals and combines this knowledge with our own compliance and testing expertise to help you create successful products.

Website: www.nts.com

NORTHWEST EMC

Booth 823

Testing/Certification

Northwest EMC, Inc. is an independent, accredited, commercial EMC compliance test laboratory. Locations in California, Minnesota, New York, Oregon, and Washington with the newest facility in Texas opening summer of 2014.

Facilities include FCC listed 10M, 5M, and 3M chambers with a full complement of immunity and wireless testing capabilities. The latest addition at our Minnesota facility allows us to address Antenna Pattern and Over The Air Measurements for devices over the frequency range of 400 MHz to 6 GHz.

We can show you the advantages of testing with a proven leader.

Website: www.nwemc.com

OAK-MITSUI TECHNOLOGIES
MITSUI KINZOKU CORPORATE GROUP

Booth 218

Manufacturer
Filters
Passive Electronic Components
Shielding Products & Materials

Oak-Mitsui Technologies is the leading global company at developing and manufacturing advanced technology ultra thin laminates for Embedded Capacitance for current and next generation PCBs, modules, and package substrates. FaradFlex® is the market leading family of ultra thin laminate materials that has properties that minimize resonance, EMI, eliminates system noise, and improves signal and power integrity.

Website: www.oakmitsui.com

OnRule

Booth 334

Software

OnRule is a cloud-based platform developed by compliance engineers to help organizations exercise better control and increase visibility over their product regulatory compliance. OnRule features:

- Intuitive Dashboards to visualize portfolio certification status across markets.
- Automatic Alerts for upcoming expirations of certificates and other records.
- Flexible Reports to provide accurate and timely visibility to relevant stakeholders.
- Documents Repository to organize, securely store and quickly access test plans, test reports, approvals, certificates and all other important regulatory records.

Companies big and small use OnRule to simplify the process of monitoring, communicating and reporting product certification status across markets, minimizing the risk of non-compliance and giving compliance teams bandwidth to focus on evaluating the latest regulations and improving time to market. We cordially invite you to come meet us at our booth and check out our product showcase presentation on Tuesday, August 5 at 11:00 AM. If you have any questions before, during and after the show please contact Cyril Mecwan at cmecwan@onrule.com or +1 (408) 204-2521.

Website: www.onrule.com

2014 Exhibitor Profiles

Booth 419

Manufacturer
Anechoic Chambers/Materials
Shielding Products & Materials

Panashield, Inc. provides EMC facilities servicing commercial and government clients worldwide. Our products and services include RF Shielded Enclosures and EMC Chambers for radiated emissions and immunity testing, wireless, antenna measurement, automotive, military and aerospace. For 24 years we have been committed to providing our clients with expertise reflecting current developments and specifications in the global electromagnetic compliance industry.

Website: www.panashield.com

Booth 727

Manufacturer
Test & Measurement Equipment

Pearson Electronics, Inc.
manufacturers Precision Wide Band Current Probes used for accurate measurements of EMI, surge, lightning, pulse and other complex current wave shapes. New from Pearson Electronics is the Powerline Ripple Detector which greatly simplifies the measurement of injected ac ripple on an ac power bus required in MIL-STD-461 CS101.

Website: www.pearsonelectronics.com

Booth 434

Manufacturer

Rigol Technologies USA is transforming the Test and Measurement Industry. Our premium line of products includes Digital and Mixed Signal Oscilloscopes, Spectrum Analyzers, Function/Arbitrary Waveform Generators, Programmable Power Supplies, and Digital Multimeters.

Our test solutions combine uncompromised product performance, quality, and advanced product features; all delivered at extremely attractive price points. This combination provides our customers with unprecedented value for their investment, reduces their overall cost of test, and helps speed time to completion of their designs or projects.

Rigol's Headquarters is in Beijing China with a new state of the art R&D and Production Facility in Suzhou. Rigol has two International subsidiaries located in Beaverton, OR, United States and Munich, Germany. Some 400 employees are serving our customers in more than 60 countries and regions worldwide.

Website: www.rigolna.com

Booth 402

Manufacturer
Antennas & Antenna Products
Test & Measurement Equipment
Software Development/Products

For more than 80 years, **Rohde & Schwarz** has stood for quality, precision and innovation and is one of the world's largest manufacturers of electronic test & measurement, communications and broadcasting equipment.

Rohde & Schwarz offers a broad range of EMC, EMI, EMS and EMF test equipment for pre-compliance and full compliance measurements, providing accurate results across a wide frequency range. Rohde & Schwarz also provides customers with complete turnkey systems, significantly enhancing productivity and product performance by enabling precise results when measuring complex waveforms.

For more information, visit www.rohde-schwarz.us/en/products/test_and_measurement/emc_field_strength/products.

Booth 726

Manufacturer
Shielding Products & Materials

Schlegel Electronic Materials, Inc. (SEM) invented highly conductive fabric over foam shielding gaskets in 1987, marking a major breakthrough for the electromagnetic interference shielding of electronic enclosures and has become the pre-eminent manufacturer of electromagnetic interference (EMI) shielding products.

SEM offers a full range of EMI shielding products including gaskets, I/O backplane shielding gaskets, Conductive Tapes, DYNASHEAR, DYNAGREEN, Greenshield, (Halogen Free line) Conductive FR Foams, Elastomers, EPDM Hybrid gaskets, SHIELDED CANS, ORS-II for ETHERNET applications, Transformers and Be Cu Finger stock. These enable the computer, telecommunications, military and medical, and Electronics Industries to meet global requirements for electromagnetic compatibility (EMC). NOW you can get your THERMAL INTERFACE MATERIALS through Schlegel EMI!!!

The company's world-renowned EMI shielding gaskets are available in hundreds of profiles and unique designs, with attachment options that include mechanical self-attaching, clip, rivet, and a variety of pressure-sensitive adhesives.

Website: www.schlegelemi.com

Booth 303

Manufacturer

Spira Manufacturing Corporation has been serving the EMC community with quality engineered EMI/RFI shielding products for over **35 years**! We are AS9100/ISO-9001 certified and offer the finest most reliable EMI/RFI shielding gaskets in the market. Spira's strength lies in our exceptional products, on-time delivery, superior customer service, and technical support.

Spira's patented EMI/RFI and environmental gaskets offer excellent solutions for both cost-sensitive and high-performance applications. The unique spiral design offers extremely low compression set, long life and high shielding. Gaskets available in: groove or surface mount, EMI and Environmental protection, Honeycomb Filters, Connector-Seal Gaskets, O-Rings, Die-Cut Gaskets, and custom configurations.

Our shielded honeycomb filters offer the performance of a welded panel at the price of aluminum. Flexi-Shield is soft, durable and offers a rain/wind/dust seal like elastomers.

Our new Connector-Seal gaskets provide the best EMI & Environmental seal on the market! Visit our website for more info, free samples and an EMI Educational seminar.

Website: www.spira-emc.com

Booth 411

Manufacturer

- Anechoic Chambers/Materials
- Antennas & Antenna Products
- Ferrite/Suppression Products
- Filters
- Passive Electronic Components
- Power Supplies
- Shielding Products & Materials
- Test & Measurement Equipment

Software Development/Products
Testing/Certification

TDK Corporation is your Total EMC Solutions Provider offering products and services from several TDK Group companies under one roof at the EMC Symposium.

TDK RF Solutions is a world leader in the design, development & manufacture of technical solutions for the EMC testing industry. Offering offer a complete range of solutions including automated test systems, anechoic chambers, RF absorber, antennas, software, and a wide range of test products & accessories.

TDK also offers board level solutions with passive electronic components including ferrite beads and common mode filters to EMI filters, as well as the EMC filter module for shielded rooms offered by EPCOS (a TDK group company).

TDK-Lambda will also offer their latest line The Genesys™ family of programmable AC/DC power supplies.

Website: www.tdk.com

Booth 519

Manufacturer

- Antennas & Antenna Products
- Power Supplies
- Test & Measurement Equipment

Software Development/Products
Testing/Certification
Training & Seminars

Teseq Inc., a unit of AMETEK Compliance Test Solutions, offers the world's most comprehensive range of EMC systems for immunity and emissions testing. This includes the Milmega and IFI RF amplifiers.

We take great pride in our world-class research and development program, backed by state-of-the-art global manufacturing. Teseq Inc. is the only pulsed immunity manufacturer in North America with an ISO 17025 accredited calibration lab.

Website: www.teseq.com

Booth 326

Manufacturer

- Test & Measurement Equipment

ThermoFisher Scientific is the leader in conducted immunity (EMC) solutions for regulatory compliance and quality/performance testing.

ThermoFisher EMC equipment supports global certifications such as CE Marking, and offers one of the only commercial test platforms for RTCA DO-160 indirect lightning test for avionics products.

Thermo's MiniZap-15 ESD simulator has been the best-selling product of its type for over 30 years. Additional EMC tests supported include: IEC 61000-4-XX series (ESD, EFT/B, Surge, Magnetic Field, Dips), Telecom surge for FCC and Telcordia/GR-1089, and Lightning surge testing to 20kV/10kA.

Website: thermoscientific.com/esd

www.emc2014.org

2014 Exhibitor Profiles

Booth 830

Manufacturer

Passive Electronic Components
Connectors
Cords/Cord Sets
Antennas & Antenna Products

TRU Corporation is an industry leading supplier of engineered RF & microwave cable assemblies and interconnect products.

For over 60 years, TRU has provided innovative solutions to solve complex interconnect challenges. TRU offers the most comprehensive line of RF cable assembly and interconnect solutions for EMC immunity and emissions testing.

Our TRUflexTM PWR series with quick-disconnect interfaces provide maximum power handling and mating efficiency for immunity testing requirements, while our TRUcoreTM series provides low loss and broadband frequency up to 50 GHz for emissions testing applications.

TRU maintains the highest level quality standards and a dedicated Applications Engineering team to continually meet your challenge. Our products are used in many demanding applications in defense, aerospace, and industrial semiconductor equipment.

Contact us to experience TRU innovation.

Website: www.trucorporation.com

Booth 531

Testing/Certification

TUV Rheinland is uniquely qualified to help its clients get their products to market quickly. Customers can choose conveniently located EMC labs equipped with 5 and 10 meter chambers to handle a variety of products. As an EMC Notified Body (CAB) and international service provider, we offer a flexible, competent service to help you meet the requirements of the EMC directive 2004/108/EC as well as FCC and Industry Canada requirements.

For wireless radio compliance needs, TÜV Rheinland is a TCB for the U.S. and an FCB for Canada and can provide the wireless product certifications required.

***All TÜV Rheinland's EMC labs are 17025:2005 accredited, FCC listed, VCCI registered, IC recognized and our Pleasanton, California lab carries both WiFi & Zigbee accreditations.

Website: www.us.tuv.com

Booth 330

Testing/Certification

UL, LLC is a premier global independent safety science company that has championed progress for 120 years. Its more than 10,000 professionals are guided by the UL mission to promote safe working and living environments for all people. UL uses research and standards to continually advance and meet ever-evolving safety needs. We partner with businesses, manufacturers, trade associations and international regulatory authorities to bring solutions to a more complex global supply chain. For more information about our certification, testing, inspection, advisory and education services, visit www.UL.com.

Website: www.ul.com

Booth 738

Manufacturer

Anechoic Chambers/Materials
Shielding Products and Materials

Universal Shielding Corporation
USC designs, manufactures, installs, and certifies prefabricated shielded enclosures for customers throughout the world. The enclosures meet Tempest and Hemp specifications of IEEE-299, NSA-94-106, NSA65-5, NSA-65-6 and MIL-STD-285. The doors are of the Recess Contact Mechanism (RCM) and can be utilized for tempest, acoustic and weather resistant applications. The doors provide 100 dB of attenuation at 20 GHz.

We provide a complete turnkey installation of anechoic rooms, as well as screen enclosures and shielded cabinets.

Website: www.universalshielding.com

August Consultants Corner

EMC 2015

DRESDEN, AUGUST 16 - 22

"Where Baroque meets High-Tech ..."

EMC 2015: Joint IEEE International Symposium on Electromagnetic Compatibility and EMC Europe

DON'T MISS THIS UNIQUE OPPORTUNITY TO MEET THE INTERNATIONAL EMC COMMUNITY!

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- Bring yourself up to speed on Automotive EMC and new requirements due to e-Mobility and increasing use of Wireless Technologies.

- Papers will be reviewed by a high level technical committee consisting of the TCs of the IEEE EMC Society and the members of the EMC Europe technical committees.
- Annual Awards of the IEEE EMC Society will be presented during the traditional Awards Luncheon.
- Network with you colleagues during our Social Events hosted in some of Dresden's most charming locations.
- Experience the beautiful baroque city of Dresden located in the heart of Europe.

Call for Papers is available at www.emc2015.org.

Deadline for Preliminary Full Papers: Jan 30th 2015

IEEE EMC SOCIETY VDE EMC EUROPE

www.emc2015.org

2014 Exhibitor Show Stoppers

In Compliance advertisers bring it on Southern style in Raleigh, NC! See what they have in store for you on the 2014 Exhibits floor.

A.H. Systems, Inc.

Booth 719

Stop by and say Hi!

Find out the latest information about our antenna manufacturing and testing services. We manufacture a complete line of affordable, reliable, individually calibrated EMC Test Antennas and Current Probes that satisfy FCC, MIL-STD, VDE, IEC, and SAE testing standards. Delivering high quality products at competitive prices with immediate shipment plus prompt technical support for the entire product line are goals we strive to achieve at A.H. Systems.

We really take pride in providing a fast turn around schedule to help minimize any down time you may experience during testing.

We stock over 95% of our inventory, and provide NEXT-DAY ON-TIME DELIVERY.

At our facility, we calibrate most other brand antennas, as well as our own antennas in accordance with SAE, ANSI, IEEE, and CISPR specifications.

We have the solution to your EMC testing requirements. Looking forward to seeing you at our booth 719.

Advanced Test Equipment Rentals (ATEC)

Booth 522

Take advantage of the vast rental inventory of EMC test equipment that Advanced Test Equipment Rentals (ATEC) is known for! ATEC is A2LA ISO 17025 certified for calibration and specialize in the application of transient immunity for surge, EFT/burst, ring wave, dips and interrupts, harmonics and flicker, and ESD. ATEC supplies complete testing solutions for EMC applications in military/defense, telecom, commercial CE, aerospace, and automotive markets. No other rental company has the breadth and depth of our inventory and the expertise to match your test needs with the right equipment.

- IEC 61000
- MIL-STD-461
- DO160 Sect 22
- Automotive ISO 7637
- Telcordia GR-1089
- Medical IEC60601-1-2
- DO160 HIRF
- Indirect Lightning Strike
- Harmonics & Flicker
- and many more…

You can depend on ATEC's knowledge and expertise for your EMC test equipment needs, as do the many accredited EMC test labs in North America.

Order now! (888) 544-2832 or www.atecorp.com

AE Techron, Inc.

Booth 518

AE Techron, EMC Audio Bandwidth experts, introduces an expanded line of radiated and conducted test solutions with the 3100 series of products at this year's show in Raleigh NC.

Make sure to visit us at booth 518 to learn about new automated test solutions for DO 160 Section 18 and 19, Boeing, Airbus, MIL STD 461 CS101 and CS109, ISO 11452-10, and CS 2009.1

Also make sure to pick up your ticket for the fun on Tuesday night. It will get you into the first annual Bowling event jointly sponsored by AE Techron, ATE, and Haefely.

2014 Exhibitor Show Stoppers

Altair Engineering - FEKO

Booth 902

FEKO is a comprehensive electromagnetic simulation software tool, based on state of the art computational electromagnetics (CEM) techniques enabling users to solve a wide range of electromagnetic problems. The multiple solution techniques available within FEKO make it applicable to a wide range of problems for a large array of industries.

Typical applications include EMC (analysis of diverse problems including shielding effectiveness of an enclosure, cable coupling analysis in complex environments, e.g. wiring in a car, radiation hazard analysis), Antennas (analysis of horns, microstrip patches, wire, reflector, conformal & broadband antennas and arrays), antenna placement (analysis of radiation patterns, hazard zones, etc. with antennas placed on large structures, e.g. ships, aircrafts, armored cars) bio-electromagnetics (analysis of homogeneous or non-homogeneous bodies, SAR extraction), RF components (analysis of waveguide structures, e.g. filter, slotted antennas, directional couplers (3D EM circuits: analysis of microstrip filters, couplers, inductors, radomes (analysis of multiple dielectric layers in a large structure, and scattering problems (RCS analyses).

Please visit the FEKO (www.feko.info) booth #902 at the EMC symposium for more information, interesting demonstrations, brochures & articles.

AR RF/Microwave Instrumentation

Booth 505

What has AR done for you lately?

Stop by Booth # 505 and see!

We will be demonstrating our latest state of the art products for numerous EMC applications. Our MultiStar line of products including our DSP EMI Receiver, Multitone Tester, and Field Analyzers will be on display. These products feature amazing speed and incredible accuracy, and save you time and money. We have also introduced our line of .7 to 6 GHz single band Class A linear amplifiers for EMC and wireless applications with output powers now exceeding 200 watts which will also be demonstrated. Another major product release is our new W Series Class A amplifiers with output power levels up to 4000 watts that are extremely efficient and deliver the power you require even into harsh loads. In addition, we have developed additional new dual band solid-state Class A amplifiers that cover the .7 -18 GHz frequency band in one package.

A new family of solid-state microwave amplifiers provides power up to 2000 watts covering 1 – 2.5 GHz; making them excellent replacements for traveling-wave tube amplifiers. We're also giving you more power in our single band 0.8 – 4.2 GHz solid-state microwave amplifiers – up to 1200 watts!

Don't forget to test your AR knowledge and be entered into our daily prize drawings. There are 3 chances to win each day!

Astrodyne Corporation

Booth 635

Astrodyne Corporation was founded in 1994 and is a global developer and manufacturer of specialized power solutions for demanding applications, including power supplies, EMI filters, and electronic control products. We offer a wide selection of EMI filters from our Radius and LCR brands for medical, military/aerospace, industrial, and commercial applications.

Astrodyne's recent acquisition of Filter Concept, Inc. further enhances and diversifies the company's already broad range of commercial and military EMI filter product lines. Through recent acquisitions, Astrodyne is now one of the largest, most capable EMI filter providers in North America and reaches customers worldwide.

Stop by and visit us at booth 635 to learn more about the latest in the design and manufacture of custom EMI/EMC/RFI filters and suppression components, electronic and motor control boards, and power supplies, as well as a variety of EMC testing, engineering, and contract manufacturing services.

CST of America, Inc.

Booth 711

CST will be presenting the latest developments of CST STUDIO SUITE® at booth #711

EMC and EMI issues can arise from structures and components at every scale, from aircraft and vehicle bodies down to cables and even individual seams. To simulate scenarios such as emissions or lightning strikes accurately, it can be necessary to include all these structures in the 3D simulation. However, the difference in scale between, for example, the length of a cable harness and the width of an individual conductor, or the size of an enclosure and the thickness of its seams, can make these models challenging to solve.

The TLM solver in CST STUDIO SUITE® lets complex structures be represented with accurate compact models, and enables bi-directional transient co-simulation. The electromagnetic behavior of complex cables and cable harnesses can be modeled in a 3D environment using computationally-efficient models in CST CS, with the ability to model real shields and twisting of wires among other factors. With bi-directional simulation, it's possible to calculate the complex couplings that arise when fields absorbed by a cable in one part of the device are conducted and re-radiated in another part.

Visit booth #711 and learn more about the latest techniques for cable co-simulation and modeling across a range of scales.

Cuming-Lehman Chambers Inc.

Booth 527

Cuming-Lehman Chamber Incorporated (C-LCI) specializes in the design and construction of anechoic chambers and host facilities tailor made to fit your performance needs and personal preferences. Our experienced staff and highly skilled project managers provide C-LCI with the capacity to be the total turnkey solution for all of your testing needs.

From the formulation of an advanced material in our laboratory to the construction of a host facility in the field, we are the world's leading authority on the development of technology and products for the RFI/EMI Absorber, Radar Cross Section Reduction and Anechoic Chamber markets.

Core Capabilities

- 3M, 5M, 10M EMC; MIL STD; Compact Ranges; Near Field; Antenna Measurement Chambers
- Shielded Enclosures, (welded, modular or "stick built" construction).
- Retrofits & Relocations
- Refurbishments and relocations
- Large Shielded Doors
- Turntables, Antenna Masts, Controllers
- Specialty Boxes
- Microwave absorbers
- Host facilities (Certified Star Building Systems)
- CCTV's & Intercom Systems
- Ramps, Ladders, Lifts, Platforms & Cranes
- Lighting – LED, Fiber Optic
- Filters
- HVAC Systems
- Fire Detection / Protection Systems
- Antenna Mounts
- Ferrite Tiles, Specialty Absorbers & di-electrics

Dutch Microwave Absorber Solutions (DMAS)

Booth 214

DMAS supplies high performance polystyrene microwave absorbers suited for (semi/full) anechoic chambers. Our product range consists of both hybrid (EMC) and broadband (microwave) absorbers. DMAS polystyrene absorbers are sustainable, environmental friendly and fully compliant with REACH and ROHS.

The benefits of DMAS absorbers are:

- Superior product life time (>40 years).
- Resilience to humidity.
- Alternating taper design (vertical – horizontal)
- Light weight (5,7 kg/m2)
- Compliant with clean room class spec. class 10.000 / ISO14644-1 class 4
- Rigid and superior tensile strength (no drooping tips)
- Removable tapers

DMAS is part of Comtest Engineering.

2014 Exhibitor Show Stoppers

EM Test USA

a unit of AMETEK Compliance Test Solutions

Booth 410

Come see the latest in conducted immunity test solutions for automotive, hybrid and electric vehicles, as well as green energy test solutions. Learn about our new harmonics and flicker test solutions for energy regeneration systems that both consume and deliver energy back to the grid.

We will showcase our latest test products at our booth including IEC & ANSI conducted immunity (surge, burst, dips and interrupts, ESD, conducted RF, and harmonics/flicker), military and avionics power anomaly test solutions as well as automotive test solutions. Technical experts are on hand to demonstrate the equipment and to answer all your questions about conducted EMC testing and the latest changes to the standards.

While at our booth meet EM Test's new North America sales manager, Dan Odum, who has over 30 years of EMC experience. With his vast knowledge of the industry and expertise, Dan will continue to forge expansion of our North American market.

EM Test offers its customers the broadest range and highest performance conducted EMC hardware portfolio, test software, and standards libraries. Each is unparalleled in its completeness, ease-of-use, and flexibility, and features excellent worldwide support and service led by the most experienced technical team in the industry – come by and see why we are the benchmark for EMC.

EM Test is part of AMETEK Compliance Test Solutions, a unit of AMETEK Inc., a leading global manufacturer of electronic instruments and electromechanical devices. With four product brands, EM Test, IFI, MILMEGA and Teseq, it offers the world's most comprehensive range of EMC systems for immunity and emissions testing.

ETS-Lindgren

Booth 703

Visit Booth 703 and see what's new from ETS-Lindgren!

Solutions for DO-160, IEC 61000, and MIL-STD testing will be on display along with the latest version of TILE!™ lab management software.

Several new products will also be introduced, adding to ETS-Lindgren's family of robust solutions for totally integrated RF test systems.

Visitors who have not yet signed up for the Wednesday TILE! User's Group meeting or Thursday's tour of IBM's boat-shaped chamber can do so at the booth.

Fair-Rite Products Corp.

Booth 623

Fair-Rite Products Corp. introduces industry leading Low Frequency Suppression cores and expands our product line with Flexible Ferrite Sheets.

Fair-Rite Products Corp., a family owned and operated corporation, is proud to announce its new 75 Material Suppression cores. These new cores display the highest impedance values for low frequency suppression on the market today, will suppress common mode EMI at frequencies below 5 MHz and can be used in applications up to 30 MHz. Now available in split core Snap-Its, solid cable cores, and toroids.

Another addition to their extensive product line is the Flexible Ferrite Sheet. These RoHS compliant flexible sheets are offered in four thicknesses (0.1, 0.2, .04 and 0.5mm) and six material grades. Functioning primarily as an EMI suppressor, the flexible ferrite blocks noise at lower frequencies and absorbs it at higher frequencies. Applications include shielding antennas and RF circuits from reflection and eddy currents induced by metal surfaces, suppressing radiated noise on PCBs and for use in RFID and Near Field Communication (NFC) applications. Wireless charging pads and receiver coils can also benefit from the use of ferrite sheets by improving connectivity between devices and to protect from unwanted power transmission to internal components. The NiZn ferrite is placed between a 0.01 mm layer of PET film and 0.02 mm adhesive tape. Each sheet can be cut to size enabling it to conform to a multitude of applications.

In addition to our standard product offering, Fair-Rite provides custom designs and shapes to meet your specific requirements. We have an experienced team of engineers to assist you with new design and technical support.

Fischer Custom Communications, Inc.

Booth 203

Meet the technologists of Fischer Custom Communications, Inc. in booth 203 to discuss our expanding tool box of innovative solutions for:

- RTCA / DO – 160 G
  - o 2 kW Bulk Current Injection Probe
- IEC 61000-4-6 Edition 4
  - o EM Injection Clamp and fixture
  - o BCI probe fixture
  - o CDN
- CISPR 16-1-4
  - o CMAD

Fischer Custom Communications, Inc. continues to push the limits of performance with new current monitor probes, bulk current injection probes, TEM Cells, Telecom Surge CDN's, very high current LISN's.

For more information contact us by e-mail at sales@fischercc.com or by phone at 310-303-3300.

HV Technologies, Inc.

Booth 718

Stop by, we have the answers!

New standards for EFT and Surge put new verification requirements on your test equipment. Make sure you have what you need to be ready. Come talk with us we have the answers you need about upcoming conducted immunity requirements.

- IEC 61000-4-4 and IEC 61000-4-5 Edition 3 have been released or soon will be.
- MIL-STD-461G is in committee with many additions on the horizon. Be prepared.
- New requirements for Smart Grid. IEC 61000-4-19

CE Mark Applications

- See the NEW IMU3000 and IMU4000!!! the most versatile generator on the market
- High current CDNs AC and DC for any application
- ESD3000 See the best ESD simulator on the market andfind out why it is preferred

Avionics Lightning and Voltage spikes

- Meet ALL levels and requirements, we can do it all!
- Airbus, Boeing, and DO160 with larger couplers
- Future MIL-STD-461G

Solid State Amplifiers & more

- Class A, 100% Mismatch tolerance
- Deliver power into any load
- The power you need where you need it in the band
- Unmatched quality and great value in one package
- Antennas and Accessories
- Full line of antennas, LISN, CDNs, Mag coils

Chambers, Anechoic, Turntables, Antenna Masts, Camera systems, and more

Keysight Technologies

Booth 323

In EMC testing, success depends on the tools that can help you do more in less time—today and tomorrow. Learn how Keysight can help you keep the test queue flowing with its N9038A MXE, a standards-compliant EMI receiver and diagnostic signal analyzer built on an upgradable platform.

The MXE EMI receiver meets both commercial (CISPR 16-1-1) and military requirements (MIL-STD-461), allowing you to fully test a range of devices with outstanding accuracy and excellent sensitivity. Easily upgrade the MXE's CPU, memory, disk drives, and I/O ports to keep your test assets current and extend instrument longevity. Together with Keysight's proven customer service and a standard 3-year warranty, the MXE delivers the precision, repeatability, and reliability you need to test with confidence.

In addition to full compliance measurements with the MXE, Keysight offers precompliance measurements and diagnostic evaluation with the N6141A EMI measurement application on X-Series signal analyzers. Through Keysight Solutions Partners, use a single point of contact to combine the MXE with chambers, antennas, software, value-added integration, probes, and more for a complete EMI test solution.

Visit Booth 323 to find out how Keysight's EMI test solutions can support you in the lab and on the bench.

2014 Exhibitor Show Stoppers

Oak Mitsui Technologies

Booth 430

Oak-Mitsui Technologies is the global leader at developing and providing ultra thin advanced laminates for high technology PCBs and electronics.

FaradFlex® is Oak-Mitsui Technologies' leading edge family of ultra-thin laminate products used in next generation PCBs, modules, and packages. This market leading brand of materials has properties that:

- Reduce EMI
- Reduce power buss noise
- Enable embedded capacitance
- Eliminate surface mount passives
- Minimize jitter
- Improve SI
- Lower inductance
- Reduce the design form factor and weight

We look forward to seeing you at our booth and helping you with your design/ material solutions.

OnRule

Booth 334

Check out our product showcase on Tuesday August 5th at 11:00 am.

OnRule makes product regulatory compliance simple and predictable. Our cloud-based software helps organizations increase control, visibility, confidence, and speed of the product certification process. Our product offers two modules with distinct value propositions:

1. Accelerate time to market with Become Compliant:

Standards Finder
- Discover standards to certify your unique products in different markets.
- Alerts of changes in standards and impact to portfolio.

Workflows
- Collaborative workflows for easy navigation through the compliance processes.

Labs & Agents Portals
- Tools for lab discovery and project awards.
- Collaboration platform to exchange information throughout the testing and certification process.

Added-benefits: Minimize redesigns, increase lab collaboration, and improve time & spend visibility.

2. Minimize holds & stop ships with Stay Compliant:

SmartCerts™
- Give 'Smarts' to all certifications records and ignite your compliance BI.
- Enable faster document searches and retrieval.

Document Management
- Secure, organized and searchable repository for all of your legacy, existing and new product certification information.

Dashboards & Reports
- Real-time visualization of your product portfolio certification status across all your markets.

Alerts & Notifications
- Automatic Alerts for upcoming expirations of certificates.

Added-benefits: Anticipate workload and democratize information access within the organization.

Panashield, Inc.

Booth 419

Panashield continues to bring new solutions to the EMC marketplace, with this year in Denver being no exception.

We will be exhibiting the Diamond Engineering DRG Horn, which Panashield will be distributing. This Horn breaks the mold for what has been the industry solution for more than 25 years.

- Broadband - 700 MHz to 26 GHz
- Increased Monotonic Gain – Superior to all existing Broadband DRGHs
- Improved Beam performance – No flowering at higher frequencies
- Custom Configurations available – Using Diamond's Single Antenna Mirror method, custom designs can be quickly configured

Panashield will also be displaying their improved LED panel lighting system and new anechoic absorbers meeting the latest international standards.

Stop by and say hello to your friends on the Panashield Team – the Team that brings the highest level of quality products and customer service to the EMC industry.

Pearson Electronics, Inc.

Booth 727

Pearson Electronics is pleased to introduce the new Powerline Ripple Detector, Models PRD120 and PRD-240, which greatly simplifies the measurement of injected audio ripple on an ac power bus in measurements such as MILSTD461 CS101. We will have a demonstration on the PRD120's ability to accurately measuring lowlevel audio ripple voltage on a 115 Vac power bus. In conjunction with a spectrum analyzer, the PRD120 separates the injected ripple from the waveform in the frequency domain, allowing for accurate measurements of the injected waveform. The PRD120 is a simplified, cost efficient way to monitor the entire frequency range in MILSTD461 CS101, RTCA/DO160 section 18, and MILHDBK7042 through 6.

We will also have our Precision Wide-Band Current Probes on display that are used for accurate measurements of EMI, surge, lightning, pulse, and other complex current wave shapes. Pearson Current Probes are an excellent choice for the various measurements required by the MILSTD461 and RTCA/DO 160 requirements. The Pearson model 3525 will be compared to other passive EMI probes to demonstrate its efficiency and its 6 decade flat transfer impedance, 10 Hz to 10 MHz, best in the industry. This probe is a great choice to meet the 30 Hz to 10 kHz frequency requirement for CE101. The Pearson model 4160, with its 50 kAmp peak current rating and fast rise time, is another excellent choice for the lightning susceptibility tests required in RTCA/DO160. Stop by booth 727 to see what Pearson Current Probe will best meet your requirements.

Rigol Technologies

Booth 434

Get Precompliance EMC Measurements beyond 7 GHz with Rigol's new Spectrum Analyzers

Rigol Technologies new additions to the successful DSA800 series of spectrum analyzers now extends up to 7.5 GHz with the same unprecedented value customers have found in the popular DSA815. With the new 3.2 and 7.5 GHz instruments engineers can investigate the full range of EMC requirements with their Rigol spectrum analyzer. Additionally, Rigol's DSA1000 series spectrum analyzers are available with frequency ranges up to 2 and 3 GHz and these come with free support for the Quasi-Peak detector and EMI precompliance measurements.

In today's design process, compliance testing has become a critical task, yet each compliance lab trip can potentially cost thousands of dollars. Before going to the expense of another failure at the test lab utilize one of Rigol's spectrum analyzers to pretest your devices for hot spots, shield problems, design issues, and component interactions. With options starting at $1295 and new models spanning the complete EMC spectrum for most devices, the DSA800 series, redefines the product category by setting new standards for performance and price. Rigol DSA800 series spectrum analyzers save significant time and money… and it pays for itself by reducing failures at the compliance lab.

Rohde & Schwarz

Booth 402

Rohde & Schwarz is one of the world's largest manufacturers of electronic test & measurement, communications, and broadcasting equipment. EMC and EMI test equipment and systems from Rohde & Schwarz determine the causes and effects of electromagnetic interference.

With over 40 years of EMC and EMI measurement experience, Rohde & Schwarz's broad EMC & field strength test equipment product portfolio provides accurate results across a wide 3 GHz to 67 GHz frequency range.

Rohde & Schwarz not only offers EMC, EMI, EMS and EMF test equipment for pre-compliance and full-compliance measurement, but it also provides customers with complete turnkey systems. Rohde & Schwarz test solutions significantly enhance productivity and product performance by enabling precise results to be achieved when measuring complex waveforms.

For more information, visit www.emc.rohde-schwarz.com.

2014 Exhibitor Show Stoppers

Schlegel Electronic Materials

Booth 726

Schlegel Electronic Materials has been a global leader in the design and production of EMI shielding products since 1987. Initially, with the invention of the Conductive Fabric Over Foam core gaskets, we have now created more than 300 Profiles from gaskets with PSA to a myriad of clip on and pop fit gaskets made with a variety of conductive fabrics designed to meet your low and high shielding performance requirements. Schlegel revolutionized the approach to simple and complex shielding challenges in electronic devices for automotive, avionics, medical, computers, telecommunications, military, and commercial equipment. Today, Schlegel Electronic Materials, as a world leader in the supply of a diverse range of EMI shielding products, now offers a complete line of shielding products.

Spira Manufacturing Corporation

Booth 303

Newest InSpiration in EMI shielding!

- Come by booth #303 for an EMI Educational DVD by one of the leaders in EMI Shielding (FREE while supplies last!) "EMI Shielding Gasket Selection, Testing & Effective Use." It covers the requirements to select the proper EMI gasket to last the LIFE of a system and explains the importance of choosing a compatible gasket and joint surface to avoid corrosion. It also details and evaluates the accuracy of Shielding Effectiveness Test Methods and introduces a more effective Transfer Impedance Test Method.
- See our newest product inSpiration including Spira's EMI & Environmental Connector-Seal Gaskets - the unique Spira design provides the BEST environmental seal and EMI shielding for flange mounted connectors.
- Also see our Honeycomb Fan Filters and ask us about our patented blending process that makes them top quality and cost effective too.
- Talk to the EMI technical experts on your specific shielding applications.
- And don't forget your FREE boomerang – Spira has something for everyone!!

All products manufactured in California. ISO9001:AS9100 Certified.

www.spira-emi.com/whatsnew

Teseq Inc.

a unit of AMETEK Compliance Test Solutions

Booth 519

Serving the global electronics community, Teseq delivers test equipment, test systems, and end-to-end solutions, especially for fast-evolving technology sectors that demand rapid, reliable results in compliance with current standards. Teseq's test systems are guaranteed to be standards compliant. Its systems accelerate product development and production as well as deliver immediate and reliable results.

Teseq's systems and solutions provide compatibility, connectivity, ease of use, and sustainable hardware and software. With a broad product suite, Teseq employs advanced technologies and offers modular test system architectures that enable the construction of comprehensive, integrated, and expandable test systems with significant ROI.

The company's user-friendly application software enables the use of convenience features that enhance efficiency and provide low-cost and customized solutions. The company also offers a worldwide network of experts to provide customers with rapid responses and effective communication. Teseq now operates internationally recognized accredited calibration laboratories for calibration services around the globe.

Teseq is now part of AMETEK Compliance Test Solutions, a unit of AMETEK, Inc., a leading global manufacturer of electronic instruments and electromechanical devices. With four product brands, Teseq, IFI, MILMEGA and EM Test, it offers the world's most comprehensive range of EMC systems for immunity and emissions testing.

ADVANCED SEMINAR SERIES

BEYOND THE BASICS OF EMC AND SI

October 2014 | Massachusetts

Gain a greater understanding of the fundamental physics involved in EMC and SI. Develop decision making skills that contribute to successful project outcomes.

Start Solving your real-world engineering problems today!

Course Overview

This course is intended for working engineers who are interested in using the latest state-of-the-art tools to help meet project cost and schedule requirements. It will also be of value to managers and engineers who are interested in obtaining a better understanding of electromagnetic computational modeling so they can better evaluate which commercially available software tool would best suit their needs.

Meet Dr. Bruce

Dr. Bruce Archambeault is an IEEE Fellow, an IBM Distinguished Engineer Emeritus and an Adjunct Professor at Missouri University of Science and Technology. He received his B.S.E.E degree from the University of New Hampshire in 1977 and his M.S.E.E degree from Northeastern University in 1981. He received his Ph. D. from the University of New Hampshire in 1997. His doctoral research was in the area of computational electromagnetics applied to real-world EMC problems. He has taught numerous seminars on EMC and Signal Integrity across the USA and the world, including the past 12 years at Oxford University.

Course Topics

EMC Fundamentals

- Common Mode Noise from High Speed Differential Signals
- High speed board-to-board connector analysis
- Electromagnetic Band Gap Filters
- PCB power decoupling myths busted

Signal Integrity

- Using lossy materials to mitigate EMI at GHz frequencies
- Survey of EMC/SI simulation techniques and tools and their strengths/weaknesses

Decision Making Tools

- Breaking real-world complex problems into realistic simulation models
- Validation of modeling/simulations
- Possible pitfalls with specific vendor modeling tools

This event is hosted in partnership with

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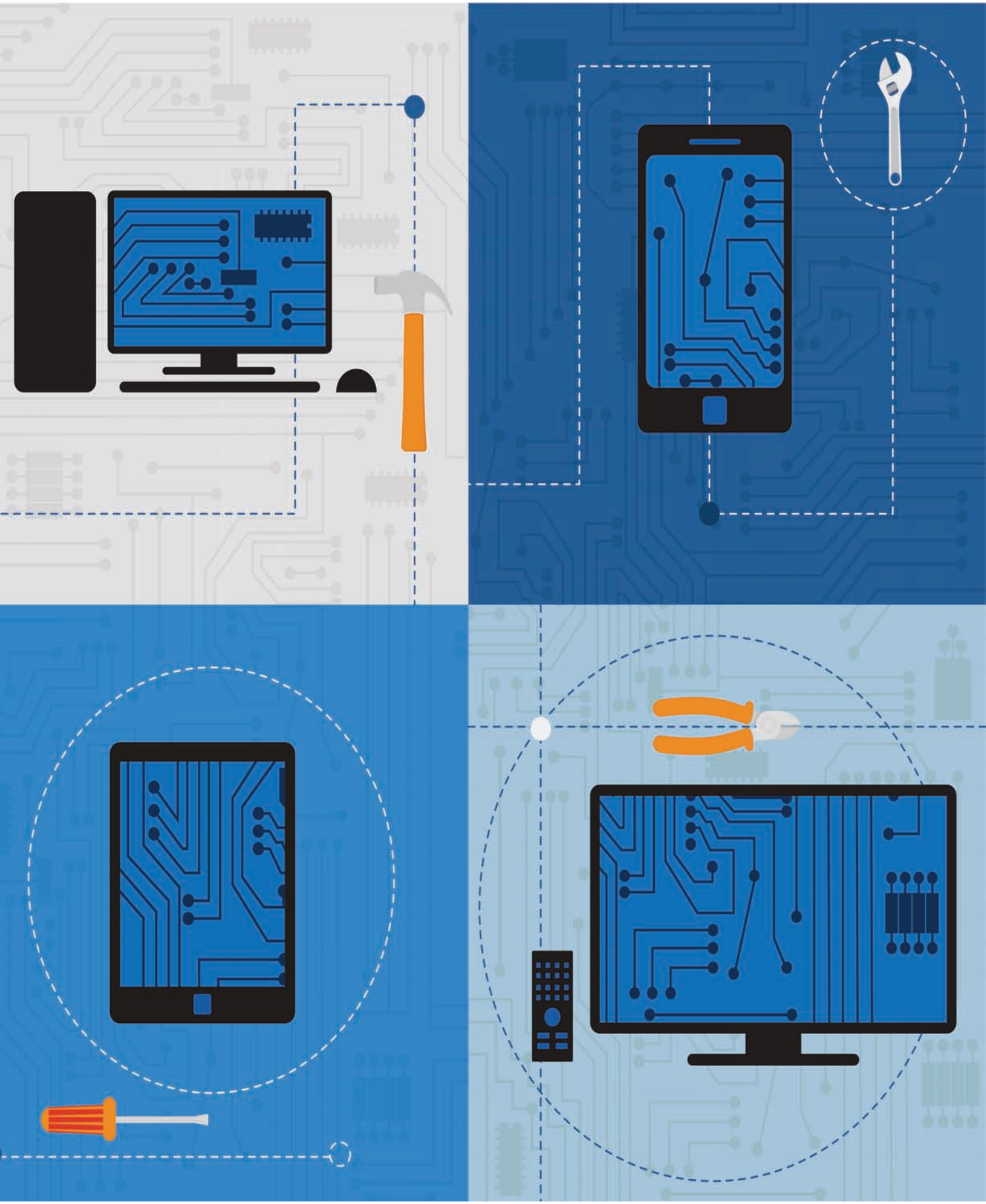
To register or learn more visit
incompliancemag.com/events/advancedemcsi



Using EMC Tools to Help Designs Pass the First Time

BY BRUCE ARCHAMBEAULT, PhD

This is a true story. When I first joined IBM as an EMC engineer, my new manager handed me a document titled 'EMC Design Process at IBM' and asked me to comment. I quickly read the short document that basically said that the EMC engineer would provide the design engineers a list of EMC rules, which would be largely ignored.

The product would be built and when tested in the EMC laboratory it would fail. The EMC engineer would then spend anywhere from a week to a month to try various band-aid fixes (not the term used in the document, of course) before making recommended changes back to the design team. The changes (or some of the changes) would be implemented, and a new version of the product built. Testing would be repeated, and this process might need 2-3 iterations before completed and the product was ready to ship.

I handed the document back to my brand new manager, and asked if he had fired this EMC engineer yet? He was shocked, and told me this was one of the more senior EMC engineers! I told him that if I told my boss I expected to fail every time I *should* be fired. Of course, this was not the design process that was desired, but rather the one that had evolved.

Using software tools helped IBM turn this process around completely. So now, instead of failing the first time, every time, products usually pass the first time in the EMC chamber! Using these tools (along with education of the design engineers) made all the difference!

There is a variety of tools available and they operate at different levels. This article will discuss using these tools and point out the benefits and where they can be used most effectively in the design process. Many people had told me they have no time to learn how to use new tools. I equate this to a story a friend of mine told me years ago. A woodsman is tasked to clear five acres of forest in a very short time. He begins with his double-bladed axe and is working hard when someone tries to show him a new invention, called a chain saw. The woodsman replies that he has no time to learn new tools! He is busy with a short deadline!

BEFORE THE DESIGN BEGINS – SIMULATION

There are many EMC rules, and some of them are in direct conflict with each other! These rules need to be evaluated to see which ones will work for your particular product family.

For example, EMC rules for large main frame computers may or may not apply to a small hand held device where large metal shields and finger stock can not be used. Furthermore, some published EMC design rules do not follow physics! All rules need to be examined to make sure that they make sense, and are appropriate for your product types.

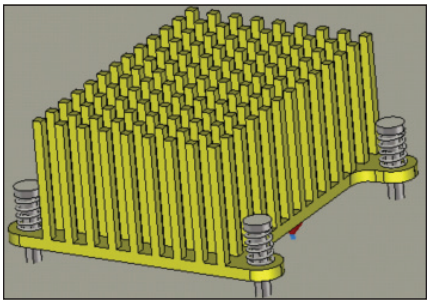


Figure 1A: Heatsink example

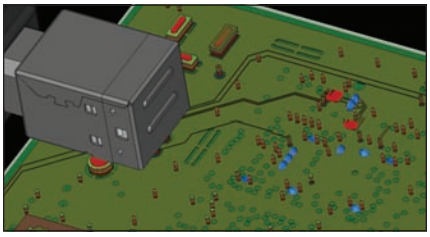


Figure 1B: PCB example

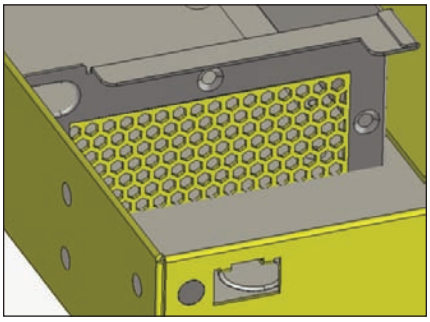


Figure 1C: Internal shielded air vent example

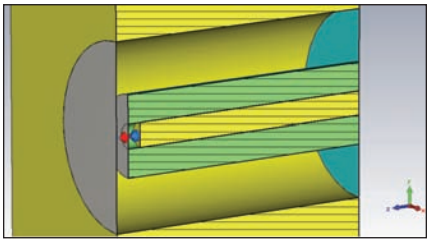


Figure 1D: Coax cable example

One of the best ways to validate rules is to use full wave simulation software. There are a variety of vendors offering a variety of different software simulation tools. These tools use a variety of different simulation techniques, each having areas where they excel and areas where they are not the best tool for the job. A tool box approach is strongly recommended so the user will have a variety of tools at their disposal and can optimize their particular simulation for the type of problem at hand. Figure 1 shows a number of different possible problems[1] that might be simulated and represent only a small number of examples possible for simulation tools. However, each of these problems are very different, and so a different simulation technique would be best for some of the problems. There is no *one size fits all* in the world of simulation techniques.

For example, the heatsink in Figure 1A would usually require an open boundary condition and would likely be easiest to simulate using Finite-Different Time Domain (FDTD), Finite Integration Technique (FIT), or the Method of Moments (MoM). PCB problems often require dielectric materials to be included as well as open boundaries, so FDTD or FIT might be best suited. If the PCB problem includes many discrete components (such as capacitors, equivalent inductances, etc.) then the Partial Element Equivalent Circuit (PEEC) would probably be the most efficient way to perform the simulation. Internal shielded air vents (Figure 1C) could easily be solved with FDTD, FIT, or the Finite Element Method (FEM). Problems such as the coax cable in Figure 1D might be optimized using FEM, since it is a problem with metal boundaries (open boundaries not needed) and the non-rectangular shape of the grid can be well suited to curved surfaces.

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Very seldom is a single simulation run to determine pass/fail of a system. Usually there are a family of simulations, each with something slightly different, to help define the grey area between the absolutes. A classic example would be to determine how many posts are required to connect the heatsink in Figure 1A to the ground-reference plane in order to reduce the emissions over a certain frequency range. In this example, a number of simulations would be performed, each with a different number of grounding posts, to observe the frequency range where the emissions are reduced. Using these multiple simulations, a set of design guidelines can be created that are optimized for the specific type of product that is to be designed.

A word of caution should be mentioned here. Simulation tools are very powerful and useful. They can help fill in the grey areas, and also help understanding of the engineers and non-engineers who often must be convinced to implement a certain design rule even though it might add a little cost, weight, etc. to the product. However, all simulations should be validated. The software vendors spend a lot of time to insure their tools give an accurate answer to whatever question was asked. However, the user is often the primary source of error. A good rule of thumb about validating simulations: if you have never made a mistake in your life, you might be safe to ignore the recommendations for validation!

One of the primary potential sources of error are the types of source used in the simulation. Wave ports are an easy source of error. If the boundaries of the wave port are too close to a microstrip (for example), then the fields will interact with the perfect electrical conductor boundary and incorrect wave modes are established (see Figure 2).

Validation can take many forms. Probably the most common, and often the most difficult is to use measurements to validate the

simulation. After all, measurements are a great emotional comfort! However, there are a lot of measurement artifacts that may or may not be included in the simulation. Antenna patterns, ground plane reflections, and equipment input impedance loading for direct measurements can all make it difficult to compare measurements and models unless all these effects are included in the simulation.

Another popular way to validate simulations is to use a completely different simulation technique. For example, using FDTD and MoM for the same problem will use very different physics for the simualtion. Of course, this means the simulation must be run twice, but if both simulations give the same results, then the user must have understood the problem well enough to create models for the different simulation techniques, and the results are probably good.

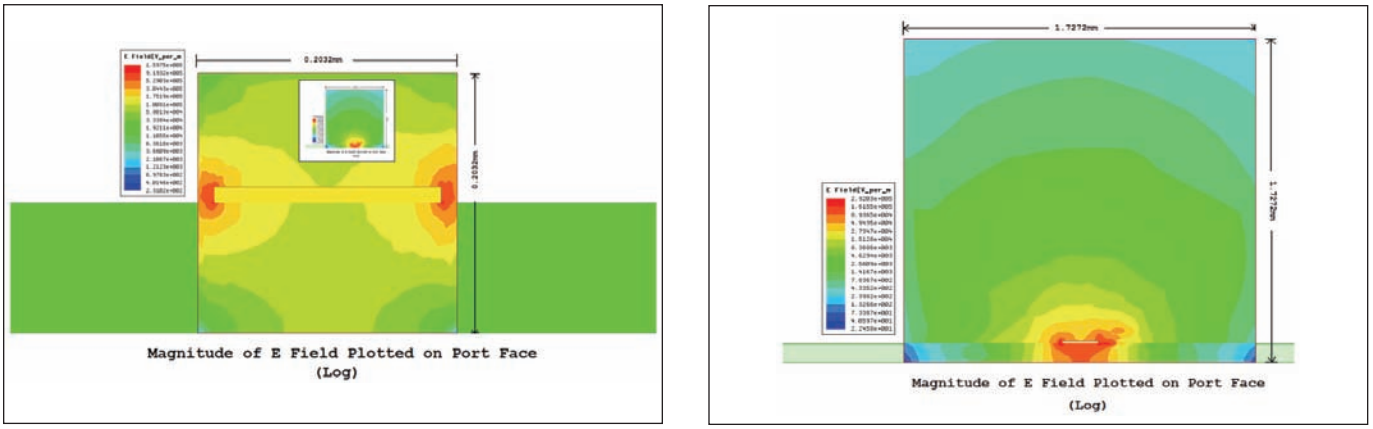

Figure 2: Incorrect and correct electric fields in wave port

BEFORE THE DESIGN BEGINS – TRAINING

Training is an important part of the preparation for the coming design project. While there are a number of training seminars available, it is important to make sure that it is not just a listing of EMC design rules collected over the years, but rather training that explains how the physics work, why the rule is important, and how to determine if the rule is appropriate for this product/project or not. This does not mean that a lot of heavy math is required! We can leave the math for the universities and those who love to solve equations. Understanding the physics means that the students should learn the fundamentals of how current flows, the true nature of ground vs. return current path, how shielding really works, and especially a good understanding of inductance concepts. Remember, once the seminar is completed, the student/engineer must rely on the knowledge gained during the seminar to be able to know when a rule must be enforced, when the rule can be bent a little (and how far) or when a rule does not make sense for the product under design.

DURING THE DESIGN – RULE CHECKING SOFTWARE

Once the design has begun, there is seldom time to do multiple simulations, etc. The design rules that were vetted prior must be used since time is usually short. When designing many layer high speed printed circuit boards (PBCs), it can be impossible for an engineer to double check all the proper design rules were followed. There are software tools available that can read the PCB CAD design file, quickly check against a wide variety of EMC and Signal Integrity (SI) design rules, and highlight the areas where design rule violations occur.

These software EMC/SI design rule checking tools usually include a variety of rules that are more complex than the simple manufacturability Design Rule checkers (DRCs) that are included in PCB layout CAD tools. For example, a typical EMC design rule is that high speed traces must not cross a split in the nearby reference plane. However, depending on the data rate, rise time, etc. for the signal on that trace, a stitching capacitor might be used to allow the return current to cross from one plane to the other *if* the capacitor is located within a certain specified distance from the crossing point. Complex rules, such as this one, are too complex for the DRC in the CAD tools.

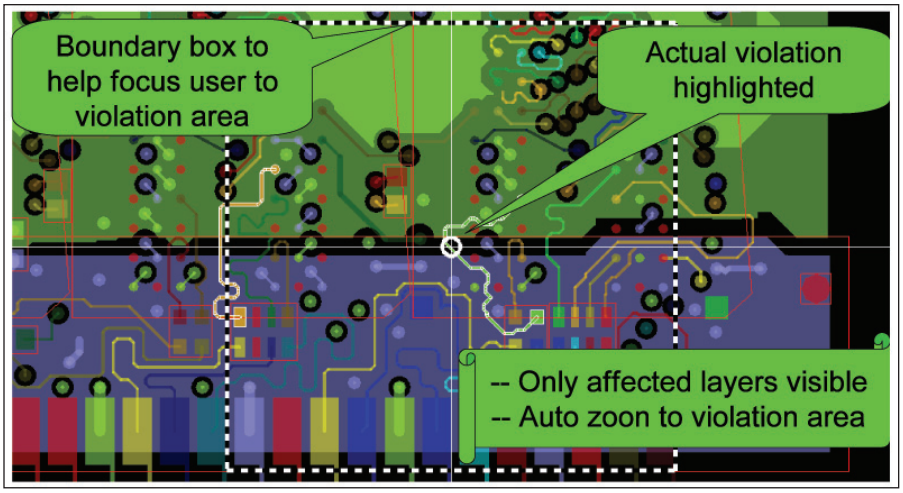

Figure 3: Example of EMC Rule checking tool Violation Viewing

One of the major advantages of these EMC/SI rule checking tools is that they will highlight the area where the violation occurs, turning on only the PCB layers involved, and often even drawing a box around the violation to draw the engineer's eyes to the right location quickly. Figure 3 shows an example screen shot[2] of a violation of the trace crossing a split reference plane rule.

Typical rules for printed circuit boards cover a wide range of potential violation, including distance from decoupling capacitor (and IC) pads to vias, decoupling capacitor density, traces close to the edge of a PCB, distance from signal via to return current via, and many more. Users can tailor the limits for the various rules depending on the product specific requirements, data rates etc.

Rule checking software tools are usually very fast, doing an entire high speed PCB in minutes or at most, tens of minutes. This is in contrast to most full wave simulations which typically take hours or even days to complete. The full wave simulation gives a complete solution to Maxwell's equations, vs. a relatively simple geometry checking against a rule. Therefore the rule checking tools can be incorporated into the typical product design process easily and quickly. The visual aid of the violation viewing allows the engineer to quickly evaluate which violations are important and to make the necessary changes before building the hardware and possibly failing during EMC testing.

AFTER THE DESIGN IS COMPLETED

Once the product has been successfully designed, built, and passed the EMC testing, feedback into the EMC rules can help the next product development as well as help reinforce

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the importance of the tools used before and during the design process. Of course, if the product happens to fail during initial EMC testing, once the offending portion of the product is determined, the feed back into the EMC rule checking tool will tighten the appropriate rule limits as necessary.

SUMMARY

A variety of software tools are available to design engineers that can help increase the probability of passing EMC requirements the first time. Full wave tools are most useful to help understand the shades of grey for various design approaches, and are less useful to predict the pass/fail performance directly (due to the excessive amount of details required and excessive simulation run times for such complex models).

Rule checking software tools are very fast, accurate and helpful to identify potential design issues for high speed complex PCBs. The engineer still must make a decision about the relative importance of the violation and whether or not it must be corrected. The visual feedback and focusing on a violation allows engineers to make quick and informed decisions.

The bottom line is that none of these tools replace the need for the engineer to have a fundamental understanding of the physics of high frequency electromagnetics. These are simply tools to help the engineer, not replace the engineer! Imagine taking your auto to a repairman who knows nothing about engines, but has a full set of mechanics tools. Equally absurd!

In this time of short design cycles, product cost pressures, and increasing RF noise from wireless devices etc., no one can afford to *not* use these tools to their fullest potentials. Don't be like the woodsman and ignore things that will help you be successful! IN

(the author)

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is an IBM Distinguished Engineer at IBM in Research Triangle Park, NC and an IEEE Fellow. He received his B.S.E.E degree from the University of New Hampshire in 1977 and his M.S.E.E degree from Northeastern University in 1981. He received his Ph. D. from the University of New Hampshire in 1997. His doctoral research was in the area of computational electromagnetics applied to real-world EMC problems. He is the author of the book "PCB Design for Real-World EMI Control" and the lead author of the book titled "EMI/EMC Computational Modeling Handbook".

Shielded vs. Unshielded Square Magnetic Field Loops for EMI/ESD Design and Troubleshooting

Square magnetic loops are very useful troubleshooting and noise investigation tools for electronics. They are adequate for coupling signals into a PCB or measuring noise in a circuit. This article describes the construction and characteristics of unshielded and shielded magnetic loops as well as comparing them.

BY DOUG SMITH AND ARTURO MEDIANO

Often the simplest of tools can be used to successfully track down a problem in a circuit. Magnetic loops (magnetic near field probes) are very useful troubleshooting and noise investigations tools for electronics both in emissions and susceptibility subjects [2]-[3]. They can be found from many vendors [4]-[5] both shielded and unshielded usually in round forms.

Square loops are very useful for making measurements of circuit voltage and current while either square or round loops are suitable for measuring magnetic fields in free space [6].

A magnetic field probe built from a short piece of wire is very useful for making Mdi/dt voltage measurements in circuits, to measure the relative phase or time delay between two signals, to locate a noise source or to inject signals into a path on a circuit board. The application of this technique to impulsive signals has been made practical with the advent of relatively inexpensive, portable, and fast digitizing scopes.

Occasionally, a shielded loop is called for and usually shielded loops are made from semi-rigid coaxial cable.

In this article square unshielded wire loops are compared to shielded solutions including simple techniques to build them in your lab. Some examples are included to show that unshielded loops often work as well as shielded loops in some applications, especially for injecting signals into circuits.

UNSHIELDED MAGNETIC LOOPS

Figure 1 (page 74) shows the construction of a paper clip probe. Two minutes, some heat shrink tubing, and a pair of needle nose pliers are all that

is needed. A BNC barrel adapter makes a convenient mounting for the loop. The result is a square shape, covered with insulation, forming an unshielded magnetic loop probe.

A conductor carrying a current, i, will have a voltage drop across it given by:

$$e1 = Ldi/dt + Ri \quad (1)$$

where L is the inductance per unit length of the conductor; R is the resistance per unit length and e1 is the voltage drop per unit length. The unit length will be small compared to a wavelength at the highest frequency of interest. That means the conductor is electrically short.

At frequencies above a few hundreds of kHz, the resistive component becomes negligible and (1) simplifies to just:

$$e1 = Ldi/dt \quad (2)$$

A conductor nearby the current carrying conductor, such as a side of the square loop above, will pick up an open circuit voltage of:

$$e2 = Mdi/dt \quad (3)$$

where M is the mutual inductance between the current carrying wire and the nearby wire per unit length.

Since L and M are constants, then e1 and e2 are only different by a constant. M must be smaller than L for two parallel wires (due to the magnetic flux that flows between the wires instead of enclosing both), so e1 is a lower bound estimate for the magnitude of e2 and has the same wave shape.

Using that principle, a simple square loop, such as the one above, can be used to estimate the voltage drop across conductors. When the probe is held up to a conductor carrying high frequency current, the probe's open circuit output voltage is a lower bound for the voltage between the corners of the probe along the current carrying conductor as measured by the magnetic field captured in the area of the loop.

The probe should be connected to an oscilloscope or spectrum analyzer using a coaxial cable terminated in its characteristic impedance. This resistive load on the loop in combination with the self inductance of the loop forms a low pass filter on the probe output. For a loop with sides of 1 cm, this corner frequency will be between 200 and 300 MHz.

Possible uses are estimating the drop across bonding wires and lead frames of integrated circuits [7] or measuring noise effects on a printed wiring board [8].

AN EASY TO BUILD SHIELDED MAGNETIC LOOP PROBE

Occasionally, a shielded loop is called for and usually shielded loops are made from coaxial cable. The loop is formed by making a square from the coax with a gap and soldering inner conductor to shield in point (A) as in Figure 2.

Figure 3 (page 76) shows the construction steps for quickly and simply making a shielded magnetic loop in the lab.

Step 1: Take a piece of stiff copper wire or rod (16 gauge is best for fitting in BNC connector). The wire is covered with heat shrink tubing and then copper tape is wound around the heat shrink tubing so that it is covered with three layers of tape. In that way, when the wire is bent to form a square loop, the outermost layer may crack slightly. Since the crack is only on the outside of the bend and it is small, it does not pose much of a problem because the gap will be closed by the underlying layers.

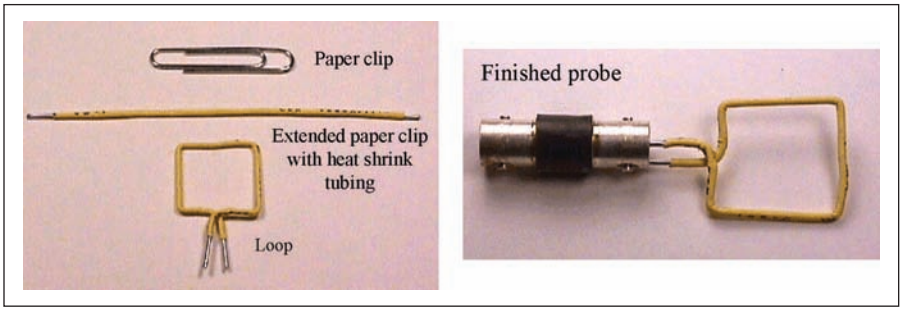

Figure 1: Magnetic field probe build from a paper clip.

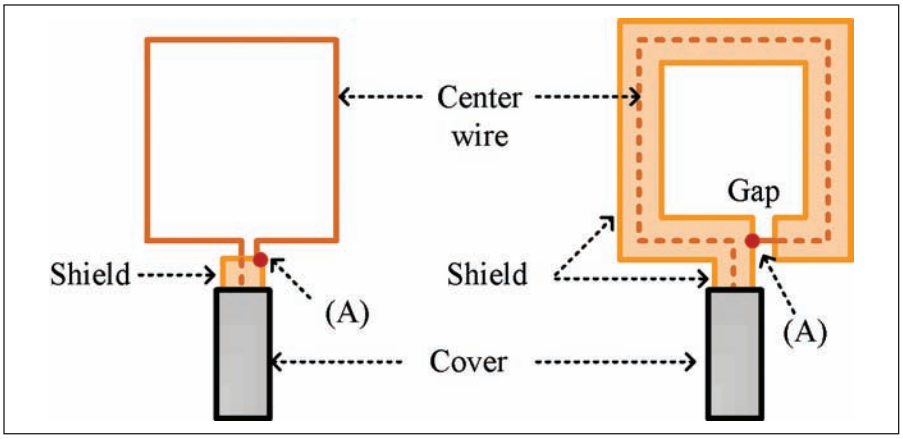

Figure 2: Square loop from a coax cable unshielded (left) and shielded (right).

Have Some EMC Pie

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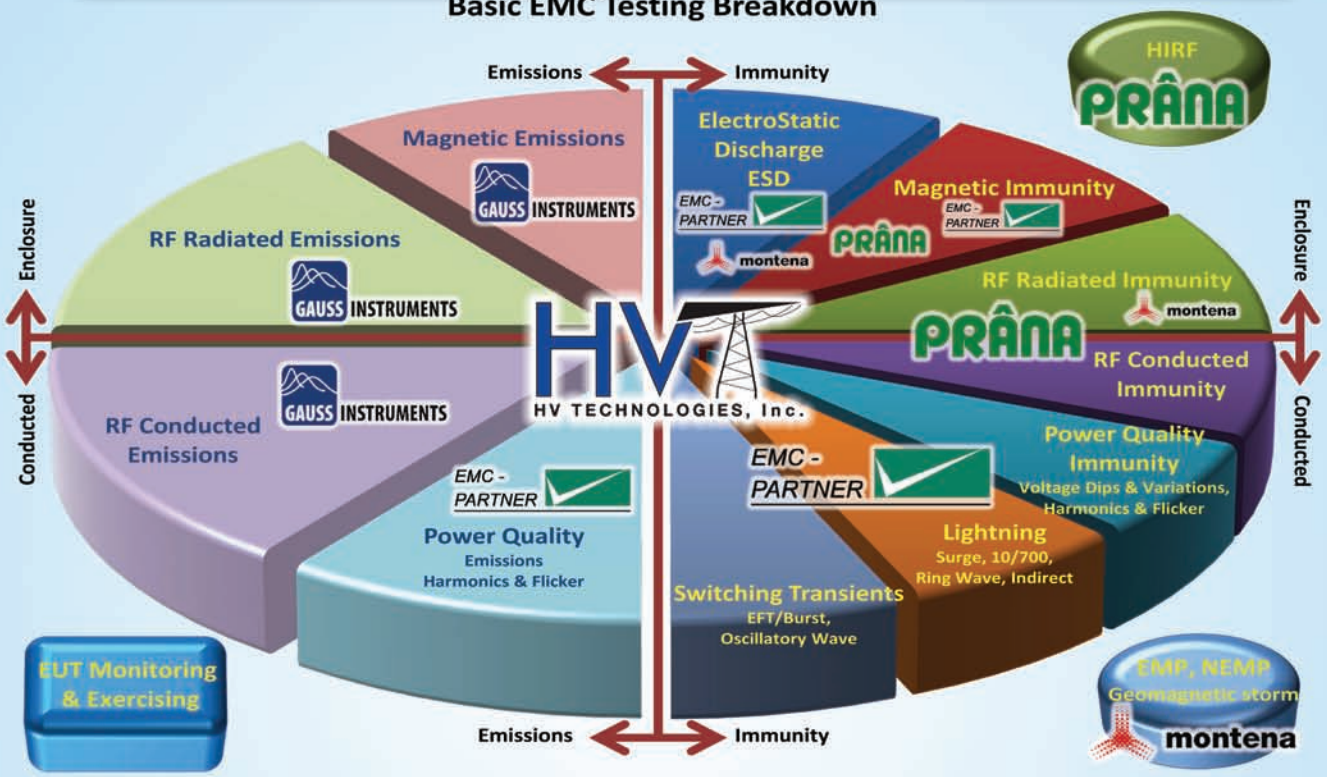
Basic EMC Testing Breakdown



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The characteristic impedance of the coax formed by the foil and stiff wire is probably not 50 Ohms like the feed cable likely is. But, it does not matter much since the two parasitic transmission lines formed by the two halves of the loop and their shields are un-terminated at the gap in any event.

Step 2: Put a second layer of heat shrink tubing over the assembly.

Step 3: The loop is then bent and one end inserted into a BNC connector. Both the other end of the wire and copper tape are soldered to the side of the BNC connector.

Step 4: Next, the end of the BNC connector and two ends of the loop are covered in copper tape which is soldered to the copper foil of the loop. The added copper tape may also be soldered to the BNC connector as well.

Step 5: Finally, the assembly is covered with heat shrink tubing to make the final product. The position of the gap is very important to the performance of the shield. A shielded loop that is not symmetric (e.g. gap at base of loop) will be somewhat sensitive to E fields. E field induces current in shield so there is voltage drop across shield that will be induced into center conductor loop [8].

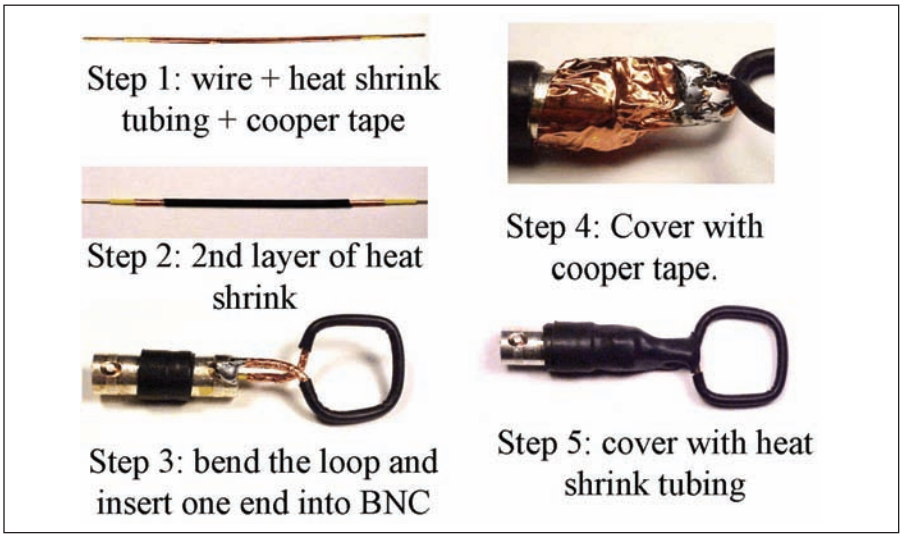

Figure 3: Building a shielded loop.

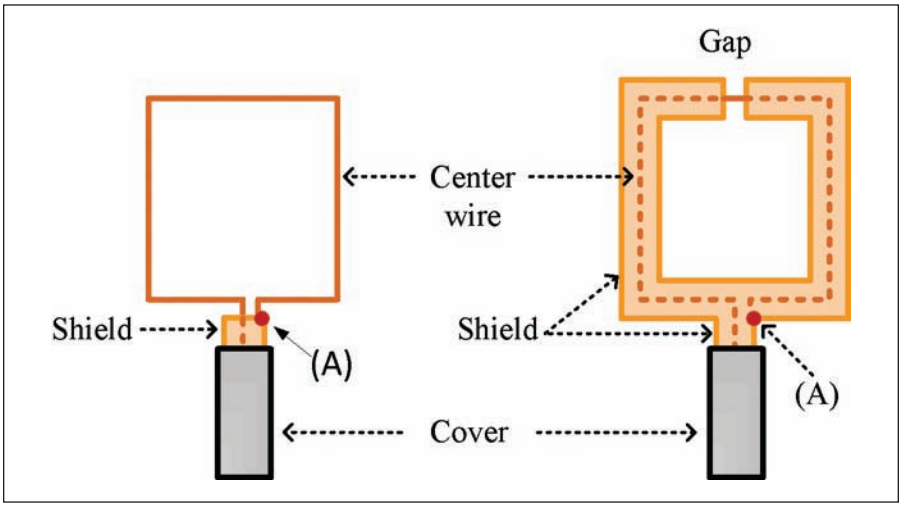

Figure 4: Square loop from a coax cable unshielded (left) and shielded (right).

Better shielding effectiveness is obtained if the gap is located in the middle of the loop as shown in Figure 4. In that way, electric field symmetry is obtained.

The loop is formed by making a square from the coax with a gap placed symmetrically in the middle of the loop as in Figure 4. The center wire is connected again to shield in point (A).

The loop's shielding may be tested as described in [8] by applying an electric field source to the loop. The loop should be least sensitive over the gap with the maximum sensitivity just off the gap in either direction. The sensitivity should gradually fall off as the electric field source is moved toward the side of the loop (at the BNC connector) opposite the gap.

SQUARE SHIELDED LOOP WITH SEMI-RIGID COAX

One can minimize the work required to build a shielded loop by buying a short length of small semi-rigid coaxial cable with SMA connectors already mounted on each end [9]. The assembly can be cut in half to make two shielded loops saving the trouble of mounting the connectors on the semi-rigid cable.

Use a small diameter semi-rigid cable as the smaller the semi-rigid coax diameter, the better coupling between the center conductor of the coax and the adjacent circuit.

For our purposes, one can think of the loop as starting with a straight length of semi-rigid coax of small diameter with an SMA connector on one end and shorting the center conductor to the shield with solder at the other end. Then the loop is bent around to form a square (being careful not to bend the coax too sharply at the corners) and the solder shorted end is soldered back on the coax so as to form a square symmetric loop. A small gap is made in the shield in the middle of the side opposite the feed line. Figure 5 shows

a square shielded loop built [8] into a plastic housing which has been split to show the loop inside.

Shielding against electric fields is best achieved if the field is symmetric around a line from the solder junction to the gap in the shield, a condition that is met when a shielded loop is used to measure a field much further from a source than the size of the source itself.

To help ensure electric field symmetry when the loop is used on the surface of a circuit board in the near field, the gapped side should be held against the board with the loop itself perpendicular to the board. And therein lies the main reason for using a square loop, most circuit boards are flat and one side of the loop can be held directly against a circuit board resulting in better coupling to the circuit than a round loop of the same size would give.

The performance of a loop constructed in the previous section (Figure 3) should compare favorably with one made from semi-rigid coaxial cable up to the first resonance of the loop. The first resonance occurs at the frequency where the circumference of the loop is one half wavelength. At this frequency,

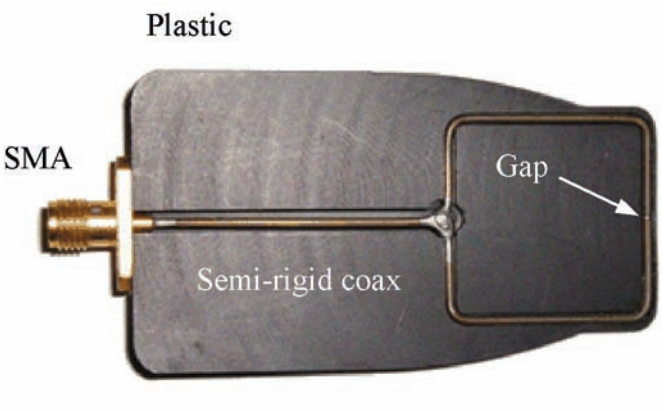

Figure 5: Cutaway View of a Square Shielded Loop

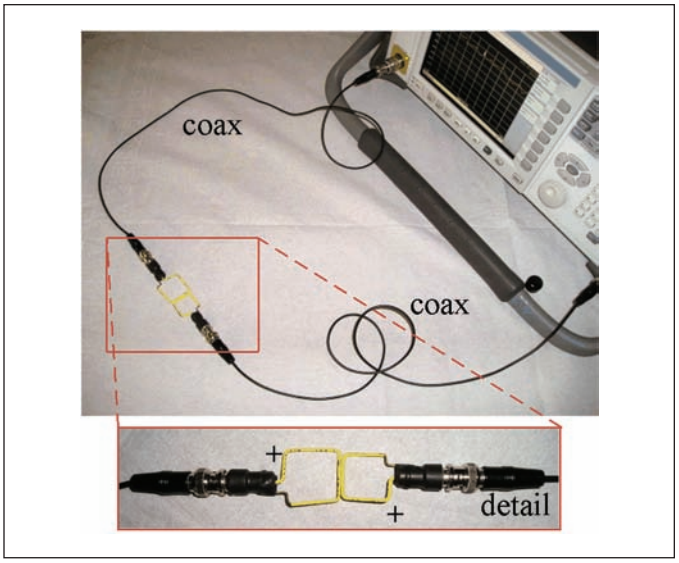

Figure 6: Measuring loop to loop coupling for a pair of square shielded loops (end-to-end) in reversed direction.

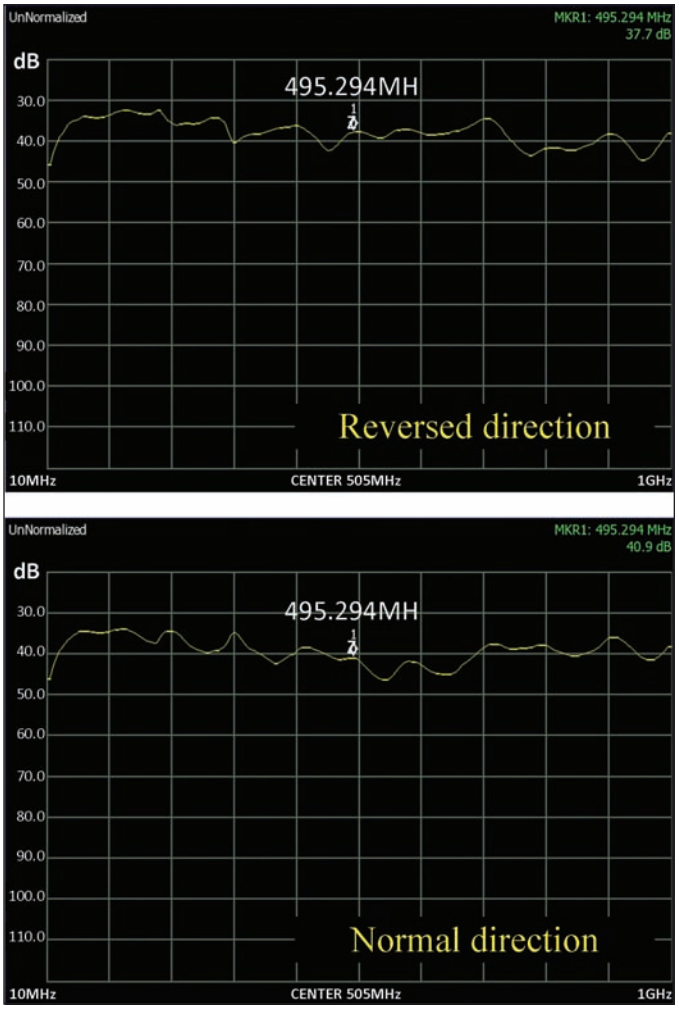

Figure 7: Response end-to-end loops reversed and normal directions.

the parasitic transmission lines formed by the two shields and the underlying stiff wire are one quarter wavelength un-terminated stubs.

Square shielded loops can be used both to measure many kinds of signals and to inject small RF signals (~0 dBm) into circuits. Some of the techniques involve coupling high voltage/current short pulses into a circuit. For that application shielded loops made from small semi-rigid coax are not a good option for this purpose because of possible voltage breakdown in the coax and even heating under some conditions. For large pulses, use unshielded stiff wire loops.

PARASITIC COUPLING BETWEEN UNSHIELDED WIRE LOOPS

Unshielded wire loops are inexpensive and easy to build but capacitive (electric field) coupling has always been a concern when using these simple loops. Coupling between unshielded wire loops is investigated, included parasitic capacitive coupling.

Figure 6 shows an overall view of the test setup comprised of a pair of square wire unshielded loops connected to an Agilent N1996A spectrum analyzer set up to perform a two port insertion loss measurement. The two loops are about one inch, a few cm, on a side and they are positioned end-to-end.

In Figure 6, the loops are reversed in position, that is the + side of one loop (center conductor of BNC) is opposite the - of the other loop (ground side of BNC). This will be referred to as the "reversed" direction. By inverting one of the loops the "normal" direction is obtained (+ side to + side of the loops). Data is presented for both directions.

If only magnetic field coupling existed between the loops, the change resulting when one of the loops is reversed would be a 180 degree phase shift in the output, which would not change the spectrum analyzer plot.

If significant capacitive coupling existed between the loops, the output of the receiving loop would be the combination of the inductive and capacitive components. Since the phase of the inductive component is reversed when one loop is reversed but the phase of the capacitive component is not, the spectrum analyzer plot will be different.

In other words, capacitive coupling between the loops would cause the normal and reversed positions of the loops to yield different responses.

Figure 7(a) and 7(b) show the loop-to-loop transmission from 10 MHz to 1 GHz for the reversed case and normal cases of the two loops. No resonance is found, with the frequency response being relatively flat by comparison. The differences are about 6 dB maximum at a few frequencies and the traces are not as smooth as the shielded loops. However the "lumps" in the frequency response are only a few dB in peak amplitude. The relatively flat frequency response in Figure 7 is indicative that simple wire loops may be useful for injecting signals into circuit board paths and cables by inductive coupling. Using loops for this purpose will be covered in parts VII and VIII.

Figure 8 shows the overview of a related case where the loops are overlapped to insure maximum coupling. Notice that the loops are arranged in the normal position as opposed to reversed in Figure 6, that is the sides of the loops connected to the BNC center pin (or shield connection) are both on the same side.

Figures 9(a) and 9(b) (page 80) show the coupling from 10 MHz to 1 GHz for the setups in both the reversed and normal orientations. The difference between the two traces is only a few dB, and without shielding!

Frequency response plots of the coupling between small simple wire loops are reasonably flat.

Parasitic coupling electric field Shielding in square shielded magnetic loops.

We have introduced before that shielded magnetic loops are used to reduce electric field coupling to the

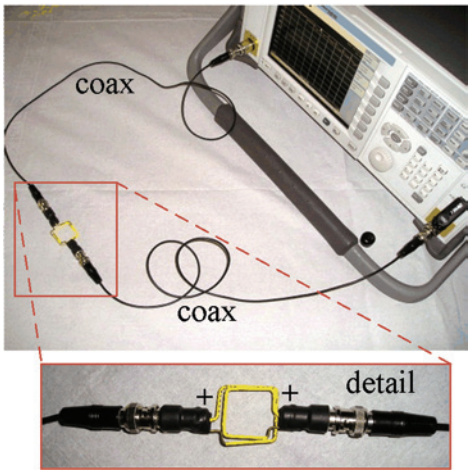

Figure 8: Measuring loop to loop coupling (loops overlapped).

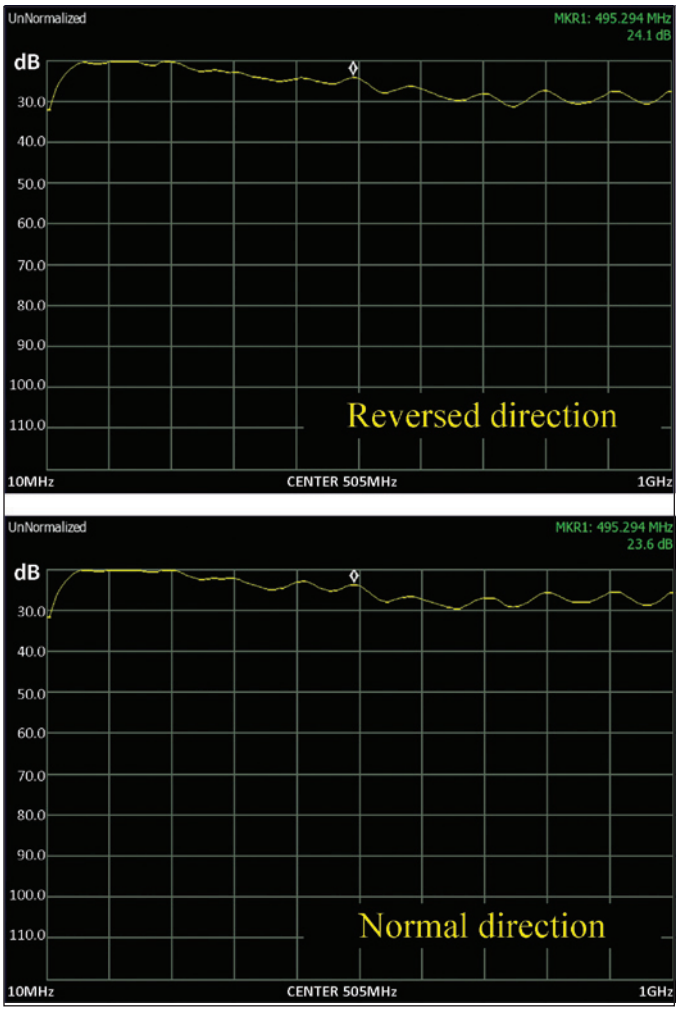

Figure 9: Response of overlapped loops reversed and normal directions.

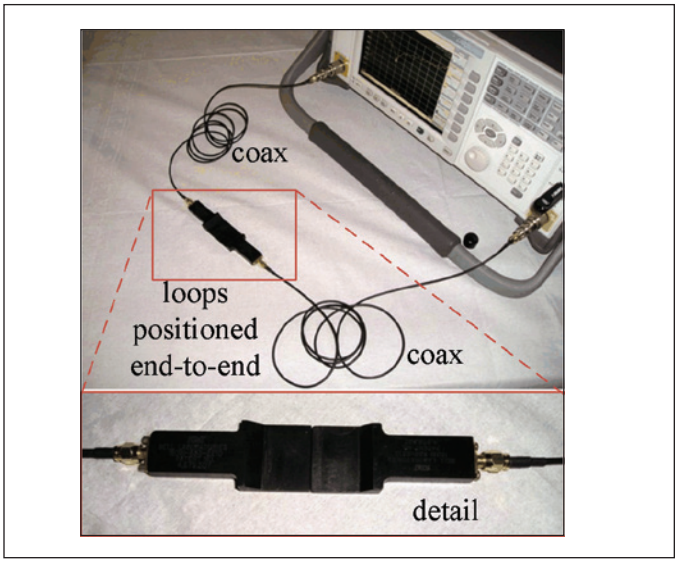

Figure 10: Measuring loop to loop coupling for a pair of square shielded loops and close-up of loops for coupling measurement.

loop and square magnetic loops are useful for coupling signals into a PCB or measuring noise in a circuit. However, significant electric field coupling can still occur with shielded loops. One case of electric field coupling between a pair of shielded loops is presented which results in a significant resonance between the shielded loops. Such a resonance can cause errors in signal injection used for troubleshooting circuits.

Figure 10 shows an overall view of the test comprised of a pair of square shielded loops connected to an Agilent N1996A spectrum analyzer with a tracking generator which is set up to perform a two port insertion loss measurement. The two loops are positioned end-to-end and held in place with paper tape on the back of the loops. The semi-rigid coax used to form the loops is encased in plastic as explained in Figure 5.

Figure 11 shows the resulting plot of insertion loss (un-normalized) between 10 MHz and 1 GHz. Notice the significant dip of around 30 dB at about 394 MHz.

This resonance can be explained with reference to Figure 12.

The capacitance Co between the shield segments shown in Figure 12, form a resonant circuit with the inductance of the two loops. The current path for the resonance is

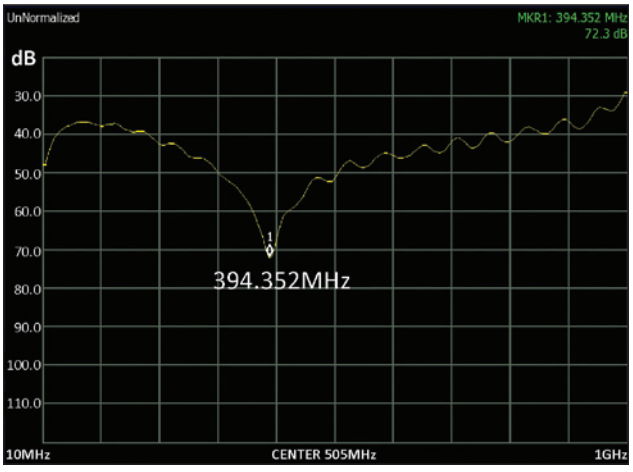

Figure 11: Plot of loop to loop coupling showing resonance.

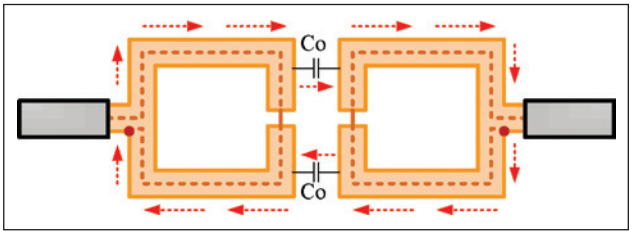

Figure 12: Circuit of parasitic resonance

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Current flowing in the center conductor of the driven loop generates inductive voltage drop (Ldi/dt) around the loop. A shielded cable is nearly an ideal transformer, so the voltage drop on the center conductor under each of the two shield segments is magnetically coupled into the shield segments as Mdi/dt.

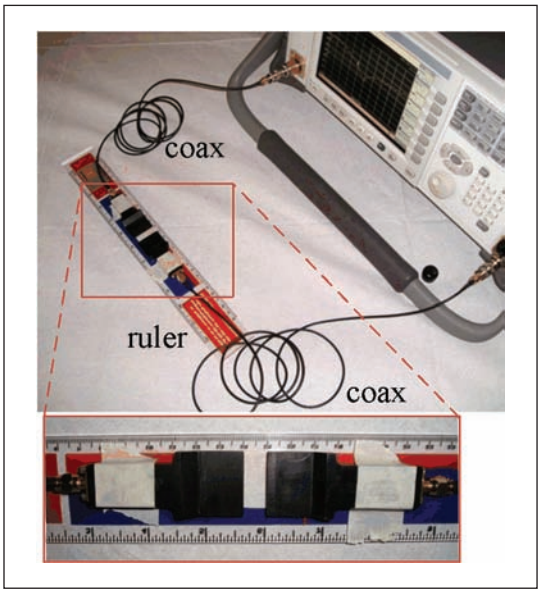

Figure 13: Measuring loop to loop coupling for a pair of square shielded loops at one cm spacing including a close-up.

shown by red arrows. The loops used for this test are one inch on a side, so the effective loop for the resonant circuit is approximately two inches by one inch.

The theoretical calculation of inductance [10] gives a value of about 125 nH for such a loop assuming a wire (shield) radius of 10 mils. The resonant frequency of 394 MHz then yields a capacitance of about 1 pF for the total capacitance in the tuned circuit of Figure 12. Adding ferrite to the coax cables feeding the loops did not change the characteristics of Figure 11 so the current loop of Figure 12 is the controlling feature.

Current flowing in the center conductor of the driven loop generates inductive voltage drop (Ldi/dt) around the loop. A shielded cable is nearly an ideal transformer, so the voltage drop on the center conductor under each of the two shield segments is magnetically coupled into the shield segments as Mdi/dt. The mutual inductance, M, between the center conductor and the shield, is the inductance of the shield itself.

This driving voltage on the two shield segments causes current to flow around the four shield segments coupled by the parasitic capacitance between the loop shields as shown in Figure 12 thus driving the resonant circuit. In this discussion, we are treating the circuit as composed of lumped elements since each segment and the loops themselves are small compared to a wavelength at 400 MHz.

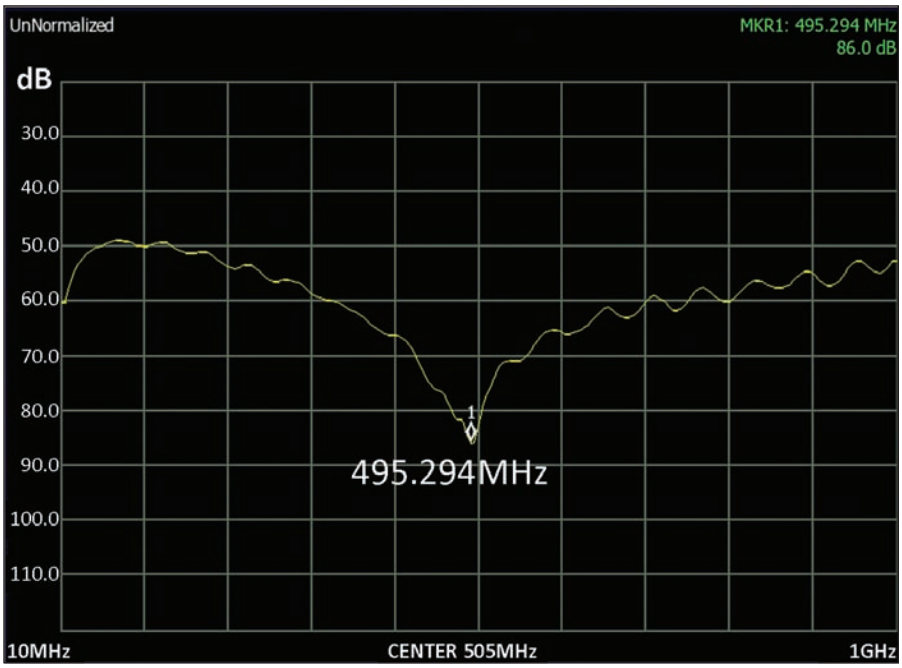

Figure 14: Loop to loop coupling with 1 cm spacing.

If a resonance caused by the current path of Figure 12 is the reason for the dip in plot in Figure 11, then moving the loops apart should increase the resonant frequency. This would happen because the capacitance Co between the loops is reduced. Figure 13 shows the test setup modified to space the loops one cm apart. The two loops are taped to a plastic ruler to maintain the spacing during the measurement as shown in the close-up detail.

The resulting two port insertion loss plot is shown in Figure 14. Note that the resonant dip has moved to about 495 MHz. This would represent a significant drop in capacitance on the order of 40%. As the loops are moved further apart, L gets slightly larger but C gets much smaller. As the distance is increased, the capacitance between all

parts of the loops begins to contribute an increasing portion of the capacitance between the loops complicating the picture somewhat. One would not expect the capacitance to decrease as much as just that of the facing sides as the loops are separated.

The problem is that using a shielded loop can sometimes give a false sense of security that electric field effects are not important. Parasitic capacitance coupled to a shielded magnetic loop can affect its performance. In this case, a resonance was caused that significantly affected the signal induced into a second shielded magnetic loop.

CASE 1: COUPLING TO A PCB

A case is shown where using a shielded loop to inject signals into a path on a circuit board results in a significant resonance whereas using an unshielded wire loop results in a relatively flat frequency response of the injected signal.

Figure 15(a) shows a square unshielded wire loop held up to a path crossing a break in the ground plane of a test board. The injected signal was measured at the BNC connector on the board (left side) for the cases where the loop is positioned as shown and for a 180 degree rotation of the loop and similarly for a square shielded loop, embedded in plastic for strength, as shown in Figure 15(b). Figures 16(a) and 16(b) (page 84) show the measured signal at the BNC connector on the board for the unshielded wire loop in the normal position and for the 180 degree rotated position of the loop respectively. The data was taken

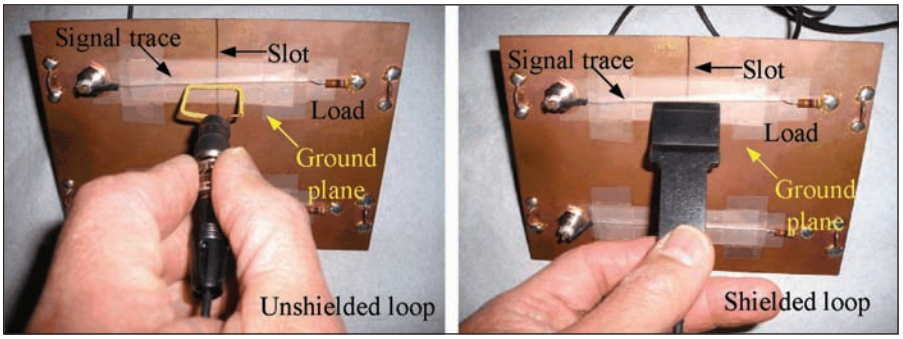

Figure 15: Coupling into a circuit with loop: Unshielded (left) and Shielded (right).

using an Agilent N1996A spectrum analyzer as a two port insertion loss measurement. The square loop was connected to the tracking generator output and the BNC connector on the board was connected to the receiver input of the analyzer.

Capacitive coupling between the loop and the board will cause either a resonance effect (dip or peak in the response) or a directional effect when the loop is rotated 180 degrees because the phase of the inductive coupling changes by 180 degrees whereas the capacitive coupling remains the same.

As can be seen in Figures 16(a) and 16(b), there is no resonant effect, the frequency response is nearly flat. The capacitive coupling itself is very low compared to the inductive coupling because the difference is only a few dB and then only at the higher frequencies above 600 MHz.

Contrast the responses for the unshielded loop to the responses in Figures 17(a) and 17(b) for the shielded loop. In both Figures 17(a) and 17(b), a resonant dip in the response is seen similar to that shown for coupling between shielded loops in part V. In this case, the resonance is due to the sum of the inductance of the shields of the loop and the inductance around the split in the ground plane interacting with the capacitance between the shields and the ground plane of the board. As one would expect for a shielded loop, the plots in Figures 17(a) and 17(b) are not very sensitive to the normal and rotated positions of the loop.

One can conclude from the above plots that the unshielded loop works better for injecting signals into a path crossing a ground plane split than does the shielded loop. Surely this result holds in general for injecting signals into circuit boards with ground and power planes.

CASE 2: MEASUREMENTS IN THE TIME DOMAIN

A case is shown where using both unshielded and shielded magnetic loops to inject signals into a path on

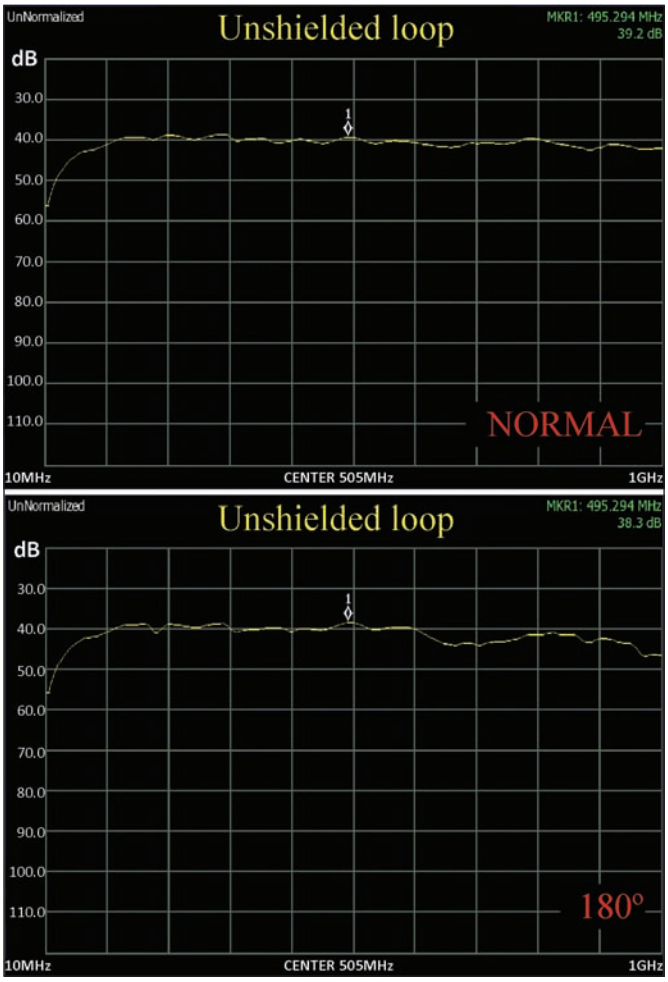

Figure 16: Injected signal for unshielded loop normal orientation and reversed 180º

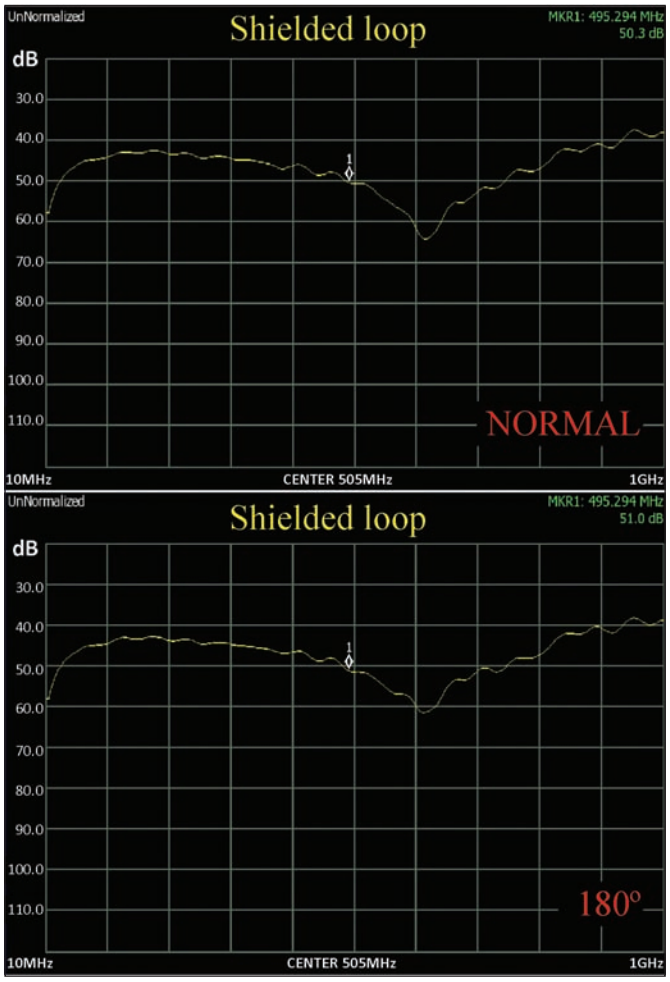

Figure 17: Injected signal for shielded loop normal orientation and reversed 180º

a circuit board results in an injected signal that is about the same for both loops. Figure 18 shows a square unshielded loop held next to a path crossing a break in the ground plane of a test board.

The injected signal from a Fischer Custom Communications TG-EFT pulse generator connected to the loop was measured at the BNC connector on the board (left side) using an oscilloscope for cases where the loop is positioned as shown and for a 180 degree rotation of the loop. Bandwidth of the oscilloscope used was 500 MHz and the TG-EFT was set to generate open circuit pulses of 100 V with a rise time of about 2 ns and pulse duration of about 100 ns.

Figures 19(a) and 19(b) (page 86) show the results as displayed on the oscilloscope using the unshielded

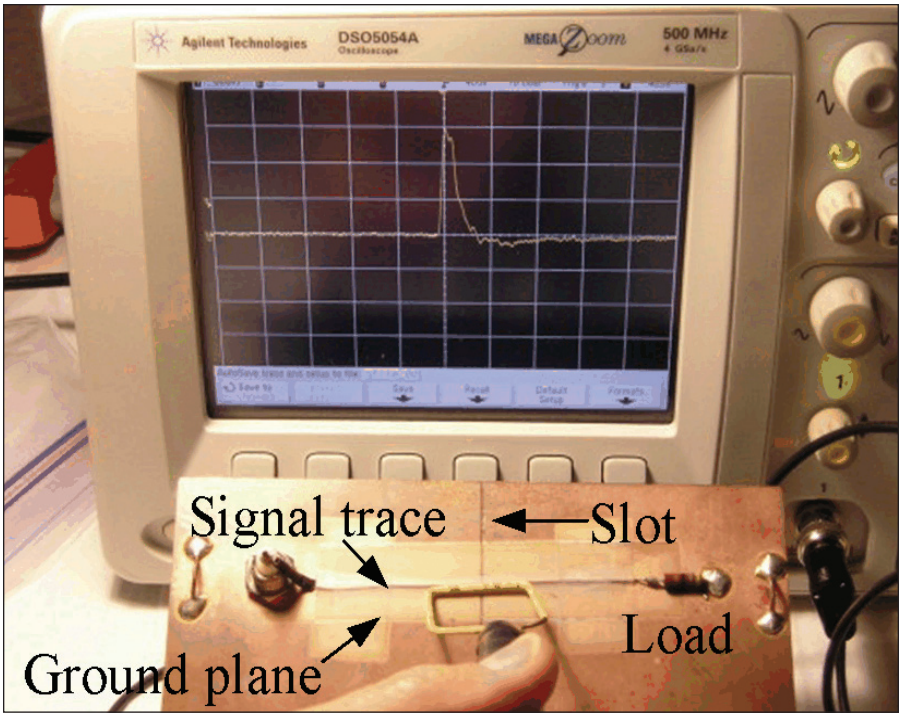

Figure 18: Measuring the coupled signal into a circuit in the time domain

This article on square shielded loops has shown that unshielded loops are useful in many cases and for injecting signals into circuit boards specifically. Unshielded loops can even outperform shielded loops in some applications. Given the ease of constructing an unshielded loop and its low cost, this is an important result.

loop oriented in the both positions parallel to the path over the break in the ground plane, 180 degrees rotated from each other.

Both plots have about the same pulse shape, amplitude, and width. Any change between the plots might be attributable to capacitive coupling, however the only difference of any note is that the rise time in Figure 19(a) is a little faster than in Figure 19(b). The overall difference in the plots is not significant enough to make much difference when using pulse injection for troubleshooting designs.

The plots in Figures 20(a) and 20(b) for the shielded square loop are also very similar as well as having about the same rise time for both plots. The amplitude of the injected pulse is about 20% less because the distance between the center conductor of the semi-rigid coax forming the loop is further from the path on the circuit board due to the diameter of the coax and the thickness of the plastic housing. The slight improvement in matching of rise times is not significant enough to warrant the extra complication and cost of shielded loops. In addition, if the scope had greater bandwidth, the resonance at about 600 MHz between the shielded loop and the board would likely cause distortions in the pulses displayed in Figure 20.

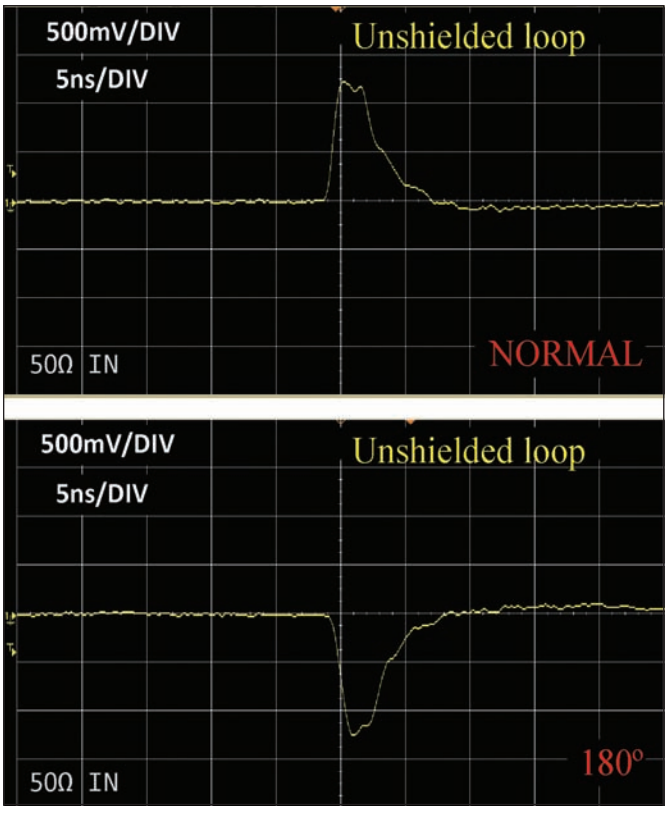

Figure 19: Injected Signal for normal and reversed unshielded loop.

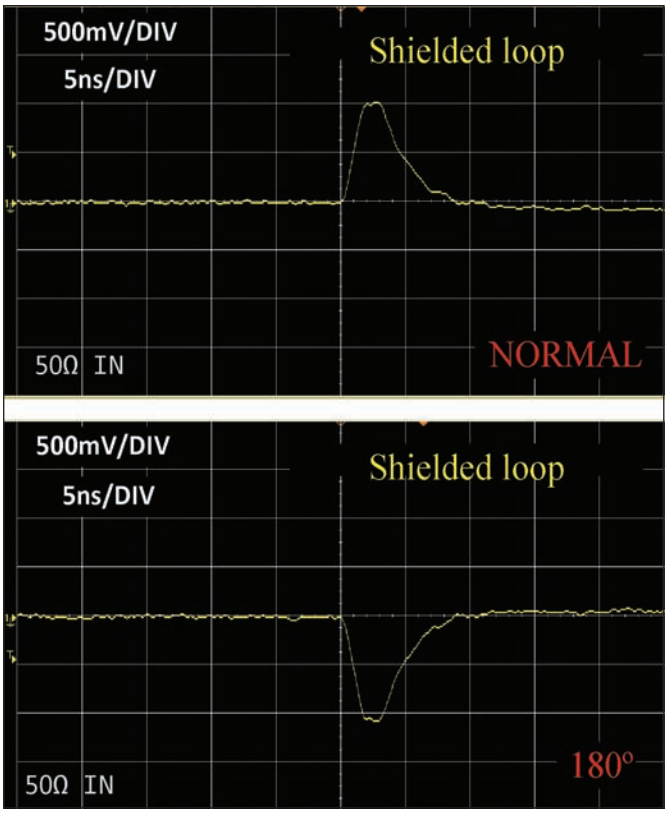

Figure 20: Injected Signal for normal and reversed shielded loop.

CONCLUSION

Capacitive coupling from an unshielded loop is not always a problem that requires the use of shielded loops to solve. On the contrary, unshielded loops often work as well as shielded loops as was demonstrated by pulse injection in this example.

This article on square shielded loops has shown that unshielded loops are useful in many cases and for injecting signals into circuit boards specifically. Unshielded loops can even outperform shielded loops in some applications. Given the ease of constructing an unshielded loop and its low cost, this is an important result.

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Mr. Smith held an FCC First Class Radiotelephone license by age 16 and a General Class amateur radio license at age 12. He received a B.E.E.E. degree from Vanderbilt University in 1969 and an M.S.E.E. degree from the California Institute of Technology in 1970. In 1970, he joined AT&T Bell Laboratories as a Member of Technical Staff. He retired in 1996 as a Distinguished Member of Technical Staff. From February 1996 to April 2000 he was Manager of EMC Development and Test at Auspex Systems in Santa Clara, CA. Mr. Smith currently is an independent consultant specializing in high frequency measurements, circuit/system design and verification, switching power supply noise and specifications, EMC, and immunity to transient noise. He is a Senior Member of the IEEE and a former member of the IEEE EMC Society Board of Directors.

His technical interests include high frequency effects in electronic circuits, including topics such as Electromagnetic Compatibility (EMC), Electrostatic Discharge (ESD), Electrical Fast Transients (EFT), and other forms of pulsed electromagnetic interference. He also has been involved with FCC Part 68 testing and design, telephone system analog and digital design, IC design, and computer simulation of circuits. He has been granted over 15 patents, several on measurement apparatus.

Mr. Smith has lectured at Oxford University, The University of California Santa Barbara, The University of California Berkeley, Vanderbilt University, AT&T Bell Labs, and internationally at many public and private seminars on high frequency measurements, circuit design, ESD, and EMC. He is author of the book High Frequency Measurements and Noise in Electronic Circuits. His very popular website, http://emcesd.com (www.dsmith.org <http://www.dsmith.org>), draws many thousands of visitors each month to see over 150 technical articles as well as other features.

He also provides consulting services in general design, EMC, and transient immunity (such as ESD and EFT), and switching power supply noise. His specialty is solving difficult problems quickly, usually within a couple of days. His work has included digital and analog circuits in everything from large diesel powered machinery to IC chip level circuits. His large client base includes many well known large electronic and industrial companies as well as medium sized companies and start-up companies.

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Arturo Mediano received both his M.Sc. (90) and Ph. D. (97) in Electrical Engineering from the University of Zaragoza, Spain where he has held a teaching professorship in EMI/EMC/RF since 1992. He is member of the Group of Power Electronics and Microelectronics (GEPM) of the Aragon Institute for Engineering Research (I3A). Since 1991 he is working in EMI, EMC and RF (HF/VHF/UHF) fields for communications, industry and medical applications with substantial experience in collaboration with industries, focusing on training, consulting, design and troubleshooting.

He is Instructor of Besser Associates (CA, USA), offering periodically public and on-site courses in EMI/EMC, Signal Integrity (SI) and RF subjects through the USA, specially in Silicon Valley/San Francisco Bay Area and he has taught tens of RF/EMI/EMC/SI courses through Europe. He was Invited Lecturer for the École Polytechnique Fédérale de Lausanne (EPFL) in Lausanne (Switzerland) and for the Institut National des Télécommunications (INT) in Evry (France).

He is author/co-author for many publications and patents and a frequent speaker in the most important symposiums and conferences related to RF/EMC. Arturo is Senior Member of the IEEE, member of the EMC Society (ESAC Committee), and member (Chair since 2013) of the MTT-17 (HF/VHF/UHF technology) Technical Committee of the Microwave Theory and Techniques Society. Arturo shares free time between his family, fly fishing, and drawing cartoons.

Prepping for EMI Testing

BY DARYL GERKE AND BILL KIMMEL

Like it or not, most electronic designs today are subject to formal EMI testing. So even if you are new to EMI/EMC (electromagnetic interference/compatibility), you need to understand what is involved and how to best prepare for a trip to the EMI test lab.

Like any trip, good preparations are key. We'll look at three phases — *pretest, test,* and *post test*. Try to anticipate problems, and don't overlook contingencies. Most EMI tests are not successful the first time. As engineers we always need to have "Plan B" ready, and maybe even "Plan C."

Before we begin, however, a little philosophy. Too often designers take EMI failures personally. So change your mind set — think *verification*, not testing.The goal is not to criticize your designs, but rather to assure your designs will work in the field. Make it a positive experience. As we learn, we improve — even us grumpy old EMC consultants.

PHASE 1 - PRETEST

The first step is to write a plan. If you are working in the defense industry, a test plan is usually a contract requirement. We find an EMI test plan very useful for communicating among the design team, the test lab, and the customer.

But even if not required, a test plan is still a good idea as it forces one to address critical issues ahead of time. Here is a summary, which you can even use as a checklist.

Identify necessary tests. If you are not sure what tests are needed contact your test lab prior to your visit.

Nothing is worse than showing up without knowing what needs to be done. You should also determine the test configuration for each test, which is usually defined in the relevant test specification.

Define failure criteria. With emissions, this is easy. Are the levels above or below the limits? But with immunity/susceptibility, however, you may need to define failures. For example, is a reset with recovery acceptable? How much perturbation can you withstand in an analog sensor?

Depending on the equipment under test, the failure criteria are already specified. Other times you have more

The first step is to write a plan. A test plan is a good idea as it forces one to address critical issues ahead of time.

flexibility. The different failure levels prescribed in the European Union EMI specifications are a useful place to start. Be sure to include this in your plan, and to get advance agreement on the failure criteria.

Determine failure monitors. Again, with emissions this is easy - just watch the spectrum analyzer. Immunity/susceptibility are not as easy. How will you determine a failure? Special software? Or special hardware, such as a blinking "heartbeat" detector? Or maybe just indicators on the EUT (equipment under test) via a video camera.

Determine equipment hardware. What specific equipment will you test? Are peripherals needed? What about memory or I/O configurations? Probably best to test a "worst case" configuration, which assumes that lesser configurations will have lesser EMI issues.

Determine equipment software. Will you need special test or diagnostic software? Some software may even be prescribed. For example, the prescribed emissions test software for personal computers includes reading/writing to hard drives and peripherals, along with a "scrolling H" test pattern for monitors. Not fair to let the system idle - you need to exercise the hardware.

For immunity/susceptibility, how will you monitor, recognize, and report failures? Will the standard software do it, or do you need additional special software? Will that software run on the EUT, or on remote equipment?

Determine support hardware. Passive peripherals, or active exercisers? Will you need to develop special hardware (and associated software?) Are there special power or cooling needs?

Don't forget about cables and connectors. If shielded, make sure they are properly terminated. If necessary, how will the cables penetrate the test chamber? You may need to develop a special test fixture for this.

We've see too many problems with cables — check them out *before* going to the lab. We still recall one engineer admonishing his colleague with, "I thought we brought the *good* cables."

Put together a tool kit and spares. As a minimum, you should bring spare boards. Better yet, bring an extra system or two. There is nothing worse than having equipment break during the tests, with no backup. Bring backup software too.

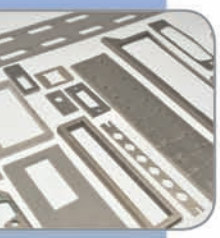
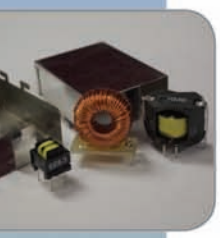
You may also want to include some spare parts - ferrites, small caps, EMI copper tape, and a roll of heavy duty aluminum foil. A soldering station can be useful too if you need any minor board modifications. Much of this may be available at the lab, but better to be prepared.

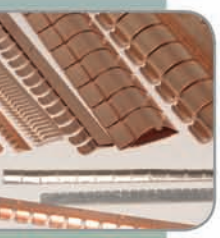
Consider multiple configurations. For cost sensitive designs, we often recommend three test samples (ABC method.) The A unit has minimal modifications (management's dream); the C unit has all the EMI fixes you can think of (the EMI engineer's dream): and the B unit is somewhere in between (the designer's dream.).

If you're an optimist, start with A. If you pass, life is great! If you are a pessimist, start with C. If you fail, you're still in trouble. In most cases, you'll be somewhere in between, which is where the B unit comes into play. But this approach lets you quickly bracket things. It also means you have spares on hand if needed, and that can be modified as needed.

Schedule your tests. With all this preparation, don't forget to call your test lab for scheduling. Test labs can get pretty busy, so don't expect to get in right away. The more advance time you can give the lab, the better. They will appreciate your courtesy. But for emergencies and panic situations, most labs will do their best to accommodate you. Just don't make every test a panic.





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MEETING THE CHALLENGE

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All your planning and prepping is done, and you are now at the lab. Somebody from your company should attend the tests. Don't just throw the design over the wall to the lab. Yes, it is done but very often is not effective, particularly if problems arise.

PHASE 2 - TESTING

All your planning and prepping is done, and you are now at the lab. Regardless of your overall responsibilities, somebody from your company should attend the tests. Don't just throw the design over the wall to the lab. Yes, it is done but very often is not effective, particularly if problems arise.

Many EMI tests take a week or less. In that time, not only will you learn a lot, but by being on site you'll also save your company time and money. After all, you know the design, how it works, and how to fix it if it breaks. Here are some issues to consider.

Setup the EUT. Do the basic stuff - connect power, peripherals, ventilation (if needed), etc. Run a diagnostic to be sure everything is working as it should.

Start a test log. Note date, time, test configuration, and summary results. Keep it simple but organized, as you will get a full set of data at the end of the tests. This is very useful if you start troubleshooting. Without it, you will soon be confused as to what has been tried. Photos are a good idea too.

Baseline tests. For emissions, run an ambient test (power to the EUT off.). This is normally done anyway, but make sure it happens. For immunity, run a pre-scan. This verifies proper operation before you begin subjecting the EUT to the EMI torture chamber. This is the time to catch any glitches in the test setup. Note and record the results.

Dealing with test failures. Unless you are incredibly lucky, you will encounter test failures, particularly with initial tests. Expect two or three trips to the lab before achieving full success. Even with the best design techniques, there are always unknown factors. That is why we test - it is still the most cost effective way to assure EMC, and ultimate successful operation of our equipment in the field.

If you fail a test, don't just stop and give up. Do some quick troubleshooting instead. If you are lucky, you may fix the problem right away. If not, at least gather enough information to narrow the possible failure mechanisms. Think like a doctor trying to diagnose an illness.

Do the simple stuff first. Add ferrites to cables, or better yet pull cables to see if emissions drop (or immunity improves.) If you think the box is leaking, wrap the EUT in aluminum foil, sealing the seams in copper tape. You did bring your ferrites, aluminum foil, and tape with you, right? If not, the lab probably has a supply, but better to be prepared.

For immunity, back off the test levels to determine the actual failure levels. How bad is the problem, anyway? If you are close, maybe a ferrite will fix things. But if you are a long way from success, more serious fixes may be needed. You need to know this.

Ask for suggestions. Your test engineers and technicians have seen a lot of problems, and may have some ideas to try. Be polite, and don't be a hot shot trying to impress everyone. Worst of all, do NOT blame the test lab or question their equipment or abilities. Wish we didn't have to include this last piece of advice, but we've seen it happen.

Verify operation. Finally, regularly check to see if the EUT is still working right. This is particularly important with immunity tests that might cause damage or subtle changes, such as ESD or power transients. But even random equipment failures can invalidate your test data.

How often to verify? The answer is how much data are you willing to discard. If you are willing to lose a day's data, then once a day is enough. For a half day, then twice a day suffices. Test time is expensive, so we usually recommend revalidating every two to four hours, assuming the revalidation does not take a lot of time.

PHASE 3 - POST TEST

If all has gone well, you've passed the necessary tests. If not, hopefully you have gathered enough data and ideas to fix things for the next round of testing. Rest assured - eventually you *will* achieve test success. So what now?

Test report. It is not enough to just pass the tests — you need to document the results. For military designs, the test report is another contractually required document. As such, it can be quite formal and detailed. For commercial products, the test report can be less formal, but should still contain enough relevant data to show that you have, in fact, passed the tests.

You can have the test lab prepare the test report, or you can do so yourself. Since most engineers do not like

to write reports, we usually recommend paying the test lab to provide the report. With their experience and templates, they can do so in a cost effective manner. Either way, keep the test report on file in case there are future questions about the tests.

Raw data. Before leaving the lab, it is a good idea to leave with raw data — graphs, tables, and photographs. Of course, you have your lab notes too , right?

In addition, we like to record other relevant data — test equipment, serial numbers, calibration dates, etc. That will be included in formal reports, but it only takes a few minutes to gather.

Last, but not least, thank everyone for their help. Not only is this courteous but will be very much appreciated. You will also find youself welcomed back on your next trip to the EMI lab.

IN CONCLUSION

We hope this makes your next trip to the EMI test lab both easier and more enjoyable. EMI testing is an important step to assure our equipment will work properly in its intended environment. The ultimate goal is a better design, which is what we all want as engineers. IN

(the authors)

DARYL GERKE, PE AND
BILL KIMMEL, PE

are the founding partners of Kimmel Gerke Associates, Ltd. The firm specializes in EMC consulting and training, and has offices in Minnesota and Arizona. The firm was founded in 1978 and has been in full time EMC practice since 1987.

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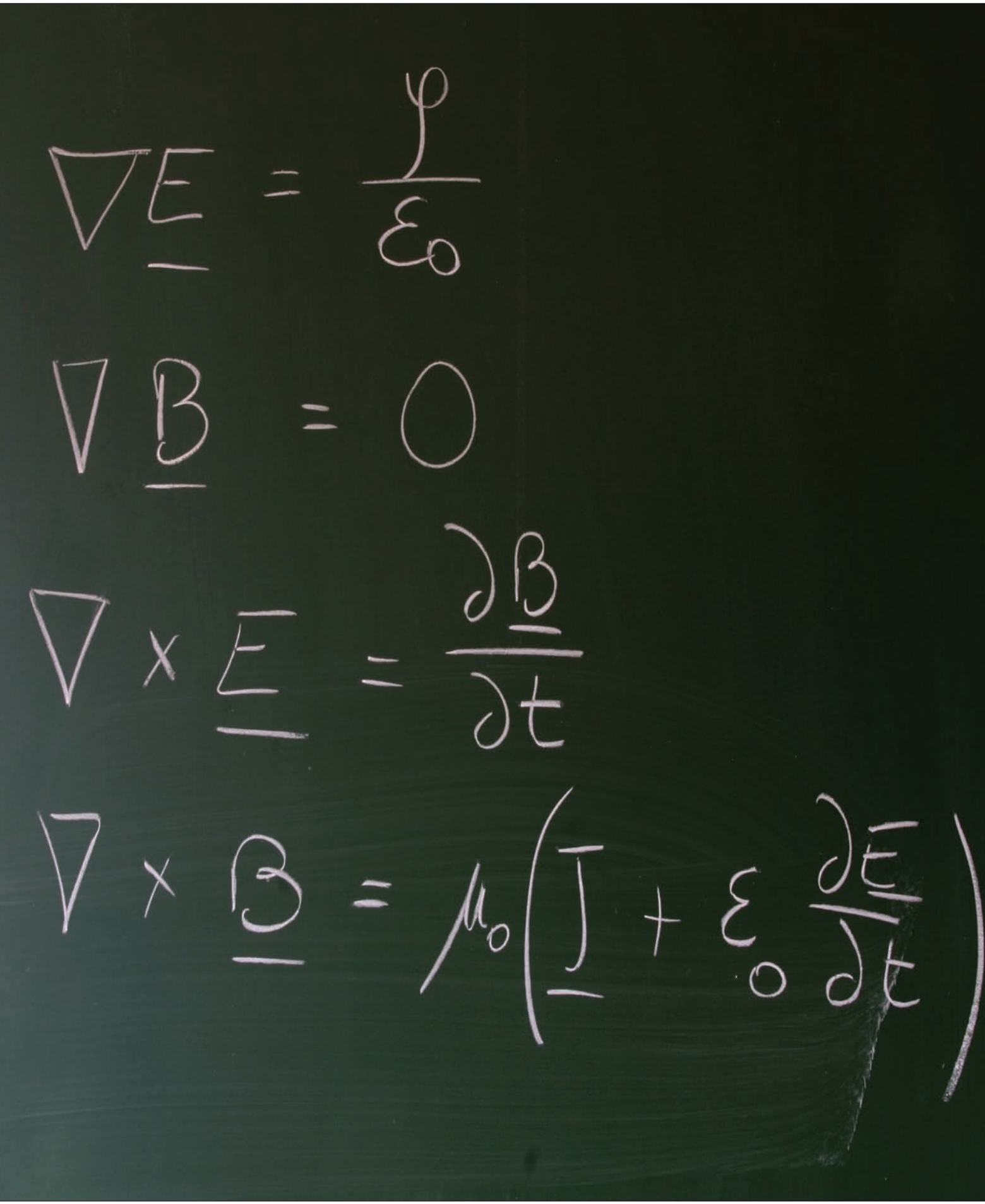
Daryl and Bill are both degreed Electrical Engineers, registered Professional Engineers, and NARTE Certified EMC Engineers. Between them, they share over 80 years of industry experience. For more information and resources, visit their web site at www.emiguru.com.


$\nabla \underline{E} = \frac{\rho}{\varepsilon_0}$
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$\nabla \times \underline{E} = \frac{\partial \underline{B}}{\partial t}$
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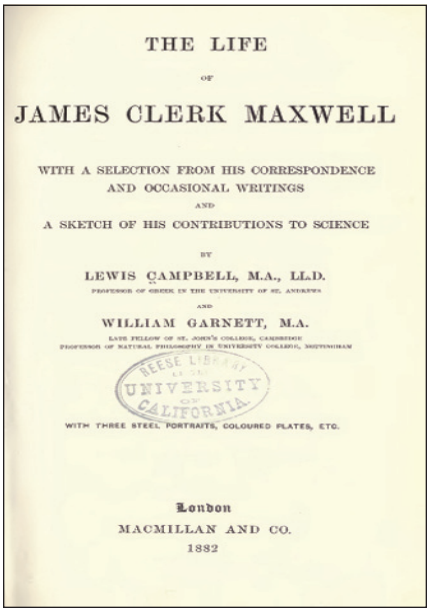
Faraday's Lines of Force and Maxwell's Theory of the Electromagnetic Field

A note from the Editor: In celebration of the 150th Anniversary of Maxwell's Equations, we are honored to bring you a chapter from the book *The Life of James Clerk Maxwell*, the 1882 original biography of James Clerk Maxwell. This chapter, entitled "Faraday's Lines of Force and Maxwell's Theory of the Electromagnetic Field," provides a unique insight to Maxwell's theory of electromagnetic fields.

BY LEWIS CAMPBELL AND WILLIAM GARNETT

This paper was characterised by the late Astronomer Royal as "one of the most remarkable applications of Mathematics to Physics that I have ever seen."

But notwithstanding the investigations above referred to, and many other original papers on almost every branch of Physical Science, it is for his researches in Electricity and in Molecular Science that Maxwell stands pre-eminent among the men of science of the present century. After taking his degree in 1854, Maxwell read through Faraday's Experimental researches, a course which he always recommended his students to follow. In Faraday he found a mind essentially of his own type. Thoroughly conversant himself with the Theory of Attractions as developed in Mathematical Treatises, and with the laws of electrical action as illustrated by Sir William Thomson in his paper "on the Uniform motion of heat in homogeneous solid bodies, and its connection with the Mathematical Theory of Electricity" a paper published in the Cambridge Mathematical Journal, February 1842, and "on a Mechanical representation of Electric, Magnetic, and Galvanic Forces," published in the Cambridge and Dublin Mathematical Journal, January 1847, Maxwell saw the connection between Faraday's point of view and the method of research adopted by the mathematicians. He used to say


THE LIFE
OF
JAMES CLERK MAXWELL
WITH A SELECTION FROM HIS CORRESPONDENCE AND OCCASIONAL WRITINGS
AND
A SKETCH OF HIS CONTRIBUTIONS TO SCIENCE
BY
LEWIS CAMPBELL, M.A., LL.D.
AND
WILLIAM GARNETT, M.A.
WITH THREE STEEL PORTRAITS, COLOURED PLATES, ETC.
London
MACMILLAN AND CO.
1882

that he had not a good nose to smell heresy, but whatever was good and true Maxwell would detect beneath the mass of misconception, or even falsehood, which had gathered round it, and which caused its rejection by nearly every one else without inquiry. Faraday's conception of a medium he adopted as a guide throughout his electrical researches.

Until the sixteenth century all that was known respecting electricity was the one fact that amber when rubbed possesses the power of attracting light bodies. This property was shown (Physiologia Nova, 1600) to be possessed by a variety of substances by Dr. Gilbert of Colchester, who was Physician to Queen Elizabeth, and who may be regarded as the founder of the Science of Electricity. From this time rapid strides were made in the experimental portion of the science, and the law according to which the attraction or repulsion between two small bodies charged with electricity varies with the charges, and the distance between them, was determined by Coulomb with his torsion balance, an instrument whose value to the experimental investigator can hardly be over-estimated. But it is to Cavendish (1771-1781) that we are mainly indebted for the foundation of the Mathematical Theory of Electricity, and for the highest experimental evidence of the law of electrical action. As the preparation for the press of The Electrical Researches of the Honourable Henry Cavendish was the last of Maxwell's contributions to science, the work being published only a few weeks before his death, we shall again have to refer to Cavendish's investigations, and need only state that his experiments proved conclusively, and in the best possible manner as far as the instruments at his disposal would allow, that the attraction or repulsion between two small charged bodies varies directly as the product of their charges, and inversely as the square of the distance between them, so that the law of electrical action is the same as Newton's law of gravitation, except that the stress between similarly charged bodies is repulsive, and that between dissimilarly charged bodies attractive. After Cavendish's time comparatively little was added to the theory of statical electricity, if we except the elaborate mathematical investigations of particular problems by Poisson, and the papers of George Green, which until recently were read by few, and appreciated by only two or three, until Faraday took up the subject. Most of Cavendish's work remained unpublished and unknown, and some of his results were independently obtained by Faraday. It is difficult to conceive what would have been the effect on Faraday's mind of perusing Cavendish's "thoughts on electricity," -as well as his own accounts of his experiments. Perhaps it is best for the world that Faraday was left to work and think on independent lines; certainly it has been a boon to Mathematicians and Physicists alike that Maxwell has appeared to expound and develop, if not to perfect, the work of both.

The mathematical theory of attractions had, prior to the time of Faraday, attained a very high degree of development in the hands of Laplace, Lagrange, Poisson, and others, and could be applied to the solution of many very interesting problems in electricity. But Faraday was not satisfied with the hypothesis of direct action at a distance between charges of electricity, and held that there must be some mechanism by which electric and electromagnetic actions can be communicated from point to point. Not all the arguments by which he supported this view are conclusive, for the force upon an electrified body and the induced electrification of any conductor will be the same whether we adopt the hypothesis of direct action at a distance or of the transmission of electrical action in lines, straight or curved, through an intervening medium. But any view, whether the arguments in its favour are conclusive or not, is of value if it lead us to inquire more closely into the mechanism by which a phenomenon is brought about; and thus Faraday's conception of lines of force, transmitted through a medium, and exerting tension and pressure wherever they are to be found, are of more value as an instrument of mental research than Weber's Theory of Electro-magnetism, however perfect the latter may be from a mathematical point of view.

The following quotation, from the preface to the Electricity and Magnetism, gives Maxwell's views of Faraday in his own words[1]:

Before I began the study of electricity I resolved to read no mathematics on the subject till I had first read through Faraday's Experimental Researches on Electricity. I was aware that there was supposed to be a difference between Faraday's way of conceiving phenomena and that of the mathematicians, so that neither he nor they were satisfied with each other's language. I had also the conviction that this discrepancy did not arise from either party being wrong. I was first convinced of this by Sir William Thomson, to whose advice and assistance, as well as to his published papers, I owe most of what I have learned on the subject.

As I proceeded with the study of Faraday, I perceived that his method of conceiving the phenomena was also a mathematical one, though not exhibited in the conventional form of mathematical symbols. I also found that these methods were capable of being expressed in the ordinary mathematical forms, and these compared with those of the professed mathematicians.

For instance, Faraday, in his mind's eye, saw lines of force traversing all space where the mathematicians saw centres of force attracting at a distance; Faraday saw a medium where they saw nothing but distance; Faraday sought the seat of

1 See also Maxwell's article on "Faraday" in Ency. Brit., 9th edit.

the phenomena in real actions going on in the medium, they were satisfied that they had found it in a power of action at a distance impressed on the electric fluids.

Suppose a small positively electrified body to start from a point close to a positively electrified surface, and suppose it to move always in the direction in which it is urged by the force acting on it, it will, of course, be repelled by the surface, and will move away along some path straight or curved, and will continue to move indefinitely, the force diminishing as it proceeds, unless it meet with a negatively electrified surface, which will attract it, and coming into contact with this surface its career will terminate. The path traced out by such a small electrified body constitutes Faraday's line of force, which is therefore a line whose direction at any point is that of the resultant force at that point. Such lines of force always proceed from positively electrified surfaces, and terminate upon negatively electrified surfaces; or, failing this, they must proceed to infinity. Lines of force proceeding from a positively electrified body placed in a room, unless there be other negatively charged bodies in the neighbourhood, will in general terminate upon the walls, floor, and ceiling of the room, or upon objects in the room in electrical communication with these. Faraday thus conceived the whole of the space in which electrical force acts to be traversed by lines of force which indicate at every point the direction of the resultant force at that point. But Faraday went further than this: he conceived the notion of causing the lines of force to represent also the intensity of the force at every point, so that when the force is great the lines might be close together, and far apart when the force is small; and since the force in the neighbourhood of a small charged body is proportional to the charge, he endeavoured to accomplish this object by drawing from every positively electrified surface a number of lines of force proportional to its charge, and causing a similar number of lines of force to terminate in every negatively electrified surface. In a paper entitled "On Faraday's Lines of Force," read before the Cambridge Philosophical Society on December 10th, 1855, and February llth, 1856, Maxwell showed that if a system of lines could be drawn according to Faraday's method, then, in virtue of the law of electrical action being that of the inverse square of the distance, the number of lines of force passing through a unit area of any surface, drawn perpendicular to the direction of the force, is proportional to the magnitude of the force in the

neighbourhood, and that the number of lines passing through the unit area of any other surface is proportional to the component of the force at right angles to that surface. Maxwell therefore imagined the positively electrified surfaces from which the lines started to be divided into areas, each containing one unit of electricity, and lines of force to be drawn through every point in each bounding line. These lines therefore divide the whole of space into "unit tubes," whose boundaries are lines of force, and Maxwell showed that, in virtue of "the law of inverse squares," the force at any point in any direction is inversely proportional to the area of the section of the unit tube of force made by a plane perpendicular to that direction. Maxwell further showed that on the negatively electrified surface upon which these tubes terminate, each tube will enclose one, unit of negative electricity, and consequently, if a metallic surface be introduced so as to cut the lines of force, the surface being placed at right angles to the tube, a unit of negative electricity will be induced on each portion of the surface contained within the trace of a tube of force; and hence, in any isotropic medium, these unit tubes of force are also unit tubes of induction. If, therefore, a system of tubes of force be drawn in connection with any electrified system, and in accordance with this plan, the whole of the space in which the force acts will be divided into tubes each originating from a unit of positive electricity and terminating upon a unit of negative electricity, while the direction of the force at any point will be indicated by that of the tube, and the magnitude of the force will be inversely proportional to the area of the cross section of the tube. Now, if the law of force had been any other than that of the inverse square, and tubes had been drawn starting from an electrified surface as above, and such that the area of any section of a tube is inversely proportional to the force across the section, these tubes would either leave spaces between them as they recede from the surface, or would intersect one another; so that it is only for the law of inverse squares that the system of tubes above described is possible. Faraday pointed out that there is not only a tension exerted along each line of force, but that the several lines exert a repulsion upon one another, and Maxwell showed that a tension along the lines of force, accompanied by an equal pressure in every direction at right angles to these lines, is consistent with the equilibrium of the medium. Taking an illustration from the flow of water in a river, Maxwell pointed out that the stream lines or paths along which particles of water flow, are analogous to lines of electric force, the velocity of the water being analogous to the intensity of the force. If the river be supposed to be divided into tubes, the boundaries of which are lines of flow, and if these tubes be so drawn that unit volume of water passes across a particular section of each tube in a second, then, if the flow be steady, unit volume of water will flow across every section of each tube in a second, since no water enters or leaves the tube except at its ends. Such tubes may be called unit tubes of flow, and if no tributaries enter the river there will be the same number of unit tubes crossing each section of the river. Where the bed widens the section of each tube increases, being always inversely proportional to the velocity of the water, and hence the number of unit tubes of flow which cut any unit of area in a cross section of the river will be proportional to the velocity of the water in the neighbourhood. Such a system of tubes, therefore, will represent both the direction of motion and velocity of the water at every point, and will exactly correspond, *mutatis mutandis*, with a system of unit tubes of electric force.

The following letter was addressed to Maxwell by Faraday on receiving a copy of the paper on "Lines of Force:"

> Albemarle Street, W.,
> 25th March 1857.
>
> MY DEAR SIR I received your paper, and thank you very much for it. I do not say I venture to thank you for what you have said about " Lines of Force," because I know you have done it for the interests of philosophical truth ; but you must suppose it is work grateful to me, and gives me much encouragement to think on. I was at first almost frightened when I saw such mathematical force made to bear upon the subject, and then wondered to see that the subject stood it so well. I send by this post another paper to you; I wonder what you will say to it. I hope however, that bold as the thoughts may be, you may perhaps find reason to bear with them. I hope this summer to make some experiments on the time of magnetic action, or rather on the time required for the assumption of the electrotonic state, round a wire carrying a current, that may help the subject on. The time must probably be short as the time of light ; but the greatness of the result, if affirmative, makes me not despair. Perhaps I had better have said nothing about it, for I am often long in realising my intentions, and a failing memory is against me.
>
> Ever yours most truly,
> M. FARADAY. Prof. C. Maxwell.

The paper, read before the Cambridge Philosophical Society, and published in vol. x. of their *Proceedings*, is confessedly only a translation of Faraday's ideas into mathematical language, with illustrations and extensions, and it makes no attempt at explaining the nature of the action in the dielectric, or the mechanism by which the observed effects are brought about. About five years later, in a series of three papers communicated to the *Philosophical Magazine* in 1861 and 1862, Professor Maxwell gave a simple sketch of a system of mechanism, capable of producing not only the electrostatic effects above alluded to, but also of accounting for magnetic attraction, the action of electric currents upon one another, and upon magnets, and electromagnetic

induction; but before giving an account of these papers it will be necessary briefly to mention the principal phenomena, an explanation of which was required.

The ordinary phenomena of magnetism, including the attraction between dissimilar and the repulsion between similar poles, as well as the still more familiar phenomena of the attraction of soft iron by a magnetic pole, are too well known to require more than a passing mention. Coulomb showed that the law of inverse squares obtained equally for magnetic repulsions as for electrical, so that the stress between two magnetic poles is proportional to the product of the strengths of the poles and inversely proportional to the square of the distance between them, provided the steel of which the magnets are composed is sufficiently hard to prevent the actions of the magnets on each other altering the strengths of their poles.

If a sheet of paper be supported horizontally above the poles of a magnet, and iron filings be sprinkled over the paper, each filing becomes magnetised by induction in the direction of the resultant magnetic force at the point where it is situated, and if the paper be gently tapped so as to overcome friction, the mutual attraction of the unlike poles in the filings causes them to adhere together in threads or filaments, the North pole of one filing attaching itself to the South pole of a neighbouring filing, and so on, the points of attachment all lying along a line of force. In this way the filings form a graphic representation of the lines of magnetic force, and it was this experiment which first suggested to Faraday the idea of the physical existence of such lines; and as he found it difficult to conceive of curved lines of force being due to "direct action at a distance" (Exp. Kes.1166), he considered that there must be some medium which is the vehicle both of magnetic and electric forces, and that such forces are propagated from particle to particle of the medium. Faraday also supposed that the same medium might serve as the vehicle for the transmission of light. The investigation of the properties of the medium necessary to account for observed electric and magnetic actions, the explanation of these actions, and the determination of the velocity of light from purely electro-magnetic considerations on the hypothesis of the existence of a such a medium constitute Maxwell's greatest contribution to electrical science. The action of an electric current upon a magnet was first observed by (Ersted. It is said that he made many attempts in his laboratory to discover an action between a magnet and a wire conveying a current, but in all his attempts he carefully placed the wire at right angles to the magnetic needle, and could detect no effect whatever. On attempting to repeat the experiment in the presence of his class he placed the wire parallel to the needle, and the latter immediately swung round and ultimately came to rest nearly at right angles to the wire. Whenever the North pole (i.e. the *North seeking* pole) of a magnet is brought near to a wire conveying a current, the pole tends to go round the wire in a certain direction, while the South (or *South seeking*) pole of the magnet tends to go round the wire in the opposite direction, and hence if the magnet be free to turn about its centre, the magnet will come to rest at right angles to the wire. Many *memoriae technicce* have been given for determining the manner in which a magnet will behave in the neighbourhood of a current. Maxwell's rule was as follows: Suppose a righthanded screw to be advancing in the direction of the current, and of necessity rotating as it advances, as if it were piercing a solid. The North pole of a magnet will always tend to move round the wire conveying the current in the direction in which such a screw rotates, while the South pole will tend to move in the opposite direction.

We may thus suppose every wire conveying a current to be surrounded by lines of magnetic force which form closed curves around the wire, and the direction of the force is that in which a right-handed screw would rotate if advancing with the current. In the case of a straight wire of infinite length,

these curves are of course circles. Since action and reaction are equal and opposite, it follows that whatever be the mechanical force exerted by a current upon a pole of a magnet, the latter will always exert an equal and opposite force upon the wire or other conductor conveying the current. Many experiments have been devised to show this. Maxwell used to illustrate it in a very simple way. Having attached a piece of insulated copper wire to a small round plate of copper, he placed the plate at the bottom of a small beaker. A disc of sheet zinc was then cut of such size as to fit loosely in the beaker, a small "tail" of zinc being left attached to it; this was bent up and united to the copper wire above the top of the beaker, while the plate of zinc was suspended in a horizontal position an inch or two above the copper plate. The beaker was filled up with dilute sulphuric acid and placed on one pole of an electromagnet, some sawdust or powdered resin being placed in the liquid to show its movements. On exciting the magnet the liquid rotated in one direction, and on reversing the polarity of the magnet the direction of rotation was reversed. If the plates be suspended by a string, so that they can readily turn round in the beaker about a vertical axis, the action of the magnet on the current in the vertical wire will cause the plates to turn always in the direction opposite to that of the liquid.

The laws of the mechanical action of conductors conveying currents upon magnets and upon each other were investigated by Ampere in a series of experiments which were at once conclusive and exhaustive. These experiments were alluded to in the highest terms by Professor Maxwell. Any account of them would be out of place here, and we only refer to them as furnishing the experimental evidence for the statements which follow.

We have already described the manner in which magnetic lines of force may be supposed to surround a wire conveying a current. Now let such a wire be bent into a closed curve or ring which need not necessarily be circular. The lines of force, which themselves form closed curves around the wire, will all pass in the same direction through the ring formed by the wire conveying the current, as if they were strung upon the wire, and hence the North pole of a magnet will tend to pass through the ring in the direction of the lines of force; and a moment's reflection will show that this direction is that in which a right-handed screw would advance if rotating in the direction of the current in the wire. Hence, if the North pole of a magnet be brought near to such a small closed circuit, on the one side it will be attracted and tend to pass through the circuit ; on the other side it will be repelled. The South pole of a magnet will be acted upon in precisely the opposite manner. Hence if a small magnetic needle be suspended within a coil of wire conveying a current, it will tend to set itself at right angles to the plane of the coil. Such an arrangement constitutes a galvanometer.

Now suppose that we have a small disc of steel of the same size and shape as the ring formed by the wire, and that this disc is magnetised so that one side is a north pole and the other a south pole. Such a disc will act upon external magnets in the same manner as the current if it be magnetised, so that a right-handed screw rotating with the current would enter at the south face and emerge at the north face. Such a magnetised disc is called a magnetic shell, and it will of course be acted upon by a magnet with forces exactly equal and opposite to those with which the magnet is acted upon by it. The magnetic lines of force proceeding from a circuit conveying an electric current are therefore the same as would proceed from the magnetic shell above described, the strength of the magnetization being properly adjusted; in other words, the magnetic field around such a circuit is the same as that surrounding the magnetic shell, and hence it follows that two circuits, each conveying electric currents, will act upon one another in the same way as two magnetic shells whose circumferences coincide with the wires, and which are magnetised as above described.

Now if the shells be parallel and magnetised in the same direction, they will have their opposite faces presented towards each other, and will attract one another. If they are magnetised in the opposite directions they will repel one another. Similarly, two parallel circuits will attract one another if the currents be passing in the same direction in both, and will repel one another if they be going in opposite directions. Also two parallel wires, which may be considered as parts of such circuits, will attract one another hen the currents in them are going in the same direction, and repel one another if they are going in the opposite directions. Maxwell's rule for determining the manner in which a circuit conveying a current will behave in the presence of other currents or of magnets is a very simple expression of Faraday's results. Defining the positive direction through a circuit as that in which a right-handed screw would advance if rotating with the current, he enunciated the rule thus:

> If a wire conveying a current be free to move in a magnetic field it will tend to set itself so that the greatest possible number of lines of magnetic force may pass through the circuit in the positive direction.

Since the magnetic field may be produced either by magnets or by electric currents themselves, as above described, this rule combined with the principle that action and reaction are equal and opposite will serve to determine the character of the action either upon circuits conveying currents or upon magnets in every possible case which may arise, and, in fact, embodies the magnificent results of Ampere's investigations in this subject.

Previously to the experiments of Faraday the induction of electric

currents was unknown. The principal phenomenon depending upon this action, which had been observed, and of which no satisfactory explanation had been offered, was that of Arago's rotating disc. In this experiment a disc of copper was made to rotate rapidly in its own horizontal plane above a compass needle, when the needle was observed to follow the disc and rotate on its vertical pin. This experiment was subsequently repeated by Sir John Herschel and Mr. Babbage, who employed discs of various substances, and found that it was only when the discs were good conductors of electricity that Arago's result was obtained. Faraday, in the first series of his Experimental Researches, describes an experiment in which a copper disc was made to rotate between the poles of an electro-magnet, while one electrode of a galvanometer was connected with the axis of the disc, and the other with a wire which was held in contact with the edge of the disc, which edge was amalgamated to secure a good connection. On spinning the disc a current was immediately obtained, the direction of which was reversed with that of the rotation. This experiment may be regarded as the starting-point of the dynamo machines of Wilde, Gramme, Siemens, and others, which seem destined to play so important a part in the civilized life of the future.

Faraday also showed that when two circuits are placed near to one another, if a current be started in one circuit there is an instantaneous current produced in the *opposite direction* in the neighbouring circuit, while on stopping the "primary" current a transient current in the same direction as the primary occurs in the other or "secondary" circuit. This experiment was the origin of the now well-known induction coil. Again, when the current was flowing steadily in the primary circuit, if the secondary circuit were brought nearer to it, a current was induced in the secondary in the direction opposite to that in the primary, and continued during the approach of the circuits. On removing the secondary circuit a transient current was set up in the same direction as that in the primary.

We cannot here spare space to trace the development of the laws of induced currents. The character of the action may in all cases be inferred from the very concise statement of Lenz, generally quoted as Lenz's law, and which may be thus expressed:

> If a conductor move in a magnetic field, an electromotive force will be induced in the conductor which will tend to produce a current in such direction that the mechanical force upon the conductor tends to oppose its motion.

This law, taken in conjunction with the statements made above respecting the mechanical action in a magnetic field upon a conductor conveying a current, serves to determine the character of the induced current whenever a conductor moves in the neighbourhood of magnets or electric currents. Moreover, the starting of a current in a neighbouring circuit must have the same effect upon the wire as if the conductor were suddenly brought from an infinite distance into the position which.it actually occupies. Hence Lenz's law will apply to every case of induced currents.

Maxwell's statement expresses the laws of induced currents quantitatively as well as qualitatively. It is as follows:

> *Whenever the number of lines of magnetic force passing through a closed circuit is changed there is an electro-motive force round the circuit represented by the rate of diminution of the number of lines of force which pass through the circuit in the positive direction.*

If, then, the number of magnetic lines of force passing through a circuit is diminished, there will be an electromotive force round the circuit in the direction in which a right-handed screw would rotate if advancing along the lines of force; a line of force being always supposed to be drawn in the direction in which a north magnetic pole tends to move along it. If the number of lines of force passing through the circuit is increased, the electro-motive force will be in the opposite direction. This law can be deduced from that which expresses the mechanical action upon a circuit conveying a current when placed in a magnetic field together with the principle of the conservation of energy. That it may be numerically true all the quantities involved must be expressed in terms of the electromagnetic system of units.

The telephone is a beautiful example of the application of this law. Every movement of the iron disc in front of the pole of the magnet alters the number of magnetic lines of force passing through the coils of wire surrounding the pole, and hence induces a current in one direction or the other in the coil, which current, increasing or diminishing the strength of the magnetism in the receiving telephone, causes a corresponding motion in the iron disc of the receiver, which therefore emits sounds similar to those incident upon the receiving instrument.

From what has been stated it will appear that the motion of a conductor will produce a current therein only when the conductor is moving in a magnetic field, that is, a portion of space through which magnetic lines of force pass. Faraday supposed that a conductor under these circumstances was thrown into a peculiar condition, which he termed "the electrotonic state," and that a current was induced whenever this state varied. Maxwell showed that this electrotonic state, on the variations of which the induced current in a circuit depends, corresponds to the number of magnetic lines of force which pass through the circuit. Because every change in this quantity involved the action of electromotive force, its relations to electromotive force being the same as those of momentum to force in dynamics, he called the quantity itself electromagnetic momentum. Maxwell's conception of the physical nature of this quantity will be described presently.

The determination of the laws of self-induction in electric currents is another of Faraday's many contributions to electrical science. After one of the Friday evening lectures at the Royal Institution, a certain Mr. Jenkin informed Faraday that when he broke the connection of the circuit in his electromagnet by separating two pieces of wire which he held in his hands, he felt a smart shock. Faraday said that this was the only suggestion, out of a very great number, made to him by ordinary members of a popular audience which ever led to any result. On investigating the matter, Faraday found that when a current is flowing in a coil of wire if the battery be removed there is a tendency for the current to continue after the removal of the battery, and that this tendency is increased by increasing the number of turns of wire in the coil, and still more so by inserting soft iron in the centre of the coil. This tendency does not depend so much on the length of the wire as upon the relative positions of its parts, and if the wire be first doubled and then wound into a coil the tendency disappears. If a few Grove's cells send a current through a short straight piece of wire and the circuit be broken a very feeble spark will be seen on breaking, but if a large electromagnet be introduced into the circuit a very much brighter spark will appear on breaking contact, though the current sent by the battery is feebler. Thus, when a current flows in such a coil its behaviour reminds us of that of water flowing in a pipe which, when an obstruction is suddenly introduced so as to stop the flow, exerts an enormous pressure for a short time upon the pipe and obstruction, in virtue of the momentum which the water has acquired; but that the action is not due to any momentum actually possessed by the moving electricity is shown by the fact that it depends on the configuration of the wire.
This property of a coil is called self-induction. If the poles of an electro-magnet be joined by a wire of great resistance as well as by the battery, when the battery is removed a considerable current will flow through the wire. This current Faraday called

the extra- current. It is more generally referred to as the self-induction current.

A similar action takes place when connection is made between a battery and a coil. The current does not at once acquire its full value, but for a short time goes on steadily increasing; the self-induction of the coil causing it to behave as if the current in it possessed considerable mass, which has in the first instance to be put into motion. All these actions are immediate consequences of the law of induced currents stated on p. 526. (input correct information here)

There is a well-known experiment of Faraday in which a specimen of his heavy glass, or borate of lead, was placed between the poles of a powerful electro-magnet and a beam of plane polarised light was passed through the glass in the direction of the magnetic force. Faraday found that when the light passed from the north to the south pole of the magnet the plane of polarisation was turned through an angle in the same direction as a right-handed screw would rotate if piercing a solid and advancing with the light. When the light passed in the opposite direction, the rotation of the plane of polarisation was in the same direction with respect to the magnet, and therefore reversed with respect to the path of the light. In this respect the heavy glass under the influence of the magnet behaved differently from a solution of sugar which always turns the plane of polarization of the light in the same direction with reference to its direction of transmission. This was the first experiment which showed any relation between light and magnetism, and indicated that the medium which serves as the vehicle of light the luminiferous ether must at least be affected by the presence of magnetic force, though the fact that the presence of ponderable matter is necessary to the production of this rotation, and that the direction of the rotation depends on the nature of the matter, renders it doubtful how far magnetic force affects the ether directly.

All transparent solids and liquids exhibit the same action on light in different degrees. If a tube of water with plate glass ends be placed within a coil of wire through which an electric current is passing, and plane polarised light be transmitted through the tube, the plane of polarisation will be turned through an angle in the direction in which the current circulates, and this angle will be proportional to the current,

Verdet showed that in the case of a transparent (para-)magnetic substance the rotation is in the opposite direction to that of the current.

The curious effect of a magnet upon the luminous discharge in a vacuum tube and the recent experiments of Dr. Kerr, may indicate other relations between light and electricity and magnetism. Having thus very briefly referred to the principal phenomena of magnetism and electromagnetism, we may proceed to give a short explanation of the medium or mechanism by which Maxwell accounted for these phenomena and their mutual interdependence.

From the well-known laws of the propagation of light, Maxwell assumed "as a datum derived from a branch of science independent of that with which we have to deal, the existence of a pervading medium, of small but real density, capable of being set in motion, and of transmitting motion from one part to another with great, but not infinite, velocity." Inasmuch as this medium can transmit undulations with finite velocity, it follows that it possesses a property analogous to mass, so that its motion implies kinetic energy; in addition to elasticity, in virtue of which its deformation implies potential energy.

It is well known that if a body rotate about a fixed centre there will be a tension along any radius drawn in the plane of rotation. The form which the earth would assume under the action of gravity only, if there were no rotation, would be that of a sphere. The diurnal rotation tends to cause the polar axis to contract and the equatorial diameter to increase; and this action would go on

indefinitely were it not that at a certain early stage it is balanced by the attraction of gravitation, and thus the earth assumes a nearly spherical form, in which the polar axis is shorter than the equatorial diameter.

Referring again to the case of the earth, it is demonstrable from the fundamental laws and principles of dynamics that if matter were conveyed from the equatorial regions to the poles, and there deposited so as to lengthen the polar axis at the expense of the equatorial diameter, the ' rate of rotation of the earth would be increased and the length of the day would be diminished; while if the earth became more oblate its velocity of rotation would diminish. In fact, if any body be in rotation, and be unacted upon by external forces, or if the forces acting upon it be such as not to affect its rotation, and if the system be altered in shape by internal stresses or otherwise, so that its moment of inertia about the axis of rotation is increased, the angular velocity will be diminished and, in the case of a sphere becoming an oblate spheroid, the velocity at the circumference will also be diminished, while if the moment of inertia be diminished, the reverse effect takes place.

Now Maxwell supposed that any medium which can serve as the vehicle of magnetic force consists of a vast number of very small bodies or cells capable of rotation, and which we may consider to be spherical or nearly so when in their normal condition, until we have reason to believe them to be of some other form. When magnetic force is transmitted by the medium, these bodies are supposed to be set in rotation about the lines of magnetic force as axis, and with a velocity depending on the intensity of the force. For the sake of fixing our ideas he supposed the rotation to be in the direction in which a right-handed screw would turn if it advanced in the direction of the force. We thus have the magnetic field filled with "molecular vortices," all rotating in the same direction about the lines of magnetic force as axes. As we have seen, these vortices will tend to contract in the direction of their axes of rotation, and to expand at right angles to this direction, so that if initially they are elastic spheres, they will tend to become oblate spheroids like the earth. This tendency will involve a tension in the medium along the lines of force, these being the lines along which contraction tends to take place, and this will be accompanied by an equal pressure in every direction perpendicular to the lines of force, on account of the tendency of the vortices to expand equatorially.

Now suppose that we have a north magnetic pole and a south magnetic pole placed near to one another. Lines of force will proceed from the North pole, generally in curved lines, to the South pole. The space in the neighbourhood of the poles will be filled with molecular vortices, which will be most energetic along the line joining the poles, and the velocities of the vortices will diminish as we pass into weaker portions of the field. The tension along the lines of force, tending to draw the North and South poles together, affords sufficient explanation of the apparent attraction between the poles; the kinetic energy of the molecular vortices accounts for the potential energy of the separated poles, which we thus suppose to be really kinetic energy, though possessed by the medium between the apparently attracting bodies and not by the bodies themselves. (Perhaps all examples of so-called potential energy we shall some day find to be really kinetic energy possessed by a medium with the properties of which we have been hitherto unacquainted.) When the poles approach one another, the field which is occupied by the vortices is diminished in extent, and though the velocity of the vortices is increased, the whole energy of the field is diminished, and the difference is expended in work done upon the approaching magnets. If the poles are of equal strength, and can come absolutely to coincide, the field is destroyed, all the vortices come to rest, and the energy possessed by them is all expended in work done on the magnets.

If two like poles, north poles for example, be placed near to one another, the lines of force proceeding from the one, instead of going to the other, will be turned aside, and if the poles be of equal strength, a plane bisecting, at right angles, the line joining the poles, will separate the lines of force due to the one from those due to the other, so that no line will cut the plane (Fig. 10). The lines of force thus passing nearly parallel to one another, the pressure exerted by the molecular vortices in every direction at right angles to the lines of force will cause an apparent repulsion between the poles.

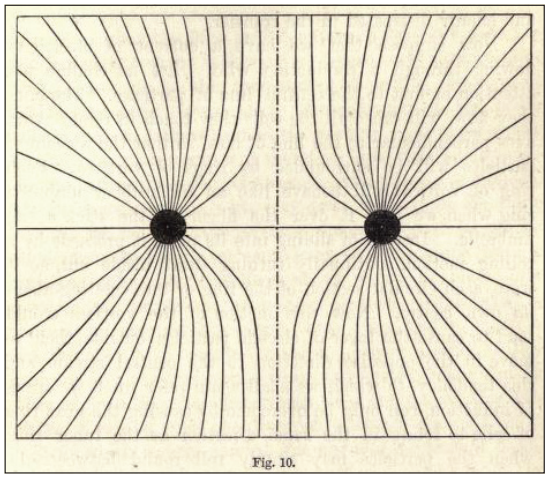


Figure 10

To account for the transmission of rotation in the same direction from one molecular vortex to the next, Maxwell supposed that there exists between them a number of extremely minute spherical bodies which roll, without sliding, in contact with the surfaces of the vortices. These bodies serve the same purpose as "idle wheels" in

machinery, which, coming between a driver and follower, transmit the motion of the former to the latter unchanged in direction. These minute spherical particles Maxwell supposed to constitute electricity. They roll upon the cells or vortices as if the surfaces in contact were *perfectly* rough, or provided with teeth gearing into one another, and thus, whatever forces may be applied, sliding is impossible. What we ordinarily consider as molecules of matter are supposed to be very large compared with the molecular vortices, and therefore *d fortiori* with the particles of electricity. In an insulator, or dielectric, it is supposed that the electric particles are unable to pass from molecule to molecule of the body, but in a conductor they can do so, the passage, however, being opposed by friction, so that heat is generated and energy dissipated in the transfer.

Now suppose that we have a current of electricity flowing through a conducting wire. Let us confine our attention at first to the central line of particles. These, as they flow, will cause all the cells they touch to rotate about axes perpendicular to the line of flow, so that the stream of particles will be surrounded by rings of vortices. Each ring of vortices will behave like an indiarubber umbrella ring when we pass it over the finger or the stick of an umbrella. Instead of sliding into its place it proceeds by a rolling motion, continually turning itself inside out, as it were, each circular section of the ring or tore rotating about its own centre. Now this motion of the vortices would tend to cause the layer of electric particles outside them to move in the opposite direction to the central stream, and this tendency, to which we shall again refer when we speak of induction, can only be overcome by causing the next ring of cells to rotate in the same direction as the inner ring, when the particles may simply roll round between the coaxial rings of vortices without moving backwards or forwards. But if the layer of particles be compelled to move forwards like the inner stream the layer of vortices surrounding it must rotate more rapidly that the layer within it, and so on, each successive shell of vortices rotating more rapidly until we reach the extreme layer contained within the conducting wire. The shell of vortices which bounds the conductor must by the same mechanism set up molecular vortices in the dielectric, the motion being communicated in ever-widening circles to an unlimited distance. It does not follow that this communication of motion is instantaneous. The cells may consist of elastic material which does not assume its final state of motion as soon as the tangential action of the electric particles is exerted upon it, but begins at first to undergo a deformation, the time taken to set up a given rotation in each depending on its density and elasticity. Hence electro-magnetic induction, which is the name given to the action we are now discussing, will be propagated through space with a finite velocity, but of this we must say more hereafter.

From what has been said it appears that when a steady (i.e. constant) current is flowing in a wire, molecular vortices will be set up in the surrounding dielectric, the axis of rotation of each vortex being perpendicular to the plane passing through the wire and the vortex. The axes about which the vortices turn will therefore form circles surrounding the wire, while the vortices themselves will constitute vortex rings, spinning with very great velocity in the same manner as the indiarubber ring above referred to, or the rings of smoke which are sometimes seen to emerge from a tobacco pipe. But the lines about which the molecular vortices rotate are magnetic lines of force, there being a tension in the medium along these lines, and a pressure everywhere at right angles to them. Hence a straight line carrying an electric current will be surrounded with magnetic lines of force, forming circles with their centres on the axis of the wire, and since the direction of the magnetic force is that

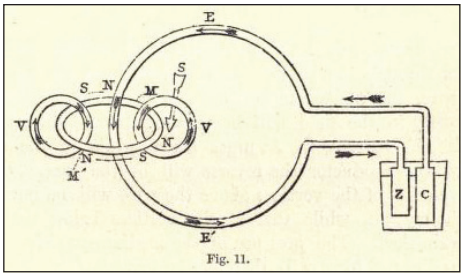


Fig. 11.

Figure 11

in which a right-handed screw would advance if rotating with the vortices, it follows that the direction of the magnetic force around the wire will be that in which a righthanded screw would rotate if advancing with the current. The medium will be subject to tension in circles around the wire, and to pressure in planes passing through the wire, reminding us of the cylinders of an Armstrong gun.

If the wire be bent the same will be true in kind, but the lines will no longer be accurately circles. All the magnetic lines of force pass through a closed circuit in the direction in which a right-handed screw would advance if rotating in the direction of the current. Fig. 11, taken from the paper in the *Philosophical Magazine*, shows the relations between the current, the lines of magnetic force, and the direction of motion of the vortices, the arrows E E' representing the current, S N indicating the direction of the magnetic force, while the arrows V V' show the direction of rotation of the vortices.

Now suppose a wire conveying a current to be placed in a magnetic field at right angles to the lines of force. Let S N (Fig. 12) represent the lines of force, A the section of the conductor, and let the current be travelling from the reader through the paper. In the space immediately above the wire, the molecular vortices due to

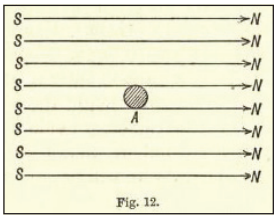


Fig. 12.

Figure 12

the magnetic force originally in the field will be rotating in the direction in which the current A urges them, while in the space below the conductor the reverse will be the case. Hence the velocity of the vortices above the wire will be increased by the current, while that of the vortices below the wire is diminished. The pressure of the medium at right angles to the lines of force will therefore be greater above the wire than below it, and the wire will be urged downwards at right angles to the lines of force and to its own direction.

Again, suppose two parallel wires to be near together and to convey currents in opposite directions. The strength of a current determines the difference between the velocities of the molecular vortices on opposite sides of it, the electric [particles being related to the vortices in the same way as a differential wheel in mechanism; but the vortices on one side of a moving stream of electric particles may be brought to rest if the velocity of those on the other side be doubled, the current remaining the same though the electric particles themselves will now have to spin round, but this makes no difference. Hence, when parallel wires convey currents in opposite directions, the vortices between them being made to spin in the same direction by both currents, will rotate faster than those on the opposite sides of the wires, and pressing as they do with force proportional to the squares of their circumferential velocities, the wires will be pushed apart as if they repelled one another.

When two parallel wires convey currents in the same direction, they tend to make the cells in the space between them spin in opposite directions, and the velocities of the molecular vortices there will consequently be less than on the other side of the wires. The pressure of the medium between the wires will therefore be less than in the space beyond, and the wires will be pushed together as if they attracted one another.

Now, suppose that a current of electricity commences to flow in a wire. Molecular vortices will be set up in the immediate neighbourhood of the wire, and these vortices acting on the electric particles on the other side of them, remote from the wire, will endeavour to set them in motion in the direction opposite to the current in the wire. But if the medium be a dielectric, the particles cannot be displaced through a sensible distance. They will therefore be made to rotate and start another and larger layer of vortices surrounding the wire, and so the motion will be propagated as above explained. But suppose that at a certain distance there is placed another wire parallel to the first, and forming part of a closed circuit in which no current is flowing. The particles of electricity in this wire will be acted on in the same way as those in the dielectric, but meeting with very little resistance to their motion along the wire, they find it easier to move through the wire than at once to transmit the vortex motion to the elastic bodies on the other side of them. But when a driver and follower are connected by a differential wheel, if the follower be retarded only by its own inertia, however small a resistance the differential wheel may experience to its motion of translation it will at length cause the follower to turn at the same rate as the driver, and will itself cease to move. Hence the resistance of the conductor at length brings the electric particles to rest, and causes them to communicate the vortex motion to cells beyond them. Thus when a current is started in a wire transitory currents in the opposite direction will be induced in neighbouring conductors, while electric stress will be produced in the dielectric, the elastic cells whose motion constitutes the molecular vortices being at first deformed by the tangential stress of the electric particles, but both the induced currents and the stress will have entirely ceased as soon as all the molecular vortices are in full swing.

Before a current can be maintained in a primary wire, the molecular vortices in the surrounding field must be properly started, and this requires the expenditure of work in consequence of the mass of the bodies which constitute the vortices. It is therefore impossible for a finite electromotive force to start a finite current in an indefinitely short time, in the same way as it is impossible for a finite force to produce instantaneously a finite velocity in a material body, and, just as in dynamics we sometimes speak of the reaction of a body against acceleration as though it were a force opposing the force applied, so we sometimes speak of the corresponding action in the case of the current as though it were a force opposing the battery or other electro-motor, and speak of it as the electro-motive force of self-induction. As, however, this depends not on the current in the wire simply, but on the molecular vortices in the surrounding medium, it is clear that the self-induction of a wire will depend on the energy of these vortices, and this must depend on the relations of the several portions of the wire to one another and to the medium, as well as on the density of the medium. The density of the medium Maxwell identified with its magnetic permeability. This is greater in (para-)magnetic substances than in air or vacuum; greatest of all in iron. In fact, it is so great in the case of iron, that Maxwell supposed the particles of the iron itself to take part in the vortex motion. Hence the energy of the field, and therefore the self-induction of the wire, is greater the greater the magnetic permeability of the surrounding medium, and the presence of an iron core in a coil immensely increases its self-induction and the energy corresponding to a given current flowing in the coil.

If, after a current has been established in a wire, the circuit be broken or the electro-motive force removed, the

molecular vortices refuse to come to rest till they have expended their energy. The only outlet for this energy is a current in the wire, since there is no opportunity of doing work in a non-conducting medium, where there can be no slipping between the elements of the mechanism. The vortices, therefore, keep the electricity moving in the wire after the battery has been removed, until they have expended all their energy in doing work against the resistance of the wire.

But if there be another conductor in the field parallel or slightly inclined to the first, there is another partial outlet for the energy of the system, and a "secondary" current will be set up in the second wire in the same direction as the current in the primary, while that in the primary will be less than it would have been if no secondary circuit had existed. In this way the hypothesis of molecular vortices affords an explanation both of the mutual induction of two circuits and the self-induction of one.

Suppose a wire to be placed in a magnetic field at right angles to the lines of force, and then to be moved so as to cut the lines at right angles, we should expect that in front of the moving wire the lines of force or threads of vortices would be squeezed together transversely, but extended in the direction of their length, somewhat in the same way as elastic strings would be affected by the wire before they broke and allowed it to pass through. Behind the wire the lateral pressure will be relieved, the vortices will contract in the direction of their axes and expand equatorially. But we have seen that the effect of stretching a rotating elastic body in the direction of its axis of rotation, and compressing it at right angles to this direction, increases the velocity of rotation so that the actual velocity of every point on the surface is increased; while the contraction of the body along the axis of rotation diminishes the velocity. Hence as long as the wire is moving across the lines of force the velocity of the vortices in front of the wire will be greater than that of the vortices behind, and the electric particles in the wire, coming, as they do, between two sets of vortices, which are rotating with different velocities, will flow in a stream along the wire. The direction of the current in the wire will be that which would cause the vortices in front to rotate more rapidly than those behind, and therefore to exert a greater pressure on the wire; in other words, there will be a current induced in such direction as to oppose the motion of the wire. We arrive at a similar result if we suppose the lines of force to be cut obliquely instead of orthogonally. Thus Lenz's law is a consequence of the hypothesis of molecular vortices. If we suppose the magnetic force to act from south to north horizontally, the wire to be vertical and to move from west to east, we have magnetic force acting from south to north, mechanical force acting from east to west, and opposing the motion of the wire, and electro-motive force acting in the wire vertically upwards.

Suppose that all over a certain area the electricity is pushed forwards through a very small distance along the normal, so that it does not pass from molecule to molecule of the substance, but in each molecule undergoes a displacement from back to front. The electric particles pressing tangentially on the walls of the elastic cells are unable to set them rotating, because each cell is acted upon equally all round in the direction in which the electricity tends to move, and the substance of the cell therefore undergoes a shearing strain which is resisted by its elasticity, and the state of strain of the cells is propagated through the dielectric by means of the displacement of the electric particles which behave like perfectly incompressible bodies. When the force producing the original displacement is removed the cells resume their original form in virtue of their elasticity, the electric particles return to their normal positions, and the energy of the strained elastic cells expends itself in the work done during the electric discharge. Thus the same medium which serves as the vehicle of magnetic force and produces all the phenomena of electromagnetism also serves for the transmission of the force between charges of statical electricity and as a reservoir of the energy due to electrostatic charges. If the dielectric be divided into cells by unit tubes of force and equipotential surfaces drawn for every unit difference of potential, each cell will contain the same amount of energy.[2] The following quotations from the paper in the *Philosophical Magazine* explain the application of the hypothesis of molecular vortices to statical electricity in Maxwell's own words:

> According to our theory the particles which form the partitions between the cells constitute the matter of electricity. The motion of these particles constitutes an electric current; the tangential force with which the particles are pressed by the matter of the cells is electromotive force, and the pressure of the particles on each other corresponds to the tension or potential of the electricity.
>
> A conducting body may be compared to a porous membrane which opposes more or less resistance to the passage of a fluid; while a dielectric is like an elastic membrane, which may be impervious to the fluid, but transmits the pressure on the one side to [the fluid] on the other.
>
> In a dielectric under induction, we may conceive that the electricity in each molecule is so displaced that one side is rendered positively and the other negatively electrical, but that the electricity remains entirely

2 See *Elementary Treatise on Electricity* by Professor James Clerk Maxwell, published by the Clarendon Press, 1881.

> connected with the molecule, and does not pass from one molecule to another.
>
> The effect of this action on the whole dielectric is to produce a general displacement of the electricity in a certain direction. This displacement does not amount to a current, because when it has attained a certain value it remains constant, but it is the commencement of a current, and its variations constitute currents in the positive or negative direction, according as the displacement is increasing or diminishing. . . . When we find electromotive force producing displacement in a dielectric, and when we find the dielectric recovering from its state of electric displacement with an equal electromotive force, we cannot help regarding the phenomena as those of an elastic body, yielding to a pressure and recovering its form when the pressure is removed.

Suppose we have a body positively electrified. This means that a displacement of the electricity in the medium takes place in all directions around the body and away from its surface. The cells are thus exposed to a shearing strain, diminishing as the distance increases, because the surface over which the displacement takes place being increased the linear displacement of the electricity is proportionately diminished, the particles of electricity behaving like a perfectly incompressible fluid. The medium being isotropic the lines of electric displacement coincide with those of electric stress, which stress is everywhere proportional to the displacement. The distortion which the cells experience by the pressure of the electric particles induces an elastic pressure in all directions, at right angles to the direction of displacement, so that there is a pressure in the medium at right angles to the lines of force.

Now suppose that we have two positively charged bodies in the field, which we may suppose to possess equal charges. Each produces a displacement of the medium outwards from itself, but the electric particles behaving like an incompressible fluid, it is clear that there can be no lines of displacement from the one to the other, but that between the bodies the lines of displacement will be curved so as to avoid one another in the same way as the stream lines emanating from two pipes, each of which is supplying water to a tank, would be curved round, and would avoid one another. The lines of displacement, and consequently the lines of force which coincide with them, will therefore be bent in exactly the same manner as the magnetic lines of force represented in Fig. 10, and the pressure in the medium at right angles to these lines will cause an apparent repulsion of the bodies.

For the same displacement, that is, for the same charges of the little bodies, the repulsion will be proportional to the elasticity of the medium. It is also proportional to the product of the charges, or, since they are equal, to the square of one of them. Suppose then that the medium is exchanged for one of greater elasticity. If we wish to keep the repulsion between the bodies the same, the displacements and therefore the charges must be diminished, the product of these charges, that is, the square of either charge, being made inversely proportional to the elasticity of the medium. The magnitude of each charge must therefore vary inversely as the square root of the elasticity of the medium when the dielectric is changed. Hence, if we define the electrostatic unit of electricity as "that quantity of positive electricity which, acting on an equal quantity at unit distance repels it with unit force," it follows that the unit will vary with the character of the dielectric, being inversely proportional to the square root of its elasticity.

But the attraction or repulsion between two given charges of electricity varies inversely as the specific inductive capacity of the dielectric, so that the electrostatic unit of electricity varies directly as the square root of the specific inductive capacity, and thus the specific inductive capacity is a quantity which varies inversely as the elasticity of the medium.

Suppose we have two parallel wires conveying equal electric currents in the same direction. Other things remaining unchanged, the velocity of the molecular vortices at any point is proportional to the strength of the currents. The attraction between the wires we know to be proportional to the product of the strength of the currents, that is to the square of one of them. The pressure excited by the vortices is, *cœteris paribus*, proportional to their density and the square of their velocity. Suppose we keep the attraction between the wires the same, but change the density of the medium. Then the velocity of the vortices at any point must vary inversely as the square root of the density of the medium. But the velocity of the vortices is proportional to the strength of the currents. Hence the strength of each current must vary inversely as the square root of the density of the medium. If then the electromagnetic unit of current be defined as that current which, flowing in a certain wire, attracts an equal current in another given wire with unit force, the unit of current, and therefore the unit of electricity, which is the amount flowing per second across any section of a wire conveying a unit current, will vary inversely as the square root of the density of the medium.

The ratio of the electromagnetic to the electrostatic unit of electricity will therefore be proportional to the ratio of the square root of the elasticity to the square root of the density of the medium. But this is known to be the velocity with which

a transverse vibration is propagated through the medium. Hence the ratio of these units is a concrete velocity, and is proportional to the velocity of propagation of an electromagnetic disturbance, or of the vortex motions above described, through the dielectric. If the units are chosen according to the ordinary system their ratio is not only proportional to but identical with this velocity.

In a paper published in the *Phil. Trans*, for 1868, Professor Maxwell gave an account of an experiment for determining the ratio of the electrostatic and electromagnetic units of electricity where air is the dielectric. The principle of the method lay in balancing the attraction between two electrified discs by the repulsion between two coils of wire in which currents were flowing in opposite directions. One of the discs and one coil was placed at one end of the beam of a torsion balance, the other disc and coil being fixed, but a third coil, conveying the same current as the other two, was placed at the other end of the beam in order to eliminate the magnetic action of the earth and the suspended coil. The apparatus is now in the Cavendish Laboratory. The result of the experiment gave for the ratio of the units a velocity of 288,000,000 metres, or 179,000 statute miles per second. The result obtained by another method by MM. Weber and Kohlrausch is 310,740,000 metres per second. The battery employed for the electrostatic charges was M. Gassiot's battery of 2600 cells, charged with corrosive sublimate. The accuracy of this result depends on that of the B. A. unit of resistance, the velocity being in fact represented by 28 · 8 Ohms.

Now, according to the undulatory theory, light consists of transverse vibrations of an elastic substance pervading space and all bodies, and the velocity of light as determined by Foucault is 298,000,000 metres per second, or very near the mean of the values obtained by Maxwell, and by Weber and Kohlrausch, for the velocity of propagation of electromagnetic disturbances. If this is found to be always the case, clearly the same medium will serve to account for the phenomena of electrostatics and electromagnetism, and for the propagation of light which must consequently be of the nature of an electromagnetic disturbance.

If an electromagnetic disturbance take place in a perfect insulator we have seen that it must be transmitted to an unlimited distance, for as no slipping can take place between the electric particles and the cells, and as the particles themselves cannot be displaced except by inducing a corresponding elastic stress in the medium, there is no outlet for the energy of the disturbance, which must therefore be communicated from cell to cell without limit. But if the medium be a conductor, that is, if the electric particles can undergo a permanent displacement passing from molecule to molecule against a frictional resistance and without any tendency to return, the energy of the electromagnetic disturbance will be gradually dissipated ; for the electric particles, instead of communicating the whole of the motion of one layer of cells to the next, will themselves be set in motion, and part of the energy will be dissipated as heat instead of being imparted to the external layer of cells. The disturbance will therefore continually diminish as it is propagated, until it very soon becomes insensible. The behaviour is the same as that of a driver and follower connected by a differential wheel, whose epicyclic motion is retarded by forces of the nature of friction. Hence electromagnetic disturbances cannot be propagated in conductors of electricity, and we therefore infer that all true conductors are *opaque* to light.

The transparency of electrolytes, such as saline solutions and the like, offers no difficulty in the face of this conclusion, as the transference of electricity in them is by a process entirely different from true conduction and more allied to the convection of heat, but Maxwell pointed out that the transparency of gold leaf is much greater than the theory would indicate.

Thus the resistance of a particular piece of gold leaf was such that it ought to transmit only 10~50 of the light incident upon it, which would be totally imperceptible, while the amount of green light actually transmitted by it was easily perceived. This result Professor Maxwell could reconcile with the theory only by supposing "that there is less loss of energy when the electromotive forces are reversed with the rapidity of the vibrations of light than when they act for sensible times, as in our experiments."

We have seen that the velocity of transmission of an electromagnetic disturbance in any medium is expressed by the quotient of the square root of the elasticity divided by the square root of the density of the dielectric. We have learned that the elasticity is inversely proportional to the specific inductive capacity of the medium while the density corresponds with the magnetic permeability. Hence we infer that the velocity of transmission of an electromagnetic disturbance varies inversely as the square root of the specific inductive capacity, and also inversely as the square root of the magnetic permeability of the dielectric, and this must be true for the velocity of light if light be an electromagnetic disturbance. Now the magnetic permeability of most transparent media, such as glass, quartz, sulphur, hydro carbons, and the like, does not differ sensibly from that of a vacuum, and hence in these substances the velocity of light must be inversely proportional to the square root of their specific inductive capacity; or, since the index of refraction of a medium is the ratio of the velocity of light in a vacuum to its velocity in that medium, it follows that the refractive index must be directly proportional to the square root of the specific inductive capacity. As all our measurements of specific inductive capacity refer to the action of electromotive forces which continue for a much longer time than the duration of a luminous vibration, we should expect the last mentioned relation to agree most nearly with experiment the longer the wave length of the light, or, as it is sometimes stated, the specific inductive capacity of a dielectric should be equal to the square of its refractive index for "*light of infinite wave length.*"

The results of the measurements of the specific inductive capacity of certain liquids by Silow, and of gases, sulphur, paraffin, and resin, agree with this theory as well as can be expected. Boltzmann also finds that the specific inductive capacities of crystalline sulphur along its three crystallographic axes are different, these differences coinciding with the differences of the squares of the refractive indices for light transmitted along these three directions.

Dr. Hopkinson (*Phil. Trans*. Part II. 1881) has recently measured the specific inductive capacities of turpentine, benzol, petroleum, ozokerit lubricating oil, castor oil, sperm oil, olive oil, and neats' foot oil. The hydrocarbons give results which are quite in accordance with Maxwell's theory, but the fatty oils, which are compounds of glycerine with fatty acids, have inductive capacities far too great. The same appears to be the case with all the varieties of glass tested by Hopkinson, the specific inductive capacities of which vary from 6 · 61 in the case of very light flint to 9 · 896 for "double extra-dense" flint. In the case of solid paraffin, Hopkinson's result agrees very nearly with that of Boltzmann and with Maxwell's theory. In the case of glass, as in that of the fatty oils, the high specific inductive capacity is associated with a complex chemical constitution, glass consisting essentially of metallic silicates, including silicates of the alkaline and alkaline-earthy metals. The measurement of the specific inductive capacity of glass is attended with great difficulty on account of the phenomenon generally known as residual charge or electric absorption, that is the apparent soaking of the electricity into the substance of the glass. This is a subject in which Maxwell took very great interest, and in his work on electricity and magnetism he has given a mechanical illustration of the action on the supposition that it is due to a want of homogeneity in the glass, some parts of which he supposed to conduct electricity better than others, though badly at the best. A form of experiment, very beautiful in its design, was devised by Maxwell for measuring specific inductive capacities, and was carried out by Mr. J. E. H. Gordon, who was able to reverse the electric stress in the glass 12,000 times per second; but this is of course no approximation to the rapid alternations of the "waves" of light. With the apparatus employed, however, the reduction of the observations involves great mathematical difficulties, and the results must therefore be received with caution whether we regard them as supporting the theory or as opposed thereto.

In applying the hypothesis of molecular vortices to the action of a magnetic field on polarised light, Maxwell "found that the only effect which the rotation of the vortices will have on the light will be to make the plane of polarization rotate in the same direction as the vortices, through an angle proportional

(A) to the thickness of the substance.

(B) to the resolved part of the magnetic force parallel to the ray.

(C) to the index of refraction of the ray.

(D) inversely to the square of the wave length in air.

(E) to the mean radius of the vortices.

(F) to the capacity for magnetic induction."

The relation (E) between the amount of rotation and the size of the vortices, shows that different substances may differ in rotating power independently of any observable difference in other respects. We know nothing of the

absolute size of the vortices; and on our hypothesis the optical phenomena are probably the only data for determining their relative size in different substances.

Now, independently of the action of a magnetic field on polarised light, all the phenomena of diamagnetism can be accounted for on the hypothesis that the magnetic permeability of diamagnetic substances is less than that of a vacuum, so that they behave like a paramagnetic substance immersed in a medium more magnetic than itself. But Maxwell has pointed out that "since M. Verdet has discovered that magnetic substances have an effect on light opposite to that of diamagnetic substances, it follows that the molecular rotation must be opposite in the two classes of substances."

We can no longer, therefore, consider diamagnetic bodies as those whose coefficient of magnetic induction is less than that of space empty of gross matter. We must admit the diamagnetic state to be the opposite of the paramagnetic; and that the vortices, or at least the influential majority of them, in diamagnetic substances, revolve in the direction in which positive electricity revolves in the magnetising bobbin, while in paramagnetic substances they revolve in the opposite direction.

Perhaps we cannot conclude this account of the hypothesis of molecular vortices better than by quoting Maxwell's own words: [3]

> I think we have good evidence for the opinion that some phenomenon of rotation is going on in the magnetic field; that this rotation is performed by a great number of very small portions of matter, each rotating on its own axis, this axis being parallel to the direction of the magnetic force, and that the rotations of these different vortices are made to depend on one another by means of some kind of mechanism connecting them.
>
> The attempt which I [have] made to imagine a working model of this mechanism must be taken for no more than it really is, a demonstration that mechanism may be imagined capable of producing a connection mechanically equivalent to the actual connection of the parts of the electro-magnetic field. The problem of determining the mechanism required to establish a given species of connection between the motions of the parts of a system always admits of an infinite number of solutions. Of these some may be more clumsy or more complex than others, but all must satisfy the conditions of mechanism in general.
>
> The following results of the theory, however, are of higher value:
>
> (1) Magnetic force is the effect of the centrifugal force of the vortices.
>
> (2) Electromagnetic induction of currents is the effect of the forces called into play when the velocity of the vortices is changing.
>
> (3) Electromotive force arises from the stress on the connecting mechanism.
>
> (4) Electric displacement arises from the elastic yielding of the connecting mechanism.

In a paper entitled "A Dynamical Theory of the Electromagnetic Field," read before the Royal Society on December 8, 1864, Maxwell deduced all the above results by purely mechanical reasoning, only assuming the existence of a medium capable of receiving and storing up potential and kinetic energy, and therefore capable of doing work in "recovering from displacement in virtue of its elasticity," while the parts of the medium are connected by" a complicated mechanism capable of a vast variety of motion, but at the same time so connected that the motion of one part depends, according to definite relations, on the motion of other parts, these motions being communicated by forces arising from the relative displacements of the connected parts, in virtue of their elasticity." For the existence of such a medium we have evidence independent of electrical actions. With regard to the mechanism no attempt is made in the paper to give to it any definite constitution. This paper has been regarded as Maxwell's greatest contribution to electrical science, but most of the results obtained in it have been already mentioned.

The following is a good specimen of Maxwell's humorous irony, of which there are many samples in his scientific works. He is discussing certain developments by Bernhard Riemann Lorenzo, of Weber and Neumann's theory of Electro-magnetism, which is based on the assumption that the action between two quantities of electricity is direct action at a distance, and depends not only on the distance between the charges but upon their relative motion.

From the assumption of both these papers we may draw the conclusions first, that action and reaction are not always equal and opposite; and second, that apparatus may be constructed to generate any amount of work from its own resources.

I think that these remarkable deductions from the latest developments of Weber and Neumann's theory can only be avoided by recognising the action of a medium in electrical phenomena.

While at the Cavendish Laboratory Maxwell constructed a mechanical model which illustrates in a very beautiful manner the principal phenomena of induced currents. As

3 Electricity and Magnetism, vol. ii. Art. 831 (1st ed.)

a piece of mechanism it is simply a differential train, such as is often employed as a dynamometer for measuring the power absorbed by a machine. The apparatus is sketched in Fig. 13. The grooved wheel P is keyed to the same shaft as the bevel wheel A, which therefore turns with it, and the rotation of this piece represents the primary current. A second bevel wheel D turns loosely on the arm C D, which is one of four arms (of which only two are shown in the figure) forming a cross, which can turn freely on the central shaft at C. Sliding weights M M', etc., can be fixed in any desired position on these arms so as to alter the moment of inertia of the cross, which is the differential piece in the mechanism. A third bevel wheel B is keyed to the same hollow shaft with the wheel S, which is similar to P, and the rotation of the piece B S represents the current in the secondary circuit. As the shaft B S is hollow, and rides loosely on the shaft A C, the wheels A and B can turn quite independently of one another, except in so far as they are connected by the wheel D. P' is an index attached to the interior shaft and turning with P. A loop of string is hung over each of the wheels P and S, and carries a small weight. These strings act as friction brakes to the wheels, and the friction represents the resistance of the primary and secondary circuits respectively. The moment of inertia of the loaded cross, or differential piece, represents the moments of inertia of the cells which constitute the molecular vortices in the dielectric. Its kinetic energy when rotating represents the energy of the vortices, and its angular momentum is proportional to the electromagnetic momentum of the system. The moments of inertia of the other portions of the mechanism are very small compared with that of the loaded cross. The motion of the cross and the wheel D is impeded by as little friction as possible.

Suppose that the wheel P is made to revolve, representing a current in the primary wire ; the heavy cross will not at first move, but the wheel D will revolve and communicate the motion to B, which, with S, will rotate in the direction opposite to that of P, representing a current in the secondary circuit opposite in direction to that in the primary. But the motion of S is resisted by the friction brake, and a finite force must therefore be exerted by D on B to drive it. The reaction of B, together with "the force exerted by A, will constantly tend to make the cross revolve in the same direction as P, and the velocity of the cross being constantly accelerated, it will presently revolve with a velocity half that of P, and then D will roll round B, which, with S, will remain at rest. The piece B S will then continue at rest as long as the rotation of P remains constant corresponding to the cessation of the current in the secondary circuit, while that in the primary remains unchanged, but if P be accelerated, S will revolve in the direction opposite to the motion of P. Now suppose P to be suddenly stopped. The kinetic energy of the cross will cause it to continue to revolve until it has done a corresponding amount of work against resistances, and A being at rest, D will roll upon it and compel B, with S, to revolve in the same direction as the cross, that is, in the same direction in which P formerly revolved, and whatever be the resistance to the motion of S, it will be overcome, and S will revolve till the work done against resistance is equal to the kinetic energy originally possessed by the cross. This corresponds to a current induced in the secondary coil on stopping the current in the primary, which current is in the same direction as the primary current, and continues until the energy of rotation of the molecular vortices has been used up in work done against electrical resistance.

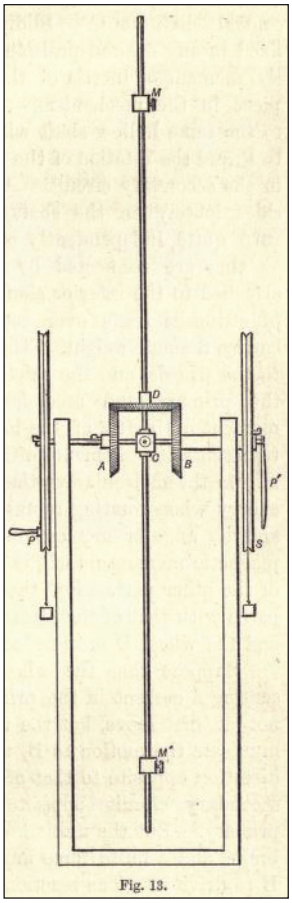


Fig. 13.

Figure 13

If one operator lay hold of the wheel S, and endeavor to keep it at rest while another applies a steady force to P, the motion of P will be accelerated much less rapidly than if the same force had been applied to it, and S had been free, because P can only move by setting in motion the cross with its great moment of inertia. If the operator who is turning P now suddenly stops it, a great shock will be experienced by the machinery, and the wheel S will slip from the grip of the other operator however firmly he may hold it. The force applied to S may correspond to an airbreak in the secondary coil, and this is sufficient to prevent a spark when the battery current is started in the primary, but by suddenly stopping the primary current, as in KuhmkorfFs coil, a disruptive discharge or spark passes through the air between the terminations of the secondary wire. (If the operator who endeavours to keep the wheel S at rest is inexperienced the effect upon him is very striking).

If a pin be placed in the face of the wheel S, and one end of a spring press

against the pin, while the other end is fixed to the frame of the apparatus, we have a representation of a secondary coil in which the circuit is broken, and a Leyden jar inserted with its coatings in connection with the ends of the wire. When the motion of P is changed, S will begin to move, and will deflect the spring, corresponding to a current in the secondary coil charging the Leyden jar. If the spring admit of very great deflection, so that a great amount of work must be done upon it before it slips from the pin, the primary current may have attained its full strength before the slip takes place. This corresponds to the capacity of the Leyden jar being too great to allow of its being charged to a sufficient potential to produce a spark. In this case no spark takes place, but when the force between the wheels D and B diminishes on account of the diminution of the acceleration of P, the spring relieves its strain by forcing the wheel S backwards, and the Leyden jar under corresponding circumstances quietly discharges itself through the secondary coil, reversing the operation by which it was charged. But if the pin slips from the spring, the wheel S will revolve, and the spring will fly back corresponding to a disruptive discharge through the air, and if the acceleration of P continue long enough several such disruptive discharges may take place.

We must, of course, be careful not to endeavour to learn from such a model lessons which it was not designed to teach, and we must remember that the behaviour of the mechanism does not represent the electrical action in all respects.

For many years Maxwell rendered valuable service to the British Association, especially in connection with electrical science. Some account of the meetings which he attended will be found in the letters printed in another part of this work, and though during the last few years of his life other engagements prevented his attendance at the annual gatherings, he always showed signs of keen enjoyment when discussing the "British Asses." In 1862 he was appointed a member of "The Committee on Standards of Electrical Resistance." In the report issued in 1863, the Appendix, "On the Elementary Relations between Electrical Measurements," bears the name of Professor Maxwell in conjunction with that of Professor Fleeming Jenkin, while the general description of the method employed in the determination of the Ohm or B. A. unit of resistance, together with the mathematical theory and details of the experiments, are from Maxwell's pen. In 1863-4 Maxwell was again at work on the same subject in the laboratory of King's College, and most of the "spins"[4] were conducted under his own supervision. In 1869 the results of Maxwell's experiments on the relation of the electromagnetic to the electrostatic unit of electricity, described above, were embodied in the Report to the British Association at the meeting at Dundee, and this forms the last of the Reports of the Committee.

In 1874 Professor Maxwell was elected a member of the committee appointed by the British Association for the purpose of investigating Ohm's law. Most of the work executed by this committee was carried out by Professor Chrystal in the Cavendish Laboratory, under the supervision and at the suggestion of Professor Maxwell. An account of the investigations will be found in the report presented to the Association at the Glasgow meeting in 1876.

Before concluding our notice of Maxwell's contributions to electrical science we must mention the preparation for the press of The Electrical Researches of the Honourable Henry Cavendish, published in 1879, only a few weeks before the death of its editor. The amount of labour which Professor Maxwell bestowed on this work during the last five years of his life can only be known to those who were constantly in his company. Nearly all the MS. he transcribed with his own hand, the greater part being copied after midnight, while he watched over Mrs. Maxwell during the long illness to which allusion has elsewhere been made. Every obscure passage or allusion was the subject of a long and searching investigation; and many were the letters written to the Librarian of the Royal Society and to scientific and literary friends in different parts of the country, to gain information respecting the meaning of obsolete words and symbols, or the history of individuals. But besides this, and a comparison of Cavendish's results with those obtained by subsequent investigators, Maxwell repeated many of Cavendish's experiments almost in their original form, only employing modern instruments for the purposes of measurement. The introduction and the appendices to the work evidence much labour, patient investigation, and very extensive acquaintance with the literature bearing on the subject. Maxwell was by no means one of the class of "thinkers" who only read their own writings; his acquaintance not only with scientific literature, but with nearly every other class of books was astonishing; and if any question of physics was brought before him, he could generally give an account of nearly all that had been done in the subject. In this respect he resembled the late Professor W. H. Miller, whom Cambridge men used to consult about everything. IN

4 See Part I. p. 316.

REFERENCE

Campbell, Lewis, and William Garnett. *The Life of James Clerk Maxwell: with a Selection from His Correspondence and Occasional Writings and a Sketch of His Contributions to Science.* London: Macmillan and Co. 1882. 513-556.

EVENTS in Compliance

August 2014

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Measurement, Control and Laboratory Use Equipment: Designing for Compliance to IEC 61010-1 3rd Ed
UL Knowledge Services
San Jose, CA
www.incompliancemag.com/events/140812

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Understanding Ground Resistance Testing Training Seminar
AEMC Instruments
Cleveland, OH
www.incompliancemag.com/events/140813

20-22
Fundamentals of Random Vibration and Shock Testing
Equipment Reliability Institute
Santa Barbara, CA
www.incompliancemag.com/events/1400820

September 2014

1-4
EMC Europe 2014 - International Symposia & Workshops on Electromagnetic Compatbility
The Swedish Exhibition & Congress Centre
Gothenburg, Sweden
www.incompliancemag.com/events/1400901

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Understanding Ground Resistance Testing Training Seminar
AEMC Instruments
Dallas, TX
www.incompliancemag.com/events/140909_1

9-10
EMC Essentials: Theory, Product Design & Troubleshooting
Washington Laboratories Academy
Gaithersburg, MD
www.incompliancemag.com/events/140909_2

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Safety of Household and Similar Electrical Appliances; General Requirements, IEC 60335-1, 5th Ed
UL Knowledge Services
Raleigh, NC
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2014 Minnesota EMC Event
Ramada Mall of America
Bloomington, MN
www.incompliancemag.com/events/140916_1

16-19
Failure Analysis of Electronics Short Course University of Maryland, Center for Advanced Life Cycle
CALCE and Buehler
College Park, MD
www.incompliancemag.com/events/140916_2

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Globalability: The Key to International Compliance
UL Knowledge Services
Chicago, IL
www.incompliancemag.com/events/140917

22-25
Understanding, Planning and Performing Climatic and Dynamic Tests to MIL-STD-810G
National Technical Systems (NTS)
Boxborough, MA
www.incompliancemag.com/events/140922_1

22-26
Reverberation Chamber Theory / Experiment Short Course
Oklahoma State University
Stillwater, OK
www.incompliancemag.com/events/140922_2

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CST Space Applications Workshop 2014
CST - Computer Simulation Technology
Toulouse, France
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23-25
Electromagnetic Compatibility Engineering Seminar
Henry Ott Consultants
Towson, MD
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October 2014

5-10
European Microwave Week 2014
Fiera di Roma
Rome, Italy
www.incompliancemag.com/events/141005

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Understanding Ground Resistance Testing
AEMC Instruments
Richmond, VA
www.incompliancemag.com/events/141007_1

7-8
EMC UK 2014
Newbury Racecourse
Newbury, Berkshire, United Kingdom
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7-8
ESD Device Design Essentials
Electrostatic Discharge Association
Munich, Germany
www.incompliancemag.com/events/141007_3

7-9
Thermal & Vibration Reliability For Advanced Rugged Electronics 3-day Course
National Technical Systems (NTS)
Santa Clarita, CA
www.incompliancemag.com/events/141007_4

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Advanced ESD Characterization and Test Methods
Electrostatic Discharge Association
Munich, Germany
www.incompliancemag.com/events/141009

PRODUCT Showcase

EVENTS in Compliance

October 2014 *continued*

12-17
36th Annual Symposium of the Antenna Measurement Techniques Association (AMTA)
JW Marriott Tucson Starr Pass
Tucson, AZ
www.incompliancemag.com/events/141012

14-17
MIL-STD-461F Course
Washington Laboratories Academy
Gaithersburg, MD
www.incompliancemag.com/events/141013

21-22
Electronic Product Design & Retrofit for EMC Class
SILENT Solutions LL
Chelmsford, MA
www.incompliancemag.com/events/141021_1

21-23
Introduction to Electromagnetic Interference and Compatibility (EMI/EMC) and Best Practices
University of Wisconsin-Madison
Madison, WI
www.incompliancemag.com/events/141022_2

27-30
Power Supply Design Workshops
Ridley Engineering
Cambridge, United Kingdom
www.incompliancemag.com/events/141027

28-29
Electronic Product Design & Retrofit for Electromagnetic Compatibility (EMC)
Global EMC Inc
Gormley, ON, Canada
www.incompliancemag.com/events/141028

BUSINESS News

Advanced Test Equipment Rentals and Kaelus Announce Partnership

Advanced Test Equipment Rentals (ATEC) has announced they have partnered with Kaelus to become a rental distributor of Kaelus products. Kaelus manufactures Passive Intermodulation (PIM) Testers for the wireless telecommunications sector, and ATEC is one of the largest rental companies of test equipment for the telecommunications, aerospace, semiconductor, consumer electronic, and many other sectors. For a complete list of all Kaelus products visit www.atecorp.com/kaelus.

AMETEK GUI Software Now Supports Aviation DO-160G Spec

AMETEK Programmable Power announced that the GUI (Graphical User Interface) software for its California Instruments AC sources now supports the aviation industry's critical specification for RTCA DO-160G test requirements. AMETEK's GUI test software option is unique in that it is the only test software that supports all revisions of the DO-160 standard, Revisions A through G. The GUI software is compliant with a wide variety of AMETEK systems, including California Instruments CSW Series, MX Series, iX and Compact iX Series, Ls/Lx Series and RS Series sources. AMETEK DO-160 option customers may download the upgrade at www.programmablepower.com/support/Downloads.

New Ametherm High-Accuracy NTC Disc Thermistors Offer R25 From 4 Ohms to 150 Kilohms, Tol to 1%

Ametherm introduced new NTC disc thermistors, recently acquired from Measurement Specialties (formerly RTI Electronics), featuring a wide range of resistance values and precision tolerances to 1 % for high-accuracy temperature measurement. With diameters from 2.54 mm to 12.7 mm and profiles from 0.64 mm to 5.33 mm, the devices released feature resistance at 25 °C from 4 Ω to 150 kΩ, Beta from 3000°K to 5000°K, and high-temperature operation to + 150°C. For more information or to request a sample, visit www.ametherm.com.

AVX Launches New DC-Link Film Capacitor Series with Snap-in Terminals for Easy PCB Mounting

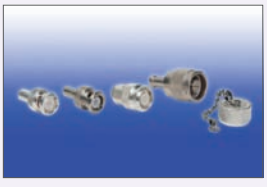
AVX Corporation has launched the new FRC Series medium power DC-link film capacitors, which feature a wide range of capacitance and voltage values in addition to self-healing properties. FRC Series capacitors are available in nine voltages spanning 400V-1500V, two tolerances (±5% and ±10%), two lead lengths (4mm and 8mm), and with capacitance values spanning 4.7µF to 35µF. For more information about AVX's FRC Series medium power DC-link film capacitors, please visit www.avx.com/docs/Catalogs/FRC.pdf.

New Guide Describes Benefits of Bal Seal Capabilities

A new guide highlights the benefits of collaborating with Bal Seal Engineering Inc. to develop sealing, connecting, conducting and EMI shielding solutions. Using photorealistic images, the four-page guide describes how the company's precision-engineered Bal Seal Canted Coil Spring® is employed as a seal energizer or stand-alone electrical-mechanical component to improve overall equipment performance and reliability. The Bal Seal Canted Coil Spring®, a current-carrying, locking, latching and holding solution already at work in thousands of critical applications worldwide, is available in a broad range of coil heights and materials. The guide can be downloaded free of charge from the company's website at www.balseal.com/general-capabilities-catalog.

CDM Electronics Offers Kings® by Winchester's Full Lines of Mil-Spec RF Interconnects and Adapters

CDM Electronics has announced they now carry the full line of Kings® by Winchester Electronics' RoHS-compliant, 50- Ohm Mil-Spec RF connectors and accessories for today's mission-critical military and aerospace communications applications. CDM now stocks one of the industry's largest inventories of standard and customizable Kings' 50-Ohm RF interconnect products, which notably features parts engineered to perform resonance-free thru 11 GHz. Included are MIL-PRF-39012 coaxial



connectors (BNC, C, N, SMA and TNC series) and MIL-PRF-49142 triaxial connectors (TRT and TRB series). Visit www.cdmelectronics.com/kings-electronics for information regarding CDM's ready-to ship inventory and customization of Kings' Mil-Spec RF interconnects.

Chroma Adds 2kW Solar Array Simulator to Programmable DC Power Supply Series

Chroma Systems Solutions, Inc. has announced the release of the new 62020H-150S 150V/40A/2kW Programmable DC Power Supply with Solar Array Simulation (SAS). This new 2kW model is an addition to Chroma's line of programmable DC power supplies designed specifically for PV inverter testing. The latest 62000H-S series programmable SAS power supply released by Chroma provides simulation of Voc (open circuit voltage) up to 150V and Isc (short circuit current) up to 40A. Visit www.chromausa.com for more information on Chroma's 62000H Solar Array Simulators.

Antenna Magus Version 5.0 Released

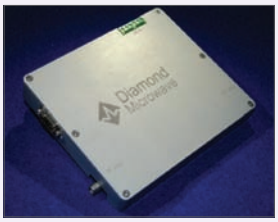
Computer Simulation Technology AG (CST), announce the release of Antenna Magus Version 5.0 - a tool that helps engineers deliver antenna design projects faster and more effectively than ever before. The design capabilities for all 250 antenna types in the Antenna Magus database have been upgraded to include 'Smart Design' functionality. This feature can automatically suggest practical design objectives and, as needed, can also instantly convert information provided by the designer between different representations. For more information, visit www.antennamagus.com.

Desco Launches Statshield® Foil Moisture Barrier Bag with IPC/JEDEC Moisture Sensitive Caution Markings

Desco now manufactures a series of foil moisture barrier bags pre-labeled with the IPC/JEDEC J-STD-033B moisture sensitive caution markings. The Statshield® Foil Moisture Barrier Bag identifies moisture sensitive devices for levels 2, 2a, 3, 4, 5, and 5a as defined by J-STD-020. The 4 mil thick material is designed for electrostatic discharge (ESD) shielding protection when dry packing components and meets the requirements of ANSI/ESD S20.20, ANSI/ESD SS41, and ANSI/ESD S11.4 Level 1. Visit www.desco.com for information on the different sizes of bags and to request samples or custom sizes.

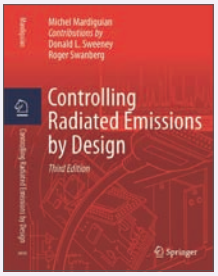
Diamond Microwave Launches Ultra-Compact 2 + 6GHz GaN SSPA

Diamond Microwave, a specialist in high performance microwave power amplifiers, is extending its range of GaN-based solid-state power amplifiers (SSPA) to include a 2 - 6GHz model that can be operated in either pulsed or CW mode. The DM SC50 01 is an ultra-compact broadband amplifier that complements Diamond Microwave's existing SSPAs in X-Band and Ku-Band. For more information, visit www.diamondmw.com.



Third Edition of Controlling Radiated Emissions by Design Book Published

Design Techniques for Controlling Radiated Emissions (now called Controlling Radiated Emissions by Design) has been considered by Donald Sweeney to be the ideal textbook for his EMC By Your Design Seminars since 1992, when the book was first published. And now in its new third edition, Don is pleased to have contributed to many parts of the book, including updating the Worldwide Standards and many of the graphics, as well as editing the entire book. All 13 chapters have been revised and updated addressing newer technologies, especially the updating of clock speeds and the examples worked out in the book. A special feature of the book will be a link to a continuous update of world standards and requirements as they change. For more information, click on www.dlsemc.com/emcdesignseminar.



DMAS Reaches 16th Position at 2014 Dutch Innovation Awards Top 100

Dutch Microwave Absorber Solutions is proud to announce they have reached the 16th position at 2014 Dutch Innovation Awards top 100 for their innovative polystyrene absorbers. From the jury report, the environmental friendly benefits of the green and sustainable absorbers are highly appreciated. DMAS absorbers do not contain poisonous fire retardant chemicals, they are 100% environmental friendly and fully compliant with REACH and RoHS. The Dutch innovation awards are sponsored by Mercedes-Benz, Dutch chamber of commerce and NRC-Media. For more information about DMAS product offerings, visit www.dmas.eu.

BUSINESS News

E2S Warning Signals Creates a Library of Technical Bulletins

E2S designs and manufactures high performance audible and visible signalling devices for use in industrial, marine and hazardous area applications. To assist system integrators and specifiers to choose an effective signal for their specific application E2S has launched a technical bulletins library offering product information in a concise format. The first three bulletins published cover two specialist products, Hootronic and Appello, and the dB(A) performance of their AlertAlarm industrial range.
The bulletins are available on www.e2s.com/technicalbulletins.

Fairview Microwave Announces New Lines of RF Rotary Joints

Fairview Microwave, Inc. has announced their new line of single-channel/single-axis and single-channel/multi-axis RF Rotary Joints. These rotary joints boast a compact design, excellent VSWR, low insertion loss, and minimal variation of RF performance during rotation. The operating frequency ranges from 0 to 18 GHz depending on the model. Fairview Microwave's RF rotary joints are needed wherever RF signals have to be transmitted between stationary and moving parts of a system, commonly used in commercial and military radar, land-mobile-radio communications and anti-missile defense applications.

For additional details on the expanded line of rotary joints, please visit www.fairviewmicrowave.com/rf-products/rf-rotary-joints.html.

Laird Engineer Awarded "Inventor of the Year"

Laird announced Larry Creasy, director of technology, has received the "Inventor of the Year" award from The Bar Association of Metropolitan St. Louis (BAMSL). The award honors the top inventors in the region based on the innovation and commercial success of their products. Creasy was nominated for the award based on his work with EcoGreen™ fabric-over-foam (FOF) gaskets. The EcoGreen™ gaskets line from Laird uses halogen-free adhesive, allowing the company to avoid the use of environmentally sensitive chemicals such as brominated and chlorinated fire retardants, while still maintaining overall product performance.
For additional information, visit www.lairdtech.com.

Harden a DUT After a Failed EMC Test at the Developer's Workplace with the Langer-EMV E1 System

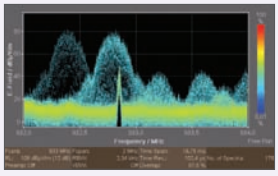
The E1 immunity development system from Langer-EMV GmbH is an advanced tool that allows electronic developers to perform practical pulsed disturbance immunity measurements (burst/ESD) on modules. The E1 has been specially designed for the development process and helps developer suppress interference in devices/modules or further harden them. It allows the developer to clarify the immediate cause of immunity problems and test the effects of the counter measures directly. For more information about the E1 immunity development system, visit www.langer-emv.com.

MITEQ Introduces Two New Low Noise Amplifiers and One Medium Power Amplifier

MITEQ has announced the introduction of three new low noise, wideband and ultra-small coaxial LNAs and rugged, single bias coaxial amplifier. Model AMF-4D-02001800-20-13P covers the 2 to 18 GHz band, and has over 35 dB of gain in a housing that is only 0.89" long and 0.64" wide without the field replaceable SMA connectors. Model AMF-5F-02000800-09-10P operates in the 2 to 8 GHz band, and has over 42 dB of gain in a housing that is only 0.89" long and 0.64" wide without the field-replaceable SMA connectors. Model AMF-6D-01002650-50-25P is the latest addition to MITEQ's family of rugged, single bias coaxial amplifiers. This amplifier has over 30 dB of gain from 1 to 26.5 GHz, in a housing that is only 1" long and 0.83" wide without the field replaceable K-connectors. For more information on these three new models, visit www.miteq.com.

Narda Safety Test Solutions Hand Held Direction Finder IDA 2 Detects Signals Under Signals

The Interference and Direction Analyzer IDA 2 from Narda Safety Test Solutions now generates persistence spectrums. Interference hidden beneath strong signals can now be detected and traced on the spot. IDA 2 captures persistence spectrums with a usable bandwidth of up to 22 MHz. Various triggers can be set in order to capture brief events. Even unknown interferers can be "nailed", thanks to the resolution bandwidth (RBW) down to 0.1 Hz, and time resolution as fine as 1 µs as well as the display of level characteristics versus time at up to 32 ns resolution. For more information, visit www.narda-sts.com.



Pasternack Releases New Family of Millimeter Wave Antennas

Pasternack Enterprises, Inc., an industry leading manufacturer and supplier of RF, microwave and millimeter wave products, releases a new family of high frequency, WR-15 waveguide antennas, which are perfectly designed for high-bandwidth applications.

Offered in this release are four high gain WR-15 horn antennas operating between 50 GHz and 70 GHz and are available in 20 dBi, 24 dBi, 34 dBi and 42 dBi gain models. For additional information and details about these products, visit www.pasternack.com/pages/Featured_Products/60-GHz-WR-15-Antennas.htm.

Reliant EMC Now Carries the Schwarzbeck Mess Elektronik Family of Antennas

Reliant EMC is proud to offer the complete line of Schwarzbeck Mess Elektronik Antennas. With over 60 years of experience, the Schwarzbeck Mess Elektronik Antennas offer high quality and reliable antennas a reasonable cost. For additional information on the Schwarzbeck Antennas, visit www.reliantemc.com/Schwarzbeck-Mess-Elektronik.html.

New Spectrum Analyzers up to 7.5 GHz from Rigol

Rigol Technologies, Inc. announced their latest series of products: 2 new high-performance, high frequency spectrum analyzers built on the extremely popular DSA800 series platform. The DSA832 and DSA875 expand the DSA800 series spectrum analyzer family to 3.2 and 7.5 GHz respectively. With specifications that far exceed the DSA815-TG these new instruments enable direct measurements of higher performance signals and systems. The new DSA832 and DSA875 have a broad set of features and options including a VSWR measurement toolkit for configuring and evaluating antennas as well as an advanced measurement kit (DSA800-AMK) that enables additional measurement functions including channel boundaries and signal to noise ratio factors. For more information, visit www.rigolna.com.

Precise BroadR-Reach Interface Verification with R&S RTO Oscilloscope

Rohde & Schwarz has expanded the application field of the R&S RTO oscilloscopes to include the testing of automotive Ethernet interfaces. In line with the OPEN Alliance test specification, the new R&S RTO-K24 compliance test software enables users to perform automated tests on BroadR Reach Ethernet interfaces. BroadR Reach technology makes it possible to combine multiple applications such as video streaming from rear view cameras and signal transmission from automotive radar systems to create a single, open and scalable Ethernet network inside the vehicle. Visit www.rohde-schwarz.com for more information.

Supercon, Inc. Upgrades Superconducting Wire Website

A new website offering high quality superconducting wire for accelerator and commercial magnet applications has been introduced by Supercon, Inc. of Shrewsbury, MA. The Supercon Website describes the superconducting wire and cable products and expertise offered by this firm which specializes in low-temperature superconductors (LTS). The website also provides complete product descriptions and specifications of all their products. Visit Supercon's website at www.supercon-wire.com.

TÜV Rheinland Tests, Certifies Wearable Technology Devices for Global Markets

TÜV Rheinland presented its services to help wearable device makers access global markets at the Wearable Technologies Conference from July 8 - 9 in San Francisco. The company tests wearable devices for healthcare, fitness and wellness, infotainment, industrial, and military markets. With years of expertise in products safety, EMC and radio testing, TÜV Rheinland helps wearable technology manufacturers meet international and country-specific technical requirements, with support available over the entire product lifecycle. For more information about TÜV Rheinland's testing services, visit www.tuv.com/us.

New Vishay Intertechnology Infrared Receivers for Data Transmission

Vishay Intertechnology has broadened its optoelectronics portfolio with the release of two new miniaturized infrared (IR) receivers designed specifically for low-speed data transmission. The TSDP34138/56 and TSDP34338/56 are optimized for low-complexity, low-cost signaling in metering, sensor, automation, and gaming applications. As an alternative to radio frequency (RF) transmission, the use of IR components such as the TSDP34138/56 and TSDP34338/56 simplifies designs, lowers costs, and eliminates the need to obtain regulatory approvals. In addition, by requiring line-of-sight, IR enhances privacy and minimizes interference with adjacent systems. For more information, visit www.vishay.com.

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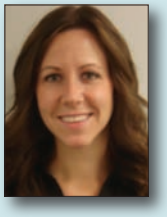

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