Component Variables

Global parts procurement presents challenges to any product designer

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CONTENTS

28 Components Variables

Global parts procurement presents challenges to any product designer. If a component is sourced from multiple suppliers, how do you keep track of these suppliers from initial design to production, especially in a global manufacturing environment where products are made in multiple locations?

Dennis W. Bartelt and Peter S. Merguerian

Electromagnetic Compatibility
Engineering

a course in noise and interference control in electronic systems

September 25-27, 2012
Millennium Harvest House Boulder
Boulder, CO

Presented by Henry Ott Consultants
in partnership with

IN COMPLIANCE

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.

EMC EXHIBITS AND EVENING RECEPTION: WEDNESDAY, SEPTEMBER 26, 2012
Exhibitors: for information contact Sharon Smith - e-mail: sharon.smith@incompliancemag.com or call (978) 873-7722

REGISTRATION

COURSE DATES/TIME: September 25-27, 2012
Tuesday and Thursday 8:30 a.m. to 4:30 p.m.
Wednesday 8:30 a.m. to 5:00 p.m.

COURSE LOCATION: Millennium Harvest House Boulder, 1345 28th Street, Boulder, CO 80302

COURSE FEE: $1,495 ($1,295 until 8/17/2012). 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 or mail the registration form.

HOTEL RESERVATIONS: Call the Millennium Harvest House Boulder at 303-443-3850. Room rates start at $126 per night (tax not included). Book by September 8 to receive this rate. Rate is based on availability. You must mention In Compliance Magazine when making reservations to get this special rate. The hotel is holding a limited block of rooms.

*<u>Electromagnetic Compatibility Engineering</u>, by Henry W. Ott

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.

Feedback from recent participants

"This is really a fantastic course. Everything is very practical, and I have a much more intuitive feel for what is important in EMC and why."

"Very enjoyable presentation; passionate about subject, used good practical examples."

"Henry is the best in EMC."

"Probably the most useful technical seminar I have ever attended. Should have learned this 20 years ago."

"Thank You. Your work is very valuable and your presentation style is refreshing!!"

"Really happy I flew all the way here."

"Excellent course! Presented in a very understandable way, even for a mechanical engineer."

"Should be required training for all engineers."

"This is the best practical course available."

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"This seminar exceeded by far my expectations, and my expectations were high already."

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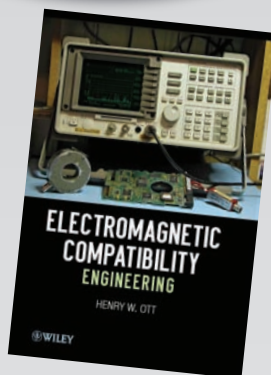
HENRY OTT

Henry W. Ott is President and Principal Consultant of Henry Ott Consultants (www.hottconsultants.com), 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.

Prior to starting his own consulting company, Mr. Ott was with AT&T Bell Laboratories, Whippany, NJ for 30 years, where he was a Distinguished Member of the Technical Staff and a consultant on EMC.

Mr. Ott is a Life Fellow of the IEEE and has served the EMC Society in various capacities including: membership on the Board of Directors, Education Committee Chairman, Symposium Committee Chairman and Vice President of Conferences. He is also a member of the ESD Association and a NARTE certified ESD engineer. He is a past Distinguished Lecturer of the EMC Society, and lectures extensively on the subject of EMC.

REGISTRATION FORM

ELECTROMAGNETIC COMPATIBILITY ENGINEERING

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Title: _____

Company: _____

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City: _____ State: _____ Zip: _____

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○ Discover   ○ Visa   ○ MC

Card # _____

Exp date: _____ Security Code: _____

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Call 973-992-1793, fax to 973-533-1442 or mail registration form to: Henry Ott Consultants, 48 Baker Road, Livingston, NJ 07039-2502.
Make checks payable to Henry Ott Consultants.

FCC News

FCC Proposes Fines Against Google for "Noncompliance"

The Federal Communications Commission (FCC) has proposed a fine of $25,000 against Internet search giant Google for its failure to comply with Commission requests for documents and information related to the company's collection of personal user data as part of its Street View project.

According to a Notice of Apparent Liability issued in April 2012, Google collected data from Wi-Fi networks in the U.S. and around the world between May 2007 and May 2010 for the purpose of supporting its location-based user services. However, in addition to collect-

Based on its investigation, the Commission's Enforcement Bureau decided not to pursue enforcement action against the company for its collection of payload data, noting that there did not exist a clear precedent for applying provisions of the Communications Act to Wi-Fi communications. Further, as noted in the Commission's Notice, a key witness in the case employed by Google asserted his constitutional right not to provide testimony to the Enforcement Bureau, thereby preventing the thorough investigation of a number of factual questions related to the company's data collection efforts.

However, according to the Commission, "Google deliberately impeded and

T-Mobile Receives Notice of Apparent Liability Regarding HAC Headsets

The Federal Communications Commission (FCC) has proposed a forfeiture penalty of over $800,000 against T-Mobile USA for failing to offer their customers the required number of hearing aid-compatible (HAC) handsets.

In a Notice of Apparent Liability for Forfeiture issued in April 2012, the Commission proposed the fine for what it calls the company's willful and repeated violation of the Commission's rules during 2009 and 2010.

Under those rules, so-called Tier 1 service providers are required to

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> In addition to collecting necessary location data, Google also reportedly collected so-called payload data, including email, text messages, passwords, Internet usage history and other personal information not required for the location database project.

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ing necessary location data, Google also reportedly collected so-called payload data, including email, text messages, passwords, Internet usage history and other personal information not required for the location database project.

When initially questioned in early 2010 by European authorities investigating the company's data collection procedures, Google reportedly denied that it had collected payload data as part of the project. Nevertheless, by October 2010, Google publically acknowledged that "in some instances, entire emails and URLs were captured, as well as passwords." As a result, the FCC Enforcement Bureau launched an official investigation into Google's data collection activities in November 2010.

delayed the Commission's investigation by failing to respond to requests for material information and to provide certifications and verifications of its responses…(and) apparently willfully and repeatedly violated Commission orders to produce certain information and documents the Commission required for its investigation." On that basis, the Commission has proposed a $25,000 forfeiture for Google's noncompliance with the Enforcement Bureau's information and document requests.

The complete text of the Commission's Notice of Apparent Liability for Forfeiture against Google is available at incompliancemag.com/news/1207_01.

ensure that a minimum number of wireless phones that meet or exceed the minimum rating for hearing aid compatibility are offered to consumers. The requirements regarding the number of HAC handsets were initially implemented in February 2009, and were gradually increased over the next 22 months (through December 2010). Service providers were required to file status reports with the FCC during that period verifying compliance with the requirements.

In its Notice of Apparent Liability for Forfeiture, the Commission cited data submitted by T-Mobile in mandatory filings regarding the number of HAC handsets available for sale to consumers.

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The Power You Need Here,
It Doesn't Exist.
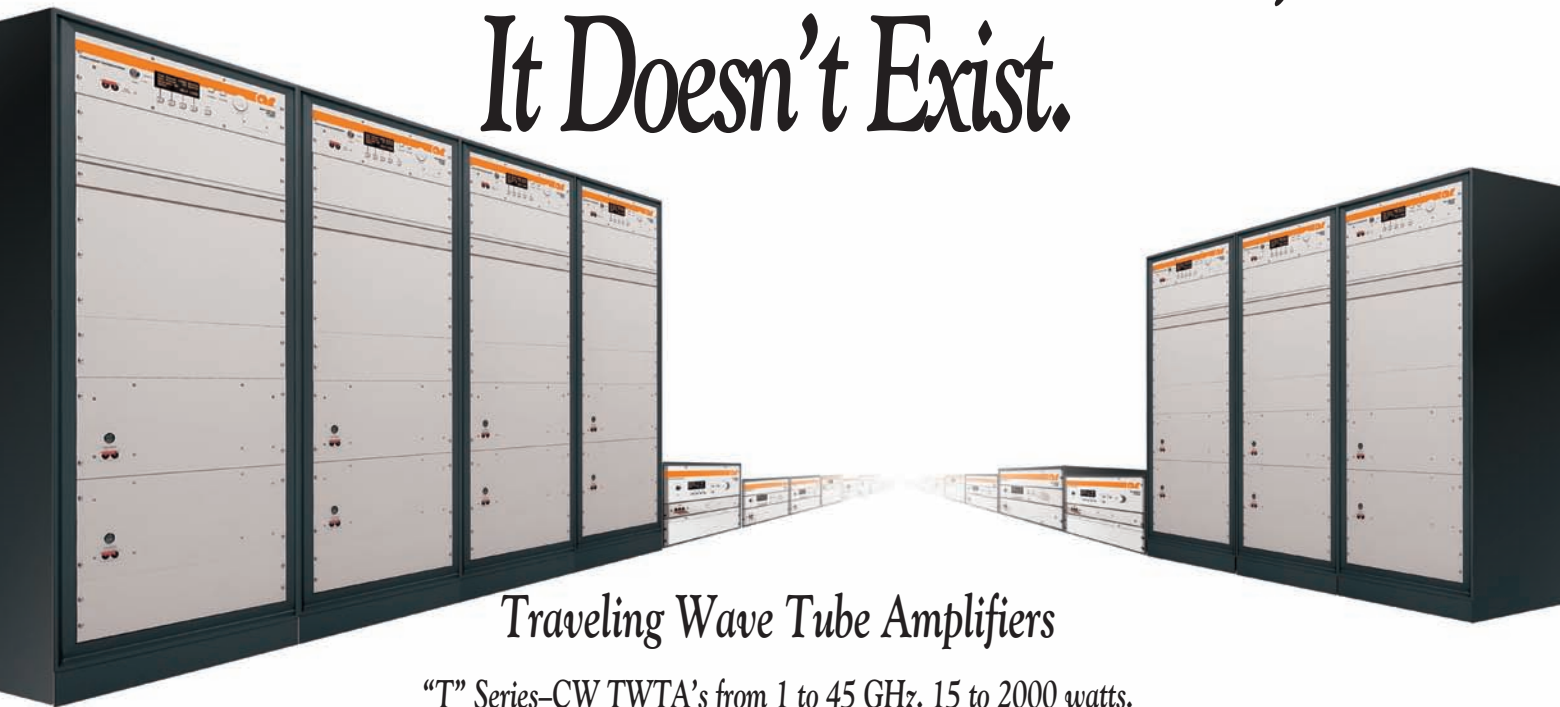
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So before you choose a look-alike traveling wave tube amplifier, examine all the features and benefits that come along at no extra charge with an AR amplifier. If you want a TWTA that will take you farther, you'll choose the one with the AR logo on it ... the company that stands behind our products with the global service and support that you demand.

To learn more, visit www.arworld.us or call us at 215-723-8181.

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News in Compliance

FCC News

The Commission's Notice of Apparent Liability against T-Mobile is available at incompliancemag.com/news/1207_02.

FCC Implements New Rules Against Cramming

The Federal Communications Commission (FCC) has issued new rules that will provide consumers with additional protections against the practice of adding unauthorized charges and fees to residential phone bills, also known as "cramming".

company's website) of the option to block third-party charges on their telephone bills.

2. Strengthen existing Commission requirements that all third-party charges on landline telephone bills be clearly separated from the phone company's own charges.

The Commission also requested comments on whether it should adopt additional protections against cramming, such as requiring landline telephone companies to obtain consumer consent prior to placing third-party charges on their telephone bills

impacted by cramming are aware of the monthly charges being applied to their bills.

The FCC's newly proposed rules are part of a larger effort by the Commission to address cramming and other so-called mystery fees on consumer telephone bills. In a settlement reached with the Commission in 2011, Verizon Wireless agreed to refund $50 million in overcharges to subscribers, and to make a $25 million "voluntary payment" to the U.S. Treasury. Further, in June 2011, the Commission issued Notices of Apparent Liability totaling $11.7 million against

> The FCC has issued new rules that will provide consumers with additional protections against the practice of adding unauthorized charges and fees to residential phone bills, also known as "cramming".

Detailed in a Report and Order and Further Notice of Proposed Rulemaking issued in April 2012, the Commission's new rules are as follows:

1. Require landline telephone companies to notify consumers clearly and conspicuously (at the point of sale, on each bill, and on the

if the company already offers to block those charges.

According to the Commission, an estimated 15-20 million American households receive "mystery" fees on their monthly landline phone bills each year, and only 5% of consumers who are

four separate telecommunications companies allegedly engaged in widespread cramming.

The complete text of the Commission's Report and Order on cramming is available at incompliancemag.com/news/1207_03.

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European Union News

EU Commission Updates List of Standards for Medical Device Directive

The Commission of the European Union (EU) has issued a revised and updated list of standards that can be used to demonstrate conformity with the essential requirements of its Directive 93/42/EEC concerning medical devices.

The Directive defines a 'medical device' as "any instrument, apparatus, appliance, material or other article, whether used alone or in combination, including the software necessary for its proper application….to be used for human beings for the purpose of: 1) diagnosis, prevention, monitoring, treatment or alleviation of disease; 2) diagnosis, monitoring, treatment, alleviation of or compensation for an injury or handicap; 3) investigation, replacement or modification of the anatomy or of a physiological process; or 4) control of conception."

The revised list of CEN and Cenelec standards replaces all previously published standards lists for the Directive, and was published in April 2012 in the *Official Journal of the European Union*.

The revised list of standards for the EU's Medical Device Directive is available at incompliancemag.com/news/1207_04.

EU Commission Issues New Standards List for In Vitro Diagnostic Medical Devices Directive

The Commission of the European Union (EU) has published an updated list of standards that can be used to demonstrate compliance with the essential requirements of its Directive 98/79/EC, dealing with in-vitro diagnostic medical devices.

According to the EU's Directive, an in-vitro diagnostic medical device is "any medical device which is a reagent, reagent product, calibrator, control material, kit, instrument, apparatus, equipment, or system, whether used alone or in combination, intended by the manufacturer to be used in-vitro for the examination of specimens, including blood and tissue donations, derived from the human body."

Under the Directive's definition, specimen receptacles are considered to be in-vitro diagnostic medical devices, while products for general laboratory use are not, unless such products are intended to be used for in vitro-diagnostic examination.

The updated list of CEN and Cenelec standards that can be used to support compliance with the Directive was published in April 2012 in the *Official Journal of the European Union*, and replaces all previously published standards lists for the Directive.

The list is available at incompliancemag.com/news/1207_05.

News in Compliance

European Union News

Updated Standards List for Active Implantable Medical Devices Issued by EU Commission

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 90/385/EEC, relating to active implantable medical devices.

According to the EU's Directive, "an 'active medical device' means any medical device relying for its functioning on a source of electrical energy or any source of power other than that directly generated by the human body or gravity."

Further, "an 'active implantable medical device' means any active medical device which is intended to be totally or partially introduced, surgically or medically, into the human body or by medical intervention into a natural orifice, and which is intended to remain after the procedure."

The updated list of CEN and Cenelec standards that can be used to support compliance with the Directive was published in the *Official Journal of the European Union* in April 2012, and replaces all previously published standards lists for the Directive.

The list can be viewed at incompliancemag.com/news/1207_06.

Updated Standards List Published for EU's ATEX Directive

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

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

The updated list of standards was published in May 2012 in the *Official Journal of the European Union*, and replaces all previously published standards lists for the ATEX Directive.

The complete list of standards can be viewed at incompliancemag.com/news/1207_07.

EU Commission Releases 2011 RAPEX Summary Statistics on Unsafe Consumer Products

The Commission of the European Union (EU) has released statistics on notices of unsafe consumer products that have been processed through the EU's rapid information system (RAPEX) for the year ending December 31, 2011.

According to the Commission's report, 1803 notifications of products posing a serious risk to health and safety were processed through the RAPEX system during 2011. This represents a 20% decrease in notifications over 2011's 2244 notifications, but still a nearly 400% increase in the number of notifications received in 2004, when the RAPEX system processed just 468 notifications.

In its annual report, the Commission attributes the 2011 decrease in notifications to the end of joint enforcement actions by EU member states and budgetary restrictions that led to enforcement resource constraints. However, the Commission also noted that a wider and more thorough use of RAPEX risk assessment guidelines allowed enforcement authorities in member states to better focus their attention on products posing the most serious safety risks. Seen in this light, the Commission believes that the quality and reliability of notifications were enhanced, thereby supporting more effective follow-up actions against dangerous products.

Of the 1803 notifications of products processed through the RAPEX system during the year as presenting a serious risk to consumers, 423 (27%) were related to clothing, textiles and fashion items, with an additional 324 (21%) related to toys, and 153 (10%) related to electrical appliances. There were also 171 notifications related to motor vehicles (11%), and 66 notifications (4%) related to childcare articles and children's equipment.

Regarding the country of origin identified in connection with products posing a serious safety risk, more than half of all notifications (54%) were related to products originating from China, including Hong Kong. Another 19% of unsafe products originated in EU member states, while 8% failed to identify any country of origin.

To view the complete text of the EU Commission's 2011 annual report on RAPEX statistics, go to incompliancemag.com/news/1207_08.

News in Compliance

News in Compliance

CPSC News

Lenovo Expands Recall of ThinkCentre Desktop Computers

Lenovo of Morrisville, NC has expanded a product recall affecting about 13,000 additional units of its ThinkCentre-brand desktop computers manufactured in Mexico.

The company reports that the recall is due to a defect in an internal component of the power supply, which can overheat and pose a fire hazard to consumers. Lenovo says that it has received reports of one fire incident and one smoke incident related to the recalled computers, but no reports of injuries.

The computers included in this recall were sold online through Lenovo's website, and by telephone and direct sales through authorized Lenovo dealers, from May 2010 through March 2012 for between $500 and $800, depending on the model.

Additional details about this recall are available at incompliancemag.com/news/1207_09.

Company Recalls Battery Chargers

Sakar International, Inc. of Edison, NJ has recalled about 48,000 of its compact travel chargers manufactured in China.

According to the company, the plastic holding screws that secure the casing can break, potentially exposing energized components and posing a risk of electric shock or electrocution for users. Sakar International says that it has not received any reports of the charger falling apart, or of electrocution or electric shock, but has initiated the recall to prevent future incidents and injuries.

The recalled battery chargers were sold at Radio Shack, Ocean State Jobbers, Lot-Less and Cobra Digital from

January 2011 through February 2012 for about $10.

More information about this recall is available at incompliancemag.com/news/1207_10.

Do you have news that you'd like to share with your colleagues in the compliance industry? We welcome your suggestions and contributions.

Send news items to the editor:

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From Our "You Can't Make This Stuff Up" File

As we enter the summer vacation season, travelers connecting through one of the metro New York's three major airports should be on the lookout for customer service agents in the form of life-sized human-shaped holograms.

The Port Authority of New York & New Jersey, which operates JFK, La Guardia and Newark Liberty airports, has announced a series of initiatives to improve customer service for passengers. In addition to the installation of more power outlets for electronic devices and cleaner restrooms, the Authority will deploy "virtual customer care representatives," in key locations in the airports.

The computer generated avatars will be programed to provide responses to basic traveler inquiries, and are guaranteed not to lose their patience when asked "where's the men's room" for the hundredth time in the course of an afternoon. The virtual customer care representatives are slated to be "installed" in early July.

For travelers who are skittish about asking a hologram for help, the Authority has also pledged to increase by 20% the number of its red-jacketed human customer care representatives stationed at the airport. So, between the airports' virtual and human customer care representatives, air travel in the New York area should be a little easier this summer!

UL Standards Updates

Underwriters Laboratories has announced the availability of these standards and revisions. For additional information, please visit their website at www.ul.com.

STANDARDS

UL 126: Standard for Sustainability for Plastic Film Products
New Edition dated May 1, 2012 :

UL 144: Standard for LP-Gas Regulators
New Edition dated May 25, 2012 :

UL 977: Standard for Fused Power-Circuit Devices
New Edition dated April 30, 2012 :

UL 1727: Standard for Commercial Electric Personal Grooming Appliances
New Edition dated May 21, 2012 :

UL 2353: Standard for Safety for Single- and Multi-Layer Insulated Winding Wire
New Edition dated May 14, 2012 :

UL 2796: Standard for Sustainability for Odor Control Products
New Edition dated May 8, 2012 :

UL 61010-2-030: Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 2-030: Particular requirements for testing and measuring circuits
New Edition dated May 11, 2012 :

UL 61010-1: Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use - Part 1: General Requirements
New Edition dated May 11, 2012 :

REVISIONS

UL 48: Standard for Electric Signs
Revision dated May 4, 2012 :

UL 183: Standard for Manufactured Wiring Systems
Revision dated May 10, 2012 :

UL 484: Standard for Room Air Conditioners
Revision dated May 21, 2012

UL 493: Standard for Thermoplastic-Insulated Underground Feeder and Branch-Circuit Cables
Revision dated May 30, 2012

UL 555: Standard for Fire Dampers
Revision dated May 15, 2012

UL 555S: Standard for Smoke Dampers
Revision dated May 15, 2012

UL 639: Standard for Intrusion-Detection Units
Revision dated May 15, 2012

UL 778: Standard for Motor-Operated Water Pumps
Revision dated May 25, 2012

UL 840: Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment
Revision dated May 4, 2012 :

UL 1577: Standard for Optical Isolators
Revision dated May 4, 2012 :

UL 1703: Standard for Flat-Plate Photovoltaic Modules and Panels
Revision dated May 8, 2012 :

UL 1746: Standard for External Corrosion Protection Systems For Steel Underground Storage Tanks
Revision dated May 24, 2012

UL 2061: Standard for Adapters and Cylinder Connection Devices for Portable LP-Gas Cylinder Assemblies
Revision dated May 9, 2012 :

UL 2218: Standard for Impact Resistance of Prepared Roof Covering Materials
Revision dated May 1, 2012 :

UL 2344: Standard for Material Lifts
Revision dated May 15, 2012

UL 2572: Standard for Mass Notification Systems
Revision dated May 11, 2012 :

UL 60730-2-8: Standard for Automatic Electrical Controls for Household and Similar Use; Part 2: Particular Requirements for Electrically Operated Water Valves, Including Mechanical Requirements
Revision dated May 25, 2012

iNARTE Informer

Making the Move

BY BRIAN LAWRENCE

Technology transfer and moving of hardware from our New Bern, NC office to the RABQSA Milwaukee office has begun. This process will take place gradually over the next two months in order that it is not too disruptive to our operations.

Nevertheless, we expect that some longer than normal times will be needed in processing certification requests and marking of examination results during this period. By the end of August all systems should be operating smoothly in the new RABQSA offices.

iNARTE attended the High-speed digital engineering and EMC series of courses at the University of oxford in June, and received considerable support and interest in the new EMC Design Engineer Certification program. It is expected that iNARTE will become a regular feature of these Continuing Education programs at Oxford.

Our congratulations go to Mike Violette, President of Washington laboratories and to Elya Joffe, President of the IEEE PSE Society and past President of the IEEE EMC Society. These two members of the now disbanded iNARTE Board of Directors have been invited onto the RABQSA Board of Directors. Most other members of the iNARTE Board will be invited to serve on an iNARTE/RABQSA Advisory Board

Learn more about RABQSA at http://www.rabqsa.com.

The RABQSA 2011Annual Report is available at http://rabqsa.com/docs/rabqsa-annual-report-fy2011.pdf.

THE NEW EMC DESIGN ENGINEERING PROGRAM

At the end of May, our partner in Japan, KEC Electronic Industry Development Centre, administered their second iNARTE EMC Design Engineer certification examination. Although very new the examination attracted 35 participants, more than half of which succeeded in achieving a passing grade. All examinations were at the basic Engineer level for recent graduates and engineers with just two or more years of electronics design experience.

This same examination level will be offered at the IEEE EMCS 2012 in August as well as the more advanced Senior EMC Design Engineer examination for those with five or more years of related work experience.

Applications for certification as a Master EMC Design Engineer will be available once again in September. Plan to visit the iNARTE web site in September to get this latest information.

OPTIONS FOR PRODUCT SAFETY ENGINEERS AND TECHNICIANS THROUGH RABQSA

Now that iNARTE is a brand of the RABQSA International organization, there are more than 30 other certification schemes that iNARTE engineers and technicians could consider. One of the most closely comparable credentials would be that of a Certified Safe Design Professional. The iNARTE Certified Product Safety Engineer and Technician go into more technical details than the RABQSA Safety Design Professional does. The RABQSA scheme is for individuals who conduct design appraisals. These individuals would not be a part of the actual design of the products, as the iNARTE engineers and technicians would be. Instead they would be responsible for verifying that the product design does in fact meet the required market safety standards. Page 17 shows a comparison of the requirements for the RABQSA scheme with the iNARTE program.

(the author)

BRIAN LAWRENCE began his career in electromagnetics at Plessey Research Labs, designing "Stealth" materials for the British armed services. In 1973 he moved to the USA and established a new manufacturing plant for Plessey to provide these materials to the US Navy. In 1980 he joined the Rayproof organization to develop an Anechoic Chamber product line. As a result of acquisitions Rayproof merged into Lindgren RF Enclosures and later into ETS-Lindgren. Following a career of more than 40 years in the EMC field, Brian retired as Managing Director of ETS-Lindgren UK in 2006. Later that year he assumed the position of Executive Director for the National Association of Radio and Telecommunications Engineers. NARTE. Now renamed iNARTE, the Association has expanded its operations and in 2012 merged with RABQSA International, a subsidiary of the American Society for Quality, ASQ. Brian remains associated with RABQSA through this merger process.

	RABQSA Safe Design Professional	iNARTE Product Safety Engineer/Technician
Scope of responsibility	Design appraisals on consumer products	Engineering and practice to reduce types of risk to persons, animals and property that have to be covered by a formal hazard analysis to meet the requirements of the relevant legislation
Education	Tertiary education or national equivalent	Relevant tertiary education that can be equated to technical experience. Engineers should have a 4 year degree.
Work experience	Two years work experience 1) in a technical or managerial position with direct product design, development, manufacturing, or testing/quality experience; or 2) working for a regulatory agency conducting/managing consumer product hazard analysis/risk assessment.	Nine (9) years engineering experience, part of which could be tertiary education Six (6) years of technician experience, part of which could be tertiary education
Knowledge requirements	• Market place product entry requirements; • Data analysis; • Foreseeable use analysis/consumer behavior; • Engineering, chemical and microbiological analyses; • Product-consumer-products; and • Product characteristics.	Written exam in PS engineering fundamentals Written exam in PS technology EXAM TOPICS A. Connection to supply B. Isolation of supply C. Mechanical hazards D. Earthing E. Types of Insulation F. Protection against electrical shock G. Resistance to fire H. Fire hazards I. Limits on fuel J. Limits on heat K. Insulation damage L. Creepage and clearance M. Inter system and intra system design N. Equipment design O. Hazard analysis P. Risk assessment Q. Design review R. Legislation US,EEC and International S. Military and Civil Electrical Safety Standards T. Safety tests U. Assessment authorities V. Competent Bodies W. Safety certification X. Declarations of Conformity Y. Operating and maintenance instructions and handbooks.
Skill requirements	• Testing, inspection, and market place product entry requirements; • Data analysis; • Foreseeable use; • Engineering, chemical and microbiological analyses; • Consumer-product interactions; and • Product characteristics.	None other than knowledge
Attributes	PAAS Master PAAS Master® is a simple e-based online examination consisting specific questions which examine your ability to demonstrate personal attributes. The attributes were determined following extensive national and international research and interview with the aim of determining what, in terms of personal attributes, separates the more effective and efficient auditors. Software matrix-analysis of each answer determines whether the applicant has the potential to demonstrate the required attributes.	

**Mike Violette seems happy
at the prospect of joining RABQSA**

How Fast Does a Charge Decay?

BY NIELS JONASSEN, sponsored by the ESD Association

There's a phrase that has been bothering me for years: "How do you remove static electricity?" At one level the question makes sense. Everybody involved in electrostatics understands what the inquirer is trying to ask. But at a physics level, as well as a linguistic one, the phrasing is more dubious. A better expression of the question would be "How do you neutralize the field from static charges?"

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

Why is this phraseology better? Well, first of all, the field from a charge (distribution) is a well-defined concept, which static electricity is not. And secondly, when you do neutralize a field (or "remove static electricity"), you very rarely remove anything from the charged body. (When you ground a negatively charged conductor with a metallic wire and avoid all kinds of discharges, you lead away the excess electrons. But that is the only case where charges can be removed.)

In order for neutralization to happen, the charged area has to be in contact with a medium containing charge carriers of the opposite polarity. A force from the field then acts upon these charge carriers, and, if they have some ability to move, they'll eventually plate out on the charged area. The field from the plated-out carriers will superimpose the original field, resulting in a steadily decreasing "total" field. In other words the static charge is decaying.

So let's change the question from how to remove static electricity to how fast does a charge decay.

BULK AND SURFACE DECAY

It is easier to describe the decay if we consider separately bulk decay, where charges move through the interior of the material, and surface decay, where the movement of charges takes place primarily in a surface layer.

Bulk Resistivity. The rate at which neutralization takes place in a given field depends upon the conductivity γ of the medium. A field E will release a current with the density (current per unit area) j given by

$$j = \gamma E \qquad (1)$$

Equation 1 is often written

$$E = \rho j \qquad (2)$$

where

$$\rho = \frac{1}{\gamma} \qquad (3)$$

is the bulk resistivity of the medium. Equations 1 and 2 are both versions of Ohm's law (in differential form). The field from a given charge will always be proportional to the charge, but the factor of proportionality will depend upon the geometry and dielectric properties of the charged body and its surroundings.

Let's look at a simple example. Figure 1 (situation 1) shows a piece of a material, with the resistivity ρ and the permittivity ε, resting on a grounded plane. A charge q is evenly distributed on the surface of the material. We assume that the distance to other grounded objects is much larger than the dimensions of the charged sample.

If the charge density is σ (C • m^2), then the field strength in the material is

$$E = \frac{\sigma}{\varepsilon} \qquad (4)$$

According to Equation 2 this field will produce a (negative) current

$$j = \frac{1}{\rho} E = \frac{\sigma}{\varepsilon\rho}$$

But the current density j is also the rate at which the surface density decreases, that is

$$(j=) - \frac{d\sigma}{dt} = \frac{\sigma}{\varepsilon\rho} \qquad (5)$$

The solution to Equation 5 is

$$\sigma = \sigma_o e^{\frac{-t}{\varepsilon\rho}} \qquad (6)$$

where σ_o is the initial value of the charge density. Thus it appears that the charge is being neutralized exponentially with the time constant

$$\tau_o = \varepsilon\rho \qquad (7)$$

Equation 7 is generally valid when the field from the charge to be neutralized extends exclusively through the medium with the resistivity ρ and the permittivity ε.

Consider a sample of Plexiglas with $\rho \approx 10^{13}\,\Omega \bullet$ m and $\varepsilon \approx 3 \bullet 10^{11}$ F • m^1 ($\varepsilon_r \approx 3.4$). A charge on it will decay with a time constant of about 300 seconds. It should be appreciated that the rate of decay is determined not only by the resistivity, but also by the permittivity. So if we have a sample with the same resistivity as the Plexiglas, but with twice the permittivity, the rate of decay will be half that of the Plexiglas.

The situation is more complicated, however, if the field from the charge,

or rather the flux, extends through several dielectrics with different resistivities and permittivities. Thus, a brief digression to discuss electrical flux is useful here.

The electrical flux or E-flux Φ_E through a surface S is defined as

$$\Phi_E = \int_s E \bullet dS$$

If the surface S is a closed surface surrounding a charge q, then, assuming you have the same permittivity all over the surface S, the previous equation becomes

$$\Phi_E = \int_{closed\ surface} E \bullet dS = \frac{q}{\varepsilon}$$

This is simply Gauss' theorem, which enables calculation of the field from various charge distributions. Flux being a rather abstract concept, it can be helpful to envisage the situation as a charge "emitting" a certain number of field lines. The number of those field lines through a unit area (perpendicular to the field strength) is equal to the field strength. So the flux through a given area is, roughly speaking, the number of field lines through that area.

Now back to the more-complex situation. Figure 2 (situation 2) shows a sample with the thickness d, permittivity ε, and resistivity ρ, resting on a grounded plane, like that shown in Figure 1. But in this case another grounded plane is placed parallel to the sample at a distance x. Let us assume that the sample is Plexiglas, and that the space above the sample is vacuum (or air) with $\varepsilon = \varepsilon_o$ and $\rho \approx \infty$. The field (flux) from the charge is now shared between the Plexiglas and the air in
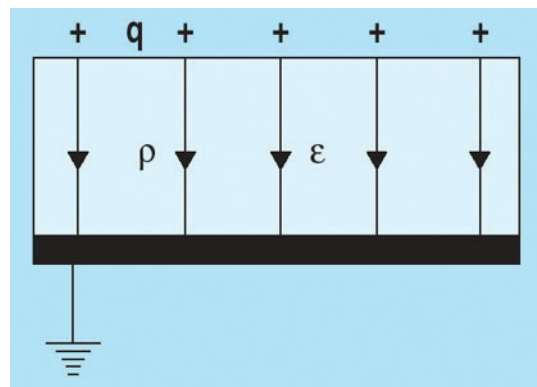
Figure 1: Bulk decay of charge, situation 1.
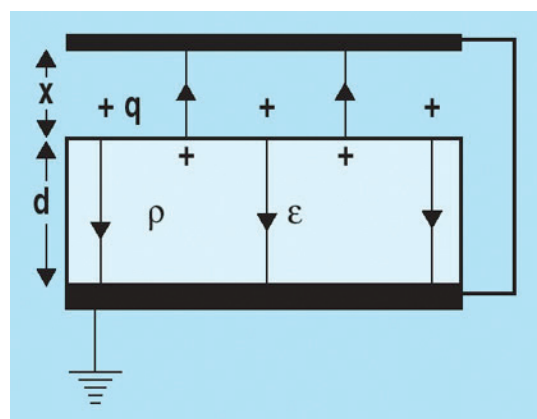
Figure 2: Bulk decay of charge, situation 2.

such a way that the surface potential of a point on the charged surface is the same whether it's calculated as the field strength in air multiplied by x or as the field strength in the dielectric multiplied by d. Thus the charge is expected to decay exponentially again, but now with a time constant τ given by

$$\tau = \tau_o \left(1 + \frac{d}{\varepsilon_r x}\right) \qquad (8)$$

For instance if we choose d = 0.01 m and x = 0.003 m (ε_r = 3.4, the relative permittivity of Plexiglas), we find that τ= 594 seconds. In other words, it takes about twice as long for the charge to decay, even from the same sample of material, simply because of the proximity of another grounded conductor.

The example shown in Figure 2 is a very simplified case, and often it will not be

possible to predict the relevant value of the time constant for a given sample in a given geometrical environment.

Surface Resistivity. Special cases are the ones in which neutralization takes place in a shallow layer on the surface of the material. This could be a material treated with an antistatic agent or an insulative substrate onto which a conductive layer is evaporated. If such a layer is highly conductive as compared with the contacting materials, the neutralizing current will run only in this layer. However, part of the flux from the charge will run in the adjoining layers, and the "driving field," that is, the field in the conductive layer, will depend upon the permittive properties of the adjoining insulators. Thus the rate of decay (and the time constant) will depend not only on the properties of the region where the decay takes place, but also on properties outside the region of decay. This is, in principle, the same problem shown in Figure 2. Usually the processes in thin layers are characterized by defining a surface resistivity ρ_s (in a way similar to the definition of bulk resistivity) by the equation

$$E_s = \rho_s j_s \qquad (9)$$

This version of Ohm's law states that a field E_s along a surface with the surface resistivity ρ_s will cause a current with

Figure 3: Surface decay of charge, situation 1.

Figure 4: Surface decay of charge, situation 2.

the linear current density j_s (current per unit length, A • m^1) in the layer given by equation (9).

Although in the matter of bulk resistivity it is possible in certain simplified cases (Figures 1 and 2) to derive a connection between the resistivity and the rate at which a charge is being neutralized, it is not nearly as simple in the matter of surface resistivity.

Figure 3 (situation 1) shows a piece of material A. At one end of A is a spot of negative charge and, at the other end, a grounded electrode B in direct contact with A. Between B and A is a field. Only that fraction of the flux that runs through the conductive layer will cause a current to neutralize the charge. There is no doubt that if the charge is, say, doubled, then the field strength will be doubled in every point, but the field distribution will be the same. And if the surface resistivity is doubled, the decay rate will be halved. With this geometry, it seems likely that we will have a time constant proportional to the surface resistivity. But, in contrast to simple situation 1 for bulk decay (Figure 1), we cannot theoretically predict--even if we measure the surface resistivity and know the permittivity of the conductive layer--the time constant for surface decay. This is because we don't know how the flux is distributed between the conductive layer and the environment.

Figure 4 (situation 2) shows a state similar to situation 2 for bulk decay (see Figure 2). Another grounded conductor C is in the neighborhood of the charged sample, but not in direct contact with it, so no neutralizing current will flow to C. And since the flux to B is now lower, so is the neutralizing current, and the time constant will

have increased, even if the sample, the charge, and the grounding electrode arrangement is the same.

This discussion has tacitly assumed that there is only one value for the resistivity (be it bulk or surface) independent of the field applied. Yet it is often found that the resistivity increases with decreasing field strength. Nevertheless, resistivities are usually determined at only one field strength (one voltage difference between a set of electrodes on the sample), and we have no way of knowing if this particular field strength is typical for the physical conditions during a decay process.

MEASUREMENT OF DECAY TIME

The previous considerations illustrate that only under very ideal conditions is it possible to calculate reasonably accurately from material parameters (resistivity and permittivity) how fast a charge on an insulator will decay. This is because of two main reasons:

- The resistivity depends on the field strength from the decaying charge (and we rarely know this relationship), and even more importantly,

- The driving field from a given charge depends on the permittive properties of the environment in a usually incalculable way.

So the obvious question is why not measure the decay time directly? If we are dealing with a highly resistive item, it is certainly possible to charge the material and measure how fast the field from the charge decays when the item is placed in a relevant environment. Usually we are interested in semiinsulative materials where the charges are neutralized in seconds or less. And the procedures of measurement have to allow for this.
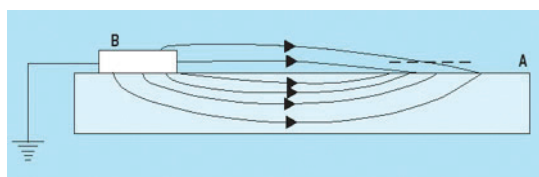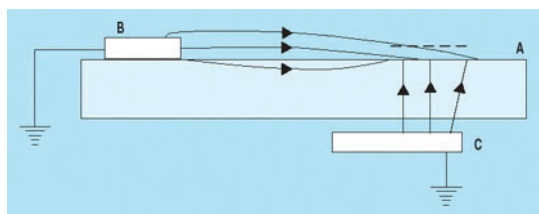
Over the years several procedures have been developed, and, to be kind, none of them were very successful. A general shortcoming of all these methods is that they do not measure in situ. That is, the measurements are performed not on the material as it normally appears when it gets charged, but rather on sheet samples suspended in such a way as to facilitate charging as well as field measurement.

Probably the most commonly used method is Federal Test Method (FTM) Standard 101C, method 4046.1, where a sample is clamped between two electrodes (see Figure 5). A field meter is mounted pointing at the center of the sample midway between the electrodes. The sample is allegedly charged by the electrodes when they are connected to a voltage supply, and the charge decay is taken as the reading of the field meter after the electrodes are grounded. It seems difficult (at least to this author) to be sure that a reading of the field meter is a sign of an excess charge on the material, unless the material is truly conductive. Polarization may certainly show itself, at least with some materials, as an external field, and the rate of relaxation of polarization is not necessarily the same as that of a true excess charge.

Several other questions could be raised concerning this method. The most important one is that a decay time obtained by method 4046.1 for a sheet of a material of a given small size does not reveal much about how fast the field from a charge will be neutralized on a larger sample or item in another location.

In another method, the sample (again a suspended sheet) is charged by a corona discharge. The charger is then removed and replaced by a field meter. (Incidentally, we developed this method, which has the merit of placing a real charge on the surface

of the material under investigation, at our laboratory as early as 1977, but ultimately abandoned it since our instrumentation was not fast enough.) Although it has been argued that the corona charging with air ions may be irregular, one could also argue that the charging experienced in everyday life is irregular too. So this should rather be deemed a virtue of the method. Still the main argument is that one does not measure the charge neutralization (decay) rate under circumstances that
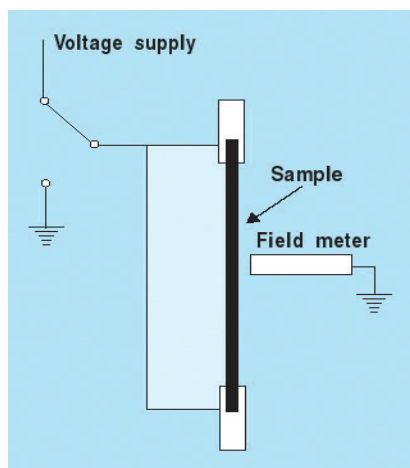
Figure 5: FTM Standard 101C decay of field from charge.

resemble normal use of the materials. It should also be mentioned that it is not possible to distinguish between bulk and surface decay using either of these methods, or probably any other method for that matter. It may even be argued that the distinction does not make sense at all. Another objection to any principle, suggested or applied, for determination of charge decay time is that any method capable of detecting the presence and time variation of a charge on an object will occupy a certain fraction of the electrical flux from the charge, a fraction which, without the presence of the measuring equipment, might contribute to the rate of neutralization or decay of the charge. Thus the measured rate of decay will

normally be different from (often larger than) the «natural,» undisturbed rate.

CONCLUSION

The considerations presented in this paper may make it seem as if we know nothing about the laws of decay of charges on insulators. This is not the case.

Although we can accurately predict the current I through a resistor with the resistance R from a voltage supply with output voltage V, we have to accept that static electricity (ESD, if you insist) is a little more complicated (and interesting). We also have to accept the fact that there's no way you can predict the decay behavior of a manufactured item placed in an arbitrary environment by doing some laboratory measurements on a sample of the material of said item.

So what do we do when we have to choose between different materials? Well, we know that if we have two materials with different resistivities, bulk or surface, under similar circumstances the one with the lowest resistivity will mean the fastest decay time, although not in an unambiguous way. So the obvious advice is to choose the material with the lowest resistivity. ◼

(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.

ON Your Mark

GHS and Global Consistency

BY GEOFFREY PECKHAM

Today's international marketplace demands consistency of labeling and symbols. In this article, we'll explain how the OSHA Globally Harmonized System (GHS) of Classification and Labeling of Chemicals initiative provides a *global* system of chemical hazard warning symbols.

Currently, it can be difficult to decipher how to comply with domestic and global regulations regarding symbols. As an example, Figure 1 illustrates different ways flammability has been indicated over the years and in different parts of the world.

According to estimates from some multinational companies, there are over 100 diverse hazard communication regulations in existence for their products around the world. The United Nations (UN) recognized that this is an inhibiting barrier to international trade, which led to the international mandate at the Earth Summit in 1992 calling

for "a globally harmonized hazard classification and compatible labeling system"[1]. They concluded that the only way to transport chemicals safely across international borders is by applying universal consistency in labeling, including the graphical symbols used to indicate various chemical hazards.

Chemical products come into the U.S. workplace from all parts of the world. They may be manufactured in a foreign country, transported to their docks, shipped overseas, transported to various distribution warehouses, and finally delivered to the door of your facility. What good are the labels that appear on those chemical

Figure 1: From left to right, the GHS, Canadian, German and ISO warning symbols indicating flammable hazards.

Carcinogen
Mutagenicity
Reproductive Toxicity
Respiratory Sensitizer
Target Organ Toxicity
Aspiration Toxicity

Flammables
Pyrophorics
Self-Heating
Emits Flammable Gas
Self-Reactives
Organic Peroxides

Irritant
Skin Sensitizer
Acute Toxicity
Narcotic Effects
Respiratory Tract Irritant
Hazardous to Ozone Layer

Skin Corrosion/Burns
Eye Damage
Corrosive to Metals

Explosives
Self-Reactives
Organic Peroxides

Gases under Pressure

Acute Toxicity

Oxidizers

Aquatic Toxicity

Figure 2: The nine GHS pictograms, from top to bottom: "Health Hazard," "Flame," "Exclamation Point," "Corrosion," "Exploding Bomb," "Gas Cylinder," "Skull and Crossbones," "Flame over Circle" and "Environment."

products if they were written to comply with the country of origin's local standards but don't comply with U.S. regulations? Without standardization on a global basis, there is no hope for accurate, uniform, easy-to-understand information regarding hazardous chemicals. Thus, GHS was born.

GHS is short for "Globally Harmonized System for Classification and Labeling of Chemicals". Nation-by-nation and market-by-market this system of chemical labeling is taking the world by storm. Undertaken by the UN, this global effort to develop and implement a standard way of communicating chemical hazard information serves an incredibly noble cause: the prevention of accidental exposure to chemical hazards that could injure people or the environment. With better,

more uniform and standardized communication tools (i.e. labels and safety data sheets (SDS), or the procedures for safely working with a specific substance), people can more responsibly use, handle, store and dispose of hazardous chemicals.

In the field of hazard communication, there are many standardized symbols available, but it is often difficult to decide which graphic is applicable for use on your particular safety sign or label. GHS establishes nine specific pictograms to indicate a wide range of chemical hazards and names these symbols according to their pictorial elements rather than the actual hazards they refer to. Presumabl,y the titling of the symbols was done this way because several of the symbols stand for multiple hazards, as Figure 2 illustrates.

The purpose of establishing this set of global pictorial standards is instant recognition and understanding – even when a product is shipped from one country to another.

This is not a "performance-based" standard that you can meet any way you want. Companies that manufacture chemicals and chemical substances must label their products exactly according to the GHS categories with the appropriate associated signal word, symbol and text. Further, they must provide accompanying SDS that describe the exact information for that category of chemical according to GHS. There are two primary benefits associated with GHS. The first is that the chemical manufacturers no longer have to struggle with multiple national labeling schemes and don't
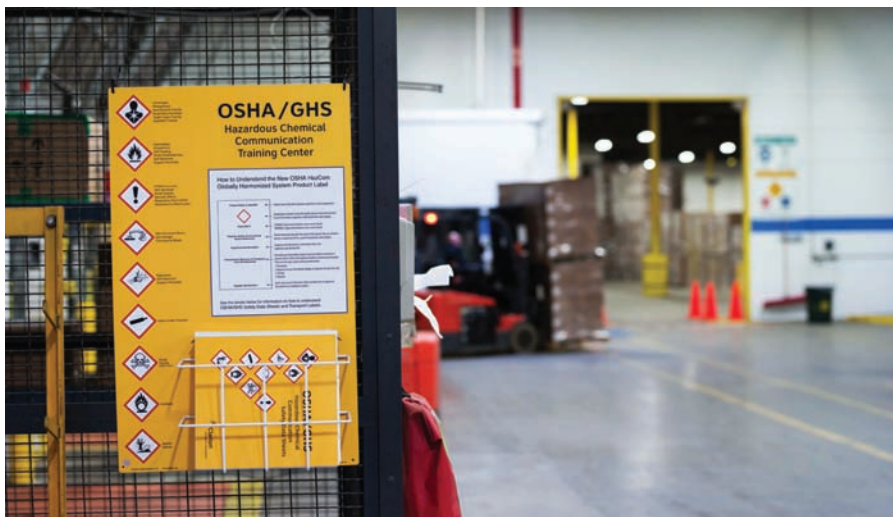
Figure 3: OSHA/GHS hazardous chemical communication training center installed in a facility.

have to write their labels and SDS from scratch. They simply implement GHS. The second benefit is that the end user now has a single uniform information system which is more easily read and understood, and provides the ability to compare chemical labels and SDS. Overall, the information is more intelligently and reliably utilized.

Before GHS was adapted by OSHA, Clarion recommended that its clients use warning symbols that had been standardized by ISO for chemical hazards. But now things have changed. In our view, global regulations trump voluntary standards. With that in mind, we now recommend that our clients utilize the GHS symbols to indicate chemical hazards for safety labels on

their products or for safety signs in their facilities. Moreover, Clarion serves as a resource in safety communication by manufacturing a centralized OSHA/GHS hazardous chemical communication training center to aid employers in training workers in the new system by December 2013, according to the new OSHA regulation (see Figure 3).

The ultimate goal is global consistency for all types of hazard communication, not just for communication of information about chemical hazards. Consistency of symbol use should lead to greater recognition and understanding, less confusion, and fewer accidents as the goal. Figure 4 shows how a GHS symbol can replace a non-GHS symbol in a safety label that might be used on

equipment where exposure to a chemical hazard might exist. Though this label is not meant to be a design for a GHS label going on a chemical product or a GHS sign intended to be used for the transport of a chemical, the illustration shows how the new GHS symbols will likely replace all other symbols when the intended safety message pertains to chemical hazards. OSHA/GHS represents a great example of how a new global language for safety is being established here and now. In the next column, I look forward to explaining another area in which global symbol standardization is taking place to help reduce risk and improve safety. ∎

For more information about safety signs and symbols, visit www.clarionsafety.com.

NOTE

1. http://www.osha.gov/dsg/hazcom/ghs.html

(the author)

GEOFFREY PECKHAM is president of Clarion Safety Systems and chair of both the ANSI Z535 Committee on Safety Signs and Colors and the U.S. Technical Advisory Group to ISO Technical Committee 145- Graphical Symbols. Over the past two decades, he has played a pivotal role in the harmonization of U.S. and international standards dealing with safety signs, colors, formats and symbols.

Figure 4: Old (left) and new (right) equipment safety labels pertaining to a potential corrosive chemical hazard, courtesy of Clarion Safety Systems © 2012.
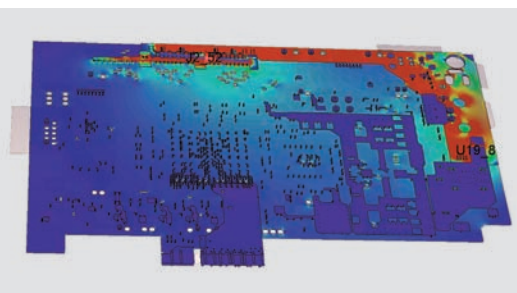
Signal Integrity Versus EMC During Printed Circuit Board Design

BY MARK I. MONTROSE

Engineers are beginning to face new challenges related to the design of printed circuit boards (PCBs) and their integration into an enclosure, either metal or plastic. These challenges will increase in the future with higher speed components and systems.

With the need to maximize functionality, while at the same time shrinking the physical size of a product to lower cost of development and production, we are discovering that signal integrity is becoming a greater concern than EMC. Although a system may radiate EMI in a broadband environment, will EMI be a concern in the future or should we enhance immunity protection against any and all electromagnetic threats that may occur?

To quote Eric Bogatin, signal integrity evangelist, "There are two kinds of design engineers, those that have signal integrity problems and those that will." This means EMC engineers need to take a greater role in working with designers on creating products. The concern is that both system and PCB designers along with EMC engineers must understand multiple aspects of doing a board layout in a manner that ensures not only functionality but also compliance. What I tell students and clients is, "The magnitude of a signal integrity problem is the magnitude of common-mode RF current that is developed." Basically I am saying that losses in a transmission line create common-mode EMI and that it is sometimes easier to work in the time domain instead of the frequency domain.

A transmission line, commonly called a trace on a PCB, allows an electrical signal to travel from a source to load through a dielectric as an electromagnetic field. During propagation, we must ensure there is no loss in any parametric value (voltage, current, propagation delay, timing, edge rate distortion, etc.). If the transmission line is perfectly lossless, the RF return current will be equal to the source path. This is called differential signaling. Any loss in the transmission line creates common-mode current. Thus, if there is significant loss in either the source or return path of the transmission line, common-mode EMI is developed and will propagate by any means available.

As frequencies get higher, we notice that second order effects cause loss to occur in a transmission line. While EMC engineers focus on making sure there are sufficient decoupling capacitors and that no traces cross a moat or is routed adjacent to a plane with a proper referencing along with

To quote Eric Bogatin, signal integrity evangelist,

"There are two kinds of design engineers, those that have signal integrity problems and those that will."

other standard rules of thumb, there are now additional items of concern that can cause a signal integrity problem. In the future, engineers must learn about the following sample list of signal integrity concerns:

Incorrect transmission line routing; improper terminations; power and/or return plane bounce; rise time degradation; lossy lines at high frequencies due to board material usage; hidden parasitics (RLC); skin depth losses; dielectric loss in the board material; propagation delays due to high dielectric constant board material; crosstalk; excessive inductance in the transmission line routing; delta I noise; overshoot and undershoot; IR drops; copper roughness; anisotropic aspects of the board material; and RoHS (affects delamination and creates tin whisker), to name a few.

In essence, we can no longer consider only electromagnetic aspects of both time and frequency domain design, but must now become knowledgeable in material science to enhance signal integrity and minimize development of common-mode current. Almost all of the items mentioned above that affects signal integrity are caused by improper selection of the material used to create the PCB, generally FR-4. My definition of a PCB is "a physical structure used to mechanically support transmission lines".

(the author)

MARK I. MONTROSE is an EMC consultant with Montrose Compliance Services, Inc. having 30 years of applied EMC experience. He currently sits on the Board of Directors of the IEEE (Division VI Director) and is a long term past member of the IEEE EMC Society Board of Directors as well as Champion and first President of the IEEE Product Safety Engineering Society. He provides professional consulting and training seminars worldwide and can be reached at mark@montrosecompliance.com.

Component Variables

BY DENNIS W. BARTELT AND PETER S. MERGUERIAN

Global parts procurement presents challenges to any product designer. If a component is sourced from multiple suppliers, how do you keep track of these suppliers from initial design to production, especially in a global manufacturing environment where products are made in multiple locations?

Do you really have the right manufacturing and process controls to manage such an environment? The unit submitted to a certified test facility had a specific supplier but is there assurance that other suppliers will perform the same during testing? If not watched carefully, these variables could wreak havoc with product certification and regulators worldwide.

Coupled with the drive to continually decrease cost and the pressure to reduce the time to market, product performance can be at risk due to the scenarios noted. That, coupled with the fact that circuits generally contain more than a single component, creates a complex situation to analyze and multiple risks could be present.

The following example takes the reader thru a real-life example of the complexities and inter-relationships between: 1) the component, 2) its deployment into a typical consumer product, and 3) how the manufacturing environment can exacerbate an already difficult situation. The investigation speaks to a consumer-based product that contains radio frequency transmitters and receivers as part of its architecture. Buckle your seat belts!

WHAT A STARTING POINT – THE CUSTOMER!

A consumer product employing a transmitter and receiver is produced in high volumes while being manufactured in multiple locations around the globe. Additionally, multiple

The Basics of Risk

In the real world, most problems that a manufacturer, supplier, or design engineer faces have multiple reasons, or variables, that contribute to the problem and its occurrence.

suppliers are used due to the volume demands placed on the manufacturing facility. After six months of production and customer shipments the service team (**Px**) began reporting warranty returns from customers. The primary customer complaints were two-fold: poor product performance along with excessive heat being felt on the exterior packaging, especially after long product usage times.

As the frontline, customer-facing organization, the '**Px**' team was the recipient of those happy customers returning their units. Their diagnosis noted:

1. low RF power output or no power from the transmitter

2. 3x increase in RF PA field failure rate as compared to the prior 3 months

3. conducted spurious emissions that were over the specification limit

4. multiple sources of the RF PA were present in the customer returned products

5. several manufacturing locations for the product were used

6. excessive or abnormally high surface temperatures on the products surface

THE BASICS OF RISK

In the real world, most problems that a manufacturer, supplier, or design engineer faces have multiple reasons, or variables, that contribute to the

problem and its occurrence. This is represented in Figure 1 where a problem could be caused by anyone, or multiples of, four (4) separate root causes or variables.

Some of these variables can be major contributors to the problem occurring while others are less likely to create the problem unless combined with other less minor ones. Variables can take many different forms, such as process or manufacturing defects, actual material defects in the component, design defects or a mix of all of them. Trying to sort thru these in a logical manner can be time consuming as well as frustrating.
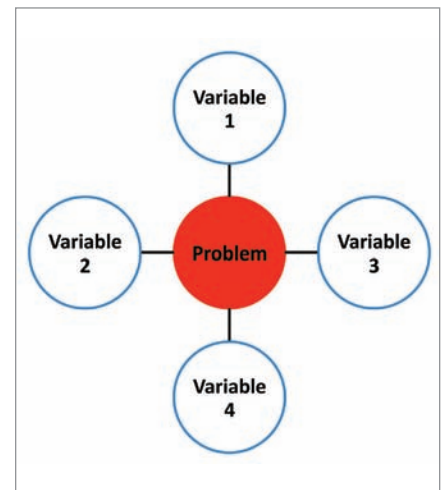

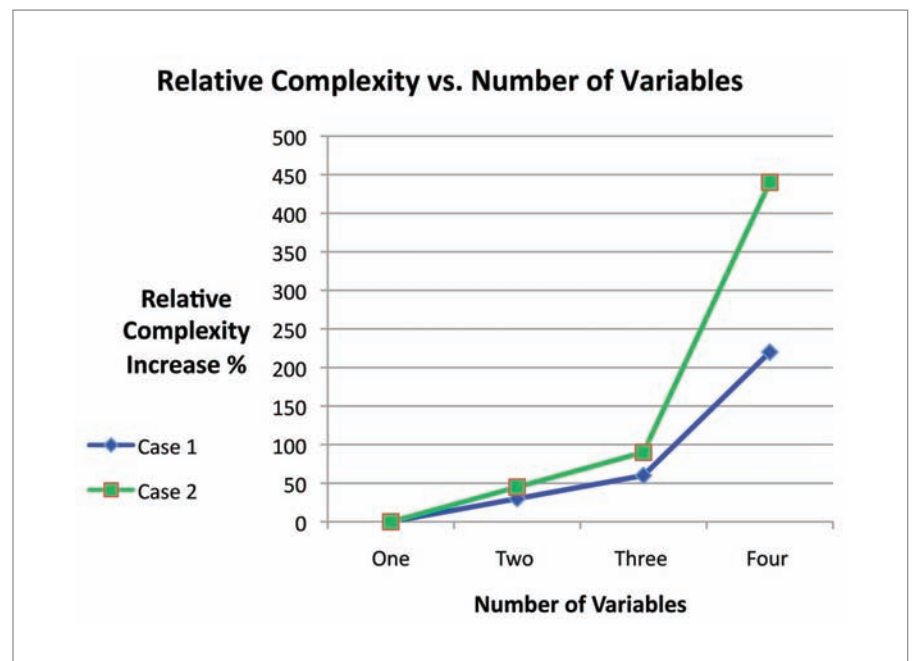**Figure 1: Four separate root causes or variables**

Figure 2: Relationship to complexity relationship

Part of the challenge in fixing problems with multiple variables is to properly identify all the possible root causes or variables that could potentially contribute to the problem and not rule out the "obvious". This process can be problematic as the number of possible variables increase. In situations where there are many variables, more discipline and rigor are needed in order to result in an effective solution to the problem. Industry has adapted many tools to help identify and resolve problems with multiple variables, probably the most popular being the Six Sigma approach. Figure 2 is a general representation of how complex it can be to solve a problem as the number of variables increases.

Problems do not always occur at the same interval or frequency, and when they occur it could be either a major or minor issue. There is a logic that states the cost to solve a problem, i.e. minimize the risk of it occurring again in the future, may be more than the total cost had the problem actually occurred. For example, if it costs $5000 to prevent a problem, but the actual impact of the problem occurring is $2000, why worry about it? Why spend $3000 more on a bet that the problem may occur again? The answer here lies on what type of impact the problem has. Is it regulatory? Is it safety related? Is it a customer issue? Is it a business or market ethics challenge? Did it create a situation where multiple clients could be lost? The bottom line is that caution is needed when examining and identifying risks.

PROBLEM ANALYSIS AND RESULTS

The point of this article is not to debate the effectiveness of a Six Sigma or other approach in problem solving. Rather, the results are summarized in a context intended to point out 1) how a defective process impacts product performance and 2) the importance of component variables in that environment.

ASSIGN THE RIGHT OWNER - WHO IS THE BEST OWNER?

When faced with many variables and unknown ties, the first step is to assign an owner. This is paramount to anything else. Thinking this is a simple decision can be a dangerous assumption. The right owner needs to be multi-task orientated, possess the ability to step out of the box and think strategically in a broad sense and, most importantly, know the tools that are at his/her disposal (i.e. Six Sigma) to resolve the issue. This person should not be quick to rule out the obvious or to dismiss the items or data that appear unrelated.

> *In our real-life scenario*, the business tapped a program manager who had broad skills in interfacing across the organizations, was a strong networker, and possessed the leadership skills to manage multidisciplinary teams. Supported by a Six Sigma Black Belt, he identified key team members needed to resolve the issue.

PROGRAM MANAGER – IDENTIFIED THE RIGHT TEAM MEMBERS

In our real-life scenario, the business tapped a program manager who had broad skills in interfacing across the organizations, was a strong networker, and possessed the leadership skills to manage multidisciplinary teams. Supported by a Six Sigma Black Belt, he identified key team members needed to resolve the issue. Talent in the design engineering, supply chain manufacturing, product service and component supplier support teams were chosen. The program manager assembled the team and the **'Px'** service organization was contacted to get first-hand, non-filtered information.

VALIDATE THE CURRENTLY KNOWN DATA – IT PAYS TO DOUBLE CHECK!

The process of making sure the existing facts are accurate ensures a foundation exists upon which future effort can be based. In many cases, wasted time is prevalent when an issue is being addressed without having accurate data. Inaccurate data can quickly take investigations down an entirely wrong or parallel path that is inconsequential to the real cause.

SPURIOUS

In our example, the spurious report provided by the service organization was reviewed along with the test fixture/system used by the **'Px'** service team that took the original data. That investigation discovered the **'Px'** team's test fixture for measuring spurious used an out-of-calibration RF spectrum analyzer and had cables not traceable to a calibration date. Engineering then re-measured the same defective RF PA devices and found all spurious to be in specification.

HEAT RISE

As part of validating the reported heat rise, it was found to originate from an older prototype unit that was pre-production. There was no indication on any service repair log for any incoming repair on this pre-production unit. Yet why then did the service team include it in the failure rate calculations and reports? The heat topic became real, as opposed to being a non-issue, because the **'Px'** service organization **thought** that the original prototype issue may be related to the current problem and appended to the service report with some comments in an attempt to provide added information that might be of help.

GET THE GLOBAL DATA

Globally, all service locations were queried for the problem but the resulting data indicated that only the Asia regional center was reporting the customer issue. Sample units of all failed product were collected and catalogued from the Asia branch. Each unit and suspect RF PA was analyzed for the RF PA manufacturer ID number, lot number, and manufacturer. Service records were analyzed to get the RF PA manufacturing location, RF PA date code, and other information pertinent to the manufacturing history. The manufacturing history was summarized.

COMPONENT DIFFERENCES

From these records, two RF PA suppliers (VG, XJ) were found in the suspect units, each with two versions of the RF PA device – d2 and d3. Three RF PA manufacturing date codes (V2, V3, V4) were logged from two manufacturing locations for the RF PA (EU4, EX4). All available RF PA devices were catalogued for ID marking details. The failed RF PA's were validated as defective with limited or no power output in the standard test fixture. Heat rise was also measured on the RF PA surface on the operating RF PA's. Shown below are some examples of how the RF PA was marked and the specific meanings.

Using the catalogued information from all defective RF PA's, the results were summarized as shown in Table 1.

RF PA SUPPLY CHAIN INVESTIGATION

Since the data indicated more than one supplier, an entire history of the RF PA device was reviewed. Each supplier, XJ and VG, was contacted and requested to send all of their release records pertaining to revisions of the RF PA. In house purchasing sent all purchase records for review and comparison to the supplier provided data.

Examination of these records indicated that the two versions of the RF PA from each supplier (d2, d3) were approved for purchase along with the original d1 from each; the versions were qualified by the component qualification team, and delivered quality audits passed. These RF PA versions (d1, d2, d3) were shipped globally to all locations, had the same base part number, and had version indicator stamped next to the base part number.

Globally, all RF PA product manufacturing histories were examined from initial production to current inclusive of changes. A total of five (5) RF PA manufacturing date codes (v1, v2, v3, v4, v5) were noted as approved for production in all RF PA manufacturing facilities, including EU4 and EX4, globally for the RF PA's by the Vendor Quality Organization.

ENGINEERING INVESTIGATION

Engineering writes and releases all changes to the factory, including component changes or revisions with suppliers. It then relies on the manufacturing team to complete all other tasks. Examination of the engineering records indicated they were aware of all date code versions v1-v5 of the RF PA. However, in their records the RF PA manufacturers (XJ and VG) advised them that some internal grounding changes inside the RF PA device would be present in date codes v2-v5, for all versions
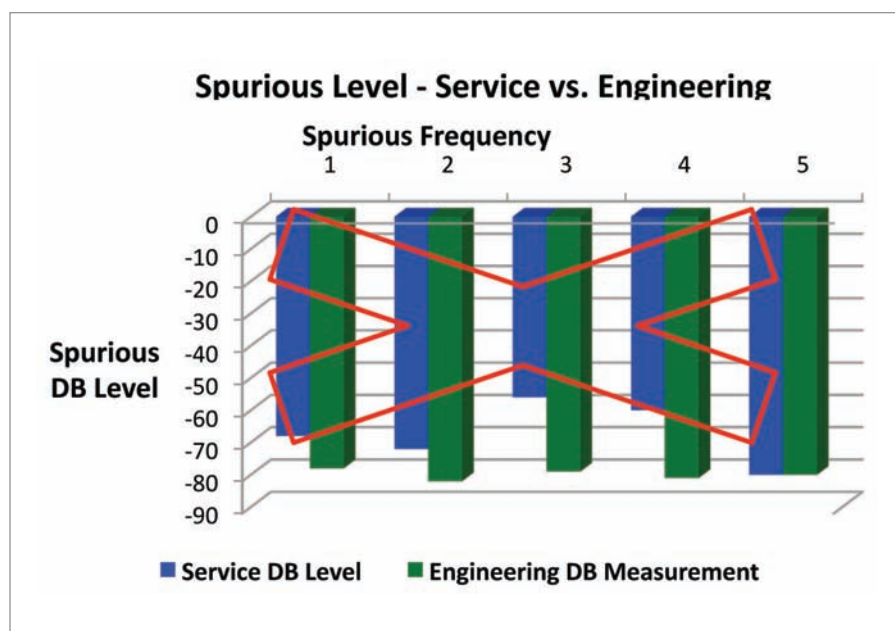

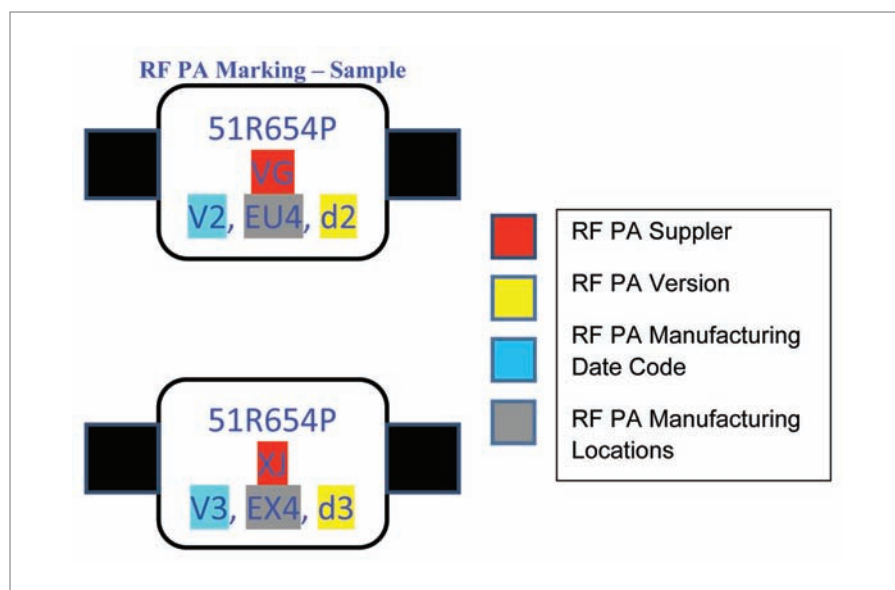**Figure 3: Service versus engineering data**

Figure 4: Examples of RF PA markings and specific meanings

RF PA Suppliers Noted	RF PA Versions Found	RF PA Manufacturing Locations	RF PA Manufacturing Date Code
XJ	d2, d3	EU4	V2, V3, V4
VG	d2, d3	EX4	V2, V3, V4

Table 1: Summary of defective RF PA data

Exposure to so many variables can result in a comedy of errors and assumptions, with the victims being cost and performance, as well as the customer. From a regulatory view, it creates significant risk which could potentially lead to recalling products from the market place and/or fines. It is critical that variables be understood and embedded into day-to-day operations before they can create problems.

of the RF PA itself (d2-d3), which resulted in a different power output versus frequency performance of the RF PA. To compensate for that, engineering had to change the phasing requirements for the actual consumer product so its RF performance would continue to meet specifications when used with date codes v2-v5 and RF PA versions d2-d3.

PRODUCT MANUFACTURING

Knowing the RF PA history thoroughly, the next step was to contact the manufacturing locations that produced the consumer product. In examining the engineering change notice sent to the manufacturing site for v2 - v5 approvals, it was verified that version v2 date codes and greater did require the factory making the consumer product to change the phasing criteria for the product transmitter to match

with the d2 and d3 versions of the RF PA that had v2-v5 date coded RF PA's. Knowing this, the **'Px'** team was contacted and asked to measure each defective customer unit to determine the phasing table values. The phasing data embedded in each of the defective consumer products was then checked and found to be the older version of the phasing data, which is not compatible with RF PA devices with date codes between v2-v5.

PRODUCT FACTORY TEST ORGANIZATION

Since there was a needed change in the phasing of the product, the test organization supporting the factory was contacted. They confirmed they were contacted by engineering and did change the parameters but had no effective date of implementation into production, so the older phasing

version stayed as is pending them hearing back on when date codes v2-v5 would be incorporated into the consumer product. No confirmation was ever received so the master IT system that controls all phasing data used in the consumer product was not activated.

INVENTORY CONTROL

Once this was discovered, inventory control was contacted to check their records of material release to the factory. Their files indicated all versions of the RF PA, d1 – d3, were released to production along with all versions V1-V5 of the RF PA.

THE STORY CLOSES - SUMMARY RESULTS

After calm heads prevailed, the following solutions and improvements were implemented:

A. The change control document was updated requiring signatures from all parties involved as opposed to verbal communications. Crossover dates were added that specifically tied to all organizations involved.

B. A new supplier change control order was implemented that required all suppliers to report in writing any change relative to the specification of components, including the RF PA.

C. Going forward, unique RF PA part numbers were assigned to minimize intergroup coordination during complex crossovers.
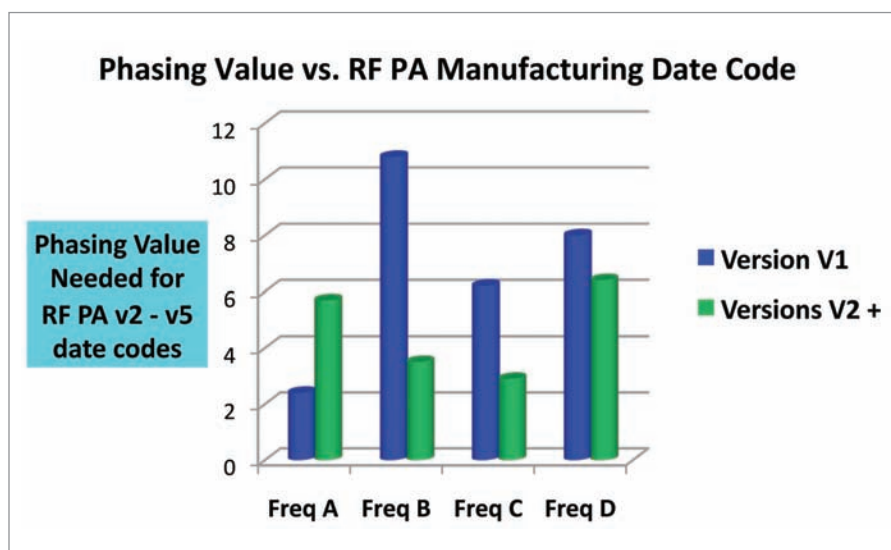

Figure 5: Summary of phasing values and RF PA data codes

D. The quality program overseeing the 'Px' team updated their procedures to ensure only customer reported data was entered in the 'Px' defect reports and that traceable calibration activities were implemented.

THE BOTTOM LINE

The story above reflects a real-life scenario, with names changed to protect the innocent. It points to how important a robust process can be and delineates the linkage to the component, how it is used and manufactured in a product, the effects it can have on a customer and/or business, and the potential to create major disruptions in delivery.

Exposure to so many variables can result in a comedy of errors and assumptions, with the victims being cost and performance, as well as the customer. From a regulatory view, it creates significant risk which could potentially lead to recalling products from the market place and/or fines and business impacts such as a dropping stock price or reduced market share. It is critical that variables be understood and embedded into day-to-day operations before they can create problems. It is an incorrect to assume that including them always increases complexity. Separately, product certification needs careful examination to determine if and when a product needs to be tested and/or resubmitted to a country regulator for approval. Not doing so, or assuming that no variables exist that could impact regulatory approval, is wishful thinking.

Change is always healthy and having an independent view on just how robust a business process is should be considered. N

(the authors)

PETER S. MERGUERIAN
is President and CEO of Go Global Compliance Inc. and provides regulatory engineering consulting and global certifications for companies worldwide. He has 30 years global regulatory compliance experience with an emphasis on safety, EMC, wireless and telecoms where he had corporate-wide responsibility in various global test laboratories for Market and Conformity Surveillance, Regulatory and Testing Services, Global Engineering, Accreditation and Global Certifications. Mr. Merguerian holds a Bachelor of Science Degree in Electrical Engineering from the Illinois Institute of Technology, Chicago. He speaks five languages and owns and moderates two popular global regulatory groups, one on Linked In: "Global Regulatory Compliance" and the other his blog at www.goglobalcompliance.com/blog. Mr. Merguerian can be reached at peter@goglobalcompliance.com.

DENNIS W. BARTELT
is President of Bartelt Consulting Corp. (BCC). He has 30+ years of past experience in telecommunications and consumer products with Motorola Mobility Inc.(formerly the cellular division of Motorola Inc.). His credentials include product design, software quality, service and repair, product safety, regulatory and environmental compliance, customer satisfaction and process enhancement. Under his leadership the teams he managed provided approvals for more than 100,000 unique products. Dennis has a Master's Degree in Electrical Engineering Technology from Northern Illinois University along with 30 hours pre-doctorate work. He is currently consulting with industry firms and specializes in process enhancement in the product regulatory and safety compliance areas. Dennis can be reached at barteltconsultingcorp@yahoo.com or dennis@goglobalcompliance.com.

Developing a Transfer Function for FM Band Transmitters

BY TOM O'BRIEN, JEAN TEZIL AND SYED MURAD

Low power, license-exempt FM transmitters are used in vehicles to transmit a weak signal onto a vacant channel in the FM Broadcast Band (88-108 MHz) for the purpose of receiving Sirius-XM broadcasts on the vehicle's FM Radio. The only method for determining compliance of these transmitters according to the FCC Rules and Regulations is to measure the field strength from the transmitter installed in three typical vehicles. This article describes an alternative method for determining compliance by measuring conducted RF power output and using a transfer function derived by measuring the radiated field strength from transmitters installed in a number of vehicles.

Compliance can then be determined by applying the empirically derived transfer function to the conducted power and comparing the result to the FCC limit.[1] This article also shows the validity of using a proposed tabletop measurement procedure which will achieve the same result for the fundamental emissions but which could also be used for out-of-band and spurious emissions.

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1. This procedure was developed in conjunction with the work of the Wireless Working Group of Subcommittee 1 of the American Standards Committee on Electromagnetic Compatibility, C63®. The procedure is to be incorporated into C64.10-20xx – *American National Standard for Testing Unlicensed Wireless Devices*.

INTRODUCTION

A low power transmitter may be operated without an individual license, provided it is certified to comply with Section 15.239 of the FCC Rules and Regulations. For these devices, the FCC field strength limit is 250 microvolts per meter at a 3 meter measurement distance. Typically, field strength measurements are made on a tabletop at an open area test site (OATS) or other approved facility. However, since there is uncertainty as to the validity of tabletop measurements for certain types of FM transmitters, and since radiated emissions may be significantly attenuated when the transmitter

is installed in a vehicle, the FCC requires measurements to be made at a minimum of three installations (vehicles) that can be demonstrated to be representative of typical installation sites.[2] In other words, compliance is determined by making "in situ" measurements on three typical vehicles. However, performing these in situ measurements is a difficult, expensive, and time consuming process. Furthermore, the vehicle-to-vehicle variations which are inherent in these types of measurements make them poorly suited in terms of their ability to show compliance to FCC limits. Yet this is the only procedure

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2. See 47 CFR 15.31(d).

This article analyzes certification results for multiple products which have been tested at accredited labs over the past two years and for which the radiated data can be found on the FCC OET website.

currently permitted by the FCC. This article analyzes certification results for multiple products which have been tested at accredited labs over the past two years and for which the radiated data can be found on the FCC OET website. It compares those results with conducted RF power measurements for the same devices which were made separately, but also at accredited labs. As a result of the analysis, a transfer function value which takes the associated standard deviation into account is proposed. Additionally, measurements from a proposed tabletop method are also shown to be valid for the purposes of showing compliance to FCC limits.

DERIVATION OF TRANSFER FUNCTION

For an isotropic radiator, the equation that defines the relationship between conducted power in dBm and radiated field strength in dBuV/m for frequencies less than 1,000 MHz is:

$$E_0 \left(\frac{dB\mu V}{m} \right) = EIRP\ (dBm) - 20 \log D\ (meters) + 109.5 \quad (1)^3$$

where E_0 is the electric field strength, D is the reference measurement distance, and the value of 109.5 includes a factor of 4.7 dB to account for reflections from the ground plane.

To the extent that the actual measured field strength is lower than the theoretical value, it means that additional losses are present which are not accounted for in the equation.

These losses can be due to shielding provided by the vehicle itself, by non-isotropic radiation from the radiator, or by other factors.

To account for these variations when analyzing empirical measurements, a correction factor (CF) can be added into the equation. If a statistically significant number of measurements are made, and if the variations are random, then the CF measurements may be expected to form a normal distribution around the mean. For the case where the measurement distance is 3 meters and with the term for the CF added, Equation 1 can be modified to the following:

$$E_0 \left(\frac{dB\mu V}{m} \right) = EIRP\ (dBm) - 9.54 - CF + 109.5\ dB \quad (2)$$

And combining like terms:

$$E_0 \left(\frac{dB\mu V}{m} \right) = EIRP\ (dBm) - CF + 100\ dB \quad (3)$$

Now rearranging to put the equation into the familiar form of a transfer function (Output (dB) – Input (dB)):

$$E_0 \left(\frac{dB\mu V}{m} \right) - EIRP\ (dBm) = [100\ dB - CF] = TF \quad (4)$$

This can be visualized as in Figure 1.

From Equation 4 it can be seen that the correction factor is inversely related to the transfer function (TF) with an offset of 100 dB. Once the TF is determined, it can be used for the purposes of determining a conducted power limit. By rearranging Equation 4 and substituting the FCC part 15.239 limit at FM frequencies for the output, the following equation results:

$$EIRP_{LIMIT}\ (dBm) = 48 \left(\frac{dB\mu V}{m} \right) - TF \quad (5)$$

Or if using a correction factor instead:

$$EIRP_{LIMIT}\ (dBm) = 48 \left(\frac{dB\mu V}{m} \right) - 100 + CF \quad (6)$$

From these equations it can be seen that a higher TF yields a lower conducted power limit, and a higher CF yields a higher conducted power limit.

As mentioned previously, for in situ measurements of FM transmitters, a high CF means that either the vehicle body provides high attenuation or the radiation pattern is non-isotropic such that the E field measured at the receive antenna is lower than it would be if the pattern were isotropic. Of
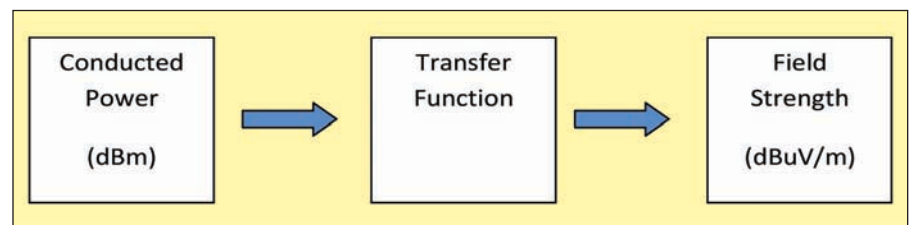
3. *Guidelines for Compliance Testing of Unlicensed National Information Infrastructure (U-NII) Devices - Part 15, Subpart E.*

Figure 1: Relating conducted power to field strength using a transfer function

WIRELESS AND ENERGY STAR WORKSHOP: ALL YOU NEED TO KNOW!

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DATES

September 19-20, 2012
8:30 am - to 5:00 pm daily

LOCATION

THE WESTIN WALTHAM-
BOSTON HOTEL
70 Third Avenue,
Waltham, Massachusetts
617-969-1000

ABOUT THE SEMINAR

Join the experts with American Certification Body and Washington Laboratories and TUV Rheinland for a comprehensive overview of methods and requirements for the latest Wireless Device Approvals. This seminar will cover methods of testing, evaluation and certification requirements for commercial equipment with demands for EMC compliance. We'll provide specific focus on radio regulations compliance for products bound for global markets.

Learn the specific requirements of the FCC Rules and Regulations including recent interpretations and policies and the impact of the new edition of ANSI C63.4 and the recently-adopted ANSI C63.10. This seminar is a two-day comprehensive presentation on FCC, IC, EU, Japan and China requirements for Radio Certification. **And a new special feature will be a comprehensive update on Energy Star.**

WHO SHOULD ATTEND

Design, development and test engineers and technicians will benefit from receiving the latest in critical updates on test methodology. As the technologies evolve, measurement and certification of devices are constantly evolving and creating challenges for the electronics industry. Keeping abreast of these changes and the nuances of the regulations is critical for speeding electronics products' time-to-market. Fierce competition from rival developers creates additional pressure to design the devices for compliance with the regulatory requirements and "getting it right the first time."

INSTRUCTORS

Michael Derby with AmericanTCB
Mike Violette with the Washington Labs Academy
Uwe Meyer with TUV Rheinland of North America, Inc.
Bill Holz with TUV Rheinland of North America, Inc.

Our Lecturers have a wealth of experience and information in the field of product testing and certification and will share their perspective and insight on EMC regulations and evolving requirements for radio frequency systems. This goal of this seminar is to present the latest information on these evolving requirements and to give attendees better understanding of the processes and procedures for approving equipment.

SEMINAR OVERVIEW - Specific topics include:

Explanation of new technologies

Energy Star

The latest requirements and changes from FCC, IC and Europe

Practical testing techniques

Testing methodologies for radio transmitter devices

Sweep time considerations (probability of intercept for broadband signals)

Extending the frequency range beyond the coax medium (external mixing)

Measurement methods using spectrum analyzers including proper methods of determining power, averaging techniques, ACP measurements (and implemented algorithms), bandwidth and spurious emissions

Dynamic range considerations

Measurement system sensitivity and overload considerations for linear measurements

Test accreditation, including calibration, uncertainties and engineer proficiency

COURSE OUTLINE

Radio Transmittal Approvals Workshop: All You Need To Know

Wed September 19, 2012

8:00 AM Registration
8:30 AM Introduction and overview of course
9:00 AM Licensed verses unlicensed devices
9:30 AM Measurement requirements
11:00 AM Break
11:15 AM RF Exposure, Maximum Permissible Exposure (MPE)
12:00 Lunch
1:00 PM LTE, 4G and beyond
2:00 PM Break
2:30 PM 802.16, 802.11, WiMAX, LTE=, MIMO Devices
3:30 PM RF hazards considerations
4:30 PM Questions and Answers

Thur September 20, 2012

8:30 AM US/FCC Radio Regulations overview
9:30 AM Energy Star and Energy Efficiency
10:00 AM Break
10:15 AM Wireless approvals for Developing Markets
11:30 AM Modular approvals and permissive changes
12:00 PM Lunch
1:00 PM CE Marking for the R&TTE Directive
2:00 PM Japan and China Certification Requirements
3:00 PM Break
3:30 PM RTTED Approval for European market
4:30 PM Certification requirements for Industry Canada

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Figure 2: Top view of radiated emissions test setup for initial measurements using a turntable

Figure 3: Histogram using worst case in situ measurements

course, it is also possible that a non-isotropic radiator can increase the gain in the direction of the receive antenna as well. Because of the variability of vehicle shielding and the potential for non-isotropic radiation, in situ measurements of FM transmitters have an inherently high degree of variability.

MEASUREMENT DATA

The initial arrangement used for measuring radiated field strength emissions from transmitters installed in a vehicle is shown in Figure 2. The general procedure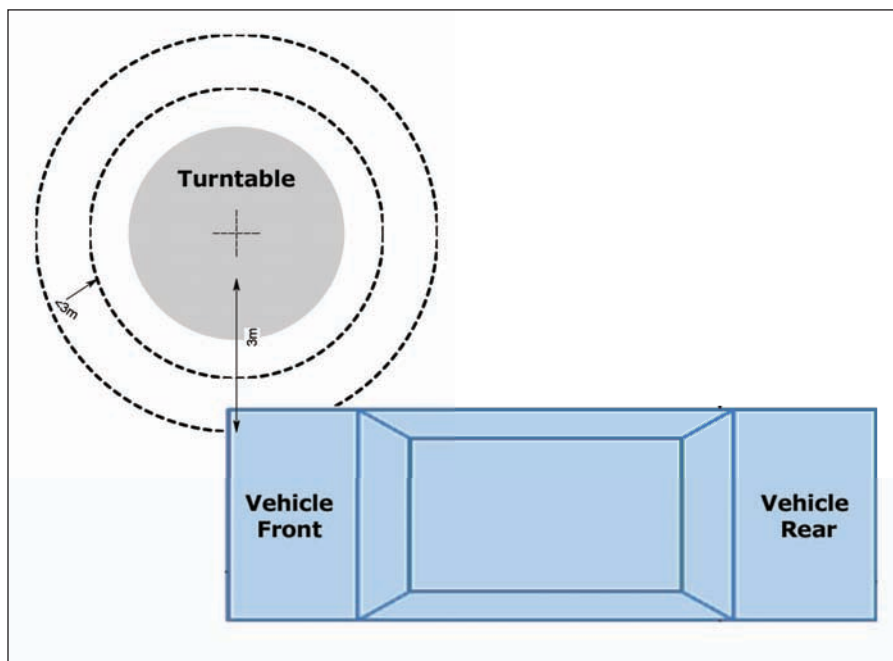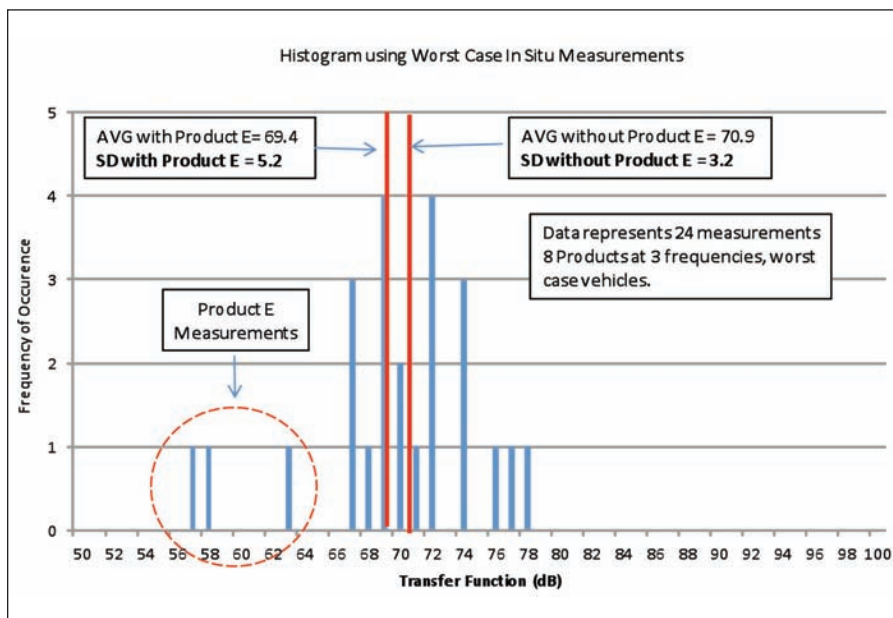s for measuring radiated emissions in situ are contained in Clause 6.12 of C63.10-2009.[4] For certification of the SiriusXM Satellite Radio FM transmitters subject to 47 CFR 15.239, measurements were made of transmitters installed on three vehicles and at three frequencies in the high, low, and mid-band of 88-108 MHz. Currently, tabletop emissions measurements are also being requested by the FCC in addition to the in situ measurements. Sirius XM Satellite Radio Inc, has received certifications for eight products with FM transmitters since August of 2009. The data for these certifications was taken by four different accredited test labs in Virginia, Maryland, Georgia and Florida. All of the in situ and tabletop data in this article was taken from the certification data and can be found on the FCC Office of Engineering and Technology website. After being certified, conducted FM power measurements were made at accredited labs using the same products at the same FM frequencies which were used for the certifications. Since many of the in situ measurements were made at an OATS, only frequencies which were relatively free of strong ambient signals could be used. Thus, in some cases, different frequencies were used for different products.

4. The American National Standard for Testing Unlicensed Wireless Devices is available from the IEEE website at https://www.ieee.org/membership-catalog/index.html?N=0.

Since in situ measurements have high variability, for the purposes of finding the appropriate TF and the associated conducted power limit it was thought that a useful approach might be to minimize the effects of that variation by looking at only the worst case measurements. Worst case is defined as those measurements which yielded the highest TF, because those measurements correspond to the lowest conducted power limits. The results from the frequency and vehicle combinations that met those criteria are plotted in the histogram in Figure 3 .

Note from this plot that 'Product E' appears to be an outlier. Initially, it was suspected that the data for that product could be in error, so TF averages and standard deviations were calculated both with and without the data from that product included. Using Equation 5, it can be seen that the average TF values of 69.4 (with Product E)

and 70.9 (without Product E) would correspond to conducted power level limits of -21.4 dBm and -22.9 dBm respectively. The standard deviation (SD) was 5.2 and 3.2 respectively for those measurements.

From statistics, it is known that for a normal distribution, approximately 68.3% of the values lie within ±1 SD of the mean, approximately 95.4% of the values lie within ± 2 SD of the mean, and approximately 99.7% of the values lie within ± 3 SD of the mean. If we assume that the Product E measurements were not part of the

normal distribution, then the mean is 70.9 and adding 3 SD's (3 x 3.2) yields a TF limit of 80.5, which corresponds to a conducted power limit of -32.5 dBm. If only 2 SD's are used, then the TF limit is 77.3, which corresponds to a conducted power limit of -29.3 dBm.

It is instructive here to compare these limits with the actual measured conducted power for those certificated devices. For the eight products measured, the conducted power average, minimum, and maximum, are shown in Table 1.

Average	- 28.9 dBm
Minimum measured conducted power	- 33.1 dBm
Maximum measured conducted power	- 26.1 dBm

Table 1: Conducted average, minimum, and maximum power

From the data in Table 1 it can be seen that if the conducted power limit of -29.3 dBm is used, based on worst case measurements with Product E results removed, using 2 SD's from the mean and assuming that the distribution is truly normal, then about half of the products that have previously been certified would not pass.

A plot of conducted power levels for the eight products that are the subject of this investigation makes it easy to see that that limit would not be valid (See Figure 4).

Yet as shown in Figure 5, those same products when tested in situ, despite the wide variation, all fall below the FCC limit for radiated emissions.

And tabletop emissions, measured as per the proposed new ANSI C63.10 procedure, pass as well, but with a tighter distribution (See Figure 6.

A complete table of measured conducted power is shown in Table 2 (page 44), along with all in situ data and the associated transfer function and correction factor values.

Using All In Situ Measurements

When all measurements are used instead of worst case only, the range of measurement values increases as expected. As previously mentioned, this likely reflects the fact that some vehicles provide significantly more attenuation than others or that the radiation from within the vehicle structures is not isotropic.

Note too that when all measurements are used, it can be seen that the Product E measurements are encompassed by the wider distribution and, in fact,
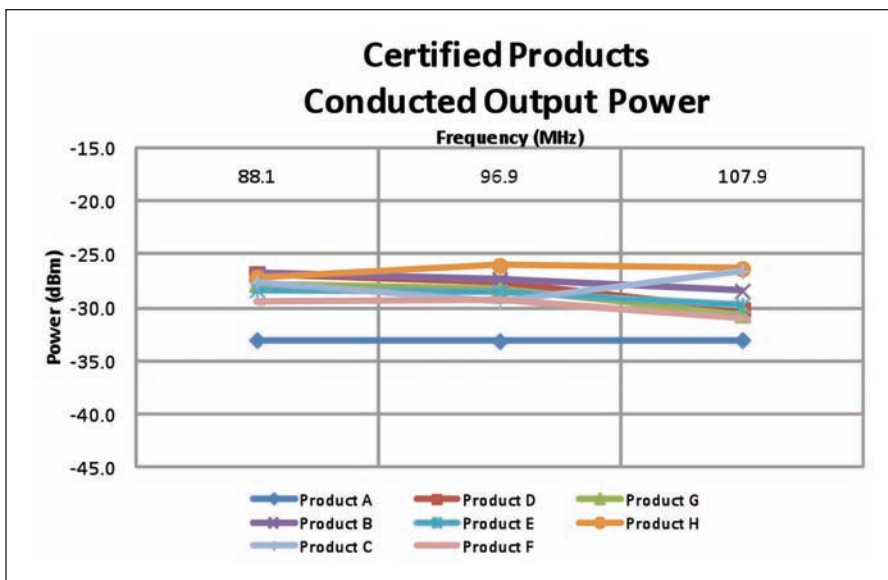
Figure 4: Plot of conducted output power for eight products
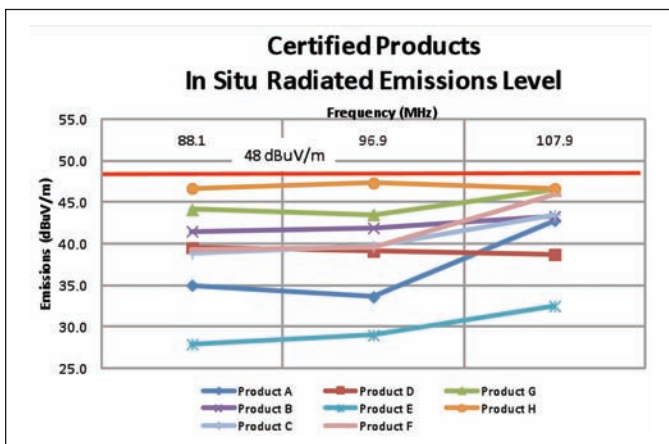
Figure 5: In situ radiated emission levels for same eight products
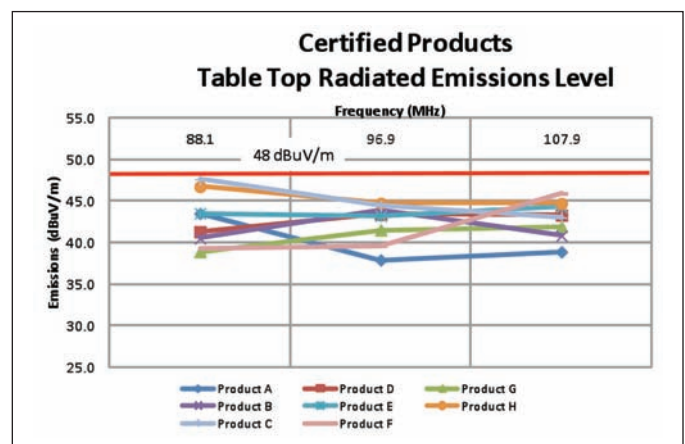
Figure 6: Tabletop radiated emissions for same eight products

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EUT	Freq (MHz)	Measured Power (conducted) (dBm)	Corresponding E0 @ 3m (dBµV/m)1	In-Situ Measured E0 @ 3m (dBµV/m)	Δ (dB) Correction Factor	Δ (dB) Transfer Function
Product A small car	88.1	-33.0	67.0	35.0	32	68
	96.9	-33.1	66.9	38.6	28.3	71.7
	107.9	-33.0	67.0	42.8	24.2	75.8
Product A mid size	88.1	-33.0	67.0	29.3	37.7	62.3
	96.9	-33.1	66.9	35.1	31.8	68.2
	107.9	-33.0	67.0	37.1	29.9	70.1
Product A large	88.1	-33.0	67.0	28.7	38.3	61.7
	96.9	-33.1	66.9	33.2	33.7	66.3
	107.9	-33.0	67.0	32.1	34.9	65.1
Product G small car	89.1	-27.8	72.2	44.1	28.1	71.9
	97.7	-28.3	71.7	43.5	28.2	71.8
	106.3	-30.6	69.4	46.5	22.9	77.1
Product G mid size	89.1	-27.8	72.2	39.0	33.2	66.8
	97.7	-28.3	71.7	34.8	36.9	63.1
	106.3	-30.6	69.4	32.2	37.2	62.8
Product G large	89.1	-27.8	72.2	33.1	39.1	60.9
	97.7	-28.3	71.7	35.5	36.2	63.8
	106.3	-30.6	69.4	35.5	33.9	66.1
Product E small	89.1	-28.4	71.6	27.9	43.7	56.3
	97.7	-28.5	71.5	29.0	42.5	57.5
	106.3	-29.8	70.2	31.1	39.1	60.9
Product E mid size	89.1	-28.4	71.6	24.7	46.9	53.1
	97.7	-28.5	71.5	27.0	44.5	55.5
	106.3	-29.8	70.2	31.7	38.5	61.5
Product E large	89.1	-28.4	71.6	26.7	44.9	55.1
	97.7	-28.5	71.5	26.7	44.8	55.2
	106.3	-29.8	70.2	32.5	37.7	62.3
Product B small car	89.1	-26.8	73.2	41.5	31.7	68.3
	97.7	-27.4	72.6	41.9	30.7	69.3
	106.3	-28.5	71.5	43.3	28.2	71.8
Product B mid size	89.1	-26.8	73.2	30.6	42.6	57.4
	97.7	-27.4	72.6	33.7	38.9	61.1
	106.3	-28.5	71.5	33.0	38.5	61.5
Product B large	89.1	-26.8	73.2	28.7	44.5	55.5
	97.7	-27.4	72.6	30.5	42.1	57.9
	106.3	-28.5	71.5	32.8	38.7	61.3
Product H small	91.7	-27.2	72.8	46.1	26.7	73.3
	98.3	-26.1	73.9	47.4	26.6	73.45
	105.3	-26.4	73.6	42.9	30.7	69.28
Product H mid size	91.7	-27.2	72.8	44.5	28.3	71.7
	98.3	-26.1	73.9	45.6	28.4	71.65
	105.3	-26.4	73.6	46.7	26.9	73.08
Product H large	91.7	-27.2	72.8	46.7	26.1	73.9
	98.3	-26.1	73.9	44.6	29.4	70.65
	105.3	-26.4	73.6	46.6	27.0	73
Product D small Nissan Sentra	89.1	-26.9	73.1	39.5	33.6	66.4
	97.7	-27.7	72.3	39.1	33.2	66.8
	106.3	-30.3	69.7	38.7	31.0	69
Product D mid size	89.1	-26.9	73.1	30.6	42.5	57.5
	97.7	-27.7	72.3	24.3	48.0	52
	106.3	-30.3	69.7	32.2	37.5	62.5
Product D large	89.1	-26.9	73.1	33.4	39.7	60.3
	97.7	-27.7	72.3	38.9	33.4	66.6
	106.3	-30.3	69.7	35.6	34.1	65.9
Product F small	88.1	-29.5	70.5	38.0	32.5	67.5
	96.9	-29.3	70.7	39.6	31.1	68.9
	107.9	-30.9	69.1	45.9	23.2	76.8
Product F mid size	88.1	-29.5	70.5	39.3	31.2	68.8
	96.9	-29.3	70.7	34.6	36.1	63.9
	107.9	-30.9	69.1	33.6	35.5	64.5
Product F large	88.1	-29.5	70.5	38.6	31.9	68.1
	96.9	-29.3	70.7	36.2	34.5	65.5
	107.9	-30.9	69.1	33.6	35.5	64.5
Product C small	88.1	-27.7	72.3	38.8	33.5	66.5
	96.9	-29.5	70.5	39.7	30.8	69.2
	107.9	-26.6	73.4	43.5	29.9	70.1
Product C mid size	88.1	-27.7	72.3	37.8	34.5	65.5
	96.9	-29.5	70.5	38.7	31.8	68.2
	107.9	-26.6	73.4	40.4	33.0	67.0
Product C large	88.1	-27.7	72.3	35.4	36.9	63.1
	96.9	-29.5	70.5	30.8	39.7	60.3
	107.9	-26.6	73.4	32.1	41.3	58.7

Table 2: Conducted power, In-Situ data, CF, and TF

seem to be legitimate values in what appears to be a normal distribution.

The in situ measurements, which represent eight products, measured at three frequencies and in three vehicles, are plotted in the histogram in Figure 7.

The average TF value is 66.5 without Product E and 65.4 with Product E. The standard deviation (SD) is 5.3 and 5.9 respectively for those measurements. Since Product E appears to be part of the normal distribution, it does not make sense to remove it from the data set, so it is believed that a conducted limit should only be calculated with it included. Thus, with Product E included and using the same formulas and calculations as described above, if 2 SD's are used then the TF mean is 65.4 and the associated conducted power limit is -29.2 dBm.

Figure 7: Histogram using all in situ measurements

Using Tabletop Measurements

The arrangement used for making tabletop measurements of radiated emissions from a device which directly injects an FM signal into a vehicle's wiring system through the CLA socket is shown in Figure 8. The proposed method in fact is the same method that was used to collect the tabletop data for the certifications that
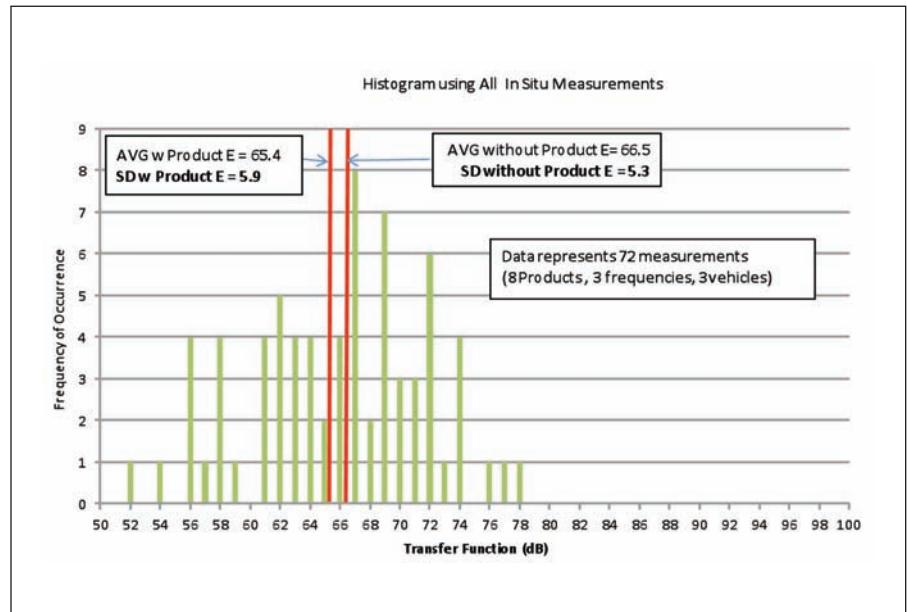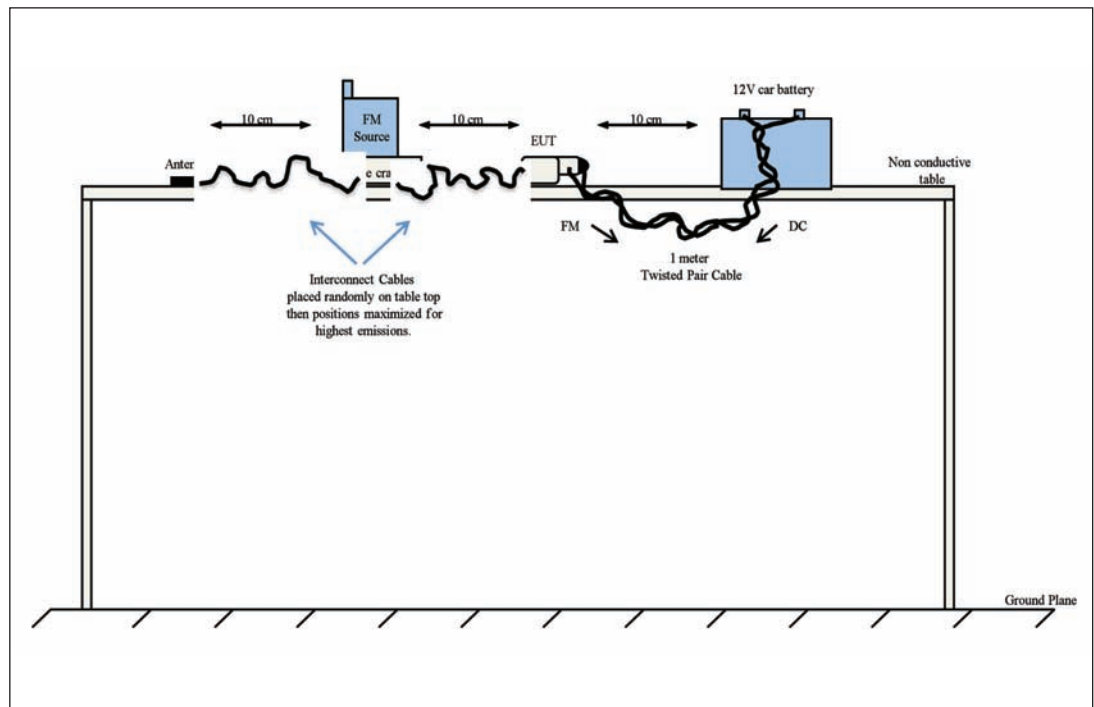

Figure 8: Tabletop arrangement for radiated emissions measurements

are described in this article. All of the products utilized a method of directly injecting the FM signal into the vehicle wiring system through the CLA socket. Thus the procedure described in the ANSI draft revision for those types of transmitters was followed as closely as was possible by all of the test labs.

The transfer function and various other equations described above for in situ measurements can also be applied to tabletop measurements. However, it can be seen from the data that, for these measurements, the distribution is tighter and the mean is higher. This likely reflects the fact that there is no opportunity for vehicle shielding and thus less opportunity for a higher CF (lower TF).

Figure 9: Histogram of all tabletop measurements

The certification data for eight products, measured at three frequencies, is represented in the histogram in Figure 9. The average TF value is 71.8 and the SD is 2.6. Using the same formulas and calculations as described above, if 2 SD's are used then the TF value is 77 and the associated conducted power limit ius -29.0 dBm.
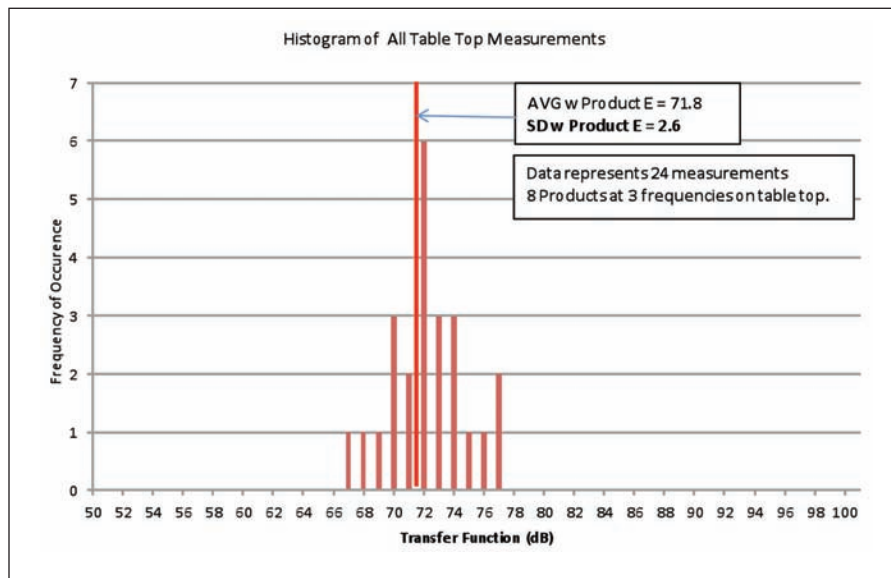
A complete set of radiated tabletop measurements, with the associated transfer functions, is shown in Table 3.

A COMPARISON OF ALL IN SITU AND TABLETOP MEASUREMENTS

When all of the data is overlaid on one plot, as in Figure 10, it can be seen that in situ measurements have the widest variation. Worst case in situ measurements have a slightly smaller SD and are distributed nearer to the highest TF values, but can still include outliers. Tabletop measurements have the smallest SD and are distributed most closely to the highest TF values.

EUT	Freq (MHz)	Measured Power (conducted) (dBm)	Conducted pwr Converted to dBuV/m	Corresponding E_6 @ 3m (dBµV/m)[1]	Table Top (dBµV/m)	Δ (dB) Table Top
Product A	88.1	-33.0	74.0	67.0	43.5	76.5
	96.9	-33.1	73.9	66.9	37.9	71.0
	107.9	-33.0	74.0	67.0	38.9	71.9
Product G	89.1	-27.8	79.2	72.2	38.9	66.7
	97.7	-28.3	78.7	71.7	41.5	69.8
	106.3	-30.6	76.4	69.4	41.9	72.5
Product E	89.1	-28.4	78.6	71.6	43.5	71.9
	97.7	-28.5	78.5	71.5	43.2	71.7
	106.3	-29.8	77.2	70.2	44.3	74.1
Product B	89.1	-26.8	80.2	73.2	40.5	67.3
	97.7	-27.4	79.6	72.6	43.9	71.3
	106.3	-28.5	78.5	71.5	40.8	69.3
Product H	91.7	-27.2	79.8	72.8	46.7	73.9
	98.3	-26.1	80.9	73.9	44.7	70.8
	105.3	-26.4	80.6	73.6	44.7	71.1
Product D	89.1	-26.9	80.1	73.1	41.3	68.2
	97.7	-27.7	79.3	72.3	43.4	71.1
	106.3	-30.3	76.7	69.7	43.3	73.6
Product F	88.1	-29.5	77.5	70.5	43.1	72.6
	96.9	-29.3	77.7	70.7	43.2	72.5
	107.9	-30.9	76.1	69.1	45.6	76.5
Product C	88.1	-27.7	79.3	72.3	47.6	75.3
	96.9	-29.5	77.5	70.5	44.4	73.9
	107.9	-26.6	80.4	73.4	43.0	69.6

Table 3: Complete table of radiated tabletop measurements with associated transfer functions

SUMMARY

A summary of the measurements, with transfer functions and associated conducted power limits for 1, 2 and 3 standard deviations, is shown in Table 4.

Previously, it was noted that, for a normal distribution, approximately 95.4% of the values lie within ± 2 SD of the mean. From the histograms, it does appear that the data is distributed normally about the mean. If this supposition is accepted, then a conducted power limit based on the TF calculated using the tabletop method plus 2 SD's would mean that 95.4% of the products which meet the conducted limit would also pass on the tabletop. For those products which are outside of the 95.4%, only half would be on the high side of the distribution and the other half would be on the low side of the distribution. Further, a diminishing percentage of those products would reach even 1 additional SD of 2.6 dB.

Thus, a transfer function value of 77 is proposed for the purpose of determining radiated emissions levels from conducted power levels at FM frequencies, yielding a conducted power limit of -29 dBm for the fundamental emissions. Further, it is proposed that the tabletop method, as described herein and in the ANSI C63.10 publication scheduled for release in 2012, be used to determine compliance of the out-of-band and spurious emissions to FCC limits so that in situ measurements are no longer required.
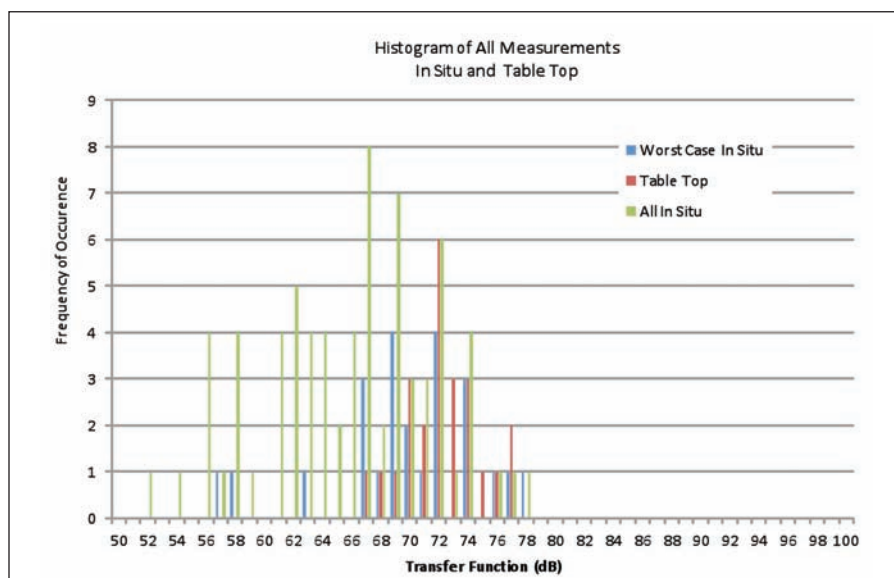

Figure 10: Histogram of all measurements in situ and tabletop

Test Description	Size of data set	Transfer Function (TF) mean	TF Standard Deviation (SD)	TF mean + 1 SD	associated conducted power limit for TF + 1 SD (dBm)	TF mean + 2 SD	associated conducted power limit for TF + 2 SD (dBm)	TF mean + 3 SD	associated conducted power limit for TF + 3 SD (dBm)
worst case in situ results with NO Product E	7 products 3 frequencies = 21 measurements	70.9	3.2	74.1	-26.1	77.3	-29.3	80.5	-32.5
worst case in situ results with Product E	8 products 3 frequencies = 24 measurements	69.4	5.2	74.6	-26.6	79.8	-31.8	85.0	-37.0
all in situ results with NO Product E	7 products 3 frequencies 3 vehicles = 63 measurements	66.5	5.3	71.8	-23.8	77.1	-29.1	82.4	-34.4
all in situ results with Product E	8 products 3 frequencies 3 vehicles = 72 measurements	65.4	5.9	71.3	-23.3	77.2	-29.2	83.1	-35.1
Results from proposed table top method all products	8 products 3 frequencies = 24 measurements	71.8	2.6	74.4	-26.4	77.0	-29.0	79.6	-31.6

Table 4: Summary of all test measurements

(the authors)

TOM O'BRIEN
has worked on RF and EMC related issues for over 15 years. He worked for the Florida Atlantic University EMI lab while in college, and continued to work on RF and EMC related projects while at Motorola. He has recently participated in ANSI standards development activities, and he is currently employed by Sirius XM Satellite Radio where he continues to address a variety of SW Test and certification issues.

JEAN EDNER TEZIL
holds a BA in electrical engineering and is currently pursuing a master in bioengineering at Florida Atlantic University. Since 2010, he has contributed valuable efforts in SW test at Sirius XM Satellite Radio and has been part of the resource team for occupied bandwidth and NSA measurements. Always excited by opportunities to learn, he recently joined the Advanced Compliance Solutions where he contributes his support in compliance certification testing.

SYED SHAKIL MURAD
holds a BA in Electrical Engineering from Florida Atlantic University. He works part time for Sirius XM Satellite Radio as a software test engineer. He also works full time for Advanced Compliance Solutions as an engineering technician where he performs compliance testing.

New Voltage Sag Testing Requirements for Industrial Equipment

A New Power Quality Measurement Technology

BY ANDREAS EBERHARD

Immunity from voltage sags is vital for reliable operation of our ever more sophisticated electronic controls and equipment. Every electrical product should be able to ride through typical voltage sags, but in many cases the first sag test occurs after equipment is installed and in operation. Select the appropriate sag immunity specification and equipment compliance testing, and you'll be glad you did.

Modern equipment can be sensitive to brief disturbances on utility power mains. Electrical systems are subject to a wide variety of power quality problems that can interrupt production processes, affect sensitive equipment, and cause downtime, scrap and capacity losses. The most common disturbance in the process industry, by far, is a sag (a brief reduction in voltage lasting a few hundred milliseconds).

Sags are commonly caused by fuse or breaker operation, motor starting, or capacitor switching; but they are also triggered by short circuits on the power distribution system caused by such events as snakes slithering across insulators, trenching machines hitting underground cables, and lightning ionizing the air around high-voltage lines. Many utilities report that 80% of electrical disturbances originate within the user's facility.

A decade ago, the solution to voltage sags was to try to fix them by storing enough energy somehow and releasing it onto the AC mains when voltage dropped. Some of the old solutions included an uninterruptible power supply (UPS), flywheels, and ferroresonant transformers.

More recently, engineers have realized that voltage sag is really a compatibility

Three main primary voltage sag immunity standards are discussed: IEC 61000-4-11, IEC 61000-4-34, and SEMI F47.

problem with at least two classes of solutions: you can improve the power, or you can make the equipment tougher. The latter approach is called "voltage sag immunity" and is getting more important around the world.

STANDARDS DEVELOPED

Three main primary voltage sag immunity standards are discussed in the following paragraphs: IEC 61000-4-11, IEC 61000-4-34, and SEMI F47. There are others in use, such as IEEE 1100, CBEMA, ITIC, Samsung Power Vaccine, international standards, and MIL-STD, but the first three seem to have the widest acceptance in the marketplace. (IEC is the International Electrotechnical Commission, SEMI is the Semiconductor Equipment and Materials Institute, CBEMA is the Computer Business Equipment Manufacturers Association, ITIC is the Information Technology Institute Council, and MIL-STD is the U.S. Defense Department's specification.)

IEC 61000-4-11 and the very new IEC 61000-4-34 are a closely related set of standards that cover voltage sag immunity. IEC 61000-4-11 Ed. 2 covers equipment rated at 16 amps per phase or less, while IEC 61000-4-34 Ed. 1 covers equipment rated at more than 16 amps per phase. The latter was written after IEC 61000-4-11, so it seems to be more comprehensive.

SEMI F47 is the voltage sag immunity standard used in the semiconductor manufacturing industry, where a single voltage sag can result in the multi-million-dollar loss of product if a facility is not properly protected (Figure 1). The semiconductor industry

has developed specifications for its manufacturing equipment and for components and subsystems in that equipment. Enforcement is entirely customer-driven in this industry, as semiconductor manufacturers understand the economic consequences of sag-induced failures and generally refuse to purchase new equipment that fails the SEMI F47 immunity requirement. SEMI F47 is currently going through its five-year revision and update cycle.

All three standards specify voltage sags with certain depths and durations for the equipment under test (EUT). For example, a specification may state 70%

of nominal for 500 milliseconds. The percentage is the amount of voltage remaining, not the amount that is missing. Each standard specifies pass-fail criteria for EUT when a voltage sag is applied; the IEC standards have a range of pass-fail criteria, but the SEMI F47 standard is more explicit (Figure 2).

THREE-PHASE TESTING

For three-phase EUT's, the sags are applied between each pair of power conductors, one pair at a time. If there is a neutral conductor, this implies that there are six different sags at each depth-duration pair: three different

Figure 1: Immunize your products and facilities. Voltage sag immunity testing has been common in the semiconductor industry for years and has proved its economic value. New IEC standards for voltage sag immunity will expand this kind of testing and certification to other industries.

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• Two ... "Year in Review" sessions of factory standards and device standards.

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phase-to-phase sags, and three different phase-to-neutral sags. If there is no neutral conductor, there are just three different sags at each depth-duration pair in the standard, or just three different phase-to-phase sags. In all of the standards, all three phases are never sagged at the same time.

Note that IEC 61000-4-11 and 61000-4-34 (Figure 3) specifically forbid creating phase-to-phase sags by sagging two phase-to-neutral voltages simultaneously, an approach that is permitted in SEMI F47. Instead, you must create phase shifts during your phase-to-phase sags – something that sag generators designed for these standards do automatically.
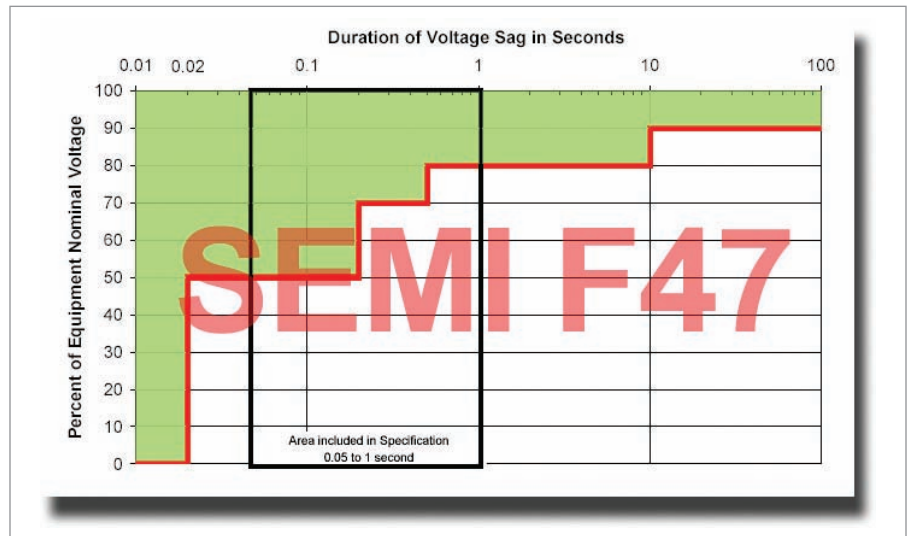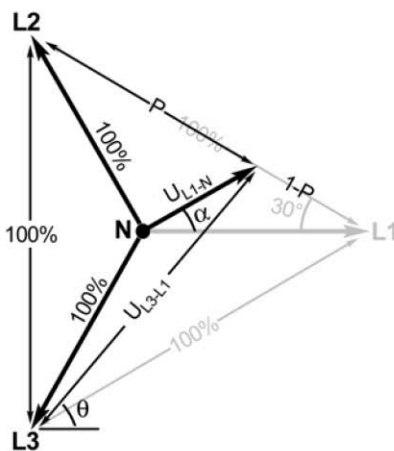

Figure 2: Playing through -- a typical example of a voltage sag ride-through curve compared with the SEMI F47 specification commonly used in the semiconductor industry

$$U_{L1-N} = \sqrt{1 + 3P^2 - (2\sqrt{3})P\cos(30^0)} \qquad eq.\ C.2.a$$

$$\alpha = 120^0 - \sin^{-1}\left(\frac{P\sqrt{3}\sin(30^0)}{U_{L1-N}}\right) \qquad eq.\ C.2.b$$

$$U_{L3-L1} = \frac{\sqrt{1 + (U_{L1-N})^2 - 2U_{L1-N}\cos(\alpha + 120^0)}}{\sqrt{3}} \qquad eq.\ C.2.c$$

$$\theta = 60^0 - \sin^{-1}\left(\frac{U_{L1-N}\sin(\alpha + 120^0)}{\sqrt{3}U_{L3-L1}}\right) \qquad eq.\ C.2.d$$

P is the percent phase-to-phase dip, expressed as a fraction of the nominal phase-to-phase voltage.

U_{L1-N} is the voltage from L1 to Neutral (if a Neutral conductor exists), expressed as a fraction of the nominal phase-to-neutral voltage.

U_{L3-L1} is the voltage from L3 to L1, expressed as a fraction of the nominal phase-to-phase voltage.

Figure 3: The IEC standards require phase shifting during sags on three-phase systems, but sags on all three phases simultaneously are not required.

WHAT MAKES VOLTAGE SAG TESTING DIFFERENT

In contrast to most other emissions and immunity testing, voltage sag testing requires the engineer to control and manipulate all of the power flowing into the EUT. For smaller devices such as personal computers, this is not a great challenge. But for larger industrial equipment, perhaps rated at 480 volts three-phase at 200 amps per phase with an expected inrush current of 600 amps or more, the test engineer must be prepared for serious performance and safety challenges.

A voltage sag generator is a piece of test equipment that is inserted between the AC mains and the EUT (Figure 4). It can generate voltage sags of any required depth and duration. Some, like the PSL Industrial Power Corruptor, include preprogrammed sags for all of the IEC, SEMI or MIL standards.

Because a common EUT failure mechanism is a blown fuse or circuit breaker during the current inrush after a voltage sag, the sag generator must be specified for delivering large peak currents – typically in the hundreds of amps. This peak current requirement in the IEC standards means that electronic amplifier AC sources generally can only be used for pre-compliance testing, not certification

Certain software, such as the sag immunity testing software from Power Standards Lab, comes with extensive safety checklists. Some of the checklist items are obvious (Who on the test team is trained in CPR? Where is the closest fire extinguisher?) and some are less obvious (How do we get access to

at least two upstream circuit breakers? Where is the closest trash can?).

This kind of testing requires a fully-functional EUT and someone who knows how to operate it. The only way to determine if an EUT is immune to the required voltage sags is to have it fully operating during the voltage sags.

In many cases, the sags will need to be applied during different stages of EUT operation. Remarkably often, the EUT is not ready on time for voltage sag testing. Development work may need to be completed, or no one is available to operate the EUT, or the supplies to operate the EUT (raw materials, cooling water, compressed air, etc.) are


Figure 4: The voltage sag test engineer will insert a sag generator between the AC source and the EUT. Often, high currents (200 amps) and high voltages (480 volts 3-phase) must be handled.

not available, or the EUT software is broken. Test engineers should plan for these kinds of problems.

EUT failure mechanisms can be complicated, too, and the test engineer will be expected to help diagnose them. The built-in digital oscilloscopes in most sag generators will help, but the test engineer must figure out where to connect the channels to circuits inside the EUT.

Figure 5: Anatomy of a voltage sag. To test a new product, a voltage sag is introduced in the power source (a). The waveform, which was about 40 amps peak before the sag in this example, then increases to 450 amps peak after the voltage sag (b). The same current, this time expressed as an RMS value, is shown. The next graph shows the same current, this time as an RMS value. Before the sag, it was about 23 amps RMS (this equipment was rated at 30 amps), but after the sag the current increased to 175 amps RMS. This behavior is not unusual (c). The final graph shows the output of a DC supply during this sag (d). The second most common failure mechanism, surprisingly, occurs just after the sag has finished. In such cases, all of the bulk capacitors inside the EUT recharge at once, causing a large increase in AC mains current. This increase can trip circuit breakers, open fuses, and even destroy solid-state rectifiers. Most design engineers correctly protect against this inrush current during power cycling, but many do not consider the similar effects of voltage sags. Be careful when the test procedure is developed; if you use a sag generator that lacks sufficient current capability it will incorrectly pass the equipment if there is insufficient current available to blow a fuse or trip a circuit breaker in a half-cycle.

COMMON FAILURE MECHANISMS DUE TO VOLTAGE SAGS
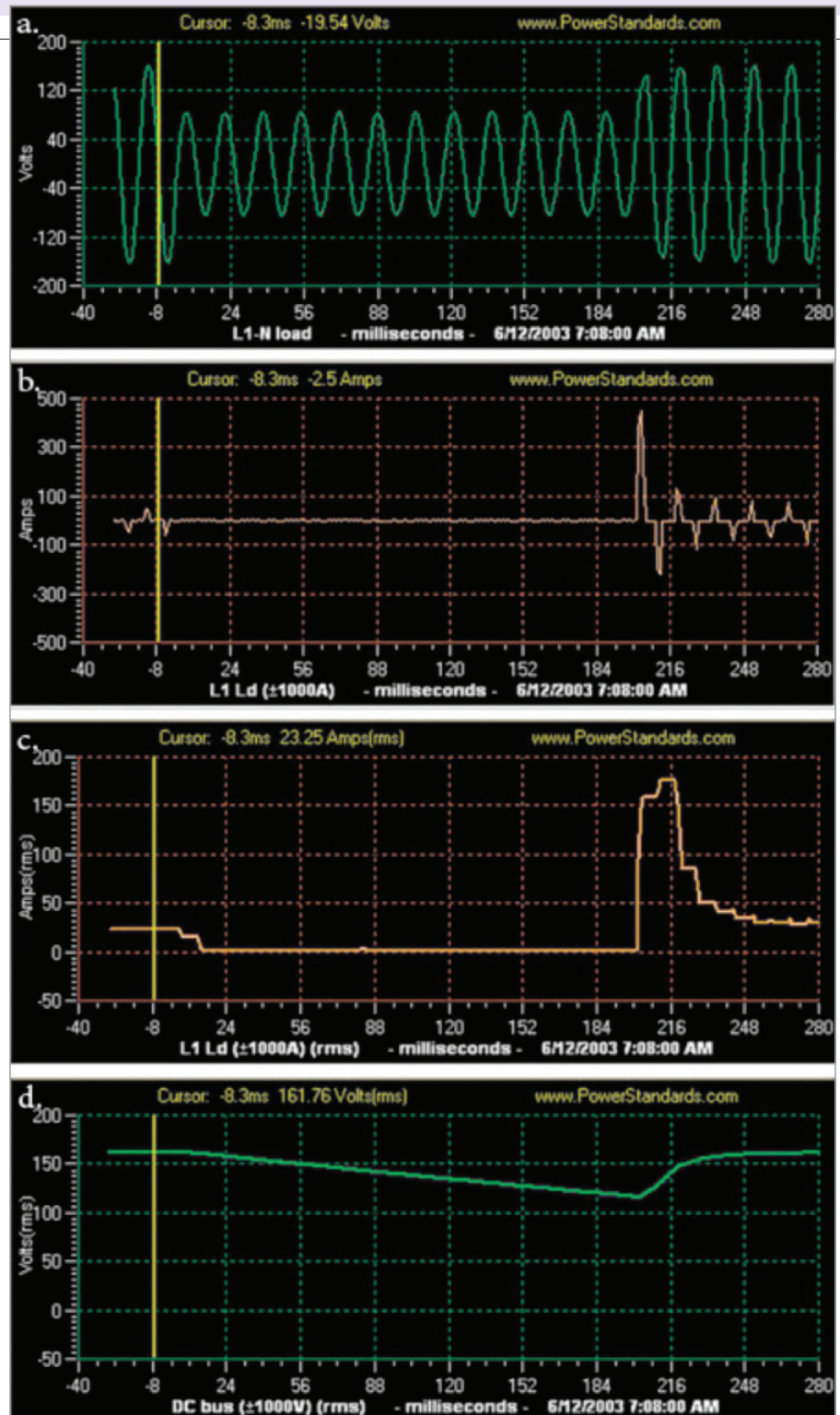
The most common failure mechanism is lack of energy. This can manifest itself in something as simple as insufficient voltage to keep a critical relay or contactor energized or something as complex as an electronic sensor with a failing power supply giving an incorrect reading, which would cause EUT software to react inappropriately (Figure 5).

Another common EUT failure mechanism occurs when a sensor detects the voltage sag and decides to shut down the EUT. In a straightforward example, a three-phase EUT might have a phase-rotation relay that incorrectly interprets an unbalanced voltage sag as a phase reversal and therefore shuts down the EUT. A more atypical example would be if you had an airflow sensor mounted near a fan, it detected that the fan had slowed down momentarily, and the equipment software misinterpreted the message from this sensor as indicating that the EUT cooling system had failed. In this case, a software fan failure signal delay is the solution to improve sag immunity.

One more typical EUT failure mechanism involves an uncommon sequence of events. For example, in one case, a voltage sag was applied to the EUT and its main contactor opened with a bang. But further investigation revealed that a small relay, wired in series with the main contactor coil, actually opened because it received an open relay contact from a stray water

sensor. That sensor, in turn, opened because its small 24-VDC supply output dropped to 18 V during the sag. The solution was an inexpensive bulk capacitor across the 24-VDC supply.

Many other failure mechanisms can take place during voltage sags. The question to the test engineer will always be: how do we fix this problem? Usually, there is a simple, low-cost fix once the problem is identified.

A NEW EMBEDDED POWER QUALITY MEASUREMENT TECHNOLOGY

There is a new way to increase the reliability of products due to common power quality and voltage sag problems. How about making the product more intelligent so it can react depending on severity of the voltage sag problem?

You will see more and more of such permanently installed power quality monitors on a product level. This new embedded technology comes with the huge advantage that power quality problems and energy consumption can be evaluated directly within the product or machine.

With the ever-increasing use of sophisticated controls and equipment in industrial, commercial, institutional and governmental facilities, the continuity, reliability and quality of electrical service has become extremely crucial to many power users. The power hardly gets better in the future, so the ultimate goal for any product manufacturer is to make its product

immune to voltage sags. As all modern cars should be able to drive through regular bumps on the road, every electrical product should be able to ride-through any regular voltage sags that will occur - despite of the best power that a facility can provide. ◼

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(the author)

ANDREAS EBERHARD is member of various power quality standard committees around the world. He is involved in the IEC 61000-4-34 and SEMI F47 standard committees and offers over 15 years of experience in product compliance based on international standards. He is Vice President of Technical Services at Power Standard Labs and can be contacted at aeberhard@powerstandards.com.

Discontinuing Use of the Machine Model for Device ESD Qualification

BY CHARVAKA DUVVURY, ROBERT ASHTON, ALAN RIGHTER,
DAVID EPPES, HARALD GOSSNER, TERRY WELSHER,
AND MASAKI TANAKA

The machine model (MM) test, as a requirement for component electrostatic discharge (ESD) qualification, is being rapidly discontinued across the industry.

This article is intended to illustrate why MM evaluation is not necessary for qualification. The following major conclusions can be made about MM in general:

- MM is redundant to the human body model (HBM) at the device level since it produces the same failure mechanisms, and the two models generally track each other in robustness and in failure modes produced.

- MM testing has more variability than HBM due to MM's greater sensitivity to parasitic effects in the tester circuitry.

- There have not been any significant engineering studies (with verified data) which could be used to establish required passing level.

- The test method was incorrectly given the name "machine model", though no firm unique connection between the model and actual machine-induced device failures was ever established. In fact, the model was developed as a "low-voltage HBM".

- The charged device model (CDM) does a better job of screening for fast metal-to-metal contact events than MM.

- The vast majority (>99%) of electrical failures in manufacturing correlate to CDM and electrical overstress (EOS), and not to MM.

- MM testing has not shown any additional failures not explained by CDM, HBM or EOS.

- MM testing consumes resources and creates time-to-market delays while only providing failure modes or protection strategies that HBM and CDM already cover.

It is important to understand the scope of this article. It summarizes what has been learned about the test method *only*. The information summarized here in no way diminishes the importance of adequately grounding any metal which may come in contact with ESD-sensitive devices nor the importance of avoiding hard metal-metal discharges.

BACKGROUND TO THE ISSUE

As will be explained below, the machine model is a widely misunderstood component ESD qualification test method. It continues to generate confusion for both original equipment manufacturing (OEM) customers and their integrated circuit (IC) suppliers during ESD qualification. Many companies and design organizations continue to use MM, mostly as a

legacy "required" practice, despite the fact that it has been downgraded by three standards bodies and is no longer recommended for qualification testing in accordance with JEDEC JESD47. The automotive industry, a longtime user of this method, no longer requires it in their AEC-Q100 list of qualification tests. The scopes of the JEDEC (JESD22-A115) and ESDA (ANSI/ESD STM5.2) test method documents have also been changed to reflect this status. There are a number of reasons for these changes, as outlined below. The continued use of MM for qualification based solely on legacy requirements has no technical merit given the information that has been gathered over the last few years. Those companies who continue to use MM take on an unnecessary and burdensome business approach. The reasons against use of the MM are given below.

1. Historically speaking, the 200pF, "0 ohm" model, which later became known as the machine model, originated with several Japanese semiconductor corporations as a worst-case representation of the human body model. The model was later presumed by some, because of the lower discharge impedance, to simulate abrupt discharge events caused by contact with equipment and empty sockets (functional testing, burn-ins, reliability testing, pick and place operations, etc.). This happened at a time when the very fast rise time of metal-metal discharges was not well-understood. Since that time, the charged device model has been proven to quite adequately cover these events.

2. Recently, M. Tanaka-san (Renesas Electronics) at the September 2011 JEITA meetings [3] presented rationale and data supporting the elimination of the MM test. According to his historical account, the so-called "machine model" originated at Hitachi (now Renesas Electronics) about 45 years ago and was introduced to Japanese semiconductor customers as a test case to represent the HBM test in their IC product test report. This test method spread widely to the Japanese customer base and was later established as an ESD test standard by the EIAJ in 1981. Around 1985, some people began mistakenly to refer to the test as the machine model. Then, starting in 1991, ESDA, JEDEC and IEC adopted the model and its name as a new test standard. As use of the model increased, it was realized that the machine model name caused a lot of misunderstanding that needed to be clarified.

3. In the early days of ESD device testing, there was also a desire to avoid the high pre-charging voltages of the HBM test (2kV and higher). The 200pF and low impedance of MM was thought to be an equivalent but safe lower voltage test to address the same failure mechanisms as HBM. However, establishment of a single translation from MM voltage to HBM voltage has been difficult to achieve. Protection design has traditionally been focused on meeting the HBM requirement, but MM testers are susceptible to parasitic circuit elements; these parasitics from relay switching networks in the simulators cause more variation in the MM waveform than waveforms from HBM testers. In spite of this and without any supporting data,

200V MM became established as a *de facto* requirement. It was thought to be the safe level for handling, and that this level had to be simultaneously met along with the *de facto* 2kV HBM standard. In reality a device with a 2kV HBM withstand voltage might have an MM withstand voltage anywhere from 100 to 300V, depending on the device characteristics and the MM tester parasitics. This led to much of the confusion associated with specifying both HBM and MM specification levels.

4. The next important reason for discontinuing MM is that fast discharges to or from a metal surface are not correctly represented by the MM. The characteristics of the MM rising pulse were not established based on comparison to measurements on machine pulses, but rather were determined by characteristics of the already developed HBM simulators. The fast rising leading edge of metal-to-metal discharges are actually more effectively simulated using the current standard CDM test methods. This is known today because of the development of high speed oscilloscopes. However, during the 1980s there was a misunderstanding that MM was a good representation for CDM. This misunderstanding
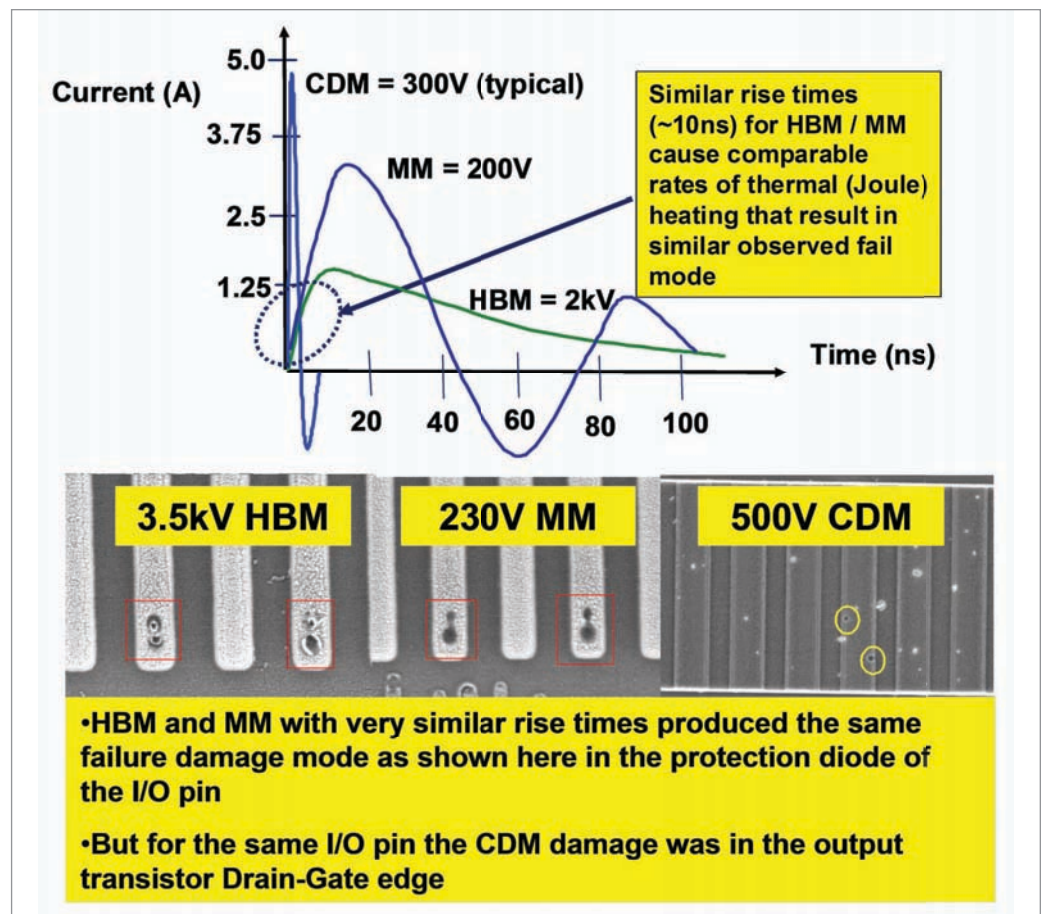
actually delayed the eventual development and acceptance of the CDM standards used today. Later in the 1990s, with much improved and accurate test for CDM and wider recognition that the fast discharges are covered by CDM alone, the test for MM frequently became replaced with CDM.

MM VS. HBM AND CDM

The waveforms for HBM, MM and CDM are compared in Figure 1. The HBM and MM have similar ranges of rise time (2-10ns). Therefore any thermal heating in silicon taking place in this time period leads to the same failure mechanisms for both models. This holds true for all technologies, including advanced technology nodes. This early part of the waveform determines where protection circuits must be deployed in design. With similar rise time characteristics, HBM and MM encourage the same protection designs. For CDM, on the other hand, the rise time is much faster (0.1 – 0.5 ns) and often leads to a unique failure mechanism like oxide

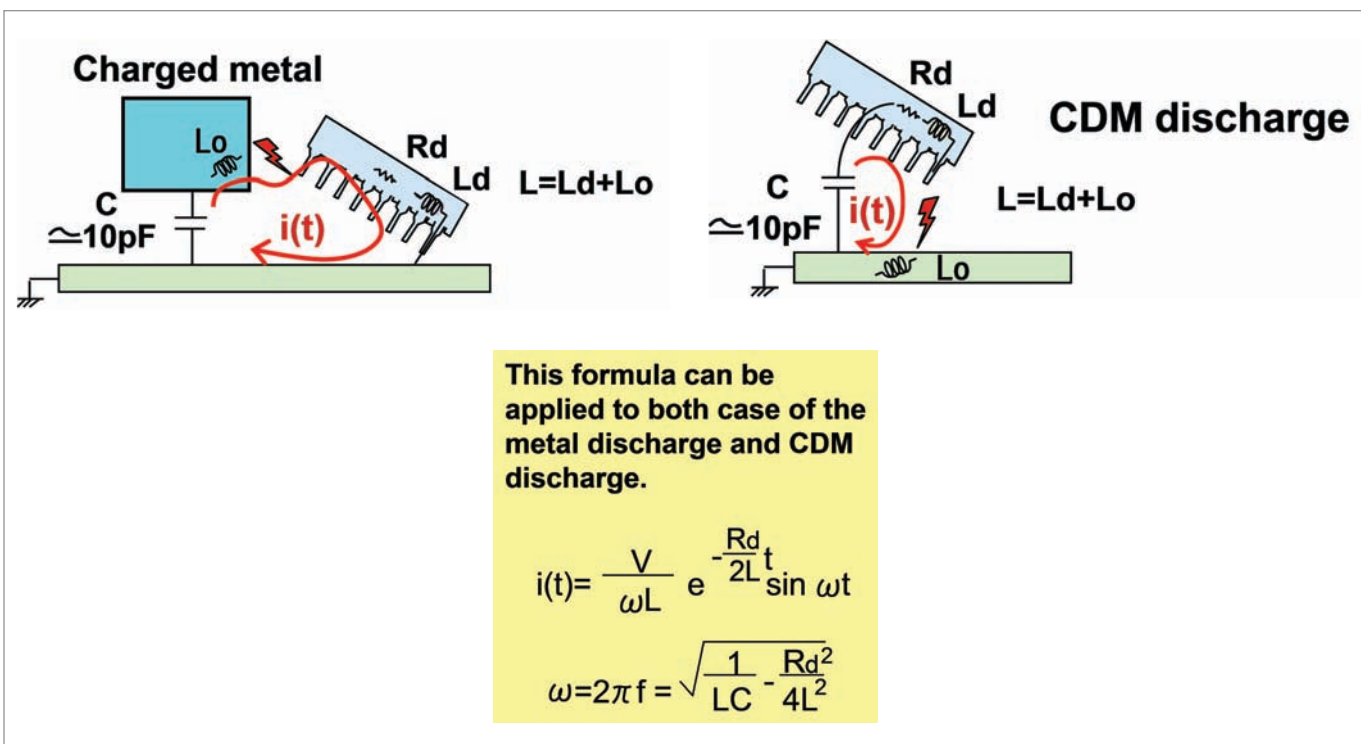Figure 1: Comparison of HBM, MM and CDM waveforms

Figure 2: Discharge current equation for metal discharge or CDM discharge [1]

breakdown. Even more important, the observed ESD field failures are dominated by oxide breakdown when the CDM level is not adequate. Thus, a different set of protection strategies are generally needed for CDM. This makes it even more critical to focus on CDM qualification, instead of duplicating the HBM test information by using the MM. In Figure 1, we also show the observed failure modes for the same I/O pin after stressing with HBM, MM and CDM. It is clear that with HBM and MM the damage sites were the same in the protection diode, but with CDM stress the damage site corresponds to oxide breakdown in the output transistor. This also illustrates the fact that meeting high levels of MM does not improve CDM performance until the right effective design techniques are employed.

Commercial MM testers have inductors built into the MM stimulus circuit. These inductors must be present to produce the oscillatory waveform required in the MM test method. The inductors, however, actually slow down the MM waveform (Figure 1), and therefore MM cannot represent very fast metal-to-metal contact discharge as CDM does. On the other hand, the CDM test is directly represented by elevating the package potential and directly grounding the pin to produce the fast discharge. MM cannot be relied on to accurately model fast metal to metal contact discharges, which are known to occur in the field.

METAL DISCHARGE VERSUS CDM DISCHARGE

The analysis of M. Tanaka [2] is shown here to demonstrate that a metal discharge from a small metallic object to a device is similar to the commonly used CDM test. Tanaka considers small objects because large machines (typically >10 pF) are almost always grounded for reasons beyond ESD and thus pose little practical threat for these events. On the other hand, tools and small machines are difficult to ground and may lead to charging effects where the capacitance of the metal object is related to surface area and distance. These values can range from <1pF to nearly 10 pF. For example, this value could be as much as 1pF for a small metal object of 10 cm^2 at a distance of 0.5 cm. Both the small metal discharge and the CDM discharge can be represented by the same set of equations for I(t), and thus both can be expected to generate the same discharge event if the values of the parameters are similar. Figure 2 illustrates the case for a small object of 10 pF for both metal discharge and CDM discharge.

The above analysis is confirmed by measurements as shown in Figure 3, [2] where the discharge in (A) from a charged tweezer to IC pin is the same as the direct discharge from metal as shown in (B), and both are similar to the generated CDM discharge in (C). The time scale for both metal discharge and CDM discharge are indeed the same, clearly indicating that CDM is a good representation of the metal discharge in the Electrostatic Protected Area (EPA).

- *Metal discharge events are well represented by the CDM test.*
- *Most of the field failure returns for ESD have been replicated by the CDM test, but none with MM testing that are not also produced by HBM.*

The Industry Council on ESD Target Levels has studied HBM and MM results on a wide variety of designs in many technologies and concluded that MM is intrinsically related to HBM, with a correlation factor range that is dependent on the HBM design level [3]. This data is represented in Figure 4 (page 62). However, the most important conclusion of the study was that MM is a redundant test and a sufficient level of MM robustness is automatically included in an adequate HBM design. This also includes the bipolar nature of the MM stress. Any oscillatory waveform which might be measured during discharges in the field is sufficiently covered if the part is proven to have an adequate HBM design.

This minimum design value, as measured by a MM tester, is well above any voltage remaining on all properly grounded machines in an ESD protected manufacturing environment. In essence, meeting a safe value for HBM (and CDM) is sufficient for production of ICs without needing to evaluate MM as an additional qualification.

- *The machine model test method specification to qualify ICs does not model or advance the real world ESD protection of IC products.*

- *IC evaluation with MM does not give any additional information as to how to address machine ESD control.*

- *While MM is an unnecessary qualification test, it is important to emphasize that control of voltage on machine parts that might contact device pins in accordance with ESD programs specifications such as S20.20 programs is still important.*

FIELD DATA ANALYSIS

The work from the Industry Council has shown that most of the overstress field returns exhibit failure signatures of higher energy EOS, and that the level of HBM ESD from 500V to 2000V (shown as the HBM Failure Analysis Return (FAR) window in Figure 2) on 21 billion shipped units did not show a correlation to the customer field return rates. Similarly, these very same shipped units (500V to 2kV HBM) also had MM levels in a range between 50-300V, as also seen from Figure 2. Therefore it can be concluded that the EOS field returns are indeed not related to this range of intrinsic MM levels. That is, it does not matter if a shipped device has a measured MM value of 50V or 300V.

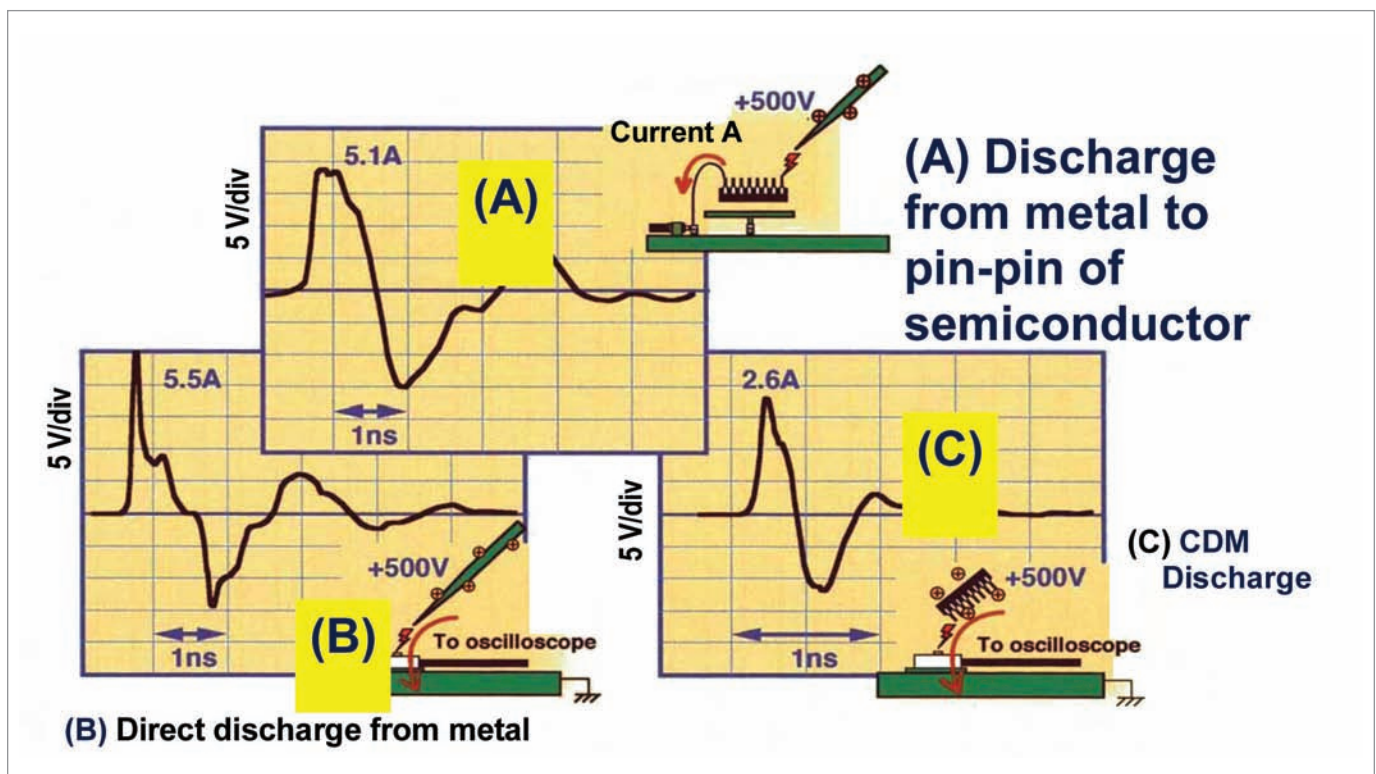- *Devices with various measured MM levels have shown no correlation to real world EOS failure returns.*

Figure 3: Comparison of measured waveforms for metal discharge and CDM discharge events [2]: (A) discharge from a charged tweezer on pin, (B) direct discharge from metal and (C) CDM test discharge

STANDARDS BODIES AND POSITIONS ON MM

During the last two decades, the electronics industry's standards bodies have changed their viewpoint with regard to MM and its requirement for IC qualification. At present, JEITA in Japan does not recommend MM. The Automotive Electronics Council's AEC Q100 standard gives a choice between HBM and MM, but does require CDM. In recent years, JEDEC has strongly recommended discontinuing use of the MM for ESD qualification because of its test variability and non-correlation to real-world failure modes. In general, standards bodies have come to recognize that:

- IC Qualification to HBM and CDM provides all the necessary ESD test requirements.

- MM testing of ICs is redundant to HBM and does not reflect unique real-world component ESD failure modes.

- Billions of IC components have been shipped worldwide and qualified using HBM and CDM testing only. No field failures have been found that would have been prevented by additional MM qualification.

The following statements are from the JEDEC web site:

- "JESD22-A115B is a reference document; it is not a requirement per JESD47G (Stress Test Driven Qualification of Integrated Circuits)."

- "Machine Model as described in JESD22-A115B should not be used as a requirement for IC ESD Qualification."

- "Only human body model (HBM) and charged device model (CDM) are the necessary ESD Qualification test methods as specified in JESD47G."

The ESD Association has downgraded the MM document from a Standard (S5.2) to a Standard Test Method
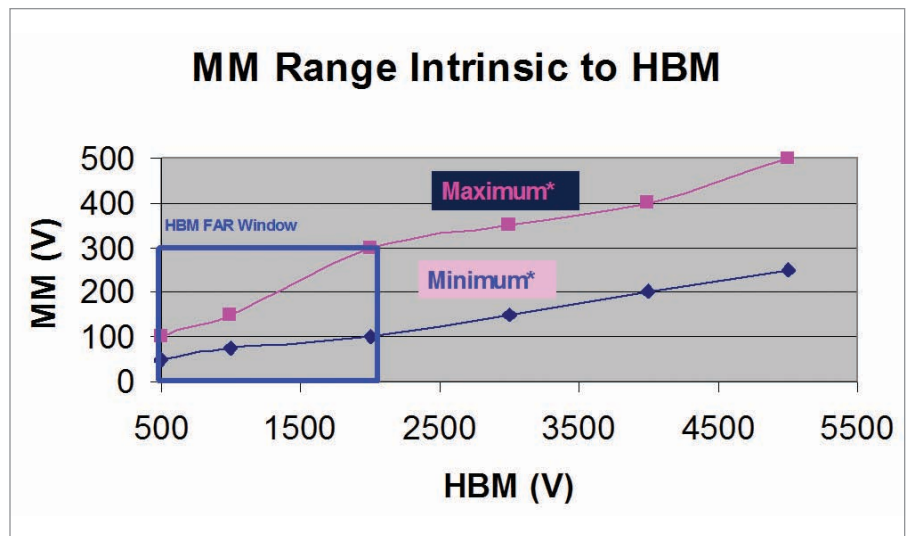

Figure 4: Correlation between HBM and MM measured on the same devices

(STM5.2) [4] and has adopted the following position:

- The ESD Association does not recommend using MM ESD as described in STM5.2 for IC qualification. IC Qualification should be done using the current standard HBM and CDM methods.

CONCLUSIONS

The information in this document supports the discontinuation of MM as part of IC qualification. The most important point to note is that a wide range of products, having only HBM and CDM testing performed, are being shipped today at volume levels in the billions with no field returns due to ESD. These products, passing at or above the recommended minimum HBM and CDM levels, are being routinely shipped by major suppliers and are accepted by major OEMs. No increase in field return rates has been observed with MM removed from qualification for these products.

The confusion generated by MM has persisted in the industry for over two decades. The presumed need for this test is causing additional qualification delay due to an extraordinary consumption of design/test resources,

added delays in time-to-market and, in some cases, an impact on IC speed and performance. Maintaining safe HBM and CDM levels is sufficient to meet all IC manufacturing, handling and assembly needs.

EPILOGUE

Different customer sectors may feel that they need enhanced ESD requirements for specific reasons. For example, some automotive customers have more consistently required MM model testing; the impression being that an independent and redundant test provides enhanced safety, improved quality and reduced defectivity. However, industry experience has shown that passing a redundant (to HBM) MM qualification test does not help automotive manufacturers achieve these goals. Meeting current industry standard HBM/CDM will insure that a product can be safely handled with sufficient margin to prevent ESD damage and maintain the quality/reliability of the product as shipped from the component manufacturer. Since many suspected ESD failures turn out to be higher energy EOS in nature, methods to prevent electrical overstress during manufacturing will also help maintain product reliability.

COMMON GOALS

We have presented evidence and arguments that the MM test of ICs is redundant and there is no proof that devices have failed in the field because MM evaluation was not done. We strongly recommend that this test be discontinued for ESD qualification. This will save the semiconductor industry a tremendous and an unnecessary burden by greatly reducing the routine characterization that is done to support the qualification process. The ESD robustness designed into integrated circuits to survive HBM and CDM testing will provide protection against any MM-like stress. Eliminating MM testing of ICs has no deleterious effects and will free up resources for more important engineering challenges.

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3. JEP155, "Recommended Target Levels for HBM/MM Qualification," at www.jedec.org and at www.esdtargets.blogspot.com.

4. ESDA, standards document definitions and hierarchy summarized at www.esda.org/Documents.html.

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

(the author)

CHARVAKA DUVVURY

is a Texas Instruments Fellow working in the Silicon Technology Development Group. His current work is on development and company wide support on ESD for the nanometer submicron CMOS technologies. Charvaka has made numerous international presentations on ESD phenomena and protection design. He received his Ph.D. in Engineering Science from the University of Toledo. After working as a Post-Doctoral Fellow in Physics at the University of Alberta in Canada, he joined Texas Instruments in 1977. He has published over 140 papers in technical journals and conferences and holds 65 patents. He has co-authored books on hot carriers, modeling of electrical overstress, and ESD reliability phenomena and protection design. (John Wiley & Sons, 1995, and 2nd Edition in 2002).

He is a recipient of the Outstanding Contributions Award from the EOS/ESD Symposium (1990), Outstanding Mentor Award from the SRC (1994), numerous Best Paper and Best Presentation awards from the EOS/ESD Symposium. He has served as the General Chairman both in 1994 and in 2005. He is a contributing Editor for the IEEE Transactions on Device and Materials Reliability (TDMR). Charvaka has been a member of the ESD Association Board of Directors since 1997, promoting university education and research in ESD. He is a co-chair of the Industry Council on ESD Target Levels. Charvaka is also a Fellow of the IEEE.

iNARTE QUESTION OF THE MONTH

Last month we asked:

The skin depth of a metal conductor is defined as _____.

A) The distance into the conductor at which currents have been attenuated to 1/e of their value at the surface.

B) The distance into the conductor at which currents have been attenuated, by 2.718–1.

C) The distance into the conductor at which currents have been attenuated 1 neper.

D) All of the above

E) None of the above

Of course the answer is D), All of the above.

This month's question is:

Adding depth to an opening in a shielded enclosure can help in the overall shielding effectiveness. What is the total shielding effectiveness to a 10 MHz field with the strength 10 V/m if the only opening in the structure is 1.5 cm round with a 3cm long tube, or waveguide bonded to it?
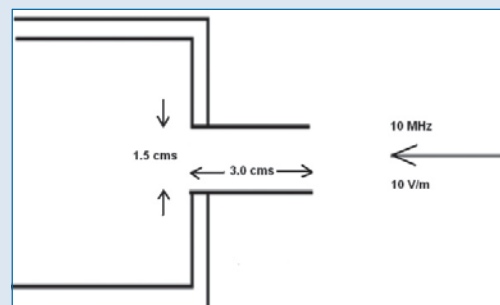
A) 120 dB

B) 60 dB

C) 90 dB

D) 30 dB

(Authors)

DENNIS W. BARTELT
is President of Bartelt Consulting Corp. He has 30+ years of past experience in telecommunications and consumer products. His credentials include product design, software quality, service and repair, product safety, regulatory and environmental compliance, customer satisfaction and process enhancement. For Dennis's full bio, please see page 35.

CHARVAKA DUVVURY
is a Texas Instruments Fellow working in the Silicon Technology Development Group. His current work is on development and company wide support on ESD for the nanometer submicron CMOS technologies. For Charvaka's full bio, please see page 63.

ANDREAS EBERHARD
is member of various power quality standard committees around the world. He is involved in the IEC 61000-4-34 and SEMI F47 standard committees and offers over 15 years of experience in product compliance based on international standards. For Andreas's full bio, please see page 55.

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. Mr. Jonassen passed away in 2006. For Mr. Jonassen's full bio, please see page 21.

BRIAN LAWRENCE
began his career in electromagnetics at Plessey Research Labs, designing "Stealth" materials for the British armed services. In 1973 he moved to the USA and established a new manufacturing plant for Plessey to provide these materials to the US Navy. For Brian's full bio, please see page 16.

PETER S. MERGUERIAN
is President and CEO of Go Global Compliance Inc. and provides regulatory engineering consulting and global certifications for companies worldwide. He has 30 years global regulatory compliance experience For Peter's full bio, please see page 35.

MARK I. MONTROSE
is an EMC consultant with Montrose Compliance Services, Inc. having 30 years of applied EMC experience. He currently sits on the Board of Directors of the IEEE (Division VI Director). For Mark's full bio, please see page 27.

SYED SHAKIL MURAD
holds a BA in Electrical Engineering from Florida Atlantic University. He works part time for Sirius XM Satellite Radio as a software test engineer. He also works full time for Advanced Compliance Solutions as an engineering technician where he performs compliance testing.

TOM O'BRIEN
has worked on RF and EMC related issues for over 15 years. He worked for the Florida Atlantic University EMI lab while in college, and continued to work on RF and EMC related projects while at Motorola. For Tom's full bio, please see page 47.

GEOFFREY PECKHAM
is president of Clarion Safety Systems and chair of both the ANSI Z535 Committee and the U.S. Technical Advisory Group to ISO Technical Committee 145- Graphical Symbols. For Geoff's full bio, please see page 24.

JEAN EDNER TEZIL
holds a BA in electrical engineering and is currently pursuing a master in bioengineering at Florida Atlantic University. Since 2010, he has contributed valuable efforts in SW test at Sirius XM Satellite Radio and has been part of the resource team for occupied bandwidth and NSA measurements. For Jean's full bio, please see page 47.

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