JULY 2013

IN COMPLIANCE™

THE COMPLIANCE INFORMATION RESOURCE FOR ELECTRICAL ENGINEERS

EMI in Components

PLUS

Experiments In EMC: How Common Mode Currents Are Created

Why Didn't I See This Coming?

A Broadband, Low-Noise Time-Domain System for EMI Measurements through K_a-Band up to 40 GHz


All you
need in one
small package
Antennas | Probes | Accessories | Preamplifiers | Low-Loss Cables | Recalibration Services
Travel Made Easy
with Next-Day,
On-Time
Delivery

IN COMPLIANCE

In Compliance Magazine
ISSN 1948-8254 (print)
ISSN 1948-8262 (online)
is published by

Same Page Publishing Inc.
531 King Street, Suite 5
Littleton, MA 01460-1279
tel: (978) 486-4684
fax: (978) 486-4691

editorial staff

editor/publisher Lorie Nichols
lorie.nichols@incompliancemag.com
(978) 873-7777

production director Erin Feeney
erin.feeney@incompliancemag.com
(978) 873-7756

contributing editor Mary Ann Kahl
maryann.kahl@incompliancemag.com

publishing staff

director of sales Sharon Smith
sharon.smith@incompliancemag.com
(978) 873-7722

national sales manager Shellie Johnson
shellie.johnson@incompliancemag.com
(404) 991-8695

marketing communications specialist Heather Stehman
heather.stehman@incompliancemag.com
(978) 873-7710

circulation manager Alexis Harrington
alexis.harrington@incompliancemag.com
(978) 873-7745

subscriptions

In Compliance Magazine subscriptions are free to qualified subscribers in North America.

Subscriptions outside North America are $129 for 12 issues.
The digital edition is free.

Please contact our circulation department at circulation@incompliancemag.com

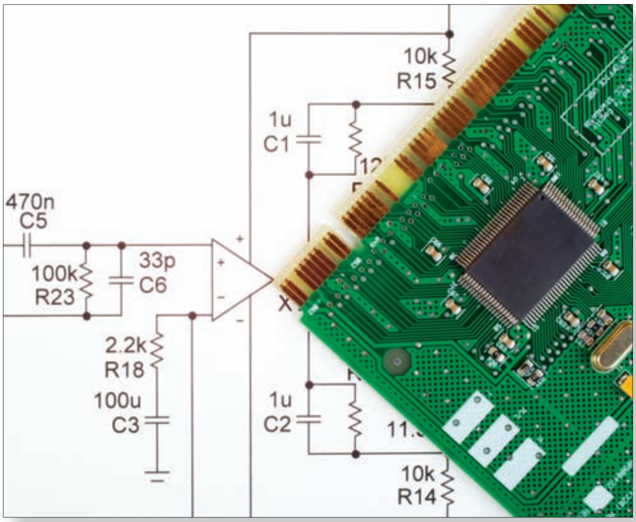
advertising

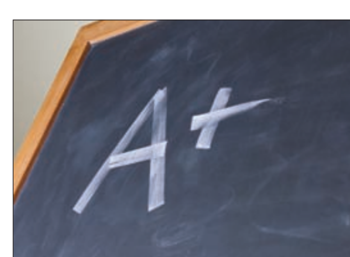
For information about advertising contact:
Sharon Smith at 978-873-7722
sharon.smith@incompliancemag.com

CONTENTS

July 2013

Volume 4 • Number 7





Join us for this 3-Day Intensive Course

presented by renowned EMC expert Henry Ott

Electromagnetic Compatibility Engineering

a course in noise and interference control in electronic systems

September 24-26, 2013
University of Michigan-Dearborn
College of Engineering and Computer Science
Dearborn, MI

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 25, 2013
Exhibitors:for information contact Sharon Smith - e-mail: sharon.smith@incompliancemag.com or call (978) 873-7722

REGISTRATION

COURSE DATES/TIME: September 24-26, 2013
Tuesday and Thursday 8:30 a.m. to 4:30 p.m.
Wednesday 8:30 a.m. to 5:00 p.m.

COURSE LOCATION: University of Michigan-Dearborn, College of Engineering and Computer Science, 2050 Institute for Advanced Vehicle Systems, 4901 Evergreen Road, Dearborn, MI 48128

COURSE FEE: $1,495 ($1,295 until 8/16/2013). 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: Accommodations are available at the Adoba Hotel, 600 Town Center Drive, Dearborn, MI 48126-2793. For reservations call 313-592-3622. Room rates start at $99 per night plus tax. You must mention In Compliance Magazine when making reservations to get this special rate. The hotel is holding a limited block of rooms. You may also visit www.adobadearborn.com and use the group code of IMENC.

*Electromagnetic Compatibility Engineering, 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."

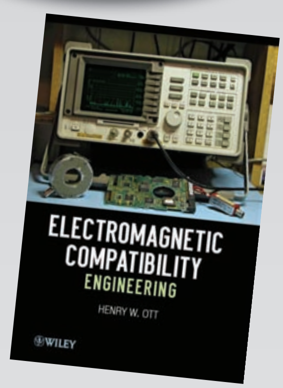
"Should be required training for all engineers."

"This is the best practical course available."

"An excellent seminar presented by a pragmatic, knowledgeable and entertaining teacher."

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

Includes Henry Ott's latest book!



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
September 24 - 26, 2013
University of Michigan-Dearborn, College of Engineering and Computer Science
Dearborn, MI

Fee: ___ $1,495 ___ $1,295 until 8/16/13
Payment required prior to start of course.

Register by 8/16/13 and save $200!

Name: ______________________________

Title: ______________________________

Company: ______________________________

Address: ______________________________

City: ____________ **State:** ______ **Zip:** ________

PAYMENT METHOD

❍ Check ❍ P.O. ❍ AMEX
❍ Discover ❍ Visa ❍ MC

Card # ______________________________

Exp date: __________ **Security Code:** __________

Signature: ______________________________

Office Phone: ______________ **Fax:** ______________ **E-Mail:** ______________

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.

News in Compliance

FCC News

FCC Seeks to Expand In-Flight WiFi Access

The U.S. Federal Communications Commission (FCC) is seeking comment on a proposal to expand the availability of in-flight broadband connectivity to air travel passengers.

In a *Notice of Proposed Rulemaking* issued in May 2013, the Commission proposed the establishment of an air-ground mobile broadband service, operating as a secondary allocation in the 14.0-14.5 GHz band. This spectrum band is currently used for fixed-satellite service (FSS), and the new air-ground mobile broadband service would be required to protect FSS from harmful interference.

The Commission says that the expanded availability of broadband service in flight would meet the increased demand from travelers for access to a full range of communications services while traveling by air in the contiguous United States.

The complete text of the Commission's *Notice of Proposed Rulemaking* is available at incompliancemag.com/news/1307_01.

The U.S. Federal Communications Commission is seeking comment on a proposal to expand the availability of in-flight broadband connectivity to air travel passengers.

FCC Amends Definition of Auditory Assistance Devices

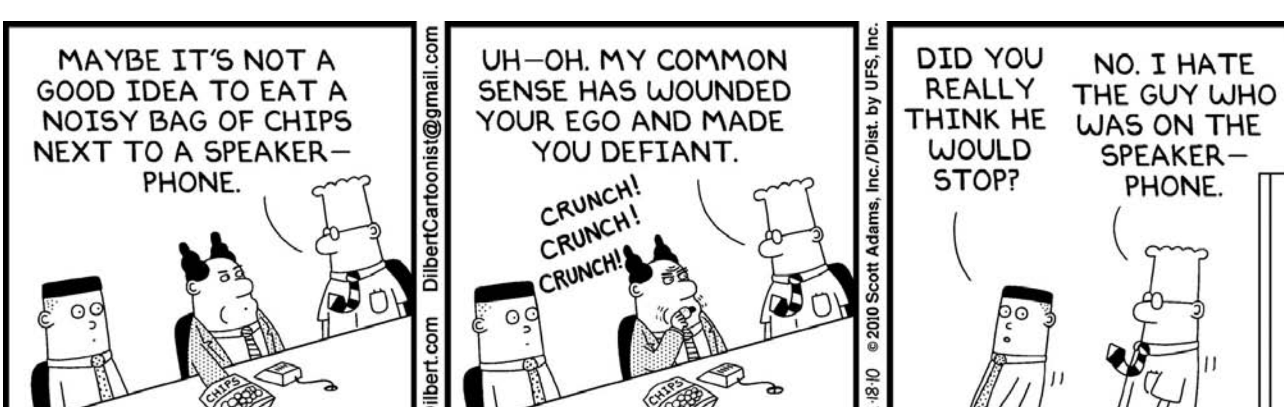
In an effort to expand access to auditory assistance devices used by people with certain disabilities, the U.S. Federal Communications Commission (FCC) has modified the definition of such devices as found in its Part 15 rules.

According to a *Report and Order* issued in May 2013, auditory assistance devices are now permitted to operate in the 72-76 MHz spectrum bands on an unlicensed basis. In addition, the Commission has expanded the permissible use of auditory assistance devices to include simultaneous language interpretation, thereby allowing the development of devices that can be used for both purposes.

The Commission notes that these actions should expand opportunities for the use of auditory assistance devices, and help to remove barriers to communications for people with hearing and sight disabilities.

At the same time, the Commission has lowered the limit for unwanted emissions from auditory assistance devices to support improved reception of VHF television service. The Commission has established an 18 month transition period after which new auditory assistance devices introduced to the market must comply with the lower limits in order to receive FCC equipment authorization, and a three year transition period for manufacturing, marketing and importation purposes. However, approved auditory assistance devices in use prior to the end of the three year transition period may continue to operate without having to meet the lower emissions limits.

The complete text of the Commission's *Report and Order* is available at incompliancemag.com/news/1307_02.



FCC News

FCC Releases Data on Internet Access

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

According to the Commission's report, entitled *Internet Access Services: Status as of June 30, 2012*, 76% of fixed Internet connections to households meet or exceed the speed tier that most closely approximates the target set in the National Broadband Plan of 3 megabits per second (Mbps) downstream and 768 kilobits per second (kbps) upstream. This penetration rate for fixed high-speed service compares with just 49% in 2009, 53% in 2010, and 73% in 2011.

At the same time, high-speed Internet access (defined at 3 Mbps downstream or greater) for subscribers of mobile wireless service continues to grow. As of June, 2012, 31% of mobile subscribers had access to high-speed service, more than double the 14% penetration rate achieved by June 2011.

Without accounting for speed, Internet connections overall are growing. By the end of June 2012, there were 243 million Internet connections offering access at speeds of at least 200 kpbs, an 18% year-over-year increase. Overall growth continues to be driven by dramatic increases in mobile connections, which increased by 28% in just one year. With 153 million subscribers, the number of mobile Internet connections at the end of June 2012 was 70% greater than the number of fixed Internet connections.

The complete text of the Commission's latest report on Internet access is available at incompliancemag.com/news/1307_03.

News in Compliance

European Union News

EU Commission Releases 2012 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, 2012.

According to the Commission's report, 1938 notifications of products posing a serious risk to health and safety were processed through the RAPEX system during 2012. This represents a 24.5% increase in notifications over 2011's 1556 notifications, but nearly equal to the 1963 notifications received in 2010, the highest annual number of recorded notifications of products posing a serious risk.

In its annual report, the Commission attributes the 2012 increase in notifications to the "increased circulation of unsafe products," but also to "vigilant and proactive" efforts for enforcement authorities in EU Member States to protect consumer safety through the removal of unsafe products from the market.

Of the 1938 notifications of products processed through the RAPEX system during the year as presenting a serious risk to consumers, 668 (34%) were related to clothing, textiles and fashion items, with an additional 366 (19%) .related to toys, and 205 (11%) related to electrical appliances. There were also 149 notifications related to motor vehicles (8%), and 43 notifications (2%) 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 (58%) were related to products originating from China, including Hong Kong. 17% of unsafe products originated in EU Member States, while 11% failed to identify any country of origin.

To view the complete text of the EU Commission's 2012 annual report on RAPEX statistics, go to incompliancemag.com/news/1307_04.

The Commission of the European Union (EU) has released RAPEX statistics on unsafe consumer products for 2012. The EU has also updated standards lists for the Electrical Safety Directive, the Pressure Equipment Directive, and the Toy Safety Directive.

Updated Standards List Published for the EU's Electrical Safety Directive

The Commission of the European Union (EU) has published an updated list of standards that can be used to demonstrate conformity with the essential requirements of its directive relating to electrical equipment designed for use within certain voltage limits (2006/95/EC).

The Directive defines 'electrical equipment' as any device designed for use with a voltage rating of between 50 and 1000 V for alternating current, and between 75 and 1500 V for direct current.

The updated list of standards that can be used to demonstrate compliance with the Directive was published in May 2013 in the *Official Journal of the European Union*, and replaces all previously published standards lists.

The complete list of standards can be viewed at incompliancemag.com/news/1307_05. (Note that the list runs 90 pages!)

EU Commission Publishes Standards List for Directive on Pressure Equipment

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 97/23/EC concerning pressure equipment, also known as the Pressure Equipment Directive (PED).

The PED addresses safety requirements covering the design, manufacture and testing of a range of equipment subject to a pressure hazard. The types of equipment covered under the scope of the Directive include pressurized storage containers, heat exchangers, steam generators, boilers, industrial piping, and other equipment used in the process and energy production industries, and in the supply of utilities, heating, air conditioning and gas storage.

European Union News

The list of CEN standards, which was published in May 2013 in the *Official Journal of the European Union*, replaces all previously published standards lists for the PED. The complete list of standards can be viewed at incompliancemag.com/news/1307_06.

EU Commission Updates Standards List for Toy Safety Directive

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

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

The most recently updated list of CEN standards for the Directive was published in May 2013 in the *Official Journal of the European Union*, and replaces all previously published standards lists for the Directive.

The revised list of standards can be viewed at incompliancemag.com/news/1307_07.

News in Compliance

CPSC News

Williams Sonoma To Pay $1 Million Penalty for Failing to Report Defects

Williams Sonoma, Inc. of San Francisco, CA has agreed to pay a civil penalty of $987,500 to settle allegations that it failed to immediately report defects involving the company's Pottery Barn wooden hammock stands.

According the U.S. Consumer Product Safety Commission (CPSC), Williams Sonoma imported the wooden hammock stands between March 2003 and July 2008, and distributed them through its Pottery Barn and PBteen catalogs and websites, as well as through its Pottery Barn Outlet stores. The wood within the hammock's metal brackets allegedly deteriorated when subject to outdoor conditions, but the deterioration would go undetected until the hammock collapsed under normal use.

Federal law requires that manufacturers, distributors and retailers immediately (i.e., within 24 hours) report to the CPSC information that a product contains a defect which could create a substantial product hazard, or pose a risk of injury or death to consumers. In this case, Williams Sonoma reportedly received reports of 45 separate incidents involving the hammocks, including 12 reports of injuries requiring medical attention, before filing a report with the CPSC in September 2008. The company and the CPSC announced a recall of 30,000 hammock stands in October 2008.

In agreeing to the civil penalty, Williams Sonoma neither admitted nor denied CPSC allegations that the wooden hammock stands posed an unreasonable risk of injury or death, or that the company violated the reporting requirement of the U.S. Consumer Product Safety Act.

> Williams Sonoma, Inc. has agreed to pay a civil penalty of almost $1 million due to failure of reporting defective wooden hammock stands. In further CPSC news, recalls have been issued for motorized window shades and portable electric heaters.

Company Recalls Motorized Window Shades

Insolroll Window Shading Systems of Louisville, CO has recalled about 1500 of its solar powered and rechargeable motorized roller window shades manufactured in the U.S.

According to the company, the motor of the recalled window shades has a built-in lithium battery that can overheat while being charged, posing a fire risk to consumers. Insolroll has received one report of the motor in a roller shade overheating and creating a fire. However, no injuries have been reported.

The recall motorized roller window shades were sold through Insolroll independent window covering retailers nationwide from June 2012 through March 2013 for between $400 and $700 per window shade.

Additional information about this recall is available at incompliancemag.com/news/1307_08.

Portable Electric Heaters Recalled

Optimus Enterprises of Anaheim, CA has announced the recall of about 355,000 portable electric space heaters manufactured in China.

According to a recall summary published by the U.S. Consumer Product Safety Commission (CPSC), the design of the recalled infrared radiant quartz electric space heaters is inadequate to prevent the ignition of nearby combustible materials that come in contact with the unit. This design flaw presents a fire hazard to consumers. To date, Optimus Enterprises has not reported any incidents or injuries associated with the recall space heaters.

The recalled space heaters were sold at Best Buy Market Place, Family Dollar, Heartland, Northern Tool, Rite-Aid and other retail stores nationwide, and online at Amazon.com, ebay.com and Walmart.com from October 2011 through December 2012 for between $25 and $30.

Further details about this recall are available at incompliancemag.com/news/1307_09.

Re-Inventing State Of The Art

700 MHz To 6 GHz Single Band Benchtop Amplifiers & Hybrid Power Modules To Complement Our 4 To 18 GHz Designs

Output Power Up To 200 Watts CW

AR's new line of solid state Hybrid Power Modules (HPM's) and benchtop amplifiers not only provide the best value in a single self contained unit, but they're big on power and performance.

In addition to our solid state 4-18 GHz modules and amplifiers, we now have a line of high gain units that instantaneously cover the ultra-wide 0.7 to 6 GHz frequency band.

Our SMA connectorized modules provide output powers up to 30 watts CW in a class A configuration and up to 50 watts with class AB biasing.

The class A bench top amplifiers available as a complete self- contained air cooled assembly provide output powers up to 200 watts with a 0 dBm input, include an integrated power supply, a digital control panel, gain control, integrated software and RF input protection.

Both the Class A modules and bench top units provide excellent gain flatness, low noise figure and have the ability to survive an infinite output mismatch to provide trouble free state-of-the-art performance.

Applications for these high performance products are limited only by your imagination but a small sampling are: Jammers, Radars, ECM, ECCM, Data Links, EMC, Wireless, TWTA replacements/drivers and communications.

To obtain more detailed information on these and other products call AR RF/Microwave Instrumentation at 215 723 8181 or visit us at www.arworld.us.

www.arworld.us/hpm

RoHS

ISO 9001:2008 Certified

rf/microwave instrumentation

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

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

In Europe, call ar United Kingdom +44 1908 282766 • ar France +33 147 917530 • ar GmbH +49 6101 80270-0 • ar Benelux +31 172 423000

www.arworld.us

iNARTE Informer

The iNARTE Informer

BY RABQSA STAFF

ASSOCIATE EMC, ESD, AND PRODUCT SAFETY CERTIFICATIONS

Many of you may not be aware that iNARTE offers an Associate level of certification for individuals who are new to the fields of EMC, ESD and Product Safety and do not yet have the work experience required for these iNARTE certification programs. Those eligible for the associate certifications include recent engineering graduates who have interest in these fields. The associate certifications provide these committed individuals a valuable credential as they develop their careers.

These levels were originally incorporated to allow for recent graduates of iNARTE Accredited Universities, Schools, or Institutes to enter into the certification program. The program has now been updated to accept educational degrees and evidence for any applicable education or training acquired, according to the current requirements of the EMC, ESD, and Product Safety programs.

Individuals who achieve the Associate level of iNARTE certification gain immediate recognition for their knowledge in the applicable industry, even though they do not meet the required number of years of work experience for the "Engineer" or "Technician" levels.

To be eligible for an Associate certification for EMC, ESD, or Product Safety, an individual must:

- Pass the applicable examination;
- Provide evidence of the applicable education and training;
- Submit the required references for the applicable program, including one letter from a school official; and
- Submit the three (3) test questions that can be used on future iNARTE examinations

To learn more about the EMC, ESD or Product Safety programs, visit www.narte.org.

To register for an EMC, ESD or Product Safety examination, visit:

- Within the US www.narte.org/h/examregform.asp
- Outside the US www.narte.org/h/examregformint.asp

RABQSA ONLINE PORTAL

Over the past months, RABQSA has requested iNARTE certified individuals to provide their current email address in preparation for the launch of the RABQSA Online Portal. We continue to collect that information, and the availability of the Online Portal for iNARTE certified individuals is still under development.

In an effort to ensure a seamless migration when the development process is completed, if you have not already done so, please send your name, certificate number, and current email address to Laura Funk, RABQSA Office Assistant, Certification Services, at lfunk@rabqsa.com.

RABQSA IS SEEKING TEST CENTERS TO ADMINISTER EXAMINATIONS

In an effort to accommodate our iNARTE customers to ensure they travel fewer miles from their home, RABQSA is recruiting test centers and individual proctors to administer the iNARTE and FCC examinations.
If you are interested in becoming an

QUESTION OF THE MONTH

Last month's question was from the Product Safety Engineer pool:

An Information Technology Equipment rack mount power distribution unit connects to the AC mains via a NEMA L5-30P attachment plug. It has a series of NEMA 5-15R panel mount AC output receptacles and incorporates UL Listed panel mounted circuit breakers in the front panel protecting the outlets. What is the required current rating for each of these circuit breakers?

A) 30 A

B) 20 A

C) 15 A

D) The current rating of each circuit breaker shall be greater than the maximum rated current to be delivered by each series of outlets.

The correct answer is C) 15 A

This month's question is from the EMC Design Engineer pool:

When designing high-speed Printed Wiring Boards, what is the benefit of routing the power and return planes on adjacent layers?

A) To reduce noise on the power plane at high frequencies.

B) The material that separates the power and return planes will typically fail and short the power plane.

C) So the connectors are designed so that they are forced to feed the power and grounds on adjacent layers.

D) To route the planes next to each other so the boards will warp during fabrication.

See the next iNARTE Informer for the correct answer to this month's question.

iNARTE Authorized Test Center or iNARTE Individual Test Proctor, please fill out the application form located at www.narte.com/h/tchome.asp#TC.

iNARTE (International Association of Radio and Telecommunications Engineers) is a product of RABQSA (Registrar Accreditation Board and Quality Society of Australasia) International, Inc.

RABQSA's mission is to provide world-class products and services that add value to professionals in industry through competency-based certification. RABQSA creates value for you and your customers. We design, develop, and deliver personnel and training certification services relevant to your industry. Our certification services are designed to be efficient, consistent and relevant to Industry's needs. We create and maintain value to industry, our certified professionals, and training providers by ensuring that our certification remains relevant and also compliant to international standards. RABQSA International certification delivers the right people, with the right abilities, to achieve the right outcomes.

RABQSA's principal offices are located in Sydney, Australia, Milwaukee, USA and Seoul, Korea and international offices located throughout the world.

To learn more about the iNARTE certification programs, visit www.narte.org. To learn more about RABQSA, visit www.rabqsa.com.

Abatement of Static Electricity

Part II: Insulators

BY NIELS JONASSEN, sponsored by the ESD Association

The damaging effects of static charges on insulators can be reduced or even negated.

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

The first of this two-part series ("Abatement of Static Electricity - Part I: Conductors," *In Compliance Magazine,* June 2013) covered the abatement of static charges on conductors. This second installment addresses charges on insulators, which must be neutralized differently than charges on conductors.

In principle, there are three methods for neutralizing charges on insulators: conductance through the bulk of the material, conductance along the surface of the material, and the attraction of oppositely charged ions from the air.

BULK CONDUCTANCE

If a material contains mobile charge carriers, it is said to be bulk conductive. If a field strength *E* in the material releases a current density *j*, the bulk conductivity γ of the material is defined by

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

or, as it is usually written,

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

where $\rho = 1/\gamma$ is the bulk resistivity. These equations are forms of Ohm's law. It appears from Equation 2 that the unit for r is $(V/m)/(A/m^2) = \Omega \cdot m$.

Figure 1 shows a material, A, with bulk resistivity ρ and relative permittivity ε_r. "A" is resting on a grounded plate, G. If A is charged with a surface charge density σ, a field E is established in A and is directed toward G. It is assumed that all the field lines (the total electric flux) from the charge run through A (i.e., the field outside A is negligible). This field makes positive charge carriers move toward G and negative charge carriers move toward the surface of A, eventually neutralizing the field from the original charge.

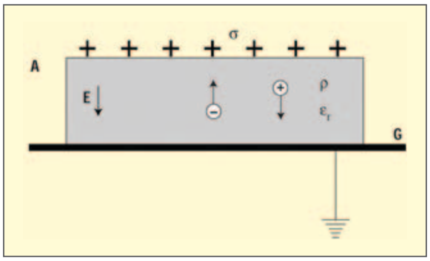


Figure 1: Material A has bulk resistivity r and relative permittivity e_r.

Charge density σ appears to decay through material A according to the equation

$$\sigma = \sigma_o e^{-\frac{t}{\tau}} \qquad (3)$$

where σ_o is the initial charge density,

$$t = \varepsilon_r \varepsilon_o \rho, \qquad (4)$$

is the time constant, with $\varepsilon_o = 8.85 \times 10^{-12}\ F \cdot m^{-1}$. It is therefore possible from the measurement of material parameters r and e_r to predict how fast a surface charge is being neutralized. The question is then how to make insulators bulk conductive.

BULK CONDUCTIVE INSULATORS

It is contradictory to talk about transporting charges through an insulator. If this were possible, the material would not really be insulative. Over the years, many attempts have been made to give insulative materials a suitable conductivity without ruining their other (usually mechanical) desirable properties. Normally, this is done by mixing the material with inherently conductive additives. The best-known example of such an intrinsic antistatic agent is carbon black. Carbon black can be added to a variety of polymeric materials and is used when the resulting blackening of the base material is acceptable.

For many years, the most important area of use for carbon black was conductive rubber. Ordinary vulcanized rubber can have a bulk resistivity of 10^{13} $\Omega \cdot$ m, but adding carbon black can lower the resistivity by a factor of up to 10^{15}. Normally, however, a resistivity of about 10^5–10^6 $\Omega \cdot$ m is low enough to prevent dangerous or annoying charge accumulations.

Conductive rubber is used extensively in hospital operating rooms, tubing for anesthetic machines, wheels on carts, soles for antistatic footwear, and car tires. It should be mentioned that the shock a driver or passenger can receive when getting out of a car is not caused by discharging the car to ground. Instead, the driver may get charged when sliding over the seat cover, in much the same way a person gets charged when getting up from a chair with an insulative seat. As a result, a spark can jump between the person and any metal part of the car, which is virtually at ground potential.

Another use of carbon black is in the manufacturing of solid and textile antistatic floor coverings. The textile fibers can be made with either a central core of carbon black and a sheath of polyamide or, conversely, with a central core of polyamide and a sheath of carbon black.

The most important use of carbon black, at least economically, is no doubt in the electronics industry. By loading the base materials for carrier trays, holders, tubes, tote boxes, bags, etc., with carbon black, these items are made sufficiently conductive to ensure a rapid neutralization of static charges on the material itself. Usually, the loading is done uniformly throughout the matrix of the material to increase the bulk conductivity, but it can also take the form of a thin conductive surface layer.

SURFACE CONDUCTANCE

In many static-electric processes, it appears that not only the charge separation but also the subsequent charge neutralization takes place in or along the surfaces of the materials involved. It may therefore seem practical to define quantities similar to the bulk parameters of Equations 1 and 2 to characterize a surface's resistive properties.

If a field with strength E_s along a surface releases a current with linear density j_s, the surface conductivity γ_s can be defined by

$$j_s = \gamma_s E_s \qquad (5)$$

or, as it is usually written,

$$E_s = \rho_s j_s \qquad (6)$$

where $\rho_s = 1/\gamma_s$ is the surface resistivity. Because j_s is a linear current density with the unit A/m, it appears from Equation 6 that the unit for ρ_s is (V/m)/(A/m) = V/A = Ω. Equations 5 and 6 both express Ohm's law for surface conductance.

Knowledge of the bulk resistivity (and the permittivity) can be used to predict how quickly a charge is neutralized by conductance through the bulk of a material (see Equation 3), as long as the field from the charge runs primarily in the material itself. This condition is often fulfilled with sufficient accuracy with bulk conductance, but rarely with surface conductance.

Figure 2 shows an insulative material, A, on top of which is a thin conductive layer, B. A grounded electrode, C, is placed in direct contact with one end of B, and a positive charge q is placed on the other end of B. If C is the only conductive grounded item near the system, all the field lines from q will eventually end at C. The parts of the field lines running through B will cause negative charge carriers to move toward q and eventually neutralize it. However, the field running through the insulator A or though the air does not contribute to the neutralization process at all.

SURFACE-CONDUCTIVE INSULATORS

It is well known that static-electric problems seldom occur in environments with high relative air humidity, say, greater than 50–60%. This fact has sometimes been erroneously interpreted to mean that humid air has higher conductivity than dry air. However, if anything, humid air is less conductive, because the mobility of small air ions decreases slightly with increasing humidity. The effect of increased air humidity is to increase the thickness of the moisture layer on or in all surfaces, and this layer contains electrolytic ions that provide neutralizing charges.

The amount of moisture absorbed or adsorbed from the air is strongly dependent on the material in question. At humidities as low as 30–35%, a material like cotton may show little charge retention, whereas a material like polyamide may require humidities of 50% or greater to be considered antistatic. Generally speaking, no resulting charges appear at humidities of 60% or greater. Humidities at such high levels, on the other hand, often pose practical, technical, or hygienic problems if they are maintained over extended periods.

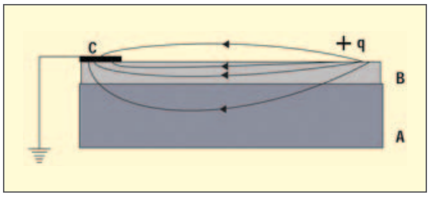


Figure 2: Insulative material A with conductive layer B

TOPICAL ANTISTATS

It is often possible to render highly insulative materials sufficiently surface-conductive, even at relatively low humidities, by treating the surface with antistatic agents (topical antistats). These agents function by forming a surface layer a few molecules thick that attracts moisture from the air much more readily than an untreated surface.

Antistatic agents obviously must be hygroscopic, but they also must show a low vapor pressure in order to keep from evaporating too quickly from the treated surfaces. Further requirements concern color, toxicity, inflammability, etc.

Chemically speaking, antistatic agents are amphipathic compounds, their molecules containing a hydrophobic group to which is attached a hydrophilic end group. According to the nature of the end group, the agents are divided into cationic, anionic, and nonionogenic agents. Cationic materials are usually high-molecular quaternary ammonium halogenides or ethoxylated fatty amines or amides. Anionic materials can be sulfonated hydrocarbons, and nonionogenic materials can be polyalkylene oxide esters.

Topical antistats are used extensively in the textile, plastic, and printing industries. A common use is the treatment of floor coverings to reduce the body voltage of persons walking across the floor. With textile floor coverings, a proper antistatic treatment may be effective for two to three months. With hard floor coverings, the antistatic treatment must normally be repeated after each washing.

PERMANENT ANTISTATIC MATERIALS

In some cases, antistatic agents may be compounded with a polymer, either before polymerization or at least before extrusion. The best-known example of this technique is probably the manufacture of antistatic polyethylene, commonly known as pink poly. Ethoxylated fatty amines or amides are mixed with a resin, such as low-density polyethylene, and an antiblock, such as calcium carbonate, to prevent stickiness. After extrusion or molding to the required end product (film, sheets, trays, boxes, etc.), the additive has to diffuse (bloom) to the surface to attract moisture from the air and thus render the material antistatic.

Pink poly, which may appear in a variety of color shades besides pink, is no doubt the most widely used material in the electronics industry for packaging, storing, and transporting sensitive components and circuits. Materials with built-in additives maintain their antistatic properties as long as the additive is present on the surface.

Although the vapor pressure of most additives is fairly low, a certain level of evaporation always takes place from the surface. For fresh materials, this evaporation is counterbalanced by diffusion from the interior of the material. As the supply of additive in the solid is depleted, the surface concentration cannot be maintained. The surface is said to "dry out," resulting in an increasing surface resistivity and the eventual loss of antistatic properties.

The effective lifetime of a permanent antistatic material depends on many factors, the most important of which are the temperature of the environment and the thickness of the material, which (for a given volume concentration) determines the amount of additive available for diffusion to the surface. It should also be mentioned that the additive diffusing to the surface, besides attracting moisture from the air, may react in unwanted ways with components and devices coming into contact with the material. Such unwanted reactions include printed circuit boards and other items made of polycarbonate crazing and cracking when packed in antistatic materials containing fatty amines.

CHARGE NEUTRALIZATION BY AIR IONS

In all the methods discussed above for neutralizing charges on insulators, some kind of modification of material parameters, such as surface or bulk resistivity, is involved. However, such modifications are often neither possible nor acceptable. In such cases, only one method remains: Neutralize the charges with oppositely charged air ions. In a previous article ("Ions," *In Compliance Magazine,* November 2011), the physical properties of air ions and their formation were discussed. This article concentrates on the processes of charge neutralization.

The charge carriers, either electrons or electrolytic ions involved in bulk and surface conduction, are fairly stable quantities that are always present and ready to move when exposed to a field from a charge. The neutralization processes do not change the concentrations, and negative and positive (electrolytic) ions exist side by side without trying to annihilate each other. In some cases (bulk conduction), it is even possible to predict how fast a charge is being neutralized.

However, this is not so with air ions. First, air ions are not naturally present where they are to be used, except in environments with high radon and radon-daughter concentrations. They must be produced (by high electric fields or radioactive decay) somewhere else and brought to the charge by a field, sometimes aided by airflow. Furthermore, air ions are unstable structures with a limited lifetime. Whereas a stable, high bulk or surface conductivity can be created in or on suitable materials, this is not the case with air ionization.

Suppose a high density of ions is created in a room with comparable concentrations of positive and negative ions: The ions will disappear if there is no supply of new, freshly formed ions. The ions disappear by combining with airborne particles; by positive and negative ions recombining and turning into oxygen, nitrogen, and a few water molecules; or by plating out on any surface in the room.

Despite the apparently negative qualities of air ions, the use of air ions is the only way to neutralize charges on insulators.

AIR CONDUCTIVITY AND RESISTIVITY

Air containing ions is conductive in a way similar to solid materials containing mobile charge carriers (see Equations 1 and 2). However, when dealing with air ions, conductivity caused by negative ions and conductivity caused by positive ions must be distinguished from each other.

In an atmosphere with positive and negative ions, an electric field E will cause a current with density j_+ in the direction of E,

$$j_+ = \gamma_+ E \tag{7}$$

where γ_+ is the conductivity caused by positive ions (positive conductivity).

Equation 7 can be rewritten as

$$E = \rho_+ j_+ \tag{8}$$

where $\rho_+ = 1/\gamma_+$ is the positive resistivity of the air.

The same field E also causes a current (carried by negative ions) with density j_- in the direction opposite to that of the field, giving

$$E = \rho_{-} j_{-} \qquad (9)$$

where ρ_{-} is the negative resistivity of the air.

Figure 3 shows a positively charged insulator, A, in an atmosphere with positive and negative ions. The positive ions are repelled (as long as A itself is positively charged) and therefore have no influence on A's charge.

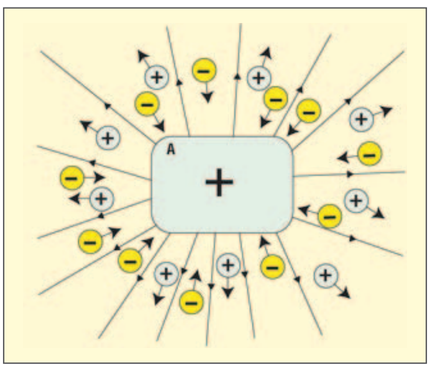


Figure 3: Positively charged insulator in ionized atmosphere far from grounded objects

The negative ions, on the other hand, are attracted toward A and plate out on the surface. Whether the charge of the negative ions actually neutralizes the positive charge on A or the field from the plating-out ions just superimposes the field from the charge on A is a question of academic interest. The result is that A appears to gradually lose its charge. If the field from A (the flux) extends mainly into an atmosphere with negative resistivity ρ_{-}, the charge q^{+} on A would appear to decay according to the equation

$$q_{+} = q_o^{+} e^{-\frac{t}{\tau_{+}}} \qquad (10)$$

where q_o^{+} is the initial charge and τ_{+} is the time constant for positive charge decay given by

$$\tau_{+} = \varepsilon_o \rho_{-} \qquad (11)$$

It therefore appears that the neutralization rate for a positive charge is determined by the negative resistivity of the surroundings, or, more precisely, by the resistivity caused by the negative ions.

Equations 10 and 11 are parallel to Equations 3 and 4 for bulk decay through a solid material, but it should be stressed that a time constant calculated from Equation 11 is usually lower than what can be found experimentally. The reason for this is that a charged body is rarely far from other bodies (especially conductors), as assumed in Figure 3.

The situation in Figure 4 may be closer to reality. Here, the charged insulator, A, is placed close to a grounded conductor, B, maybe even touching it. Parts of the field lines from A terminate on B and run through a space with no or very few ions. This part of the field does not contribute in full to the neutralization, and, consequently, the process is slower than if A had been suspended freely in an ionized atmosphere.

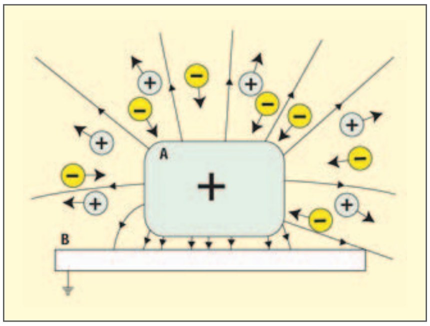


Figure 4: Positively charged insulator in ionized atmosphere near grounded conductor

MR. Static

This series of articles is not intended to be a handbook on fighting the risks and nuisances of static electricity.

This situation corresponds rather closely to the situation illustrated in Figure 2 for surface conduction. There is, however, a major difference. Whereas a surface decay time cannot be calculated or predicted and can hardly be measured, the neutralization time by air ions can often be accurately estimated with a charged-plate monitor or similar instrument.

IONIZER TYPES

Any ionization process in air starts with an electron being knocked off an oxygen or nitrogen molecule. This process is done in different ways in radioactive ionizers and field ionizers.

Radioactive Ionizer: A radioactive material (typically an alpha-emitting nuclide with a half-life on the order of half a year) is placed on a base material and covered by an extremely thin protective layer, often made of gold.

The alpha particles are emitted from the nuclide with an energy of, say, 5 MeV (» 8 x 10^{-13} J). A small part of this energy is dissipated in the protective layer, but the alpha particle is still able to create maybe 150,000 positive and negative ion pairs along its range of a few centimeters.

The ionizer is consequently placed in front of the charged material at a distance that is a little farther than the range of the alpha particles. If the material is positively charged, negative ions will be attracted and plate out on the material, gradually reducing the field.

The neutralizing efficiency of radioactive ionizers is not very high, but with relatively low levels of static charges and especially in confined spaces, radioactive ionizers are very handy. They do not require any electrical installation, and they cannot cause potentially harmful electrical discharges.

Because a fairly short-lived nuclide is used, the ionizer is replaced at regular intervals and not left unattended for extended periods. Because alpha-active nuclides are used, the external radiological dose is insignificant. However, if the radioactive material is accidentally spread into the environment and becomes airborne, it can be inhaled. In this case, the highly energetic alpha radiation may give off an internal dose which can eventually cause radiological damage to the respiratory tract. With modern ionizers, however, the risk is extremely low.

Field Ionization: In a radioactive ionizer, alpha particles are emitted with sufficient energy to cause ionization of a large number of air molecules. In the more commonly used electrical or field-based ionizers, the necessary energy is delivered by accelerating an electron in a strongly inhomogeneous field.

Figure 5 shows a point electrode, a so-called emitter. If the electrode is kept at a sufficiently high potential with respect to grounded surroundings, the field strength E in the immediate neighborhood of the electrode will exceed the breakdown field strength E_b.

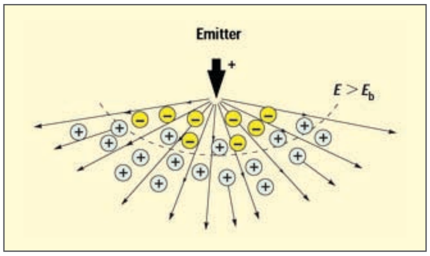


Figure 5: Field ionization

In this range, positive and negative ions are formed. If the emitter is positive (see Figure 5), the negative ions will move toward the emitter, where they will be neutralized, delivering their negative charge to the emitter. Accordingly, the positive ions will move away from the emitter, making it look as if the emitter has indeed emitted positive ions. But it hasn't. The emitter does not emit anything. The ionization process takes place exclusively in the air in front of the emitter. In addition, the ionization is not caused by the voltage of the emitter but by the field.

Passive Ionizer: The simplest form of field ionizer is a passive ionizer. It is essentially a single grounded emitter or (more often) a row of grounded emitters placed parallel with and close to the charged material. The charge provides an electric field. If the charge density is high enough, the breakdown field strength is exceeded near the emitter and positive and negative ions form in the region. Negative ions move to the emitter and become neutralized, and positive ions move to the charged material and gradually neutralize the charge located there.

When the charge density becomes too low, the ionization stops; hence, the neutralization stops. A passive ionizer will therefore not be able to render a material totally neutral, but it will be able to reduce high levels of charges, which in many industries is sufficient.

It should be stressed that the emitter should not touch the charged material.

Rather, it is meant to give an overview of the various ways of attacking these problems and, to some extent, to describe the pros and cons of implementing different methods.

The neutralization is not caused by contact but by the ionization process.

Ac Ionizer: In cases where a passive ionizer does not provide sufficient neutralization, an ac ionizer can often do the job. The emitter is connected to an ac voltage supply, usually in the kilovolt range. In front of the emitter, the formation of positive and negative ions alternates, and the polarity of the charged material determines the polarity of attracted ions.

It is a shortcoming of ac ionizers that ionization only happens in that part of each half-cycle when the voltage of the emitter exceeds the breakdown voltage. Therefore, if the charged material is moving rapidly past the ionizer, neutralization can be incomplete. Furthermore, the ac signal should not be symmetrical—the breakdown voltage is lower for negative ionization than for positive.

Dc Ionizer: The most effective neutralization is obtained by the use of a dc ionizer, which usually consists of two emitters held at a positive and a negative potential, respectively (see Figure 6).

When the ionizer is properly balanced, positive and negative ions are provided in the same concentrations in front of the charged material, and, as explained for the ac ionizer, the polarity of the charge determines the kinds of ions used for neutralization.

If the charge to be neutralized is always of the same polarity (for instance, the negatively charged material in Figure 6), it might seem natural to use only a positive dc ionizer. This, however, may not ensure neutralization but instead may lead to a positive charge caused by the ionizer. It is therefore important that the ionizer be able to balance the ion concentrations where the neutralization will take place.

GENERAL REMARKS ON IONIZATION AND IONIZERS

Practical, commercial ionizers do not look much like those shown in Figures 5 and 6. Often, they are mounted in front of a fan to propel the ions to where they are needed. Such ion blowers are handy for localized neutralization.

If it is necessary to secure neutralization in larger areas or in larger volumes, whole-room ionization may be employed. In such systems, a number of ionizers are mounted beneath the ceiling. Emitters can alternate positive and negative or all can be connected to an ac voltage, either sinusoidal (50 or 60 Hz) or square-pulsed (1–2 Hz). With the square-pulsed technique, ions with alternate polarities are constantly produced, and, because the pulses are fairly long, ions of a given polarity have a chance to move away from the emitter before ions of the opposite polarity are produced and recombination sets in. Separating shorter positive and negative pulses by half a second (or so) in the stepped-pulse technique can enhance the process. The ions are carried to workplaces and items where neutralization is needed by fields, diffusion, and, most often, by laminar airflow.

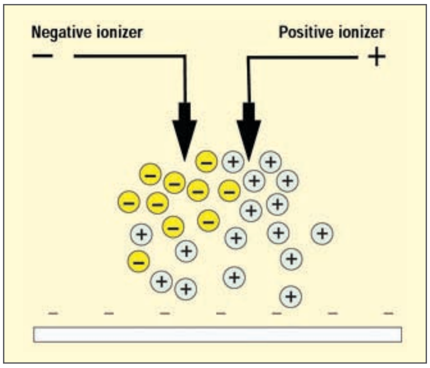


Figure 6: Dc ionizer

CONCLUSION

This series of articles is not intended to be a handbook on fighting the risks and nuisances of static electricity. Rather, it is meant to give an overview of the various ways of attacking these problems and, to some extent, to describe the pros and cons of implementing different methods.

(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.

OSHA Validates ANSI Product Safety Labeling Formats Through Update to Facility Safety Sign and Tag Regulations

BY GEOFFREY PECKHAM

In this column, we'll discuss the Occupational Safety and Health Administration's (OSHA) newly proposed update to rules on safety signage in the workplace and how it validates the efforts of product design engineers to create safer products.

When it comes to safety in our workplaces, an important advancement was made this past spring: OSHA announced a proposed update to its rules on safety signs and tags – regulations which have not been updated since their inception in 1971. The new rule will incorporate the appropriate ANSI Z535-2011 standard reference into OSHA's standards wherever safety signs, colors and tags are specified.

Because OSHA must be sensitive to imposing additional costs on facility owners, the ANSI Z535-2011 reference will appear next to the 1967 USASI Z53 and 1968 USASI Z35 standards currently referenced in OSHA's regulations. This will allow employers to use either the old or new standards and be in compliance with OSHA. In the past, if the facility owner wanted to use the ANSI Z535 signs or tags, they would run the risk of being cited for violating OSHA standards because the OSHA standards only referenced the old 1967-68 standards. But now that problem has been eliminated.

The benefits of using the latest ANSI Z535 signs and tags over signs and tags designed with the outdated 1960's-era standards include:

- The new signs and tags typically provide a more substantial level of information so people can make safer decisions (e.g. the nature of the hazard, the consequence of interaction with the hazard, and how to avoid the hazard).
- The concepts contained in the ANSI Z535 standards are supported by human factors research on effective warnings and by modern risk assessment methodologies.
- The newer formats better accommodate multiple language panels and graphical symbol panels so safety is better communicated to non-English readers.
- The ANSI Z535 standards contain design principles that exemplify current legal criteria for "adequate warnings" as defined by the past thirty years of U.S. case law.

Since the older-style signs and tags do not embody the above benefits, they risk confusion on the part of the viewer as to what is dangerous and/or how to avoid potential hazards. Signs and tags that are intelligently designed to meet the new standards, on the other hand, provide a much more substantial (and defendable) warning. As an example, compare the minimal content of the old OSHA-style sign and tag shown in Figure 1 with the more complete information found on the new ANSI Z535-style sign and tag shown in Figure 2.

The ANSI-formatted examples should be familiar, in concept, to every product design engineer who is in charge of safety labels for their products for a simple reason: the *2011 ANSI Z535.2 Standard for Environmental and Facility Signs* is closely aligned with the *2011 ANSI Z535.4 Standard for Product Safety Signs and Labels*. (See Figure 3 for an example of an ANSI-formatted product safety label.) The two standards are nearly identical and there are two reasons why this development in OSHA's regulations is important to the product design engineer.

First, in very real terms, the new rule change represents the U.S. government's validation of the ANSI Z535 design concepts that have been defining best practices for product safety labeling for the past 20+ years. This should give the

Figure 1: Example of an old-style OSHA USASI-1967 Z35.1 sign and corresponding USASI-1968 Z35.2 tag.

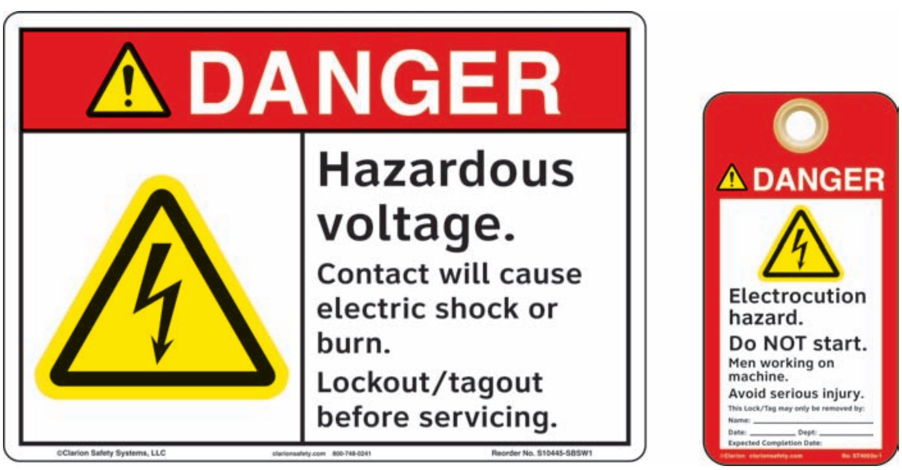


Figure 2: Example of a new-style OSHA/ANSI 2011 Z535.2 sign and corresponding OSHA/ANSI 2011 Z535.5 temporary safety tag with best practice formatting and more complete content. (Designs ©Clarion Safety Systems.)

Figure 3: Example of an ANSI 2011 Z535.4 electrical hazard product safety label. (Design ©Clarion Safety Systems.)

product design engineer's company an even better defense position should an accident occur and the company needs to defend its warning labels. Of course this only works if you have put in place a process of risk assessment that has, as one of its results, well-designed ANSI Z535.4 product safety labels.

Second, the OSHA update means that, over time, as employers adopt the newer ANSI Z535 best practice safety tag and sign formats, the U.S. will eventually have a single, national uniform system of hazard recognition – meaning the safety signs installed in facilities and public areas, the temporary safety tags placed on equipment, and the safety labels you place on your products will all be designed using the same formatting principles. The outcome of such consistency should be more effective communication and that should help achieve the objective of fewer accidents and lives saved from tragedy. And that's an incredibly fine goal.

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

(the author)

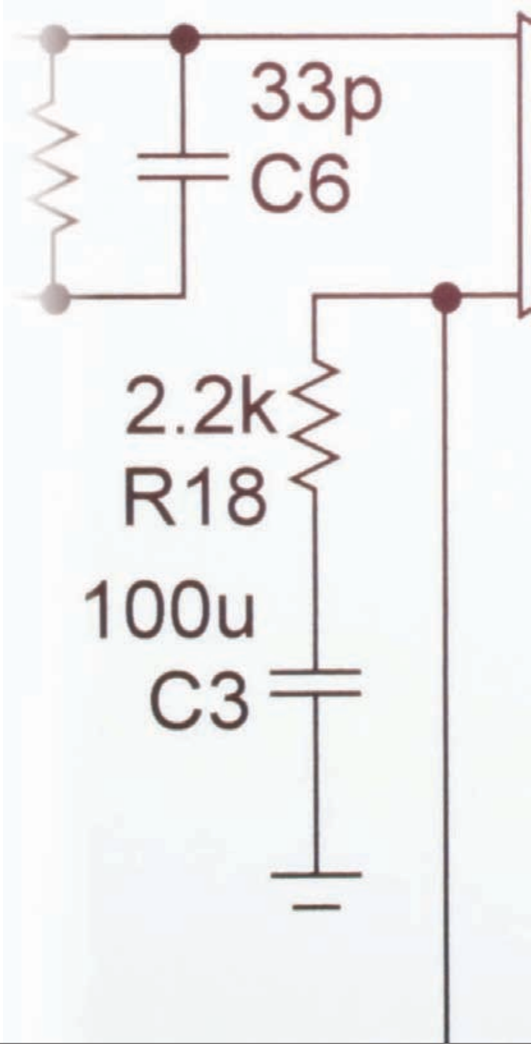
GEOFFREY PECKHAM

is CEO 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. 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. This article is courtesy of Clarion Safety Systems

EMI in Components

Every EMI (electromagnetic interference) problem ultimately starts or ends at an electronic circuit. And since electronic components are the building blocks of circuits, it only makes sense to pay attention to the EMI impact of those individual components.

BY DARYL GERKE, PE AND BILL KIMMEL, PE



Probably the most important thing to remember about electronic components is that nothing is ideal. Components change values with frequency, current, voltage, and even physical size. And those changes may be nonlinear, adding a new level of complexity. Like a pilot, you need to know the limits so you stay within the envelope of safe performance.

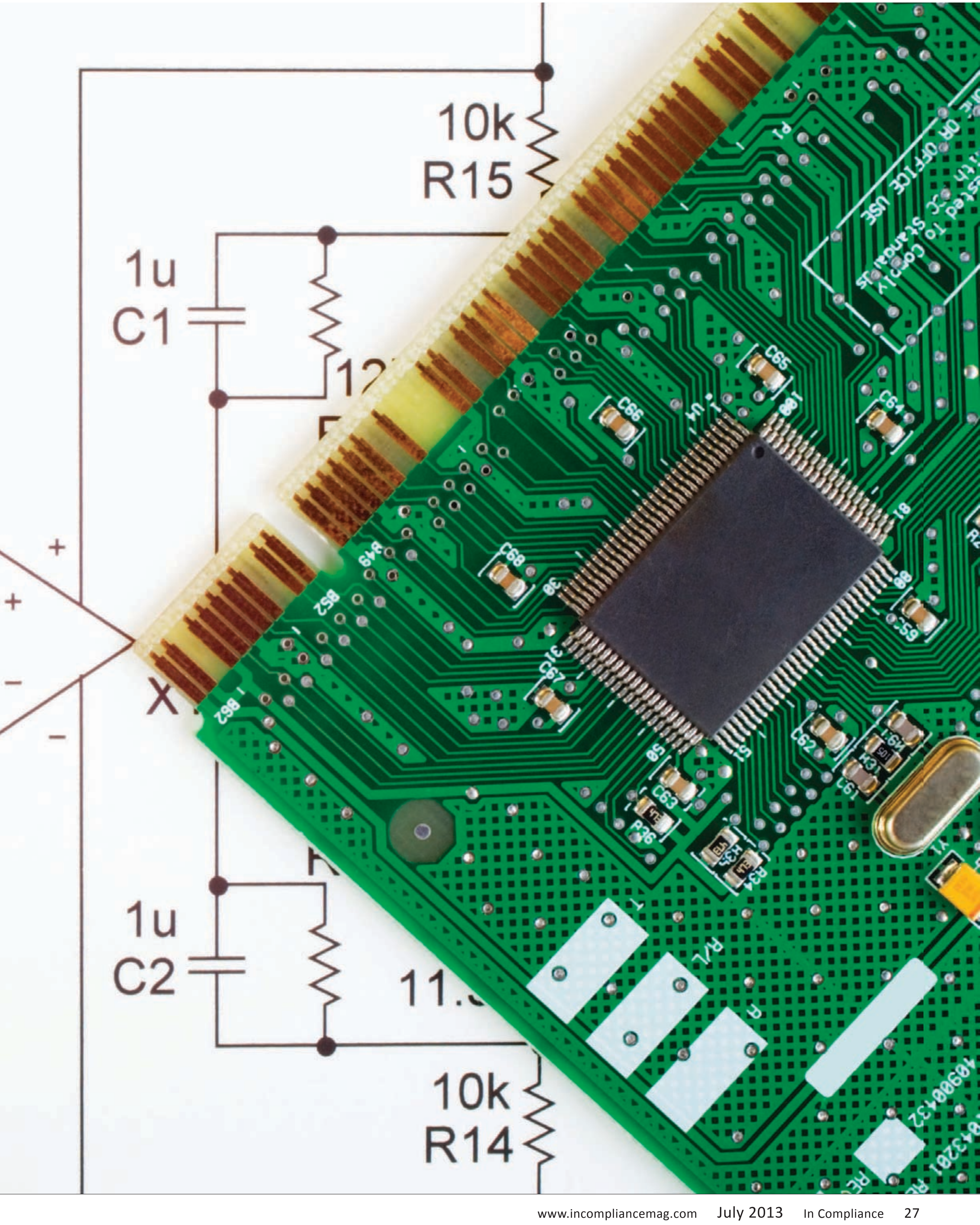
Two key EMI factors are parasitic inductance and capacitance. As frequencies increase, so do their unwanted effects. In fact, parasitic inductance can convert a capacitor to an inductor, and parasitic capacitance can convert an inductor to a capacitor.

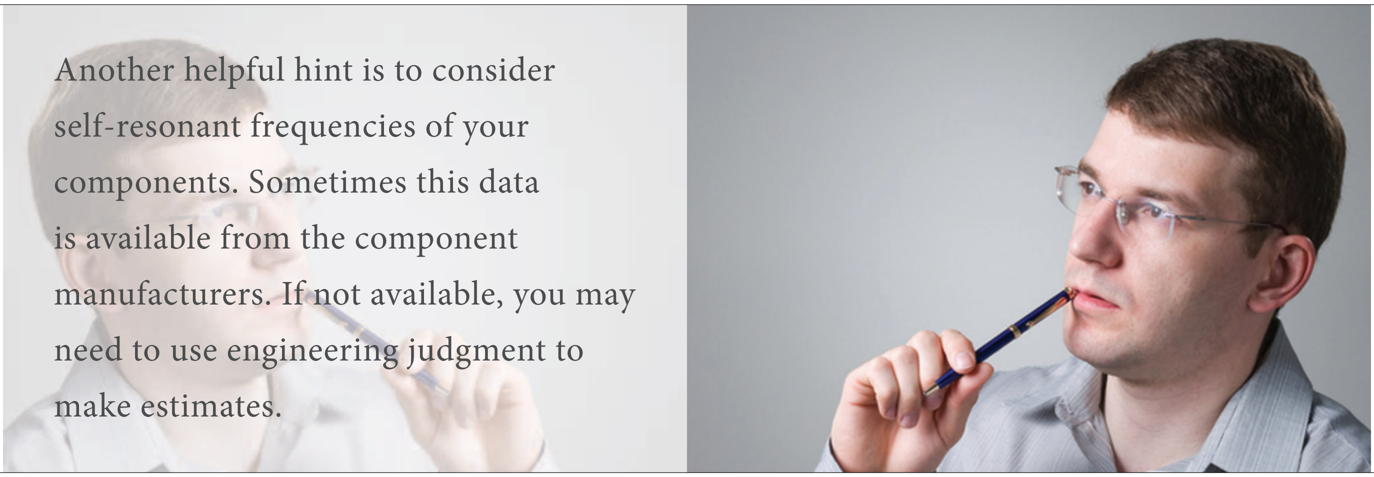
As these factors are not documented on schematics, we are often left looking for the "hidden schematic". In fact, when diagnosing EMI problems, we often add these parasitic components to the schematic to better understand what might be happening. Simple, but effective.

One helpful hint is to examine circuits at three different frequencies - low, medium, and high. This is like using a microscope at different levels of magnification. For example, in an AC power supply we might focus on the following frequencies:

- 50, 60, or 400 Hz (normal operating frequencies)
- 1 MHz (a good starting point for routine power transients)
- 100 MHz (a good starting point for radiated emissions or immunity)

Of course, if you have specific EMI problems, you can refine the focus as follows:


10k
R15
1u
C1
1u
C2
10k
R14
X
C65
C66
C64
C68
C67
C63
C62
R36
R34
B62
B52
B49



Another helpful hint is to consider self-resonant frequencies of your components. Sometimes this data is available from the component manufacturers. If not available, you may need to use engineering judgment to make estimates.

- Substitute a known failure frequency for radiated/susceptibility test failures
- EFT (electrical fast transient), use 60 MHz (based on a nominal 5 nsec rise time)
- ESD (electrostatic discharge), use 300 MHz (based on a nominal 1 nsec rise time)

Another helpful hint is to consider self-resonant frequencies of your components. Sometimes this data is available from the component manufacturers. If not available, you may need to use engineering judgment to make estimates. We'll provide some general examples in the article.

PASSIVE COMPONENTS

Let's begin with the simple passive components -- resistors, capacitors, inductors, and transformers. We'll also consider the lowly circuit trace. Yes, for EMI purposes we must often consider connections as components too.

Figure 1 shows the frequency response of several passive components. At low frequencies, the components behave as expected. Inductors induct, resistors resist, capacitors capacitate, etc. But as frequencies increase, the components may no longer behave like the text book models we all learned in school. This is often due to parasitic inductance and capacitance within in the components, or is associated with how they are installed.

But is it not just frequency that changes behavior. To further complicate things, high currents and voltages can also affect components. In extreme cases, the behavior may even become nonlinear, such as inductor saturation.

Resistors

Although the simplest of components, even resistors can exhibit EMI problems. While old-fashioned carbon

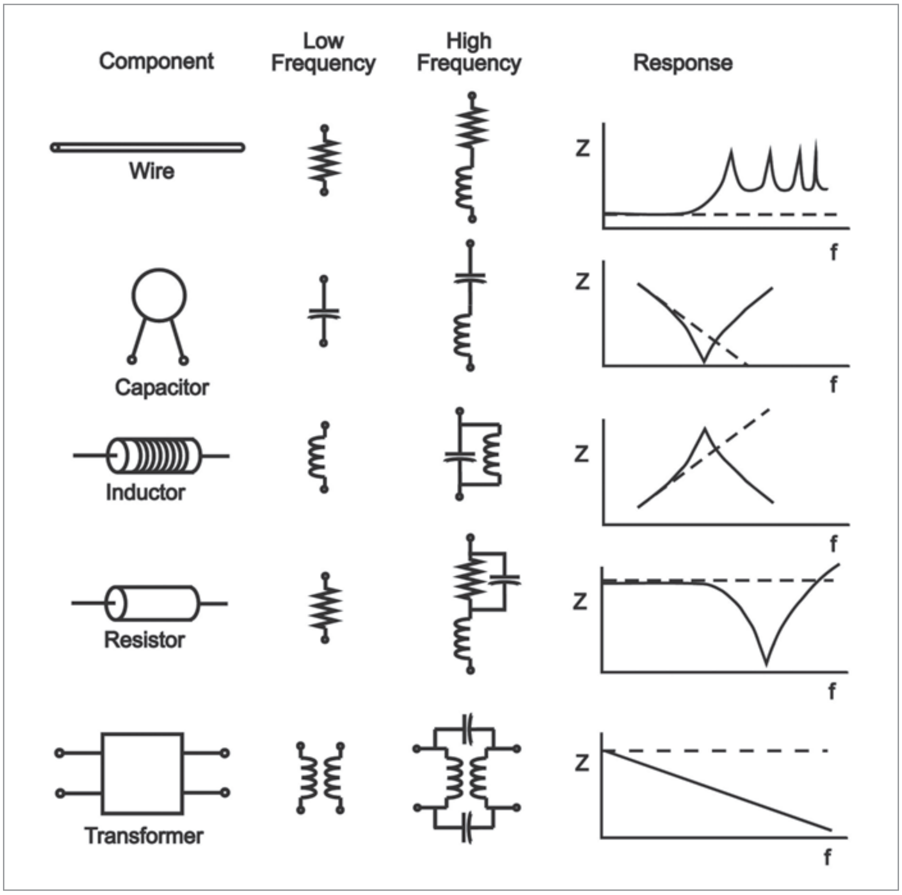


Figure 1: High frequency behavior of real world components

> All capacitors resonate! This can be due to both internal and external series inductance. The capacitor impedance is actually low at resonance, which might be seen as good. But above the resonant frequency, the capacitor actually looks like an inductor, increasing in impedance with frequency.

resistors were pretty well behaved up to several hundred MHz, wire wound or tape wound resistors often show inductive effects at lower frequencies, thereby raising the overall impedance.

At higher frequencies, however, parasitic capacitance (between windings or end-to-end) limits impedance. For example, 3 pF at 100 MHz is about 500 ohms. Put that in parallel with anything over a few kilo-ohms, and you still only have 500 ohms.

High voltage transients, such as ESD, can arc between winding or across the entire component. Though not a well-documented problem, we've seen this occur several times. Furthermore, the ESD currents can cause permanent damage to small resistors due to heating effects.

Capacitors

All capacitors resonate! This can be due to both internal and external series inductance. As a result, the capacitor impedance is actually low at resonance, which might be seen as good. But above the resonant frequency, the capacitor actually looks like an inductor, increasing in impedance with frequency. Not good if you are looking for a high frequency short.

The internal inductance is a function of component size. As a result, most electrolytic capacitors are self-resonant in the 1-10 MHz range. This means they may be fine for power frequency filtering or energy storage, but they are useless for decoupling (shorting) at 10 MHz and higher. See Figure 2 for typical safe frequencies for various types of capacitors.

Type	Maximum Frequency
Aluminum Electrolytic	100 kHz
Tantalum Electrolytic	1 MHz
Paper	5 MHz
Mylar	10 MHz
Polystyrene	500 MHz
Mica	500 MHz
Ceramic	1 GHz

These values assume no lead length, which will additionally degrade the operating frequency due to resonances.

Figure 2: Typical safe frequencies for various types of capacitors

For most higher EMI frequencies, ceramic capacitors are preferred. By themselves, small surface mount ceramic capacitors are typically good up to 1 GHz. However, the inductance in external traces (and even vias) can still limit performance.

For example, assuming 20 nH per inch for a wire or trace, a perfect 1000 pF capacitor will resonate at about 70 MHz with a total lead length of only ¼ inch. At ½ inch, that drops to about 50 MHz. Our constant advice on decoupling capacitors -- keep the leads short!

What value of capacitor do I need for EMI decoupling? Enough, but not too much. Since you are trying to provide a high frequency short, something under an ohm is a good goal. No need to go too much lower, as you become limited by the capacitor's internal resistance.

You can calculate capacitor values for different frequencies, but we use the "rule of one". If the product of MHz x uF is one, then Xc is 0.16 ohms. Thus, at 100 MHz, a 0.01 uF is suitable. You can even back this off to 0.001 uF and still have 1.6 ohms of reactance. At 1 MHz, you need to scale up to 0.1 to 1 uF to get the same results.

Inductors

Inductors resonate too, due to the interaction of the inductance and capacitance between turns. This forms a parasitic parallel resonant circuit. Thus, at resonance the impedance increases, but then decreases above the resonant frequency. In effect, the inductor becomes a capacitor above resonance. Once again, not a desirable trait.

As a rule of thumb, we use 50 MHz as a default resonant frequency for small wire wound single layer inductors, common for EMI applications. You can get a better estimate with the following formula:

$f = 200/\text{sq rt}(L)$

where

f = the self-resonant frequency in MHz, and L = inductance in uH

> Inductors resonate too, due to the interaction of the inductance and capacitance between turns. This forms a parasitic parallel resonant circuit. Thus, at resonance the impedance increases, but then decreases above the resonant frequency. In effect, the inductor becomes a capacitor above resonance.

Using this formula, a 1 uH choke would be self-resonant at about 200 MHz, while a 100 uH choke would be self-resonant at about 20 MHz. These numbers are pretty close to measured values.

At frequencies above about 50 MHz, we prefer ferrites. As permeable materials, they increase the inductance over air core devices. With ferrites you get more inductance with fewer turns, which means better high frequency performance.

Unlike air core inductors, ferrites become quite lossy as the frequencies increase. While this is seen as a negative by RF (radio frequency) designers, we embrace the loss for EMI uses and actually prefer to use them in their lossy range. In effect, they become high frequency dependent resistors.

There are numerous ferrite materials, but the most popular for EMI applications are nickel-zinc ferrites. Common vendor nomenclatures are Fair-Rite type 43/44 or Steward type 28/29. In single-turn configurations (beads or cable ferrites), these materials exhibit a fairly flat resistive loss between 100 MHz and 1 GHz. In fact, they are often specified in terms of ohms @ 100 MHz.

High currents can affect all inductors, wire wound or ferrite. Power frequency inductors can saturate, which means their impedance can drop to about zero. Ferrites exhibit this characteristic too, but are much more forgiving. For example, under heavy currents a 100 ohm ferrite (@100 MHz) doesn't drop to zero, but may drop to 20-25 ohms. As such, we typically derate EMI ferrites in high current applications by a factor of four.

Transformers

The main transformer EMI problem is parasitic capacitance between the windings. This is true for both power and signal transformers. Fortunately, Faraday shields between the windings can break up this capacitance. Unfortunately, these shields do not completely eliminate this unwanted coupling, but they do significantly extend the operating frequency range.

Experience suggests that while isolation is very good at power frequencies, unshielded transformers are very leaky by the time the frequency reaches 1 MHz. Since lightning and many power transients have equivalent frequencies in this range, these transients can easily pass through the transformer.

Adding a Faraday shield between the windings, however, extends this range into the tens of MHz, providing significant protection against most power related transients. This protection does not extend to higher frequency events, such as the EFT or ESD, nor to radiated emissions and susceptibility. In those cases, you will need filters and other high frequency protection.

A secondary EMI problem with transformers is voltage breakdown between the primary and secondary windings. This can be due to arcing at high voltages or insulation breakdown over time at lower voltages. We've seen the latter a few times, with failures after months of operation. Thus, it is very important not to exceed the manufacture's voltage isolation specifications, even if device appears to work.

Circuit Traces

Yes, the lowly traces (and their cousins, interconnecting wiring) are components too. At frequencies above about 10 kHz, the inductive impedance exceeds the resistance, so the traces start acting as small inductors. When the length exceeds about 1/20 wavelength, the traces start to exhibit transmission line and antenna effects. At multiples of ¼ wavelength, resonances can occur, and at many wavelengths, the traces can even act like long antennas with gain!

Are these effects serious? Much of the time these effects can be ignored, but you still need to be aware of these potential problems. Even traces can be part of the "hidden schematic".

Now that we've looked at basic electronic components, let's look at two special EMI components - transient protectors and optical isolators.

Transient Protectors

These components are typically used to protect power and signal lines from voltage spikes. Some are faster than others, so the choice will often depend on the type of transients involved. Here are three of the most common types of transient protectors:

Arc Devices

These devices are quite rugged, but relatively slow. Once the arc ignites, the voltage across the protector drops to a low voltage, resulting in a near short across the protected line. As a result, very little power is dissipated in the device -- rather, the energy is reflected. Gas tubes fall into this category.

A major drawback to these devices is speed. As a result, they are generally not fast enough for the EFT or ESD transient, but are suitable for lightning and other slower power line transients.

MOV (Metal Oxide Varistors)

These devices are moderately rugged, and moderately fast. Since they clip the excess voltages, the excess energy is dissipated in the device. Nevertheless, even relatively small MOVs can dissipate a lot of energy at low cost. As such, they are widely used to protect lower cost consumer electronics.

Two drawbacks to these devices are speed and fatigue. The response speeds are comparable to arc devices, making them generally unsuitable for ESD and EFT, but well suited for power transients. They wear out over time due to cumulative effects and often fail open, leaving you unprotected for future transients.

Silicon Devices

Based on Zener diode technology, these devices are the fastest, and some can protect against sub-nanosecond transients. As such, they are suitable for all transients - power, EFT, and ESD. The also typically fail short and thus blow fuses or circuit breakers.

The drawbacks are size and cost, but we usually recommend these devices for expensive electronic systems where the cost of failure is high.

Since transient protectors are nonlinear devices, they can contribute to RF susceptibility problems, particularly when they are the first component seen on power or signal lines. In a sense, they act like a crystal radio and rectify the RF energy. As such, high frequency filters may need to be installed ahead of the transient protectors to prevent rectification at the device.

Optical Isolators

These devices are widely used in rugged environments (such as industrial controls) to provide isolation and transient protection for I/O circuits. While quite effective, nothing is perfect. Wish we had a dollar for every time somebody said "Don't worry about that interface-- it has optos."

Two EMI problems are leakage across the capacitance and voltage breakdowns. The former can be a problem in the hundreds of MHz, creating sneak paths for radiated emissions and susceptibility. The latter can be a problem with ESD or other high voltage transients that exceed the device breakdown ratings. Thus, additional filtering or transient protection may be needed.

ACTIVE COMPONENTS

Now that we've covered the most common passive components, let's take a quick look at EMI problems in active devices.

Digital ICs (Integrated Circuits)

Key EMI drivers are speed and size. In simple terms, the faster and smaller the devices, the more likely the EMI problems - both emissions and immunity.

For emissions, both edge rates and clock rates are critical. As both increase, so do the higher frequency EMI problems. Both have been the industry trend for many years and will likely continue in the future.

For immunity, only the edge rates matter, as these represent bandwidth. Simply stated, as the edge rates increase, the window of susceptibility increases. This makes digital circuits more vulnerable to spikes and transients such as ESD or EFT events.

Many modern digital ICs are much faster than they need to be, so slowing things down can yield EMI benefits. Don't use faster clocks than necessary, and filter critical nodes such as resets or control lines. And pay attention to power decoupling -- often the back door for emissions due to the high speed current pulses due to changing loads.

Analog ICs

Once again, key drivers are speed and size. Also, many analog circuits operate with small signal levels, and resulting smaller noise margins than digital signals. For example, a sensor input may be upset by a millivolt or less, while digital signals can usually tolerate hundreds of millivolts before malfunctions occur.

For emissions, most analog ICs are pretty well behaved since they operate at low frequencies. In recent years, however, we've seen an increase in parasitic oscillations, often occurring in the VHF/UHF frequencies. These free running oscillations are often large enough to exceed radiated emissions regulatory limits. Good high frequency decoupling can prevent this problem. For immunity, analog circuits are particularly susceptible to high levels of RF energy. The failure mode is rectification, resulting in any modulation now appearing in the normal frequency range of the analog devices. Once the rectification occurs, there is no way to undo it. One must prevent it from occurring in the first place. Good high frequency decoupling and filtering of inputs and outputs can prevent this problem.

Incidentally we usually consider RF and power ICs (such a voltage regulators) special cases of analog ICs, subject to the same EMI issues. We regularly recommend 1000 pF capacitors at regulator inputs and outputs. We also pay attention to very low-level inputs, such as radio receivers. GPS receivers, with their extremely low-level inputs are particularly vulnerable.

CONCLUSIONS

When dealing with EMI issues in components, expect the unexpected. Look for the hidden schematic, and be aware of your performance limitations (frequency, voltage, current).

Finally, please remember this article is intended as an introductory overview to EMI problems in components. Entire books have been written on many of these components. Although we've been brief, we hope we have increased your awareness, stimulated your thinking, and perhaps even demystified some EMI problems you have may encountered.

(the authors)

DARYL GERKE, PE, AND BILL KIMMEL, PE are partners in Kimmel Gerke Associates, Ltd., an engineering consulting and training firm that specialized in EMI/EMC design and troubleshooting issues. Both are degreed engineers (BSEE), iNARTE Certified EMC Engineers, and registered Professional Engineers (PE).

Daryl and Bill have prevented or solved hundreds of EMI problems in a wide range of industries - computers, military, medical, industrial controls, automotive, avionics, railroad, telecomm, facilities, and more. They have also trained over 10,000 engineers through their public and in-house training classes. They just celebrated 25 years in full-time practice as EMI/EMC consulting engineers.
For more EMI information, visit their web site at www.emiguru.com.


Esc
F1
F2
F3
F4
Tab
CapsLk
Shift
Fn
Ctrl
Alt
F5
F6
F7
F8
F9
F10
PrtSc

Experiments In EMC: How Common Mode Currents Are Created

BY GLEN DASH

"I've all ready read the books on EMC and visited a lot of home pages... But all these references did not mention anything about the physical phenomenon that causes common mode currents... Are common mode emissions inherent in any physical system? Can I model them?" *Overheard on the 'Net*

It's by no means a trivial question. And, in spite of decades of hand waving by authors and consultants, the principal mechanism by which common mode currents are created in digital devices was not well understood until the decade of the 90s. In this article, we'll explore the physics behind the creation of common mode currents, and perform some experiments to verify our understanding.

We begin with the simplest of circuits, a signal source driving 10 cm of 300 ohm twin lead shown in Figure 1. In one way or another, all wire line communication has as its goal transmitting signals faithfully from a source to a load. Here the load is matched to the line, and good fidelity can be expected. (Note that since the transmission line is matched to the load, there will be no reflection at the load end. Therefore, it is not necessary that the source be matched to the line.)

The radiation that could be expected from the circuit in Figure 1 is relatively small. We can simulate the circuit on our Method of Moments simulator [1]. It predicts the radiation at 3 meters for the circuit in Figure 1 to be approximately 1200 uV/m at 3m (in free space).

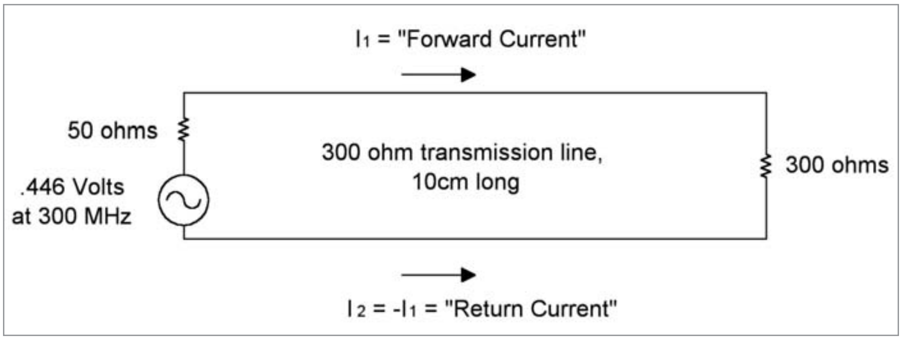


Figure 1: Our analysis starts with a simple circuit. A voltage source drives a short length of 300 ohm twin lead, terminated in a 300 ohm load.

We will make the circuit a bit more challenging by adding two wires to the return path as shown in Figure 2. I_1, the "forward" current, will now be split at Node 2, some of it returning via the twin lead to the source, and some of it moving down the wire now attached at that node. Current moving down the added wire, which acts as an antenna, will partially be reflected back when it reaches the end of the wire, and partially radiated into space.

Can I_3 be readily predicted? It can, using a few simplifying assumptions. Suppose the wire "antennas" of Figure 2 are resonant at the drive frequency, 300 MHz. These two wires will have the characteristic impedance of a dipole antenna at resonance: 73 ohms. Each "arm" of the antenna can be modeled as a resistance to earth ground of one half of that figure, or 36.5 ohms. The twin lead itself, being very much shorter than the wavelength, can be modeled electrically by the use of two inductors, L_1 and L_2 as shown in Figure 3. Each is approximately one half the total inductance of the loop shown in Figure 1. The formula for the inductance of a short strip of twin lead is well known and the inductance is approximately 140 nH. If we assume that half of this inductance can be assigned to L_2, then this "partial inductance" L_2 is approximately 70 nH. Knowing that, we can readily calculate I_3 from the circuit model of Figure 3. We predict that $I_3 = I_4 = 1.2$ mA.

These currents are "common mode" currents. Here's how common mode and differential currents are defined:

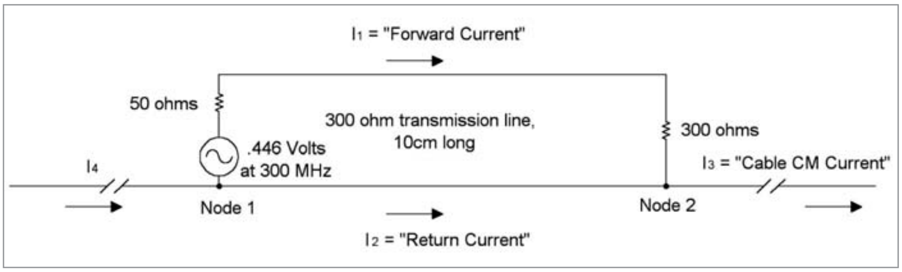


Figure 2: Adding wires to the return in Figure 1 create a more complicated circuit. Radiation increases dramatically because of common mode currents driving the wires attached.

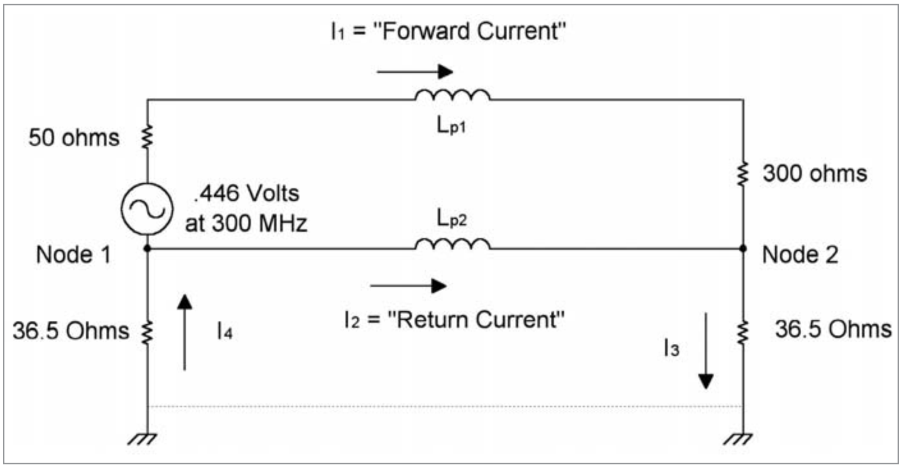


Figure 3: The radiation from the circuit in Figure 2 can be calculated using the circuit model of Figure 3. To calculate radiation accurately we will need to know the partial inductances of the forward and return conductors. The added wires of Figure 2 are assumed to be at resonance.

$I_1 = I_{diff} + I_{cm}$

$I_2 = -I_{diff} + I_{cm}$

Where:

I_{diff} = Differential current
I_{cm} = Common mode current

Rearranging terms, we find that:

$$I_{diff} = \frac{I_1 - I_2}{2}$$

$$I_{cm} = \frac{I_1 + I_2}{2}$$

A loop's differential and common mode currents are defined as follows. Since, by definition $I_{1\,diff} = -I_{2\,diff}$ and $I_{1\,cm} = I_{2\,cm}$:

$I_3 = I_1 + I_2$

$I_3\ (I_{diff} + I_{cm}) + (-I_{diff} + I_{cm})$

$I_3 = 2\ (I_{cm})$

Our Method of Moments program can be used to predict the radiation from the circuit of Figure 2. It is 27,500 uV/m at 3 m in free space, a gain of 27 dB over the circuit in Figure 1. Adding a couple of wires to the return of Figure 1 increases radiation dramatically, and that radiation is due to common mode currents.

Digital devices, of course, are far more complex than our simplified model. For one, the various I/O cables (which act as antennas) vary in length and geometry. Any variation in length or geometry quite clearly will affect emissions. Even devices with a good earth ground (such as a solid metal plate beneath the circuit whose smallest dimension is on the order of a wavelength at the lowest frequency of interest) will not necessarily result in lowered emissions. For example, in Figure 4b we show schematically the assembly of Figure 5, one in which one end of our return wire is bolted solidly to our earth ground, and the other end

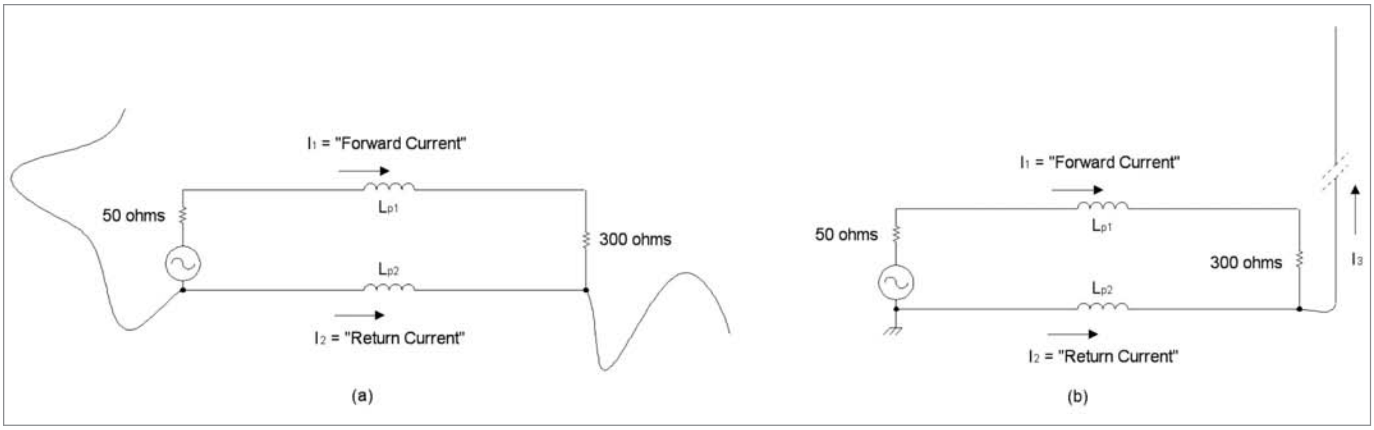


Figure 4: Any I/O cables attached to a circuit are directly or incrementally connected to return wires (or planes). How much radiation results is strongly affected by the length and layout of the attached wires. Even a circuit whose source is bonded to a perfect ground plane will exhibit some radiation.

is connected to a wire which is run up a short mast creating a vertical antenna.

We built and tested this assembly. Our assembly consisted of a 50-ohm source driving 300 ohms of twin lead that was terminated in its characteristic impedance. The circuit was suspended .5 inch (1.27 cm) above a large ground plane, and one end of the return wire was bolted to that ground plane. Another wire was connected to the far end of the return wire and run up a short pole, creating the vertical antenna. At resonance, a vertical has one half the impedance of a true dipole, 36.5 ohms. Vertically suspended above a large ground plane, it also produces an image antenna, the net result being a dipole with vertical polarization.

Measurements made with a Tektronix CT1 current probe showed that 1.2 mA of current was flowing into base the vertical wire. Simulations with our Method of Moments software yielded a similar result, 1.34 mA flowing into the base of the vertical wire with predicted field strength of 27,500 uV/m.

Therefore, we can show that even simple circuits, well-matched in terms of their load and suspended a short distance over a wide ground plane can still produce radiation when wires are connected to their return structure. Whether a two-sided or multi-layered

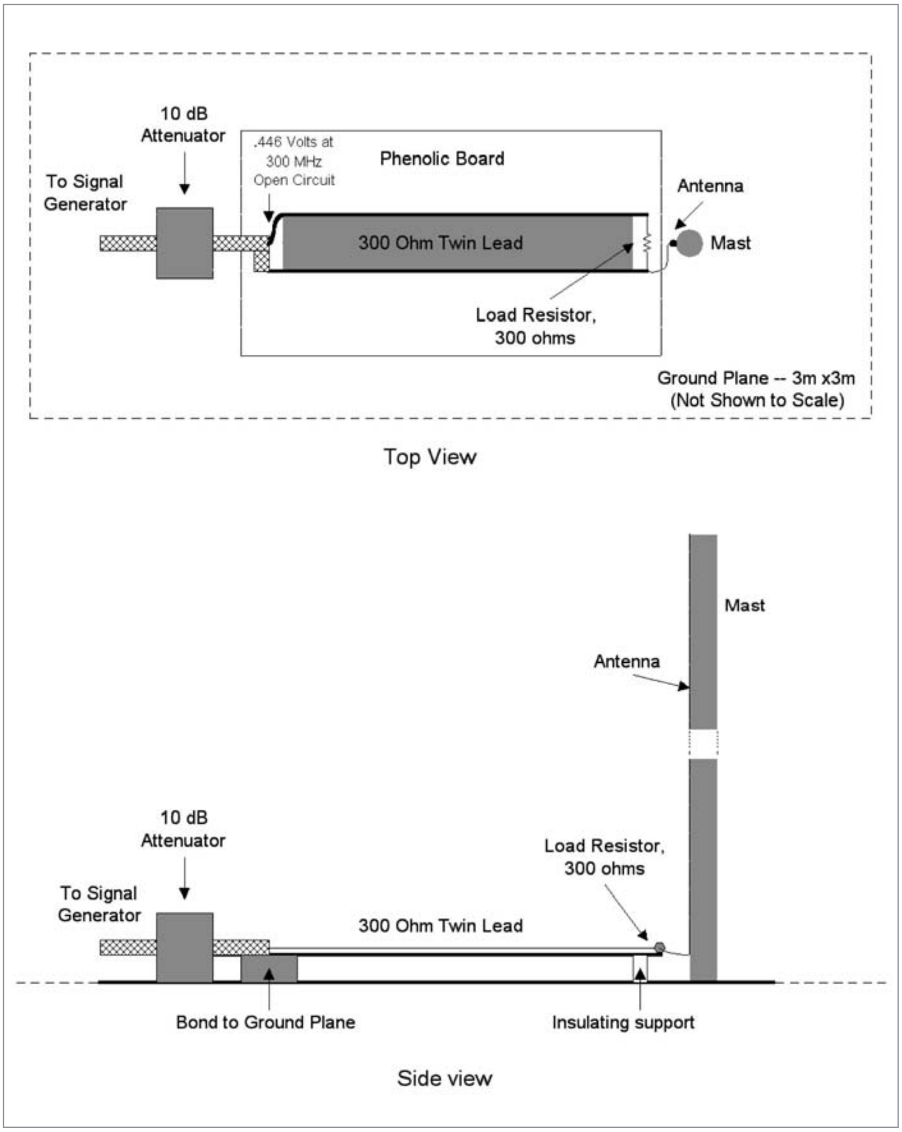


Figure 5: We built this assembly to measure radiation from the circuit shown in Figure 4b.

How can such radiation be avoided? One method is shown in Figure 6. Here a 360 degree shield has been thrown around our circuit. Note that we have not connected that shield directly to our ground plane, or to any portion of the circuit, except to its return wire.

board is used, there will always be some partial inductance in the return, and therefore some voltage driving wires attached, even those wires attached to what is sometimes (incorrectly) called "signal ground."

How can such radiation be avoided? One method is shown in Figure 6. Here a 360 degree shield has been thrown around our circuit. Note that we have not connected that shield directly to our ground plane, or to any portion of the circuit, except to its return wire.

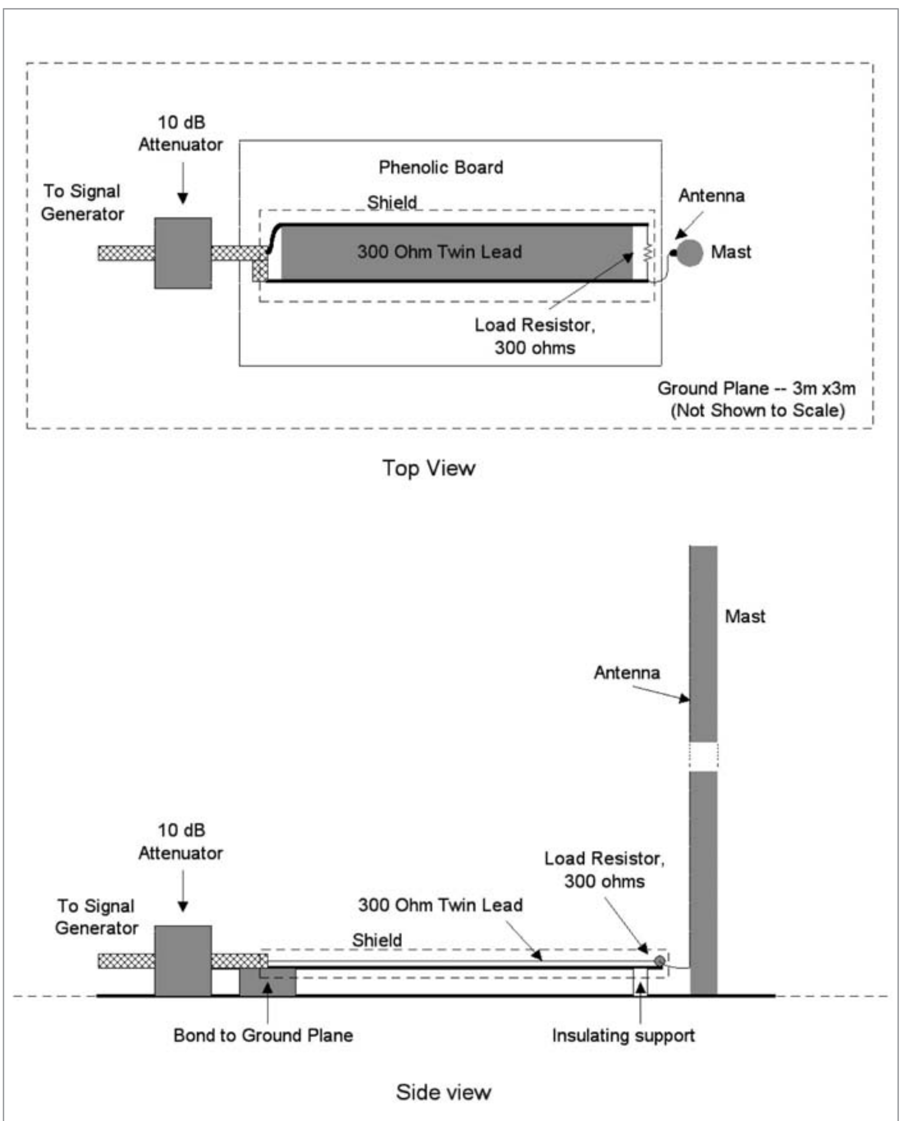


Figure 6: One sure fire way of reducing emissions dramatically is to wrap our circuit in a shield. This forces return currents to flow on the inside of the shield.

The measured current in the vertical wire falls dramatically -- to 80 uA. The conclusion? Wrapping a complete shield around a circuit will work just about every time.

Why does such a shield work? It works because the return currents travel on the *inside* of the shield. They don't travel on the outside of the shield, and therefore, there is no voltage drop between the source and the load. Said another way, a complete shield has a partial return inductance of near zero.

That, in fact, is also why a shielded cable works. The shield formed by the braid or metalized foil traps nearly all the current inside the shield. A perfectly shielded cable has an effective return inductance of zero. However, nothing being perfect, some current does leak through to the surface of a shielded cable. That current produces a small amount of "lost flux," which, in turn results in a small amount of radiated energy.

How do we use what we have learned in practice? Designers have used two methods to reduce emissions from circuits like that shown in Figure 2 through 4. First, they have abandoned the return wire for the return plane of a multi-layer board. The effective inductance of a plane is far lower than a wire, but is by no means zero. Even in multi-layer boards, significant radiation can result. Wrap a tight shield around the multi-layer board, however, and the radiation will drop dramatically.

Sources of RF currents do not refer just to clock drivers and the like. Each time an IC switches, it creates a pulse across its supply. These pulses can be a nanosecond or less in time and tens

In most applications, some other technique has to be used to further lower emissions. This may consist of the use of ferrite cores over I/O cable or the use of a 360 degree shield surrounding the whole circuit. A complete shield will trap RF currents on the inside, leaving no voltage to cause radiation across its surface.

of amps in amplitude for devices such as a microprocessor. These pulses are referred to as I_{DD} currents or I_{DD} noise. How does I_{DD} noise become common mode radiation? Take a look at Figure 7. In essence it is no different than Figures 1 through 4 except that we have exchanged our 300 ohm twin lead for a transmission line made of plates. Though of lower characteristic impedance, plates form a transmission line nonetheless. Exactly the same effects illustrated above will cause such a circuit to radiate. The extent of the radiation can be calculated if the return plane's partial inductance is known. From Reference 2, it is:

$$L_P = \frac{\mu_0 l}{2} \frac{d}{w}$$

Where:

L_P = Partial inductance of the return plane in Henries

$\mu_0 = 4 \pi \times 10^{-7}$

l = Length of the return plane in meters

d = Distance between the planes in meters

w = Width of the planes in meters

That is why the use of a multi-layer board, while in itself a powerful technique for mitigating emissions, is not a perfect solution. In most applications, some other technique has to be used to further lower emissions. This may consist of the use of ferrite cores over I/O cable (which effectively places an impedance in series with the radiation resistance) or the use of a 360 degree shield surrounding the whole circuit to which shielded I/O cables can be attached or unshielded wires bypassed. A complete shield will trap RF currents on the inside, leaving no voltage to cause radiation across its surface.

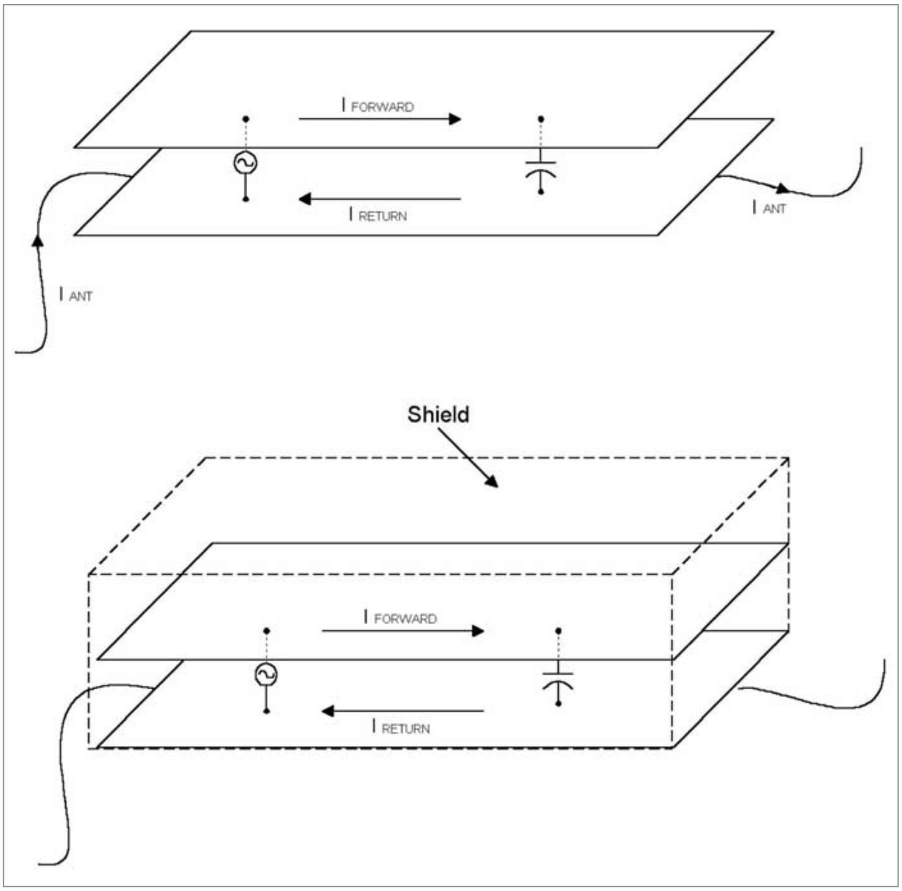


Figure 7: I_{DD} currents drive supply planes as surely as our source in Figure 1 drives its transmission line. Even though the planes are close together, wide and uniform, they still exhibit an effective inductance that causes radiation. The use of planes alone may reduce emissions, but is not as effective a technique as one that would trap returning currents, such as the shield shown at the bottom of the figure.

REFERENCES

1. EZNEC is available from Roy Lewallen, W7EL@teleport.com.
2. F. Leferink, "Inductance Calculations; Methods and Equations" 1995 IEEE Symposium on Electromagnetic Compatibility, page 16.

(the author)

GLEN DASH

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

Why didn't I see this coming?

BY PATRICK G. ANDRÉ

The equipment should have passed the emissions scan. It should not be susceptible to this noise. The filter analysis said this was not a problem. The case should be an excellent shield. Why doesn't this pass?

There are two statements I have heard about electromagnetic interference which are both related and true: EMC is the science and engineering of things that are typically not on the schematic[1], and EMI is often caused by issues of geometry[2]. The first statement speaks to the issues of parasitics, or cross coupling of energy due to magnetic induction or capacitance. The second says that the parasitics can be controlled or reduced if the proper routings and separations are maintained, and that once a degree of understanding about these coupling mechanisms is understood the control of them can be obtained.

Rules of thumb are dangerous in this field. Yes, there are some concepts that often work. But there can be so many variables that create these problems, that using only "rules of thumb" can lead you down the wrong path or not explain the reason the issue exists.

However, much of what will be stated is based on these general rules. They may often work. They may not. To coin a phrase we, as consultants, often use, "It depends". But hopefully they can inform, instruct and help you to avoid the issues stated earlier. So here, rules of thumb will be avoided but not totally ignored.

GENERAL CONCEPTS

It is important to remember how these energies move around and cause problems. First consider the concept of common mode energy. Common mode energy, or CM, is energy which moves on two or more wires in the same direction and in phase. It is quite different from differential mode energy, which travels in opposite directions on adjacent wires. An input power line and power return line are a differential mode pair – the currents on one travelling in the opposite direction from the other.

Common mode energy may also exist on that same pair of power line wires. The source may be from an inductor or transformer located near the lines inside the unit (inductive coupling), from the circuit board power plane voltage which may be driven with respect to the chassis (a form of conducted coupling), or from a high voltage source, maybe a heat sink, located near these lines (capacitive coupling). It can also be coupled onto these lines outside the equipment from various sources, either radiated onto the lines (radiated coupling), or capacitively or inductively coupled onto the lines, as performed during conducted immunity/susceptibility testing.

1 Stated by Chris Kendall among others

2 Stated by Dr. Tom Van Doren among others

In each of these cases, the energy on these lines is found to be common mode – energy induced on both or all lines at the same time and in phase.

When I was in college, my professor wrote on the board the following formula:

$$L = L_1 + L_2 \pm 2M_{12}$$

where L is the total inductance of a wire loop from source to load and back, L_1 is the inductance in the first wire from the source to the load, L_2 is the inductance in the second wire from the load back to the source, and M_{12} is the mutual inductance between the wires, which is doubled because each wire has the same effect on the adjacent wire. But the equation is $\pm 2M_{12}$. Yes, plus or minus. The question is, when is the formula $+ M_{12}$, and when is it $– M_{12}$?

Without using names like "Maxwell", which tends to just detune the reader from any further input, it must be noted that when you move an electron, it creates a magnetic field. This is the basis for inductance. In a wire, we move a bunch of electrons, creating a bunch of magnetic field. If a second wire is nearby, this bunch of magnetic field wants to generate a current in the wire in the opposite direction. This is mutual inductance "M". This is how transformers work. But assume that the other wire already has current in it in the opposite direction. Then there is a beneficial arrangement and the induced magnetic fields in each wire end up assisting the adjacent wire, which is a "reduced impedance". Then the formula uses $– M_{12}$.

But what about common mode noise? Well, common mode energy is routed in both wires together and in the same direction in phase. This means that the induced currents in each wire do not benefit but oppose each other, and this ends up increasing the overall inductance. Then the formula uses $+ M_{12}$.

This whole concept is part of the reason why twisted wires work so well. Twisted wires have a mutual affinity to differential energy over common mode energy. The same concept works with traces over ground planes. As long as a clock or data trace is routed over a single plane and does not pass over any cut in that plane, and the return current is referenced to that same plane, then the return path will couple directly under that trace. This reduces the trace impedance, and also the loop area between the signal and return, resulting in much lower radiated emissions and higher immunity to external energy interfering with the signals. This works for frequencies above 100 kHz.

Now all this talk about wire inductance brings up another concept: wires do not make good RF grounds. This is true if you are using a wire to try to conduct noise to some type of grounded structure or using a pig tail to terminate a shield. Shielded cables terminated into a pigtail tend to have several issues. They are inductive and thus have high impedance. They carry a current that generates a magnetic field which can couple energy into the adjacent lines they are trying to shield. Suffice it to say that it is best to use a symmetric termination of the shield, if not a full 360 degree termination at the connector.

As for using a wire to ground out a noise source: first remember that currents flow in complete circuits. If there is a current flowing in that wire, it has to be returning to the source by some other path. The farther away that path is, the larger the loop, and therefore the higher the inductance of that path. There are no RF sinks or holes that you can pour the noise into. But there may be a good deal of induced currents on the chassis from inductive and capacitive circuits, and those currents must find a path back to the source. Several low impedance paths are always best and, again, symmetry is desirable.

Finally, what is low impedance? Lower than you have now, otherwise you likely would not be reading this article to begin with. The "rule of thumb" used for a long time was that 2.5 mΩ was the required bonding resistance for chassis, connectors, and other metal to metal contacts. Your mileage may vary, but this might be a good goal to strive for. And in case you were wondering, 4½ inches of 18 gauge wire is 2.5 mΩ, not including the minimum 0.15 µH of inductance (depending on return path inductance, loop area and so forth, and 0.15 µH is about 1 Ω at 1 MHz, so that won't work very well at all…).

EMISSIONS ISSUES

Please note that radiated emissions energy is likely due to common mode energy on the wires. Why? First, common mode energy radiates much more effectively than differential mode energy. Many formulas state the level is effectively about 10^6 or 120 dB more. Also, since the typical wavelengths for most radiated emissions found are rather long, the types of antennas needed to transmit these must also be significant in size. Remember that at 300 MHz, a wavelength is about 1 meter. At 100 MHz it is 3 meters. The ratio between frequency and wavelength is linear in this regard. Also, for something to radiate well at lower frequencies, it may need to be physically long or large. This does not mean you can't have a small object radiate at low frequency, only that if you place a long wire on the small object which is tied to the noise source, it will likely radiate much better.

So if the radiated emissions are below about 200 MHz, first check the cables. Are the cables filtered? Are there shields used? And if they are, are the shields well terminated at *BOTH* ends? The first argument against grounding a cable at both ends is that it causes ground loops. Unless you are a guitar player who gets 60 Hz hum in the sound system, why are you worried about ground loops? It is rare that the shield grounded at both ends causes more problems than it cures.

Also, if performing commercial testing, it may be found that emissions below 80 MHz or so are vertically polarized and the antenna is at the lowest point on the mast. One issue to look for is the amount of capacitance the equipment has to the ground plane. Is there a power cord draped across the ground plane? Are there cables which are hanging down to the ground plane? Is this floor standing equipment where you typically have the unit isolated from a ground plane, but now it is resting directly on the conductive surface? These issues can create a capacitive coupling network which can couple back to the antenna. Remember that broadband antenna, vertically polarized and at the bottom of the mast, have much higher capacitance to the ground plane than, say, a dipole antenna (Figure 1).

In the top drawing, a broadband antenna is used to measure radiated emissions; in the bottom, a tuned dipole. Note that the tuned dipole has less capacitance to the ground plane as compared to the broadband antenna. Also, due to the length, the minimum height for the dipole forces the center to be higher off the ground plane and thus less on-line with the EUT.

So how did that noise get on the cables? First, every line which is routed in and out of the equipment must somehow be filtered or very well shielded. Every line that penetrates the enclosure of the equipment must be treated as a noise carrying device. It does not matter what the wire does – whether it is an input or an output; whether it carries hundreds of amperes of current or a microampere at a microvolt. The presence of a conductor routed from near noise generating circuits to a location away from those generators can carry radio frequency energy down the cable, where it radiates back to the source. Unfortunately the test laboratory puts an antenna in the return path, and then reports the results in unkind terms.

Second, when a filter is used, the location of the filter is critical. In order to have the best results, filters must be

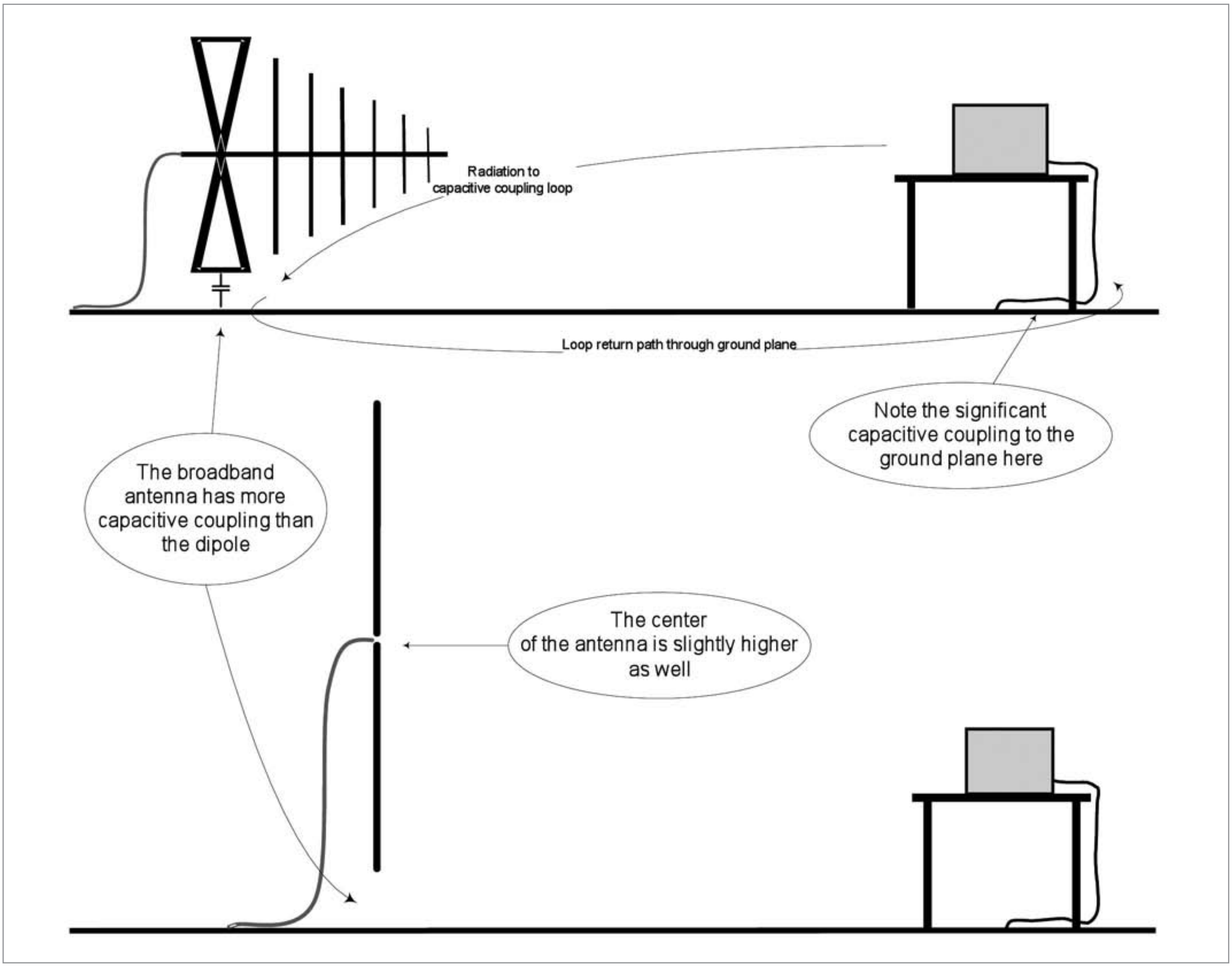


Figure 1: Radiated emissions vertically polarized antennas

So what types of components make a good filter? Capacitors should be the first line of defense. They are inexpensive and can be relatively small and light weight. But there are many reasons that capacitors do not work.

placed near the point of penetration in or out of the equipment. When a filter is placed inboard and away from the connector, radio frequency energy can cross couple and contaminate the filtered lines. In Figure 2 and Figure 3, the effects of filter placement are seen. In these two graphs, the filter component and the essential layout was the same. Only the location of the filter was moved, from about 6 inches from the connector to the edge of the board by the connector.

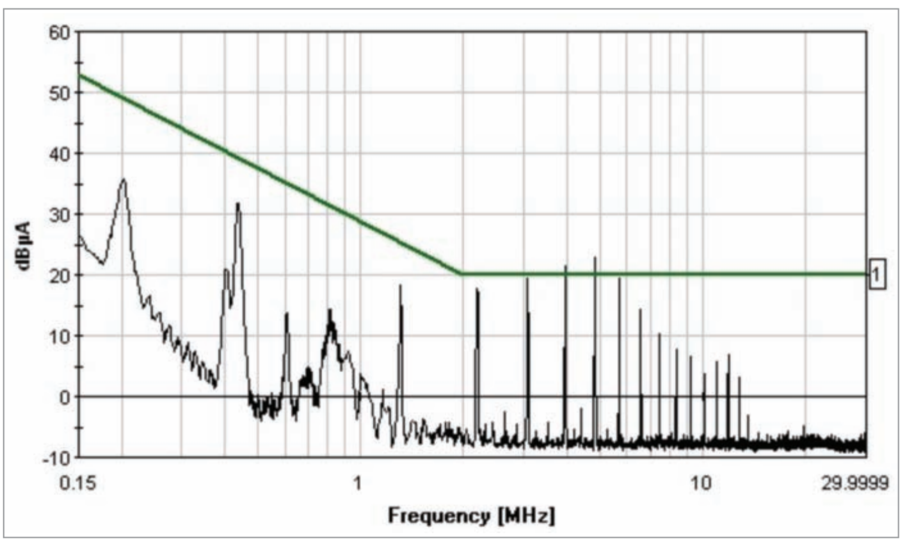


Figure 2: Filter location inboard of equipment

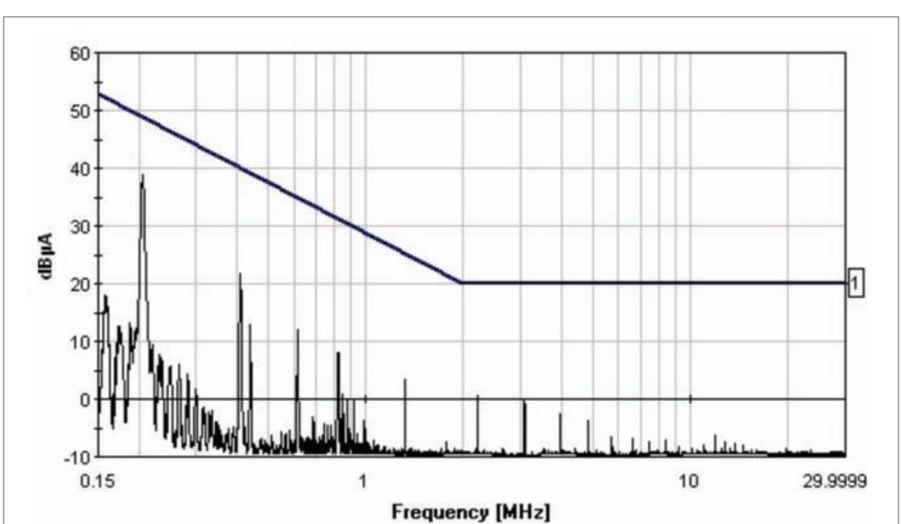


Figure 3: Filter location near the equipment connector

COMPONENTS

So what types of components make a good filter? Capacitors should be the first line of defense. They are inexpensive and can be relatively small and light weight. But there are many reasons that capacitors do not work. The most obvious is the value or size of the capacitor. For lines which do not carry clock or data signals, the capacitor can be large … or as large as practical. However, on data and clock lines, care must be taken not to filter the signal. Thus the value must be carefully chosen to maintain the data frequency and five to ten harmonics of the signal.

Figure 4: "No Ground" symbol

Another issue with capacitors is the type of capacitor used. Electrolytic capacitors provide high capacitance per volume, albeit polarized and therefore not useful for AC. However, they tend to have high equivalent series resistance (ESR) and may have high equivalent series inductance (ESL) as well. This limits the useful frequency range to 100 kHz or so. For this reason, ceramic capacitors are often used for high frequency applications. And yet…

Issues of lead inductance, trace inductance and routing, inductive cross coupling, and other issues are common with the use of capacitors. Designs can be careful to assure the circuit has very short traces to the decoupling capacitor, and then disregard how the return side of the capacitor gets the energy back to the source. The entire loop from the source to the capacitor and back to the source must be analyzed and verified. Too often circuit designs rely on a ground symbol to dump the noise into, and then ignore how that symbol connects to the same symbol on the noise source. To make a point that the layout engineer should know where the return traces should go, and avoid an Auto Routing feature, the consultant would use the symbol shown in Figure 4.

It should be pointed out that the purpose of a capacitor is to bypass RF currents and return them to the source of the noise. However, the process of doing so can in itself create issues. Consider Figure 5, which shows how a capacitor passes these currents back to the return path. However, if the leads on the capacitor are long, or if the traces to the capacitor are long, this can create a source of inductive coupling. And if that coupling is in the loop that is trying to be filtered, the whole process ends up bypassing the filter. Admittedly, this is a lossy system, and there is benefit to the capacitor. But consider how much better the results might be in a setup using current routings seen in the lower drawing.

Another issue often missed is the presence of a DC bias on a capacitor. When a voltage is placed on a capacitor, the total available capacitance is reduced. In Figure 6, the presence of a DC bias voltage on a capacitor rated for 16 VDC is shown. The higher the voltage placed on the capacitor, the less capacitance will be found. This is more true for the very small format capacitors, e.g. 0603, 0402, and so forth. Looking at Figure 6, note the effect on the 0402 format as compared to the larger 0805 format. If an 8 VDC bias is placed on these capacitors, the 0805 will still have 93% of the rated capacitance, whereas the 0402 is down to 22% - a 12 dB change in value (based on a 20Log system).

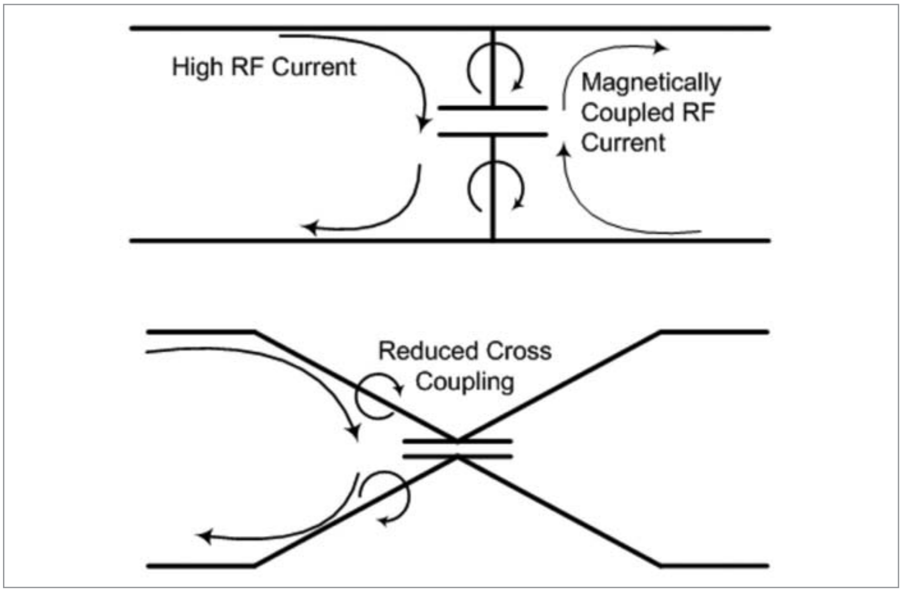


Figure 5: Capacitor cross coupling

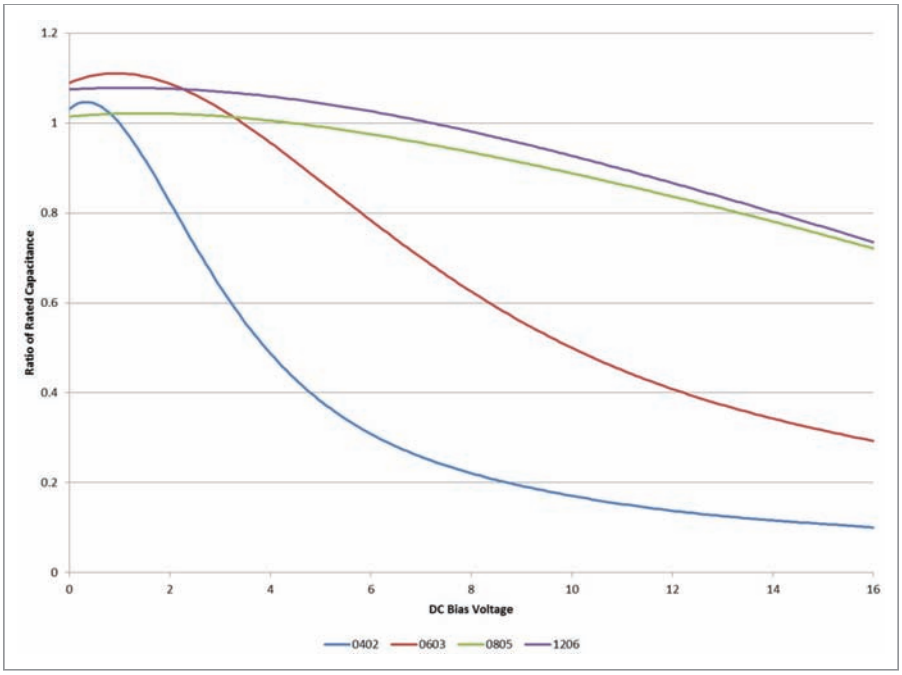


Figure 6: How DC bias voltage effects capacitance

Ferrites are very commonly used in EMI control. However, how they are used and where to use them is often a mystery.

It should be understood that ferrite core inductors are somewhat different than standard inductors. A common inductor is a reactive device that creates an impedance mainly though the creation of magnetic fields, up to a frequency where the capacitance of the windings become dominant and start to reduce its effectiveness. The core material for these inductors tends to include nickel, iron, and possibly molybdenum or other materials. They have permeability which is relatively low, typically below 100. However they are designed to work with significant current and not suffer from "saturation", an effect where the core cannot accept any more magnetic flux.

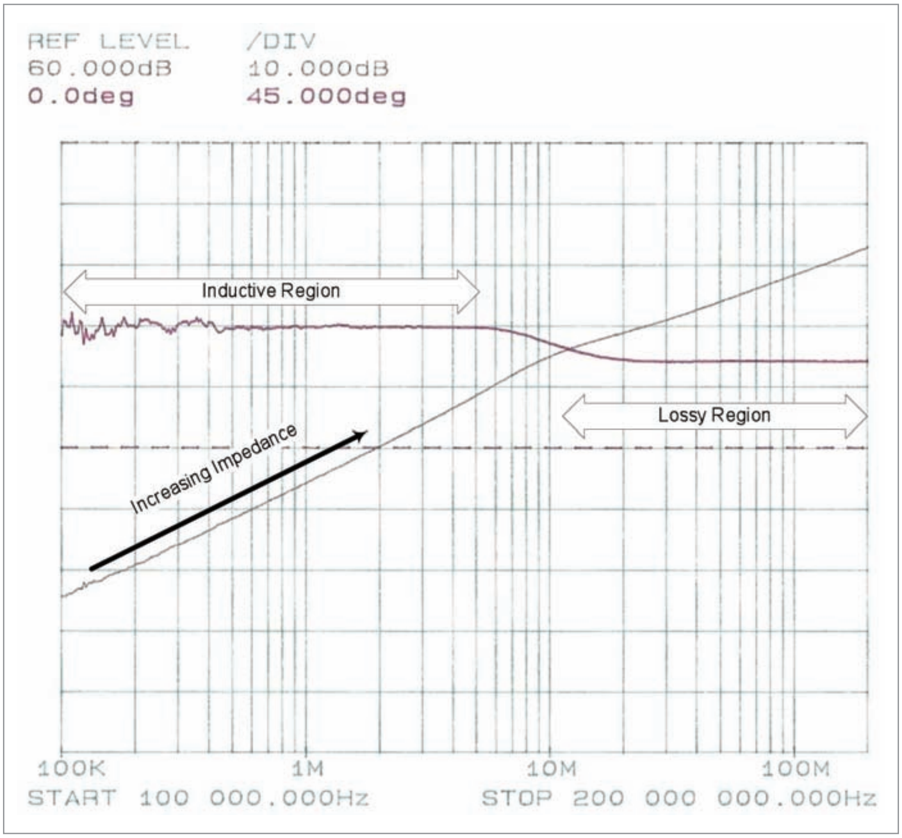


Figure 7: High frequency ferrite characteristics

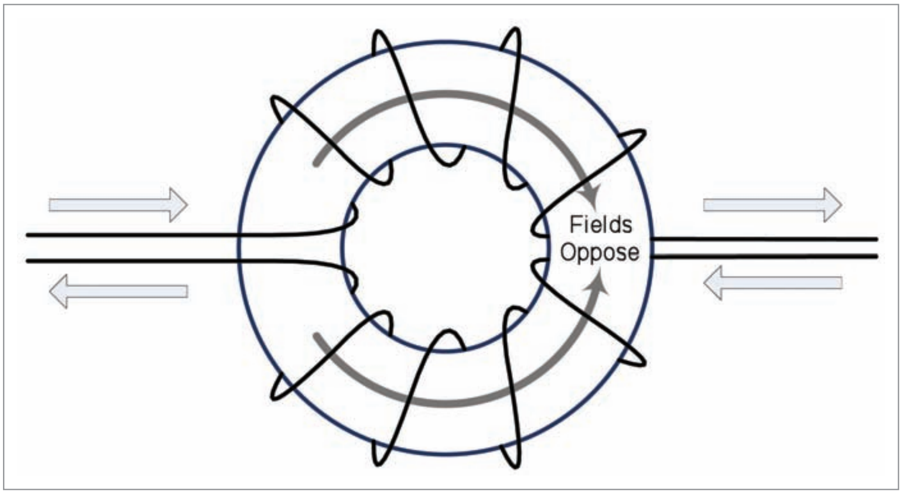


Figure 8: Differential mode fields in a common mode core

Ferrites work in a similar way at low frequency. However, as frequency increases, a ferrite becomes lossy and begins to have a resistive aspect. In Figure 7, a high frequency ferrite is analyzed for its impedance over frequency. The sloping line from lower left to upper right is the impedance with a single turn (no wraps) though a bead. The horizontal line shown in two steps is the phase of the signal. Starting at the right, the signal is at +90 degrees, indicating the inductance of the ferrite (ignore the noise, which is due to the measurement limits of the impedance analyzer). Note that at 10 MHz the phase makes a step down to 60 degrees, indicating a resistive nature is being introduced.

This particular "high frequency" ferrite has a nickel zinc, or NiZn, formulation with a ferrous oxide. These ferrites are commonly used for most commercial radiated emissions and susceptibility control. A characteristic of NiZn ferrite is that the permeability of the material is typically less than 1000, and for very high frequency material may be less than 125.

The other common ferrite material is mangnese zinc, or MnZn, again formulated with a ferrous oxide. These cores can have high permeability, typically over 1000. However, with the high permeability comes a reduced bandwidth of usefulness. So MnZn ferrites are best used for conducted emissions and susceptibility problems.

Note that ferrites can become saturated with less current than many inductors. The best use for ferrites is to use them common mode, on all lines with all return currents routed in the same core. In this regard, the core would be

As more electronic applications are added to vehicles, additional EMI shielding for these systems is necessary to ensure the safety and functionality of the automobile. And let us not forget the portable electronic devices many of us like to bring into the vehicle.

an impedance mainly for the common mode aspect of the noise, while allowing the differential mode noise to pass through with minimal impedance. See Figure 8 for how most differential mode energy is canceled inside a common mode wound toroid, and Figure 9 for how common mode energy increases inside the same toroid.

The layout of the above toroids is often best when used on power lines, where spacing adds isolation which may be needed for safety concerns. However, if a common mode inductor is needed for a data line, the separation of these wires may create issues with respect to high frequency data transfer. In Figure 10, the windings are shown wrapped together, as would be required for data lines. Note that the additional benefit is that it reduces the leakage inductance found in the previous figures.

SHIELDS

There is equipment in which the shielded case is so thick, it has "Two Man Lift" warnings on the cover, even though it is the size of a laptop. Yet I have seen these fail. Conversely, I have seen aluminum foil work to shield a unit with wide margins. Why does one work and the other not?

For radiated emissions, say above 30 MHz, a metal shield does not need to be thick. Aluminum foil has over 80 dB of shielding, and that is for both electric and magnetic fields. The conductivity of the metal makes a great reflective shield for the electric fields, while the magnetic fields are highly absorbed due to eddy current losses. So why is an enclosure that is made of heavy metal not a good shield?

Several things are involved in the breakdown of the shield. First are the cables and wires. Every wire that penetrates the shield must be filtered at that point. If it is not, then noise on the inside of the equipment can couple onto that line, and then transmit on the outside of the chassis. Likewise, during immunity / susceptibility testing, energy is coupled onto those lines and will be conducted into the unit. This must be shunted to chassis or impeded in some manner, otherwise susceptibility may be found. In this case, all the shielding in the world will not help to remove this coupling.

In the event that the filter is in place and is working well, a shield may break down at seams and joints. As stated earlier, bonding impedances of milliohms or less are needed to create a

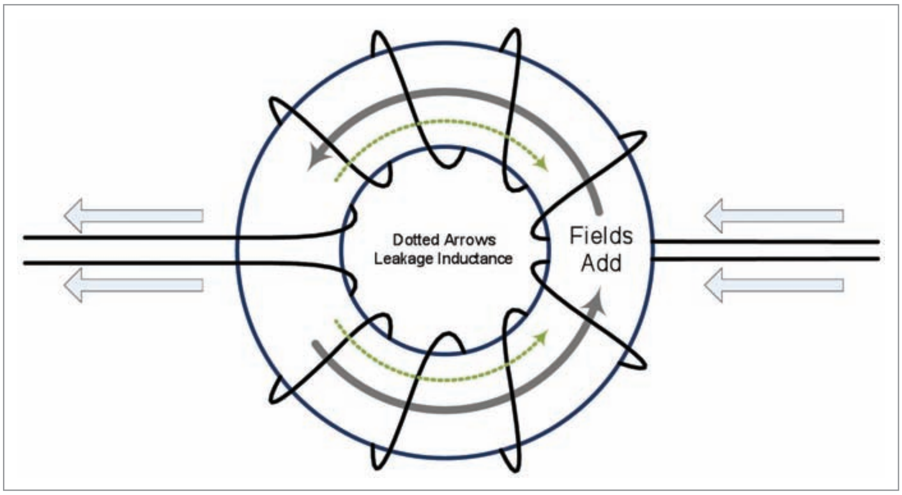


Figure 9: Common mode fields in a common mode core

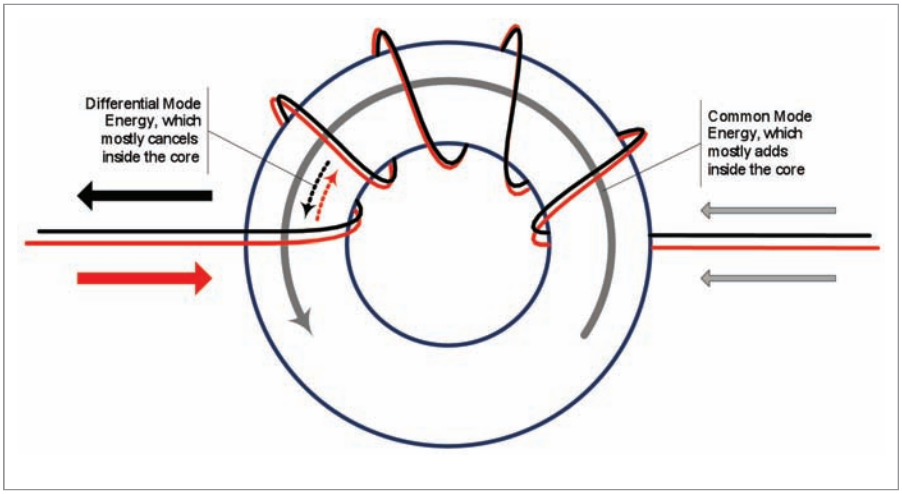


Figure 10: Common mode core wound for data signals

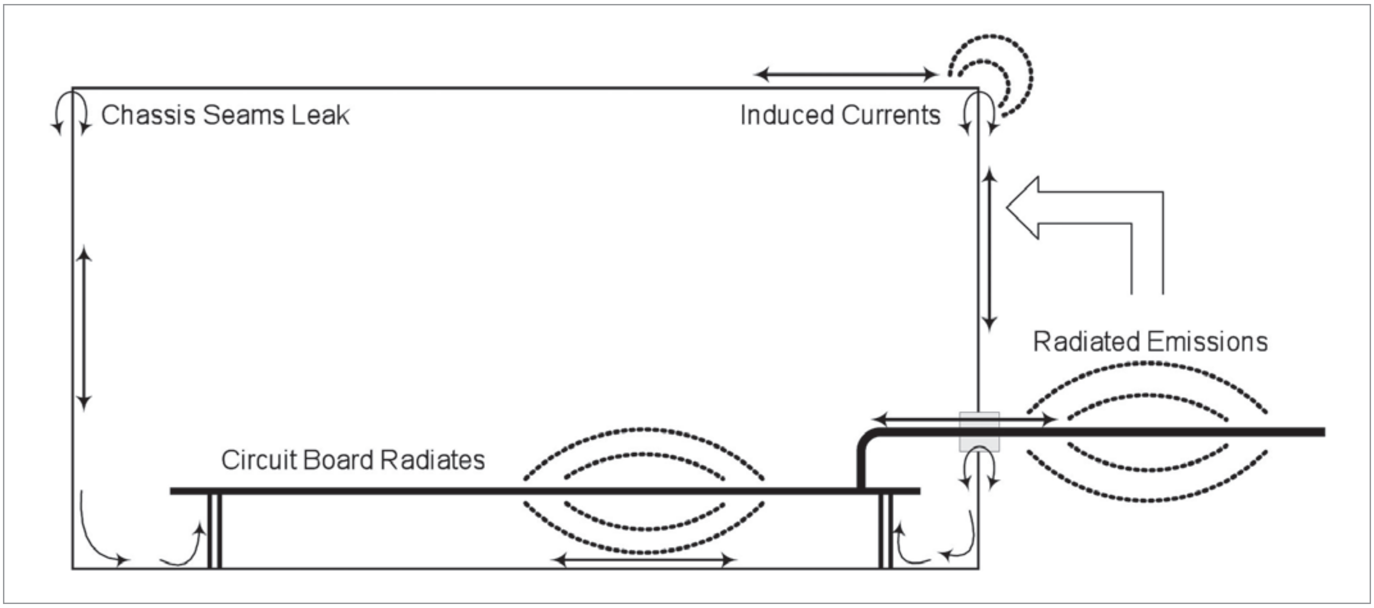


Figure 11: Shield currents

good bond. This is even more important at shields joints. The circuit inside the equipment will generate fields which will create currents on the metal structures, staying on the inside surface due to skin effects. These currents must be allowed to flow back to the source with minimal impedance. As long as the metal does not have joints, the current flows with micro-ohms of impedance. When a seam is crossed, an impedance may be thousands of times higher than one traveling to the outside of the shield, where it can radiate.

The solution is to assure the lowest possible impedance between any metal contacts. Wide and continuous contacts are best. This means that coatings and paint on metal surfaces must be masked at joints and seams. The type of coatings used must assure contact will be of the highest quality possible. And before you go to the lab for a test, make sure to put in all the mounting screws. Do not assume that one in each corner is good enough.

IN CLOSING

This article is not intended to address every aspect of EMI issues; there are many books, papers, and week long lectures that can help. Instead, remember the following points:

- Follow the currents. Electromagnetic interference is based on currents, and currents must flow in a loop. There may be a displacement current involved (read: capacitance), but it is still a current. Success depends on allowing those currents to flow back to the source.
- Assure local returns. The closer to the source these currents return to the source, the less emission and susceptibility you will find.
- Keep impedances low for return currents. Enough said.
- Remember parasitics. Most of these issues are caused by cross coupled noise in some regard. The cause did not appear on your schematic. So look to see how it might be cross coupled.
- Remember the geometries. Loops of wires and thus currents both radiate and will be susceptible to radiation. Keep the loops small. Return currents with the signals as close as possible.

There are many other such items that could be noted. But basically, many are just "rules of thumb".

(the author)

PATRICK G. ANDRÉ

received his physics degree in 1982 from Seattle University. He has worked in the electromagnetic compatibility (EMC) field for 30 years. Patrick is an iNARTE Master Design Engineer and a Certified Engineer in both EMC and ESD. He has worked in the military and aerospace environment for his entire 30 years career, and worked in the commercial electronics environment for the last 20. Patrick has a strong ability in both the test and measurement and troubleshooting areas of EMC. He is president of André Consulting, Incorporated.

Patrick has been a member of the IEEE EMC Society for 29 years, serving as chairman, vice chairman and arrangements chairman of the Puget Sound Section. He also works for the Seattle Gilbert and Sullivan Society as a Sound Design Engineer and Photographer.

Patrick can be contacted at pat@andreconsulting.com or through http://andreconsulting.com.


A+

A Broadband, Low-Noise Time-Domain System for EMI Measurements through K_a-Band up to 40 GHz

BY CHRISTIAN HOFFMANN, AYOUB SIDHOM, STEPHAN BRAUN AND PETER RUSSER

In this article, a time-domain EMI measurement system for the frequency range from 10 Hz to 40 GHz is presented. Signals with a frequency of up to 1.1 GHz are sampled by an ultra-fast floating-point analog-to-digital-converter (ADC) and processed in real-time on a field-programmable-gatearray (FPGA). An ultra-broadband multi-stage down-converter allows for the measurement of signals with frequencies up to 40 GHz. Measurement times can be reduced by several orders of magnitude compared to traditional EMI-receivers that work in frequency-domain.

With preselected integrated low-noise amplifiers, the system offers high sensitivity especially in the K_a-band from 26.5 GHz to 40 GHz. The low system noise figure from 26.5 GHz to 40 GHz yields an average noise floor level of around 12 dBμV using an IF-filter bandwidth of 1 MHz in this range. With a high system dynamic range of more than 70 dB, the system is excellently suited for the measurement of broadband, transient emissions or high-dynamic signals like radar pulses. Non-stationary emissions can be measured via the real-time spectrogram or via the multi-channel amplitude probability distribution (APD) measuring method.

INTRODUCTION

Because of the steadily increasing demand for broadband transmission of information, communication systems and consumer electronics utilize higher and higher frequency bands. In order to protect those systems and services from electromagnetic interference (EMI), the radiated and conducted EMIs have to be measured by dedicated measurement equipment in order to fulfill the requirements of electromagnetic compatibility (EMC) standards like CISPR 16-1-1 [1], MIL-461F [2] or DO-160F [3].

In comparison to traditional measurement receivers, time-domain EMI measurement systems can significantly speed up EMI measurements, saving time and

development and testing costs.
In previous work we already have increased the upper frequency limit of time-domain EMI measurement systems to 18 GHz and 26 GHz by broad-band down-conversion of the measurement signals [4],[5]. The presented system allows for the measurement of electromagnetic emissions in the frequency range from 10 Hz to 40 GHz. Measurements that are fully-compliant to the requirements of CISPR 16-1-1 can be done and the system also offers the required frequency range and IF-filters for measurements according to MIL461F and DO-160F. Measurements of the conducted emissions on a PC power supply line in the frequency range from 150 kHz to 30 MHz are presented, that show a reduction in scan time by a factor of 1350 compared to traditional measurement receivers. The measured spectrogram of the radiated emission of a microwave oven in K_a-Band shows the system's ability to characterize the time-behaviour of non-stationary EMI. Finally a measurement of a frequency-hopping signal in the frequency range from 36 GHz to 37 GHz is presented.

TIME-DOMAIN EMI MEASUREMENT SYSTEM

The presented time-domain EMI measurement system consists of an ultra-fast sampler with high-dynamic range in combination with FPGAs for the digital signal-processing and a multi-stage broadband down-converter that enables measurements above 1.1 GHz. The block diagram of the system is shown in Figure 1. The electromagnetic emissions are received e.g. via a broadband antenna for radiated emissions or a lineimpedance-stabilization-network (LISN) for conducted emissions. Signals in the frequency range from 10 Hz to 1.1 GHz are lowpass-filtered to avoid aliasing. A floating-point ADC samples the signal with high resolution as described in [6]. To achieve high dynamic range, the signal is divided in three paths with different gain. The signals in each path are sampled in parallel with three ADCs at a sampling rate of around 2.6 GS/s. The sampled signals are combined, thus yielding a dynamic range of the floating-point ADC of 16 bits.

To compute the EMI signal spectrum, the digitized EMI signal is transformed by an FFT on an FPGA. For non-stationary signals, a spectrogram can be calculated via the short-timefast-Fourier-transform (STFFT). During the selected dwell-time, a Gaussian window function $\omega[n]$, corresponding to the IF-filter of a conventional measurement receiver, is shifted in time with a discrete time-coordinate τ. For every value of τ, the momentary spectrum is calculated via FFT. The short-time spectrum X[τ, k] is calculated by

$$X[\tau, k] = \sum_{n=0}^{N-1} x[n]w[n-\tau]e^{\frac{-j2\pi kn}{N}} \quad (1)$$

where ω[n − τ] is the shifted window function and x[n] is the discrete input signal. The calculated spectra over time describe a spectrogram. It can be shown that the short-time FFT corresponds to a set of parallel receivers, where the time-domain signal extracted from the spectrogram corresponds to the envelope of the IF-Signal of each receiver [7].

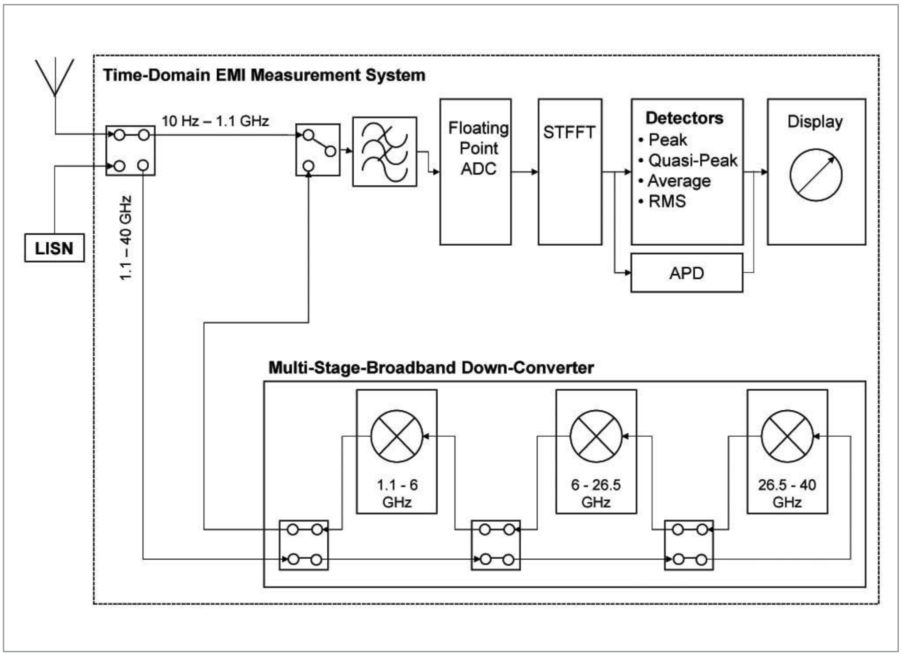


Figure 1: Block diagram of the time-domain EMI measurement system

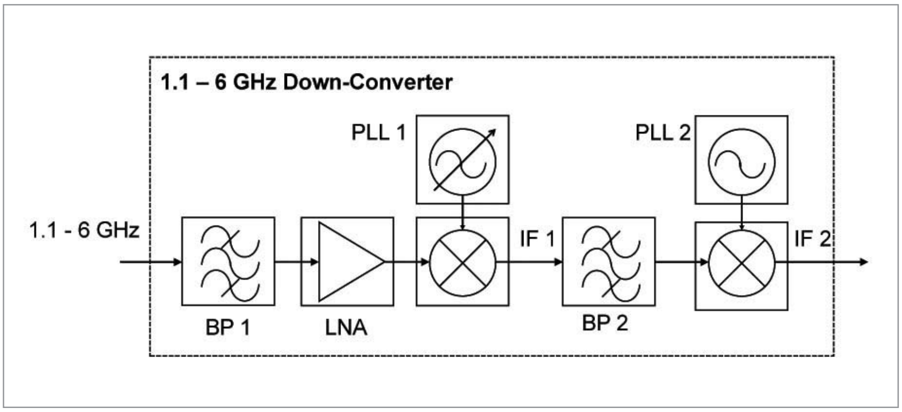


Figure 2: Block diagram of the 1.1-6 GHz down-converter

The amplitude spectrum can be calculated using various digital detector modes like the average, peak or quasi-peak mode and is subsequently displayed. In addition, a multiple-frequency amplitude probability distribution measurement method was implemented [8]. Besides the spectrogram, this method allows to evaluate non-stationary emissions by calculating the statistical properties of the signal.

MULTI-STAGE DOWN-CONVERTER

For emission measurements in the frequency range from 1.1 GHz to 40 GHz, a three-stage broadband down-converter is used. Emissions from 1.1 GHz to 6 GHz are bandpass filtered with a single, wideband preselection filter to increase system dynamic range, as can be seen in Figure 2. A wideband low-noise amplifier increases system sensitivity. To maximize the spurious-free dynamic range, the band is subdivided into 16 bands of around 325 MHz bandwidth. Each of those bands is sequentially up-converted to a first high intermediate frequency above 6 GHz by the use of a mixer and a low-noise PLL-synthesizer. An IF-filter is applied and a second mixer converts the subbands to the frequency band below 1.1 GHz, where the signals are fed to the floating-point ADC for sampling [4]. According to Figure 1, the frequency band from 6 GHz to 26.5 GHz is down-converted by the 6-26.5 GHz down-converter. The preselection divides this frequency band into 5 ultra-wide subbands with bandwidths between 3 and 5 GHz. As the assembly is similar to the 26.5-40 GHz down-converter, it is not described in detail. The block diagram of the 26.5-40 GHz down-converter is shown in Figure 3. The input band is divided into three ultra-wide subbands according to Table 1. High-order planar bandpass filters with mid-band insertion losses of 1.5-2.5 dB increase the system dynamic range by attenuating out-of-band emissions and maximize the IF dynamic range by preventing that higher order mixing products are generated in the intermediate frequency band. The switching between the bands is done via SP3T PIN-diode switches with insertion losses of less than 3.5 dB in the frequency range from 26.5 GHz to 40 GHz. Broadband low-noise amplifiers increase the sensitivity of the system. A broadband mixer described in the next section is used to down-convert the bands into the input frequency range of the 6-26.5 GHz down-converter. The local oscillator signals are generated by a low-noise PLL-synthesizer and a frequency multiplier.

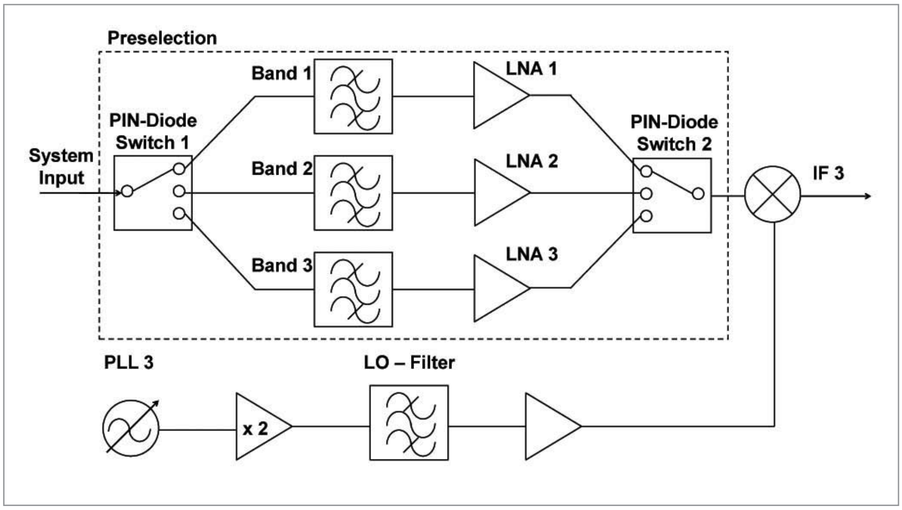


Figure 3: Block diagram of the 26.5-40 GHz down-converter

Preselection Band	Frequency
Band 1	26.5 - 29.25 GHz
Band 2	29.25 - 33 GHz
Band 3	33 - 40 GHz

Table 1: Preselection bands in the frequency range from 26.5 to 40 GHz

IMPLEMENTATION

The components for the down-converters have been realized on glass reinforced hydrocarbon/ceramic and alumina substrates in hybrid assembly. The broadband mixers that have been designed for the down-conversion of the K_a-Band from 26.5 GHz to 40 GHz will be exemplarily described in the following.

In order to realize the ultra-broadband down-conversion of the input signals from 26.5 GHz to 40 GHz into the frequency range from 6 GHz to 13 GHz, a mixer with an exceptionally wide IF-bandwidth is needed. Double-balanced diode designs were implemented, because they provide high port-port isolation and low conversion-loss without the need for an active bias. To achieve high dynamic range, Schottky-diodes with medium to high barrier heights were chosen. Two mixer designs were realized: mixer 1 incorporates an anti-parallel diode pair, mixer 2 uses a quad-diode-ring. As the mixer diodes have to be fed with a balanced signal, balanced-to-unbalanced transformers (baluns) are one of the main elements of the mixer. In [9], broadband Marchand baluns have been described. Such baluns were used for the mixer RF-and LO-ports and have been realized in a planar design on aluminum substrate. The manufactured substrate for mixer 2 can be seen in Figure 4. In contrast to a conventional transformer with center-tap, the common-mode IF-signal is tapped at the radial stubs of the RF-balun, where these taps do not disturb the RF-signal. As the tap-lines have an electrical length of λ/4 at the center frequency of the RF input band, the power divider junction acts as a virtual ground for the odd-mode RF-signal. This yields a low conversion-loss and high RF-IF isolation.

The manufactured mixers were measured inside their respective housings equipped with 2.92 mm connectors. For each frequency band, a local oscillator signal between 20 GHz and 27 GHz with a power of 15-18 dBm was fed to the LO-port. The IF-signal power level was measured with a precision power meter in the frequency range from 6 GHz to 13 GHz, while a calibrated signal generator fed the RF input signal to the RF-port. Figure 5 shows the measured conversion losses of both mixers. The average conversion loss of mixer 1 is 11.1 dB in the frequency range from 26 GHz to 40 GHz. Mixer 2 exhibits a lower average conversion loss of 8.5 dB because the used diodes have a higher cutoff-frequency than the ones used in mixer 1. Both mixers have very low conversion losses in K_a-band, allowing for a low system noise figure and achieve very wide IF-bandwidths from DC to 14.5 GHz.

Port-port isolations are important figures of merit for mixers. A high LO-IF isolation is of special importance for our measurement system, because the strong LO-signal can cause undesired mixing products to be generated at the intermediate frequency of the subsequent mixer. The measured LO-IF isolations of both mixers are shown in Table 2. While mixer 1 achieves a high LO-IF isolation of over 30 dB for local oscillator signals from 20 GHz to 27 GHz, a LO-IF isolation of 8.6-21.4 dB was measured for mixer 2 in the same frequency range. The reason for this behaviour is the additional air-bridge needed to route the LO-signal over the RF-signal for the case of the

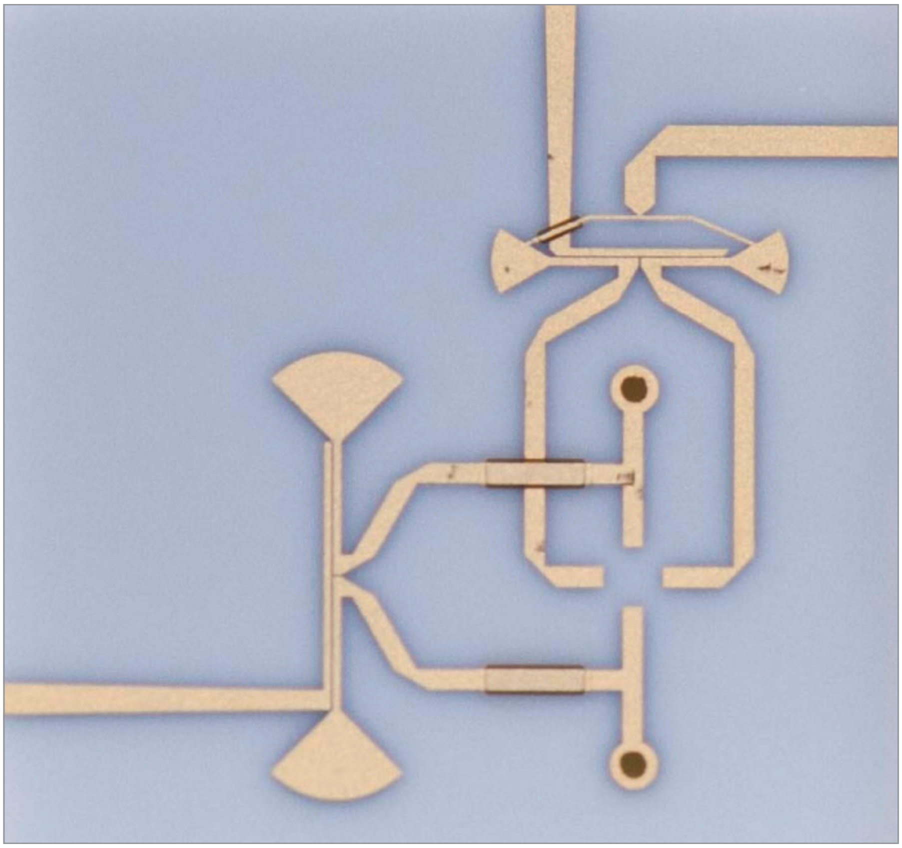


Figure 4: Picture of the manufactured mixer 2 substrate without diode chip

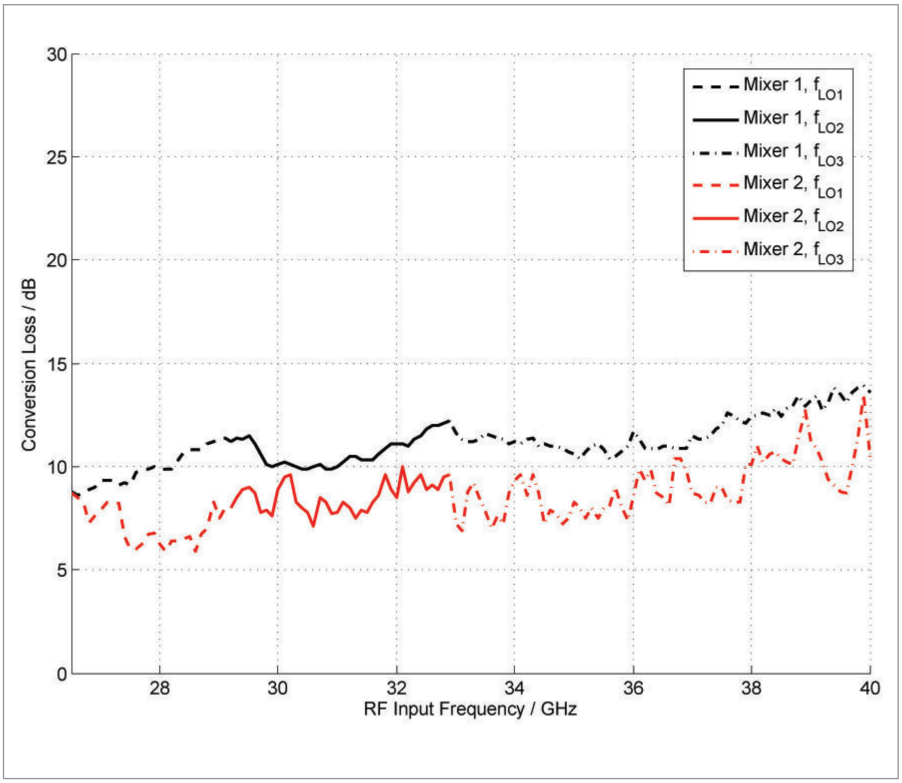


Figure 5: Comparison of the measured conversion losses of the implemented mixers

quad-diode-ring in mixer 2. The diodes in mixer 2 have two internally-crossed diode-pairs, rendering such an external crossing unnecessary. Because of the low-conversion loss, the high IF-bandwidth and the exceptionally high LO-IF isolation, mixer 2 was used in the time-domain measurement system.

SYSTEM MEASUREMENTS

K_a-band radiated emissions commonly exhibit low power levels. Therefore the measurement system should exhibit a low system noise figure to achieve the required sensitivity. Losses in feed lines considerably aggravate this problem.

The noise power at the output of a system, that exhibits the noise figure F can be calculated by

$$P_N = FkT_0B_{\mathrm{ENB}} \qquad (2)$$

where

k is the Boltzmann constant

T_0 is the ambient temperature

B_{ENB} is the equivalent noise bandwidth

The system's theoretical average noise floor level can be calculated using (2). The equivalent noise bandwidth B_{ENB} of the IF-filters with Gauss-characteristic is obtained with

$$B_{\mathrm{ENB}} = \int_{-\infty}^{\infty} |H(f)|^2 df \qquad (3)$$

using the filter's transfer functions H(f). With the 1 MHz IF-filter and the system input noise figure estimated from the components values of the 26.5-40 GHz down-converter we obtain an estimated average noise floor level of around 11.9 dBµV in the frequency range from 26.5 GHz to 40 GHz.

f_{LO} / GHz	LO-IF isol. mixer 1 / dB	LO-IF isol. mixer 2 / dB
20	31.6	21.4
23.5	32.7	13.2
27	30.2	8.6

Table 2: Comparison of the measured LO-IF isolations of the implemented mixers

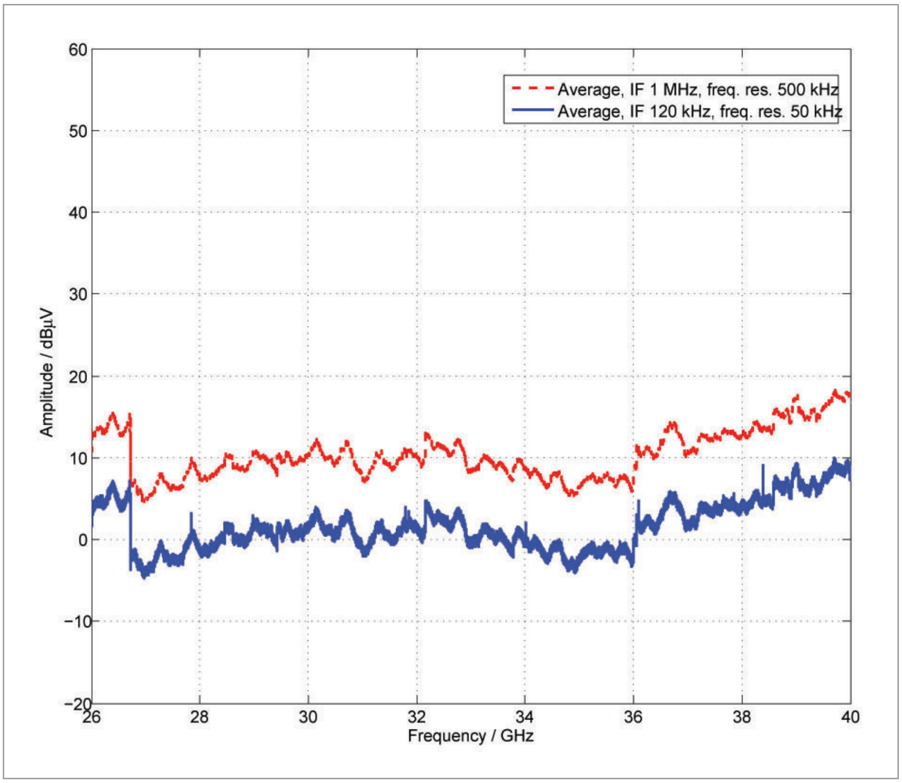


Figure 6: System noise floor from 26 -40 GHz

Figure 6 shows measurements of the system noise floor in the range from 26 GHz to 40 GHz using the average detector and IF bandwidth of 1 MHz and 120 kHz respectively. The system input was matched and the variable input attenuator was set to an attenuation of 0 dB. The time-domain EMI measurement system exhibits a very low noise floor of below 20 dBµV for the 1 MHz IF bandwidth and of below 10 dBµV for the 120 kHz IF bandwidth in this frequency range. The scan time with 1 MHz IF bandwidth and a frequency resolution of 500 kHz was around 30 s, while the scan time using a 120 kHz IF bandwidth and a frequency resolution of 50 kHz was around 90 s.

In order to measure broadband transient emissions or general high-dynamic signals like radar pulses, the dynamic range is an important specification for such a system. CISPR 16-1-1 defines broadband pulses for the detector calibration in Band E above 1 GHz and requires an IF dynamic range of at least 40 dB when using a 1 MHz IF-filter. For the characterization of the system IF dynamic range, a pulse generator fed a pulse modulated sinusoidal signal with a frequency of 35 GHz to the system input. The signal pulse width was set to 1 µs and the pulse period to 40 ms. The spectrum was weighted by peak and average detectors and an IF-filter bandwidth of 120 kHz and is shown in Figure 7. With this pulse period, the average detector already shows the system noise floor. The difference in level between the peak and average detector measurements is defined as the IF dynamic range.

The measurements in Figure 7 show an IF dynamic range of 62.6 dB. The corresponding value for an IF-filter bandwidth of 1 MHz as specified by CISPR 16-1-1 can be calculated by calculating the change in pulse level ΔAPulse and noise level ΔANoise by

$$\Delta A_{\text{Pulse}} = 20log_{10}\left(\frac{B_{\text{imp},1}}{B_{\text{imp},2}}\right) \quad (4)$$

$$\Delta A_{\text{Noise}} = 10log_{10}\left(\frac{B_{\text{Noise},1}}{B_{\text{Noise},2}}\right) \quad (5)$$

where $B_{imp,x}$ and $B_{Noise,x}$ are the equivalent impulse and noise bandwidths of the IF-filters. The measurements indicate an IF dynamic range of 62.6 dB + (18.4 dB -9.2 dB) = 71.8 dB for an IF-bandwidth of 1 MHz, exceeding CISPR 16-1-1 requirements by over 20 dB.

The avionic EMC standard DO-160F defines limit lines for the conducted interference signals on supply lines. The presented time-domain EMI measurement system allows to conduct those measurements due to the implementation of the required IF filter bandwidths. The supply lines of a personal computer's power supply were measured using a current clamp with a bandwidth from 10 kHz to 1 GHz. The measurements are shown in Figure 8. For the measurements, the peak detector was selected with a dwell time of 100 ms. The scan time for the DO-160F scan from 150 kHz to 30 MHz was around 4 s, whereas this measurement would take over 1.5 hours with a traditional heterodyne receiver. The conducted interference currents in the frequency range from 150 kHz to 30 MHz clearly exceed the limit lines defined in DO-160F. The measured power supply would not be suitable for use with sensitive equipment defined in DO-160F.

Household appliances can radiate considerable spectral energy densities in the frequency range above 1 GHz. The spectrogram enables the detection of singular or frequency-shifting events in real-time. A microwave oven was measured at a distance of 3 m to a broadband quad-ridged horn antenna with a bandwidth from 1.7 GHz to 20 GHz. To compensate for cable losses and to give the electric field strength of the radiated EMI, the corresponding transducer factors and the antenna factor were applied. Figure 9 shows the time behavior of the magnetron's 6^{th} harmonic over a time period of 20 s. The magnetron turns on at about 3 s in time and turns off at around 9 s. The free-running oscillator's output frequency exhibits a frequency drift of around 10 MHz.

Figure 10 shows measurements of a frequency-hopping signal. The spectrum was measured in the frequency range from 36 GHz to 37 GHz using peak and average detectors and an IF-filter bandwidth of 1 MHz. As the detectors are applied on the same sampled data simultaneously, both detectors show the same frequency components, although the signal is non-stationary. The variable attenuator was set to 10 dB. The scan time for those measurements using a frequency resolution of 500 kHz was around 10 s.

CONCLUSION

A time-domain system for EMI measurements from 10 Hz to 40 GHz which allows for measurements according to CISPR 16-1-1, MIL-461F and DO-160F was presented. The system offers high sensitivity due to a low system noise floor and achieves an average noise floor level of around 12 dBμV in K_a-band using an IF bandwidth of 1 MHz and of around 2 dBμV using 120 kHz IF bandwidth.

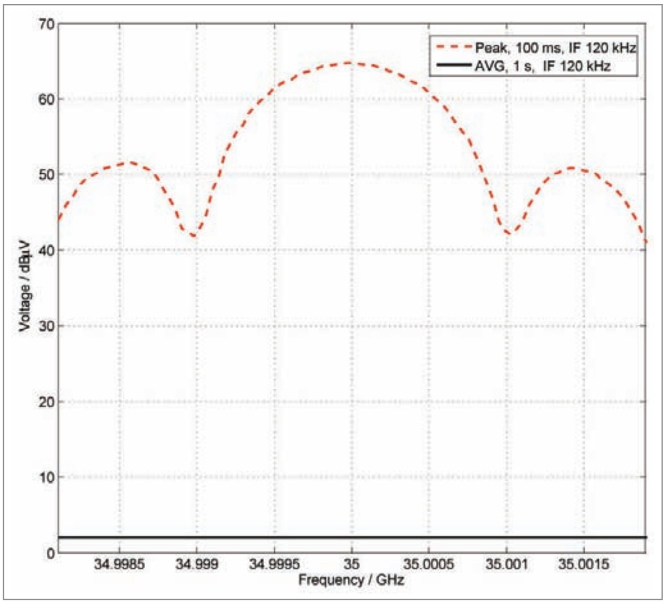


Figure 7: Measured pulse-modulated signal

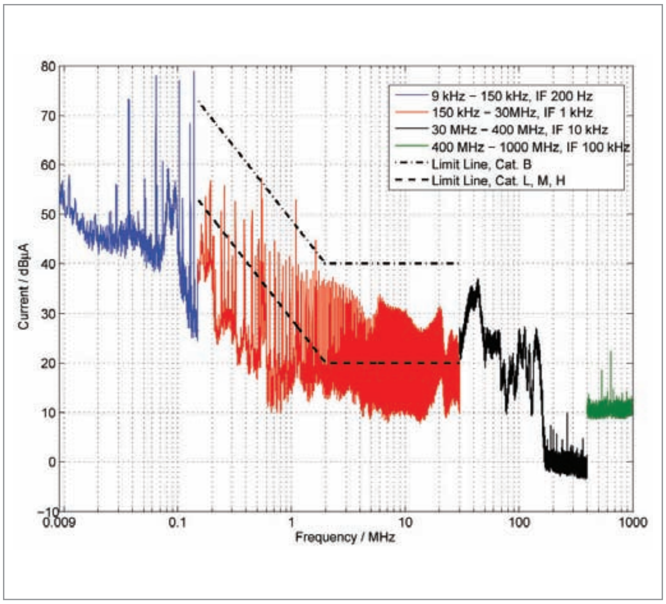


Figure 8: Measured spectrum of the conducted interference currents on a PC power supply line

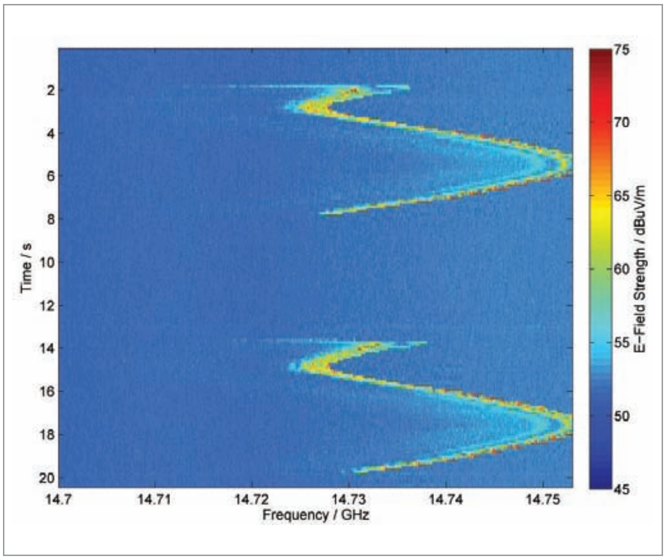


Figure 9: Spectrogram of the 6th harmonic of a microwave oven

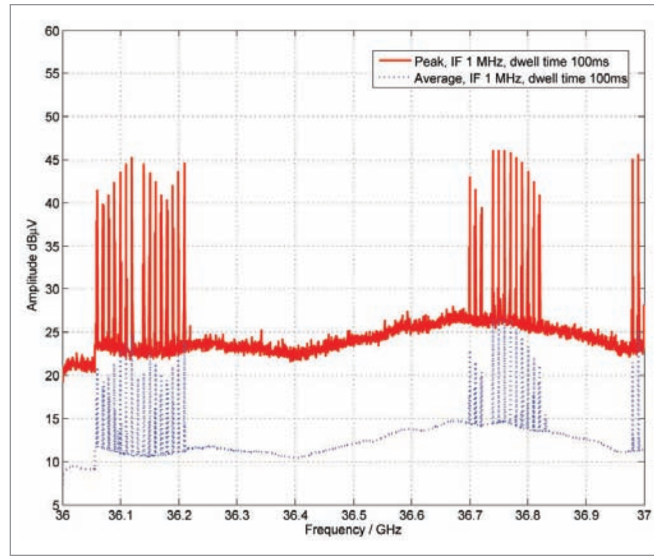


Figure 10: Measured spectrum of a frequency-hopping signal

With a dynamic range of more than 70 dB, the system fulfills the requirements of CISPR-16-1-1 and is excellently suited for the measurement of high dynamic signals like radar pulses. An STFFT-based spectrogram and a multiple-frequency amplitude probability distribution measuring method can be used to investigate the properties of non-stationary EMI. Measurements of the conducted emissions on a PC power supply line using DO160 IF-bandwidths, spectrogram measurements of the radiated emissions of a microwave oven in K_a-band and of a frequency-hopping signal in the frequency range from 36 GHz to 37 GHz were presented.

ACKNOWLEDGEMENT

The authors would like to thank the Bayerische Forschungsstiftung for co-funding this project.

REFERENCES

1. CISPR 16-1-1, Ed. 3.0, “Specification for radio disturbance and immunity measuring apparatus and methods Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus,” *International Electrotechnical Commission*, 2010.
2. MIL-STD-461f: Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, Department of Defense Interface Standard, 2010.
3. DO-160F: Environmental Conditions and Test Procedure for Airborne Equipment, RTCA, Incorporated, 2007.
4. C. Hoffmann and P. Russer, “A Real-Time Low-Noise Ultra-Broadband Time-Domain EMI Measurement System up to 18 GHz,” *IEEE Transactions on Electromagnetic Compatibility*, Vol. 53, Issue 4, 2011.
5. C. Hoffmann and P. Russer, “A Broadband High-Dynamic Time-Domain System for EMI Measurements in K-Band up to 26 GHz,” *IEEE Symposium on Electromagnetic Compatibility 2011, Long Beach, USA*, pp. 489-492, 2011.
6. S. Braun and P. Russer, “A low-noise multiresolution high-dynamic ultra-broad-band time-domain EMI Measurement System,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, pp. 3354 -3363, Nov. 2005.
7. J. Allen, “Short term spectral analysis, synthesis, and modification by discrete Fourier transform,” *IEEE Transactions on Acoustics, Speech and Signal Processing*, vol. 25, pp. 235 -238, 1977.
8. H. H. Slim, C. Hoffmann, S. Braun, P. Russer, “A Novel Multichannel Amplitude Probability Distribution for a time-domain EMI Measurement System According to CISPR 16-1-1,” *EMC Europe 2011, York, Great Britain*, 2011.
9. N. Marchand, “Transmission Line Conversion Transformer,” *Electronics*, vol. 17, no. 12, pp. 143-145, 1944.

(the authors)

Christian Hoffmann, GAUSS INSTRUMENTS GmbH, Munich, Germany, choffmann@tdemi.com

Ayoub Sidhom, Technische Universität München, Institute for Nanoelectronics Munich, Germany

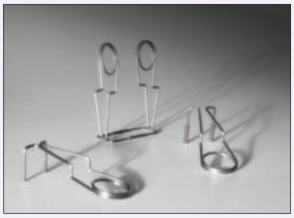
Stephan Braun, GAUSS INSTRUMENTS GmbH, Munich, Germany, braun@tdemi.com

Peter Russer, Technische Universität München, Institute for Nanoelectronics Munich, Germany, russer@tum.de

BUSINESS News

Connecticut Spring & Stamping Pursues ISO 13485 Medical Certification for Quality Management

Connecticut Spring & Stamping (CSS) has announced that it is on schedule to be certified in 2013 to the ISO 13485 standard for quality management for design and manufacturing of medical devices.



CSS is currently certified to AS 9100, the standardized quality management system for the aerospace industry. Achieving the ISO 13485 standard demonstrates CSS's commitment to its existing medical customers, and signals its desire to expand its growing medical customer base and further enhance its capabilities with Tier 1 suppliers. For further information, visit www.ctspring.com or call 860-677-1341.

InterCloud Systems Announces Roger Ponder as COO

InterCloud Systems, Inc., a global single-source provider of value-added services for both corporate enterprises and telecommunications service providers, announced the appointment of Roger Ponder as Chief Operations Officer. Roger Ponder served as President and CEO of Time Warner Cable Kansas City Midwest Division from 2005 to 2009 where he drove a multi-state division to increased profitability and operational efficiency. For more information on InterCloud Systems, visit www.intercloudsys.com.

New TPR Series Temperature Protection Fusing Resistors

KOA Speer announced the latest development in resistors, the TPR series temperature protection fusing resistors. TPR series resistors safely interrupt open circuits up to AC250V voltage and completely isolate the circuit after quickly fusing to the overload. These fusing resistors feature the pulse capability of wirewound resistors and are approved by UL1412 safety standards. For more information, visit www.koaspeer.com.

ON Semiconductor's New LGA-Packaged MOSFETS Help Maximize Efficiency and Battery Life in Space Limited Smart Phones and Tablet PC Applications

ON Semiconductor has introduced two new MOSFET devices designed for use in smart phone and tablet PC applications where they provide a crucial part of the Lithium ion (Li-ion) battery charging / discharging protection circuit switching. The EFC6601R and EFC6602R help designers to reduce solution size, improve efficiency and maximize battery life. ON Semiconductor plans to add five further devices to the EFC MOSFET family within the year that will help designers of an even wider range of mobile devices achieve their application objectives for reducing solution size and extending battery life.
For detailed specifications, visit www.onsemi.com.

TDK RF Solutions Introduces New EMC Camera

TDK Corporation has developed the VC-06, a high-definition color video camera which offers high performance and is an all digital, shielded camera, designed for remote monitoring of equipment during EMC testing. The camera, which is available now, is ideal for wide angle anechoic chamber monitoring, shielded access control, and test action archiving. Please contact TDK RF Solutions at info@tdkrf.com for more information.

TÜV Rheinland Commissions New Power Inverter Testing Laboratory

TÜV Rheinland has completed the construction of its new testing laboratory designed to inspect and certify small- to mid-sized power inverter devices. Inverters—devices that change direct current (DC) into alternating current (AC)—are used extensively within photovoltaic solar, wind, fuel cell and other renewable energy systems. The applicable international standards of product safety and grid connections to which the new facility will test include UL 1741; CSA C22.2 No. 107.1; IEEE 1547; IEEE 1547.1; IEC 62109-1 & -2; EN 50438; VDE 4105; AS 4777-2 &-3; BDEW; JET and others. For more information, visit www.tuv.com/us.

Vishay's New FRED Pt Hyperfast & Ultrafast Recovery Rectifiers Reduce Switching Losses

Vishay Intertechnology, Inc. introduced 10 solderable FRED Pt® Hyperfast and Ultrafast recovery rectifiers that include the industry's first 3 A devices in the SMA package, 3 A and 4 A devices in the SMB package, and 4 A and 5 A devices in the SMC package. Combining extremely fast and soft recovery characteristics with low forward voltage drop and low leakage current, the new rectifiers reduce switching losses in consumer products, LCD TVs, power supplies, and electronic ballast lighting.

For additional information, visit www.vishay.com.

PRODUCT Showcase

EVENTS in Compliance

July 2013

29–1
NFPA 79: Electrical Standard for Industrial Machinery with Industrial Control Panels UL 508A
UL Knowledge Services
Research Triangle Park, NC
www.incompliancemag.com/events/130729

31
Industrial Control Panels UL 508A and Short-Circuit Current Ratings
UL Knowledge Services
Research Triangle Park, NC
www.incompliancemag.com/events/130731

August 2013

5-9
International Symposium on Electromagnetic Compatibility
Colorado Convention Center
Denver, CO
www.incompliancemag.com/events/130805

6
Understanding Ground Resistance Testing
AEMC Instruments
Detroit, MI
www.incompliancemag.com/events/130806_1

6
International Approvals Briefing for Russia/Customs Union
TÜV Rheinland
Webinars
www.incompliancemag.com/events/130806_2

10
BRIC Seminar
SIEMIC
Denver, CO
www.incompliancemag.com/events/130810

(Authors)

We wish to thank our community of knowledgeable authors, indeed, experts in their field - who come together to bring you each issue of *In Compliance*. Their contributions of informative articles continue to move technology forward.

PATRICK G. ANDRÉ
received his physics degree in 1982 from Seattle University. He has worked in the electromagnetic compatibility (EMC) field for 30 years. Patrick is an iNARTE Master Design Engineer and a Certified Engineer in both EMC and ESD. For more about Patrick, please visit page 50.

GLEN DASH
is the author of numerous papers on electromagnetics. He was educated at MIT and was the founder of several companies dedicated to helping companies achieve regulatory compliance. For more about Glen, please visit page 40.

DARYL GERKE, PE
is a partner in Kimmel Gerke Associates, Ltd., an engineering consulting and training firm that specialized in EMI/EMC design and troubleshooting issues. He is a degreed engineer (BSEE), iNARTE Certified EMC Engineer, and registered Professional Engineer (PE). For more about Daryl, please visit page 33.

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 23.

BILL KIMMEL, PE
is a partner in Kimmel Gerke Associates, Ltd., an engineering consulting and training firm that specialized in EMI/EMC design and troubleshooting issues. He is a degreed engineer (BSEE), iNARTE Certified EMC Engineer, and registered Professional Engineer (PE). For more about Bill, please visit page 33.

GEOFFREY PECKHAM
is CEO 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 visit page 25.

(Advertisers)

Advertiser Name	Page	Advertiser Name	Page
A.H. Systems	C2	Monroe Electronics	61
AR	13, 61	Nemko USA	29
CST of America	3	Okaya Electric America, Inc.	61
E. D. & D., Inc.	17	Panashield Inc.	11
EOS/ESD Association Inc.	41	Quell Corporation	19
ETS-Lindgren	C3	Schurter, Inc.	31
Fair-Rite Products Corp.	21	Swift Textile Metalizing LLC	15
Henry Ott Consultants	6/7	Teseq	C4
IEEE EMC 2013 Symposium	39	Washington Laboratories Academy	33
LCR Electronics	9		

VERSATILITY IN THE LIMELIGHT:

NSG 3060 – THE NEW EMC IMMUNITY TEST GENERATION

The Teseq NSG 3060 multifunctional generator system is perfect for every need: A basic start up unit with all expansion options for the most demanding EMC laboratory systems. This new combination of high contrast color touch screen display with thumb wheel guarantees fast and simple operation. The NSG 3060 is designed for the world market, with convenient operation in several languages. In addition to the traditional IEC requirements, the NSG 3060 features ANSI/IEEE coupling modes and continuous monitoring of the EUT supply voltage. In conformance with ANSI/IEEE requirements, the peak surge level is automatically corrected for any phase angle and supply voltage – now that's versatility!

NSG 3060 Highlights:

- **Large touch screen color display**
- **Surge, ring wave and telecom pulse up to 6.6 kV**
- **Burst, Dip/Interrupt and magnetic field options**
- **Coupling as required by ANSI and IEC**
- **Extensive range of accessories**
- **Quickly launch tests from extensive Standards Library or User Test folders**

Teseq Inc. Edison, NJ USA
T +1 732 417 0501 F +1 732 417 0511
usasales@teseq.com www.tesequsa.com

a TESEQ Company

MILMEGA
a TESEQ Company

TESEQ
Advanced Test Solutions for EMC