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

Same Page Publishing Inc.
531 King Street, Suite 5
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fax: (978) 486-4691

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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

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PRINTED WITH SOY INK

CONTENTS February 2014

Volume 5 ● Number 2

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

April 22-24, 2014
Embassy Suites Hotel | Seattle, WA

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

COURSE CONTENT

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

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

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

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

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

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

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

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

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

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

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

Presented by Henry Ott Consultants
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IN COMPLIANCE

HENRY OTT

Henry W. Ott is President and Principal Consultant of Henry Ott Consultants, an EMC training and consulting organization. He has literally "written the book" on the subject of EMC and is considered by many to be the nation's leading EMC educator. He is the author of the popular EMC book <u>Noise Reduction Techniques in Electronic Systems</u> (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, <u>Electromagnetic Compatibility Engineering</u>, is the most comprehensive book available on EMC. While still retaining the core information that made <u>Noise Reduction Techniques</u> an international success, this new book contains over 600 pages of new and revised material.

Learn more at
www.hottconsultants.com

Who Should Attend

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

EMC EXHIBITS AND EVENING RECEPTION: WEDNESDAY, APRIL 23, 2014

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

REGISTRATION

COURSE DATES/TIME: April 22-24, 2014
Tuesday and Thursday 8:30 a.m. to 4:30 p.m.
Wednesday 8:30 a.m. to 5:00 p.m.

COURSE LOCATION: Embassy Suites Hotel
15920 West Valley Highway, Seattle, Washington 98188, USA

COURSE FEE: $1,495 ($1,295 until 3/7/2014). Fee includes notes, textbook*, breakfast, luncheon and beverage breaks. Payment required prior to course. Hotel accommodations are NOT included.

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

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

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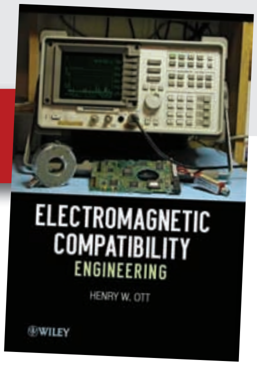
Includes Henry Ott's latest book!



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

News in Compliance

FCC News

FCC Proposes $3.5 Million Fine for Slamming/Cramming

The U.S. Federal Communications Commission (FCC) has proposed a fine of more than a $3.5 million against a Nevada-based telecommunications firm that allegedly changed the preferred long-distance telecommunications service of a group of consumers without authorization (a practice known as “slamming”), and for placing unauthorized charges on consumers’ telephone bills (known as “cramming”).

In a recent *Notice of Apparent Liability for Forfeiture*, the Commission proposed a fine of $3,560,000 against Consumer Telecom Inc. of Henderson, NV for multiple instances of slamming or cramming. In this case, Consumer Telecom telemarketers allegedly represented themselves to consumers as employees of their incumbent long-distance carrier. According to the Commission, “CTI apparently took advantage of consumers by masking the true purpose of the call, and then profiting from their obvious confusion about the questions they were asked.”

The Federal Communications Act prohibits carriers from changing a subscriber’s selection of telephone service providers without their explicit permission, or for billing them without authorization.

The proposed forfeiture in this case is more than twice the amount proposed by the Commission in December 2012 against a California-based company. In that instance, the Commission proposed a forfeiture of more than $1.4 million against Preferred Long Distance, Inc. of Encino, CA for allegedly switching long-distance telephone service for 14 consumers without authorization.

The complete text of the Commission’s *Notice of Apparent Liability for Forfeiture* against Consumer Telecom is available at incompliancemag.com/news/1402_01.

The Federal Communications Act prohibits carriers from changing a subscriber’s selection of telephone service providers without their explicit permission, or for billing them without authorization.

FCC Releases Consumer Complaints Report for Q2 2013

The U.S. Federal Communications Commission (FCC) has released its report on inquiries and complaints

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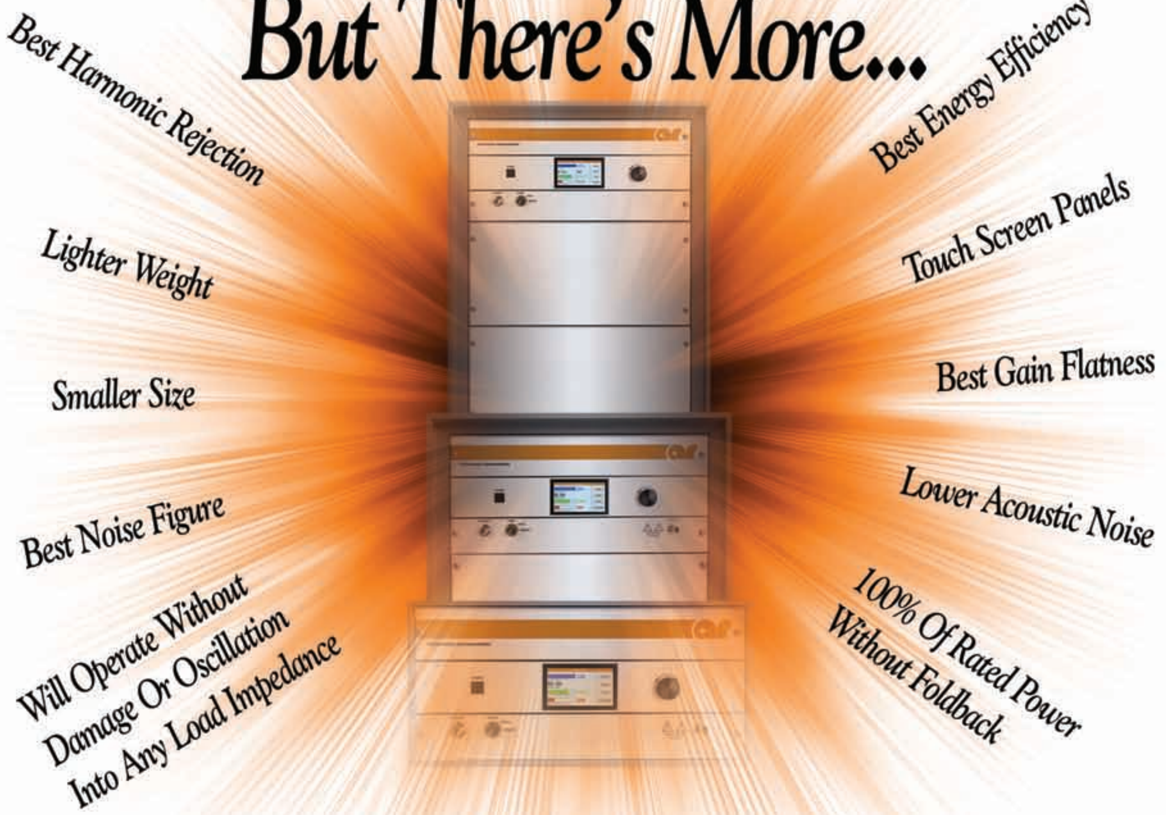

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News in Compliance

FCC News

made by consumers to the agency's Consumer & Government Affairs Bureau during the quarter ending June 30, 2013.

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

During the period from April through June 2013, the Bureau received a total of 36,531 TCPA-related complaints in connection with wireline telecommunications services, and an additional 17,959 TCPA-related complaints in connection with wireless services. Of the wireline TCPA complaints, 18,682 (51.1%) involved violations of the "Do Not Call" registry, and 2909 were connected with unsolicited faxes.

In addition to complaints, the Bureau also received 4133 TCPA-related inquiries in connection with wireline services, and an additional 163 TCPA-related inquires in connection with wireless services.

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 December 31, 2012*, nearly 70% 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.

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 December 2012, nearly 38% of mobile subscribers had access to high-speed service, compared with a 21% penetration rate as of December 2011.

Without accounting for speed, Internet connections overall are growing. By the end of December 2012, there were 262 million Internet connections offering access at speeds of at least 200 kpbs, a 14% year-over-year increase. Overall growth continues to be driven by dramatic increases in mobile connections, which increased by 18% in just one year. With 169 million subscribers, the number of mobile Internet connections at the end of December 2012 was nearly 82% 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/1402_02.

FCC Proposes $44 Million in New Penalties for Lifeline Program Violations

The U.S. Federal Communications Commission (FCC) has proposed more than $44 million in new monetary forfeitures against three wireless Lifeline service providers who allegedly established multiple Lifeline wireless phone service subscriptions for individual consumers, in violation of the program's rules.

The Commission issued Notices of Apparent Liability (NALs) in December 2013 against Cintex Wireless ($9.4 million), Telrite Corporation ($22.4 million) and Global Connection ($11.7 million). In each instance, the Commission says that the carriers knew or should have known that targeted consumers were already participants in the Lifeline program, and therefore ineligible for multiple subscriptions under Lifeline program rules.

The proposed monetary forfeitures were based on the number of unlawful payment requests made by each respective carrier, which was then adjusted upward by three times the total duplicate payments requested.

Established in 1985, the Lifeline program provides discounted wireless service subscriptions to low-income consumers. However, evidence of widespread abuse led the Commission to overhaul the program in 2012, and to aggressively pursue investigations of duplicate service and fraud. During the last three months of 2013 alone, FCC enforcement in connection with Lifeline program violations has resulted in proposed fines of $90 million.

European Union News

EU Commission Updates Standards List for PPE Directive

The Commission of the European Union (EU) has an updated list of standards that can be used to demonstrate conformity with the essential requirements of its Directive 89/686/EEC concerning personal protective equipment.

For the purposes of the Directive, personal protective equipment (or PPE) is defined as "any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards." Specifically excluded from the scope of the Directive is equipment designed specifically for private use (such as seasonal outdoor clothing), equipment for use by armed forces or law enforcement personnel, and equipment intended for the protection or rescue of individuals on vessels or aircraft.

The extensive list of CEN and Cenelec standards was published in December 2013 in the *Official Journal of the European Union,* and replaces all previously published standards lists for the Directive.

The complete updated standards list for the EU's PPE Directive is available at incompliancemag.com/news/1402_03.

News in Compliance

CPSC News

Bed Bug Heating Units Recalled

Nuvenco, Inc. of Fort Collins, CO. is recalling about 9000 of its Pack-Tite brand heating units for bed bug control.

Nuvenco reports that the bed bug heating units can overheat and/or melt, potentially causing a fire and posing a burn hazard to consumers.

The company has received three consumer complaints of heaters overheating, including one case in which treated items were singed. However, there have been no reports of injuries.

The recalled heating units were sold through pest control companies and pest control product distributors nationwide from October 2009 through January 2013 for between $300 and $330 for the heating system, and for $53 for the heating unit when sold separately.

More information about this recall is available at incompliancemag.com/news/1402_04.

Google and HP Recall Chromebook 11 Chargers

Google Inc. of Mountain View, CA and the Hewlett-Packard Company of Palo Alto, CA are voluntarily recalling about 145,000 power supplies/chargers manufactured in China and intended for use with HP's Chromebook 11 tablet computer.

Google and HP report that the power supply/charger can overheat and melt, posing a fire and burn hazard to consumers. Google says that it has received nine reports of chargers overheating and melting during use, as well as one report of a minor consumer injury and a separate report of minor property damage.

The recalled power supplies/chargers were sold with HP's Chromebook 11 between October and November 2013 for about $280 at Best Buy stores nationwide, as well as through ShoppingHP.com, Play.Google.com and Amazon.com.

Additional details regarding this recall are available at incompliancemag.com/news/1402_05.

Colby TVs Recalled Due to Fire Hazard

Eight U.S. retailers have announced a voluntary recall of Colby-brand 32-inch flat screen televisions manufactured in China.

According to a press release issued by the U.S. Consumer Product Safety Commission (CPSC), an electronic component in the recalled televisions can catch fire and ignite nearby items, posing a fire and burn hazard to consumers. The CPSC says that it

CPSC News

has received six separate reports of televisions overheating, smoking or catching fire. However, there have been no reports of injuries.

The eight retailers that initiated this recall include ABC Warehouse, Best Buy, Fry's Electronics, h.h. Gregg, Nebraska Furniture Mart, P.C. Richard & Son, Sears/Kmart and Toys R Us. The recall televisions were sold at these and other retailers nationwide from August 2011 through November 2013 for between $170 and $260.

Further details about this recall are available at incompliancemag.com/news/1402_06.

Pre-lit Christmas Trees Recalled Due to Fire Hazard

Seasonal Specialties LLC of Eden Prairie, MN is recalling about 1800 of its Enchanted Forest-brand pre-lit Christmas trees manufactured in China.

The company reports that electrical components in the trees' light strings can overheat and melt, posing a fire, burn and shock hazards to consumers. There have been two separate reports of the trees' light strings overheating, melting or smoking, but no reports of consumer injuries.

The recalled Christmas trees were sold exclusively through Menards retail stores nationwide, and through Menards.com, between September and November 2013 for about $300.

More information about this recall is available at incompliancemag.com/news/1402_07.

Company Recalls PERS Transmitters

Linear LLC of Carlsbad, CA has issued a voluntary recall for about 48,000 of the company's personal emergency reporting system (PERS) transmitters manufactured in China.

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

The recalled transmitters were sold through independent PERS distributors and dealers nationwide from June through August 2013 for about $45.

Additional details about this recall are available at incompliancemag.com/news/1402_08.

REALITY Engineering

Frying the Flight Data Recorder

How *Not* to Impress

BY MIKE VIOLETTE

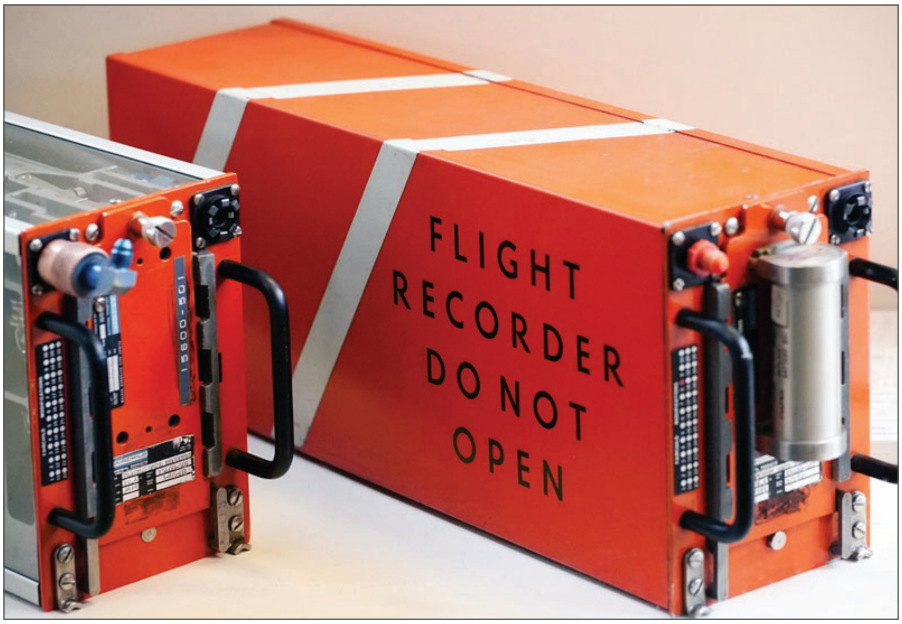
In this month's *In Compliance Magazine* the focus is on military and aerospace topics. Along those lines, we worked on a project for an aviation company some years back. In mining the archives, so to speak, we head to the lower peninsula of Michigan, to the city of Grand Rapids.

Grand Rapids is the birthplace of Gerald Ford and the home of the Gerald Ford Presidential Library & Museum, where the late President was laid to rest. Ford served a partial term on the bully pulpit after a long run in Congress (1949-1973). He succeeded Spiro Agnew as Veep under Nixon after Agnew resigned, in disgrace, in December 1973.

Those were crazy days in politics and Nixon's presidency crumbled nine months later under the weight of the Watergate scandal. It was a turbulent and challenging time, indeed, what with the imminent collapse of Saigon, the oil embargo, the threat of thermonuclear war, pastel leisure suit sightings and the woeful growth of disco music.

With all of *that* on his plate, I wonder if Mr. Ford, sometimes, wished he had stayed in Grand Rapids to practice something more peaceable than politics, like divorce law. Now, Michigan has a "no-fault divorce" provision on the books which, I suppose, makes it a bit easier to get un-hitched. One day, a few years back, I wished there was protection for "no-fault consulting."

More on that later, but first a bit on Grand Rapids. Native Americans have inhabited the area around the Grand River for millennia. Westerners, first French fur trappers and later woodsmen, started arriving in the late 1700s. Foundations of the city's industrial base were developed one hundred years later as craftsmen and



entrepreneurs built "The Furniture City." To this day, she hosts several high-end furniture manufacturers. Grand Rapids is also home to a wide variety of technology industries, including machinery, automotive and aerospace.

Where once rapids roared and riffled on the Grand River, dams, power canals and tailraces have subdued her natural flow, now largely serene as it meanders through the town. In the spirit of post-environmental awareness, there are movements in the city to bring back the natural rapids to Grand Rapids.

Motu Viget means 'strength in activity,' which is her motto and is a paean that harks even back two thousand years to Native American Mound Builders, who stayed active constructing impressive edifices of dirt and clay to bury their dead.

As the town grew in the mid 1800s and accepted immigrants from Holland, Germany, Ireland, Sweden, Italians and Poland, the city's location in the industrial heartland of America lends access to major markets and a diverse salt-of-the-Earth populace that boasts a strong work ethic, typical of the solid mid-western towns in the US. Later, refugees from war and foreign strife came to settle in the town. After the pogroms of the 1930s and World War II, European Jews found safety and peace in Grand Rapids. Hungarians settled after 1956 and Vietnamese after the fall of Saigon.

A place of activity—and strength—indeed.

The economy of Grand Rapids is diverse, too, with not as much vertical reliance on a single industry as, say, Motor City, a hundred and sixty miles to the East, with the avionics industry supplying sophisticated systems, to where this story arcs. One project that we were called to investigate was a Flight Data Recorder (FDR). These so-called "black boxes" (actually painted orange or yellow for better visibility at a crash site) have been standard in aircraft beginning in the 1950s. The earliest versions were analog and relied on a metal foil in a crash-survivable case.

The initial development of electronic FDRs for the Air Force (for the F-16)

REALITY Engineering

Something inside the unit popped and sizzled.

"Aw crap," Al said and sighed. "There goes my afternoon." I looked at him and he shrugged his shoulders.

"Might as well go to lunch now."

began in 1982, starting a continuing evolution of solid-state based digital devices. With no moving parts, they were much better suited to survive the tremendous impact and related injuries associated with a high-speed nose into *terra firma*.

The designs of FDRs have tracked heavily integrated with flight systems; very rapid advances have been occurring since the 1980s. This is especially true as more aircraft are developed with fly-by-wire controls, which allow the monitoring and recordation of dozens of sensor signals. The FDR systems consist of not just a single box, but of multiple, linked modules including the Signal Acquisition Unit, Cockpit Control Unit, Data Acquisition and Recording Unit and the Voice and Data Recorder. By the late 1990s, these systems were growing in capacity and capability. Memory units with up to several hundred megabytes meant that more parameters could be stored, for longer periods of time, giving incident investigation loads of data for analysis after crashes. This means the integration and density of electronics has increased tremendously, along with rise of clock and data rates, and EMI.

Versions of these data recorders are now being deployed in railroad applications. Following a fatal crash in Chatsworth, CA in September 2008, the National Transportation Safety Board (NTSB) made the following recommendation to the Federal Railroad Administration to "Require the installation of crash- and fire-protected inward- and outward-facing audio and image recorders capable of providing recordings to verify that train crew actions are in accordance with rules and procedures that are essential to safety as well as train operating conditions."

Passenger vehicle Event Data Recorders, monitoring speed, brake condition, seatbelt status and cruise control settings are now common in motor vehicles and have been used to prove assertions of reckless driving in court.

Our client in Grand Rapids was developing the Signal Acquisition Unit, a critical part of the FDR's distributed component of the avionics system connected via a serial 1553 bus. The unit we worked on, a gray squat rugged aluminum box, had four connectors on its face. These were dense MIL-style circular multi-pin affairs that connected to harnesses made of dozens of individual wires. The device was failing RE102 emissions in the 30-60 MHz band. A quick look at the signals showed a mix of narrowband clock-like emissions and broadband data-generated noise: ugly stuff.

We were set up in a small shielded enclosure. A biconical antenna was set up and connected to a spectrum analyzer that was sitting on a cart next to the bench. The wiring connected to the EUT was splayed out on the bench. The analyzer display bloomed with green spikes, picking up energy radiating off the harness wiring.

Because of weight issues, shielding the wires was out of the question, not to mention the complexity of making a complete shield with routing for branches and to connect to various locations on the airframe.

So, what to do? Well, these kinds of situations are really the nasty ones: few options, a complex box, tons of wiring and any number of sources, any one of them could put the unit out of compliance.

We tried clip-on ferrites inside, squeezing them over the internal wiring. No luck. The thing about ferrites is: either they work, or they don't. Besides, the mechanical guys weren't too thrilled about installing an unsecured hunk of sintered iron inside the device that had to survive multiple-G environments.

After a morning of fiddling around, checking schematics and looking at pinouts, it was time to break for lunch. Reality engineering sometimes means knowing when to put down the scope probe, but I didn't. The question kept nagging at me: which of these pins had the most energy? Could we knock these signals down one-at-a-time? One of the tricks of the trade, so to speak, is to take a dental pick and carefully connect it to suspect pins, all the while looking at the spectrum display. If a particular node was "hot" the radiated energy off of the pick would peak frequencies on the analyzer.

One of the project technicians, a calm, older guy named Al who, as I recall, was a whiz at surface mount surgery, stood by as I poked the pinouts on C1, the largest of the four circulars.

"Be careful." Al said.

The eye-hand coordination was better back then, but even so after a half-dozen pokes, my pick slipped and I crossed two pins. Something inside the unit popped and sizzled.

"Aw crap," Al said and sighed. "There goes my afternoon." I looked at him and he shrugged his shoulders. "Might as well go to lunch now."

I put the dental pick down and followed him out of the room down the hall a few paces behind, head lowered and just a little shaken.

Al turned into the room where the engineers' cubicles were arranged, tapped the lead engineer on the shoulder and told him, calmly. "The consultant fried the unit."

A nanosecond later, I walked into the room to hear the lead, jumping up from his desk yelp: "What?! Kill Him!"

Lunch that day at the company cafeteria was quiet, I sat a few seats away from the project manager, trying to stay cool. He was picking at a plate of lukewarm lasagna, muttering something about the schedule getting 'shot in the ass.' Oops.

Back at the 'shop' I debriefed John, my supervisor, somewhat sheepishly. John was calm. "Those things happen. I blew out the front-end of a forty grand receiver when I was younger. It's reality."

They ultimately got the unit working again (it turns out that I blew out a simple line driver; thankfully back then DIP packages were pretty easy to de-solder and replace). Al did a fine job, but it did take the rest of the afternoon.

Ultimately, we found some filter-pins that were retrofitted to the circular connectors as a quick-fix and sold them an EMC design course.

REFERENCES

- FDR History: http://www.boeing.com/commercial/aeromagazine/aero_02/textonly/s01txt.html
- FDR: http://www.thic.org/pdf/Oct97/smithsind.sgresley.pdf
- NTSB: http://www.ntsb.gov/investigations/summary/RAR1001.html

(the author)

MIKE VIOLETTE
is President of Washington Labs and Director of American Certification Body. For reasons that have nothing to do with frying that flight data recorder, he has not been back to Grand Rapids. He can be reached at mikev@wll.com.

TECHNICALLY Speaking

Double Fusing

or Fusing Both Sides of the Line

Product Safety Newsletter, June 1988

BY RICHARD NUTE

Every once in a while, someone asks the question whether fusing both sides of the power line is safe and permissible.

FAULTS

The first question that must be addressed is: What fault protection is the fuse providing?

There are two kinds of faults: (1) phase-to-neutral (pole-to-pole) and (2) phase-to-ground.

(Note that a fuse cannot provide protection for a neutral-to-ground fault because, by definition, the neutral is grounded. In a neutral-to-ground fault, the neutral and ground conductors become parallel conductors. In accordance with Kirchoff's Laws, the current in the neutral goes down, not up. Hence, the over-current does not occur, and a fuse cannot provide protection).

SINGLE FUSING

A single fuse in the phase conductor provides protection for both kinds of faults.

A single fuse in the neutral conductor provides protection for neutral-to-phase faults, but not for phase-to-ground faults. This is one reason why a single fuse in the neutral is not permitted.

DOUBLE FUSING

The second question that must be addressed is: Under what conditions does double-fusing provide the same or better protection than a single fuse?

We have already determined that a single fuse in the phase conductor provides adequate protection against both kinds of faults, and that a fuse in the neutral conductor does not. If double fusing is employed, the equipment is protected against both faults, but the neutral fuse is redundant for phase-to-neutral faults, and inoperative for phase-to-ground faults.

The only condition where fusing both phase and neutral conductors yields non-redundant protection against both faults is where polarity reversal is possible. That is, where the phase and neutral conductors could be interchanged on the supply side of the fuse. If polarity reversal is possible, then double-fusing guarantees that the phase conductor will always be provided with a fuse.

With double fusing, protection against both faults is provided for both normal polarity and reverse polarity.

POLARITY REVERSAL

The third question that must be addressed is: Is polarity (phase-neutral) reversal possible in the circuit on the supply side of the fuse? That is, is the fuse location (ie: phase or neutral conductor) constant or variable?

BUILDING WIRING AND PERMANENTLY-CONNECTED EQUIPMENT

If we are dealing with building wiring or permanently-connected equipment, then fuse location is not variable, and polarity reversal is not possible. In this case, one fuse, in the phase conductor, provides protection for both phase-to-neutral and phase-to-ground faults.

The NEC, CEC, IEE Wiring Regulations and IEC 364 specifically prohibit fusing the neutral in building wiring and permanently-connected equipment.

PLUG-AND-SOCKET-CONNECTED EQUIPMENT

If we are dealing with plug-and-socket-connected equipment, then we must examine the supply configuration, socket configuration, plug configuration, and wiring codes to determine whether fuse location is variable or not.

THREE-PHASE AND MULTI-VOLTAGE EQUIPMENT

For three-phase (e.g. 208/120) and multi-voltage (e.g. 120-0-120) supplies, the plug and socket must maintain polarity in order to have functionality. In these cases, the fuse location is not variable because any polarity reversal (other than phase rotation) results in incorrect voltages applied to the equipment, usually with immediate catastrophic results, and opening of the building fuse or circuit breaker.

For these cases (plug-and-socket-connected three phase equipment and multi-voltage, e.g. 120-0-120 equipment), a fuse in each phase conductor provides protection for both phase-to-neutral and phase-to-ground faults. A fuse in the neutral conductor would be redundant and should it operate (open), the voltages applied to the various circuits will change and could cause overvoltage, overcurrent, and overheating conditions in at least one of the individual loads. For this reason, a fuse in the neutral must be prohibited, or it must be “ganged” with the phase conductor fuses such that if any one, including the neutral, operates, they all open.

SINGLE PHASE EQUIPMENT

For single-phase plug-and-socket-connected equipment, the plug and socket may or may not reliably maintain polarity, depending on the electrical code and the socket configuration.

Supposedly, the NEMA 5-15R socket maintains the polarity of the building wiring, with the wide blade being the neutral conductor. However, there are several versions of the NEMA 5-15P plug, some with wide blade and some without. Therefore, some plugs allow polarity reversal, while others do not.

In continental Europe, the socket wiring for the common 220 V, 16A plug is not polarized, and the equipment fuse location would be variable. In the UK and Australia, sockets and plugs are polarized, and the equipment fuse location would be constant.

The point is that each plug, socket, and building wiring is an independent situation which must be separately evaluated as to whether polarity reversal is possible. This in turn would make the equipment fuse location constant or variable.

THE GENERAL CASE FOR SINGLE-PHASE PLUG-AND-SOCKET-CONNECTED EQUIPMENT

For single-phase, single-voltage plug-and-socket-connected equipment, single fusing ONLY provides protection for both faults when polarity reversal is not possible. If polarity reversal is possible, then a single fuse can only provide protection against phase-to-ground faults 50% of the time.

For single-phase, single-voltage plug-and-socket-connected equipment, double fusing ALWAYS provides protection for both kinds of faults regardless whether polarity reversal is possible or not.

However, there are two hitches to double fusing.

First, when operating on a polarized system, some safety authorities insist that fusing be provided only in the phase conductor such that all of the equipment is de-energized for protection of the serviceman. This seems to require one fuse only.

However, this can be accommodated by using two, different value fuses. Select the fuse for the phase conductor (when connected to a polarized system) for proper overcurrent protection. Select the fuse for the neutral conductor to be one size larger than the phase conductor fuse. Thus, when connected to a polarized system, the smaller fuse properly opens for phase-to-neutral and for phase-to-ground faults. When connected to a non-polarized system and with reverse polarization, the smaller fuse provides protection for phase-to-neutral faults, and the larger fuse provides protection for phase-to-ground faults.

Second, some safety authorities insist that fusing be provided only in the phase conductor as required for building wiring. Any fuse in the neutral is cause for non-compliance of the equipment. The only solution here is to change our building codes and regulations to exempt single-phase plug-and-socket-connected equipment.

(the author)

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

MR. Static

Ions

BY NIELS JONASSEN, sponsored by the ESD Association

The word ion (in Greek, ιον) means wanderer. It denotes an entity, a particle, that will move under the action of an electric field. So, in principle, valence electrons in metals or holes in semiconductors could be considered ions. But in practice, the name ion is reserved for two species: electrolytic ions and gaseous ions.

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

ELECTROLYTIC IONS

If you have an aqueous solution of silver nitrate, the $AgNO_3$ is dissociated as:

$AgNO_3 \rightarrow Ag^+ + NO_3-$

Ag^+ is called a silver ion and NO_3- a nitrate ion.

If an electric field is now applied to the liquid, the positive silver ions will move in the direction of the field toward the negative cathode, where they each will receive an electron, become neutralized, and plate out onto the electrode. This is the basis for electroplating.

A somewhat similar process takes place at the anode—but we are not going to discuss electrochemistry in detail. Rather, I will point out just a few facts about electrolytic ions. The silver and nitrate ions, as well as other electrolytic ions, have well-defined properties. All silver ions are identical, at least chemically speaking, and they never change their properties no matter what you do to them, as long as they remain ions.

If a given ion is exposed to an electric field with the strength E, it will move with a constant velocity v given by:

$v = kE$

where k is a constant representing the mobility of the ion. Again, a silver ion always has one positive charge and always the same mobility, at least when you consider a given isotope of silver. The same constancy is true for any other electrolytic ion.

GASEOUS IONS

Although ions may be formed in most gases, we will restrict ourselves here to discussion of those types of ions that may be formed and found in atmospheric air, the so-called air ions or atmospheric ions.

The formation of an air ion starts with an electron being knocked off a neutral air molecule, as shown in Figure 1. The now positive molecule (oxygen or nitrogen) will rapidly attract a number of polar molecules (10–15), mostly water, and this cluster is called a positive air ion. The electron will probably attach to an oxygen molecule (nitrogen has no affinity for electrons), and this negative molecule will attract a number of water molecules (maybe 8–10), forming a cluster called a negative air ion. It is important to note that ions are always formed in pairs, and always the same number of positive and negative ions.

It takes a certain energy, about 34 eV ($\sim 5.4 \times 10^{-18}$ J) to knock off the initial electron. This energy may be delivered by shortwave electromagnetic radiation (x-rays or gamma rays), or more often from a colliding particle.

NATURAL IONIZATION

Most of the ionization in the lower atmosphere is caused by airborne radioactive substances, primarily radon and its short-lived daughters. In most places of the world, ions are formed at a rate of 5–10 pairs per cm^3 per second at sea level. With increasing altitude, cosmic radiation causes the ion production rate to increase. In areas with high radon exhalation from the soil (or building materials), the rate may be much higher.

It is primarily alpha-active materials that are responsible for the ionization. Each alpha particle (for instance, from a decaying radon atom) will, over its range of some centimeters, create approximately 150,000–200,000 ion pairs.

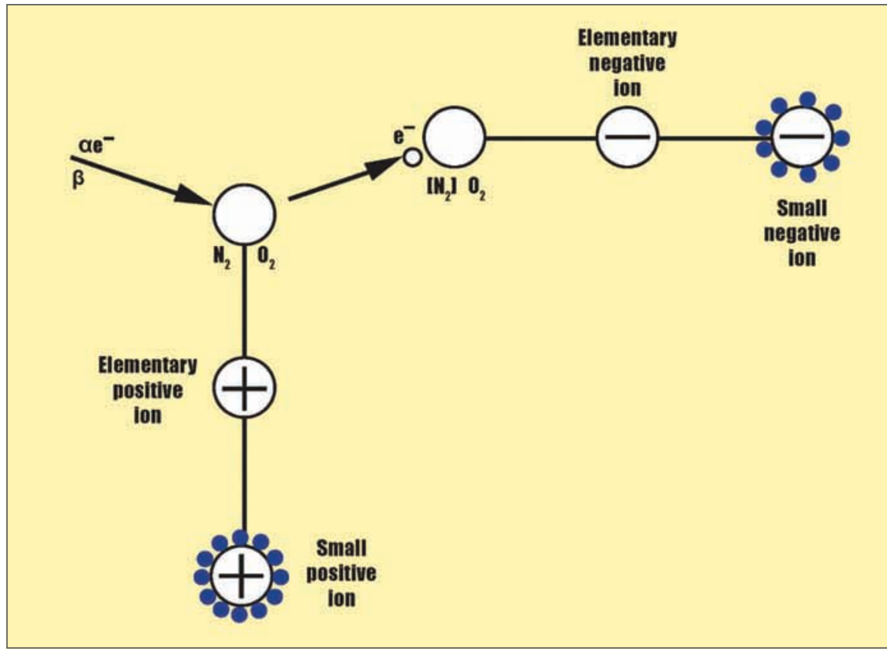


Figure 1: How air ions are formed

MR. Static

Ions don't live forever. They may recombine with oppositely charged ions or, more likely, combine with aerosol particles in the air.

FIELD IONIZATION

Although ionization from radioactive sources (often a polonium isotope) is used for technical purposes, and for certain applications it is to be preferred for any other method, the most common artificial method of producing ions is by field ionization.

It's somewhat ironic to realize that this method presupposes an ongoing, however weak, natural ionization. If a sufficiently strong electric field is established—for instance, between an electrode at a potential of some kilovolts and a ground—the electrons being freed by natural ionization may be accelerated to such velocities that they themselves can cause ionization, again creating pairs of (positive and negative) ions. It should be stressed that it does not take a high voltage, but high field strength, to cause ionization.

The breakdown field strength, as it is called, is somewhere around 3 MV/m between plane electrodes (in air at atmospheric pressure). If you have two metal plates at a distance of 1 cm, you need a voltage difference of about 30,000 V for ionization to take place in the space between the plates. If, however, one of the plates is replaced by a sharp metal point or a thin wire, the necessary voltage may be only a few kV. The explanation is that for a given voltage difference, the field strength in front of a point is much higher than between plane electrodes. Thus although the breakdown field strength is higher in front of a point, ionization is still established at lower voltages using sharp electrodes.

Now let's imagine an electrode, say a sharp metal point, kept at a positive potential of some kV with respect to ground, which may be represented by the walls of the room, as shown in Figure 2. In a small volume, perhaps a few cubic millimeters around the tip of the electrode, ion pairs are formed. The negative ions are attracted to the electrode, where they give off their charge and cease to exist as ions. The negative charge from the ions runs through the electrode to the voltage supply, making it look as though the electrode delivers a positive current to the air. The positive ions, formed in front of the electrode, are repelled by the electrode and move away. All in all, it appears that positive ions are emitted from the positive electrode.

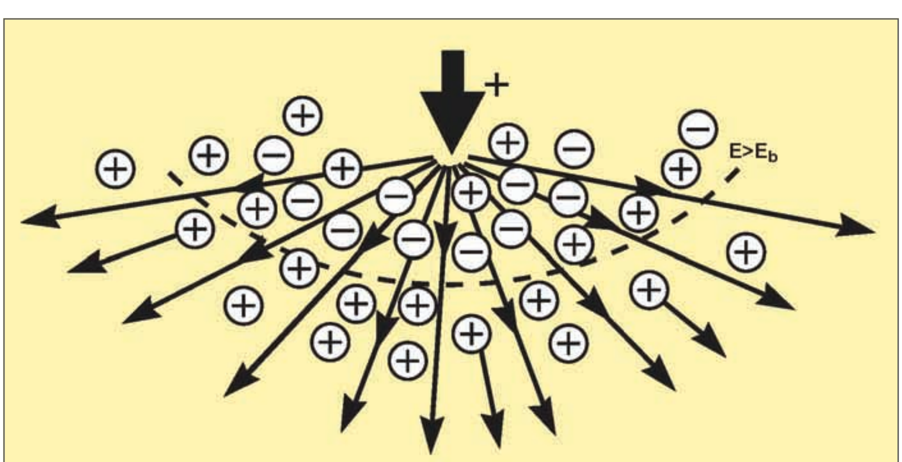


Figure 2: Field inonization, caused by an electric field between an electrode and ground

But this conclusion is completely wrong. The positive ions have never been in contact with the electrode. The electrode, often called an emitter, doesn't emit anything. Rather, it collects things (specifically, negative ions). Sadly, it's probably too late to change this linguistic malpractice.

WHAT DO IONS DO?

Ions don't live forever. They may recombine with oppositely charged ions or, more likely, combine with aerosol particles in the air. The charged particles, sometimes called large ions, will also move in an electric field, although much more slowly than the air ions do.

This is the principle for the first technical electrostatic invention, the electro filter, without which we would have no means of effectively cleaning the smoke from coal- or oil-fired power plants and many other industrial installations.

Ions may also plate out onto surfaces, either by diffusion or aided by an electric field. And this is the basis for another important technical use of ionization.

Let's assume we have a charged insulator and we want to remove the charge.

Well, let's face it. It can't be done. There's no way by which a charge can be removed from an insulator. But don't panic. The charge in itself doesn't do any harm. It's the field from the charge we have to worry about. And the field may be used to neutralize itself.

If the charged insulator is exposed to an atmosphere containing ions of polarity opposite that of the charge, the field will attract ions, which will move toward the body and neutralize the charge. At least that's what appears to happen.

But a more strict formulation would be that the original (excess) charge is still there, and so is its field. The oppositely charged ions, attracted from the air, will deposit around the original charge, but not annihilate it. The resulting field, the sum of the fields from the opposite charges, will be zero, or at least very close to zero.

The use of air ionization for abating static electric effects is a slow method, compared to methods like the grounding of conductors or surface treatment with topical antistats. But it should be stressed that when we are talking about charged insulators, exposure to ionized air is the only method to remove the effects of the charge.

IONS AND PEOPLE

Soon after the discovery of atmospheric ions about a century ago, it was suggested that the ions might have an effect on people breathing the air containing the ions. Among the effects suggested was that air with an excess of negative ions would feel fresh, while an excess of positive ions would make the air stuffy.

This popular but still undemonstrated belief will be the subject of a subsequent column on static electricity and people.

(the author)

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

EMC Education

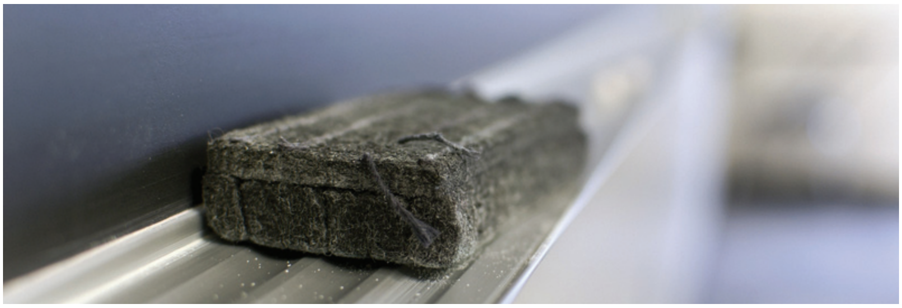
The View from the Chalkboard

BY MARK STEFFKA

Perhaps the subtitle of this month's "View from the Chalkboard" can best be called "In Compliance" - more than just a magazine name! .....or it can be put another way, "What is the importance of EMC Standards in an EMC Curriculum"?

Regardless of the title, it turns out that the topic of EMC standards is not typically part of a university-based EMC curriculum. This is interesting, since EMC standards are important (*and many times are a requirement*) to demonstrate that a product not only has met its "functional" characteristics, but that the product complies to various types of EMC standards. These standards may range from those designed to ensure customer satisfaction to those that are legal requirements imposed by national governments. Unfortunately, many times the concept of requiring products to meet or comply with various engineering standards is seen as an unneeded and an undesired sequence of steps in "checking the box" in a product's design, development, and production. Ironically, it's actually the opposite situation.

Our modern society has developed many inventions and innovations to make our lives simpler and more efficient. A key to the success of these inventions and innovations is the ability to use standards to ensure the reliable and safe operation of these devices. It also turns out that the standards themselves can also spur innovation and development across a wide range of systems and ensure new technology meets user (or customer) requirements. Over the next several paragraphs I will highlight some of the resources that are available to help EMC educators become familiar with the concept of EMC standards, and I will provide information on where to go for additional resources to help include standards education in an EMC curriculum.



One of the best places to start is the IEEE Standards association website. This is the organization that has responsibility for all types of standards that the IEEE is concerned with. Much of the modern world of electrical and electronic systems is built upon IEEE standards, such as data bus definition (IEEE 488), and, of course, one of the most common "consumer" used standards, IEEE 802, standards for wireless communications.

Figure 1 shows a good starting point into EMC standards education. These standards cover a number of topics, from antennas to RF exposure, along with information about electromagnetic propagation which is important to know in order to understand and successfully apply the standards.

Realizing that education in standards development and their use is important, there is another IEEE resource called the "EAB/SA Standards Education Committee". This website is shown in Figure 2.

As IEEE states:

> "Recognizing the important role standards play within the engineering, technology and computing fields, IEEE is providing resources to help introduce and teach undergraduate and graduate students, as well as professors and educators, about technical standards by providing free online tutorials and case studies. Knowledge of standards can help facilitate the transition from classroom to professional practice by aligning educational concepts with real-world applications.
>
> These resources will hopefully be of use in the classroom and help incorporate the teaching of standards into curricula to:
>
> - benefit both students and their faculty mentors as they face challenging design processes;
> - help electrical and computer engineering undergraduate programs incorporate standards into their learning processes;
> - provide tools for use in learning about standards and their impact on design and development."

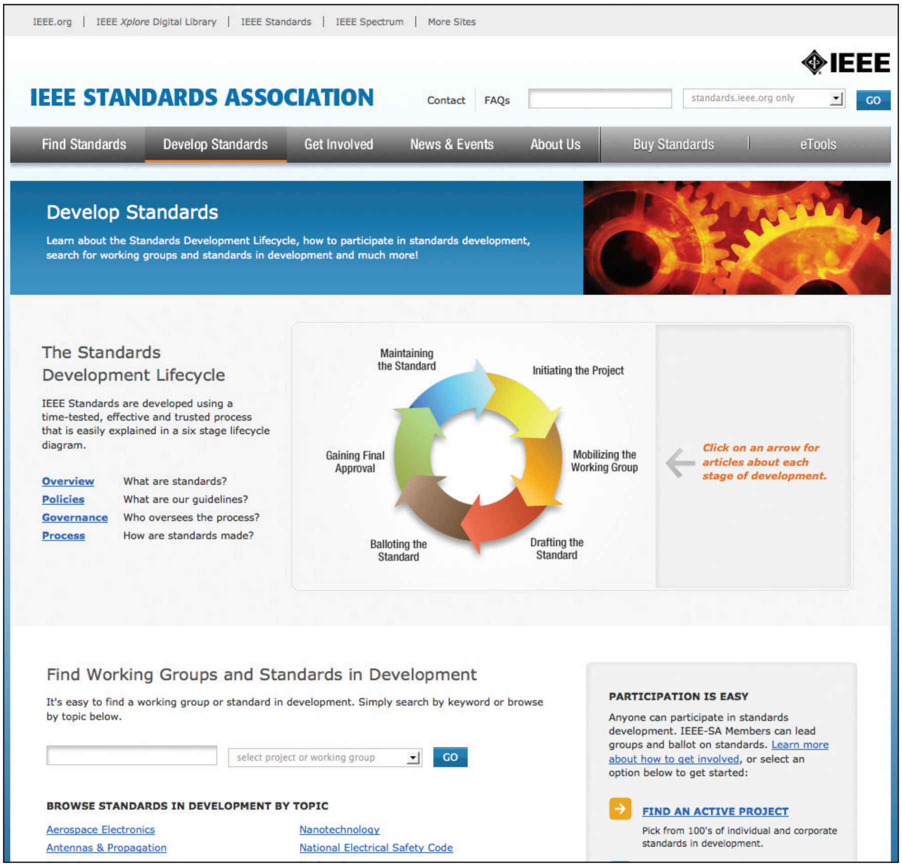


Figure 1: Information about EMC standards education http://standards.ieee.org/develop/index.html

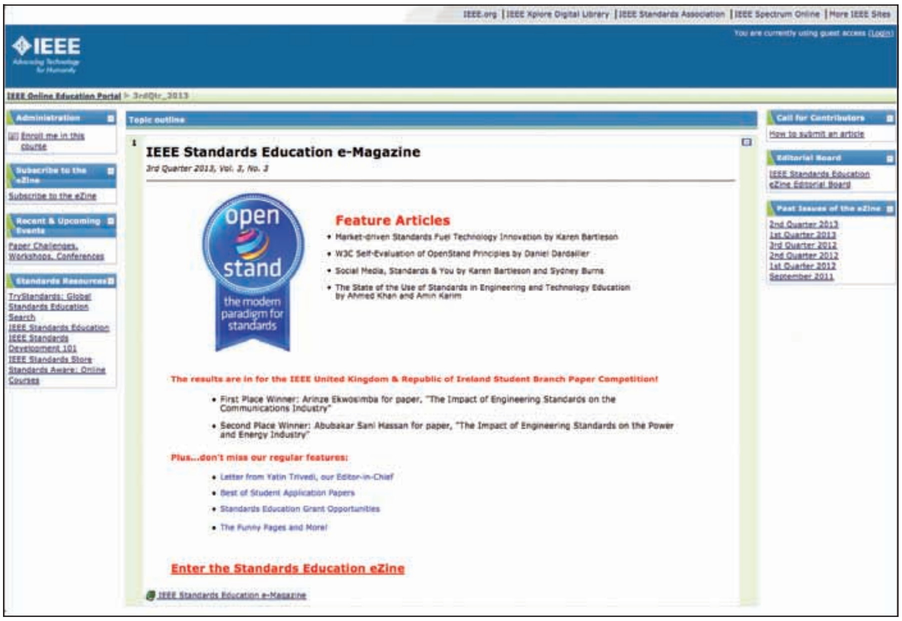


Figure 2: EAB/SA Standards Education Committee https://ieee-elearning.org/outreach/course/view.php?id=1372%3f

EMC Education

Those important points (and additional details) can be seen on the website shown in Figure 3.

A good introduction and overview of EMC specific standards that can be referenced in EMC education is at the website shown in Figure 4.

So in closing, as you can see, this has been only an overview of EMC standards, and you are encouraged to dig deeper into this topic. I am sure once you do so you will see the benefits of incorporating this topic into your EMC educational curriculum!

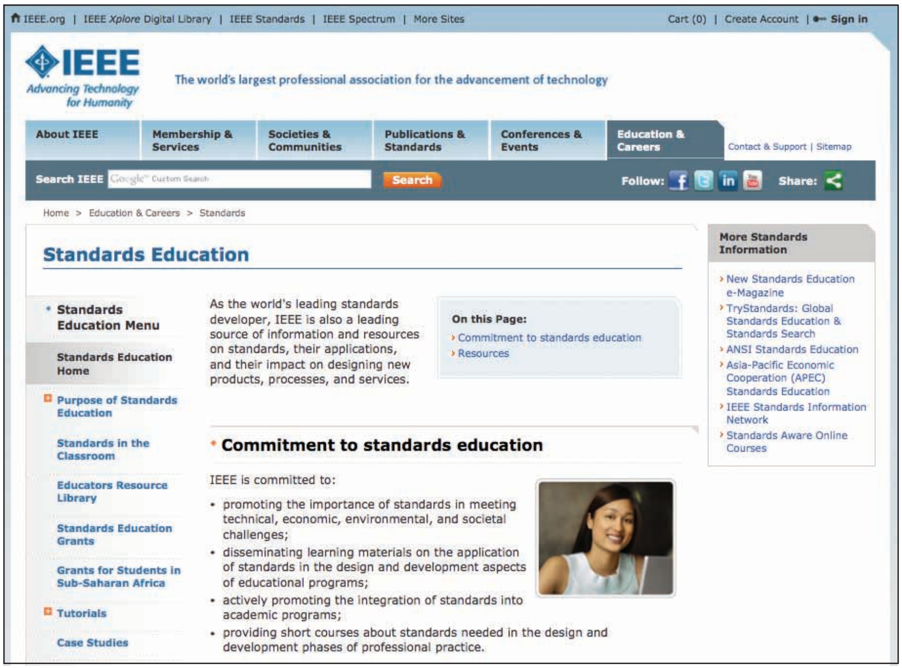


Figure 3: Information about standards education
http://www.ieee.org/education_careers/education/standards/index.html

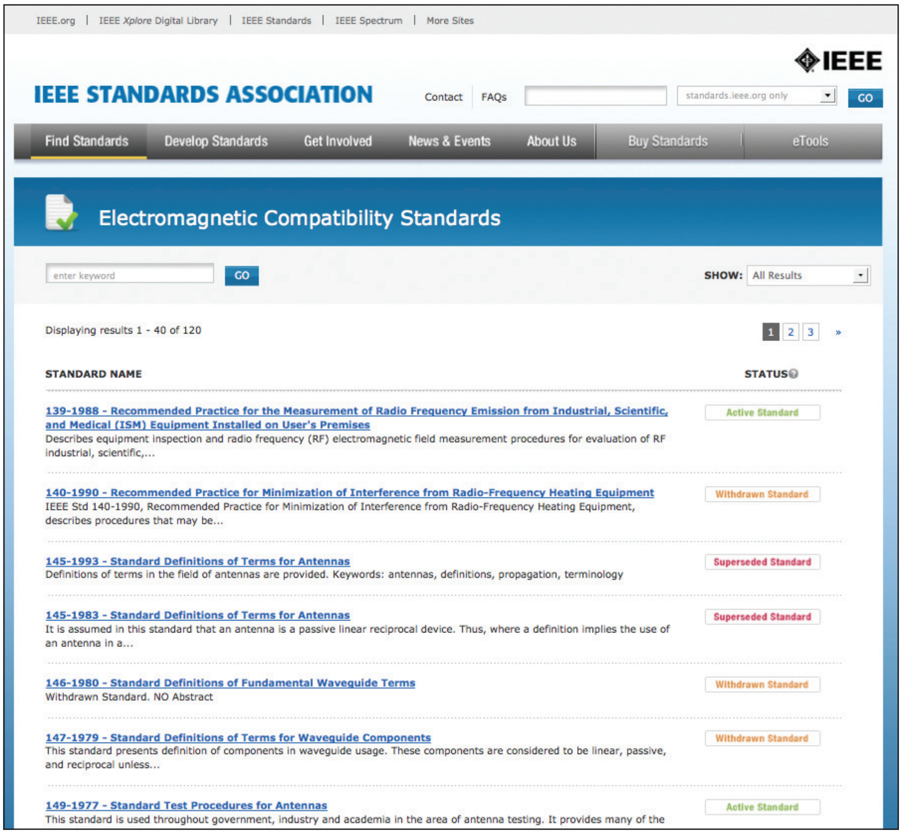


Figure 4: Introduction and overview of EMC standards
http://standards.ieee.org/findstds/standard/electromagnetic_compatibility.html

(the author)

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

EMI vs. EMC
What's in an Acronym?

"A rose by any other name would stink." – Kenneth Adamson

BY KEN JAVOR

We have all seen advertising copy for test equipment manufacturers' "EMC receivers" and "EMC test services" provided by commercial EMI test facilities. While we know what the aforementioned receiver does, and what sort of services the test facility supplies, the nomenclature is wrong and is symptomatic of a deeper problem.

In this issue dedicated to defense and aerospace, we examine defense and aerospace EMC practices, and compare/contrast these processes with those of other market sectors. EMI vs. EMC nomenclature is a good introduction.

Per ANSI C63.14 we control electromagnetic interference in order to achieve the desired state of electromagnetic compatibility:

> EMI: "Any electromagnetic disturbance … that … degrades … performance of electronic or electrical equipment."
>
> EMC: "The capability of electrical and electronic systems, equipments, and devices to operate in their intended electromagnetic environment … without … unacceptable degradation as a result of electromagnetic interference."

Requirements controlling EMI characteristics such as CISPR 22, CISPR 25, RTCA/DO-160 and MIL-STD-461 are *means to an end*. That end is electromagnetic compatibility between devices qualified to these standards and between them and radios. Conjointly, EMI requirements are *not* an end in themselves. Any device with an FCC Part 15 sticker has a disclaimer to the effect that, "This device may not cause harmful interference..." This is the desired end result - EMC. If the device does cause interference (despite having met its EMI requirements), the user is advised to separate culprit and victim, and as a last resort, shut the culprit off: the licensed user of the spectrum has priority over the unlicensed polluter.

The bottom line is that standards controlling EMI are one of the tools by which we achieve EMC and EMC is demonstrated, if at all, on the integrated system, which is typically a vehicle that drives, sails (above or below the sea) or flies (within or above the atmosphere). Equipment designed for use in homes, offices, and factories don't have a specific installation, and there is no EMC check for such equipment. EMI requirements to which they are subjected are the sole qualification relative to EMC. Hence, it is not surprising that this market segment most often fails to properly distinguish between EMI and EMC.

Photo credit: ESA–A. Le Floc'h

The essence of system engineering – any engineering – is tradeoffs. In vehicle engineering, we can review EMI test data, and decide if out-of-tolerance signatures allow an acceptable level of EMC.

Integrated vehicles are functionally evaluated – EMC tested – ensuring that each subsystem operates properly as part of the greater whole, acting as neither a source of nor a victim to EMI within the vehicle. Separately, the entire vehicle is subjected to external stresses such as steady-state and transient electromagnetic fields, and the subsystems must operate properly. "Proper operation" might include graceful degradation, such as anti-lock brakes becoming purely hydraulic brakes with no electronic control.

Most importantly for this discussion, vehicle antennas will be interrogated by an EMI receiver looking for signals coupled to that antenna in-band to the receiver. On an automobile, that would mean 530 - 1710 kHz and 87.5 - 108 MHz at the point where the coaxial transmission line disconnects from the AM/FM receiver, and perhaps the "shark fin" antenna used for satellite reception. On a military aircraft, in contrast, there could be such measurements from 0.15-1.99 MHz (ADF), 2-30 MHz (hf), 30-88 MHz (vhf-FM), 108-152 MHz (vhf-AM, with both air navigation aids and communications residing in this band), 225-400 MHz (uhf-AM), 960-1215 MHz (TACAN), and perhaps others as well.

Such testing is the ultimate high fidelity EMC check, because the test set-up is the installation. All EMI standard test set-ups are approximations of expected installations, whether vehicle, home, office, or plant, and at best provide an upper bound of what would be expected to be measured *in situ*.

Along these lines, I like to quote a forerunner standard to MIL-STD-464, which is the present day military standard for electromagnetic effects that apply to a vehicle procurement. The 1967 vintage MIL-E-6051D, "EMC Requirements, Systems," paragraph 3.2.4.1, "Subsystems and Equipment," opens as follows: "Unless otherwise specified in the contract, subsystems/ equipments shall be designed to meet the requirements of MIL-STD-461 and MIL-STD-462. Since some of the limits in these standards are very severe, the impact of these limits on system effectiveness, cost, and weight shall be considered…"

The importance of this paragraph cannot be overstated. The essence of system engineering – any engineering – is tradeoffs. In vehicle engineering, we can review EMI test data, and decide if out-of-tolerance signatures allow an acceptable level of EMC. Often we do that by test – for instance, by installing equipment with excessive radiated emissions (RE) in the vehicle and monitoring the antenna band wherein the offending signals reside to see if they do in fact couple into the receiver, or if the installation provides enough isolation via shielding, shading and distance between equipment and victim antenna to eliminate the potential for interference.

Vehicle EMC engineers can do all this because EMI qualification testing occurs after a contract has been signed between equipment vendor and integrator. Integrator and vendor can collaboratively find an optimal solution for "system effectiveness, cost, and weight" and schedule. The process can be bumpy, but it does work, especially within the military-industrial complex.

In the consumer marketplace, where FCC or European Norm or other national laws require passing EMI requirements before placing products on the market, there is no flexibility: the limit is the law. Therefore an extreme amount of attention is placed on measurement repeatability/ uncertainty. A level playing field – irrespective of where a device is tested, or by whom – is an economic *sine qua*

> It is commonplace to contrast military versus commercial EMI test practices, but that is not a fundamental distinction.

non (without which, nothing). Tight uncertainty requirements supporting repeatability requirements such as the +/- 4 dB normalized site attenuation for RE testing and the -0, +6 dB tolerance for the electric field immunity test uniform field area require more expensive test sites and more complex procedures than those required for equipments slated for vehicle usage. Two factors differentiating facility costs are the degree to which reflections are controlled, and separations between antenna and test sample, which drive chamber size.

It is commonplace to contrast military vs. commercial EMI test practices, but that is not a fundamental distinction. Commercial aerospace and automotive EMI test practices have much more in common with military practice than they do with qualification of consumer items on open area test sites (OATS) or in fully or semi-anechoic chambers (FAC/SAC). The fundamental difference is installation in a vehicle (usually metal) vs. equipment slated for use in homes, offices and industrial plants. EMI testing of equipment installed in vehicles requires acknowledgment of the immediate proximity of electrical ground (vehicle structure) and the possibility that vehicle antennas will be placed nearby culprit electrical noise generators. Neither of these are the case for non-vehicle equipment. Or more precisely, it is quite possible in the home, office or factory that someone may try to listen to or watch a broadcast program or receive a wireless phone call and find that some device in the receiver's vicinity is causing interference. But it is under their control to increase culprit and victim separation, when the

Electric field structure is qualitatively, not just quantitatively different at one meter than at three and beyond. In close, we measure not only radiating signals, which are also picked up farther out, but in addition, inductive or quasi-static fields which do not propagate into the far field.

problem usually goes away. Separations up to three meters are deemed under the control of the Class B equipment end user, and separations up to ten meters are assumed under the control of the Class A end user.

Three or more meter separations coupled with RE control starting at 30 MHz and radiated immunity starting at 80 MHz happily allow for EMI measurements under far field, or nearly far field conditions.

Automobiles, aircraft and even large ships cannot guarantee such separations, and must impose one-meter RE measurements. Not all antenna-culprit separations will be precisely one meter, and while one-meter measurements are not scalable as are far field measurements, the vehicle EMC process does not stop at the one-meter measurement.

An example of the full vehicle EMC process offers insight into the fundamental differences between vehicle and non-vehicle EMI qualification. Medical devices designed for hospital use are needed in air ambulances. Part of ambulance qualification is EMI/EMC. The equipment in question already meets all medical device certifications, as it is commercially available and used in hospitals. But when re-qualified to aircraft EMI requirements, involving antenna-test sample separations of not three meters or more, but instead one meter, these devices often fail. Because the intent is to use existing off-the-shelf equipment, design modifications are undesirable and to be avoided, if at all possible.

When RE failures against the equipment limit are found, it is standard operating procedure to place the device in the aircraft and monitor aircraft antennas covering the failing frequencies with a spectrum analyzer, looking for evidence of excessive coupling. This is nothing new; the technique has been included in MIL-STD-464 since its inception in 1997. It is only the application to equipment neither designed for vehicle use, nor permanently installed in a fixed location within a vehicle that is different.

If the rfi signal measured at the aircraft antenna is deemed low enough to not be a problem, then the equipment-level EMI test failure does not force redesign. If the level measured at the vehicle antenna is too high, redesign is indicated despite the previous far field qualification for hospital use. One-meter re-qualification is necessary despite the previous qualification involving far field testing (three or ten meter), despite persistent voices calling for a single unified far-field test approach for EMI testing, which comes from the OATS/FAC/SAC faction.

Were we to accept the oft-repeated superiority of OATS/SAC/FAC measurements and replace vehicle type one-meter measurements we would at our peril violate basic physical laws. While far field measurements are attractive for deriving analytical relationships between various circuit parameters and the resultant electromagnetic field, these predictions are not useful to vehicle integrators working in the near field.

Electric field structure is qualitatively, not just quantitatively different at one meter than at three and beyond. In close, we measure not only radiating signals, which are also picked up farther out, but in addition, inductive or quasi-static fields which do not propagate into the far field. On vehicles where the separation between culprit emitter and victim antenna is much closer than three meters, three meter and farther out measurements do not protect against interference.

The traditional automotive whip antenna used in the AM & FM broadcast bands is a good example. In the far field of a wire radiator, the electric field will be parallel to the wire, assuming the wire is long enough to develop a potential drop across its length. For other than a large ship or very large aircraft, this can't happen in the AM band, only at FM. But in close, whether AM or FM, there is a non-radiating electric field component that starts on the wire and ends on the ground plane beneath it, due to the potential on the wire relative to ground. It cannot propagate, because the magnetic field associated with that wire circulates around it, and is co-directional with it. Electromagnetic energy only propagates when electric and magnetic field vectors are at mutually non-zero angles (Poynting's theorem).

If that whip antenna can be one meter from a noisy cable, then the EMI test has to also place the antenna at one-meter separation.

Then there is the issue of separation between test sample and ground plane. In the typical vehicle installation, equipment bonds directly or indirectly to vehicle structure. The EMI test simulates this with a tabletop ground plane mounted 80-90 cm above floor height. On an OATS or in a SAC/ FAC, the test sample is 80 cm above the floor ground plane, with at most a green wire

The simple conclusion is *we test things the way we use them*. It is always better to separate noisemakers and sensitive receivers, and when we can separate them we do, but when we can't, then we have to assess the potential for EMI at the separations we expect in actual use.

connection to it. Including a tabletop ground plane on an OATS or in a SAC/FAC destroys the anechoic properties of the facility, and those who advocate for OATS/SAC/FAC use also advocate for removal of the tabletop ground plane.

But the tabletop ground plane five centimeters below test sample attached cabling is worth up to 20 dB in reduced cable radiation efficiency for emission work, and something similar in terms of the effective aperture of test sample-connected cables during immunity/susceptibility testing. Especially for automotive use, where unshielded cables are the norm, meeting very stringent radiated limits one meter away in the absence of that ground plane is at best impractical.

It is presuming to insist on OATS and SAC/FAC type measurements in lieu of one-meter measurements for vehicle equipments. The comparison is apples and oranges. Considering not only (vehicle) equipment EMI testing, but also on-vehicle EMC assessment, including the super-hi fidelity check of RE coupling to vehicle antennas, it is clear that the overall vehicle EMI/EMC program efficiently does exactly what is needed.

Finally, there is the issue of protection of off-vehicle receivers. Automobile-level RE limits are imposed at ten meters to protect radios operating near roadways. Army ground vehicle-level RE limits impose control at one meter, to protect radios in a tactical operations center adjacent to which the vehicle might be parked. Some military aircraft impose RE control at one nautical mile to protect against aircraft detection by hostiles.

The simple conclusion is ***we test things the way we use them***. It is always better to separate noisemakers and sensitive receivers, and when we can separate them we do, but when we can't, then we have to assess the potential for EMI at the separations we expect in actual use.

To demand that vehicle equipment-level EMI testing adopt SAC/FAC/OATS type methods is akin to the old joke about looking for lost car keys not where they were dropped in a dark alley, but a block away under a street lamp, because it is easier to see there.

(the author)

KEN JAVOR

has worked in the EMC industry over thirty years. He is a consultant to government and industry, runs a pre-compliance EMI test facility, and curates the Museum of EMC Antiquities, a collection of radios and instruments that were important in the development of the discipline, as well as a library of important documentation. Mr. Javor is an industry representative to the Tri-Service Working Groups that write MIL-STD-464 and MIL-STD-461 (the "G" effort presently underway). He has published numerous papers and is the author of a handbook on EMI requirements and test methods. Mr. Javor can be contacted at ken.javor@emccompliance.com.

Design Practices for Military EMC and Environmental Compliance

BY MILITARY EMC STAFF, INTERTEK

The reliable operation of complex electronic communications, control and armament systems in extreme environments demands stringent design criteria and careful validation. Severe shock, vibration, heat, humidity and airborne contaminants are common in land, sea and air platforms.

Coupled with dense packaging, high-power radio and radar illumination, Hazards of Electromagnetic Radiation to Ordnance (HERO), and a possible electromagnetic pulse (EMP), the military equipment environmental requirements can be extreme indeed.

In order to expedite equipment availability and reduce cost, the acquisition of commercial-off-the-shelf (COTS) equipment for US military applications is an attractive consideration. But many types of commercial equipment are unlikely to meet all military environmental requirements as manufactured, so some modification or re-design is usually needed. Defining the gap between the commercial equipment's environmental performance and its military expectations is a first step in determining its potential suitability.

The full cycle of US military product development from environmental assessment, to definition of requirements, to test reports, is carefully spelled out in the relevant military standards or ancillary documents for the applicable physical and electromagnetic environments. These provide the design guidance, along with competent engineering practices, for a cost-effective and robust military product design.

THE ELECTROMAGNETIC ENVIRONMENT

Electromagnetic compatibility (EMC) requires the component, equipment or system to perform its designed functions without causing or suffering unacceptable degradation due to electromagnetic interference to or from other equipment. The starting point for EMC is self-compatibility, where the final product or system does not interfere with its own operation. This is a basic requirement in military EMC standards; for example, in MIL-STD-461F clause 4.2.3:

> *The operational performance of an equipment or subsystem shall not be degraded, nor shall it malfunction, when all of the units or devices in the equipment or subsystem are operating together at their designed levels of efficiency or their design capability.*

As we shall see, this is the modest starting point for military EMC, which extends to both lower and higher frequencies than most commercial EMC standards and to both lower emission limits and much higher susceptibility requirements. Test methods generally differ from their commercial counterparts in both setup and detail.

History of Military EMC

EMC problems in commercial applications were first noted worldwide in the 1930s, when early broadcast radios were being installed in automobiles. Reception was degraded by ignition noise and electrostatic buildup caused by non-conductive rubber tires.

The first US military specification on EMC also addressed this problem. It was published by the US Army Signal Corps in 1934 as SCL-49, "Electrical Shielding and Radio Power Supply in Vehicles". It required shielding of the vehicle ignition system, regulator and generator. With the increased use of mobile military radio communications, SCL-49 became inadequate. In 1942 it was superseded by specification 71-1303, "Vehicular Radio Noise Suppression."

In the period 1950 - 1965, each major military agency imposed its own EMC specifications. The Air Force used MIL-I-6181 and MIL-I-26600; the Navy used MIL-I-16910; the Army used MIL-I-11748 and MIL-E-55301(EL). These specifications limited the levels of conducted and radiated emissions, and they set susceptibility levels which systems and equipment must reject. These specifications also detailed the test configurations and methods for demonstrating compliance.

Unfortunately, over this period of time the various military EMC standards diverged from each other in test frequency ranges, limits and required test equipment. The differences made it quite expensive for a test lab or manufacturer to be fully equipped to test to all EMC specifications.

In 1960 the US Department of Defense enacted a comprehensive electromagnetic compatibility program that charged the military services to build EMC into all of their communications and electronics equipment. In 1966, EMC personnel of the three military departments jointly drafted standards addressing the overall EMC needs of the Department of Defense. That program resulted in 1967 in military standards 461 (requirements), 462 (methods) and 463 (definitions and acronyms). After revision, MIL-STD-461A was issued in August 1968. Subsequent revisions were designated B, C, and D. MIL-STD-463 was withdrawn after 1990.

In 1999 the 461D and 462D standards were merged into one document, MIL-STD-461E. The current version is MIL-STD-461F (2007), and updates to it are in the planning stage. Prior revision levels A-E may still be specified for testing.

USA: Supporting Documentation

The designer of military electronic equipment has an abundance of guidance available for successfully meeting the EMC demands of the intended operating environments.

Standards

Active military standards (Table 1) specify a variety of scopes, environmental sub-categories, limits and test methods clearly and in great detail.

The most commonly-used MIL standards are 461 (subsystems and equipment) and 464 (systems), and they apply to ground-based, shipboard and airborne applications. Other

Reference	Title
MIL-STD-188-124	Grounding, Bonding and Shielding for Common Long Haul/Tactical Communications Systems Including Ground Based Communication-Electronics Facilities and Equipments
MIL-STD-188-125-1	High-Altitude Electromagnetic Pulse (HEMP) Protection For Ground-Based C41 Facilities Performing Critical, Time-Urgent Missions - Part 1 - Fixed Facilities
MIL-STD-188-125-2	High-Altitude Electromagnetic Pulse (HEMP) Protection For Ground-Based C4I Facilities Performing Critical, Time-Urgent Missions - Part 2 - TransporTable Systems
MIL-STD-331C	Environmental and Performance Tests for Fuze and Fuze Components
MIL-STD-449D	Measurement of Radio Frequency Spectrum Characteristics
MIL-STD-461F	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-464A	Electromagnetic Environmental Effects – Requirements for Systems
MIL-STD-704F	Aircraft electric Power Characteristics
MIL-STD-1310H	Shipboard Bonding, Grounding, and other Techniques for Electromagnetic Compatibility, Electromagnetic Pulse (EMP) Mitigation, and Safety
MIL-STD-1377	Measurement of effectiveness of cable, connector, and weapons enclosure shielding and filters in precluding Hazards of electromagnetic radiation to ordnance
DOD-STD-1399-70-1	Interface Standard for Shipboard Systems – Section 070 – Part 1 – DC Magnetic Field Environment
MIL-STD-1399-300B	Interface Standard for Shipboard Systems – Section 300 - Electric Power, Alternating Current
MIL-STD-1541A	Electromagnetic Compatibility Requirements for Space Systems
MIL-STD-1542B	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities
MIL-STD-1576	Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems
MIL-STD-1605A	Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ship)
MIL-STD-2169B	High Altitude Electromagnetic Pulse (HEMP) Environment.

Table 1: Active US military EMC standards for equipment, systems and facilities

government documents may apply to a specific platform or application, and some of these are listed in the standards such as MIL-STD-461 and -464.

Handbooks

In addition to the EMC standards listed in Table 1, there are a number of handbooks available that provide procedural, EMC assessment and design guidance for specific military applications. These provide guidance only, and are not to be construed as requirements. A list of relevant handbooks is given in Table 2.

Generally these handbooks are tutorial in nature, clearly written, and with explanations of the underlying physical principles. They provide invaluable assistance to the equipment or systems designer.

Data Item Descriptions

Finally, there are very detailed documentation specifications associated with military EMC standards. In some cases the required documentation is described in separate Data Item Descriptions (DIDs) or Test Operational Procedures (TOPs). These Data Item Descriptions cover EMC design procedures, test and verification procedures, and test reports. Table 3 contains a list of Data Item Descriptions and TOPs and the military standards with which they are associated.

For example, the Data Item Description DI-EMCS-80199C associated with standard MIL-STD-461F is very explicit in the level of detail to be provided regarding equipment design procedures:

*3.2. **Design techniques and procedures**. The EMICP [Electromagnetic Interference Control Procedures] shall describe the specific design techniques and procedures used to meet each emission and susceptibility requirement, including the following:*

a. Spectrum management techniques.

b. EMI mechanical design, including the following:

Reference	Title
MIL-HDBK-235B	Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment, Subsystems and systems
MIL-HDBK-237D	Electromagnetic Environmental Effects and Spectrum Supportability Guidance for the Acquisition Process
MIL-HDBK-240	Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide
MIL-HDBK-274	Electrical Grounding for Aircraft safety
MIL-HDBK-419A	Grounding, Bonding and Shielding for Electronic Equipments and Facilities, Volume 1 of 2 Basic Theory
MIL-HDBK-423	High-Altitude Electromagnetic Pulse (HEMP) Protection for Fixed and TransporTable Ground-Based C4 1 Facilities – Volume 1 – Fixed Facilities
MIL-HDBK-454B	General Guidelines for Electronic Equipment
MIL-HDBK-83575	General Handbook for Space Vehicle Wiring Harness Design and Testing
MIL-HDBK-83578	Criteria for Explosive Systems and Devices used on Space Vehicles

Table 2: Active US military handbooks relating to EMC

Reference	Title	Associated with
DI-EMCS-80199C	Electromagnetic Interference Control Procedures (EMICP)	MIL-STD-461F
DI-EMCS-80200C	Electromagnetic Interference Test Report (EMITR)	MIL-STD-461F
DI-EMCS-80201C	Electromagnetic Interference Test Procedures (EMITP)	MIL-STD-461F
DI-EMCS-81295A	Electromagnetic Effects Verification Procedures (EMEVP)	Engineering/manufacturing development phase - any
DI-EMCS-81528	Electromagnetic Compatibility Program Procedures	Demo of life cycle EMC com-pliance - any
DI-EMCS-81540A	Electromagnetic Environmental Effects (E3) Integration and Analysis Report (E31AR)	MIL-STD-464A
DI-EMCS-81541A	Electromagnetic Environmental Effects (E3) Verification Procedures (E3VP)	MIL-STD-464A
DI-EMCS-81542A	Electromagnetic Environmental Effects (E3) Verification Report (E3VR)	MIL-STD-464A
DI-EMCS-81777	Electromagnetic Interference Survey (EMIS) Test Report	MIL-STD-1605A
DI-EMCS-81782	Electromagnetic Interference Survey (EMIS) Test Procedures	MIL-STD-1605A
TOP-1-2-511	Electromagnetic Environmental Effects System Testing	MIL-STD-464A
TOP 1-2-622	Vertical Electromagnetic Pulse (VEMP) Testing	MIL-STD-464A and MIL-STD-2169B

Table 3: EMC Data Item Descriptions and Test Operational Procedures

(1) *Type of metals, casting, finishes, and hardware employed in the design.*

(2) *Construction techniques, such as isolated compartments; filter mounting, isolation of other parts; treatment of openings (ventilation ports, access hatches, windows, metal faces and control shafts), and attenuation characteristics of Radio Frequency (RF) gaskets used on mating surfaces.*

(3) *Shielding provisions and techniques used for determining shielding effectiveness.*

(4) *Corrosion control procedures.*

(5) *Methods of bonding mating surfaces, such as surface preparation and gaskets.*

c. *Electrical wiring design, including cable types or characteristics, cable routing, cable separation, grounding philosophy, and cable shielding types and termination methods.*

d. *Electrical and electronic circuit design, including the following:*

(1) *Filtering techniques, technical reasons for selecting types of filters, and associated filter characteristics, including attenuation and line-to-ground capacitance values of AC and DC power line filters.*

(2) *Part location and separation for reducing EMI.*

(3) *Location, shielding, and isolation of critical circuits.*

MIL-STD-461A			MIL-STD-461B/C		
Test	**Description**	**Frequency**	**Test**	**Description**	**Frequency**
CE01	Power Leads	30 Hz-20 kHz	CE01	Power / Signal Leads	30 Hz-15 kHz
CE02	Control / Signal Leads	30 Hz-20 kHz	CE02	N/A	
CE03	Power Leads	20 kHz-50 MHz	CE03	Power/Signal Leads	15 kHz-50 MHz
CE04	Control / Signal Leads	20 kHz-50 MHz	CE04	N/A	
CE05	Inverse Filter Method	30 Hz-50 MHz	CE05	N/A	
CE06	Antenna Terminal	10 kHz-10 GHz	CE06	Antenna Terminal	10 kHz-26 GHz
CE07	N/A		CE07	Power Leads	Spikes / Time Domain
CS01	Power Leads	20 Hz-50 kHz	CS01	Power Leads	30 Hz-50 kHz
CS02	Power Leads	50 kHz-400 MHz	CS02	Power Leads	50 kHz-400 MHz
CS03	Intermodulation	15 kHz-10 GHz	CS03	Intermodulation	15 kHz-10 GHz
CS04	Undesired Signal Rejection	15 kHz-10 GHz	CS04	Undesired Sig. Rejection	30 kHz-20 GHz
CS05	Cross Modulation	15 kHz - 10 GHz	CS05	Cross Modulation	30 kHz - 20 GHz
CS06	Spikes, Power Leads		CS06	Spikes, Power Leads	
CS07	Squelch Circuits		CS07	Squelch Circuits	
CS08	Undesired Sig. Rejection	30 Hz-10 GHz	CS08	N/A	
CS09	N/A		CS09	Structure Common Mode Current	60 Hz-100 kHz
CS10	N/A		CS10	Damped Sinusoidal Transients (terminals)	10 kHz-100 MHz
RE01	Magnetic Field	30 Hz-50 kHz	RE01	Magnetic Field	30 Hz-50 kHz
RE02	Electric Field	14 kHz-10 GHz	RE02	Electric Field	14 kHz-10 GHz
RE03	Spurious & Harmonic	10 kHz-40 GHz	RE03	Spurious & Harmonic	10 kHz-40 GHz
RE04	Magnetic Field	20 Hz-15 kHz	RE04	N/A	
RE05	Vehicle & Eng. Equipment	150 kHz-1 GHz	RE05	N/A	
RE06	Overhead Powerlines	14 kHz-1 GHz	RE06	N/A	
RS01	Magnetic Field	30 Hz-30 kHz	RS01	Magnetic Field, Equipment and Cables	30 Hz-50 kHz
RS02	Magnetic Induction	Powerline & Spike	RS02	Magnetic Induction, Equipment and Cables	Powerline & Spike
RS03	Electric Field	14 kHz-10 GHz	RS03	Electric Field, Equipment and Cables	14 kHz-40 GHz
RS04	Parallel Line Fields	14 kHz-30 MHz	RS04	N/A	
RS05	N/A		RS05	Electromag Pulse Field	Transients

Table 4: MIL-STD-461 requirement changes, versions A – E

This DID also requires, among other items, *analysis* (results demonstrating how each applicable requirement is going to be met) and *developmental testing* (testing to be performed during development such as evaluations of breadboards, prototypes, and engineering models). For the equipment designer, these points to be documented constitute a virtual punch list of EMC design attributes.

MIL-STD-461F – EMC for Subsystems and Equipment

This is no doubt the most widely-used standard for US military EMC assessment. Specific test requirements are grouped according to conducted (C) or radiated (R) coupling, and emissions (E) or susceptibility (S). Thus the tests are designated:

Conducted emissions: CE---
Radiated emissions: RE---
Conducted susceptibility: CS---
Radiated susceptibility: RS---

The dashes are replaced by the test reference number. Over time, the numerical test designations have transitioned from 01 to 101, 02 to 102, etc., but the prefixes have remained constant. Table 4 indicates the changes in MIL-STD-461 test requirements from versions A through E, and Table 5 (page 40) reflects the present version F requirements.

MIL-STD-461D			MIL-STD-461E		
Test	Description	Frequency	Test	Description	Frequency
CE101	Power Leads	30 Hz-10 kHz	CE101	Power Leads	30 Hz-10 kHz
CE102	Power Leads	10 kHz-10 MHz	CE102	Power Leads	10 kHz-10 MHz
CE106	Antenna Terminal	10 kHz-40GHz	CE106	Antenna Terminal	10 kHz-40GHz
CS101	Power Leads	30 Hz-50 kHz	CS101	Power Leads	30 Hz-150 kHz
CS103	Antenna Port-Intermod	15 kHz-10 GHz	CS103	Antenna Port-Intermod	15 kHz-10 GHz
CS104	Antenna Port-Rejection of Undesired Signals	30 Hz -20 GHz	CS104	Antenna Port-Rejection. of Undesired Signals	30 Hz -20 GHz
CS105	Antenna Port-Cross Modulation	30 Hz-20 GHz	CS105	Antenna Port-Cross Mod.	30 Hz-20 GHz
RE101	Magnetic Field	30 Hz-100 kHz	RE101	Magnetic Field	30 Hz-100 kHz
RE102	Electric Field	10 kHz-18 GHz	RE102	Electric Field	10 kHz-18 GHz
RE103	Antenna Spurious & Harmonics	10 kHz-40 GHz	RE103	Antenna Spurious & Harmonics	10 kHz-40 GHz
RS101	Magnetic Field, Equipment and Cables	30 Hz-100 kHz	RS101	Magnetic Field, Equipment and Cables	30 Hz-100 kHz
RS103	Electric Field, Equipment and Cables	10 kHz-40 GHz	RS103	Electric Field, Equipment and Cables	2 MHz-40 GHz
RS105	Transient Electromagnetic Field	Transients	RS105	Transient Electromanetic Field	Transients
CS109	Structure Current	60 Hz-100 kHz	CS109	Structure Current	60 Hz-100 kHz
CS114	Bulk Cable Injection	10 kHz-400 MHz	CS114	Bulk Cable Injection	10 kHz-200 MHz
CS115	Bulk Cable Injection	Impulse	CS115	Bulk Cable Injection	Impulse
CS116	Sine Transients - Cables, and Power Leads	10 kHz-100 MHz	CS116	Sine Transients - Cables, and Power Leads	10 kHz-100 MHz

ESD and lightning effects are not included in MIL-STD-461F, although they are being discussed for inclusion in the next (G) version which is currently in draft to be released in 2014. ESD and lightning protection *are* covered in MIL-STD-464A, and in the current US standard for commercial aircraft equipment DO-160G, "Environmental Conditions and Test Procedures for Airborne Equipment." DO-160G contains a number of non-EMC environmental requirements, and equipment qualified to revisions C – F of RTCA DO-160 is often suitable for military aircraft applications. A summary of DO-160G test categories is given in Table 6.

The military electronic equipment designer needs to know the types of EMC tests that will be applied to the equipment, the magnitudes or limits of the tests, and the frequency ranges of the tests, in order to design for compliance. The designer also needs to know that, where the equipment will be used in more than one environment, the most stringent requirements apply. Generally of secondary importance to the designer are the test configuration details, which are amply documented in MIL-STD-461F. These test details are of course essential to the testing personnel.

What is important to the equipment designer, for the purpose of understanding the limits, are the radiated emissions test distances – which differ from the normal commercial separations of 3m or 10m. MIL-STD-461F is almost unique among EMC standards in requiring a 1m distance between the electric field antenna and the test setup boundary (RE102). Only DO-160G and CISPR 25 (Automotive) has a similar radiated

Test	Description	Lowest Emission or Highest Susceptibility	Changes from 461E version
CE101	Conducted Emissions, Power Leads, 30 Hz to 10 kHz	76 dBµA	-
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz	60 dBµV	-
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz	34 dBµV	-
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz	136 dBµV	Applicability added for surface ships; setup modifications suggested.
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz	Per procurement specification	-
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz	Per procurement specification	-
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation, 30 Hz to 20 GHz	Per procurement specification	-
CS106	Conducted Susceptibility, Transients, Power Leads	400 V peak	CS06 absent from E, added back.
CS109	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz	120 dBµA	-
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz	109 dBµA	Adds common mode test for some applications.
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation	5A x 30 ns	-
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz	10 A peak	Testing with power off is deleted; procedure allows reduction of calibrated test signal if necessary.
RE101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz	76 dBpT @ 7 cm	Test procedure is modified to allow separations > 7cm where non-compliances are noted.
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz	24 dBµV/m @ 1m	Applicability and frequency ranges modified. Rod antenna methods modified.
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz	-80 dBc, far field	Minor test procedure changes.
RS101	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz	180 dBpT	Scan rate is reduced.
RS103	Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz	200 V/m	Sensor placement clarified; radiating antenna distance limited to $\geq$ 1m.
RS105	Radiated Susceptibility, Transient Electromagnetic Field	50 kV/m peak	-

Table 5: MIL-STD-461F requirement changes from versions E to F (2007).

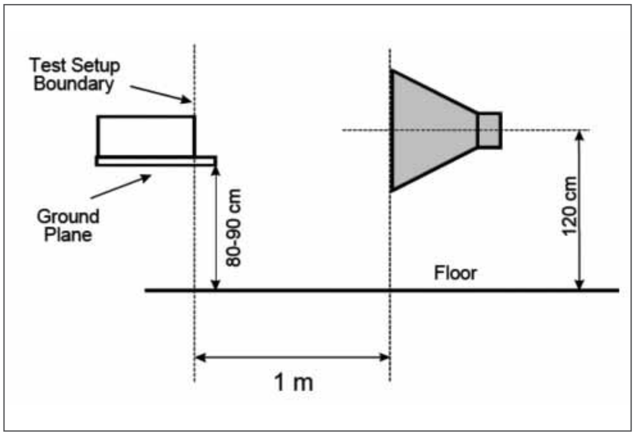

Figure 1: RE102 test setup showing 1m antenna distance, from MIL-STD-461F

emissions test distance. The magnetic field measurement distance in RE101 is 7 cm.

Radiated Susceptibility (RS 103) also has a 1m separation distance and typically requires a field strength of 200V/m in contrast to the 3V/m and 10V/m commonly encountered with commercial product standards such as EN61000-4-3. This higher field strength requirement can often be a hurdle for many designers involved with COTS or used to working on products intended for the commercial market.

In addition to the changes noted in Table 5, MIL-STD-461F addresses several topics of general applicability:

- The requirement to qualify "Line-Replaceable Modules (LRMs)" is added;
- Restricts the testing of shielded power cables;
- Includes software in the requirement to verify test procedures;
- Frequency step size above 1 GHz has been increased for susceptibility testing.

General	
Section 1.0	Purpose and Applicability
Section 2.0	Definition of Terms - General
Section 3.0	Conditions of Tests
Environmental Requirements	
Section 4.0	Temperature and Altitude
Section 5.0	Temperature Variation
Section 6.0	Humidity
Section 7.0	Operational Shocks and Crash Safety
Section 8.0	Vibration
Section 9.0	Explosion Proofness
Section 10.0	Waterproofness
Section 11.0	Fluids Susceptibility
Section 12.0	Sand and Dust
Section 13.0	Fungus Resistance
Section 14.0	Salt Spray
Section 24.0	Icing
Section 26.0	Fire, Flammability
EMC Requirements	
Section 15.0	Magnetic Effect
Section 16.0	Power Input
Section 17.0	Voltage Spike
Section 18.0	Audio Frequency Conducted Susceptibility – Power Inputs
Section 19.0	Induced Signal Susceptibility
Section 20.0	Radio Frequency Susceptibility (Radiated and Conducted)
Section 21.0	Emission of Radio Frequency Energy
Section 22.0	Lightning Induced Transient Susceptibility
Section 23.0	Lightning Direct Effects
Section 25.0	Electrostatic Discharge

Table 6: EMC and environmental requirements in RTCA DO-160G

Simultaneously with the publication of the F version of MIL-STD-461 (December 2007), the F version of RTCA DO-160 was published. DO-160F also included, for the first time, the CS106 test that was originally in MIL-STD-461 but later deleted only to be restored in the latest version. Since that time DO-160G has been released (December 2010), bringing more clarifications and updates.

RTCA DO-160F and G include the ESD and lightning requirements currently absent from MIL-STD-461F, and it includes the environmental requirements which are found in separate MIL documents discussed below. The European Union version of DO-160G is EUROCAE/ED-14G, which is identically worded.

MIL-STD-464A – EMC Requirements for Systems

This standard establishes electromagnetic environmental effects (E3), interface requirements and verification criteria for airborne, sea, space, and ground systems, including associated ordnance. MIL-STD-464A contains two sections, the main body and an appendix. The main body of the standard specifies a baseline set of requirements. The appendix portion provides a detailed rationale and guidance, so that the baseline requirements can be tailored for a particular application.

Verification is intended to cover all life cycle aspects of the system. This includes (as applicable) normal in-service operation, checkout, storage, transportation, handling, packaging, loading, unloading, launch, and the normal operating procedures associated with each aspect.

The scope of E3 as used in this standard is very broad: all electromagnetic disciplines, including electromagnetic compatibility; electromagnetic interference; electromagnetic vulnerability; electromagnetic pulse; hazards of electromagnetic radiation to personnel, ordnance, and volatile materials; and natural phenomena effects of lightning and static.

Margin requirements apply to all EMC related tests performed in a 464A verification exercise. The intent is to account for manufacturing variations, aging and maintenance to assure that all equipment, not just test samples, will be compliant in the field over the equipment lifetime. Additional compliance margins to the limits specified in the standard are required for safety-critical, mission-critical and electrically-initiated devices (EIDs) such as electroexplosive devices and fusible links. The additional margins are:

- ≥ 6 dB for safety critical and mission critical system functions;
- ≥ 16.5 dB of maximum no-fire stimulus for safety assurances;

Clause	Parameter	Lowest Emission or Highest Susceptibility
5.2	Intra-system EMC (see also MIL-STD-461F clause 4.2.3)	Self-compatibility
5.2.1	Hull-generated intermodulation interference (IMI)	Not detecTable by onboard receivers
5.2.2	Shipboard internal electromagnetic environment (EME).	50 V/m
5.2.3	Multipaction, space applications, equipment and subsystems	No effect
5.3	External RF electromagnetic environment (EME) Flight deck, ships Weather deck, ships Main beam of transmitter, ships Space and launch vehicle systems Ground systems Army rotary wing aircraft Fixed wing aircraft, excluding shipboard	 2030 V/m peak, 200 V/m average 2030 V/m peak, 200 V/m average 27460 V/m peak, 2620 V/m average 200 V/m peak, 200 V/m average 2500 V/m peak, 50 V/m average 27460 V/m peak, 3120 V/m average 7200 V/m peak, 1050 V/m average
5.4	Lightning Severe stroke Near strike	 200kA strike, 100 kA restrike 2.2 x 10^9 A/m/s @ 10m
5.5	Electromagnetic pulse (EMP) per MIL-STD-2169B	classified
5.6	Subsystems and equipment EMI	Per MIL-STD-461F
5.6.1	Non-developmental items (NDI) and commercial items	System operational performance requirements shall be met.
5.6.2	Shipboard DC magnetic field environment.	See MIL-STD-1399, Section 070
5.7	Electrostatic charge control. Vertical lift and in-flight refueling. Precipitation static (p-static) control Ordnance subsystems.	 300 kV discharge Meet operational requirements 25 kV discharge
5.8	Electromagnetic radiation hazards (EMRADHAZ) Hazards of electromagnetic radiation to personnel (HERP). Hazards of electromagnetic radiation to fuel (HERF) Hazards of electromagnetic radiation to ordnance (HERO).	 See DoDI 6055.11 No inadvertent ignition 27460 V/m peak, 2620 V/m average
5.10.3	Mechanical interfaces – DC bonding levels	2.5 – 15 mΩ
5.11.1	Aircraft grounding jacks – resistance between the mating plug and the system ground reference.	≤ 1 Ω
5.13	Emissions control (EMCON)	≤ 105 dBm/m² @ 1 km, 500 kHz – 40 GHz

Table 7: Summary of MIL-STD-464A requirements. The high field strength susceptibility values occur in radar bands.

- ≥ 6dB of maximum no-fire stimulus for other purposes.

The worst-case (lowest emission limit or highest susceptibility requirement) for the environments categorized in MIL-STD-464A are summarized in Table 7. In many cases the requirements are frequency-dependent, and are much lower than worst-case over much of the frequency range. The standard should be consulted for details and definitions.

MIL-STD-1310H – Shipboard Bonding, Grounding and Other Techniques for EMC

This document specifies standard practices in wiring, bonding, grounding and shielding to facilitate achievement of the intra-ship and inter-ship electromagnetic compatibility (EMC), electromagnetic pulse (EMP), bonding, and intermodulation interference (IMI) requirements of MIL-STD-464A. It applies to metal and nonmetallic hull ships and is applicable during ship construction, overhaul, alteration, and repair. MIL-STD-1310H is not a typical EMC standard, but it provides the methods guidance appropriate to obtaining EMC in the shipboard environment.

This revision of MIL-STD-1310 has been expanded to include procedures for Electromagnetic Pulse (EMP) hardening. It also provides procedures and guidance to more easily address MIL-STD-464A requirements in relationship to intra- and inter-ship EMC, hull-generated IMI, lifecycle electromagnetic environmental effects (E3) hardness, EMP, and electrical bonding. A separate appendix is included, with procedures to identify whether commercial-off-the-shelf equipment (COTS) or non-developmental items (NDI) meets appropriate safety requirements before use, and to provide direction to bring them into conformance when necessary.

MIL-STD-1541A – Space Systems

The requirements covered by this standard apply to launch and space vehicles plus the associated grounds airborne, or spaceborne operational and support elements of the space system. It applies to new and modified or redesigned equipment or systems, and to existing equipment used in new applications.

MIL-STD-1541A establishes the electromagnetic compatibility requirements for space systems, including frequency management, and the related requirements for the electrical and electronic equipment used in space systems. It also includes requirements designed to establish an effective ground reference for the installed equipment and designed to inhibit adverse electrostatic effects. Bonding and prevention of electrostatic buildup are covered in detail.

As with MIL-STD-464A, this standard imposes additional compliance margin requirements in critical situations:

Category I: Serious injury or loss of life, damage to property, or major loss or delay of mission capability; 12 dB for qualification; 6 dB for acceptance

Category II: Degradation of mission capability, including any loss of autonomous operational capability; 6 dB

Category III: Loss of functions not essential to mission; 0 dB

Intersystem and intrasystem analysis is required by the standard, which also references all emission and susceptibility requirements in MIL-STD-461 (as modified by MIL-STD-1541A) for the relevant class of equipment. Some of the specific requirements of this standard not covered in MIL-STD-461 are summarized in Table 8. Thorough qualification testing is emphasized in the standard.

MIL-STD-1542B – Space System Facilities

This standard is intended for selected space system facilities. The requirements are applicable to all related facilities including, but not limited to, launch complexes, tracking stations, data processing rooms, satellite control centers, checkout stations, spacecraft or booster assembly buildings, and any associated stationary or mobile structures that house electrical and electronic equipment.

MIL-STD-1542B addresses in detail the appropriate bonding, shielding, electrical power and ground network for space system facilities. The facility ground network consists of the following electrically interconnected subsystems:

Section	Test	Limit
5.2.5	Lightning protection	200 kA peak
5.2.6	Outer surface resistivity of ESD control	
	Grounded semiconductive coating over insulating material	$\leq 10^8\ \Omega$/square
	Painted surface over grounded semiconductive material-over dielectric	$\leq 4.6 \times 10^7\ \Omega$/square
	Volume resistivity of a coating(t, cm) over a grounded metal conductor	$(2.5/t) \times 10^{10}\ \Omega$-cm
5.2.10	Electrical power quality	
	Voltage ripple	≤ 500 mV peak-to-peak
	Spikes	< 3 times nominal load, $< 0.14 \times 10^{-3}$ V-s
	Surges	Return to steady-state in 5 ms (+) and 100 ms (-)
	Load switching and load faults	Remain within 65% to 130% of nominal
	Power subsystem faults – surge amplitude	Remain within 0% to 175% of nominal
	Vehicle power output ground isolation	≥ 1 MΩ
5.3.3	Performance criteria – MIL-STD-461 applies as noted	
	CE01 applies	
	CE06 and RE03 apply	Frequency extended to 30th harmonic or 100 GHz
	CS01 limit applies	Test under maximum and minimum supply
	CS02 and RS03 apply	Susceptibility signals chosen for max. effect
	CS06 limits	200 V x 10µs pulse

Table 8: Some requirements in MIL-STD-1541A

Reference	Title
Def Stan 59-188-1 (2009)	High Altitude Electromagnetic Pulse (HEMP) Protection for Ground Based Communication Facilities Performing Critical, Time-Urgent Missions - Part No: 1: Fixed Facilities.
Def Stan 59-411-1 (2007)	Electromagnetic Compatibility - Part No: 1: Management & Planning
Def Stan 59-411-2 (2007)	Electromagnetic Compatibility - Part No: 2: The Electric, Magnetic and Electromagnetic Environment
Def Stan 59-411-3 (2007)	Electromagnetic Compatibility - Part No: 3: Test Methods and Limits for Equipment and Sub Systems
Def Stan 59-411-4 (2007)	Electromagnetic Compatibility - Part No: 4: Platform and System Tests and Trials
Def Stan 59-411-5 (2007)	Electromagnetic Compatibility - Part No: 5: Code of Practice for Tri-Service Design and Installation

Table 9: UK Ministry of Defence EMC standards

Reference	Title
STANAG 3516	Electromagnetic Interference and Test Methods for Aircraft
STANAG 3614	Electromagnetic Compatibility (EMC) of Aircraft Systems
STANAG 4234	Electromagnetic Radiation (Radio Frequency) - 200 kHz to 40 GHz Environment - Affecting the Design of Materiel for Use by NATO Forces
STANAG 4239	Electrostatic Discharge, Munitions Test Procedures
STANAG 4327	Lightning, Munition Assessment and Test Procedures
STANAG 4370	Environmental testing
STANAG 4416	Nuclear Electromagnetic Pulse Testing of Munitions Containing Electro-Explosive Devices
STANAG 4437	Electromagnetic Compatibility Testing Procedure and Requirements for Naval Electrical and Electronic Equipment (Submarines)

Table 10: Some NATO STANAGs relating to EMC.

a. The earth electrode subsystem.

b. The lightning protection subsystem.

c. The equipment fault protection subsystem.

d. The signal reference (technical ground) subsystem.

EMC performance for equipment installed in space system facilities is referenced to MIL-STD-461. COTS (commercial-off-the-shelf) equipment installed in these facilities shall also meet the requirements of MIL-STD-461.

As with the other military EMC standards discussed here, MIL-STD-1542B requires electromagnetic self-compatibility of equipment and systems. Clause 4.2 stipulates:

> *Facility electrical and electronic subsystems and equipment shall be compatible with each other as well as with the technical equipment installed in the facility for support of space system operations.*

UK: DefStan Documents

Equipment procured for military purposes by the UK's Ministry of Defence must meet their defence standards (DefStan). Non-military equipment must meet the essential requirements of the EMC Directive 2004/108/EC. Ministry of Defence EMC standards are listed in Table 9.

Collectively the UK DefStan documents cover the same concerns as UK military standards. Specifically, DefStan 59-411-3 (Part 3) corresponds closely to MIL-STD-461F in methods, limits and frequency ranges. For example, Magnetic emissions are measured at 70 cm in both standards, and high-frequency radiated emissions are measured at 1m in both standards. However there are structural and content differences between the two standards:

- Individual EMC tests in 59-411-3 are denoted DCS---, DCE---, DRE---, DRS--- where the "D" denotes "Defence" and is absent from -461 test references.
- DefStan 59-411-3 uses susceptibility criteria A…D, which are familiar to users of commercial IEC and EU EMC standards. Default performance criteria are defined for each susceptibility test in terms of safety-critical or safety-related function, mission-critical function, or non-safety-critical or non-essential function.
- "Man worn" and "man portable" categories and test requirements are specified in detail in DefStan 59-411-3. Testing for man-worn applications requires the use of a non-conductive dummy approximating the shape

NATO: STANAG documents

The term "STANAG" stands for "Standardization Agreement" among the NATO member countries. There are literally hundreds of active agreements in place, usually drawing from one or more countries' existing standards. Some of the STANAG agreements relating to EMC are summarized in Table 10.

Both environmental considerations and EMC are covered under STANAG 4370. It references several separate documents termed "Allied

Design for EMC Compliance

Military product development follows well-defined program steps. MIL-HDBK-237D defines these steps clearly – including tailoring of requirements - as well as providing useful information on potentially applicable commercial standards plus standards from all branches of the US military, and NATO. An extensive list of acronyms is also included.

Definition and refinement of the product EMC environment occurs during the course of program progress. Initial EMC testing in the laboratory is only the first step toward full qualification. MIL-235B provides information on the likely levels of RF field exposure in various stages of deployment to land-based and shipboard locations.

Generally, EMC test requirements will have been fully defined before the product reaches the test laboratory, although modules or subsystems may have been previously tested. The relevant parts of MIL-STD-461F (typically) will be stipulated, and it will be up to the manufacturer to have used prudent design techniques to meet the designated requirements.

As the EMC requirements in MIL-STD-461F are generally more stringent than commercial standards, designing for successful compliance involves careful review of each level of product integration. Can the designer support each of the design criteria in Data Item Description DI-EMCS-80199C, and summarized in this review? These criteria include PC layout, wiring, shielding, filtering and enclosure design. Designers familiar largely with commercial environments will need to review and enhance the use of EMC control techniques to meet military EMC requirements. Later qualification tests may require control enhancements.

Environmental Conditions and Test Publication" (AECPT). We will explore the environmental aspects later, but we will look at EMC first.

STANAG 4370 references AECPT-500 (Edition 3, 2009), "Electromagnetic Environmental Effects Test and Verification." AECPT-500 draws for its tests and methods both from MIL-STD-461 and DefStan 59-411, as shown in Table 11. Individual EMC tests in AECPT-500 are denoted NCS---, NCE---, NRE---, NRS--- where the "N" denotes "NATO" and is absent from -461 test references.

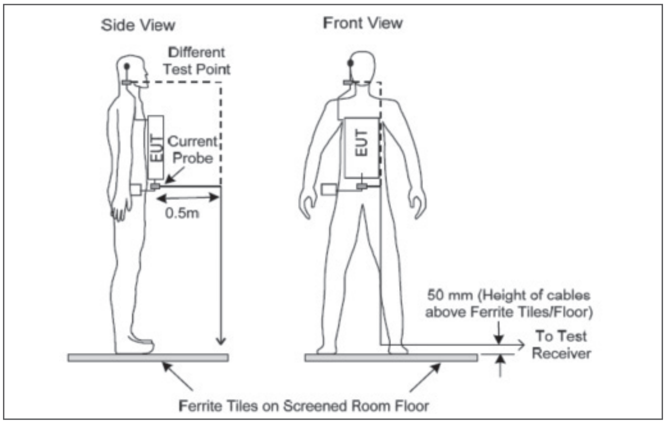

Figure 2: Man worn test configuration from DefStan 59-411-3, DCE02

AECPT-500 also contains a flow chart to guide the gap analysis between commercial and military EMC requirements, when COTS (commercial-off-the-shelf) or MOTS (military-off-the-shelf) acquisitions are being considered.

Look for Part 2 of this article in the April 2014 issue of In Compliance.

This paper was authored by Intertek. Currently Intertek sits on more than 70 SAE standards committees to help draft the test and certifications necessary to keep people safe. Find more articles on EMC issues at www.interk.com. For more information on this topic or to find an Intertek EMC testing lab near you contact icenter@intertek.com or 1-800-WORLDLAB.

Reference	Description	Test Derived from
NCE01	Conducted Emissions, Power Leads, 30 Hz to 10 kHz	MIL-STD-461F
NCE02	Conducted Emissions, Power Leads, 10 kHz to 10 MHz	MIL-STD-461F
NCE03	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz	MIL-STD-461F
NCE04	Conducted Emissions, Exported Transients on Power Leads	Def Stan 59-411
NCE05	Conducted Emissions, Power, Control & Signal Leads, 30 Hz to 150 MHz	Def Stan 59-411
NCS01	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz	MIL-STD-461F
NCS02	Conducted Susceptibility, Control & Signal Leads, 20 Hz to 50 kHz	Def Stan 59-411
NCS03	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz	MIL-STD-461F
NCS04	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz	MIL-STD-461F
NCS05	Conducted Susceptibility, Antenna Port, Cross Modulation, 30 Hz to 20 GHz	MIL-STD-461F
NCS06	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz	MIL-STD-461F
NCS07	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz	MIL-STD-461F
NCS08	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation	MIL-STD-461F
NCS09	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz	MIL-STD-461F
NCS10	Conducted Susceptibility, Imported Lightning Transient (Aircraft/Weapons)	Def Stan 59-411
NCS11	Conducted Susceptibility, Imported Low Frequency on Power Leads (Ships)	Def Stan 59-411
NCS12	Conducted Susceptibility, Electrostatic Discharge	Def Stan 59-411
NCS13	Conducted Susceptibility, Transient Power Leads	MIL-STD-461F
NRE01	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz	MIL-STD-461F
NRE02	Radiated Emissions, Electric Field, 10 kHz to 18 GHz	MIL-STD-461F
NRE03	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz	MIL-STD-461F
NRS01	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz	MIL-STD-461F
NRS02	Radiated Susceptibility, Electric Field, 50 kHz to 40 GHz	MIL-STD-461F / Def Stan 59-411
NRS03	Radiated Susceptibility, Transient Electromagnetic Field	MIL-STD-461F
NRS04	Radiated Susceptibility, Magnetic Field, (DC)	Def Stan 59-411

Table 11: Cross-reference between NATO EMC test references, MIL-STD-461 and DefStan 59-411

Usability Engineering

Observe Users, Improve Product Safety

BY FRANK O'BRIEN

Up until now there's been much emphasis on designing to make a product "idiot proof". This has provided some benefit, but what Usability Engineering is reminding us is that it is the designers who are sometimes viewed as idiots by the users. It is the users who are the experts (in usability).

For those involved in product safety, we could perhaps congratulate ourselves. Based on my testing experience over the last three decades, it is my view that products have become safer. No longer is it common to see products cause electrical shocks, burns, fires, or crushing/cutting injuries. We continue to see where we need improvements, particularly when we see new technologies, such as recent events associated with rechargeable lithium batteries. Tragic events associated with energies and materials in electrical products occur, but they have become quite remote.

The focus of this article will be on Usability Engineering for medical devices. We will look at the present state of medical device safety. The data will show poor usability is to blame for more preventable deaths than traffic collisions and firearms combined. We'll look at new Usability Engineering process requirements and provide an overview on how we can better control the risks associated with poor usability. Even though the focus of this article is on medical devices, the principals hold for all products. Poor usability represents the low lying fruit for safer products.

THE PRESENT STATE OF MEDICAL DEVICE SAFETY

As reported by the post-market surveillance group of the U.S. Food and Drug Administration (FDA), between 2005 and 2009, there were 56,000 adverse events (undesirable experience) involving infusion pumps, resulting in at least 700 deaths. There were 87 manufacturer initiated product recalls. In March 2010, the FDA ordered Baxter to recall 200,000 infusion pumps because of "numerous flaws". Other pump manufacturers took note, and voluntarily instituted their own product design reviews and, where necessary, recalls.

Based on a new study, "A New, Evidence-based Estimate of Patient Harms Associated with Hospital Care" by John T. James, PhD, published in the *Journal of Patient Safety* in September 2013, it is estimated that between 210,000 and 440,000 patients die in US hospitals due to preventable medical errors; a four-fold increase over 1999 estimates. The study also estimates that medical errors cause serious harm (e.g. loss of limb, sight, hearing), ten-fold to twenty-fold more common than lethal harm. The study details how better analysis of four past studies justifies the new estimates. These medical errors include those caused by medical and in vitro devices (IVD), both active and non-active, and the administration of pharmaceutical drugs.

Prior to this recent study, the best estimate of preventable medical errors that cause death had been an Institute of Medicine article from 1999, "To Err Is Human". This older study extrapolated data from hospitals in CO/UT, and NYC, and estimated at least 44,000 people, and perhaps as many as 98,000 people, die in hospitals each year as a result of preventable medical errors (adverse events).

Figure 1 shows the midpoint of the 210,000 to 440,000 estimated deaths due to medical error, alongside deaths due to traffic collisions and firearms.

The best source for aggregate medical device adverse incident/event data seems to be the UK based Medicines and Healthcare Products Regulatory Agency (MHRA). In Europe (including the UK), an adverse incident, causes, or has the potential to cause, unexpected or unwanted effects involving the safety of device users (including patients) or other persons.

The chart shown in Figure 2 shows adverse incidents by year, based on MHRA (UK) Annual Adverse Incident Reports from 2007 (which includes data back to 2001, and 2010 (which includes data back to 2008). We see the upward trend of adverse incidents. As this could be due to an increase in medical devices in use, I plotted as well UK population, based on World Bank data. From the population data, we begin to see some correlation between the two increases.

To better look at adverse incidents to population, I charted in Figure 3 adverse incidents per 1 million persons. I also broke out death and near death, from other adverse incidents having less severe outcomes.

Figure 4 shows adverse incidents by device type.

In Figure 4, the Other category includes (each with less than 5%) Surgical consumables, Aids for daily living, Syringes/needles, Disinfection/sterilization/disposal, Drainage/Suction, Beds/mattresses, Hoists, Artificial limbs, Walking aids, Physiotherapy equipment, and Orthoses.

Only some of reported adverse incidents are investigated by MHRA. Of those chosen for investigation, Figure 5 shows to whom responsibility for the incident was assigned. In assigning responsibility MRHA uses the following system:

- Healthcare facility, Use: After delivery; use errors, performance and/or maintenance failures and degradation
- Manufacturer: Before delivery; design, manufacture, quality control and packaging
- Unknown: intermittent faults (use error, software, EMC) or couldn't investigate

In looking at the adverse incident data one needs to be wary of reaching any definitive conclusions. Problems with the data include:

- Increase real? Or due to better reporting?
- Need to know adverse incident per devices in use
    - Are high adverse incidents for a device type due to in use numbers, device complexity, or other?
- Cause investigations should target use error specifically
    - Don't lump in with performance and/or maintenance failures and degradation by healthcare facility
    - Differentiate use error due to inadequate training by healthcare facility, etc; from insufficient usability by device manufacturer

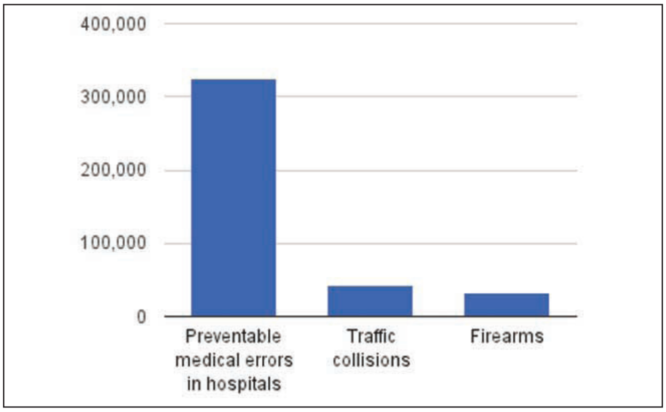

Figure 1: USA Deaths from Medical Errors (Adverse Events) in Perspective

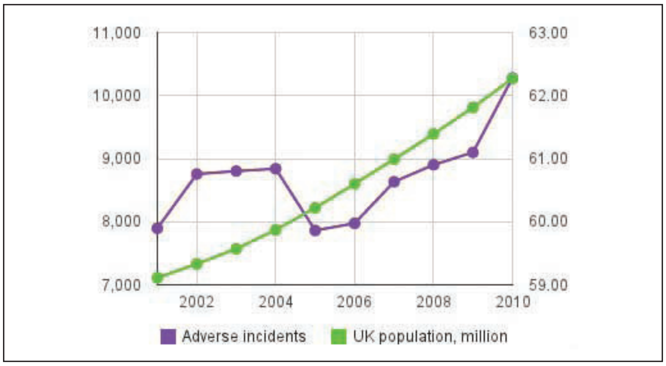

Figure 2: UK Adverse Incident and Population Trends

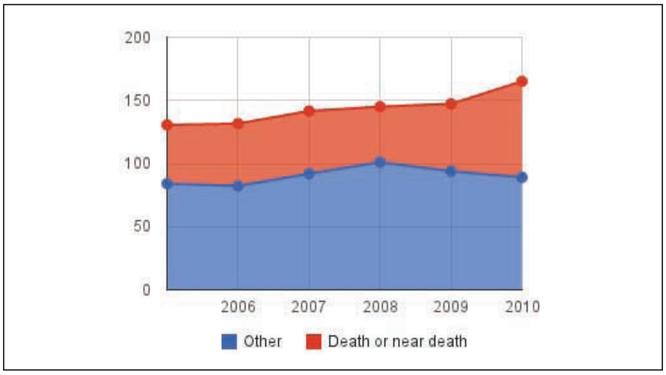

Figure 3: UK Adverse Incidents per 1 Million Persons

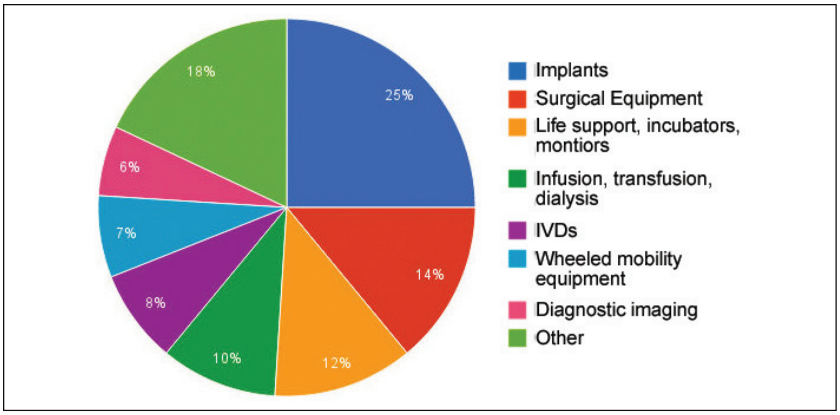

Figure 4: Adverse Incidents by Device Type

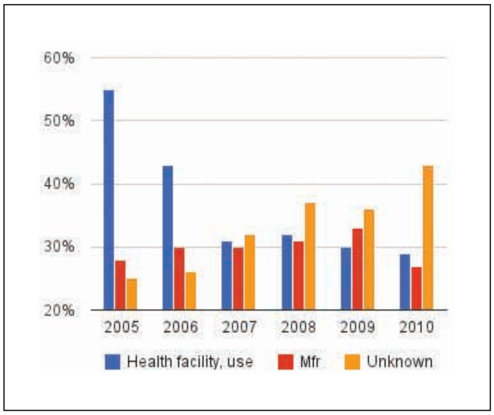

Figure 5: Cause of Investigated Adverse Incidents

- Categorize by device failure mode (e.g. transformer, switch, software, EMC), or use error
- Increase in unknown causes results in less useful data (e.g. assigned causes)
  - Pull out suspected use error, software, EMC causes

Hats off to MHRA for providing aggregate data, even if not perfect. It would be nice to see FDA publish aggregate data annually, and/or make their databases a bit more accessible (they're searchable, but for aggregate data, not easy to download and reconstruct the relational tables).

Problems aside, one could reach the following qualified conclusions:

- 26% more adverse incidents per capita
- 29% more death or near death
- 82% involve more complicated equipment, such as implants, surgical, patient monitors, infusion pumps, IVDs, wheelchairs, imaging, and similar
- During 2005-06, majority of cause was health facility, use
- During 2007-10, cause was shared between healthcare facility, use; and manufacturer design, controls

DO NO HARM

The latin phrase, *Primum non nocere*, "first, do no harm", is attributed to to Thomas Sydenham (1624–1689) in a book by Thomas Inman (1860), *Foundation for a New Theory and Practice of Medicine*. Putting things in the terminology of modern risk management, (e.g. ISO 14971:2007), where a medical device has an unacceptable risk of harm, a designer needs to implement effective risk control measures.

With the above adverse incident/event data in mind, take a look at Figure 6. What's the most likely hazard or failure mode that could result in harm? Hopefully everyone recognizes that it's the User Interface. As designers we need to recognize that this is an important, and perhaps the most important, design responsibility.

USABILITY ENGINEERING

Usability Engineering, or as FDA refers to it, Human Factors Engineering, is the process to identify where user interactions with a medical device have the potential for harm, and to implement effective risk control measures. The Usability Engineering process touches all design aspects; the hardware interface, the software interface, product markings, and any user documentation. Considered is usability associated with the full product life cycle, from transport, normal use, maintenance, to decommissioning.

Key standards to guide a manufacturer's Usability Engineering process:

- IEC 62366:2007 + A1/FDIS:2013, Medical devices - Application of usability engineering

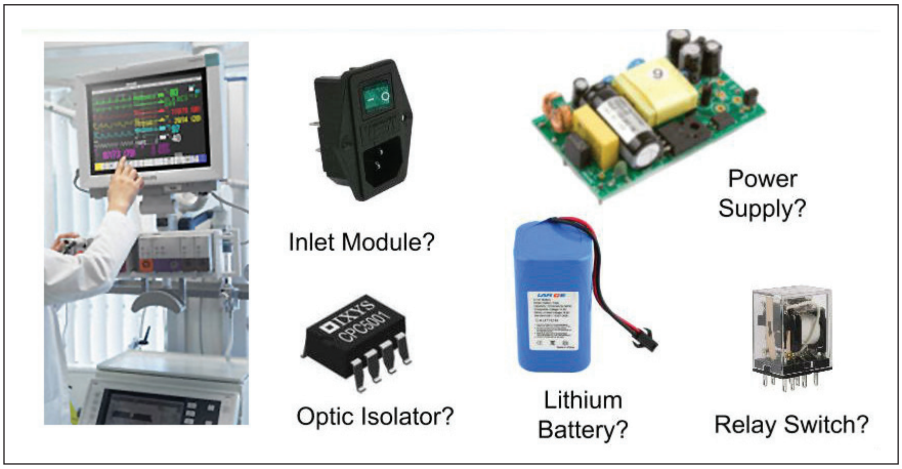

Figure 6: Failure Modes that could lead to Hazardous Situations

- IEC 60601-1-6:2010, Medical electrical equipment -- Part 1-6: General requirements for basic safety & essential performance - Collateral standard: Usability
- ISO 14971:2007, Medical devices - Application of risk management
- ANSI/AAMI HE75, 2009 Edition - Human factors engineering—Design of medical devices
- Medical Device Use-Safety: Incorporating Human Factors Engineering into Risk Management, issued 2000
- Apply Human Factors and Usability Engineering to Optimize Medical Device Design, issued 2011 (draft)

The IEC and ISO standards have EN (CENELEC) versions for Europe, and are harmonized to the essential requirements of the Medical Device Directive related to ergonomics and information supplied by manufacturer. All are in the U.S. FDA recognized consensus standards database. They become the means to provide a presumption of compliance with essential requirements and a reasonable assurance of safety and effectiveness, with regards to acceptable usability.

All these standards are consistent with each other. The scope of IEC 62366 (which I consider the high level process standard) is all medical devices, including the more prevalent non-active devices like tubing sets, luer connectors, syringes, dental implants, sterile drapes; as well as electrical equipment like surgical equipment, patient monitors, in vitro diagnostic equipment, and non-implantable accessories to active implants. IEC 60601-1-6:2010, the medical

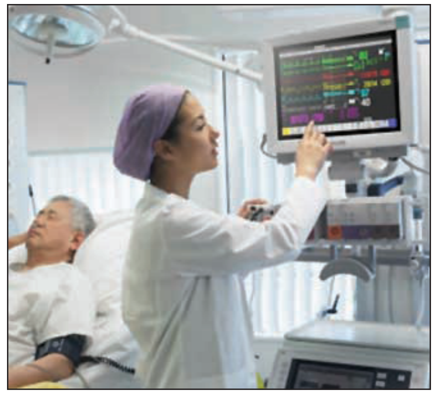

Figure 7: It's all about the User Interface

electrical equipment collateral standard for usability, contains essentially only a normative reference to IEC 62366. The AAMI HE75 is useful as it has more specific guidance and examples. FDA guidance documents are also written to provide more specific examples, use FDA terminology, and provide references for further reading. Think of the AAMI HE75 and FDA guidance documents as informative annexes to IEC 62366.

In the remainder of this article we focus on IEC 62366.

IEC 62366 tells us that users want good usability:

- Effectiveness
- Efficiency
- Ease
- Satisfaction

With these user motivations and taking into account the use environment we can anticipate and investigate user actions (or interactions) such as pushing a button, toggling a switch, sliding a door, turning a screw, tapping a menu item, speaking into a microphone, filling a reservoir, or connecting a leadset.

Figure 8 provides terminology to refer to user actions (or interactions). Discussions are helped when we all use the same terminology. Note that ideally medical devices are desired to result in what we call, Correct Use; the designers intent; the device fulfilling its intended clinical purpose/use.

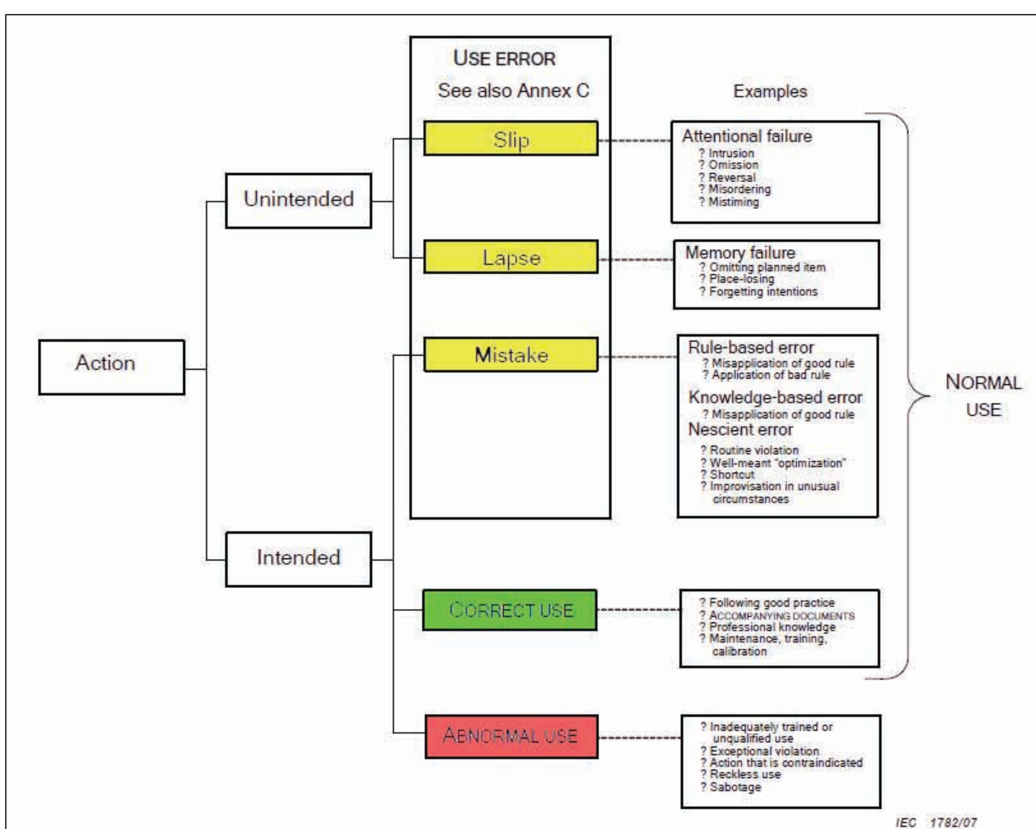

Figure 8: User action (interaction) categories (IEC 62366:2007, Figure B.1)

IEC 60601, Medical Equipment Term	Mapping to IEC 62366, Usability Term
Normal Use	Correct Use
Reasonably Foreseeable Misuse	Use Error (Slip, Lapse, Mistake)
Normal Use + Reasonably Foreseeable Misuse	Normal Use

Table 1

As designers we must also anticipate Use Error, (or reasonably foreseeable misuse), which can be Slips, Lapses, or Mistakes. Slips are due to buttons or menu items being too close together such as the maximize and close buttons in Windows. Lapses are due to too much complexity for the use environment. Slips and Lapses are unintentional. These should be fairly routine to anticipate and control.

Mistakes are more interesting. A designer needs to anticipate and investigate (assisted by user input and observation) where a user might default to behavior suggested by the user interface, or seek a shortcut. Mistakes are always intentional.

I like to think of mistakes as something Homer Simpson might do. Homer has good intentions, but nonetheless, somehow always seems to find himself in trouble.

Homer in the episode where he becomes "Max Power", says to Bart, "There's the right way, the wrong way, and the Max Power way."

Bart asks, "Isn't that the wrong way?"

Homer explains, "Yeah, but faster."
I think this sums up the new mentality that designers need to adopt.

Abnormal use is intentional and beyond any further reasonable means of risk control by the manufacturer. Think Pete Townshend from The Who and what he used to do to guitars after a concert (for young readers; he smashed them into bits and pieces). As reducing risk from abnormal use is beyond further reasonable means, a manufacturer has no further responsibility to reduce this risk.

For those versed in the terminology of the medical equipment safety standard series, IEC 60601, Table 1 provides a quick mapping.

We can see the intent of IEC 62366 is to remind us that reasonably foreseeable misuse or use error needs to be considered "normal". This is true of both IEC 60601 (clause 4.1) and IEC 62366, but IEC 62366 adds emphasis by using the term *normal use* for both correct and use error.

Consider as well that the term *use error* is NOT called *user* error. Use of the word *use* instead of *user* is intentional to emphasize that it is the designer's responsibility to risk control use error where it could result in harm. Use error should not be considered the user's fault.

Figure 9 illustrates well that the Usability Engineering process has continuous improvement provided by its post-market surveillance feedback. This is much like a quality management system with its customer feedback, process metrics, and internal auditing, feeding into the management review and CAPA (corrective action, preventative action) process. A risk management process has post-market surveillance as feedback for risk control improvement.

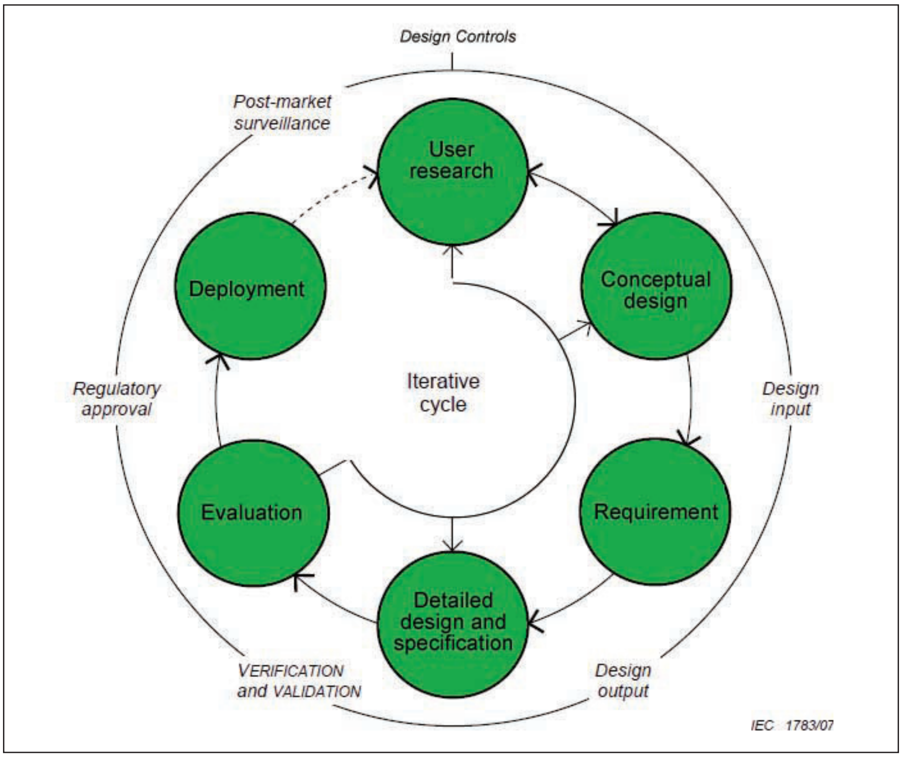

Figure 9: Usability Engineering process (IEC 62366:2007, Figure D.1)

Key aspects of a Usability Engineering process during the design phase:

- Application specification
- Frequently used functions
- Usability hazards (user input & observation)
- Primary operating functions
- Usability specification
- Validation plan
- Design & implementation
- Verification
- Validation (*user input & observation*)

The Usability Engineering process starts with a documented list of what the device is intended to do -- the application specification. We analyze and investigate this list to determine frequently used and otherwise primary operations related to safety -- frequently used and primary operating functions.

Based on our analysis and investigations, where use error could result in unacceptable risk, we add risk controls. These risk controls are defined in the Usability Specification. These can be included with other design requirements related to customer, business, and device failure risk controls, but there needs to be a means (e.g. a flag), to identify those related to usability risk controls, as these are inputs for the usability validation plan. The usability risk analysis process is repeated as the design becomes more detailed.

A validation plan needs to be formulated to define the method(s), (e.g. test user population profile, interviews, simulated clinical use, actual clinical use, etc.), and criteria for usability validation. The testing method(s) and compliance criteria allow a validation of the effectiveness of the risk control measures.

Verification can be carried out by engineering, as usability risk control measures such as the color, or blink rate, volume, or spacing to adjacent buttons can be verified. Validation necessarily involves users, as detailed in validation plan.

USABILITY TRENDS IN OTHER PRODUCT SECTORS

Not only the medical device sector recognizes the importance of Usability Engineering. With the newest version of the safety standard for equipment for measurement, control, and laboratory use, IEC 61010-1:2010, 3rd ed, we have a new clause 16, which mandates that reasonably foreseeable misuse and ergonomic issues be addressed with risk assessment (analysis, evaluation, and where needed, effective risk control). Risk assessment is a new clause 17.

In the newest version of the safety standard for information technology equipment, IEC 60950-1:2005 + A1:2009 + A2:2013 (consolidated ed 2.2), in the principles for safety it mentions the need to consider foreseeable misuse. There is no separate clause for this hazard. But, as with all product safety standards, (i.e. the physical requirements for enclosures) foreseeable misuse is taken into account.

In the newly published, but as yet not widely used, safeguards based standard IEC 62368-1:2010, *Audio/video, information and communication technology equipment - Part 1: Safety requirements*, the term *reasonably foreseeable misuse* is defined. However its use is limited to the normative Annex on batteries and fuel cells. Nonetheless, having the term defined will facilitate useful safety discussions.

RISK MANAGEMENT AND USABILITY ENGINEERING

With both risk management and usability engineering, unacceptable risk is mitigated with risk control measures, defined by design requirements, in turn verified and validated. Post-market surveillance provides feedback.

With risk management, hazards are identified and risks defined by the design team including clinical application specialists.

With usability engineering, usability hazards are identified and risks are defined by *user input and observation*. Validation explicitly requires a formal plan to define how and by what criteria *user input and observation* will be sought and evaluated. It is this emphasis on user input and observation that Usability Engineering brings to existing quality system design controls and risk management.

USABILITY ENGINEERING FOR LEGACY DEVICES

User interfaces and user manuals for legacy devices are already designed. We cannot very well go back and follow a Usability Engineering Process without having to go back and effectively undertake the whole design process again -- something that isn't going to make business sense for products that have good experience in the market. This is much like off-the-shelf software, or what IEC 62304, the software safety

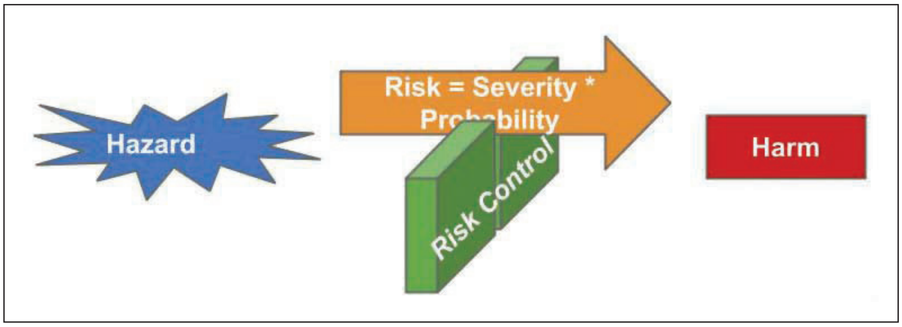

Figure 10: Cause and effect related to risk

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standard, calls Software of Unknown Provenance (SOUP).

With the forthcoming Amendment 1 to IEC 62366, we now have what we call, User Interface of Unknown Provenance (UOUP). As with legacy hardware and SOUP, with UOUP, we have a practical process for conducting a sufficient review of UOUP, taking into account our new appreciation for the importance of good usability.

Amendment 1, Annex K, anticipated in first quarter 2014, provides a UOUP process for legacy devices:

- Relook at Application specification (K.2.1); develop list of Frequently used functions (K.2.2); Primary operating functions (K.2.3)
- Relook at Post market information (K.2.4)
- Relook at Hazard, Risk Analysis records (K.2.5);
- Consider need for any additional Usability risk control measures (K.2.6)

TAKE AWAYS

Designers need to anticipate and investigate use error (reasonably foreseeable misuse):

- Optimize Usability (effectiveness, efficiency, ease, satisfaction)
- Risk control behavior that could result in unacceptable risk of harm

Users are the experts:

- User input and observation needed by design team, including clinical application specialists
- Users validate effectiveness of usability specification (risk control measures)

Based on a review of aggregate medical device adverse incident/event data, use error would seem to be a significant contributor.

Usability Engineering represents a new tool to help us design safer products. Manufacturers who adopt a Usability Engineering process will create safer products. Greater reliance on user input and observation makes intuitive sense if we are to reduce risk associated with use error.

Finally, with better adverse incident/event data collection, we will have the data to assist with root cause analysis, identify areas for improvement, and evaluate our performance.

REFERENCES

- FDA PMS Group http://www.fda.gov/medicaldevices/newsevents/workshopsconferences/ucm214408.htm
- A New, Evidence-based Estimate of Patient Harms Associated with Hospital Care, James, John T. PhD http://journals.lww.com/journalpatientsafety/Fulltext/2013/09000/A_New,_Evidence_based_Estimate_of_Patient_Harms.2.aspx
- To err is human http://www.iom.edu/Reports/1999/to-err-is-human-building-a-safer-health-system.aspx
- USA deaths rates due to traffic and fireams http://en.wikipedia.org/wiki/List_of_preventable_causes_of_death
- MRHA annual adverse incident reports http://www.mhra.gov.uk/Publications/Safetyguidance/DeviceBulletins/CON111657
- Origin of "Do no harm." http://en.wikipedia.org/wiki/Primum_non_nocere
- Max Power video https://www.youtube.com/watch?feature=player_embedded&v=Q5cEAhjcv54
- iec.ch
    - IEC 62366:2007 + A1/FDIS:2013, Medical devices - Application of usability engineering
    - IEC 60601-1-6:2010, Medical electrical equipment -- Part 1-6: General requirements for basic safety & essential performance - Collateral standard: Usability
    - ISO 14971:2007, Medical devices - Application of risk management
    - IEC 61010-1:2010, 3rd ed, Safety standard for equipment for measurement, control, and laboratory use
    - IEC 60950-1:2005 + A1:2009 + A2:2013 (consolidated ed 3.1), Safety standard for information technology equipment
    - IEC 62368-1:2010, Safety standard for audio/video, information and communication technology equipment
- aami.org
    - ANSI/AAMI HE75, 2009 Edition - Human factors engineering— Design of medical devices
- fda.gov
    - Medical Device Use-Safety: Incorporating Human Factors Engineering into Risk Management, issued 2000
    - Apply Human Factors and Usability Engineering to Optimize Medical Device Design, issued 2011 (draft)

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