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Importance of Traceability in EMI Measurements

This article introduces the concept of traceability, discuss the role an EMC test laboratory must assume to ensure traceability of test results and will introduce a future amendment to CISPR 16-1-1 which describes the requirements for calibration of EMI receivers and spectrum analyzers.

Werner Schaefer

Online Exclusive

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For Optimizing Server Cost-per-bit, Ethernet Task Force has a 25Gb/s Plan in Hand Matt Brown

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Radiated Emission Measurements 34 in the Semi-Anechoic Chamber at 3, 5, and 10 m Distance: **Results and Empirical Estimates**

Vladimir Bazhanov and Bruno Liska

Complying With the EU's EMC Directive 38 Without 3rd Party Testing

EMC test laboratories advertise their services a great deal, and it is hardly surprising that many manufacturers get the impression that it is necessary for CE marking to have 3rd-party EMC test reports for their products. But it is important to understand that the EMC Directive contains no legal requirements for performing any EMC laboratory tests.

Keith Armstrong

Parameters for the Integrated Circuit 48

Why integrated circuits are so important for the EMC of electrical devices

Apart from the layout and housing design, the characteristics of the integrated circuits (ICs) used play a key role for the EMC characteristics of devices.

Gunter Langer







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Graduate and Undergraduate Engineering Students are encouraged to participate in the 2015 Student EMC Hardware Design Competition. The competitors are required to design a differential-pair circuit producing an optimal signal with minimal distortion. Finished designs due by 1/5/2015. Learn more at: www.emc2015usa.emcss.org/students From novice to expert, across all industries and academia, the symposium is the must attend engineering event.







LETTER TO THE EDITOR

Error correction for the October issue article, "(More) On Field-to-wire Coupling Versus Conducted Injection Techniques."

Dear Editor,

In the subject article, the historical background erroneously stated that MIL-STD-461 CS114 always limited the cable-induced current to 6 dB above the calibration fixture current limit. In fact, MIL-STD-461D (1993) had a fixed, frequency-independent limit just as recommended in the subject article. MIL-STD-461E changed that to the frequencyspecific 6 dB above the calibration fixture current limit. In essence then, the subject article argues for a return to the MIL-STD-461D limit.



Ken Javor

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News in Compliance

FCC News

Marriott to Pay \$600k for Wi-Fi Blocking

Marriott International, Inc. and its subsidiary Marriott Hotel Services, Inc. have agreed to a financial penalty of \$600,000 to settle charges that its employees intentionally interfered with and disabled Wi-Fi networks set up by consumers at its hotel and conference center in Nashville, TN.

According to an investigation by the Enforcement Bureau of the U.S. Federal Communications Commission (FCC), employees at the company-operated Gaylord Opryland Hotel and Convention Center in Nashville illegally jammed mobile hotspots set up by guests in the public area of the hotel, forcing them to pay \$250 to \$1000 per device to use the Convention Center's own Wi-Fi services. The employees allegedly used containment features available in its own Wi-Fi monitoring systems to de-authenticate guestcreated hotspots, disassociating devices from Wi-Fi hotspot access

points and preventing normal transmissions.

In addition to the \$600,000 civil penalty, Marriott has agreed to monitor the use of its Wi-Fi technology at the Gaylord Opryland property, and to file compliance and usage reports with the Enforcement Bureau every three months for the next three years.

The complete text of the Commission's Order in connection with Marriott is available at incompliancemag.com/ news/1412_1.

AT&T to Pay \$100 Million for Cramming

The U.S. Federal Communications Commission (FCC) has announced a settlement with AT&T Mobility in connection with allegations that the company billed customers for unauthorized third-party subscriptions and premium text messaging services. The settlement ends an extensive investigation by the Commission's Enforcement Bureau following complaints by consumers that they were being billed for services they did not authorize, such as ringtone subscriptions and text messaging services providing horoscopes, celebrity gossip and other information. In some cases, consumers complained that efforts to reverse charges or receive refunds for unauthorized services were refused, or met with only partial refunds.

Under the terms of the settlement, AT&T Mobility will pay \$80 million to current and former AT&T customers who were billed for third-party services that were not authorized. The company will also pay \$20 million to those state governments who participated in the settlement, and \$5 million to the U.S. Treasury. The settlement also imposes strong consumer protection requirements on AT&T Mobility, including a requirement that it offer consumers a free service enabling them to block all third party charges.

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News in compliance

FCC News

The text of the Commission's Order and Consent decree is available for viewing at incompliancemag.com/ news/1412_2.

FCC Releases Report on Internet Access Services

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

According to the Commission's report, entitled *Internet Access Services: Status as of December 31,* 2013, over 81% of fixed Internet connections to households meet or exceed the speed tier that most closely approximates the target set in the National Broadband Plan of 3 megabits per second (Mbps) downstream and 768 kilobits per second (kbps) upstream. This penetration rate for fixed high-speed service compares with 70% at the end of 2012, and just 49% in 2009.

At the same time, high-speed Internet access (defined at 3 Mbps downstream or greater) for subscribers of mobile wireless service continues to grow. As of December 2013, more than 67% of mobile subscribers had access to high-speed service, compared with just 38% as of December 2012.

Without accounting for speed, Internet connections overall are



News in Compliance

FCC News

growing. By the end of December 2013, there were at least 293 million Internet connections operating at speeds over 200 kbps, a 12% yearover-year increase. Overall growth continues to be driven by dramatic increases in mobile connections. At the end of December 2013, there were over 197 million mobile Internet connections, compared with just 96 million fixed Internet connections.

The complete text of the Commission's latest report on Internet access is available at incompliancemag.com/ news/1412_3.

FCC Proposes \$10 Million Fine for Privacy Violations

The U.S. Federal Communications Commission (FCC) has proposed

a \$10 million monetary forfeiture against TerraCom, Inc. and YourTel America, Inc. for failing to protect the privacy of phone customers' personal information.

According to an investigation by the FCC's Enforcement Bureau, TerraCom and YourTel allegedly stored names, addresses and Social Security numbers of more than 300,000 customers on unsecured servers available potentially available to anyone via the Internet. Unprotected private customer information was apparently available from September 2012 through April 2013. However, even after discovering the security breach, the companies allegedly failed to notify those customers.

The Federal Communications Act requires phone companies to protect the privacy of consumer information, and limits the use of that information for marketing purposes without the consent of the consumer. The Commission believes that the companies' failure to take reasonable steps to secure personal information violates their statutory duty under the Communications Act, since their data security practices lacked "even the most basic and readily available technologies and security features."

This is the second enforcement action by the Commission in recent months in connection with consumer privacy violations. In September 2014, the FCC reached a \$7.4 million settled with telecommunications giant Verizon in connection with the company's use of personal information for marketing purposes without prior consumer approval.

FDA News

Defibrillation Electrodes Recalled

Medical supply and device manufacturer Covidien has notified customers of a voluntary Field Safety Alert for certain models of the company's defibrillation electrodes due a connector compatibility issue.

According to the company, certain Medi-Trace™ Cadence and Kendall™ model multi-function defibrillation electrodes are not compatible with Philips FR2 or FRx defibrillator units, and could result in a delay in the emergency resuscitation of patients. The FRx unit will sound an alert when incompatible electrodes have been connected, but the FR3 unit provides no such alert, making it impossible to determine a problem until the defibrillator must be used.

Covidien estimates that nearly 650,000 of its electrode products

are affected by this safety alert. The U.S. Food and Drug Administration has classified Covidien's Field Safety Alert as a Class 1 Recall, signifying a reasonable risk of a serious adverse health consequence or death.

Further details about Covidien's Field Safety Alert are available at incompliancemag.com/ news/1412_4.

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News in Compliance

CPSC News

Bed Bug Heat Treatment System Recalled

JAB Distributors of Wheeling, IL (doing business as PAB Two LLC) has announced the recall of approximately 1700 of its ThermalStrike Expedition-brand bed bug heat treatment systems manufactured in the U.S.

According to a recall noticed posted on the website of the U.S. Consumer Product Safety Commission (CPSC), the recalled systems include a flexible, electrical conducting strip at the top of the heating element that can break at the corners through regular use, posing a potential electrical fire hazard. The company says that it has receive four separate reports of the electrical conducting strip breaking, including one report of a fire in the unit and three reports of electrical sparking. However, there have been no reports of injuries or significant property damage associated with the recalled systems.

The bed bug heat treatment systems were sold through pest control companies and pest control product distributors nationwide, as well as through Amazon.com, from December 2011 through May 2014 for just under \$200.

Additional details about this recall are available at incompliancemag.com/news/1412_5.

New Federal Safety Standard for High-Powered Magnet Sets

The U.S. Consumer Product Safety Commission (CPSC) has approved new rules for high-powered magnet sets to further protect the safety of young children and teenagers.

Under the new national safety standard, an individual magnet from a high-powered magnet set must either be larger than the CPSC small parts cylinder standard, or have a magnetic force less than a specified measure. The new national safety standard will apply to high powered magnet sets manufactured or imported into the U.S. on or after April 1, 2015.

High-powered magnet sets contain approximately 200 magnets on average, although some sets may contain as many as 1700 magnets. If multiple magnets are swallowed, they can combine in the digestive track, pinching or trapping intestines or other digestive tissues, potentially leading to serious injury and even death. The CPSC estimates that emergency rooms around the country treated about 2900 injuries related to swallowed magnets during the period between 2009 and 2013.

Additional information about the CPSC's new safety standard for high-powered magnet sets is available at incompliancemag.com/ news/1412_6.

You Can't Make This Stuff Up

iPhone "Hairgate"

In addition to all of the positive attention it has received since its introduction in September 2014, Apple's new iPhone 6 has been the subject of negative press as well. First was the scandal over whether the ultra-skinny phone bends under pressure, such as when users place the phone in their back pockets. Now, we have "hairgate"!

According to Reuters News Service, some users have complained that the tiny gap between the phone's aluminum frame and its glass surface is trapping users' hair and pulling it out. If posts on social media are to be believed, the problem reportedly affects facial hair as well as hair on top of the head. The situation is attracting all kinds of attention on Twitter at both #hairgate and #beardgate, including smart-alecky remarks like "Congrats, Apple, for finally getting hipsters to shave." Even shaving giant Gillette weighed in with "Your phone may be smarter than ever, but leave the shaving to the experts."

European Union News

Commission Amends Radio Spectrum Usage for Ultra Wideband Technology

The Commission of the European Union (EU) has modified its requirements on the use of the radio spectrum for equipment using ultrawideband technology.

Published in October 2014 in the Official Journal of the European Union, the Commission Implementing Decision updates the regulatory framework in its Decision No. 676/2002/EC (also known as the Radio Spectrum Decision) to incorporate subsequent Commission actions addressing radio equipment using ultrawideband (UWB) technology. The Implementing Decision also reflects rapid changes in UWB technology while continuing to protect users of spectrum in adjacent bands.

The complete text of the EU Commission's Implementing Decision is available at incompliancemag.com/ news/1412_7.

Updated List of Standards Released for EU's Directive on General Product Safety

The Commission of the European Union (EU) has published an updated list of standards that can be used to demonstrate compliance with the essential requirements of its Directive 2001/95/EC, related to general product safety. The EU's General Product Safety Directive covers "any product... which is intended for consumers or likely, under reasonably foreseeable conditions, to be used by consumers even if not intended for them, and is supplied or made available, whether for consideration or not, in the course of a commercial activity, and whether new, used or reconditioned." The Directive is intended to ensure the general safety of products beyond those specific safety issues addressed in other product directives, such as the Machinery Directive, the EMC Directive, or the R&TTE Directive.

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

The revised list of standards is available at incompliancemag.com/ news/1412_8.



REALITY Engineering

Testing for 5G?

BY MIKE VIOLETTE

This issue of *In Compliance magazine* presents the annual ode to Test Equipment. In that vein, this month's Reality Engineering shares a brief perspective on that topic.

EARLY ESD

Our very first piece of test gear was a Schaffner NSG 430, which was initially used to debug some ESD problems on an early digital typewriter which had the curious trait of rattling off random characters without fingers involved. The NSG 430 had a sweet upper voltage of 16 kV, 2 ns rise and a single polarity discharge. It was a war-horse for many years in the lab and was once used to settle an altercation between two of my junior engineers.

Things have evolved in the measurement and EMC world quite a bit since then, non-the-more true than in the measurement of mobile devices. Expanded data rates, the drive for optimized spectral efficiency and the requirements for hardware performance have all been raised to a much higher bar. New technologies are generating test and measurement challenges 100 times higher in frequency since dad first brought home the NSG 430.

AMPS

First generation mobile phones could deliver a few kilohertz of voice using classical frequency modulation. Although it was a bit naughty, we could dial into mobile bands and listen to conversations using our (now) venerable HP 8568, my first piece of grown-up test gear, with a top frequency of 1 GHz. Most of the conversations were shopping list-instructions from harried commuters and soccer moms. "Pick up some milk on the way home, honey." Nothing too saucy, except for that *one* time...

Advanced Mobile Phone System (AMPS) replaced a funky trunked-type system, and formed the embryo of the massive

mobile system we use today. Adapting features from the plain old telephone system (PSTN), AMPS used Supervisory Audio Tones (SATs) for network control: initiating and routing calls and performing handovers at cellular boundaries.

Channel control was by *blank and burst* techniques, that is, the voice and data used the same RF channel. The voice information would be momentarily blanked and control data sent on the same RF channel. That was it for data. If you wanted to text someone, you had to stop your car and find a fax machine.



Figure 1: NSG 430 Electrostatic Discharge Simulator

GEEZ

Early AMPS systems were limited to 10 kilobits/second¹. Predictions about use was for "a typically large mature system might have up to 100,000 mobile telephones, 50 cell sites and a single telecommunications switching office." It was, in retrospect, the first generation mobile functionality or now referred to as 1G.

2G or the second generation of mobile phones featured digitally-modulated signaling (which means that my analog demodulation on nearly-mothballed 8568 now only yields a crunchy static when tuned to a cell channel). This means mobile chattering is safe (from me, at least, never mind many others, including rogue towers that are operating in the U.S., that are busy intercepting phone calls and hacking into cellular phones²).

Second generation mobile systems evolved to 2.5G and we continue to move along an arc of new paradigms in mobile networks. Since the late 1990s/early 2000s the Third Generation Partnership Project (3GPP) has been issuing specifications for new mobile functionality. We have now arguably entered the fourth-generation of mobile communications; marketeers make much hay of their systems as being 4G or LTE.

According to the 3G Partnership Project, "LTE and LTE-Advanced have crossed the "generational boundary" offering the next generation(s) of capabilities. With their capacity for high speed data, significant spectral efficiencies and adoption of advanced radio techniques, their emergence is becoming the basis for all future mobile systems."³

So now, billions of mobile phones attach to global networks. Advanced multiplexing and modulations cram more data into a tight spectrum. It is estimated that, by 2017, data from smart phones will exceed 6 **exabytes** each month!⁴ That is a whopping 6x10¹⁸ bytes of cat videos, recipe-crawling, online media, Tweeting, friending, unfriending, emailing and—for some surfing for erotica.

Depending on who you ask, there is varying agreement on what *G* we're

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REALITY Engineering

At any rate, the string of Gs keeps being strummed and the sound of 5G is now being tuned. Some posit that 5G is more of a lifestyle evolution, as opposed to a performance- or specification-driven evolution that was/is 3G/4G.

in now. (Are we fully 4G? Does LTE-Advanced make it so? And by the way, where did WIMAX fit? 2.5G?) There is certainly no clear line of demarcation; the technologies and the services blend together at the edges. Cool features like MIMO and beam-forming techniques make the coming generation of technologies ever-intriguing.

At any rate, the string of Gs keeps being strummed and the sound of 5G is now being tuned. Some posit that 5G is more of a lifestyle evolution, as opposed to a performance- or specification-driven evolution that was/is 3G/4G. That is, the services that will define 5G will be the driver of the technology, rather than data rates and throughput. The notion of 5G also feeds into the concept of the *Internet of Things* (IoT) and *Internet Everywhere* where Machine-to-Machine (M2M) connections will comprise a lot of the traffic in the future.

Whatever the outcome, the frequencies and capacities of mobile networks are going to continue to rise. Using advanced Quadrature Amplitude Modulation (QAM) encoding schemes. Constellations of 1024 states can apparently achieve a gigabit of data in a single 56 MHz channel.⁵ You'd figure a gigabit per second would be enough for most, but the lifestyle of the 5Gers will likely demand more.

When will 5G arrive? Some say a G occurs every ten years, so if 4G *happened* around 2010, then 5G may be upon us in 2020. However, elements of 5G (the lifestyle part) are already upon us, notably in the expanding landscape of M2M (your fridge ordering milk from the grocery store—no more having to call your honey on their commute home.)

BACKHAUL

To jam that kind of information over what will be the ever-blooming internet infrastructure will require multigigahertz bandwidths, mostly in the backhaul/infrastructure and when burst data streams are necessary to keep the flow of Instagram pictures going.

Which brings up one of the most fascinating areas of technology development. The millimeter-wave region, for where else can we find such high bandwidths to support such data consumption? For all of the IoTs and 5G stuff to run, RF engineers are developing equipment that operate in the 50 GHz and above. These regions of the upper-upper UHF offer the GHzwide bandwidths. Pretty tempting.

The automotive industry is already using 24 GHz for radar; microwave point-to-point links have been operating in the tens of GHz for many years. Somewhat new to these bands are other doo-dads such as Level Probing Radars (LPRs). So measurements are not a new thing, but the state-of-the-art needs to evolve to realize the 5G dream.

According to Dehos et al, a "vision of 5G networks beyond 2020 is a heterogeneous network composed of long-/medium-range macrocells that



Figure 2: 90 GHz Downconverter

operate in the sub-3 GHz band, small cells (10-50 m radius) that use the sub-6 GHz band and 60 GHz small cells with a target peak capacity of **2-7 Gb/s**" [emphasis added]. The small cells are envisioned to be mounted on traffic signs, posts and buildings and feature "automatic beam-steering and selforganizing features." The heterogeneity is provided by legacy 2G/3G and LTE equipment for voice and the lowlatency basic coverage. That is, users will do their thing on the local cell network and the 60 GHz stuff will do the heavy lifting in the background.

TENS OF BILLIONS OF HERTZ

The big challenge with these nether regions of spectrum is measurement and metrology. Although doable, solid calibration and measurement techniques kinda end at 40 GHz, above which standard analyzers with reasonable sensitivity peter out.

A solution *does* exist that employs bolt-on *harmonic mixers* that take the local oscillator from the analyzer and jams a mixer which creates products in the <10GHz range. These are pumped into the nose of the spectrum analyzer where they can be resolved, sort-of. The process is a bit of a brute force approach and the practical challenge is keeping the real signals sorted out from images and other spurious-type energy that is developed by the mixer action. Also problematic is the high conversion loss, upwards of 40 dB, which limits the sensitivity of the measurement.

At the recent Telecommunications Certification Body Council (TCBC) training (October 2014), the FCC's Office of Engineering and Technology (OET) presented a solution for the **75-85 GHz** and **92-95 GHz** frequency range (W-Band). This type of solution could be adapted for mm-wave measurements.

In the presentation, FCC personnel discussed the development of a downconverter that can be used at these higher frequencies to bridge this measurement gap. The solution was intriguing (if you're into this kind of thing). The notion is to wiggle a mixer and create an IF output that can be measured in the 1 to 12 GHz frequency range using a normal spectrum analyzer. This is a bit different from the existing solution in that the process doesn't create a mess of images and has a significantly higher sensitivity. It also allows for higher measurement bandwidth.

The device and schematic of the solution is shown in Figures 2 and 3. I want one.

I was content to measure up to 1 GHz in my twenties. Now moving steadily over the hill, the action is 100 times higher in frequency. Remarkable.

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(the author)

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Figure 3: 90 GHz Downconverter Schematic

TECHNICALLY Speaking

Theory of Equipment Grounding Impedance

Product Safety Newsletter - September/October 1989

BY RICHARD NUTE

Values for grounding impedance appear in many standards, including UL 478 and 1244, CSA C22.2 No. 0.4, and IEC 601 and 950. Values vary from 0.1 ohm to 1 ohm.

Everybody wants to know the derivation of the value of grounding impedance. And, which is the "correct" value?

Ye asked, and searched, and have never found any answer with a sound technical basis. So, I've put together my own answer, which I'll share with you. This is not a complete treatise on the purpose of equipment grounding; I'm limiting my discussion to the *value* of the impedance of the ground from accessible metal parts to the point where the power cord ground wire connects to the equipment.

Let's start with a definition:

Protective grounding is a system whereby non-current-carrying accessible conductive parts are connected to ground in such a manner as to prevent those parts from rendering an electric shock.

(I use indents and line separations in complex statements so that I can

separate and identify the modifiers from the essence of the sentence. The statement holds together if you ignore any level of indent. Note here the essence "...grounding is a system whereby parts are connected to ground..." This helps me keep track of the entire idea. I learned this technique from Jerry Hoard who, as he read a complex sentence, would ask: "What is connected? Connected to what? How is it connected? What is the connection doing? What kinds of parts?")

To do this job, we need some tools: A circuit or schematic diagram, Ohm's law, and Kirchoff's circuit laws. And a calculator. And, we need a premise. In this case, the premise is:

The impedance of the equipment protective grounding circuit shall be of such value that, in the event of a fault, the voltage at any accessible part with respect to the supply-circuit ground point shall not exceed the voltage limit value for longer than the time limit value.

Let's see what we have:

- 1. We're dealing with the equipment protective grounding circuit. That's the circuit from the point of the fault to the point where the power cord ground wire connects to the equipment. These are the parts we control in the design of the equipment. We don't control the power cord or the attachment plug cap.
- 2. We're dealing with fault conditions. That's pretty clear. Under normal conditions, the protective grounding circuit is not a deliberate current-carrying circuit. (We're ignoring its incidental function as a drain for leakage current.) The



Figure 1

protective grounding circuit is there to provide protection in the event of a fault from the primary circuit to accessible conductive parts.

- 3. We're dealing with the ground the person is connected to. This ground is the floor, or building itself. Under fault conditions, Ohm's law tells us that there will be a potential difference across the impedance of the entire protective grounding circuit. The objective is to limit this voltage to an acceptable value such that an electric shock will not occur.
- 4. Finally, we're dealing with the duration of the potential difference across the impedance of the entire protective grounding circuit. Why? If the fault has zero impedance, then the potential of accessible conductive parts will be at least one half the supply voltage - even if the equipment ground impedance is zero! This value exceeds the conventional 30-volt limit for accessible voltages. With this condition, we rely on the circuit-breaker or fuse to automatically disconnect the circuit and thus provide protection against electric shock. In this case, the equipment grounding impedance must be sufficiently low as to

guarantee that the circuit-breaker or fuse disconnects the voltage before a damaging electric shock can occur.

Now, let's turn to the circuit diagram in Figure 1. To prevent electric shock, we must limit the voltage on the conductive enclosure with respect to the building ground (the floor) to 30

volts or less. We still don't have enough data to solve the circuit.

Let's assume we have 120-volt branch circuit where the overcurrent device is rated 20 amperes. Let's further assume that the electrical engineer has sized the system so that there is no more than 5% voltage drop within the installation and power cord so that the equipment always gets at least 95% of the nominal system voltage.

With these assumptions, we can simplify the circuit as shown in the schematic diagram in Figure 2. We'll distribute the 5% installation and source voltage drops between both the Line conductor and the Neutral conductor, giving each 2.5%. Since the Protective Grounding conductor is the

same size as the Line and Neutral conductors, we'll assume it has the same value impedance.

The impedance of the Line, Neutral, and Protective Grounding conductors is given by:



Now, we are left with two unknowns: (1) the value of the fault resistance, and (2) the value of the equipment grounding impedance.

Let's first look at a corner case where the value of the fault resistance is zero. For the moment, let's also assume the equipment grounding impedance is zero. What, then, is the value of the current?

$$l = \frac{120 \ volts}{(0.15 \ ohm + 0.15 \ ohm)}$$
$$l = 800 \ amps$$

With the circuit we've hypothesized, we'll get one-half the 120 volts, 60 volts, across the protective grounding circuit. Can't avoid it.

Well, we can't get 800 amperes from a 20-ampere circuit breaker for very long. The breaker will disconnect real quick — in less than 1 cycle of the ac, which is 16.6 milliseconds long. Since it takes on the order of 200 milliseconds to cause fibrillation, we've got a reasonably safe system, roughly equivalent to the protection of a GFCI (ground fault circuit interrupter).





TECHNICALLY Speaking

Recall that we assumed a value of zero for the equipment grounding impedance. Now, let's assume some real value for the equipment grounding impedance. But, where do we start?

Let's look at the I - t characteristics of the overcurrent protection device -- the circuit-breaker or fuse. The time for operating of a circuit breaker or a fuse is *inversely* proportional to the square of the current. (This is because fuses and common circuit-breakers are thermally operated, where the power is dissipated in a small resistance, and P is equal to the square of the current times the resistance, I*I*R.) The higher the fault current, the faster the overcurrent device operates. Let's assume that, if the fault current is ten or more times the rated current of the device, the device operates in one cycle of the ac line current or less.

With a 20-amp circuit breaker, the total circuit impedance should be low enough to allow 200 amps (10 x 20 amps) from the 120-volt supply. The total impedance would be:

$$Z = \frac{120 \text{ volts}}{200 \text{ amps}}$$
$$Z = 0.6 \text{ ohms}$$

Since the L and G wires comprise a total of 0.3 ohms, we are left with the remainder, 0.3 ohms, for the equipment grounding circuit.

Now we have determined the maximum equipment grounding impedance for a zero-ohm fault. This equipment grounding impedance will allow 90 volts or more on the equipment accessible conductive parts for no more than 16.6 milliseconds. This meets our criteria for protection against fibrillation, given that we cannot limit the voltage to 30 volts or less.

What about a fault with an impedance greater than zero?

Again, we must examine the I - t characteristics of the overcurrent protective device. For a thermal circuitbreaker, one allowed corner point is 4 times rated current for no more than 2 minutes. Let's see what voltage we get when we have 80 amps (4 x 20 amps), 0.3 ohm equipment grounding impedance, and 0.15- ohm installation grounding impedance:

 $E = 80 amps \times (0.3 ohms + 0.15 ohms)$ E = 36 volts

Clearly, the 0.3 ohm value exceeds the 30-volt limit and does not meet our requirements.

Now we can work backward, using the 30-volt value, and solving for the equipment grounding impedance:

$$(Z + 0.15) ohms = \frac{30 volts}{80 amps}$$

 $(Z + 0.15) = 0.375$
 $Z = 0.225 ohm$

The value of 0.225 ohm meets both criteria, namely the case of a fault impedance of zero (maximum equipment grounding impedance which will operate the circuit breaker in less than 20 milliseconds), and the case of a fault impedance of such value as to take the longest time to operate the circuit breaker (4 times rated current). 0.225 ohm might not be the "right" answer. I selected two arbitrary points on the overcurrent device I - t curve:

- (1) the trip current at 20 milliseconds, and
- (2) the trip current at 2 minutes.

For all currents less than 2 minutes, the voltage on the accessible conductive parts with respect to building ground will exceed 30 volts.

Perhaps we should choose a value of equipment grounding impedance

that, for all times greater than 20 milliseconds, limits the voltage to 30 volts or less.

We said that at 200 amps, the circuit breaker would trip in 20 milliseconds or less. Let's calculate the value of the equipment grounding impedance which, at 200 amps, would limit the voltage to 30 volts:

$$Z + 0.15 = \frac{30 \text{ volts}}{200 \text{ amps}}$$
$$Z = 0.15 - 0.15$$
$$Z = 0$$

The value of the equipment grounding impedance which would limit the voltage to 30 volts is zero ohms. This, of course, is not possible. So, there is, indeed *must* be, some degree of risk of electric shock from the accessible conductive parts of the equipment whenever the fault impedance is such that the current is more than 80 amps and less than 200 amps, regardless of the value of the equipment grounding impedance.

As you can see, there is no one answer as to the value of equipment grounding impedance. I have shown that the greatest value probably should not exceed 0.225 ohm for a 120-volt, 20amp circuit (the most common circuit in the USA).

However, with other assumptions as to the percent voltage drop in the installation, and as to the overcurrent I - t characteristics, one can derive other values for the equipment grounding_ impedance. Suffice it to say that values in the range of 0.1 ohm to 0.2 ohm seem to fit the most common cases for 120-volt systems.

The message of this dissertation is that there are three interactive protective mechanisms at work. First is the overcurrent protection device; the second is the value of the equipment grounding impedance; and the third is the value of the distributed impedance of the electrical installation.

The overcurrent device provides protection against electric shock by disconnecting the source in a short period of time.

The value of the equipment grounding impedance affects the time of operation of the overcurrent device such that for very low impedance faults, the overcurrent device operates quickly, and for relatively high impedance faults, the equipment grounding impedance keeps the voltage low. Thus, the equipment fault current path has two significant parameters which must be considered when deciding on a value of equipment grounding impedance:

- The first is having a sufficiently robust circuit to withstand the very high current (on the order of 200 amps) when the fault is zero. Since the duration of the 200-amp current is short, 16.6 milliseconds or less, the typical equipment grounding circuit can withstand the current without overheating.
- (2) The second is having an impedance low enough to limit the voltage when the fault impedance is something greater than zero.

As can be seen, deciding a single value for equipment grounding impedance is subject to a number of variables -- the most significant being the open-circuit voltage and the overcurrent device I - t characteristics.

CSA C22.2, No. 0.4 is unique among grounding impedance standards in that it does not consider the voltage with respect to the building ground, but with respect to the point where the power cord ground wire connects to the equipment. There is some justification for this as this is controlled by the equipment designer whereas the installation is beyond his control. No. 0.4 requires that the *voltage drop* across the equipment grounding impedance not exceed 4 volts rms at a current twice that of the rating of the overcurrent device. See Figure 3.



Figure 3

In Canada, unlike the USA, 15-amp plugs can only be used on 15-amp protected circuits. So, we are dealing, then, with 30 amps (2 x 15 amps) and 4 volts:

$$Z = \frac{4 \text{ volts}}{30 \text{ amps}}$$

 $Z = 0.133 \ ohm$

This allows the remaining 26 volts to be dropped across the installation ground wire:

 $Z = \frac{26 \text{ volts}}{30 \text{ amps}}$

$$Z = 0.866 ohm$$

But, the 5% voltage drop limitation requires the installation ground wire impedance to be 0.2 ohm. So, though there is a bit of inconsistency, it is on the conservative side holding the voltage to ground to 10 volts rather than 30 volts.

I am indebted to Robert Ferguson of Unisys (London) for providing the key element in solving the riddle of grounding impedance value: electrical engineers design distribution systems for no more than 5% voltage drop at 100% of rated load.

I am also indebted to Jerry Hoard for teaching me how to analyze and write complex sentences. When I met him he was with the State of Oregon Department of Labor and Industry.

(the author)

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Explosions and ESD

BY NIELS JONASSEN, sponsored by the ESD Association

Over the years, there have been numerous reports of explosions in grain silos, of oil tankers blowing up during tank washing, of patients being killed during an operation by a pressure wave set off by an ignition of the anesthetic gas, of everything from minor accidents in the laboratory or kitchen to disasters in space vehicles.

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 republishing 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

Reprinted with permission from: Compliance Engineering Magazine, Mr. Static Column Copyright © UBM Cannon T's an interesting story in itself how the number of static-caused explosions seems to have dwindled over the last two decades, but we will leave that one to another discussion. Instead, we will look into what a discharge is and what sometimes makes it *incendive*—that is, capable of causing an explosion.

DECAY AND DISCHARGE

A charged body may lose its charge in two ways. First, let's suppose the body is a conductor. If it is connected to ground by a path containing mobile charge carriers, the charge will apparently leak away in a current. This is what happens in any wrist strap or surface layer of a topical antistat. If, by contrast, the charged body is a true insulator, this process can only take place if the body is totally immersed in a conductive fluid—in practice, always ionized air. In this case the body doesn't really lose its charge. Rather, the field is neutralized by oppositely charged ions attracted from the fluid. This is called *charge decay*.

The decay current is driven by the field from the charge to be neutralized, but all the field does is move existing charge carriers. The only effect of a decay current (apart from neutralizing the charge and field) is a dissipation of heat, as given by Joule's law.

The other way by which a body may "lose" its charge, totally or partly, is through an electrostatic discharge. A discharge happens if the field from a charge is high enough to cause ionization in the surrounding medium. The difference between decay and discharge is primarily that, in the discharge process, the charge carriers are created by the field, and the development of the process may be much more dramatic than in decay.

In a casual context, electrical discharges are often called sparks. It is, however, more practical to reserve this name for a special kind of discharge, namely that taking place between well-rounded conductors at different potentials.

TYPES OF DISCHARGE

Bowing to tradition and convenience, we may divide electrical discharges into three sometimes-overlapping groups: corona, spark, and brush discharges.

Corona Discharge. If the field strength in front of a sharp point of a conductor exceeds the breakdown field strength for the medium (air, for instance), a corona discharge will take place. This may happen if a conductor with sharp protrusions is given a high voltage, the critical value of which depends upon the geometric conditions, like distance to grounded surroundings. But it may also happen if a grounded, sharp conductor (at zero voltage) is brought near a charged object, like a piece of plastic that has been rubbed. This event

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MR. Static



Figure 1: Corona discharge

demonstrates that it does not take a high voltage to cause a discharge, only a high field strength (see Figure 1).

In a corona discharge, the ionization is limited to a small region around the electrode, where the breakdown field strength is exceeded. In the rest of the field, we have just a current of slowmoving ions and even slower-moving charged particles finding their way to some suitable counter electrode, such as the walls of the room.

A corona discharge is also called a silent discharge. It may be maintained as long as the breakdown field strength is exceeded in some region—that is, as long as the voltage of the electrode or the charge density of the charged insulator is high enough.

Spark Discharge. At the other extreme of the discharge range, we have the spark. This kind of discharge may take place between two well-rounded conductors at different potentials, one of them often grounded (see Figure 2). Again, the discharge starts at a point where the breakdown field strength is



Figure 2: Spark discharge

exceeded. But in contrast to the corona discharge, in a spark the ionization takes place all the way between the two electrodes.

If the electrodes are connected to a voltage supply, the discharge may turn into a continuous arc, but in the normal case of a spark from an insulated conductor, the discharge is a very fast process, where energy given by the equation

 $W = \frac{1}{2}CV^2$

is dissipated in the narrow discharge volume.Here C is the intercapacitance of the two electrodes, V their potential difference.

Brush Discharge. In between the corona discharge and the spark is the brush discharge, which may take place, for example, between a charged material and a normally grounded electrode with a radius of curvature of some millimeters. If a brush discharge is maintained over longer periods, it may appear as irregular luminescent paths (see Figure 3).

Almost all discharges from insulators are brush discharges, like the crackle that you hear when you pick up a charged photocopy or that you feel when you pull a sweater over your head. Only if the discharge comes from a heavily charged, thin sheet of an insulator backed by a grounded conductor (stemmed branched brush discharge) can the discharge have something close to the properties of a spark.

INCENDIVITY

For our purposes here, the difference between the various types of discharges, as just described, lies primarily in their different *incendivity* —that is, the ability of a discharge to cause ignition



Figure 3: Brush discharge

or combustion. If we have a mixture of, say, oxygen (O_2) and diethyl ether $([C_2H_5]_2O)$, the molecules may react with each other if they get into a closeenough encounter, forming water and carbon dioxide. For this to happen, a certain amount of energy has to be delivered in a sufficiently small volume and in a sufficiently short time. The amount of energy depends strongly upon the gas mixture, both in terms of the types of components as well as their relative concentrations.

Figure 4 shows the ignition energies for diethyl ether vapor mixed with either pure oxygen or atmospheric air. For a concentration of approximately 16% ether vapor in pure oxygen, it takes only about 1 μ J to start an explosion. For ether vapor in atmospheric air, the minimum ignition energy is about 0.2 mJ for a concentration of about 6% ether vapor.

Although the curves in Figure 4 are developed specifically for diethyl ether, they are fairly typical for a wide range of vapors of organic compounds, aliphatic as well as cyclic. Consequently, the value of 0.2 mJ may be regarded as a rule-of-thumb lower-energy limit for vapor-air mixtures. Thus, whether an electrostatic charge may cause an ignition in a given environment depends on whether the discharge may deliver an energy of more than 0.2 mJ (or the relevant specific value) in a small-enough volume and in a sufficiently short time. How incendive, then, are the various types of discharge weve discussed? The rate and density of the energy dissipated in corona discharges will always be too low to initiate an ignition—in other words, they are not incendive under any circumstances. In brush discharges, the total energy may easily be high enough, but in most cases either the rate or the density of the energy dissipation is too low to cause an ignition. It is nonetheless possible to create such charging and discharging conditions that a brush discharge may cause ignition in a mixture of common organic vapors and atmospheric air. But it should be stressed that such conditions are very rarely, if ever, encountered by accident. Therefore, we may conclude that brush discharges, and thus discharges from insulators, have very low incendivity.

It's a completely different story with sparks. Again, sparks are discharges between rounded conductors (one of them, often, a grounded object) at different potentials. As already suggested, such a system may be characterized electrostatically by the intercapacitance (or partial capacitance) *C* of the electrodes. If the voltage difference between the



Figure 4: Ignition energy for diethyl ether mixtures

electrodes is *V*, an energy *W* given by the equation

 $W = \frac{1}{2}CV^2$

will be stored in the system. If a spark occurs, almost all of this energy will be rapidly dissipated in the narrow discharge volume. If the discharge occurs in an explosive atmosphere, ignition may result.

By way of example, let's examine a fairly ordinary situation. A person with a capacitance of, say, 200 pF walks across an insulating carpet or takes off a sweater (or does both). She hereby gets charged to a voltage of 2000 V and is loaded with an electrostatic energy of 0.4 mJ. She then starts to remove her nail polish using a solvent that is mainly acetone, $(C_2H_5)_2$ CO. This solvent has a minimum ignition energy like that of diethyl ether, around 0.2 mJ in atmospheric air. If she next touches a grounded item and causes a spark in the vicinity of the open bottle of polish remover, will she cause an explosion?

Most likely not. If we look again at Figure 4, we notice that the curve corresponding to atmospheric air is very narrow. This means that as soon as you move just slightly outside the most easily ignited mixture (6% ether), the necessary energy is much higher. It is therefore possible only in a very small region to cause the acetone vapor to ignite by a 0.2-mJ spark.

On the other hand, somewhere between the surface of the acetone, where the mixture is too rich, to perhaps a couple of feet away, where the mixture is too lean, we'll find the most volatile mixture. If our polish-removing person is very unlucky, that's where she may draw a spark.

EXPLOSION-SAFE VOLTAGE

It is fairly safe to assume that an electric discharge disseminating an energy less than the minimum ignition energy $W_{min} \sim 0.2 \text{ mJ}$ in atmospheric air is not incendive, no matter what explosive vapors are present. For a capacitive system—that is, an insulated conductor—with the capacitance C, we may thus define an "explosion-safe voltage" V_{ex} as

$$V_{ex} = \sqrt{\frac{2 W_{min}}{C}}$$

In the case of our friend with the polish remover, we find the theoretical safe voltage to be 1400 V.

The concept of a safe voltage level refers only to explosion risks. When dealing with electronics, the acceptable voltage levels are often considerably lower. And needless to say, the safe voltage concept can also not be applied to charged insulators. Why not? Simply because there is no such thing as the voltage of an insulator.

(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.



Importance of Traceability in EMI Measurements

The recognition of the importance of measurement traceability significantly increased over the last 20 years, especially as part of the test and calibration laboratory accreditation programs that were established worldwide. The generally accepted quality system standard ISO/IEC 17025-2005 includes a set of requirements addressing the subject of traceability of measurement results. These requirements do also apply to EMC test laboratories. This article will introduce the concept of traceability, discuss the role an EMC test laboratory must assume to ensure traceability of test results and will introduce a future amendment to CISPR 16-1-1 which describes the requirements for calibration of EMI receivers and spectrum analyzers.

BY WERNER SCHAEFER

The definition of traceability that is globally accepted in the metrology community is included in the International Vocabulary of Metrology - Basic and general concepts and associated terms: "...property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty."

Traceability means that the result of a measurement, no matter where it was made, can be related to a national or international measurement standard, and that this relationship is documented. In addition, the measuring instrument must be calibrated by a measurement standard that is itself traceable. Traceability is thus defined as the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international, through an unbroken chain of comparisons all having stated uncertainties. It is essential to note that traceability is the property of the result of a measurement, not of an instrument or calibration report or a laboratory. It

is not achieved by following a particular procedure or using special equipment.

The concept of traceability is important because it allows the comparison of the accuracy of measurements worldwide according to a standardized procedure for estimating measurement uncertainty.

Within a chain of traceability, the units of measurement with the highest accuracy are realized by international measurement standards. The value of the international standard is usually determined by comparison of national standards of the highest quality (or in the case of the kilogram by the mass of the International Prototype). National measurement standards, maintained in a national metrology institute or NMI (for example, NPL in the UK, NIST in the USA) must be compared with these international standards. The result of such comparisons, together with the precision and uncertainty of the national standard will be stated and will be available on, for example, the internet (see the BIPM key comparison database at www.bipm.org/kcdb/). Then the national measurement standard serves as a reference for calibration of standards of lower precision. Reference standards are kept in a national metrology institute or in an accredited calibration laboratory for calibrations not requiring the highest accuracy. Again, the result and the uncertainty will be stated.

At each stage in such a chain of traceability, one loses a certain degree of precision. Thus the highest level standards are the international standards, known with the greatest level of precision, and the lower level standards will have been determined to a lower level of precision. This lower level of precision will be one which is acceptable or appropriate for the use of that particular standard.

For an EMC test laboratory to achieve traceability it is essential to use measuring equipment that is calibrated in a traceable manner and also meets the specifications called out in CISPR 16-1-1 to ensure that the expected measurement instrumentation uncertainty for conducted and radiated disturbance measurements or disturbance power measurements can be achieved. Since the EMC test laboratory is responsible for the selection and use of adequate measuring equipment, as well as the purchase of appropriate (meaning accredited or otherwise deemed suitable) calibration services to ensure traceability of test results, a clear understanding of the

calibration requirements is essential. The determination of the necessary specifics of a calibration service in the purchasing process and the review of the obtained calibration service upon receipt of the equipment back from the calibration laboratory before it is placed back into service at the test laboratory are major tasks the test laboratory must complete in order to ensure the proper calibration of test equipment. The importance of test equipment calibration and traceability aspects was also acknowledged by CISPR subcommittee A which is in preparation of normative Annex to CISPR 16-1-1, defining calibration requirements for measuring receivers.

ROLE AND RESPONSIBILITIES OF THE EMC TEST LABORATORY

An accredited EMC test laboratory is required to specify the details of a calibration service to be purchased (technical and/or administrative aspects) to the calibration laboratory to ensure that a suitable calibration service is provided and the equipment is calibrated for the actual application. This information can be included on a purchase order, be provided as a separate document as an attachment to a purchase order, be included in a general contract with a calibration laboratory or can be communicated in any other way. The following aspects must be considered when purchasing a calibration service:

 If a calibration standard is available for the calibration of a specific piece of test equipment like for a measuring receiver (i.e., CISPR 16-1-1) or for antennas (e.g., ANSI C63.5 or the future CISPR 16-1-6) the specification of the applicable standard must be included in the calibration request. In case the applicable standard does include multiple calibration methods (e.g., ANSI C63.5 or the future CISPR 16-1-6) the method to be used is to be included in the request as well.

- If no standard is available to calibrate a piece of test equipment like for spectrum analyzers or signal generators the EMC test laboratory should request the use of the equipment manufacturer's calibration process to ensure that compliance of the equipment under calibration with its specifications can be determined without ambiguity. It is essential to know for an EMC test laboratory that equipment still meets its specifications upon arrival at the calibration laboratory.
- Technical details like the required frequency range or amplitude range, if necessary, are to be specified if equipment is used in a limited fashion. For example, a spectrum analyzer is only used in a frequency range narrower than the capability of the instrument (e.g., the instrument covers the frequency range up to 26 GHz but the laboratory performs emission measurements under its scope of accreditation to 6 GHz only).
- The requirement for an accredited calibration envelopes all calibration parameters of the equipment to be calibrated under the scope of accreditation of the calibration laboratory. This is essential to ensure proper traceability of EMC measurement results.
- The test laboratory should also request the inclusion of the accreditation body's symbol on the calibration certificate for easy identification that an accredited calibration was performed.

When a measuring receiver is to be calibrated for the sole purpose of performing emission measurements, the EMC test laboratory has two choices: Either verification per CISPR 16-1-1 can be requested or a full calibration in accordance with the manufacturer's calibration procedure can be ordered. A calibration laboratory will perform the verification of the instrument by performing the



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EMC test laboratories are also responsible for the selection of adequate calibration laboratories. Many accreditation bodies have established policies that define requirements related to the traceability of measurement results which very often call out the requirement for use of accredited calibration laboratories.

measurements specified in CISPR 16-1-1. Parameters to be verified are summarized in Table 1 below, per identified sections in CISPR 16-1-1. If these measurements are performed under the calibration laboratory's scope of accreditation the EMC test laboratory will have a measuring receiver available for measuring emissions in a traceable manner. It is to be noted though that such a verification in accordance with CISPR 16-1-1 does not envelope all calibration parameters of a measuring receiver. For example, frequency accuracy, frequency stability, or displayed average noise level are not part of the CISPR 16-1-1 verification process. Therefore, if this instrument is also to be used for other purposes like measurements on intentional radiators (e.g., licensed or unlicensed transmitters) this verification will be insufficient and a complete calibration of the instrument in accordance with the manufacturer's calibration process is required. Compliance with the specifications of an instrument can only be determined if the manufacturer's calibration process is applied during the calibration process.

EMC test laboratories are also responsible for the selection of adequate calibration laboratories. Many accreditation bodies have established policies that define requirements related to the traceability of measurement results which very often call out the requirement for use of accredited calibration laboratories. It is to be noted that this requirement is not included in ISO 17025-2005 but established by the accreditation bodies. Use of accredited calibration service providers is the easiest way to ensure traceability for a test laboratory. Today, almost all equipment used by an EMC test laboratory can be calibrated by an accredited calibration laboratory, assuming a suitable scope of accreditation. When selecting a calibration service provider the review of the scope of accreditation of a prospect calibration laboratory is an important step in the evaluation process. EMC laboratories must maintain records of such evaluations per ISO 17025-2005, clause 4.6.4.

Upon return of calibrated equipment from the calibration laboratory the EMC test laboratory must perform an incoming inspection of the received equipment before it is put back into service. This step is essential to avoid the use of equipment for testing work which may be improperly calibrated or may have ambiguous or unclear documentation. Only after a thorough review of the equipment should it be made available for measurements in the EMC test laboratory to avoid possible non-conforming work scenarios that could cause additional investigative work or even retests.

The incoming inspection of equipment received back from a calibration laboratory should address the following items, as applicable:

- Identification: The serial number, unique identification number (if used) and the calibration date/ due date (if requested by the EMC test laboratory) on the certificate must match the information on the calibration sticker affixed to the equipment.
- Accuracy: The values provided on the certificate/report must be

adequate for the intended use of the equipment.

- Traceability: The information which establishes traceability to national/international standards is to be verified. The presence of a symbol of the accreditation body, or reference to the accreditation status of the calibration laboratory is to be determined. Note: Traceability is not established merely by making a statement to that effect.
- Measurement uncertainty: The certificate must include an appropriate statement of measurement uncertainty and where applicable, the before and after data of the calibration in case an adjustment was required.
- Special instructions: If any special instructions were given to the calibration service provider for the calibration of test equipment, it must be verified that they were carried out.
- Documentation of In/Out of Tolerance information: It is to be verified that information is included on the certificate which states the condition of the test equipment (i.e., In Tolerance or Out of Tolerance) when received at the calibration laboratory and before shipment back to the EMC test laboratory.
- Tamper-resistant seals: If the calibration laboratory applied tamper-resistant seals it is to be verified that these seals are not broken. If this is the case the calibration is deemed void.
- Completeness: It is to be verified that a complete calibration of the test instrument was performed

under the calibration service provider's scope of accreditation. The calibration documents are to be reviewed to determine if any calibration activities were performed outside the scope of accreditation (sometimes indicated by a foot note or a remark on the certificate).

When equipment was found to be out of tolerance, as stated on the calibration certificate, the test laboratory will have to use its non-conforming work process to determine how this out of tolerance situation may have impacted previous test results. Where necessary, technical evaluations (e.g., verification tests or an instrument self-test) are to be performed by the EMC test laboratory to establish that the equipment is functioning as expected.

CALIBRATION REQUIREMENTS FOR EMI RECEIVERS PER CISPR 16-1-1

The importance of equipment calibration and traceability of test results is recognized by CISPR. Since the calibration of measuring receivers (which are defined in CISPR 16-1-1 as an EMI receiver or spectrum analyzer without preselection) caused confusion in the international EMC community, CISPR subcommittee A is in preparation of a normative annex to CISPR 16-1-1 to outline the calibration requirements for measuring receivers. The following subjects will be addressed:

Calibration and verification

In CISPR 16-1-1 metrological calibration is defined as a set of operations that establishes, by reference to standards, the relationship that exists, under specified conditions, between an indication of an instrument under calibration and a result of a measurement using the corresponding traceable reference standard. Applied to the measuring receiver this means that a calibration procedure consisting of various steps is used to determine the actual values of calibration parameters like input VSWR or CW amplitude accuracy through measurements under specified environmental conditions, using measuring equipment that was calibrated by an accredited (or otherwise deemed appropriate) calibration laboratory to ensure traceability of the process. The results of these calibration measurements are used to determine if the instrument under calibration meets the specifications published by the manufacturer.

It is to be noted that the calibration process itself does not necessarily involve the instrument under calibration to be adjusted. However, adjustments may be required if the calibration process determines that the instrument does not meet the manufacturer's specifications. The goal of the instrument calibration process is the determination of compliance of the measuring receiver under calibration with its published specifications in a traceable manner.

Furthermore, *Verification* should not be confused with *intermediate checks* (also sometimes called *confidence checks* or *pre-checks*); the latter consists of a set of operations aimed at providing evidence of the proper functioning of a test instrument. An intermediate check of a measuring receiver can differ considerably from the calibration process because the purpose of these two activities is entirely different.

Calibration and verification specifics

The calibration of a measuring receiver requires a specific process that defines the various measurements to determine if the receiver meets its specifications. In general, this calibration process has also been used by the receiver manufacturer to establish the receiver specifications. Therefore, only the manufacturer's calibration process or verification process in accordance with CISPR 16-1-1 is to be applied by a calibration laboratory (or test laboratory performing its own calibrations) to determine whether the receiver meets its specifications at the time of calibration or the requirements called out in CISPR 16-1-1.

If a process different from the manufacturer's calibration process or verification process in accordance with CISPR 16-1-1 is used, the applied process must be verifiably validated to demonstrate technical feasibility and it must be stated in the issued calibration certificate that the process used deviates from the calibration process defined by the manufacturer.

The calibration process for measuring receivers is very important since it defines the following essential parameters that must be used for proper calibration:

- a) the specific set-up of the receiver under calibration for each measurement in the calibration process (e.g. in the case of an EMI receiver or spectrum analyzer the tuning frequency, attenuator setting, resolution bandwidth setting, and other parameters, for each measurement to be performed);
- b) the required test set-up for the measurement of a specific parameter (e.g. the use of power splitters for ratio measurements and any other required measuring equipment);
- c) the required accuracy of measuring equipment used to perform the measurements of the calibration process (e.g. required amplitude accuracy and frequency accuracy);
- d) the actual number of measurements to be performed and their sequence. For many types of measuring receivers this sequence is mandatory and cannot be changed because the measurements of some parameters require the measurements of previous calibration parameters

to be completed. In addition, it is possible that the interpretation of a test result for a calibration parameter is dependent on the test result of a previous measurement in the calibration sequence;

e) the required environmental conditions (e.g. required ambient temperature and relative humidity), if deemed necessary by the manufacturer.

Only if the manufacturer's calibration process is used can the results of the calibration measurements be compared to the published specifications. Consequently, the calibration laboratory or the test laboratory performing its own calibrations (also called internal calibrations) must use the manufacturer's calibration process for a specific measuring receiver. As stated before, an alternative process must be validated to determine its technical feasibility as a calibration process its use must be documented in the calibration certificate to indicate that it deviates from the calibration process defined by the manufacturer.

Measuring receiver specifics

CISPR 16-1-1 specifies measuring receiver requirements using a black box approach. This means that the instrument must show a specific response when a defined signal is applied to its input. Therefore, the demonstration of compliance of measuring receivers with specifications defined in CISPR 16-1-1 does not require the application of the manufacturer's calibration process, and the procedures and measuring equipment defined in CISPR 16-1-1 are to be used. For example, the determination of intermodulation effects per 4.6 is to be performed using the test setup and input signals specified in the standard.

In case compliance of a measuring receiver is determined with the CISPR 16-1-1 specifications, the following minimum set of parameters shown in Table 1 are to be included in the verification process.

The parameters summarized in Table 1 are only applicable to the frequency ranges covered by the instrument under verification and its implemented detector functions. Specifics described in the referenced subclauses apply in their entirety as well as the stated tolerances.

It is to be noted that the requirements called out in CISPR 16-1-1 constitute a subset of all the specifications the receiver manufacturer publishes. In addition, some requirements in CISPR 16-1-1 may be stated in a way that differs from the manufacturer's specifications (e.g. CW frequency accuracy in CISPR 16-1-1 versus a combination of absolute amplitude accuracy at a reference frequency and frequency response).

If evidence of compliance with the requirements presented in CISPR 16-1-1 cannot be directly provided through the manufacturer's calibration process, due to differences in form of the stated specifications, the verification of these requirements must be requested by the test laboratory in addition to the actual receiver calibration based on the manufacturer's calibration process.

Partial calibration of measuring receivers

Often times the complete functionality of a measuring receiver is not utilized when performing emission measurements. For economic reasons test laboratories therefore may decide to purchase a calibration service only for those functions that are actually used to perform measurements. Care must be taken when specifying such a partial or limited calibration service because the calibration of the identified functions may require calibration of other functions as a prerequisite. Such dependencies must be determined by the test laboratory or the calibration laboratory through a review of the manufacturer's calibration process. If the test laboratory does not have access to the manufacturer's calibration procedure, this review must be requested from the calibration laboratory as part of the calibration service purchase.

Parameter	Subclause in CISPR 16-1-1	Suggested Frequencies
VSWR	4.2, 5.2, 6.2, 7.2	VSWR to be determined for 0 dB and ≥ 10 dB input attenuation at the following tuning frequencies: 100 kHz, 15 MHz, 475 MHz and 8,5 GHz
Sine wave voltage accuracy	4.3, 5.4, 6.4, 7.4	Verification at the following tuning frequencies: start frequency, stop frequency and center frequency of CISPR Bands A/B/C and D/E
Response to pulses	4.4, 5.5, 6.5, 7.5	Verification at the following tuning frequencies: start frequency, stop frequency and center frequency of CISPR Bands A/B/C and D/E
Selectivity	4.5, 5.6, 6.6, 7.6	Verification at the following tuning frequencies: center frequency of CISPR Bands A/B/C and D/E

Table 1: Verification parameter summary



Figure 1: Compliance determination process with application of 276 measurement uncertainty

Determination of compliance of a measuring receiver with applicable specifications

Compliance of a measuring receiver with the specifications of the manufacturer or with the tolerances specified in CISPR standards requires that measurement results reported in calibration certificates are below an upper limit, or above a lower limit, or between an upper and lower limit. The uncertainty of the calibration or verification measurement has a direct impact on the pass/fail determination. Therefore, the measurement uncertainty must be taken into account when determining compliance of a measuring receiver with its stated specifications. The application of measurement uncertainty to a measurement result can lead to one of the four cases described as follows and depicted in Figure 1:

- a) the measurement result is within the specified limit range by a margin larger than the expanded uncertainty value applicable to the calibration measurement;
- b) the measurement result is within the specified limit range by a margin less than the expanded uncertainty value applicable to the calibration measurement;
- c) the measurement result is outside of the specified limit range by a margin less than the expanded

- d) uncertainty value applicable to the calibration measurement; or
- e) the measurement result is outside of the specified limit range by a margin larger than the expanded uncertainty value applicable to the calibration measurement, and the specification is not met.

Per CISPR 16-1-1 the four cases in Figure 1 should be interpreted as follows:

- a) the specification is met;
- b) and c) the result is inconclusive, a definitive compliance statement is not possible;
- d) specification is not met.

SUMMARY

Traceability and calibration requirements are also essential for EMC test laboratories. The interface

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He was actively involved in the development of the new standard ANSI C63.10 and the latest revision of ANSI C63.4, mainly focusing on test equipment specifications, use of spectrum analyzers and site validation procedures.

Werner Schaefer is also a RAB certified quality systems lead auditor, and an iNARTE certified EMC engineer. He published over 50 papers on EMC, RF/uwave and quality assurance topics, conducted numerous trainings and workshops on these topics and co-authored a book on RF/ uwave measurements in Germany.

between the test laboratory and external calibration laboratories can be complex, depending on the complexity of the equipment to be calibrated. Therefore, the EMC test laboratory is required to define the calibration requirements and communicate those to the calibration laboratory. Through the selection of proper calibration laboratories traceability of EMC measurement results is established. Since the calibration requirements of measuring receivers is complex, CISPR subcommittee A is in the process of preparing an annex to CISPR 16-1-1 that summarizes the calibration requirements for such instruments. This will allow the EMC test laboratories to easily identify the required calibration requirements in order to perform traceable emissions measurements.

EMC test laboratories must also ensure that the provided calibration service is the one that was initially ordered. The step of an incoming inspection is performed upon receipt of the instrument back from the calibration laboratory and before the instrument is made available for measurements in the test laboratory. A thorough inspection will help avoid that improperly calibrated equipment or otherwise questionable calibration documentation causes non-conforming work situations later on which in turn can require considerable effort to determine the impact of such a situation on test results or can result in retesting of test samples.



Radiated Emission Measurements in the Semi-Anechoic Chamber at 3, 5, and 10 m Distance: Results and Empirical Estimates

BY VLADIMIR BAZHANOV AND BRUNO LISKA

adiated emission (RE) measurements in the frequency range 30 ... 1000 MHz are usually performed at the open area test sites (OATS) or in the semi-anechoic chambers at the distances 3 or 10 m from the equipment under test (EUT).

If the RE limit in the applicable standard is given just for one measurement distance and the tests are performed at another distance it is a common practice to re-calculate the corresponding values, e.g. from 3 m to 10 m and vice versa. This is made in assumption that the field strength decreases inversely proportional to the measurement distance.

Nevertheless, this approach in many cases does not give correct results. Possible reasons are in particular:

measurement uncertainties, reflections from the reference ground plane, compliance of the measurement setup with the far-field conditions, uncertainties of the site validation, etc. There is also a concern regarding the RE measurements of the relatively large objects at 3 m distance as the results may be influenced by the near-field effects. The discussion is ongoing within the CISPR community.

Related problems, including the history of their development, are discussed by Daniel Hoolihan³. The interested reader is addressed to this excellent review.

In this article we make an attempt to improve our understanding of the following questions:

• Is it realistic to assume the inverse proportionality of the field strength

to the measurement distance in a semi-anechoic chamber?

- Is it reliable to test relatively large objects at 3 m measurement distance?
- Can we predict the field strength when the near-field influences measurement results?

MEASUREMENTS

Radiated emission measurements in the frequency range 30 ... 1000 MHz were performed in the accredited semi-anechoic chamber at the distances 3, 5, and 10 m from the EUT that was a stable reference source. The EUT had the largest linear dimension (height) equal to 2,3 m. Measurement procedure was according to ANSI C63.4-2009¹. For considered frequency range and distances the measurement uncertainties were estimated to \pm (4,6 ... 4,7) dB.

Frequency	3 m		5	m	10 m	
MHz	QP	Pk	QP	Pk	QP	Pk
30,6	37,1	38,5	35,5	37,3	31,2	32,7
34,0	37,0	38,4	34,6	36,3	30,6	32,8
38,0	39,5	41,6	37,2	40,1	33,8	35,9
41,2	39,1	41,5	35,8	38,8	33,3	36,8
69,3	41,1	43,8	39,2	42,0	37,6	40,2
74,0	41,3	43,9	37,7	41,5	37,5	40,0

Table 1: Field strength $[dB(\mu V/m)]$ of radiated emissions from the reference EUT measured in a semi-anechoic chamber at 3, 5, 10 m distance with quasi-peak (QP) and peak (Pk) detectors

RESULTS AND DISCUSSION

Measurement results are presented in Table 1.

It is usually assumed that the field strength in the far-field decreases inversely proportional to the measurement distance according to

$$E(d) = E(d_{ref}) + 20 \cdot \log(d_{ref}/d)$$
(1)

where

 $E(d_{ref})$ is the field strength, measured at the reference distance d_{ref} from the source;

E(d) is the field strength calculated at the distance d from the source;

E is expressed in $dB(\mu V/m)$.

Using equation (1) and the data from Table 1 the field strength values were computed for our series of measurements with the reference distance d_{ref} set to 5 m. Calculation results are given in Table 2.

The difference Δ between the field strength values estimated using formula (1) and the measured values is positive when d_{ref} > d and negative for d_{ref} < d. The variations of Δ are rather big for both quasi-peak and peak measurement series and the absolute values $|\Delta|$ are up to 5.8 dB. For d_{ref} = 10 m (results not shown here) maximum Δ = 7.0 dB when the values are re-calculated to 3 m. Even much larger differences were observed in other studies, see, for example, David Weston's article Egregious Errors in Electromagnetic Radiation Evaluation⁴. In this way, application of equation (1) for semi-anechoic chambers may introduce uncertainties (not included in the uncertainty budget) leading to the erroneous judgement on compliance of the tested products with the radiated emission requirements.

In attempt to make the issue more clear we applied a semi-empirical model for prediction of the values that should have been measured at 3 m distance based on the reference results obtained at 5 m distance.

From the computational form of Maxwell's Equations the real part of the field strength E at the distance d from the source at the time t = 0 may be expressed as

 $E(d) = R \bullet [(1/d^2)\cos(-\beta d) + (c/\omega d^3)\sin(-\beta d)]$ (2)

Frequency	3 m				10 m			
	QP		Pk		QP		Pk	
MHz	E	Δ	E	Δ	E	Δ	E	Δ
30,6	39,9	2,8	41,7	3,2	29,5	-1,7	31,3	-1,4
34,0	39,0	2,0	40,7	2,3	28,6	-2,0	30,3	-2,5
38,0	41,6	2,1	44,5	2,9	31,2	-2,6	34,1	-1,8
41,2	40,2	1,1	43,2	1,7	29,8	-3,5	32,8	-4,0
69,3	43,6	2,5	46,4	2,6	33,2	-4,4	36,0	-4,2
74,0	42,1	0,8	45,9	2,0	31,7	-5,8	35,5	-4,5

Table 2: Field strength E [dB(μ V/m)] at 3 and 10 m distance estimated from equation (1) and compared with measured values (Δ = Estimated – Measured). Reference distance d_{ref} = 5 m

Frequency	Quasi-peak				Peak	
MHz	Measured	Predicted	δ	Measured	Predicted	δ
30,6	37,1	43,0	5,9	38,5	44,8	6,3
34,0	37,0	44,8	7,8	38,4	46,5	8,1

Table 3: Comparison of the field strength E [dB(μ V/m)] predicted by the semi-empirical model (2) with the values measured at 3 m distance (δ = Predicted – Measured)

Derivation of equation (2) is similar to that considered by Glen Dash².

In this equation E – is in V/m; d – in m; $\omega = 2\pi f$; $\beta = \omega / c$; f – frequency in Hz; c – speed of light. R is an unknown function describing the radiation pattern of the source expressed in V • m. Physically R may be interpreted as the product

current • resistance • length

where all three parameters are integrated through the whole structure of the radiating source.

From equation (2) we obtain

 $R = E(d) \bullet [(1 / d^{2}) \cos (-\beta d) + (c / \omega d^{3}) \sin (-\beta d)]^{-1}$ (3)

We assume that the radiation pattern R calculated from (3) for d = 5 m using the values from Table 1 is also valid for measurement distance d = 3 m, i.e. R(3 m) = R(5 m). That allows predicting the field strength E at 3 m from the model (2).

The calculations were performed for low frequencies where the far-field condition $d \gg \lambda / (2\pi)$ is not fulfilled. The results are shown in Table 3.

In this way, for frequencies 30,6 ... 34,0 MHz the average difference between predicted and measured numbers is 6,85 dB and 7,2 dB for quasi-peak and peak values respectively. Thus, the near-field effects should not be ignored if the RE measurements are performed for large test objects at short distances. In our case the scaling factor, i.e. the relation between the measurement distance and the largest linear dimension of the EUT, is 3 m / 2,3 m = 1,3.

CONCLUSIONS

Commonly used assumption that in a semi-anechoic chamber the field strength decreases inversely proportional to the distance from the test object is not correct and should be considered with caution to avoid erroneous judgement on compliance of the tested products with the radiated emission requirements. Corresponding errors may be up to 5,8 dB and even more.

Near-field effects contribute to the values of RE from the relatively large objects measured in a semi-anechoic chamber at 3 m distance when the far-field condition d >> λ / (2π) becomes weak. Using the semi-empirical model it is estimated that for frequencies 30,6 ... 34,0 MHz the value of 7,0 dB should be added to the results obtained at 3 m.

The number may be recommended as the measurement correction factor. $\mathbb N$

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Complying With the EU's EMC Directive Without 3rd Party Testing

BY KEITH ARMSTRONG

common path to achieving compliance to the European Union's (EU's) EMC Directive 2004/108/EC (which I shall call the EMCD here) takes many manufacturers down the route of utilizing a thirdparty EMC test laboratory to obtain EMC test reports for their products. This process was detailed in the article "Heading for the EU? Get Your Compliance Passport Ready!" appearing in the May 2013 issue of *In Compliance*.

However, it is important to understand that the EMCD *contains no legal requirements for performing any EMC laboratory tests.*

This was also true of the original EMCD, 89/336/EEC, and will also be true for compliance with the future EMCD, 2014-30-EC, which replaces the current EMCD on 20 April 2016 (more on this below).

Manufacturers are required to affix the CE marking to their products, and to do that they must first have created and signed an EU EMC Declaration of Conformity (DoC) which is based on the evidence of EMCD compliance contained within a Technical Documentation File (TDF).

As I will show later, there are two routes to declaring EMC compliance (sometimes called conformity to the EMCD), and it is the manufacturer's choice whether his DoC relies entirely on all relevant harmonized standards (the *Standards Route*), or uses just a few or none of the relevant harmonized standards (the *EMC Assessment Route*).

Even when following the Standards Route, the DoC is effectively a legal statement by a manufacturer that: "*if my product was tested to these harmonized standards, it would probably pass.*" How a manufacturer obtains sufficient confidence to make this legal declaration *is entirely up to that manufacturer*, and should be documented (amongst other things) in the TDF.

Compliance with the EMCD certainly does not require any test reports from third-party EMC test labs. This is what makes it possible for many manufacturers of electronic products around the world to save time and money by testing in their own EMC labs.

This also makes it possible for individual entrepreneurs, who might be working out of their garages (like Mr Hewlett and Mr Packard did when they first started)³ to sell their products in the EU without the high costs associated with EMC testing to standards. In fact, the same is true for most of the so-called CE Marking Directives – third-party testing is only a legal requirement in a very few EU Directives, and only then when dealing with especially dangerous products, e.g. certain kinds of medical equipment; especially dangerous machinery such as chainsaws, bandsaws, etc.

I have often heard the EU's single market described in the USA as *Fortress Europe* – when the *exact opposite* has always been true: the EU's single market does not present any significant barriers of cost or delay to any equipment from anyone, anywhere.

OK, that's enough background. Let's get into the details!

To see how it is that manufacturers can comply with the EMCD without third -party testing, even without any testing at all, we need to understand how the EMCD works.

When we understand this, we will also understand that even passing third -party laboratory tests to all relevant EU harmonized EMC standards might not, on its own, ensure compliance with the EMCD.

APPLYING THE EMC DIRECTIVE

The EMCD² applies to both *apparatus* and *fixed installations*, with special legal meanings for both of these otherwise commonplace terms. Figure 1 shows that apparatus is treated very differently from fixed installations.

Apparatus is any electrical/electronic item that could cause or suffer EMI, *and* which is "made available for an end-user in the EU" for the first time (see later). It is important to understand that the EMCD applies to every individual item (e.g. individual serial numbers) – Chapter 2.2 in [4] and Chapters 1.2 and 3.2.2 in [5] provide much more detail on this.

The EMCD also has a special category of apparatus "...intended for incorporation into a given fixed installation, and not otherwise commercially available" (which most of us would call *custom, bespoke*, or *one-off* equipment) which can avoid having to be CE marked for EMC, although it then has to comply with other EMC activities.



Figure 1: Applying the EMC Directive

EMC Benign equipment is excluded from the EMCD's scope, and the official guide [5] contains a list of what is currently considered to be EMC Benign. As a general rule, EMC Benign equipment never contains any operational semiconductors (rectifiers, transistors, ICs, etc.) or thermionic valves, or makes sparks.

Equipment that is only made available for the exclusive use of professional integrators in the construction of their own products, and which is not made available for end-users (even by distribution) is also excluded from the scope of the EMCD.

However, such equipment will almost certainly have to be CE marked for compliance with an EU safety directive, such as the Low Voltage Equipment Directive [6], Machinery Directive [7], etc. This is one reason why a manufacturer should never assume EMC compliance when purchasing a CE-marked third-party product for incorporation into another product, system or installation.

I have seen many large projects suffer greatly from major contractors making two big errors regarding EMC:

- i. Mistakenly assuming that every item of equipment that carries a CE marking must perforce comply with the EMCD. This article describes three ways in which this assumption can be wrong, all of which are shown in Figure 1:
 - a. When the equipment is *EMC Benign*
 - b. When the equipment is only supplied to professional integrators, whether it is manufactured in volume or custom-designed (e.g. as a subcontract)
 - c. When the equipment is custommade for a particular end-user's Fixed Installation
- ii. Mistakenly assuming that an EMC compliant final system merely needs

EMC compliance for its constituent parts, often called the CE + CE = CE approach (see later).

Also exempt from the EMCD is radio amateur equipment that is not commercially available; aeronautical equipment covered by Regulation 1592/2002, and equipment covered by the R&TTE Directive (1999/5/EC).

The new Radio Equipment Directive 2014/53/EU will replace the R&TTE Directive from June 12, 2016, at which time some of the equipment that used to be covered by R&TTE will instead come under the EMCD [2] and the LVD [6].

Equipment that has EMC aspects addressed in specific product Directives (e.g. medical devices, automotive, etc.) is only exempt from the EMCD to the extent covered by those other Directives. Unfortunately, this is widely misunderstood to mean they are totally exempt from the EMCD.

Apparatus that must comply with the EMCD when made available for an end-user in the EU may be advertised or exhibited before it is EMC compliant – as long as it is clearly marked as being non-compliant with the EMCD, and as not (yet) being available to end-users in the EU.

EMC CONFORMITY OF APPARATUS

The EMCD requires all apparatus to:

- i. Comply with the Protection Requirements
- ii. Undergo a conformity assessment procedure



Who would ever want their products not to comply with these Protection Requirements? The costs of dealing with the resulting complaints (and the loss of possible future sales) would eat into the financial bottom line, making a manufacturer less profitable.

- iii. Have a TDF prepared and readily available for inspection by enforcement officials
- iv. Be supplied with specified User Information
- v. Have a signed EC DoC
- vi. Carry the CE marking

Items i - v in the above list must be complete before the CE marking is applied (item vi).

All of the items i - vi must be complete before the apparatus is made available for the first time to an end-user in the EU (see 2.2 in [4]).

It is important to note that being made available to an end-user for the first time in the EU, does not only mean new products. Used or second-hand products that are brought into the EU are *also made available for the first time in the EU*, and so have to comply with the EMCD no matter how old or how large they are.

As already mentioned, the only exclusion to full compliance with the EMCD is for apparatus intended for incorporation into a given fixed installation, and not otherwise commercially available (see later).

THE PROTECTION REQUIREMENTS

The Protection Requirements (Clause 1 of Annex I in [2]) state the essential legal requirements for compliance with the EMCD, using simple terminology in the hope (probably a vain one) that this will make it difficult for lawyers to interpret them in ways other than what was intended:

"a shall be so designed and manufactured, having regard to the state of the art, as to ensure that:

(a) The electromagnetic disturbance generated does not exceed the level above which radio and telecommunication equipment or other equipment cannot operate as intended;

(b) It has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use."

Who would ever want their products not to comply with these Protection Requirements? The costs of dealing with the resulting complaints (and the loss of possible future sales) would eat into the financial bottom line, making a manufacturer less profitable.

So even if there was no EMCD, the Protection Requirements above should still be applied to help reduce financial risks.

CONFORMITY ASSESSMENT IN GENERAL

Conformity assessment is specified in Annex II of [2], and requires an EMC Assessment that results in a TDF that demonstrates how it is that a product can claim compliance with the Protection Requirements. The TDF should cover *all* operational modes and *all* intended use configurations, and (as described in [1]) the amount of verification work required can be reduced by identifying the *worst case* combinations of configuration and operational mode – i.e. the ones that would cause the highest emissions or are the most susceptible to interference. See 3.2.1 in [5] for more information.

As I said earlier, there are two routes to conformity with the EMCD:

- i. The *Standards Route*, which uses harmonized EMC standards – see 3.2.2 in [5]
- ii. The *EMC Assessment Route*, which can use any standards or none see 3.2.3 in [5]

CONFORMITY ASSESSMENT BY USING HARMONIZED STANDARDS

When following this Standards Route, the product's DoC must list all of the relevant harmonized EMC test standards that apply to the product, which can be found in the official listing website at [8].

This route to EMC conformity requires that all these harmonized standards are *correctly applied* – but what does *correctly applied* actually mean?

Clearly, one way is to have a third-party test lab perform all of the tests exactly as described in the relevant standards, with the EMC test reports forming Some manufacturers (and not only the larger ones) have their own fullcompliance EMC test labs, and some of them even have some/all of their tests accredited. These labs are generally best used just as if they were third-party labs.

the bulk of the TDF. If the test lab is accredited by a national accreditation body to perform a particular test, there is more confidence that the test will be done correctly. Unfortunately my experience (and that of many others) is that not all national accreditation bodies are equal.

Third-party testing has been very well described in [1], so I don't need to go into it here.

Some manufacturers (and not only the larger ones) have their own fullcompliance EMC test labs, and some of them even have some/all of their tests accredited. These labs are generally best used just as if they were third-party labs, as described in [1].

(Interestingly, in-house test labs located in the same building as the design teams can pay back their original investment much more quickly than the usual business case predicts – I have seen one such lab payback in four months!)

However, as stated early on in this article, using the services of a third-party accredited test lab to *correctly apply* a harmonized standard to test exactly to the standard is <u>not</u> the only option when following the Standards Route.

The correct application of a harmonized standard, actually means that a manufacturer has done enough homework to have sufficient confidence that *if the product was fully tested in an EMC laboratory that was* accredited to test to that standard – it would pass.

Let's be perfectly clear on this: *correct application* does not mean that the product has actually been tested to that standard, only that -if it was tested at some future time -it would pass.

The EMCD leaves manufacturers totally free to decide on the amount and quality of EMC testing they do themselves, or have done for them, to have sufficient confidence to sign their DoC when using the Standards Route.

(It is important to understand that there are no absolute guarantees in the world of EMC – even with fullyaccredited third-party testing, a product that passes in one test lab can fail when tested in another lab, even though nothing has changed in the product and the exact same cables are used with it. Some manufacturers take advantage of this by always using test labs that they find are more likely to give them a pass result!)

Here are four examples of when laboratory testing might not be required to correctly apply a harmonized radiated emissions standard such as EN 55022:

i. When the product emits a certain amount of RF power spread in a particular way over a particular frequency spectrum, and calculations/simulations show that if this emitted power was measured according to the relevant EMC test standard, it would be almost certain to pass (even when

taking measurement uncertainty into account).

For examples of this approach, see [9] [10] and [11].

ii. When the product is housed in a well-shielded and well-filtered enclosure that has been proven by shielding effectiveness testing and/or simulation to provide more than sufficient RF attenuation to ensure that if its emitted RF power was measured according to the relevant EMC test standard, it is certain to pass (even when taking measurement uncertainty into account).

Many manufacturers purchase well-shielded/filtered overall enclosures, then ruin them with modifications, completely wasting their high cost, see Chapter 5 of [12]. So an expert assessment is usually required to have sufficient confidence in the final assembly.

iii. When a product fails in a test lab and a simple modification applied by hand makes it pass, and the same modification is applied on production units, there can be sufficient confidence that if a new production sample was retested, it would pass.

In this context, 'the same modification' means physically and dimensionally the same – for example an additional shield bond made with a screw-fixing is <u>not</u> the same for EMC as an additional bond made in a different place, or When following the Standards Route, the DoC should not state that the listed harmonized standards have been tested and/or passed (unless they have been, of course!). Generally, it is better for the DoC to say something like: "The following standards have been applied."

made in the same place with a braid strap or piece of green/yellow wire instead of a screw.

iv. When a product has passed an equivalent or tougher radiated emissions test and has not been changed (either in its hardware, software, or components).

A typical example is a product that has passed MIL STD 461 radiated emissions tests which set lower emissions limits than the relevant harmonized test standard, see [13].

Chapter 3.2.2 of [5] provides very good guidance on the Standards Route, and states that where a product follows this route there is no legal requirement in the EMCD to perform the EMC Assessment process outlined below.

Unfortunately, even when full testing is done in a lab that is accredited for that test, and passed, it might not ensure compliance with the Protection Requirements in real-life operation, which is, of course, what really matters for compliance with the EMCD – and also (more importantly) for financial success.

This is because no harmonized test standards cover all of the EM disturbances that could occur in real life. Also, it is because the tests have been specifically developed to ensure repeatability in testing, which can often mean they are simply not representative of real-life EM disturbances.

Also – given the inevitably slow pace of international standardization –

all published standards are behind the times. For example: none of the harmonized immunity standards cover the very close proximity of cellphones, e-book readers, Wi-Fi transmitters, RFID transmitters (including active RFID tags), etc., even though such proximity is now a normal "... electromagnetic disturbance to be expected in its intended use...".

Immunity to the *near-fields* (see [14]) that can be created by portable RF transmitters in very close proximity is arguably now a necessity for legal compliance with the Protection Requirements, even though not tested by any harmonized standards.

"Big deal", you might say, "but I don't want to spend any more on legal compliance than I have to!" OK, but think for a minute about what I said earlier in the section on Protection Requirements – if products don't comply with them they are less likely to be financially successful. If they have big problems with EMC in real life, they could even do irreparable damage to a manufacturer's brand image and future profitability. Some companies have actually been bankrupted by reallife EMC problems.

The real reason we need to achieve EMC compliance, is to have products that work well enough in real life and don't upset customers. Achieving this is important to help control financial risks, and so what if we have to produce a few pages of legal documentation for EU sales, when it merely covers EMC work we have already done? For these reasons, when following the Standards Route, in addition to correctly applying all relevant harmonized standards, I always recommend performing a full EMC Assessment as below, then doing *whatever else it takes* to ensure conformity to the Protection Requirements. This can sometimes be as quick and easy as a check for emissions or immunity using a closefield probe [15].

Note: When following the Standards Route, the DoC should not state that the listed harmonized standards have been tested and/or passed (unless they have been, of course!). Generally, it is better for the DoC to say something like: "The following standards have been applied."

CONFORMITY ASSESSMENT BY *NOT USING* HARMONIZED STANDARDS

This is the other route to EMC conformity permitted by the EMCD – the *EMC Assessment Route*.

When following the EMC Assessment Route, a manufacturer declares the EMC conformity of his apparatus directly to the EMCD's Protection Requirements, using just some of the relevant harmonized standards, or just some parts of some harmonized standards, or even ignoring all harmonized standards completely. Of course, a manufacturer may choose to follow the EMC Assessment Route simply to save time and money – which is often the case for start-up companies who cannot afford the cost of laboratory testing.

The EMC Assessment Route must follow a specified technical methodology to ensure that the Protection Requirements are met.

According to 3.2.3 in [5], the EMC Assessment Route is usually more appropriate than the Standards Route in the following situations:

- Where the Protection Requirements are not entirely covered by the application of the harmonized standards that are relevant for the product
- The apparatus uses technologies incompatible with, or not yet taken into account by, any harmonized standards
- The manufacturer uses test facilities not yet covered by harmonized standards
- The manufacturer prefers to apply other standards or specifications (even in-house specifications) that are not harmonized under the EMC Directive
- The apparatus is physically too large to be tested in the facility specified by a relevant harmonized standard, or where 'in-situ' testing is necessary (e.g. for systems or installations that are first assembled on the end-user's site) and is not adequately covered by a harmonized standard

Of course, a manufacturer may choose to follow the EMC Assessment Route simply to save time and money – which is often the case for start-up companies who cannot afford the cost of laboratory testing.

This alternative conformity route is essentially the old Technical Construction File (TCF) route under the first EMC Directive (89/336/EEC) – but with the significant difference that now there is no legal requirement for any TDFs to be assessed by a thirdparty (see Notified Bodies, later).

Non-harmonized methods of demonstrating conformity with the Protection Requirements, that may be able to be used, either singly or in suitable combinations, as part of an EMC Assessment Route include (but are not limited to):

- i. Non-EU-harmonized but published EMC test standards (e.g., FCC, military, automotive, etc.)
- ii. In-Situ / On-Site EMC tests [16]
- iii. EMC tests or checks developed by the manufacturer that are not compliant with the harmonized test methods listed in [8].
 These are often called 'precompliance' EMC tests and can vary from full-compliance tests that are just done a little more quickly than they should be, to close-field probing and a variety of other lowcost methods e.g. those described in [15], which might bear little resemblance to harmonized tests.
- iv. Calculations (e.g. [9] [10] [11])
- v. Validated computer simulations
- vi. Comparisons with known EMCDcompliant products made by the

same manufacturer, which use the same technologies, devices and construction methods (but beware – hardware and software technologies, and devices, change very rapidly – and so do their EMC characteristics!)

The EMC Assessment Route's technical methodology includes (but is not limited to)—

- Assessing the EM environment(s) normally expected at the user(s) location(s), taking into account (see [17]):
 - The likely proximity to sensitive equipment that the product's emissions could interfere with;
 - The likely EM threats that could interfere with the product, plus the degradation of functional performance that the user will accept when it is interfered with.
- b. Create the EMC specifications for the product. To help make life easier, these often use modified versions of harmonized standards, basic IEC test methods (see [1]), other EMC standards (automotive, military, aerospace, etc.), and/or guidance for systems and installations such as [12] [18] [19] or some of the many references they contain.
- c. Verify and/or validate the product's design against the EMC specifications.
 Verification and validation techniques include – but are not limited to – EMC testing.

THE 3RD EDITION OF THE EMCD, 2014-30-EC, APPLIES FROM 20 APRIL 2016

All of the technical compliance issues discussed in this article, and in [1], are unaffected by the third edition of the EMCD [20]. Its changes are more to do with adapting the existing EMCD to the EU's New Legislative Framework (NLF, see Chapter 1.2 of [4]).

The changes wrought by the NLF are mostly concerned with extending legal compliance requirements to all *economic operators* through whose hands EMCD-compliant products pass, including: the manufacturer of the products (obviously), appointed agents, distributors, importers, etc.

CE + CE DOES NOT EQUAL CE

Constructing systems only from items that are CE-marked, and *mistakenly* assuming that *this alone* takes care of the EMC compliance of the overall system or installation, is often called the CE + CE = CE approach. Which simply doesn't work!

This incorrect approach is very widely used by system integrators, installers, and major contractors. However, it is easy to show that, technically and/or legally, this approach should never be relied upon, and Chapter 1.2.2 in the official guide [5] contains a specific warning against using it. More detailed information on this is given in Chapter 1.5 of [12], Chapter 2.3.4 of [18] and Chapter 2.3.3 of [19].

Note that the CE + CE = CE approach is also incorrect technically and/or legally for most, if not all other EU Directives, including [6] and [7].

CONCLUSIONS AND MORE INFORMATION

There's a great deal more I could write on complying with the EMCD, but I've covered the main issue of how to comply without using laboratory testing, and wandered off into some related issues as well.

To find out more about related issues, here are some excellent sources of free information:

- Employing Notified Bodies see Chapter 6 of [5], [1] and [21]
- Creating and maintaining the TDF (Technical Documentation File) – see Chapter 3.3 of [5], [1] and [21]
- The EU EMC DoC (Declaration of Conformity) – see Chapter 3.3 of [5], [1] and [21]
- Correctly affixing the CE Marking see Chapter 3.4 of [5] and [21]
- The EMC information legally required to be provided with each apparatus – see Chapter 3.4.4 of [5] and [21]
- Maintaining EMC compliance in serial or batch manufacture see [21]
- Maintaining EMC compliance when the harmonized standards change – see Chapter 3.2.2 of [5], [1] and [21]
- EMC compliance of custom-designed 'apparatus intended for incorporation into a given fixed installation, and not otherwise commercially available' – see Chapter 2.5 of [18]
- EMC compliance of 'Fixed Installations' – see [18]
- Market Surveillance of EMC compliance by EU Member States – see Chapter 7 of [4]
- Compliance of used or second-hand apparatus see Chapters 2.1, 2.4, 3.1 and 4.5.1.6 of [4]

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The above URLs are correct at the time of writing, however IT people regularly change their websites and break such links, in which case a good search engine, primed with the title and/or author and/or publication should find the document.

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Keith graduated from Imperial College, London, in 1972 with an Honours Degree in Electrical Engineering. He has been a member of the IEE/IET

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Over the last 21 years, Keith has provided design consultancy and training courses to over 700 customers worldwide, presented many papers and published many articles and three books, all on good EMC engineering techniques, and on EMC for Functional Safety.

Keith's field-proven approach applies good EMC engineering techniques at every level of design to achieve: savings in design/development costs and timescales; quicker time to market; improved functional specifications with lower overall-cost-of-manufacture; greater reliability and reduced warranty costs. (Plus easy and quick compliance with EMC regulations, of course!)



Parameters for the Integrated Circuit

Why integrated circuits are so important for the EMC of electrical devices

BY GUNTER LANGER

part from the layout and housing design, the characteristics of the integrated circuits (ICs) used play a key role for the EMC characteristics of devices. Reducing the size of the structure, operating voltages and operating points makes the ICs much more sensitive. If one approaches or even surpasses the 100 nm limit, the immunity compared to earlier ICs is reduced, a trend that is reflected in the device behavior. It is important that users of ICs are able to compare various types of IC on the basis of their EMC parameters. This enables the choice of the best IC, and means that the layout design and the device can be aligned to the IC's EMC parameters.

For manufacturers of ICs, good EMC characteristics for their products mean advantages over their competitors. The objective is thus to determine those parameters which are decisive for EMC immunity and emissions and allow engineers to draw conclusions for chip design.

CURRENTLY POPULAR TEST METHODS FOR ICS

It is nowadays common to quote a value of one to several kV in specifications as the ESD strength of electronic components (ICs, transistors) with reference to the human body model. With the human body model (HBM), a capacitor (100 pF) is charged with a test voltage and discharged on the device under test via 1500 ohm. The HBM is described in the standards MIL-STD-883G and in IEC 801-2. The machine model (MM) is a further test model that works according to the same principle.

Both models are only used to validate the immunity to destruction of the IC

when handling the component during its production, packaging, transport and assembly. During MM or HBM tests, the test object is never connected to a voltage, i.e. it is not in operation.

The specified ESD strengths according to the human body model do not relate to the ESD behavior during operation. In fact, the protective mechanisms designed for the human body model (that do not take into account malfunctions during operation) may even cause faults or failures of the IC during a functional disturbance test.

Work is currently being carried out on EMC standards, test methods and limit values for ICs.

The requirements in terms of the EMC of devices (resources and equipment) are already defined in standards, test methods and limit

values. The devices are subjected to an ESD and burst test (IEC standard 61000-4-2/61000-4-4), with test voltages in the kV range. The ICs and other semiconductors used in the device are ultimately the causes of interference emissions and a lack of immunity.



Figure 1: Basic principle of measurements with the IC test system (conducted)



Figure 2: Basic principle of measurements with the IC test system (radiated)

The interference emitted by ICs can be measured at their interfaces and evaluated and defined on the basis of these measurements.

ICs have a low interference immunity with immunity levels in the volt range.

The pulse voltages introduced on the outside of the device during standard tests are attenuated on their way to the IC. A few kV outside the device are reduced to voltages of around 1 ... 100 V at the IC pin. These voltages can exceed the immunity levels of the ICs. This means that compared to the device test, the test voltages for ICs have to be in the range of 1 to several hundred volts and not in the kV range. A higher test voltage is only required in a few exceptions (special devices).

NEW IC TEST SYSTEM

The IC test system (Figure 1 and Figure 2) can be used to analyze the behavior of ICs under the selective influence of (conducted and radiated) disturbances and/or respective emissions. The insights gained from this analysis help semiconductor manufacturers optimize ICs and IC users overcome weak points in their electronic modules.

The test IC is tested in use.

The IC test system lets the user of ICs:

- identify EMC problems in the device on the IC level
- select ICs on the basis of the gained insights and
- optimize the circuit and/or layout design to the EMV parameters of ICs.

The IC test system lets the manufacturer of ICs:

- measure and check the immunity of/ emissions from ICs
- identify the causes of interference and
- optimize the ICs

Different probe sets (Figure 3) are needed to determine the various EMC parameters. The probe set can be selected by the user depending on the field of use (incl. RF, EFT, ESD, DPI, emissions 1 ohm method...).

The ICE1 IC test environment is required as an optimum test environment for the probe sets:

- a test board for the test IC which provides a uniform interface between the test IC and test system
- a CB 0708 connection board which is used to trigger the test IC
- a GND25 ground plane which provides a uniform reference potential

In addition, external equipment may be necessary depending on the probe set and the respective job:

- a disturbance generator (e.g. EFT/ burst)
- an oscilloscope
- a spectrum analyzer
- a PC
- a power amplifier

The IC under test is located on a test board in the test set-up. Filtered connections link the test board to the CB 0708 connection board located below this which connects the test IC to the PC. The IC can be controlled and monitored with the enclosed software. The connection board is integrated in the ground plane which forms a fixed ground reference system for the test. The probes from the probe set are placed onto the ground plane and used to inject disturbances into the test IC through conductive or capacitive/inductive coupling or to measure its emissions. Depending on the respective type, the probe set is supplied and controlled via an external disturbance generator (RF, EFT/burst), a spectrum analyzer or a burst power station (BPS)¹.

The burst power station is included as an accessory with certain probe sets. The probe's pulse voltage, pulse frequency and polarity can be modified with the enclosed BPS-Client control software.

EMC PARAMETERS FOR ICS

Each IC has characteristic immunity levels with regard to conducted and

radiated interference. These are its EMC parameters. The IC pins have conducted immunity levels which can be measured with corresponding probes from the probe sets.

The IC as a whole has radiated immunity levels. Disturbance fields can affect the IC from the outside and exceed these levels of immunity to magnetic fields and electric fields. These immunity levels are independent



Figure 3: IC test system overview of measuring systems/probe sets with the ICE1 IC test environment



Figure 4: Sectional view of the ICE1 IC test environment with probe and test IC (conducted)



Figure 5: Sectional view of the ICE1 IC test environment with probe and test IC (radiated)

of each other. Probes that generate suitable and defined fields are needed to determine the field immunity levels.

In addition, the conducted interference emission of an IC can be measured via the pins and the radiated (electric and magnetic near-field) emission via the IC housing. The measured curves are the EMC parameters by which the ICs can be analyzed.

SET-UP OF THE IC TEST SYSTEM

The IC under test is located on a test board in the test set-up. Filtered connections link the test board to the connection board located below this which connects the test IC to the PC. The IC can be controlled and monitored with the enclosed software. The connection board is located on the underside of the ground plane which forms a fixed ground reference system for the measurement. The probes are placed onto the ground plane and used to inject disturbances into the test IC through conductive or capacitive/ inductive coupling or to measure its emissions. The measurement connection is made via the probe's pin contact to the tested pin of the test IC. This small-scale set-up and the continuous ground layer ensure that measurements can also be carried out in the GHz range.

DEFINITION OF THE TEST METHOD

The EMC immunity and emission mechanisms active in the devices have to be analyzed. The test methods for all interfering variables (RF, ESD, EFT, emission, RF emission...) are derived from this analysis.

INTERFERENCE IMMUNITY

The test methods for devices generate electric and magnetic fields in the device under test. These fields affect the networks of the printed circuit board that lead to the IC as well as the IC housing. The fields that act on the networks generate currents and voltages in these which affect the connected IC.

Test generators for ICs have to generally simulate these electrical and magnetic parameters. Figure 6 shows the basic set-up of a burst or ESD test bench. The test pulse injected into the device under test $u_G(t)$ generates a current pulse i(t)



Figure 6: EFT test bench



Figure 7: Stimulation of interference emissions in an electronic device through electric fields of the IC and the networks of the printed circuit board



Figure 8: IC interference via pulsed magnetic fields

that flows through the device. This leads to a voltage drop Du(t) in the device. This voltage drop Du(t) produces the electric field strength E(t) in the device. The current i(t) produces the pulsed magnetic field H(t) in the device. These fields have an indirect effect on the externally connected conductor tracks (conducted) on the IC or directly on the IC housing (radiated).

INTERFERENCE EMISSIONS

Switched-mode ICs generate internal RF currents and voltages. These in turn generate electric or magnetic RF fields that escape directly from the IC housing. Furthermore, the RF voltages and currents may be transmitted to the IC pins and thus to networks outside the IC on the printed circuit board where they generate electric and/ or magnetic RF fields. The electric field E is generated by the IC and the external network of the IC in Figure 7. The electric field couples across to the neighboring component and stimulates this to emit interference. The EMC parameters of the IC in this case are the strength of the electric field emitted by the IC and the electrical parameters current and voltage (IC emission) with which the networks outside the IC are stimulated.

The parameters electric field, magnetic field of the IC housing and RF current and voltage of the IC pins have to be measured with suitable systems (probe sets). These are the characteristics of the IC.

MAGNETIC/INDUCTIVE COUPLING

The pulsed disturbance current flowing through a board generates pulsed magnetic fields. These magnetic fields BSt can couple into conductor loops and induce disturbance voltages u_{st}. The pulsed magnetic field can interfere with the function of the IC in two ways (Figure 8):

- a) The induced voltage affects the IC's pin that is switched as the input. The disturbance voltage uSt is converted into a spurious signal in the IC by the input circuit and further processed as a logic signal.
- b) The induced voltage drives a disturbance current ist into the pins of the IC. This disturbance current enters the IC's internal Vdd/ Vss system directly if these are the Vdd/Vss pins. However, it can also enter via signal pins and be led to the Vdd/Vss system inside the IC via internal drivers or protective diodes or capacitances. The Vdd/ Vss system passes the disturbance current on to other functional components of the IC so that malfunctions can arise in areas that are not functionally connected to the affected pins.

ELECTRIC/CAPACITIVE COUPLING

Modules may be exposed to pulsed electric fields of several 10,000 V/m (test set-up according to IEC 61000-4-4) which also affect board networks (Figure 9). A displacement current D flows to the surroundings via the parasitic capacitance of the line. The IC connected to the lines can be affected in two ways:

 a) The network essentially has circuit elements R, L and diodes against Vdd and Vss on the board and in the IC. The displacement current generates a disturbance pulse uSt at these elements. This disturbance pulse is converted into a spurious signal in the IC by the input circuit and further processed as a logic signal. b) The displacement current is split into two shares. The first share is discharged via the equivalent circuits of the board and any decoupling capacitors that may be present. The second share of the disturbance current iSt flows through the IC via drivers or protective diodes to the Vdd/Vss system. It produces effects similar to those of a magnetic field coupling.

REFERENCES

 The burst power station (BPS) is a Langer-EMV product. The burst power station is included as an accessory with certain probe sets. The probe's pulse voltage, pulse frequency and polarity can be modified with the enclosed BPS-Client control software.



Figure 9: IC interference via electric field

(the author)

GUNTER LANGER

Dipl. Ing. Gunter Langer (*1950) focuses on research, development, and production in the field of electromagnetic compatibility (EMC) since 1980. He founded the Gunter Langer engineering office in 1992 and Langer EMV-Technik GmbH. in 1998. His interference emission and interference immunity EMC measurement technology as well as the IC test system are used mainly in the development stage and are in worldwide demand.



BUSINESS

New Immunity Test Solution

ETS-Lindgren has announced a revolutionary solution that integrates separate components in a compact, modular and extremely efficient testing tool. The EMField is a unique, integrated solution that combines amplifiers, directional couplers, power meters and an antenna array into one remarkable, simplified design. With EMField Generator, users will now have a complete solution with minimal

loss of RF power, low installation cost, less cabling and reduced calibration costs.



www.emfieldgenerator.com

New Through-Hole Ceramic Capacitors for High Temperature and Automotive Application

KEMET Corporation introduced its expanded line of Aximax High Temperature Axial Capacitors. The industry's first X8L dielectric in an axial form factor, Aximax X8L, is a conformally coated device designed to operate in environments reaching temperatures as high as 150 degrees Celsius with capacitance up to 2.2 µF and rated voltages up to 50 V. For applications sensitive to capacitance changes such as filters, the new Aximax Ultra-Stable X8R offers superior performance and more effective capacitance when compared to competitor X8R dielectric technologies. For more information, visit www.kemet.com.

Single IC-pin Measurement Possible with the ESD Generator

Langer EMV-Technik GmbH has introduced model P331-2 probe, an ESD generator in accordance with IEC 61000-4-2. The mini ESD generator design allows direct contact to IC pins, and is designed for measurements on all types of IC pins, specifically for measurements on high-speed interfaces such as USB, LVDS, Ethernet, etc. The design of the P331-2 mini ESD generator also does not allow radiated electric or magnetic emissions to emerge from its housing. For more information, visit www.langer-emv.com.

Desktop Amplifiers with Rechargeable Battery Option

MITEQ's TTA Series of high performance Broadband Low Noise Amplifiers were specifically developed for Electromagnetic [EMC] compliance testing. The latest addition to the TTA series is a new battery operated version which allows for up 10 hours of continuous use on a single charge. This battery option can be purchased as a separate add on [TTABP] if you already

own a TTA or supplied internal in a single enclosure at the time of the order as a TTAB.



www.miteq.com

New System-on-Chip Transceiver Family

ON Semiconductor introduced an important new product family that supports high-performance, reliable and efficient communications for the Internet of Things (IoT) and smart metering applications. The NCS3651x is a family of 2.4 gigahertz (GHz) ultra-low power wireless transceivers based on the IEEE 802.15.4-2006 standard which support protocols such as ZigBee, 6loWPAN, WirelessHART, and proprietary versions. These solutions are ideal for use in low data rate, intermittent communication IoT applications in smart metering and consumer appliances. More information at www.onsemi.com.

Low Leakage Current 3-phase Filter

Schurter expanded its successful range of FMBC NEO 3-phase filters with a low leakage current series for applications where leakage currents are restricted to minimal allowable levels. The new FMBC LL family of filters is designed for rated currents

between 7 and 180 A. The new series is ideal for applications such as drive technology, where such leakage current restrictions are critical



fmbc-ll.schurter.com

High Frequency 1.0 mm (W) Connector Line

Southwest Microwave, Inc. has announced the introduction of a new line of 1.0mm (W) DC to 110 GHz connectors. The 1.0 mm (W) connectors are rugged and durable, featuring a 360° raised grounding ring and operational temperature rating of -55°C to 165°C. 1.0 mm connectors provide mode-free operation through 110 GHz, offering well-matched impedance, excellent repeatability, and the industry's lowest VSWR (1.2:1), insertion loss (0.6 dB) and RF leakage (≤ -100 dB).



www.southwestmicrowave.com

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PRODUCT Showcase



Current Sense Transformers For Automotive Electronics

TDK Corporation announces two new SMT current sense transformers for automotive electronics. The first type (B78417A285A003) is based on an EP7 ferrite core and has dimensions of only 10.6 mm x 12.2 mm x 11 mm and can measure pulse currents of up to 20 A. The second SMT current sense transformer (B78419A2251A003) contains an EP10 ferrite core and measures 12.8 mm x 13.6 mm x 14.4 mm. The measurement range of the larger type extends to 30 A. These SMT current sense transformers are designed for use in emerging 48-V automotive power systems as well as

for all xEV applications, where the components can be used to measure currents of the electric drives.



www.epcos.com

Lightning Protection Products for RF Communication Networks

Times Microwave Systems introduces the new Times-Protect® LP-GTV-T series of DC pass RF lightning and surge protection products with an extended frequency operating band

Business News

from DC to 7000MHz. This new bidirectional design with TNC and Reverse TNC type female/female and female/male connectors handles up to 150 watts of RF power and allows for up 72 volts of DC voltage to be supplied on the center pin of the coaxial cable.



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PRODUCT Showcase

KEITH ARMSTRONG BRUNO LISKA received his M.Sc. degree in electro is a Principal Consultant with Cherry Clough Consultants Ltd. Over the last engineering and radio communication 21 years, Keith has provided design from Czech Technical High School consultancy and training courses to over in Prague, in 1979. He has 25 years' 700 customers worldwide, presented experience working with EMC and many papers and published many lightning protection. Currently Bruno is articles and three books, all on good a Standardization Manager and EMC EMC engineering techniques, and on Senior Specialist at Ericsson. For more EMC for Functional Safety. Fore more information, visit page 37. information, visit page 47. **RICHARD NUTE** VLADIMIR BAZHANOV is a product safety consultant engaged received the M.Sc. degree from in safety design, safety manufacturing, Kharkov State University of Radio safety certification, safety standards, Electronics, Ukraine, 1974, and PhD and forensic investigations. Mr. Nute from the Institute of Applied Geophysics, holds a B.S. in Physical Science from Moscow, Russian Federation, 1988. He California State Polytechnic University. has a wide scientific experience from the For more information, visit page 21. university research including numerous expeditions. For more information, visit WERNER SCHAEFER page 37. is owner and Principal Engineer of Schaefer Associates. He has 29 years NIELS JONASSEN, MSC, DSC, of EMC experience, including EMI test worked for 40 years at the Technical system and software design, EMI test University of Denmark, where he method development and EMI standards development. For more information, visit conducted classes in electromagnetism, static and atmospheric electricity, page 33. airborne radioactivity, and indoor climate. For more information, visit page 25. MIKE VIOLETTE is President of Washington Labs and **GUNTER LANGER** Director of American Certification Body. focuses on research, development, and For more information, visit page 17. production in the field of electromagnetic compatibility (EMC) since 1980. He founded the Gunter Langer engineering office in 1992 and Langer EMV-Technik GmbH. in 1998. For more information, We wish to thank our community of knowledgeable authors, indeed, visit page 55. experts in their field - who come together to bring you each issue of In Compliance. Their contributions of informative articles continue to move technology forward.

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