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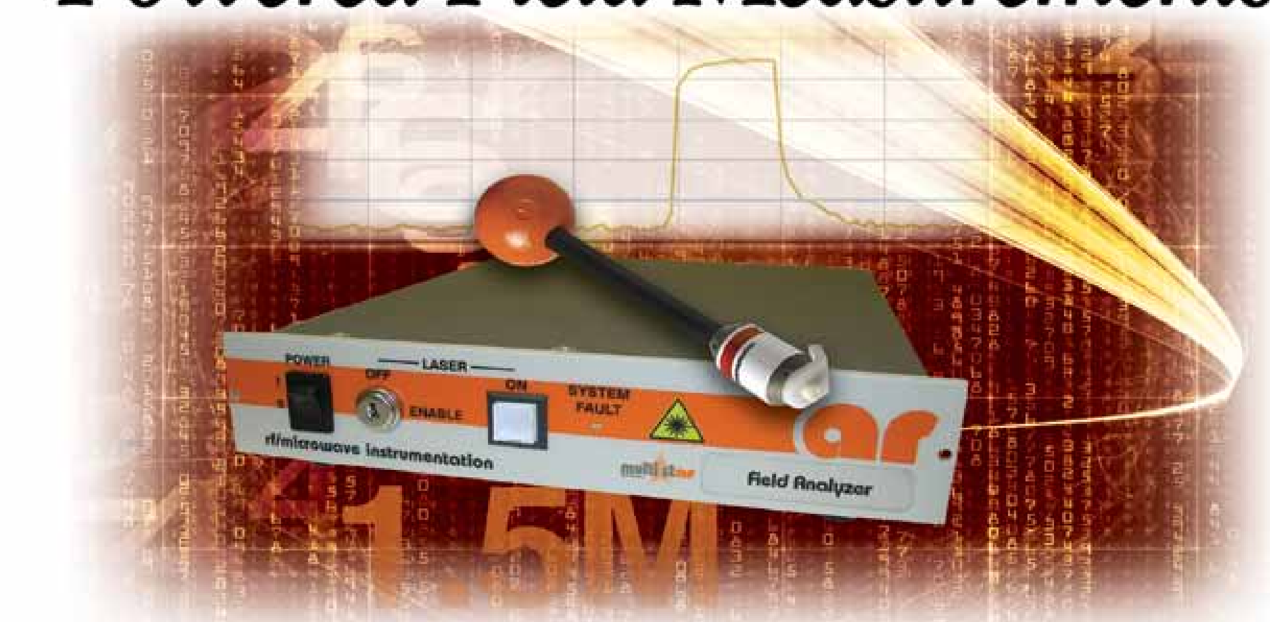

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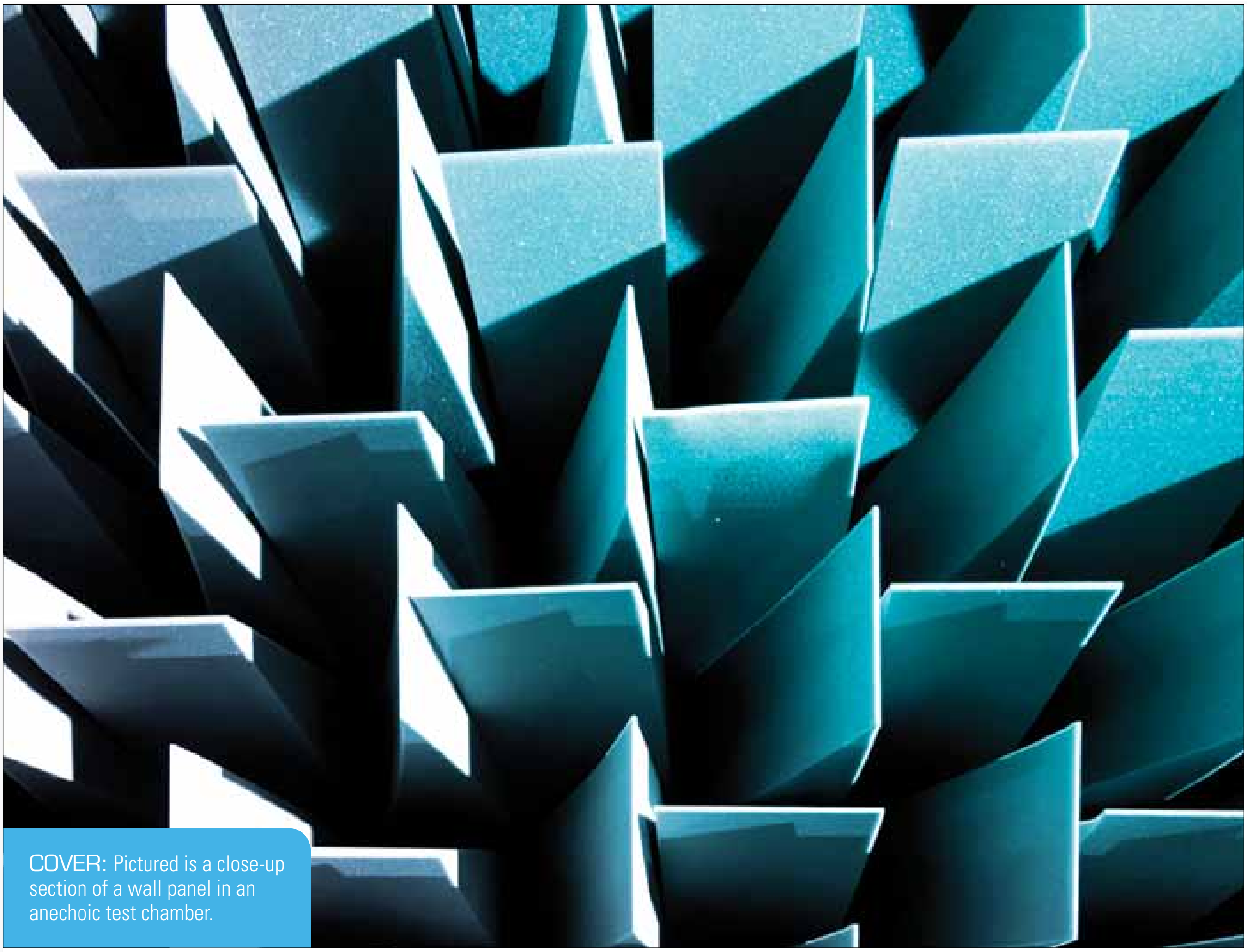

COVER: Pictured is a close-up section of a wall panel in an anechoic test chamber.

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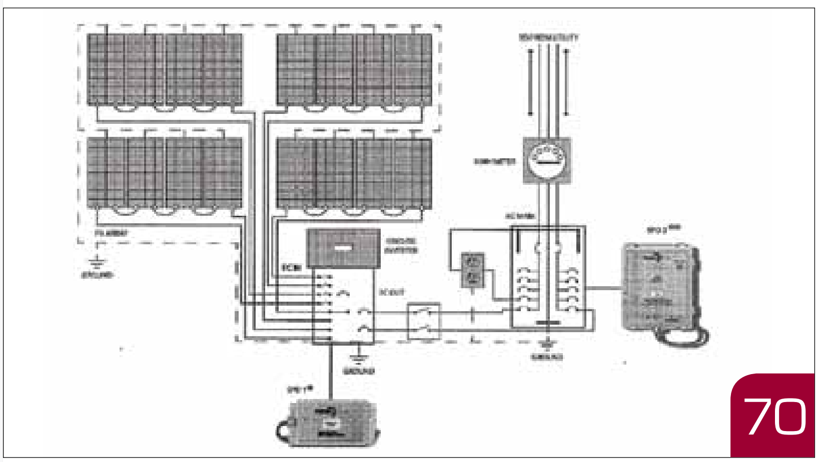

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5500: Ultra compact, standard or medical 1-10A, 125/250VAC, PCB mount
FMAB 72: Aluminum case for optimal shielding, 2-16A, 125/250VAC, PCB mount

FMBB: For standard and industrial applications such as stepper motor drives and UPS systems, 8-25A, 125/250 VAC, screw terminals

FMBB NEO: Type F has excellent low frequency attenuation, 1-16A, 125/250 VAC, quick connect terminals

FMBB NEO: Compact Type C has high differential and common mode attenuation, 1-30A, 125/250 VAC, quick connect, nut and bolt terminals

FMBB NEO: Type D has excellent high frequency attenuation, 1-36A UL, 125/250 VAC, nut and bolt connections

FMW-150: 3-Stage filter, high broadband attenuation, 4-30A, 125/250 VAC, screw terminals

FMAB Rail: DIN rail mount, 1-Stage, industrial version for control cabinets 10-20A, 125/250 VAC

FMBB Rail: DIN rail mount for easy handling, standard or industrial versions, 2-Stage, broadband attenuation, 1-10A, 125/250 VAC

FMEB: DC filter for less noise and more stable DC power distribution. 5-30A, 43/80 VDC, quick connect or screw terminals

FMEC: Optimized for DC applications in IT and Telecom, 5-30A, + 80 VDC, quick connect or screw terminals

3 PHASE AC AND DC FILTERS

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FMAD: High current filter w/neutral conductor, approved for high temperature applications, 6-550A, 275-480 VAC, screw clamp terminals

FMAC: High voltage, wide current range filter. High performance, ideal for PV inverter applications, 6-1100A, 480/520 VAC

FMAC-Out: Output filter for frequency inverters, 8-32A, high voltage rating 550 VAC , insulated safety screw terminals

FMW4-65: Compact filter for three phases, neutral conductor and ground, 3-20A, 250/440 VAC, quick connect terminals

FMAC SINE: Sine wave output filter, allows motor cables up to 200m under full load. 4-16A, 500/288 VAC, screw clamp terminals

FMAC SINE DCL: Sine wave output filter, features DC link circuit, allows motor cables up to 1000m under full load, 4-16A, 500/288 VAC

FMBC: High voltage rating for standard and industrial applications. 8-64A, 480 VAC, screw clamp terminals

FMBC ECO: Filter partially potted for lightweight solution, excellent price/performance ratio, 10-115A, 480 VAC, nut and bolt, screw terminals

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FMBC NEO: Compact size, fits in tight spaces with excellent attenuation, 7-180A, 480/520 VAC, screw clamp terminals

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FMW4-81(95): Compact filter for frequency range 10kHz to 300MHz, 4-6A, 250/440 VAC, screw mount, quick connect terminals

FMAC Rail: 3-Phase, DIN rail mount, easy and time-saving handling, for control cabinets. 3-20A, 480 VAC

FMAD Rail: Compact DIN rail mount, 3-Phase w/neutral for industrial applications. 3-20A, 275-480 VAC

FMER SOL: For use in PV systems, **25-150A @600VDC, 250-1500A @1200(1000 UL) VDC,** screw clamp or copper bar terminals

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My Intro to EMI

UNTIL RECENTLY, I never gave electromagnetic interference a second thought. I knew my cell phone sometimes interfered with my radio, or that solar flares could disrupt radio signals, but I never wondered why. Nor did I realize how many engineers were dedicated to solving EMI problems and that there was an entire magazine that focuses on helping engineers expand their learning and communicate as a community.

I recently joined the *Interference Technology* team as editor. As I started my new position, I researched technology to acquaint myself with the content. It was more interesting and complex than I anticipated. Technology has always fascinated me. The entire idea of EMI was a little hard to understand for me, as it's not a tangible object; I learned that interference happens, but you can't touch it or see it. I found an article about it on howstuffworks.com, a website that explains technical topics to laypeople. It attempts to illustrate how EMI happens to readers who are not engineers:

"Most of us experience electromagnetic interference on a fairly regular basis. For example: If I put my cell phone down on my desk near the computer, I can hear loud static in my computer's speakers ... it is not uncommon for a truck to go by and have its CB radio overwhelm a FM station; and most of us have come across motors that cause radio or TV static … None of these things, technically, should be happening … These are not dire problems; they are just a nuisance. But notice how common they are. In an airplane, the same phenomena can cause big trouble."

I have now started paying attention to how my electronic devices cooperate in the modern world. My friend's cell phone caused static on the radio — "That's electromagnetic interference!" I said. And I will continue to heed an airline's request to shut off my electronic items; now knowing why.

I recently returned from the IEEE EMC Symposium in Pittsburgh. There I met engineers, authors and company representatives who were willing to talk with me about the field. I learned a lot and forged new relationships with some of the smartest people I've ever met. What's fascinating about this industry is the broad sectors it covers: from communications, to military, to aerospace, to consumer electronics, to energy, to nearly everything that touches our modern lives.

With the scope of everything the industry touches, along with the fast paced changes in media today, my challenge is not only to produce relevant information for all EMI engineers, but to also deliver it in a variety of desired formats — both old and new.

During a press dinner at the symposium, a discussion came up about "old school" activities and new technology. The question was asked: "Do you prefer old fashioned papers and books or iPads and E-readers?" The answers differed around the table but mine was in the middle. As much as I appreciate technology and what it has done for our lives today, there's nothing like curling up with a good old fashioned book. Or a magazine (like this one… if you are indeed reading the print copy!). I hope technology and older methods of learning and reading can go hand in hand into the future. This is why I encourage our readers to not only read and refer to our print magazine — but to visit our website, where we have new information and articles every day, and check out our digital edition, which is literally the best of both worlds. We have a lot of new and exciting plans for the future and I hope you'll join us on our journey.

I look forward to hearing from the EMC community and continuing to learn about interference and the part it plays in all aspects of our lives.

Belinda Stasiukiewicz
Editor

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Basics on Designing for EMC Compliance

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ELECTROMAGNETIC interference (EMI) is the bane of many an engineer and of designs that must adhere to international and national regulations regarding electromagnetic compatibility (EMC). However, there are numerous techniques that can be applied to reduce both the emissions from and susceptibility to EMI in order to achieve EMC.

POWER SUPPLY

Starting with the power supply, any supply line loops should be minimized and the lines decoupled at local boundaries using filters with low Q (see Figure 1). High-speed sections of the system should be placed closest to the power line input, and the slowest sections further away, to help reduce power line transients.

Use low pass filters on signal lines to reduce the bandwidth to the minimum necessary. On wide bandwidth lines, keep feed and return loops close. The terminations of lines carrying HF or RF signals need to be implemented correctly to minimize reflection, ringing and overshoot. Lines carrying signals external to a board are best terminated at the board edge; avoid lead terminations within the board and loose leads crossing the board. It's important that all signals on the board are tracked with no 'flying leads' (Circuits wired by simply crimping the "leads" of a component to a terminal or another lead and soldering them together).

To avoid resonance within a signal conductor, avoid cabling or tracking which is close to a quarter wavelength or its multiple of the signal frequency. Slew rate limiting, that is, minimizing rise and fall times on signal and clock edges, reduces crosstalk since sharp edges produce wide HF spectra.

PRINTED CIRCUIT BOARD CONSIDERATIONS

There are quite a few things to consider when optimizing a PCB layout for EMC performance. First, avoid the use of slit apertures, particularly in ground planes or near current paths. Also, do not use narrow tracks for power lines as this creates areas of high impedance and gives rise to high EMI. In addition, do not overlap power planes. Keep them separate over a common ground to reduce system noise and power coupling.

Track stubs should be avoided as they

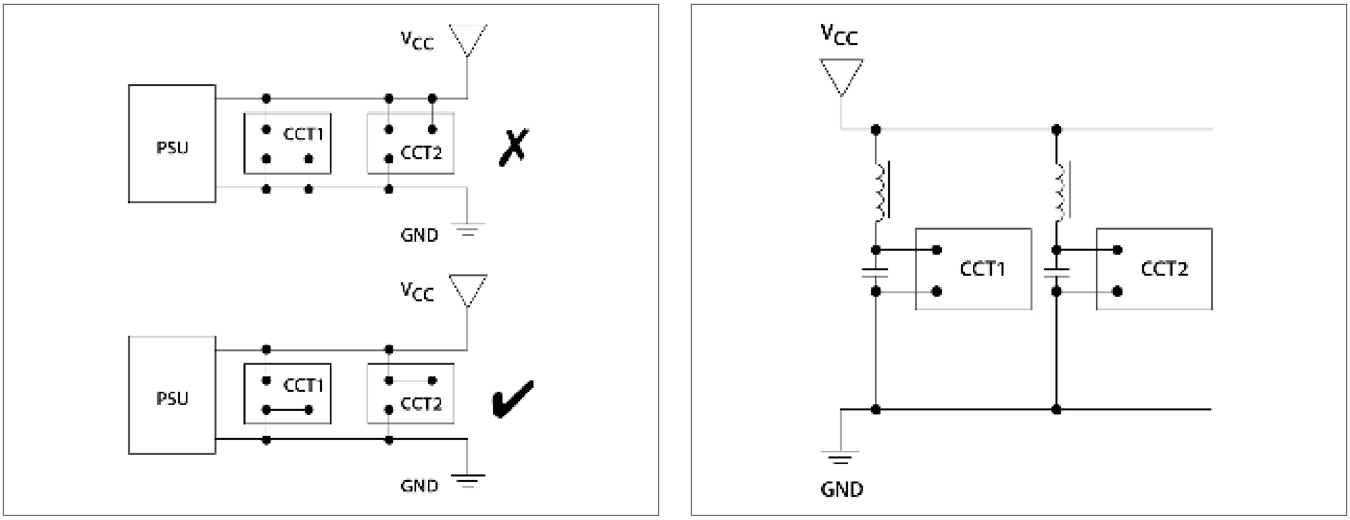

Figure 1. Supply lines — eliminate loops and decouple at local boundaries.

cause reflection and harmonics (see Figure 2). Likewise, do not make localized concentrations of via and through-hole pads. Do not loop tracks, even between layers since this forms very effective receiving or radiating antennae. In the same way, do not leave any floating conductor areas — these act as EMI radiators. If possible connect these to the ground plane. Often these sections are placed for thermal dissipation, hence polarity should be unimportant but check the component data sheet.

Ensure that all signal tracks are "stripline" (transverse electromagnetic (TEM) transmission line medium) and include a ground plane and power plane whenever you can. Remember that the return current from a signal line is 'mirrored' in a ground plane above or below it and these mirror paths should not be interrupted or combined. Keep HF and RF tracks as short as possible and lay out the HF tracks first. Track mitring (bevelling the corners) helps to reduce field concentration, which is helpful when considering EMC performance. A final tip for signal lines is, where possible, make tracking run orthogonally between adjacent layers. These tips are illustrated in Figure 2.

For sensitive components and terminations, a surrounding guard ring and ground fill can be used (see Figure 3). A guard ring around trace layers reduces emission out of the board. Connect to ground at a single point and make no other use of the guard ring (i.e. do not use it to carry ground return from a circuit).

COMPONENT CONSIDERATIONS

Now, let's look at EMC considerations surrounding specific components. A first step is to position biasing and pull up/down components close to driver or bias points. The output drive from clock circuits should be minimized. An excellent way to increase coupling between a signal line and its return and cancel stray fields between current carrying and signal lines is to use common mode chokes.

Component noise and power line transients can be reduced by decoupling close to chip supply lines. For decoupling and bypassing, ceramic multilayer capacitors are preferred due to their low impedance, high resonant frequency and stability.

Where possible, use a combination of discrete components for optimum filtering effect. Surface mounting is preferable due to lower parasitics and antenna effects of terminations on through-hole parts. Include filtering of cables and over voltage protection at their terminations. This is especially important for cabling which is external to the system. If possible, all external cabling should be isolated at the equipment boundary.

You can minimize capacitive loading on digital outputs by minimizing fan-out, especially on Complementary metal–oxide–semiconductor (define) ICs since this reduces the current loading and surge per IC.

Shielding, while effective at improving EMC perfor-

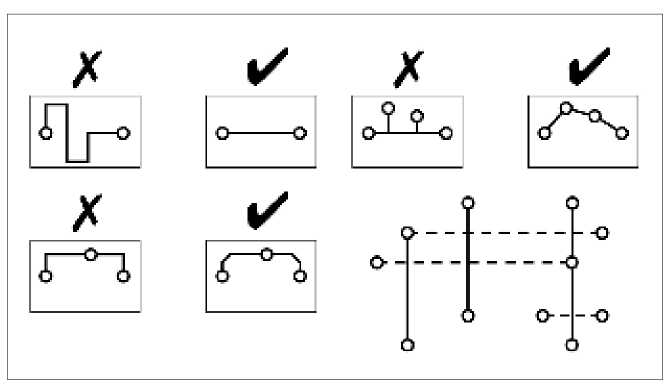

Figure 2. Keep HF tracks short, avoid track stubs, mitre corners and make tracking orthogonal on separate layers.

mance, can be expensive and can add weight to the system which could affect the overall performance or mission of the system. Its use should therefore be kept as a 'last resort'. Where shielding is available, use it on fast switching circuits, main power supply components and low power circuitry. Consider specifying magnetic shields or 'belly bands' around transformers or inductors and electrostatic shields between transformer windings. In general, keeping the bandwidth of all parts of the system to a minimum and isolating circuits where possible reduces susceptibility and emissions.

EMC-SPECIFIC COMPONENTS

Parts like transformer isolators, standard inductors and common mode chokes can offer simple solutions to specific EMC problems within an existing circuit.

INDUCTORS

Inductors are ideal for reducing EMI on power lines and for filtering high current signals. In switched mode power supply (SMPS) circuits, inductors are used for both energy storage and line filtering (see Figure 4). A toroidal or shielded inductor can be used if EMC problems are suspected. Toroidal inductors better maintain the magnetic field within the core shape and hence have virtually zero radiated field.

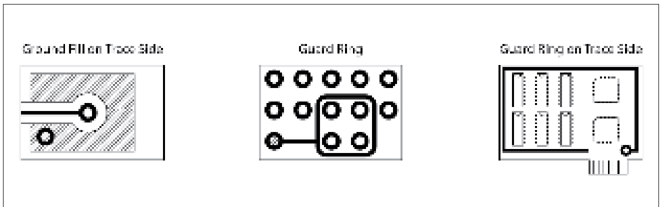

Figure 3. Use guard ring and ground fill. A guard ring around trace layers reduces emission out of the board.

By the same token, the susceptibility of a toroid to EMI is also very low.

In power sections of circuits, an inductor between the local supply and the main feed provides good filtering of the supply and reduces noise from localized circuits in the system, preventing noise from polluting the main power line. When selecting an inductor, consider the current handling and relative switching speed of the circuit section. Generally, use the lowest value of inductance that gives the desired filtering effect as higher values have lower self-resonant frequencies which can produce troublesome ringing with circuit disturbances. A resistor across the inductor is often useful to lower the Q of the filter circuit to dampen ringing waveforms. Low inductances will also generally have lower DC losses and will produce lower transient voltages with load steps.

In signal lines with a reactive load or driver, a matched termination may be required using a passive reactive circuit. The frequency response of the load/driver needs to be known, but can be matched by a relatively simple and easily characterized RCL network. Another area where inductors can be used to reduce EMI of a circuit is in an amplifier bias network (see Figure 5). By using an inductive element in the bias or compensation arms, a filter can be added to the circuit without loading the signal with additional inductance. Careful choice of inductance value is required and placement close to the amplifier is essential. This method is suitable for filtering HF noise, particularly on video and TV type signals.

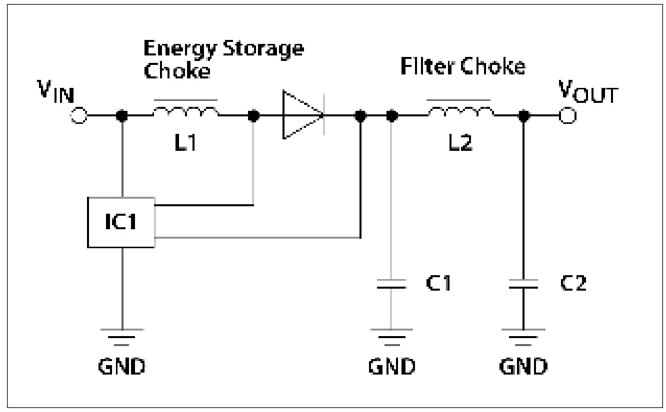

Figure 4. Example basic SMPS and filter configuration.

COMMON MODE CHOKES

Common mode chokes can be employed in signal lines to eliminate common mode noise and EMI on cables or induced in signal tracks. The choke should be located as near to the driver/receiver circuit as possible or at the entry point of a signal to a board. The choke works by cancelling interference appearing on both signal and return lines (i.e. induced EMI) while allowing wanted differential mode signals and DC to pass.

Choosing the right inductance will also help in maintaining a match to the characteristic line impedance and act as a filter to bandwidth-limit the termination.

On power lines, common mode chokes can be employed to reduce common mode EMI. Differential mode noise can also be filtered in the same component by judicious selection of a common mode choke that is deliberately designed to have less than perfect coupling between windings. This results in 'leakage' inductance which acts as a series mode choke in each line.

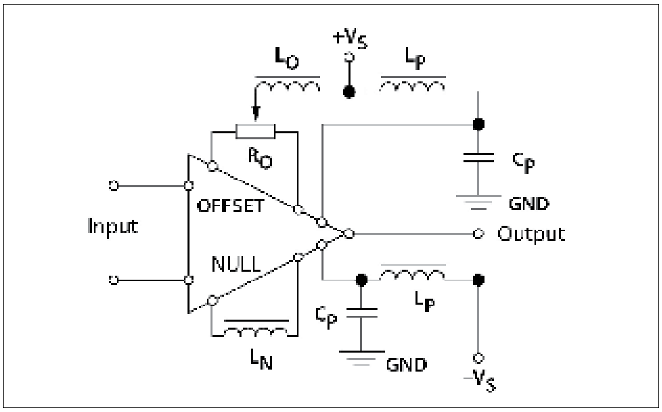

Figure 5. Amplifier filtering with inductors.

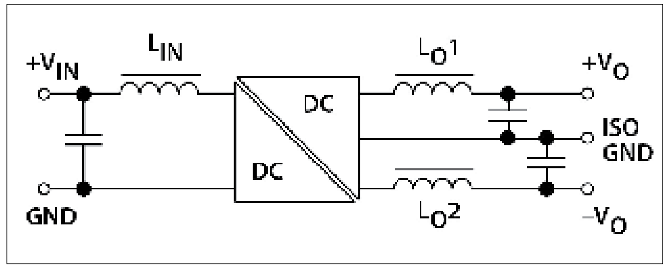

Figure 6. Filtering a DC-DC converter.

TRANSFORMERS

The main EMC benefit of using a signal transformer is to provide an isolation barrier between a signal line and associated circuits. This is particularly the case where the signal line exits the board or system. This is true of signals being driven or received, since isolating the line reduces common mode noise and eliminates ground (or signal return) potential differences between systems.

ISOLATED DC-DC CONVERTERS

An isolated DC-DC converter can substantially reduce susceptibility and conducted emissions by isolating both power rail and ground from the system supply. Isolated DC-DC converters are switching devices and as such, have a characteristic switching frequency themselves which may need some additional filtering, as shown in Figure 6.

These general design recommendations should prove a useful guide to minimizing EMI and help systems achieve EMC certification first time.

Paul Lee, who has been with Murata Power Solutions (MPS) for almost 20 years and specializes in power conversion, is responsible for all product management and business development activities for low power DC/DC and magnetic products. His previous position at MPS was director of engineering. Lee is based in the UK.

A Look at the FCC Guidance on Testing 802.11ac Devices.

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IT SEEMS THAT no matter how we plan it, the latest version of the standard at times never seems to completely address the latest technology completely. Not to say this is bad; in fact it is just the opposite, since there is limited experience on how to test some of the newer technologies. Therefore the problem to solve in the short term is how to test the product properly.

There are several avenues to address this. For example, a few years ago, this issue existed for WiMAX and the issue was partly resolved when several manufacturers got together to develop an ad-hoc procedure for testing client devices. This was vetted thru the FCC and the procedure was allowed to be used for testing some specific configurations.

The Federal Communications Commission Authorization Branch addresses these issues by developing Knowledge Data Base guidance notes on testing various technologies.

These guidance notes are used as supplements along with the recommended test standards to provide guidance to industry on how to test the devices as well as guidance for TCB's to review the reports for these new technologies.

Shortly after the C 63 work group sent the C 63.10 rev 2 to ballot, the FCC issued new draft guidance on proposed test methods for 802.11ac radios for comments. Given that the 802.11ac is still being sorted out and the technology being prepared for market is based on the draft standard, adding it to the standard would be premature at the best.

Therefore the KDB issued on this will allow the industry players from manufacturers to test labs as well as TCB reviewers to gain experience in testing these products and therefore be able to improve the KDB itself for future inclusion in a later version of the standard.

REQUIREMENTS

Before testing the systems, one needs to understand exactly what 802.11ac is exactly. For the most part as far as the general testing requirements the current procedures we use for 802.11 b,g,n or 802.11a,n will suffice in general.

However 802.11 ac allows the use of channel bandwidths of 80 and 160 MHz, in comparison with the current maximum bandwidth of 40 MHz as allowed by 802.11n. As such, with these increased bandwidths several issues arise.

First is the issue of measuring these wide band signals which will exceed some of the bandwidths of our test equipment.

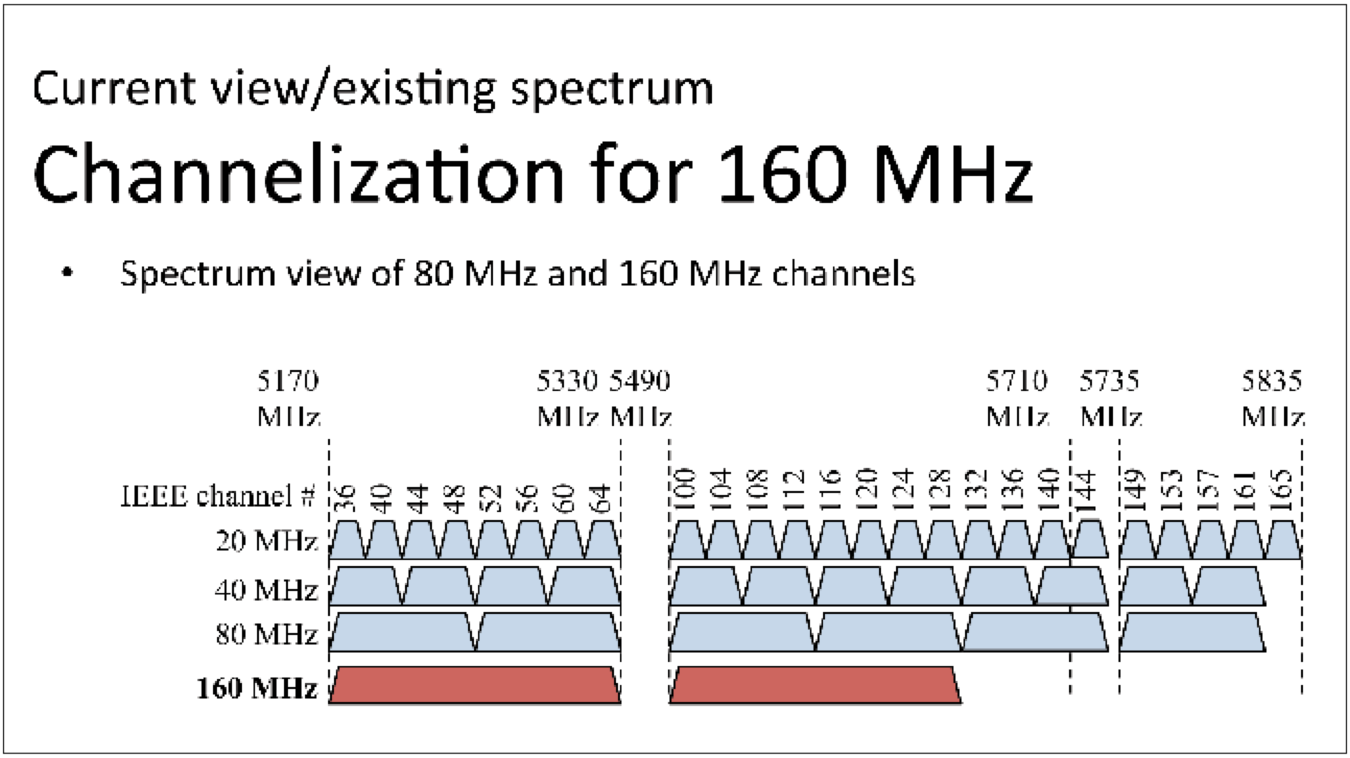

Figure 1. Operating Channels in 5-6 GHz Bands for IEEE 802.11acTM Devices Operating in the U.S.

The second is that the wider bandwidths would require that the channels exceed the allowed spectrum use in specific bands and as such, the channel will operate in frequencies that are covered by different technical regulatory requirements.

As such the challenges faced by 802.11ac will include the need in some case's to modify the various regulatory regimes requirements or adapt guidance on how to allow operation under these conditions.

The FCC addressed this by issuing guidance on this under KDB's #.644545. This guidance should be used to supplement testing per C 63.10 standard as well as several other KDB's the FCC has drafted on testing DTS, U-NII, smart antennas, as well as DFS.

The 802.11ac as drafted not only addresses 2.4 and 5GHz but the 4.9 GHz public safety band as well.

Approvals for 802.11ac currently require either filing with the FCC or thru the TCB PBA process.

802.11AC ISSUES TO CONSIDER

The testing of 802.11ac will offer some challenges for the test engineer. These challenges include:

A) Channel bandwidths up to 160 MHz;
B) Non contiguous 80 plus 80 MHz channels;
C) Allowance for up to 8 MiMo antenna outputs;
D) A higher order of modulation 256K QAM;
E) Operation of new channels between frequency bands.

There are a number of issues of regulatory to consider, first if the channel bandwidth falls into two different frequency bands, the requirements for both bands need to be addressed. If the channel falls between what is referred to as U-NII and U-NII 2 band, the operation will be restricted to indoor use only.

The requirement for Dynamic Frequency Selection operation is applicable to any part of a signal from a channel that falls within the DFS frequency band range.

As per KDB 443999, operation in the 5600-5650 Terminal Doppler Weather Radar band, is prohibited and as such a channel cannot operate across that frequency band nor can any of the channel fall into this band. All the requirements of the referenced KDB must apply.

If operating in the 5725 – 5850 MHz band under Part 15.247, one cannot also operate simultaneously in the 5725 -5825 MHz band under Part 15.407 rules. Note the FCC also issued a KDB of alternate test procedures for operation in the 5725 – 5850 MHz band .which addresses specific issues such as allowing operation in the whole 5725- 5850 MHz band for Part 15.407 for the wider channels (note one cannot operate a 20 MHz 15.407 channel in the 5725- 5850 MHz band).

As far as emissions, one needs to study the KDB's quite closely, especially in regards to Out of Band Emissions, for example as quoted from the KDB:

"For devices operating in the 5.15-5.25 GHz band, the -27 dBm/MHz peak EIRP limit applies outside of the lower pair of U-NII bands, i.e., 5.15-5.35 GHz. However, any transmission that does not intentionally extend into the 5.25-5.35 GHz band must be down 20 dB above 5.25 GHz per section 15.215(c) of the rules. If the emission does intentionally extend into the 5.25 - 5.35 GHz band, DFS and TPC must be implemented per section 15.407(h) of the rules.

(ii) For devices that operate in the 5.25-5.35 GHz band and are restricted to indoor operation, the

27 dBm/MHz peak EIRP limit applies outside of the lower pair of U-NII bands, i.e., 5.15- 5.35 GHz.

(iii) For devices that operate in the 5.25-5.35 GHz band and are not restricted to indoor operation, the -27 dBm/MHz peak EIRP limit applies outside of the 5.25-5.35 GHz band (i.e., the out-of band and spurious limit applies below 5.25 GHz)."

Therefore, in approaching the testing, depending on the channels BW and Occupied BW, the OOBE tests will not be as straight forward as previous for 802.11n devices.

Transmitter power output will also provide a challenge as one needs to address testing a wide band channel. Further given it is likely that the channel power will between to contingent bands with different maximum power level, one will need to verify that the total conducted power does not exceed the maximum Power Spectral Density. Since 802.11ac allows up to 8 antenna ports, one will need to carefully follow the guidance not only of this DB but the various KDB's on smart antenna / MiMo antennas in order to insure compliance.

As with 802.11n and other technologies, one needs to test all the legacy modes as well, which will make for a rather large report. Given this product must be approved under the PBA process, one will need to run the test program by the TCB and FCC to get approval before one tests.

Further the KDB's do not address SAR issues at this time, there is no information available when this will be addressed in the future.

David A. Case, NCE, NCT KB8GXI, is the technical leader for Cisco Systems, responsible for addressing regulatory and standard issues for Cisco Systems. He focuses mainly on wireless addressing issues for WLAN, 3G, WiMAX and other technologies. He is a member of the US World Radio Conference Advisory Committee; chairman of Mobile Manufacturers Forum Standards Workgroup; vice chairman of Wi-Fi Alliance Health and Science Group; vice chairman ITI TC 8 Wireless work group and a member C 63 drafting groups for C 63.10 licensed exempt and C 63.26 licensed wireless test standards group.

Note: The latest draft version of ANSI C 63.10 Rev 2 out for balloting addresses some of the issues on testing MiMo antennas as well as provides some background on measuring wideband signals.

2013 EMC TEST LAB DIRECTORY

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WHEREVER YOU ARE IN THE WORLD you now have access to local testing facilities. We have created an easy-to-use directory of global labs and their services grouped alphabetically by country, state and city, so that our readers can identify labs closest to them. We have strived to make this directory as accurate as possible; however, we realize that every lab or service may not be listed. If you own or work for an EMC test lab and we have missed you or omitted one of your services, please let us know. Our goal is to have the most consise, informative and up-to-date information. E-mail any additions, revisions and suggestions to bstas@interferencetechnology.com.

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
ALABAMA																						
Huntsville	EMC Compliance	(256) 650-5261			•									•						•		
Huntsville	NASA Marshall Space Flight Center www.msfc.nasa.gov	(256) 544-0694			•	•	•				•			•						•		
Huntsville	Redstone Technical Test Center (U.S. Army) http://www.atec.army.mil/DTC/who_rttc_is.htm	(256) 876-3556			•	•	•		•	•	•			•			•	•		•	•	
Huntsville	Wyle Laboratories www.wyle.com	(256) 837-4411		•	•		•	•	•	•	•			•	•	•	•		•	•	•	
ARIZONA																						
Ft. Huachuca	EPG Blacktail Canyon Test Facility www.epg.army.mil/Facilities.aspx	(520) 533-5819												•				•		•	•	•
Phoenix	Compliance Testing, LLC, aka Flom Test Lab www.compliancetesting.com	(480) 926-3100		•	•		•	•	•		•				•	•		•			•	
Phoenix	Sypris Test & Measurement www.sypris.com	(602) 395-5911																	•			
Scottsdale	General Dynamics C4 Systems	(480) 441-5321												•	•						•	•
Tempe	Lab-Tech, Inc. www.advancedtechnologieslab.com	(480) 317-0700					•															
Tempe	**National Technical Systems www.nts.com**	**(480) 966-5517**	•	•	•	•	•	•	•	•	•	•	•	•				•		•	•	
Tempe	TUV Rheinland of North America, Inc. www.tuv.com	(480) 966-1700														•						

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Tucson	RMS EMI Laboratory	(520) 665-5990												•	•							
CALIFORNIA																						
Agoura	Compatible Electronics, Inc. www.celectronics.com	(818) 597-0600		•	•		•	•	•		•			•	•					•		
Anaheim	EMC TEMPEST Engineering http://emctempest.com	(714) 778-1726			•		•					•		•				•		•	•	
Brea	CKC Laboratories, Inc. www.ckc.com	(714) 993-6112		•	•		•		•		•				•	•					•	
Brea	Compatible Electronics, Inc. www.celectronics.com	(714) 579-0500	•	•	•		•	•	•	•	•			•	•					•		
Calabasas	**National Technical Systems (NTS) www.nts.com**	**(800) 270-2516**	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•
Carlsbad	NEMKO www.nemko.com	(760) 444-3500	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	
Carlsbad	**TUV Rheinland of North America, Inc. www.tuv.com**	**(760) 929-1781**														•						
China Lake	NAWCWD EMI Lab	(760) 939-4669			•	•								•	•							
Chino	Robinson's Enterprise www.robinsonsenterprises.com/services.html	(909) 591-3648							•					•								
Costa Mesa	Independent Testing Laboratories, Inc. www.itltesting.net	(714) 662-1011			•			•			•			•						•		
E. Rancho Dominguez	Liberty Bel EMC/EMI Services	(310) 537-4235		•		•				•		•	•						•	•		
El Dorado Hills	Sanesi Associates	(916) 496-1760		•	•		•	•	•		•										•	
El Segundo	Wyle Laboratories www.wyle.com	(310) 322-1763						•														
Escondido	RF Exposure Lab, LLC www.rfexposurelab.com	(760) 737-3131													•		•					
Fremont	CKC Laboratories, Inc. www.ckc.com	(510) 249-1170		•	•		•		•		•			•	•			•		•	•	
Fremont	Underwriters Laboratories, Inc. www.ul.com	(510) 771-1000	•	•	•		•	•	•	•	•				•	•						
Fremont	**National Technical Systems (NTS) www.nts.com**	**(510) 578-3500**	•	•	•	•	•	•	•	•	•			•	•					•		
Fremont	Elma Electronics, Inc. www.elma.com	(510) 656-3400																			•	
Fremont	EMCE Engineering, Inc.	(510) 490-4307	•	•	•		•	•	•	•	•			•		•		•				
DNB ENGINEERING, INC. "One World, One EMC Solution"																						
Fullerton	**DNB Engineering, Inc. www.dnbenginc.com**	**(800) 282-1462**			•	•	•					•	•	•	•			•		•	•	
Fullerton	**National Technical Systems (NTS) www.nts.com**	**(714) 879-6110**			•	•	•					•	•	•	•			•		•	•	
Gardena	Parker EMC Engineering	(910) 823-2345			•			•	•		•		•	•			•	•		•	•	

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Garden Grove	Semtronics www.semtronics.com	(714) 799-9810					•												•			
Gilroy	Scientific Hardware Systems www.scientifichardware.com	(408) 848-8868						•														
Irvine	7Layers, Inc. www.7layers.com	(949) 716-6512			•																	
Irvine	Mitsubishi Digital Electronics America Inc. www.mitsubishi-tv.com	(949) 465-6206			•																	
NORTHWEST EMC																						
Irvine	**Northwest EMC** **www.nwemc.com**	**(888) 364-2378**		•	•		•		•		•				•							
Lake Forest	Compatible Electronics, Inc. www.celectronics.com	(949) 587-0400		•	•		•	•	•		•			•	•	•				•		
Lake Forest	Intertek www.intertek.com	(800) 976-5352		•	•	•	•	•	•		•				•	•						
Los Angeles	Field Management Services www.fms-corp.com	(323) 937-1562																			•	
Los Gatos	Pulver Laboratories, Inc. www.pulverlabs.com	(408) 399-7000			•	•	•	•	•		•	•				•					•	
Mariposa	CKC Laboratories, Inc. www.ckc.com	(209) 966-5240		•	•		•		•		•				•						•	
Menlo Park	Intertek www.intertek.com	(800) 976-5352	•	•	•	•	•	•	•		•			•	•	•						
Milpitas	CETECOM Inc. www.cetecomusa.com	(800) 976-5352		•	•		•	•	•		•				•	•						
Milpitas	SIEMIC Testing and Certification Services www.siemic.com	(408) 526 1188		•	•	•	•	•	•	•	•	•			•	•	•	•			•	
Mountain View	Electro Magnetic Test, Inc. www.emtlabs.com	(650) 965-4000		•	•		•	•	•	•	•	•			•	•						
Mountain View	EMT Labs www.emtlabs.com	(650) 965-4000			•		•	•	•	•	•				•	•						
Mountain View	EMC Compliance Management Group www.ce-mag.com/suppliers/co/07/751.html	(650) 988-0900	•	•	•		•	•	•		•			•	•	•				•	•	
Newark	**National Technical Systems (NTS)** **www.nts.com**	**(510) 578-3500**	•	•	•	•	•	•	•	•	•			•	•					•		
North Highlands	Northrop Grumman ESL www.northropgrumman.com	(916) 570-4340			•		•		•		•			•						•	•	•
Oakland	ITW Richmond Technology	(510) 655-1263					•															
Orange	G & M Compliance, Inc. www.gmcompliance.com	(714) 628-1020	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•
Pico Rivera	Garwood Laboratories, Inc. www.garwoodlabs.com	(562) 949-2727			•	•	•	•	•	•	•	•		•		•				•		
Pleasanton	MiCOM Labs www.micomlabs.com	(925) 462-0304			•		•	•	•		•				•							

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Pleasanton	**TÜV Rheinland of North America www.tuv.com**	**(925) 249-91923**		•	•		•	•	•		•				•	•	•					
Poway	APW Electronic Solutions www2.eem.com/APW_Electronic_Solutions.aspx	(858) 679-4550						•		•			•									
Rancho St. Margarita	Aegis Labs, Inc. http://aegislabsinc.com	(949) 454-8295	•		•			•	•		•				•	•						
Redondo Beach	Northrop Grumman Space Tech. Sector www.northropgrumman.com	(310) 812-3162			•	•	•				•		•	•			•	•		•	•	•
Riverside	**DNB Engineering, Inc. www.dnbenginc.com**	**(800) 282-1462**	•		•		•	•	•	•	•					•						
Riverside	Global Testing www.global-testing.com	(951) 781-4540	•		•		•			•	•	•				•						
Sacramento	Northrop-Grumman EM Systems Lab www.northropgrumman.com	(916) 570-4340			•		•		•		•			•						•	•	•
San Clemente	Stork Garwood Laboratories, Inc. www.garwoodlabs.com	(949) 361-9189			•	•	•		•	•	•	•		•		•				•		

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San Diego	Lambda Electronics www.lambda.com	(619) 575-4400			•				•		•											
San Diego	NEMKO www.nemko.com	(858) 755-5525	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	
San Diego	**TÜV SÜD America, Inc. www.tuvamerica.com**	**(858) 678-1400**			•		•	•	•		•	•	•		•	•				•		
Santa Clara	**Montrose Compliance Services, Inc. www.montrosecompliance.com**	**(408) 247-5715**			•			•	•		•					•						
San Jose	Arc Technical Resources, Inc. www.arctechnical.com	(408) 263-6486					•	•	•	•	•	•	•	•				•		•	•	
San Jose	ATLAS Compliance & Engineering, Inc. www.atlasce.com	(866) 573-9742			•		•	•	•		•	•			•	•					•	
San Jose	Safety Engineering Laboratory www.seldirect.com	(408) 544-1890						•								•						
San Jose	Underwriters Laboratories, Inc. www.ul.com	(408) 754-6500	•		•		•	•	•	•	•				•	•					•	
San Ramon	Electro-Test, Inc.	(925) 485-3400					•	•								•			•			
Santa Clara	MET Laboratories, Inc. www.metlabs.com	(408) 748-3585	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
Silverado	Compatible Electronics, Inc. www.celectronics.com	(949) 587-0400		•	•		•		•		•				•							
Sunnyvale	Bay Area Compliance Labs. www.baclcorp.com	(408) 732-9162	•	•	•	•	•	•	•	•	•				•	•						
Sunnyvale	Sypris Test & Measurement www.sypris.com	(408) 720-0006																	•			
Sunol	ITC Engineering Services, Inc. www.itcemc.com	(925) 862-2944			•		•	•	•	•	•			•	•	•		•				
Torrance	Lyncole XIT Grounding www.lyncole.com	(310) 214-4000	•									•										
Trabuco Canyon	RFI International	(949) 888-1607			•				•	•	•					•						
Union City	MET Laboratories, Inc. www.metlabs.com	(510) 489-6300	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
Van Nuys	Sypris Test & Measurement www.sypris.com	(818) 830-9111																	•			
COLORADO																						
Boulder	Ball Aerospace & Technology Corp. www.ballaerospace.com	(303) 939-4618			•		•				•		•	•				•		•	•	
Boulder	Percept Technology Labs, Inc. http://percept.com	(303) 444-7480			•		•	•	•	•	•				•	•						
Boulder	Intertek www.intertek.com	(800) 976-5352		•	•	•	•	•	•		•			•	•	•			•			
Colorado Springs	INTERTest Systems, Inc. www.intertest.net	(719) 522-1402		•	•		•	•	•	•	•	•			•	•					•	
Lakewood	Electro Magnetic Applications, Inc. www.electromagneticapplications.com	(303) 980-0070			•	•	•					•							•			
Littleton	Sypris Test & Measurement www.sypris.com	(303) 798-2243																	•			
Longmont	EMC Integrity, Inc. www.emcintegrity.com	(888) 423-6275		•	•		•	•	•		•			•	•					•	•	

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Rollinsville	Criterion Technology www.criteriontech.com	(303) 258-0100			•				•		•											
CONNECTICUT																						
East Haddam	Global Certification Laboratories, Ltd.	(860) 873-1451			•			•	•		•			•		•						
Middletown	Product Safety International www.safetylink.com/psi.html	(860) 344-1651						•								•						
Milford	Harriman Associates	(203) 878-3135															•					
Newtown	**TÜV Rheinland of North America, Inc. www.tuv.com**	**(203) 426-0888**		•	•		•	•	•		•				•	•	•					
Norwalk	Panashield, Inc. www.panashield.com	(203) 866-5888						•	•					•						•	•	
Stratford	Total Shielding Systems	(203) 377-0394				•															•	•
DISTRICT OF COLUMBIA																						
Washington	American European Services, Inc.	(202) 337-3214			•			•			•					•						
FLORIDA																						
Boca Raton	Advanced Compliance Solutions, Inc. www.acstestlab.com	(561) 961-5585	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Boca Raton	Jaro Components	(561) 241-6700					•															
Cocoa Beach	Elite Electronic Engineering Company	(800) ELITE-11		•	•	•	•	•	•	•	•			•	•	•		•		•	•	
Dade City	Product Safety Engineering, Inc.	(352) 588-2209			•		•	•	•	•	•				•	•						
Jupiter	East West Technology Corporation www.enwtek.com	(561) 776-7339	•	•																•		
Lake Mary	Test Equipment Connection www.testequipmentconnection.com	(800) 615-8378																	•			
Largo	Walshire Labs, LLC www.walshirelabs.com	(727) 530-8637			•		•	•	•	•	•	•			•	•						
Melbourne	Advanced Compliance Solutions, Inc.	(321) 951-1710	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Newberry	Timco Engineering, Inc.	(888) 472-2424		•	•		•		•	•	•				•	•						
Orlando	Sypris Test & Measurement www.sypris.com	(800) 839-4959	•										•	•	•	•				•		
Orlando	**Qualtest, Inc. www.qualtest.com**	**(407) 313-4230**			•	•	•		•		•			•	•			•		•	•	
Palm Bay	Harris Corporation EMI/TEMPEST Lab	(321) 727-6209			•		•							•	•			•			•	
Tampa	**TÜV SÜD America, Inc. www.tuvamerica.com**	**(813)-620-0202**	•		•	•	•	•	•		•	•		•	•	•		•		•	•	
GEORGIA																						
Atlanta	Intertek www.intertek.com	(800) 976-5352		•	•	•	•	•	•		•				•	•						
Alpharetta	EMC Testing Laboratories, Inc. www.emctesting.com	(770) 475-8819			•		•		•	•	•		•			•					•	
Alpharetta	U.S. Technologies, Inc. www.ustechnologies.com	(770) 740-0717	•		•		•	•	•	•	•	•			•	•				•	•	

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Buford (Atlanta)	Advanced Compliance Solutions, Inc. www.acstestlab.com	(770) 831-8048	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Lawrenceville	Motorola Product Testing Services www.motorola.com/testservices/index.html	(770) 338-3795			•		•	•	•	•	•				•	•						
Peachtree	Panasonic Automotive www.panasonic.com/business/automotive	(770) 515-1443			•		•				•				•							
SGS																						
Suwanee	**SGS North America www.sgsgroup.us.com**	**(770) 570-1800**			•		•	•	•		•				•	•				•		
IDAHO																						
Hayden	Protection Technology Group www.protectiongroup.com					•						•										
Plummer	Acme Testing Company www.acmetesting.com	(360) 595-2785	•	•	•		•	•	•		•				•	•	•				•	
ILLINOIS																						
Addison	Sypris Test & Measurement www.sypris.com	(630) 620-5800																	•			
Chicago	**TUV Rheinland of North America, Inc. www.tuv.com**	**(847) 346-0500**														•						
Downers Grove	Elite Electronic Engineering, Inc. www.elitetest.com	(630) 495-9770	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Montgomery	E.F. Electronics Co.	(630) 897-1950			•	•	•	•	•		•	•	•	•				•		•	•	
Mundelein	Midwest EMI Associates, Inc. www.midemi.com	(847) 918-9886			•		•	•	•		•			•								
Northbrook	Underwriters Laboratories, LLC. www.ul.com	(847) 664-6963	•	•	•		•	•	•	•	•				•	•					•	
Palatine	Trace Laboratories–EMC http://tracelabs.com	(847) 934-5300	•		•	•	•	•	•		•	•		•	•	•				•	•	
Poplar Grove	LF Research EMC Design & Test Facility www.lfresearch.com	(815) 566-5655			•	•	•	•	•		•	•		•		•		•	•	•	•	
Rockford	**National Technical Systems (NTS) www.nts.com**	**(815) 315-9250**																				
Romeoville	Radiometrics Midwest Corp. www.radiomet.com	(815) 293-0772	•		•	•	•	•	•		•	•		•	•			•		•	•	
DLS EMC & Product Safety Testing • Consulting																						
Wheeling	**D.L.S. Electronic Systems, Inc. www.dlsemc.com**	**(847) 537-6400**	•	•	•	•	•	•	•		•	•		•	•	•		•		•	•	


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Wonder Lake	Midwest EMI Associates, Inc. www.midemi.com	(312) 303-4910			•																	
INDIANA																						
Crane	Naval Surface Warfare Center, Crane Div. www.navsea.navy.mil/nswc/crane	(812) 854-5107												•								
Fort Wayne	Raytheon www.raytheon.com	(260) 429-4335				•	•							•	•							
Indianapolis	Raytheon Technical Services Co., EMI Lab www.raytheon.com	(317) 306-8471			•						•			•	•							•
Kokomo	Delphi Delco Electronic Systems delphi.com	(765) 451-5011			•		•				•				•							
IOWA																						
Kimballton	Liberty Labs, Inc. www.liberty-labs.com	(712) 773-2199													•				•			
Elk Horn	World Cal, Inc. www.world-cal.com	(712) 764-2197													•				•			
KANSAS																						
Louisburg	Rogers Labs, Inc.	(913) 837-3214			•		•		•		•			•	•					•		
KENTUCKY																						
Lexington	Lexmark International EMC Lab	(606) 232-7650							•													
Lexington	Intertek www.intertek.com	(800) 976-5352	•		•	•	•	•	•		•			•	•							
Lexington	dBi Corporation www.dbicorporation.com	(859) 253-1178			•		•		•		•				•							
MARYLAND																						
Annapolis	Northrop Grumman Space & Mission Systems www.northropgrumman.com	(410) 266-1700			•	•		•	•		•		•	•	•	•		•	•	•	•	
Baltimore	MET Laboratories, Inc. www.metlabs.com	(410) 354-3300	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•
Beltsville	Antenna Research Associates www.ara-inc.com	(301) 937-8888																	•			
Columbia	DRS Advanced Programs	(410) 312-5800																				
Columbia	PCTest Engineering Lab www.pctestlab.com	(410) 290-6652		•	•	•	•	•	•	•	•				•		•					•
Damascus	F-Squared Laboratories, Inc. http://f2labs.com	(301) 253-4500			•	•	•	•	•	•	•	•			•	•				•		
Elkridge	ATEC Industries, Ltd. www.atecindustries.com	(443) 459-5080				•	•					•	•	•	•						•	
Frederick	**The American Association for Lab Accreditation** **www.a2la.org**	**(301) 644-3217**													•							

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Gaithersburg	Washington Laboratories, Ltd. www.wll.com	(301) 216-1500			•	•		•	•		•	•	•	•	•	•	•	•		•	•	
Hunt Valley	Trace Laboratories–East http://tracelabs.com	(410) 584-9099	•				•															•
Patuxent River	Naval Air Warfare Ctr., Aircraft Div. www.navair.navy.mil/nawcad	(301) 342-1663			•	•	•					•		•	•		•	•		•	•	
Rockville	P.J. Mondin, P.E. Consultants	(301) 460-5864							•					•							•	•
Rockville	Spectrum Research & Testing Laboratory, Inc.	(301) 670-2818					•	•	•	•					•	•						•
Westminster	Electrical Test Instruments, Inc. www.electricaltestinstruments.com	(410) 857-1880																	•			•
MASSACHUSETTS																						
Billerica	Quest Engineering Solutions www.qes.com	(978) 667-7000																			•	
Billerica	Sypris Test & Measurement www.sypris.com	(978) 663-2137																	•	•		
Boxborough	Intertek www.intertek.com	(800) 976-5352		•	•	•	•	•	•	•	•			•	•	•		•		•	•	
Boxborough	**National Technical Systems (NTS)** **www.nts.com**	**(978) 266-1001**	•	•	•	•	•	•	•	•	•	•	•	•	•			•		•	•	

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Boxborough	**TUV Rheinland of North America, Inc.** **www.tuv.com**	**(978) 266-9500**														•						
Foxboro	N.E. Product Safety Society, Inc. www.nepss.net	(508) 543-6599														•						
Gloucester	Euroconsult, Inc. euroconsult-inc.com	(978) 282-8890			•			•			•					•						
Lexington	Design Automation, Inc.	(781) 862-8998			•	•	•		•	•	•	•				•						
Marlboro	Compliance Management Group www.cmgcorp.net	(978) 431-1985	•		•		•	•	•		•				•	•					•	
Littleton	Curtis-Straus LLC, subsidiary of Bureau Veritas www.curtis-straus.com	(978) 486-8880	•	•	•		•	•	•	•	•			•	•	•				•	•	
Mansfield	Motorola Test Lab Services Group www.motorola.com/testservices/index.html	(508) 851-8484							•						•	•						
Marlboro	Compliance Management Group www.cmgcorp.net	(508) 460-1400	•		•		•	•	•		•				•	•					•	
Marlboro	The Compliance Management Group www.cmgcorp.net	(508) 281-5985		•	•		•	•	•		•				•	•						
Milford	Test Site Services, Inc. www.testsiteservices.com	(508) 962-1662	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
Newton	EMC Test Design, LLC www.emctd.com	(508) 292-1833															•					
Peabody	**TUV SUD America Inc.** **www.tuvamerica.com**	**(800) TUV-0123**	•		•	•	•	•	•		•	•		•	•	•		•		•	•	
Pittsfield	Lightning Technologies, Inc. www.nts.com/locations/pittsfield	(413) 499-2135				•	•					•			•					•		
Wilmington	Thermo Fisher Scientific www.thermofisher.com	(978) 275-0800	•			•	•		•	•	•	•		•					•	•		
Woburn	Chomerics, Div. of Parker Hannifin Corp. www.chomerics.com	(781) 935-4850			•	•	•	•	•		•	•	•	•	•	•	•	•		•	•	
Woburn	NELCO www.nelcoworldwide.com	(781) 933-1940																			•	
MICHIGAN																						
Auburn Hills	**TÜV SÜD America, Inc.** **www.tuvamerica.com**	**(248) 393-6984**						•														
Belleville	Willow Run Test Labs, LLC www.wrtest.com	(734) 252-9785			•		•		•												•	

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Burton	Trialon Corporation www.trialon.com	(810) 341-7931			•		•				•				•							
Detroit	**National Technical Systems** **www.nts.com**	**(313) 835-0044**													•			•				
Detroit	**TUV Rheinland of North America, Inc.** **www.tuv.com**	**(734) 207-9852**														•						
Grand Rapids	Intertek www.intertek.com	(800) 976-5352			•	•	•	•	•		•	•			•	•		•		•		
Holland	**TÜV SÜD America, Inc.** **www.tuvamerica.com**	**(616) 546-3902**																	•			
Milford	Jacobs Technology, Inc. www.jacobstechnology.com	(248) 676-1101			•		•	•			•			•	•							
Novi	Sypris Test & Measurement www.sypris.com	(248) 305-5200																	•			
Novi	Underwriters Laboratories, Inc. www.ul.com	(248) 427-5300			•		•	•			•			•	•	•				•	•	
Plymouth	**TÜV SÜD America, Inc.** **www.tuvamerica.com**	**(734) 455-4841**	•		•	•	•	•	•		•	•		•	•	•		•			•	
Saginaw	Delphi Steering EMC Lab www.emisoft.co.uk/cgi-bin/link-spage.cgi?inpno=3047	(989) 797-0318			•		•				•											

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Sister Lakes	AHD EMC Lab www.ahde.com	(269) 313-2433			•		•	•	•		•			•	•						•	
Warren	Detroit Testing Laboratory, Inc. www.dtl-inc.com	(586) 754-9000					•	•							•							
MINNESOTA																						
Brooklyn Park	**Northwest EMC, Inc. www.nwemc.com**	**(888) 364-2378**			•		•		•		•				•							
Glencoe	International Certification Services, Inc.	(320) 864-4444	•		•		•	•	•		•			•	•	•				•	•	
Maple Grove	**TUV Rheinland of North America, Inc. www.tuv.com**	**(763) 315-5012**		•			•	•	•	•					•	•						
Millville	**TÜV SÜD America, Inc. www.tuvamerica.com**	**(651) 604-3490**		•	•			•														
Minneapolis	Alpha EMC, Inc. www.alphaemc.com	(763) 561-4410				•	•	•	•				•				•	•		•	•	
Minneapolis	Environ Laboratories, LLC www.environlab.com	(800) 826-3710	•		•	•	•				•	•	•	•	•		•	•		•	•	
Minneapolis	Honeywell	(612) 951-5773																•				
New Brighton	**TÜV SÜD America, Inc. www.tuvamerica.com**	**(651) 631-2487**		•	•		•	•	•		•	•		•	•	•				•		
New Hope	Conductive Containers, Inc. corstat.com	(763) 537-2090					•	•														
Oakdale	Intertek www.intertek.com	(800) 976-5352		•	•	•	•	•	•		•				•	•						
Rochester	IBM www.ibm.com	(507) 253-6201			•		•				•				•							
St. Paul	3M www.3m.com	(651) 778-4577		•	•		•	•	•		•				•						•	
Taylor Falls	**TÜV SÜD America, Inc. www.tuvamerica.com**	**(651) 638-0297**	•		•	•	•	•	•		•	•		•	•	•		•	•	•	•	
MISSOURI																						
St. Louis	Boeing-St. Louis EMC Lab www.boeing.com	(314) 233-7798												•	•			•			•	
NEBRASKA																						
Lincoln	NCEE Labs www.nceelabs.com	(402) 323-6233			•		•	•	•		•			•	•	•				•		
NEW HAMPSHIRE																						
Goffstown	**Retlif Testing Laboratories www.retlif.com**	**(603) 497-4600**		•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
Hudson	Core Compliance Testing Services www.corecompliancetesting.com	(603) 889-5545			•		•		•		•	•			•							
Sandown	Compliance Worldwide, Inc. www.cw-inc.com	(603) 887-3903			•		•		•	•	•	•			•							

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NEW JERSEY																						
Annandale	NU Laboratories, Inc. www.nulabs.com	(908) 713-9300					•							•	•						•	
Bridgeport	Analab, LLC www.analab1.com	(800) analab-X			•						•					•			•			
Bridgewater	Lichtig EMC Consulting www.lichtigemc.com	(908) 541-0213	•																			
Camden	L-3 Communication Systems-East www.l-3com.com/cs-east	(856) 338-3000																				
Clifton	NJ-MET www.njmetmtl.com	(973) 546-5393	•							•												•
Edison	Metex Corporation www.metexcorp.com	(732) 287-0800																			•	
Edison	**TESEQ, Inc.** **www.teseq.com**	**(732) 417-0501**				•				•												
Fairfield	SGS U.S. Testing Co., Inc. www.sgsgroup.us.com	(800) 777-8378	•		•			•							•	•						
Farmingdale	EMC Technologists, A Div. of I2R Corp. www.emctech.com	(732) 919-1100	•		•		•	•	•	•	•			•								

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Hillsborough	Advanced Compliance Laboratory, Inc. http://ac-lab.com	(908) 927-9288			•			•	•	•	•				•	•						
Murray Hill	Alcatel-Lucent Global Product Compliance Laboratory (GPCL) www.gpcl.com	(908) 582-5444	•		•		•	•	•	•	•			•	•	•					•	
Lakehurst	Naval Air Warfare Ctr., Aircraft Div. www.navair.navy.mil/nawcad	(732) 323-2085												•	•			•				
Lakewood	BAE Systems www.baesystems.com	(732) 364-0049			•	•	•				•		•	•			•	•		•		
Lincroft	Don HEIRMAN Consultants www.donheirman.com	(732) 741-7723			•				•													•
Piscataway	Telcordia Technologies, Inc. www.telcordia.com	(800) 521-2673	•	•	•		•		•		•	•		•	•							
Rutherford	SGS International Certification Services, Inc. www.sgs.com	(800) 747-9047						•														
Sayreville	Sypris Test & Measurement www.sypris.com	(732) 721-6116																	•			
Thorofare	NDI Engineering Company www.ndieng.com	(856) 848-0033																			•	
Tinton Falls	**National Technical Systems (NTS)** **www.nts.com**	**(732) 936-0800**	•	•	•	•		•	•	•	•	•	•	•	•	•		•		•	•	•
Wayne	Sypris Test & Measurement www.sypris.com	(973) 628-1363			•		•	•	•		•			•						•		
NEW MEXICO																						
Albuquerque	Advanced Testing Services, Inc. www.advanced-testing.com	(505) 292-2032											•				•				•	
White Sands	USA WSMR, Survivability Directorate www.wsmr.army.mil	(575) 678-6107			•	•	•				•	•					•	•			•	
NEW YORK																						
Bohemia	Dayton T. Brown, Inc. www.daytontbrown.com	(800) TEST-456	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•
College Point	Aero Nav Laboratories, Inc. www.aeronavlabs.com	(718) 939-4422	•			•			•		•	•		•	•			•		•	•	•
Deer Park	MCG Surge Protection, Inc. www.mcgsurge.com	(800) 851-1508										•										
Deer Park	Universal Shielding Corp. www.universalshielding.com	(631) 667-7900																			•	
Groton	Diversified T.E.S.T. Technologies www.dttlab.com	(607) 898-4218			•		•	•	•		•			•	•	•					•	
Groton	Source 1 Compliance www.source1compliance.com	(315) 730-5667			•		•	•	•		•			•	•	•					•	
Johnson City	BAE Systems Controls, Inc. www.baesystems.com	(607) 770-3771			•	•						•		•	•			•		•		
Johnstown	Electro-Metrics Corp. www.electro-metrics.com	(518) 762-2600																	•			
Liverpool	Diversified Technologies www.dttlab.com	(315) 457-0245			•		•	•	•		•			•		•					•	
Liverpool	Source1 Solutions www.source1compliance.com	(315) 730-5667			•		•	•	•		•			•		•					•	

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Medford	American Environments Co. www.aeco.com	(631) 736-5883	•		•	•	•	•	•		•	•		•		•				•	•	
Medina	TREK, Inc. www.trekinc.com	(585) 798-3140					•															
Melville	Underwriters Laboratories, LLC. www.ul.com	(631) 546-4346	•	•	•		•	•	•	•	•				•	•					•	
Northport	Mohr, R.J., Assoc., Inc. www.rjm.li	(631) 754-1142				•	•	•	•	•		•		•						•	•	
Owego	Lockheed Martin Federal Systems www.lockheedmartin.com	(607) 751-2938			•	•	•		•		•				•			•			•	•
Palmyra	Source1 Solutions www.source1compliance.com	(315) 730-5667			•			•			•			•		•					•	
Poughkeepsie	IBM Corp. Poughkeepsie EMC Lab www.ibm.com	(607) 752-2225		•					•													
Rochester	Chomerics, Div. of Parker Hannifin www.chomerics.com	(781) 939-4158			•	•	•	•	•	•	•	•			•	•					•	
Rochester	Spec-Hardened Systems	(585) 225-2857				•	•	•	•	•		•	•	•		•					•	
Rochester	**TÜV Rheinland of North America** **www.tuv.com**	**(585) 426-5555**		•	•		•	•	•		•				•	•	•					

RETLIF TESTING LABORATORIES

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Ronkonkoma	**Retlif Testing Laboratories www.retlif.com**	**(631) 737-1500**		•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
NORTH CAROLINA																						
Cary	CertifiGroup www.certifigroup.com	(800) 422-1651		•				•							•	•						
Cary	MET Laboratories, Inc. www.metlabs.com	(919) 481-9319	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
Concord	F-Squared Laboratories, Inc. http://f2labs.com	(704) 918-4609		•	•	•	•	•	•	•	•	•			•	•					•	
Fayetteville	Partnership for Defense Innovation R&D Lab www.ncpdi.org	(910) 307-3000			•				•					•						•		
Greensboro	Electrical South, LP www.schneiderelectricrepair.com	(800) 950-9550																	•			
Greenville	Lawrence Behr Associates (LBA) www.lbagroup.com	(252) 757-0279			•											•	•				•	
New Bern	iNARTE, Inc. www.narte.org	(252) 672-0111								•												
Raleigh	MicroCraft Corporation	(919) 872-2272			•	•	•					•	•	•		•					•	
Res. Triangle Pk.	Educated Design & Dev., Inc. (ED&D) www.productsafet.com	(919) 469-9434		•											•	•			•			•
Res. Triangle Pk.	IBM RTP EMC Test Labs www.ibm.com	(919) 543-0837			•				•		•											
Res. Triangle Pk.	Underwriters Laboratories, LLC. www.ul.com	(919) 549-0957	•	•	•		•	•	•	•	•				•	•					•	
Youngsville	Flextronics International EMC Labs ww.flextronics.com	(919) 554-0901	•	•	•	•	•	•	•	•	•	•			•	•					•	
Youngsville	**TÜV Rheinland Of North America www.tuv.com**	**(919) 554-3668**		•	•		•	•	•		•				•	•	•					
OHIO																						
Brooklyn Heights	Sypris Test & Measurement www.sypris.com	(216) 741-7040																	•			
Middlefield	F-Squared Laboratories, Inc. http://f2labs.com	(877) 405-1580		•	•	•	•	•	•	•	•	•			•	•					•	
Chesterland	EU Compliance Services, Inc. www.eucs.com	(440) 918-1425			•		•	•	•		•					•	•					
Cleveland	CSA International www.csa-international.org	(216) 524-4990						•								•						
Cleveland	NASA GRC EMI Lab http://facilities.grc.nasa.gov/emi/index.html	(216) 433-2533												•							•	
Cleveland	Smith Electronics	(440) 526-4386			•		•	•	•		•											
Fairborn	Sypris Test & Measurement www.sypris.com	(937) 427-3444																	•			

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Mason	L-3 Cincinnati Electronics www.cinele.com	(513) 573-6100			•		•				•			•				•		•		
Mentor	EU Compliance Services, Inc. www.eucs.com	(440) 918-1425			•		•	•			•					•					•	
Springboro	Pioneer Automotive Technologies	(937) 746-6600			•		•		•		•			•	•							
OKLAHOMA																						
Tulsa	Integrated Sciences, Inc.	(918) 493-3399					•															
OREGON																						
Beaverton	Tektronix www.tek.com	(407) 551-2738	•												•					•		
Hillsboro	Cascade TEK www.cascadetek.com	(503) 648-1818	•												•					•		
Hillsboro	ElectroMagnetic Investigations, LLC	(503) 466-1160			•		•	•	•		•			•	•						•	
Portland	**Northwest EMC, Inc. www.nwemc.com**	**(888) 364-2378**		•	•		•		•		•				•					•	•	
Portland	**TÜV SÜD America, Inc. www.tuvamerica.com**	**(503) 598-7580**		•		•		•								•						
Tillamook	ElectroMagnetic Investigations, LLC	(503) 466-1160			•																	

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
PENNSYLVANIA																						
Annville	CHAR Services, Division of AMS Corporation www.amschar.com	(717) 867-2788			•	•	•				•			•								
Boalsburg	**Seven Mountains Scientific, Inc. www.7ms.com**	**(814) 466-6559**								•				•							•	
Glenside	Electro-Tech Systems, Inc. www.electrotechsystems.com	(215) 887-2196	•				•														•	
	RETLIF TESTING LABORATORIES																					
Harleysville	**Retlif Testing Laboratories www.retlif.com**	**(215) 256-4133**		•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
Hatfield	Laboratory Testing Inc. www.labtesting.com	(215) 997-9080													•				•			
New Castle	Keystone Compliance LLC www.keystonecompliance.com	(724) 657-9940	•		•	•	•	•	•		•	•	•	•	•	•	•	•		•	•	
Pottstown	BEC Inc. www.bec-ccl.com	(610) 970-6880			•		•		•		•				•						•	
State College	Videon Central, Inc. www.videon-central.com	(814) 235-1111			•		•	•	•											•		
West Conshohocken	Alion Science & Technology www.alionscience.com	(610) 825-1960			•	•	•				•	•		•			•	•		•	•	
Willow Grove	Nelson Design Services www.nelson-design.com	(215) 784-9600				•															•	
TENNESSEE																						
Knoxville	Global Testing Labs LLC www.globaltestinglabs.com	(865) 525-0137			•				•		•				•							
Knoxville	Southern Testing Services, Inc.	(865) 966-5330												•								
Knoxville	AMS Corporation www.ams-corp.com	(865) 691-1756			•	•	•				•			•								
TEXAS																						
Austin	Austin EMC www.austinemc.com	(512) 219-6650			•		•				•			•					•			
Austin	BAE Systems IDS Test Services www.baesystems.com	(512) 929-2410											•					•				
Austin	MET Laboratories, Inc. www.metlabs.com	(512) 287-2500	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
Austin	**TUV Rheinland of North America, Inc. www.tuv.com**	**(512) 927-0070**														•						
Cedar Park	TDK RF Solutions, Inc. www.tdkrfsolutions.com	(512) 258-9478			•		•	•	•	•	•				•							
Euless	Ronald G. Jones, P.E.	(817) 267-1476				•						•										
Houston	DNV Certification	(281) 721-6600						•														
Lewisville	Nemko USA www.nemko.com	(972) 436-9600		•	•		•	•	•	•	•			•	•	•	•	•		•	•	

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Plano	**National Technical Systems (NTS)** **www.nts.com**	**(972) 509-2566**	•	•	•	•	•	•	•	•	•	•		•	•			•		•	•	
Plano	Intertek www.intertek.com	(800) 976-5352			•	•	•	•	•		•				•	•						
Richardson	Sypris Test & Measurement www.sypris.com	(972) 231-4443																	•			
Round Rock	Professional Testing (EMI), Inc. www.ptitest.com	(512) 244-3371			•		•		•		•	•		•	•	•			•	•	•	
San Antonio	Southwest Research Institute www.swri.org	(210) 684-5111	•		•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	
UTAH																						
Coalville	**DNB Engineering, Inc.** **www.dnbenginc.com**	**(435) 336-4433**	•		•		•	•	•	•	•					•						
Ogden	Little Mountain Test Facility (LMTF)	(801) 315-2320			•	•	•				•		•	•				•		•	•	
Salt Lake City	Communication Certification Laboratory www.cclab.com	(801) 972-6146			•		•	•	•	•	•			•	•	•						
Salt Lake City	L3 Communication Systems–West www2.l-3com.com/csw/	(801) 594-2560			•			•	•					•						•		

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VERMONT																						
Essex Junction	Huber & Suhner www.hubersuhner.com	(802) 878-0555										•									•	
Middlebury	Green Mountain Electromagnetics, Inc. www.gmelectro.com	(802) 388-3390						•	•	•			•	•								
VIRGINIA																						
Falls Church	Raytheon Prototype Services www.raytheon.com	(703) 849-1562			•						•			•								
Fredericksburg	**E-LABS INC.** **www.e-labsinc.com**	**(540) 834-0372**			•		•				•			•	•		•			•	•	
Fredericksburg	Vitatech Engineering, LLC http://vitatech.net	(540) 286-1984	•		•				•	•	•		•	•							•	
Herndon	Rhein Tech Laboratories, Inc. www.rheintech.com	(703) 689-0368			•		•	•	•		•			•	•	•				•	•	
McLean	American TCB	(703) 847-4700			•	•		•	•		•	•			•							
Reston	TEMPEST, Inc. (VA) www.tempest-inc.com	(703) 709-9543			•		•	•	•	•	•		•	•							•	
Richmond	Technology International, Inc. www.techintl.com	(804) 794-4144		•	•		•	•			•					•						•
WASHINGTON																						
Bothell	CKC Laboratories, Inc	(425) 402-1717		•	•	•	•		•		•	•		•	•			•		•	•	
Sultan	**Northwest EMC, Inc.** **www.nwemc.com**	**(888) 364-2378**			•		•		•		•				•	•						
WISCONSIN																						
Butler	Emission Control, Ltd. www.emissioncontrol.com	(262) 790-0092			•																	
Cedarburg	L.S. Research www.lsr.com	(262) 375-4400		•	•		•		•		•				•							
Genoa City	**D.L.S. Electronic Systems, Inc.** **www.dlsemc.com**	**(847) 537-6400**		•	•				•						•							
Neenah	International Compliance Laboratories www.icl-us.com	(920) 720-5555			•		•		•		•				•							
CANADA																						
ALBERTA																						
Airdrie	**Electronics Test Centre - Airdrie** **www.etc-mpb.com**	**(403) 912-0037**			•		•	•	•		•			•	•					•	•	

CITY	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461/462	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS03 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Calgary	EMSCAN Corporation www.emscan.com	(403) 291-0313			•						•										•	
Medley	Aerospace Engrg. Test Establishment (DND) www.armedforces-int.com/associa-tions/canada	(780) 840-8000			•															•		
BRITISH COLUMBIA																						
Abbotsford	Protocol EMC www.protocol-emc.com	(604) 218-1762			•	•	•	•	•		•	•		•	•	•					•	
Kelowna	Celltech Labs, Inc. www.celltechlabs.com	(250) 765-7650		•	•		•	•	•	•	•				•						•	•
Pitt Meadows	QAI Laboratories www.qai.org	(604) 460-4453			•		•	•	•		•											
Richmond	LabTest Certification, Inc. www.labtestcert.com	(604) 247-0444			•	•	•	•	•	•	•			•	•	•				•		

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ONTARIO																						
ELECTRONICS TEST CENTRE																						
Kanata	**Electronics Test Centre www.etc-mpb.com**	**(613) 599-6800**	•		•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
Merrickville	EMC Consulting, Inc. www.emcconsultinginc.com	(613) 269-4247			•	•	•	•	•		•	•	•	•							•	
Nepean	APREL Laboratories www.aprel.com	(613) 820-2730	•		•	•		•	•	•	•	•		•	•	•	•			•	•	
Nepean	Multilek Inc. www.multilek.ca	(613) 226-2365			•		•				•			•					•			
Oakville	Ultratech Group of Labs www.ultratech-labs.com	(905) 829-1570		•		•	•	•	•	•		•		•	•	•	•	•		•	•	
Ottawa	ASR Technologies www.asrtechnologiesinc.com	(613) 737-2026				•	•	•	•			•	•	•							•	
Ottawa	Nemko www.nemko.com	(613) 737-9680	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Ottawa	Power & Controls Engineering Ltd. www.pcel.ca	(613) 829-0820			•								•	•			•				•	•
Ottawa	Raymond EMC Enclosures Limited http://raymondemc.ca	(800) EMC-1495																			•	
Scarborough	Vican Electronics http://vican.ca	(416) 412-2111	•		•		•	•	•	•	•			•					•		•	•
Toronto	CSA International www.csa-international.org	(866) 797-4272		•	•			•	•		•				•	•						
Toronto	Global EMC Inc. www.globalemclabs.com	(905) 883-8189	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Toronto	**TUV Rheinland of North America, Inc. www.tuv.com**	(416) 733-7781														•						
QUEBEC																						
Montreal	Centre de Recherche Industrielle du Quebec www.criq.qc.ca	(514) 383-1550			•			•	•		•					•						
Quebec	Comlab, Inc. www.comlab.com	(418) 682-3380					•	•	•		•											
Quebec	FISO Technologies www.fiso.com	(418) 688-8065				•					•			•		•	•				•	
ASIA																						
CHINA																						
Beijing	SIEMIC Beijing (China) Laboratories www.siemic.com.cn	+86 1068049809		•	•	•	•	•	•	•	•	•			•	•						
Nanjing	SIEMIC (Nanjing) China Laboratories	+86 2586730128		•	•		•		•	•	•	•			•	•					•	
Shanghai	CETECOM Shanghai www.cetecom.com	+86 021-6879-5890		•	•		•	•			•				•	•						
Shanghai	SIEMIC Shanghai (China) Laboratories	+86 02164812901		•	•	•	•	•	•	•	•	•			•	•						

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Shenzhen	SIEMIC (Shenzhen) China Laboratories www.siemic.com	408-526-1188		•	•	•	•	•	•	•	•	•			•	•						
JAPAN																						
Tokyo	CETECOM Japan www.cetecom.com	+81 036 663 8990		•	•		•	•	•		•				•	•						
Yokohama	**TUV Rheinland Japan Ltd. www.tuv.com**	**+81 454 701850**		•	•		•	•	•	•	•					•						
KOREA																						
Gyeonggi-do	CETECOM MOVON Ltd. www.cetecom.com	+82 031 321 2988		•	•		•	•	•		•				•	•						
TAIWAN																						
Taipei	SIEMIC Certification Servces www.siemic.com	408-526-1188		•				•														
EUROPE																						
GERMANY																						
Dortmund	EMC Test NRW GmbH www.emc-test.de	+49 231 974 2750			•		•	•	•		•											
Egling	MOOSER Consulting GmbH www.mooser-consulting.de	+49 817 692250			•	•					•		•	•							•	•
Erlangen	Siemens AG www.siemens.com	+49 91 317 32977			•		•				•											
Essen	CETECOM GmbH (Germany) www.cetecom.com	+49 205 495 190		•	•		•	•	•		•					•					•	
Karlsruhe	Siemens AG www.siemens.com	+49 721 595 2039			•	•	•	•			•			•		•						
Ludwigsburg	Mooser EMC Technik GmbH www.mooser-consulting.de	+49 714 164 8260			•		•	•			•			•				•				
Moggast	EMCCons Dr. Rasek GmbH & Co www.emcc.de	+49 919 49016	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•				
Nürnberg	**TUV Rheinland www.tuv.com**	**+49 911 655 5225**		•	•		•	•	•		•					•						
Ratingen	7Layers www.7layers.com	+49 210 27490			•		•	•	•		•										•	
Saarbruecken	CETECOM ICT Services GmbH www.cetecom.com	+49 681 598 8438		•	•		•	•	•		•			•		•	•	•		•		
Siegen	EMC Testhaus Dr. Schreiber GmbH www.emc-testhaus.de	+49 271 382702			•	•	•	•			•	•		•		•			•	•	•	
Straubing	**TÜV SÜD SENTON GmbH www.tuev-sued.de**	**+49 942 155220**			•		•	•	•		•			•						•		
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HUNGARY																						
Budapest	**TÜV Rheinland InterCert Kft. www.tuv.com**	**+36 30 349 8828**		•	•	•	•	•	•		•					•	•				•	
THE NETHERLANDS																						
Dordrecht	Holland Shielding Systems BV www.hollandshielding.com	+31 078 613 1366				•	•					•		•						•		•
Eindhoven	EMCMCC www.emcmcc.nl	+31 653 811267			•	•	•				•			•		•		•				

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Eindhoven	Philips Innovation Services www.innovationservices.philips.com	+31 40 2746762		•	•		•		•		•					•						
Woerden	D.A.R.E.!! Consultancy www.dare.nl	+31 348 430 979		•	•		•	•	•		•			•		•		•	•		•	
SPAIN																						
Barcelona	GCEM-UPC www.upc.edu/web/gcem	+34 93 401 1021			•		•	•	•		•											
UNITED KINGDOM																						
Durham	**SGS** **www.sgs.co.uk**	**+44 (0) 191 377 2000**			•	•	•	•	•		•	•				•						
Northants	3C Test Limited www.3ctest.co.uk	+44 (0) 1327 857500		•	•		•	•	•		•					•						
St. Helens	Rainford EMC Systems www.rainfordemc.com	+44 (0) 1942 296190			•		•	•	•		•		•			•				•		
South Yorkshire	Frequensys Limited www.frequensys.co.uk	+44 (0) 1142 353507					•				•								•		•	
West Sussex	METECC www.metecc.eu	+44 (0) 7725 079956			•		•		•		•	•		•		•					•	

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Wales	Kiwa Blackwood Compliance Laboratories www.kiwa.co.uk	+44 (0) 1495 229219			•		•				•					•						
OCEANIA																						
AUSTRALIA																						
Melbourne	EMC Technologies Pty Ltd http://www.emctech.com.au	+61 (3) 9365 1000		•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•
Sydney	EMC Technologies Pty Ltd http://www.emctech.com.au	+61 (3) 9365 1000		•	•	•	•	•	•		•	•	•	•	•	•	•		•	•	•	
NEW ZEALAND																						
Christchurch	Braco Compliance Ltd	+64 21 208 4303			•																	

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Shanghai	**SGS-CSTC**	**+86 (0) 21 6140 2666**	**www.sgs.com**
Shenzhen	MET Laboratories Inc.	+86 755 82911867	www.metlabs.com
Kowloon	Intertek	+85 2 2173 8888	www.intertek.com
Tianjin	**SGS-CSTC**	**+86 (0) 22 6528 8000**	**www.sgs.com**
ISRAEL			
Lod	Israel Testing Laboratories	972 8 9797799	www.itl.co.il
JAPAN			
Watari	Cosmos Corporation	+81 598 60 1827	www.cosmoscorp.com
Chiba	EMC Kashima Corporation	+81 478 82 0963	www.emc-kashima.co.jp
Ise	Underwriters Laboratories Japan Inc.	+81 596 2 6717	www.ul.com
Yokohama	Kikusui Electronics Corp.	+81 45 593 7570	www.kikusui.co.jp
Tokyo	**TUV SUD Ohtama, Ltd.**	**+044 980 2050**	**www.tuv-ohtama.co.jp**
KOREA			
Seoul	MET Laboratories, Inc.	+82 (0) 2 2026 0191	www.metlabs.com
TAIWAN			
New Taipei City	MET Laboratories, Inc.	+886 2 8227 8887	www.metlabs.com
Taipei City	CETECOM Taiwan	+886 2 2564 3338	www.cetecom.com
EUROPE			
AUSTRIA			
Seibersdorf	Seibersdorf Laboratories	+43 (0) 50550 2805	www.ait.ac.at
DENMARK			
Horsholm	Delta EMC Services	+45 72 19 45 00	www.madebydelta.com
GERMANY			
Blomberg	Phoenix Testlab GmbH	+49 5235 9500 0	www.phoenix-testlab.de
Eiserfelder	EMC Testhaus Schreiber GmbH	+49 271 382702	www.emc-testhaus.de
Essen	CETECOM GmbH (Germany)	+49 20 54 95 19 0	www.cetecom.com
Hagen	HF-SHIELDING Joachim Broede GmbH	+49 54 05-99 99 04	www.hf-shielding.de
Munich	National Technical Systems (NTS)	+49 89 787475 160	www.nts.com
Neckartenzlingen	Hirschmann Car Communication GmbH	+49 7127 14 1437	www.hirschmann-car.com
Straubing	EMV Testhaus GmbH	+49 9421 568680	www.emv-testhaus.com
Stra ße	H+H High Voltage Technology GmbH	+49 2371 18530	www.hundh-mk.com
Wismar	CEcert GmbH	+49 3841 2242 906	www.cecert.com
NORWAY			
Oslo	Nemko, Inc.	+47 229 60330	www.nemko.com
SWEDEN			
Kista	Intertek	+44 20 7396 3400	www.intertek.com
SWITZERLAND			
Berikon	Euro EMC Service	+41 566 33 73 81	www.euro-emc-service.de
Geneva	**SGS International Certification Services**	**+41 44 445 16 80**	**www.sgs.com**
UNITED KINGDOM			
Bideford	ETC Ltd.	+44 (0) 1237 423388	www.etcal.co.uk
Bicaster	RFI Global Services Ltd. (UL)	+44 (0) 1256 31 2112	www.rfi-wireless.com
Eastleigh	Hursley EMC Services	+44 (0) 2380 271111	www.hursley-emc.co.uk
Essex	RN Electronics	+44 (0) 1277 352219	www.rnelectronics.com
Dorset	TRAC Global	+44 (0) 1684 571700	www.tracglobal.com
Renfrew	EMC Center	+44 (0) 1418 8867300	www.emc-centre.com
Hampshire	**TUV Product Service/BABT**	**+44 1489 558100**	**www.tuvps.co.uk**
Towcester	3C Test Ltd	+44 (0) 1327 857500	www.3ctest.co.uk
Leicestershire	Cre8 Associates Ltd	+44 (0) 1162 479787	www.cre8-associates.com
Merseyside	**SGS International Certification Services**	**+44 1513 506666**	**www.sgs.com**
Northamptonshire	3C Test Ltd	+44 (0) 1327 857500	www.3ctest.co.uk
Stropshire	Cranage EMC & Safety	+44 (0) 1630 658 568	www.cranage.co.uk
Blackwood	Kiwa Blackwood Compliance Lab	+44 (0) 1495 229 219	www.kiwa.co.uk
Solihull	TRW Conekt	+44 (0) 121 627 4242	www.conekt.co.uk
Stebbing	Electromagnetic Testing Services Ltd	+44 (03) 9365 1000	www.etsemc.co.uk
Wimborne	AQL EMC Limited	+44 (0) 1202 861175	www.aqlemc.co.uk
Worcestershire	TRaC Global (EMC Projects Ltd)	+44 (0) 1684 571700	www.tracglobal.com
OCEANIA			
AUSTRALIA			
Victoria	EMC Technologies	613 9365 1000	www.emctech.com.au
Sydney	Austest Laboratories61	029 680 9990	www.austest.com.au

Suppliers of Amplifiers

AR Worldwide RF/ Microwave Instrumentation; Souderton, PA
215-723-8181; 800-933-8181; www.ar-worldwide.com

CPI (Communications & Power Industries) Canada Inc.;
Georgetown, ON, Canada; 905-877-0161; www.cpii.com/cmp

Instruments for Industry; Ronkonkoma, NY;
631-467-8400; 631-467-8558; www.ifi.com

Suppliers of Antennas

A.H. Systems; Chatsworth, CA
818-998-0223; 818-998-6892; www.AHSystems.com

Suppliers of Filters & Ferrites

Fair-Rite Products Corp.; Walkill, NY
888-324-7748 ; www.fair-rite.com

LCR Electronics, Inc.; Norristown, PA
610-278-0840 ; www.lcr-inc.com

Quell Corp.; Albuquerque, NM
505-243-1423; www.eeseal.com/index.html

RP Radius Power; Orange, CA
714-289-0055; 714-289-21491; www.radiuspower.com

Suppliers of Shielding

Spectrum Control; Fairview, PA
814-474-2207; http://www.spectrumcontrol.com

Tech-Etch; Plymouth, MA
508-747-0300; 508-746-9639; www.tech-etch.com

Suppliers of Software

CST of America; Framingham, MA
508-665-4400; 508-665 4401; www.cst.com

FEKO; Hampton, VA
866-419 FEKO; www.feko.info

Suppliers of Test Equipment

Narda Safety Test Solutions;
Via Leonardo da Vinci 21/23
20090 SEGRATE (MI) – ITALY
phone: +39 - 02 - 269987.1
fax: +39 - 02 - 269987.00

EM TEST USA; San Diego, CA
858-699-1685; 858-458-0267; www.emtest.com

Advanced Test Equipment Rentals; San Diego, CA
800-404-2832; 858-558-6570; www.atecorp.com

Supplier of Measurement Tools

Agilent Technologies; Santa Clara, CA
408-345-8886; 408 345-8474; www.agilent.com

Supplier of Electronic Components

AMERICOR; Elk Grove Village, IL
847-956-6200 Fax: 847-956-0300 ; www.americor-usa.com

Supplier of Connectors

Fischer Connectors Holding; Alpharetta, GA
678-393-5400; 678-393-5401; www.fischerconnectors.com

Supplier of Custom Doors/Windows

Krieger Speciality Products; Pico Rivera, CA
562-695-0645; 562-692-0146 ; www.kriegerproducts.com

Practical Reasons for Shifting to the Application of Dielectric-Independent EMI Filters with Integral Surge Protection in Product Designs

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THE PROTECTION of equipment from threatening electrical disturbances that occur on the power grid and inside customer facilities and the protection of equipment from conducted disturbances (i.e., emissions) are critical to the life and operation of any electronic equipment. These are two issues for manufacturers that must not be taken lightly. Manufacturers are under continued economic pressure to design and manufacture equipment that must perform as their customer expect. Moreover, manufacturers have profit margins that must be met if they are to satisfy their investors and continue to develop new products for our digital society. Equipment failures and malfunctions caused by EMI problems and voltage surges can be dealt with in an economically effective way without compromising equipment protection or performance. Two of the technologies that have grown to be commonly used in product design in the last few decades are passive EMI filters using primarily capacitors and inductors and metal oxide varistors (MOVs), respectively. EMI filters have been used much longer than MOVs. Many new topologies for EMI filters have been designed and implemented. Essentially all of them make use of additional filter components (i.e. capacitors and inductors) to form multistage filters. Thousands of new products routinely fail conducted EMI tests when trying to achieve US or international compliance as defined by rules and regulations attempting to avoid EMI problems. Each and every product designer can a "horror story" when trying to achieve EMC compliance. Forensic analyses of many failed products on the market today revealed that product failures were caused by early MOV failure.

Many products also suffer from undetectable damage to EMI filters caused by improper or no protection of filter elements from voltage surges. The first article of a series is not intended to dive into the technical details of EMI filter design, but is intended to begin presenting discussion regarding the business case as to why more effective filters are needed in product design. The authors include a discussion of how a new passive EMI filter technology can eliminate many of the challenges associated with the design and application of traditional EMI filters and the challenges associated with product testing. This new technology makes effective use of cancellation of emissions currents resulting in the need for only a small amount of dielectric material (i.e., making it essentially a dielectric-independent FILTER) and the

elimination of the inductive element — the common mode choke. Future articles will present a few specific applications of the new filter technology including performance and economic analyses regarding the use of the technology in various types of electronic equipment.

ECONOMIC PRESSURES TO INCREASE EQUIPMENT PERFORMANCE AND COMPATIBILITY

Equipment manufacturers are constantly looking for ways to reduce operating costs. The cost of product designs, testing and manufacturing equipment has become a heightened concern that must be re-evaluated in today's economic times. The economic gains resulting from moving manufacturing lines overseas can no longer support the margins required to sustain profitable operations of manufacturing facilities in the United States. Moreover, the cost of customer service — maintaining, servicing, and honoring warranties — has become a larger financial risk that manufacturers cannot afford to leave to fate. The economics associated with applying the traditional approaches to move equipment from the "proof of concept" stage to cost-effective production inside the manufacturer's facility through to its "end of life" on the customer's floor can no longer support a health bottom line profit for manufacturers and their investors. End users are also demanding products that last longer with sustainable performance given the financial constraints of making the investment to purchase products in today's economic times.

PRODUCT DESIGNS

Product designers must spend their allotted design time applying their specific professional expertise on designing the core performance of their product. Core performance defines what their product is supposed to do for the customer. Does the product do the job fast enough and produce a high quality end result? Does the product perform without introducing errors into the final product? Is the product light enough? Is the product too large? For example, if the product is a high-definition flat screen television, product designers must spend their time focusing on picture and sound quality as well as ensuring that the functionality of the television meets the customer's expectations. Designers should not have to waste time chasing emissions back to an ineffective EMI filter and trying to figure out why electrical noise might be affecting the picture quality. This is especially important when the noise is not originating in the digital circuitry needed to process the high-definition signals and apply them to the screen array. Designers will end up with better picture quality if they can work from a noise floor in their digital designs that is lower. Designers should ask themselves, "How many board-level noise suppression components are required versus signal shaping components that actually affect the signals that define the picture quality?" Better control of radiated and conducted emissions will significantly affect the noise floor on the printed circuit boards.

In another example, a product designer working on a communications link for a smart appliance such as a refrigerator must spend his or her design time on the quality of signal integrity and transmission of the link rather than chasing the source of emissions currents affecting the quality of the link and whether or not commands initiated by the user or by an energy management company properly invoke the functions necessary to operate the appliance. Traditional noise sources on printed circuit boards can generate emissions

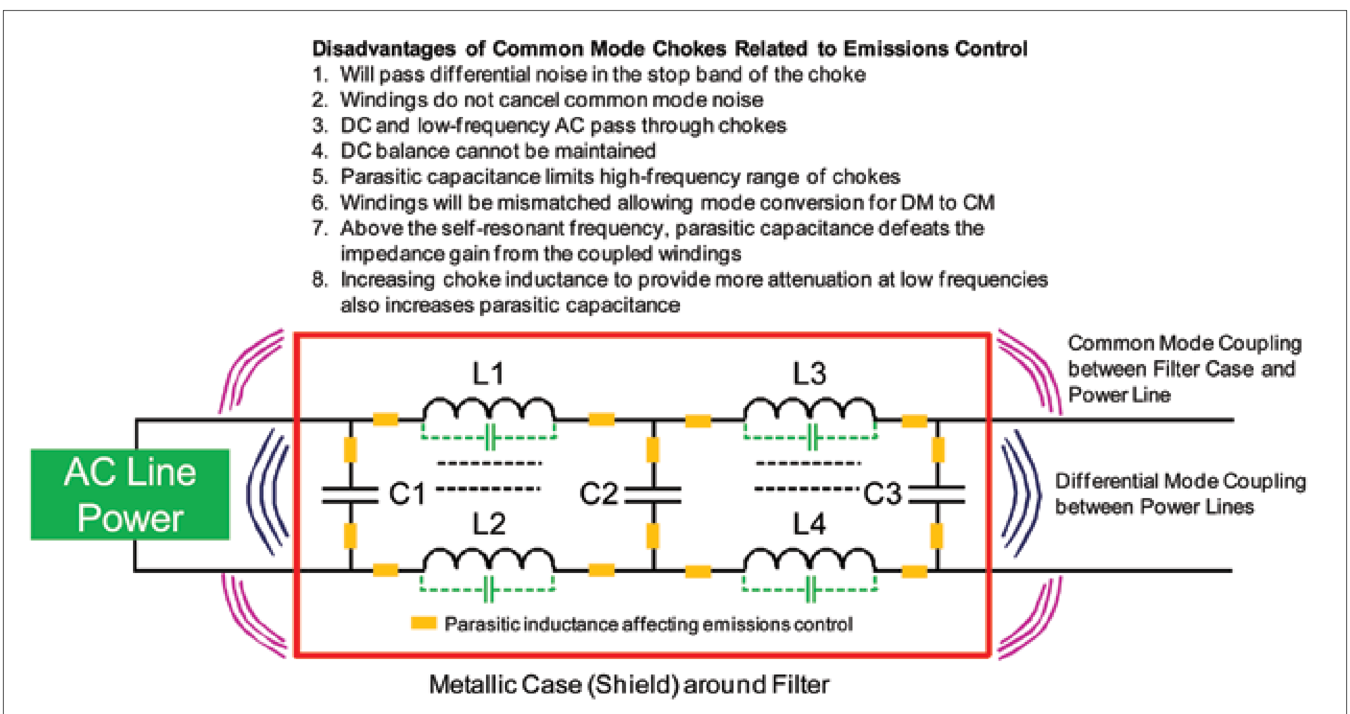


Figure 1. Disadvantages of common mode chokes and parasitics impacting the control of conducted emissions.

currents that travel through power, ground and signal traces that end up in the wrong places on printed circuit boards. Trying to mitigate these noise currents further away from their sources presents additional design challenges that end up taking additional board space and designer resources that could otherwise be attributed to components and design time affecting the core performance of the product.

PRINTED CIRCUIT BOARD LAYOUTS

The mechanics of printed circuit boards are critical to the frequency performance of any circuit and to the magnitude and phasing of voltages and currents for power and signaling that must be able to travel across boards. Lines on a schematic that connect components together to form a circuit are simple and easy to conceptualize when trying to design and understand how a circuit works. The mechanics of the board include the elements of resistance, capacitance and inductance of all the materials used in the board. This includes the copper traces and the board material. A copper trace has a distinct length, width, and thickness. These dimensions make up the resistance, capacitance and inductance of the trace. The distance between traces is also critical. There is a capacitance between the traces. The paths traces take from component to component also impact the magnitude, phasing, and frequency response. When the frequency of the voltage and current is low, the mechanics of the board does not play a critical role in how the circuit really works. However, as the frequency increases the mechanics of these elements becomes critical to the control of radiated and conducted emissions.

When a designer places a resistor in a circuit, for example, he or she desires that resistance at that location within the circuit. The same is true for other components like real inductors and capacitors. However, when two resistors are placed in the same path using the same copper trace, a small "inductance" then becomes a part of the circuit. The "inductance" is not a real inductor (or coil) like we know and see when we hold one in our hand, but it is a "parasitic" (or internal) inductance of the resistor. The parasitic inductance, like any other inductor, will become essentially an open circuit as the frequency through the resistor-parasitic inductance-resistor circuit increases until the two resistors are no longer electrically connected together. Of course, this is because the impedance (i.e., frequency dependent resistance) increases linearly with frequency. The impedance of an inductor is $X_L = j2\pi fL\ \Omega$ (ohms) where f is the frequency and L is the value of the parasitic inductance. From this, one can see that as the frequency increases, so does the impedance. Also, as the inductance, L, increases, so does the impedance. Hence, designers want to keep the parasitic inductance as low as possible to ensure that the resistor-to-resistor circuit has as little inductance as possible.

EMI filters by definition are designed to absorb (or soak up) and divert conducted emissions currents (i.e., electrical noise) generated by the operations of electronics downstream of the filter. Conducted emissions are very small voltage signals that create very small currents that "ride" on AC and DC waveforms. Emissions will "ride" on power and control signals in efforts to get outside of equipment seeking the lowest impedance possible. Emissions captured by a filter are injected into the ground conductor of the equipment. Emissions build up and circulate in the grounding system of a building. Conducted emissions must be controlled so that when the remaining emissions flow into the AC line cord, they have a much less likelihood of causing an EMI problem when they flow back into the wiring and grounding system of a building and onto the grid. While the magnitude of these emissions is low, the allowable limits for emissions on an AC line cord are low as well. Because of this, an EMI filter is designed to remove very small noise voltages and current but must allow AC (and DC in the case of DC sources and loads) power to flow from the grid to the electronics downstream of a filter. They must also be designed to "take the hits" from electri-

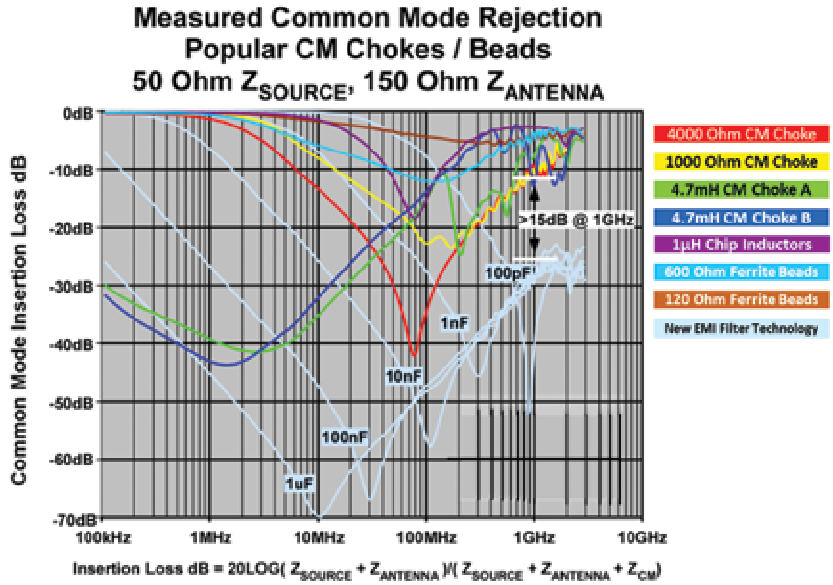


Figure 2. Common mode insertion loss for traditional chokes vs. chokeless dielectric-independent filter component.

Attribute	**Common Mode Choke** (Use of Traditional EMI Line Filter)	**No Common Mode Choke** (Use of Dielectric-Independent Filter)
Size	Large	Small
Weight	Heavy	Light
Materials	Copper and Core Material	No Copper
Cost	High	Low
Reliability	Low	High
Assembly Cost	High	Low
High-frequency Performance	Poor	Superior
Failure Modes	Vibration, Over-current	Over-voltage
Line Current	Must pass through coil	Only passes through straight line pins
Temperature	Hotter	Cooler

Table 1. Comparison of basic attributes for common mode choke and filter with no choke.

cal disturbances (e.g., voltage surges and temporary over-voltages) generated by the grid and loads inside buildings. The nature of the design of traditional discrete EMI filters makes it difficult to control the emissions when discrete filter components (i.e., capacitors and inductors) are placed on a printed circuit board. Losses in each discrete component significantly affect the filter's ability to reduce emissions. Filter designers must make these components large to overcome their losses. This makes filters large, heavy, and expensive. This is one reason why the parasitic impedances that are a part of traditional filters and their components can significantly affect how much of the emissions are filtered.

TESTING, EMI LINE FILTERS AND EMISSIONS PERFORMANCE

Manufacturers spend a tremendous amount of money having their products tested. Products must be tested for various purposes—safety, compliance, etc. Some manufacturers do pre-compliance testing in their own development laboratories in preparation for actual compliance testing where performance certificates are awarded. Whether time is spent on pre-compliance or compliance testing, that time costs manufacturers millions of dollars per year. One of the key sets of compliance tests that must be performed are the battery of EMC tests. Two primary groups of EMC tests that are performed on products are radiated and conducted tests. Radiated emissions travel from the components, circuit traces on the board and wiring into the air. Conducted emissions travel from the components, circuit traces on the board and wiring onto electrical conductors — the AC line cord and its ground conductor, data and network cables, and control cables.

Radiated and conducted emissions are linked together by the laws of physics. They significantly influence each other as Maxwell's equations predict. Their influence presents key concerns when emissions suppression devices (i.e., filters) are used anywhere on the board, inserted in a conductor, or around a component or product. This influence can easily degrade the performance of a filter whether the filter is a discrete design mounted on a board without the use of a shielded can or a shielded design where its components are placed inside a shielded can placed on top of a board or on the side wall of an equipment enclosure. When a shielded can is used, emissions on the equipment side of the filter can leak around the filter can. This leakage is influenced by the use of ground conductors inside and near the filter can and by other metallic objects around the filter can. Leakage can also occur across filter components like common mode chokes whether the chokes are inside a can or mounted directly on top of a board. Leakage of emissions is one cause of failure to achieve compliance with conducted emissions limits that designers often overlook.

Too often, manufacturers must have safety and compliance tests repeated. Repeat testing is a significant expense for the product testing budget. When traditional EMI filter technologies are used, repeat testing is necessary because a product did not pass a test the first time. Many products simply do not pass the tests even the second or third time. While some may say that passing a test the first time is not realistic, careful design practices can reduce testing time and costs. A careful design approach takes into account all of the factors that influence emissions control including board-level components not associated with the EMI filter as well as the design and implementation of the most effective filter for the application and the desired level of emissions control (i.e., meeting the conducted emissions limits of interest).

COMMON MODE INSERTION LOSS

Common mode insertion loss is a measure of the loss that the common mode function of a filter element applies to the conducted emissions profile. Loss at the right frequency range must be applied to the emissions currents generated by the electronics inside the equipment to reduce their magnitude before being allowed to travel outside of the equipment on the AC line cord. Emissions currents that flow from inside the equipment through one line conductor (e.g., hot) back through ground and from the equipment through the other line conductor (e.g., neutral) back through ground share the ground conductor as common. This gives rise to the name common mode emissions. Because most EMI problems are caused by common mode emissions, this metric is important in predicting the performance outcome of an EMI filter.

Figure 2 illustrates this loss as a function of frequency from 100 kHz to 10 GHz for eight different cases of EMI filter components. Four of the cases use typical common mode chokes found in many of today's EMI filters used in end-use products. One of the cases is for a chip inductor used on a circuit board. Two of the cases are for ferrite beads used on circuit boards or on individual conductors. The last case represents the improvement in loss for five different capacitance cases where the new EMI filter technology is used. One will notice from the graph that the loss is significantly improved over each of the comparison cases. The improvement in loss is not only important at the lower and middle frequencies but also the high frequencies in the GHz range. An increasing number of consumer products now use on-board wireless radios operating in the low (e.g., 1 to 6) GHz range. These high-frequency signals have been found in the conducted emissions profiles (i.e., test results) of many products. Take the example case of the 1 GHz signal shown in the graph where the use of traditional elements used in today's filter designs only provide about 10 dB of loss whereas the new filter technology can provide almost a 20 dB improvement in loss. This improvement will help keep GHz-frequency components off the AC power line and increase the performance of wireless-based products.

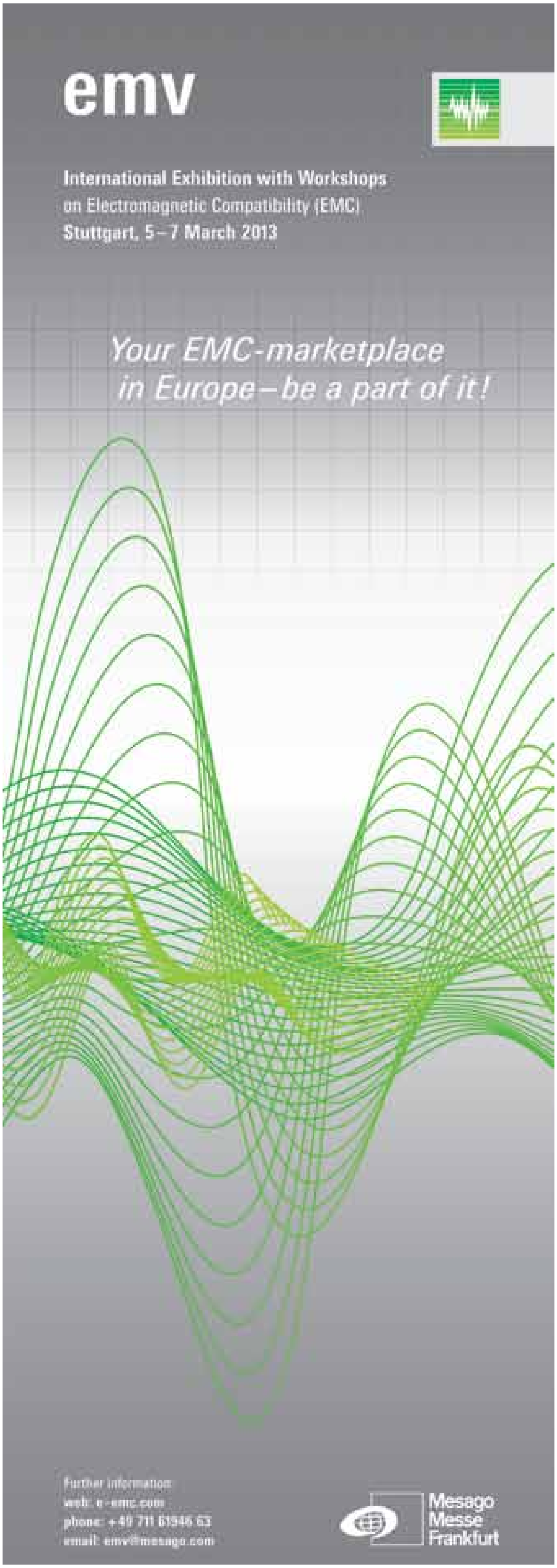
TWO BASIC FILTER TYPES AND FILTER COMPONENTS

In trying to meet a set of compliance limits for conducted emissions testing, the obvious system or device inside the product that affects emissions control is the EMI filter. Product designers choose between two approaches for their EMI filters — discrete designs or shielded can (i.e., one-piece) designs. With discrete designs, each component of the EMI filter is individually placed on a dedicated circuit board or on a circuit board with other components (e.g., power supply components). Discrete filter designs typically range from the simple filters that use anywhere from four to five components to the more complex filters that use up to twenty components. Each discrete filter component is connected to the other by use of copper traces on a printed circuit board. The design of the traces is also an important factor that influences how the filter performs and the product's emissions control. Traces play a key role in leakage and coupling. The coupling between components and the traces on the board is the vehicle that allows the emissions leakage to occur.

In a shielded can design, each filter component is electromagnetically shielded from the electromagnetic environment outside the can by the metallic material forming the shield. The shield must be grounded to the equipment ground. This helps keep the buildup of charge off of the shielded can and helps to ensure the can acts like a shield against electric fields that make up the emissions. However, the methods of grounding the filter can and the interface between the ground conductor on the board and the can heavily influence the emissions performance.

Whether the filter is made of discrete components placed on a board or a system of components on a small board placed inside a shielded can, a specific arrangement of capacitors and inductors are used to make up the filter. Other components like fuses, thermal protectors, and even MOVs may be used inside a filter can to provide a more complete solution for product designers. Many standard filters use only one inductor (common mode choke) and two across-the-line (X) capacitors — one upstream of the choke and one downstream, both of which take up a considerable amount of board space and space inside a can. This type of filter is called the pi-type filter. Many filters also use one or two line-to-ground and line-to-neutral capacitors (Y). There are limitations as to how much Y-capacitance can be used in a filter. These limitations are based on the amount of allowable leakage current that can flow from the filter to the ground. Leakage current represents the noise current captured by the filter and injected into ground.

Filter and product designers are moving towards the use of more complex filters. This is because electronic loads are



becoming noisier — generating higher levels of conducted emissions. The use of more complex filters is also attributed to tighter emissions control defined by lower conducted emissions limits. Standards in the US are slowly becoming more stringent as the harmonization of standard around the world continues to take shape. However, the limits imposed by European and Asian countries are much more stringent in efforts to further reduce the likelihood of a product causing an EMI problem. Complex filters use more than one inductor and multiple X- and Y-capacitors. These filters even use capacitors in other arrangements around the inductors and X- and Y-capacitors. Complex filters are used simply because the amount of loss that can be provided when using simple filters cannot be achieved.

OFF-THE-SHELF EMI LINE FILTERS

Some product designers elect to use off-the-shelf filters. These filters are predesigned and require the use of a shielded can to hold the filter components in place. Off-the-shelf filters are a large market for all filter manufacturers. In many cases, when a product that uses an off-the-shelf filter that fails a conducted emissions test, then another off-the-shelf filter is quickly pulled from a "convenient" batch of filters located at the EMC test house. The objective here, of course, is to very quickly find a filter that will provide a passing test result for the conducted emissions test. While this approach may very well serve the purpose and provide that passing test result, it can also precipitate the use of a filter that is insufficient in some way or a filter that is overkill is some way. There are many factors that should be carefully considered before an off-the-shelf filter is selected for use in a product.

In addition to insertion loss (if it is even known), attenuation, steady-state voltage rating, and steady-state current rating, other factors are also critical to the performance and life of the filter. For example, what are the transient voltage ratings for the front-end capacitors inside the filter? How much transient energy can they handle before they begin to suffer damage and eventually fail? How does the product designer know that any one of its customers' facilities will not be subject to voltage transients that will start degrading the reliability of the capacitors used inside the filter? How much non-linear distorted AC current does it take to cause the common mode choke inside the filter to go into saturation? Does the product generate a lot of non-linear distorted current that will affect the performance of the filter? Will the filter suddenly reduce its effectiveness when the product is switched into a different operating mode requiring a higher level of distorted line current? How does the filter performance vary with input impedance and output impedance variation? These are all important to the successful implementation of any EMI filter used on the AC line for the product.

Another challenge that presents difficulty in using off-the-shelf filters is the amount of space available on the board and inside the product to locate the filter. In many instances, the substitute filter selected from off-the-shelf is just too large to fit into the intended space where the original filter was designed to fit. This problem can cause a complete redesign of the circuit board which can introduce a whole variety of other problems (including the degradation of any emissions control already achieved) — problems that continue to eat into the product development and testing budgets which manufacturers try to control.

Some manufacturers who took this approach later found themselves with failed products — failures that were caused by the use of improperly specified (and selected) EMI filters. Regardless of what caused the product to fail, a filter failure is still a product failure to the customer. These pitfalls can be avoided if care is taken in the selection of which type of EMI filter to use in a product.

MANUFACTURING

The cost of manufacturing a product is always one of the top concerns for manufacturers. Many production lines have already been moved to overseas factories. In many cases, product warranty claims are increasing beyond expected levels. In other cases, there is just nothing left to "squeeze" out of the product budget to sustain planned profits. Further reduction in product costs must be achieved using some other cost control approach in order to boost the struggling economy of today. The invention of automatic insertion machines that use robotics to pick up small components and carefully place them in the right location on a circuit board is one excellent example of cost control that has definitely saved manufacturers millions of dollars in labor costs. Unfortunately, this approach also reduces jobs. However, many large bulky components like EMI filters still have to be placed on boards by the human hand. This is an expensive labor component for manufacturers to have to endure.

Two commonly used components in EMI line filters that in many cases must be hand inserted are across-the-line (or X) capacitors and common mode chokes (or coils). Both of these components can be large and bulky depending upon the size needed. In many cases, multiple common mode chokes must be used in multi-stage filters to introduce enough attenuation to achieve the desired level of emissions control. The amount of loss associated with the components used in filters is so large that the components must be oversized to provide the desired attenuation. Common mode chokes are also heavy, use large magnetic cores and lots of copper wire. In addition, product designers must be on constant watch for reaching an operating condition that causes the wire temperature to reach unreliable levels. The use of these chokes also affects product efficiency and increases product operating temperature. Eliminating the use of the common mode choke in EMI filters is a huge step forward in filter design and offers many benefits. Table 1 summarizes the disadvantages of common mode chokes and the advantages of dielectric-independent filters.

MAINTAINING, SERVICING AND WARRANTIES

Every product manufacturer must be able to provide a variety of customer services which include maintaining, servicing and warranting their products. The quality of power inside customer facilities affects the level and cost of these services provided to the customer since power quality directly impacts equipment performance. Common everyday electrical disturbances cannot be avoided despite the mission of utilities to provide better power quality. Weather patterns are changing significantly creating more frequent lightning strikes and natural disasters that impact the grid. Traffic accidents involving utility poles will always occur. More vehicles are being placed on the highways and roads. Animal control is always a struggle for utilities to keep squirrels, snakes, and rodents off transformers and hot conductors. Construction crews will always dig into the ground to install new infrastructures to find that their digging equipment has penetrated a power line duct. Other utility customers on the same power feeder or substation will always turn on large loads without notifying the utility. These events are beyond our control and will continue to introduce destructive electrical disturbances into the electrical systems and electronic equipment that customers depend on.

Owners of large pieces of equipment like medical imaging systems (e.g., MRI, CT, X-ray, etc.), adjustable speed drives, and copy machines will always be entered into some type of maintenance and service contracts to keep their equipment operating. Manufacturers who offer such services and service companies who are in agreement with their customers to honor these contracts must investigate equipment failures and malfunctions when their customers call. Quite a few instances involve some electrical disturbance that occurred on the building electrical system which caused equipment to fail or malfunction.

Sudden equipment failures typically involve the occurrence of voltage surges or temporary over-voltages which can damage some internal components of the front end AC line network used to protect the equipment. Surges and over-voltages can originate outside and inside a customer facility. Malfunctions typically involve some type of intermittent or recurring disturbance that causes the power supply inside the equipment to react unfavorably producing some type of DC disturbance on its output bus. High-frequency events and electrical noise can also occur on a building electrical system creating an EMI problem for the equipment.

Traditional EMI filters in older equipment still in operation may be able to mitigate a conducted disturbance ranging between 450 kHz to 30 MHz. Most new electronic loads on the grid today must meet emissions control down to 150 kHz. With the growing population of wireless devices and the increase in the wireless frequencies, new emissions control requirements will continue to reach higher frequencies well beyond what they to today. One goal of regulating emissions near and above the 1 GHz point is to maintain control of wireless signals on the AC line cord.

Disturbances that occur outside of this range may survive a trip through the filter to critical electronics inside the equipment with a high enough magnitude to cause severe malfunctions. Traditional EMI filters will not provide protection against most of the voltage surges occurring in today's electrical environment. Across-the-line (or X) and Y-capacitors (line to ground and neutral to ground) capacitors can suffer silent damage when voltage surges occur. Eventually, if the surges continue, then these capacitors will fail. The International Electrotechnical Commission (IEC) reported in 2005 that products using EMI filters being returned to manufacturers to find that the emissions levels had increased by as much as 55 dBuV. (This is a factor of 562 μV increase in noise voltage.) When such filters failed, the products continued to work with no problem except for the fact that they were injecting large levels of conducted emissions into the building electrical system. Some of the products were reported to have caused severe EMI problems with other equipment inside the buildings where they were found.

The dielectric-independent filters that use no common mode chokes and very small X- or Y-capacitors do not suffer from these problems. These filters do use a small amount of capacitance (typically in the 1,000 to 4,000 picofarad range) around each straight line pin conductor that supports the flow of AC line current through the pin. This little amount of capacitance is the only amount needed to actually provide the level of filtering needed to reduce unacceptable levels of conducted emissions. In addition, the capacitive material used around each pin has an inherent transient voltage clamping capability that acts as an internal surge protector with no metal oxide varistor (MOV) material used. The capacitive material may be removed from the filter design and substituted with an MOV material to increase the level of voltage withstand capability for surge protection. In either case, this means that no discrete MOV is needed external (upstream, downstream, or in some cases in parallel with the choke) to the filter. The elimination of a discrete MOV on the printed circuit board eliminates the failure (e,g,, thermal runaway discussed in more detail below) associated with board-mounted MOVs. These failure modes have been a growing concern to product designers for years. This mode is associated with the thermal runaway of an MOV that occurs when the AC line voltage creeps up to some value above nominal (e.g., 120 volts). The more typical MOV failure mode associated with just wearing out the MOV from repeated absorption of surge energy is also significantly reduced.

When manufacturers offer warranty programs for their products, they allocate a budget for those programs. The budget is based on an expected amount of failures given some knowledge of the performance of the equipment and a past history of failures of similar products. The questions here are "How does the knowledge of the electrical environment (or power quality), or the lack of knowledge, enter into the design of the manufacturer's warranty program? Are all of the electrical disturbances that do occur on the grid and inside a customer's facility taken into account when the warranty program is designed? Is the manufacturer experiencing any increase in failures associated with common everyday electrical disturbances? How is the manufacturer planning for a sudden increase in thunderstorms that will cause a sudden increase in equipment failures caused by lightning strikes to the grid, to the utility power distribution systems, and to customer facilities? Does the manufacturer really know the reliability of the surge protection devices (and the filter components) they use inside a piece of equipment in today's current electrical environment? Does the manufacturer need to reduce the number of warranty claims? Does the manufacturer really know the real cause of equipment failures that are logged under warranty claims? How many of these claims are related to power quality and to the level of surge protection provided by the present surge protection devices (discrete MOVs) used in their equipment designs? Can the number of warranty claims be reduced by employing a different type of EMI filter with integral surge protection instead of using discrete MOVs on the board.

SAFETY

There is no question about it — safety is of primary interest to manufacturers in the design and operation of their equipment. The use of AC line power to operate electronic equipment does present some safety concerns for customers. Leakage current is produced and can flow off the frame of equipment through the human body. Safety engineering experts have been concerned about this for years. Designers must strive to reduce the risk of electrical shock and fire caused by the operation of their equipment on the utility grid and inside customer facilities. Effective grounding and the reduction of leakage current has taken the lead in many design topics associated with safety for decades.

The fact that electrical disturbances do occur on the grid and make their way into customer facilities and electronic equipment does increase the risk of causing an unsafe condition to develop when electronic equipment is used in the presences of humans. Electrical shock from the flow of 60-hertz current through the human body has been a safety subject studied for years. Safety agencies and organizations have put standards and requirements in place to limit the flow of leakage current from an electronic load. The amount of leakage current from the 60-hertz (or power line frequency) component of ground current is a measurement requirement in safety standards for equipment. Any current that can flow from a grounded surface of a piece of equipment or a ground conductor connected to the equipment contributes to the total leakage current.

The capacitors inside EMI filters that are connected from line to ground and neutral to ground are significant contributors to leakage current. These capacitors allow currents at all frequencies with the emissions profile to flow, not just the 60-hertz components. One key disadvantage of traditional EMI filters is the presence of these capacitors in these filters and their effect on the magnitude of leakage current. In the dielectric-independent filter technology, there is a capacitance between the line and neutral. Part of that capacitance can be seen from line to ground and from neutral to ground. The advantage here is that this capacitance is very small and on the order of a few thousand picofarads or less. Thus, the contribution to leakage current from these capacitors to ground is much smaller when the dielectric-independent filters are used as compared to the larger (typically microfarad sized) across-the-line (X) and line-to-ground (Y) capacitors used in traditional EMI filters.

Another very important aspect of safety for circuit protection devices is the prevention of thermal runaway. Figures 3 and 4 illustrate examples of a metal oxide varistor (MOV) that experienced thermal runaway and ignited. These MOVs were discrete devices mounted directly on top of the circuit board with no protection over the body of the MOV. Thermal runaway occurs when the AC line voltage creeps up to a value over the maximum continuous operating voltage (MCOV) rating of the MOV. MOVs can be subjected to many high currents caused by voltage surges. This exposure which can occur in any real electrical environment causes MOV aging. In environments where surges are known to occur more frequently, premature aging can occur. Aging results in a lowering of the MCOV level. When the MCOV level is compromised, even acceptable levels of line voltage within industry standard limits can create a thermal runaway condition causing a flame and smoke on the printed circuit board. Some MOV manufacturers design their MOVs to withstand repetitive surges, but premature MOV aging can still occur in surge-rich environments — geographical areas where lightning frequently occurs and on utility feeder circuits supporting customer loads that can generate potentially high surges.

Recent power quality testing and research carried out in the past ten years on end-use equipment using MOVs and surge protection devices used in panel-mounted protection devices (e.g., surge protection modules mounted outside of a panel and encased in modules designed to be mounted in a circuit breaker slot) and power strips generated data supporting revisions to the UL 1449 – Standard for Safety for Surge Protective Devices. This resulted in new requirements for product designs to use MOVs with 130-volt MCOV ratings when equipment is designed to operate at a nominal line voltage of 120 volts. MOVs with a 150-volt MCOV rating are also available today to account for a ± 10% swing in utility line voltage specified in ANSI C84.1 (2011) – Electric Power Systems and Equipment – Voltage Ranges which nearly all US utilities follow. Although 130-volt and 150-volt MOVs cost the same, some product designers still prefer to use MOVs rated at 130 volts for the MCOV. Higher cost MOVs are available today with built-in thermal protection. Unfortunately, when an over-temperature condition is detected, the thermal protection device permanently opens one leg of the MOV removing it from the circuit. This results in the MOV being taken out of the AC line circuit, thus leaving the equipment unprotected from surges and over-voltages that occur on the AC line.

In the dielectric-independent EMI filter, much less MOV material is used internal to the filter than is used in a discrete surge protection device. In addition, the MOV material is physically protected by potting material poured around the MOV material. Further protection is provided by the electromagnetic shield that forms a complete metallic enclosure around the EMI filter. With these design characteristics, the MOV material is much less likely to become a safety concern when the AC line voltage exceeds its MCOV rating. This will allow manufacturers to avoid the use of the discrete MOV mounted in open air on the circuit board, thus providing their customers with safer surge protection inherent to the EMI filter without the risk of flame or smoke. The potting material injected around the MOV material surrounded by the metallic enclosure will increase the rate of heat transfer out of the MOV material. Testing is currently being carried out to determine this. MCOV testing can be carried out at surge currents as high as 1,000 amps.

GROWING THREATS IN THE ELECTRICAL ENVIRONMENT

Threats in the electrical environment that impact the performance of electronic equipment continue to increase. This is not because the generation, transmission, and distribution of power is getting worse (yes, the grid is aged and continues to age). Threats continue to increase in both severity and frequency because the exposure of the grid and customer facilities is increasing. How does the exposure increase? This is answered by the events that occur around the power


Figures 3 and 4. (Left and right) MOV after a thermal runaway condition occurred inside a consumer electronic device.

system and inside customer facilities that affect the power system and the quality of power inside customer facilities.

There are a number of events that continue to occur that cannot be controlled that are increasing the risk of damaging electronic equipment. Moreover, society is demanding and placing more electronic equipment in the electrical environment. Most of this equipment is being placed in areas where it is exposure is on the increase like in remote areas away from facilities closer to the utility power distribution system. End users want the modern conveniences at their fingertips. One example is the growth in the number of automatic teller machines (ATMs) in the last few years and the growth in the number of vending machines that provide users with compact video discs. Another example is in the growth of electronic lighting devices placed in customer facilities followed by these devices being placed outside on the sides of buildings and on utility power poles. Electric vehicle chargers are also being installed in a number of places remotely located to customer facilities. The growth in the number of red light cameras being placed at busy intersections is another prime example in the increase of electronic loads which are exposed to threatening electrical disturbances closer to the grid. All of these remote loads require electrical cables (power, control and signal) be buried underground. Running these cables underground forms loops which act as "collectors" of harmful voltages induced by high currents that flow underground when lightning strikes.

The growth in the number of distributed generation resources— wind turbines, microturbines, fuel cells, and photovoltaic (PV) solar systems — is causing an increase in the level of radiated and conducted emissions that impact the operation of electronic equipment on the grid and inside customer facilities. Utilities are installing millions of solid-state (smart) revenue meters to electronically record the amount of electrical energy used at each customer site. These meters can also be used to control loads inside the facility as well as report back the usage and demand data. Severe cases of EMI between solid-state meters and PV systems have already been reported in four European countries followed by several similar cases in the United States. The use of more effective circuit protection devices like dielectric-independent EMI filters with integral surge protection will increase the amount of protection provided to electronic equipment as well as decrease the threats that are caused by electronic equipment connected to the same voltage buses inside customer facilities.

The electrical environment inside customer facilities is becoming a higher exposure environment for electronic equipment as well. Many facilities are installing adjustable speed drives which increase the level of radiated and conducted emissions as well as continual degradation in the quality of the line voltage powering electronic equipment such as motors used for heating, ventilation and air-conditioning inside customer facilities. The growth in the installation in other electronic switching loads that generate electrical disturbances is on the rise as well.

STANDARDS

An array of EMC standards exist today to limit the level of radiated and conducted emissions generated by end-use electronic equipment. The limits in the standards in use today were based on philosophies developed decades ago. The limit standards in place in the United States are not near as stringent as the standards developed for member countries of European Union and other international countries. Many small signal engineers know the benefits of limiting the level of radiated and conducted emissions generated inside a piece of equipment that gets out onto the AC power line and onto data, network and control cables exiting the equipment. Signal-to-noise ratio is critical to the operation of many types of end-use equipment like electronic medical equipment designed to measure very small signals from patient–connected probes. Conducted emissions that are allowed to flow on the AC power line and through the equipment ground will impact the signal-to-noise ratio and the integrity of any small signal.

Researchers have studied and collected thousands of cases of EMI involving end-use equipment that were found to meet existing limit standards. Research must continue into the development of more stringent limits that can further improve the performance of end-use electronic equipment to combat the growing energetic electromagnetic environment. While the degree of improvement needed in limits is not yet known for most industries, researchers and product designers do agree that more stringent limits are needed to improve signal integrity and avoid an array of EMI problems as more electronic equipment comes on line in our modern digital society. The increased use of communications and connectivity to control end-use equipment and monitor the condition of the grid and the load it must support warrants the need for more stringent limits on radiated and conducted emissions.

The new IEEE 1560 standard, IEEE Standard for Methods of Measurement of Radio-Frequency Power-Line Interference Filter in the Range of 100 Hz to 10 GHz published in 2005 by the IEEE defines new test methods for measuring the insertion loss and other critical parameters associated with defining the performance of power line filters. One application of this standard that is gaining momentum is the generation of insertion loss data for traditional EMI filters. This is helping manufacturers to understand the real difference in performance for their products when they are placed in today's electrical environment. This gives rise to the importance of losses in filters and the parasitic elements in filter components that "work against filter performance" causing filters to be larger and heavier than needed. This also increases the focus on filter cost and emissions testing costs. The IEEE 1560 is also being applied to the dielectric-independent EMI filter to further gain insight to its performance comparison against traditional filters.

The development of other standards such as the basic EMC immunity standard IEC 61000-6-19 is under draft development by the IEC. This new standard will defines the test method for performing conducted disturbance immunity testing in the frequency range from 2 kHz to 150 kHz is helping to make a case for the continued control of emissions and EMI problems. This development of this standard now in progress was largely fueled by the need to avoid conducted EMI problems involving solid-state meters, specifically those EMI cases where conducted emissions in this frequency range generated by PV inverters were causing EMI problems with solid-state meters. Without the application of higher performance EMI filters like the dielectric-independent filter, it will be even more challenging to control conducted emissions in the 2 kHz to 150 kHz range and other ranges as well using traditional EMI line filters.

Research must continue on the use of integrated solutions used as integrated circuit protection devices like EMI filters, surge protection devices, current limiting devices, and thermal protection devices. This will allow protection devices to work more effectively and efficiently. Moreover, this approach will precipitate one of the most significant reductions in equipment failures and warranty claims; thus increasing the bottom line for manufacturers and their investors.

CONCLUSION

Today's EMI filters used on the AC power line to limit conducted emissions from end-use equipment are based on traditional filter designs that are years behind in design advancement. These historical designs continue to cost manufacturers millions of dollars in lost profits, limit equipment performance and allow equipment failures and malfunctions to occur that should be avoided. Settling for emissions control that is "good enough" will not allow manufacturers and end users to realize the benefits in equipment uptime and performance needed to sustain our digital society in the next few decades. End-use equipment is becoming more sophisticated and intelligent and necessitates more stringent control of conducted emissions and immunity. Products that use wireless radios will benefit from the use of new filter technologies in keeping the wireless signals off of the AC power line. Research is being conducted by the EMC engineering group at KCE Engineering, LLC located in Knoxville, Tennessee. Manufacturers who are interested in participating in this research can contact one of the authors of this article for further details.

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D. Michael Evans is a vice president of technical services at KCE Engineering. One of his areas of focus at KCE is in EMC research studying emissions profiles and the factors that influence these profiles caused by the operation of end-use equipment. Evans is also studying the application of EMI line filters in consumer, commercial, and industrial products including the design variables for filters and on printed circuit boards that affect filter performance and the reliability of end-use equipment. Evans can be reached at dmevans@kceengineeringllc.com.

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The Truth of the Matter: Surges Harm ATS and Inverters

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CONTRARY TO the popular perception that only a high-energy lightning strike can damage equipment, the truth of the matter proves otherwise. How does non-lightning damage occur?

Every day surges enter a facility via the AC power lines as a result of grid switching and other sources. These surges will not typically cause breakers to trip or fuses to operate because they are too fast and do not have sufficient energy. But their energy does exceed the maximum electrical ratings of semiconductor components used in equipment. Over time both the electrical spacings between conductors and the conductors themselves become compromised.

When the dielectric or insulator between the conductors breaks down and loses its insulating properties, the spacings are compromised because what was once a virtual open circuit is now a low resistance, unintended pathway. Failure of the spacing can also be due to arcing across the surface of the dielectric as opposed to through it. Either way, the presence of any voltage (nominal or surge) impressed on the compromised spacing can cause the conductors to bridge.

Conductor damage occurs when they've pass surge currents of sufficient magnitude and duration, resulting in changes to their molecular structure. The result is they may no longer be able to carry nominal currents and their ability to pass surge currents is greatly diminished. When tiny conductors can no longer pass the surge current, they open like a fuse. In semiconductors, constantly exceeding the maximum ratings between electrodes will eventually cause a breakdown internal to the device and subsequent failure. Surge protection prevents damage by eliminating the overvoltage and overcurrent stress caused by surges, keeping the components within their safe operating voltage region. Today's smaller and more densely packaged electronics are more susceptible to damage from surges than ever.

A common example of equipment highly susceptible to damage by surges is control boards in unprotected Automatic Transfer Switches (ATS). The ATS is one of the first components connected to the distribution transformer, consequently it receives the full brunt of the surge. Downstream equipment receives less of the energy due to dissipation and fanning out of the surge. (But it's unwise to be lulled into a false sense of security regarding equipment deep in the system. See "Data Line Protection Considerations," sidebar.) On one particular ATS

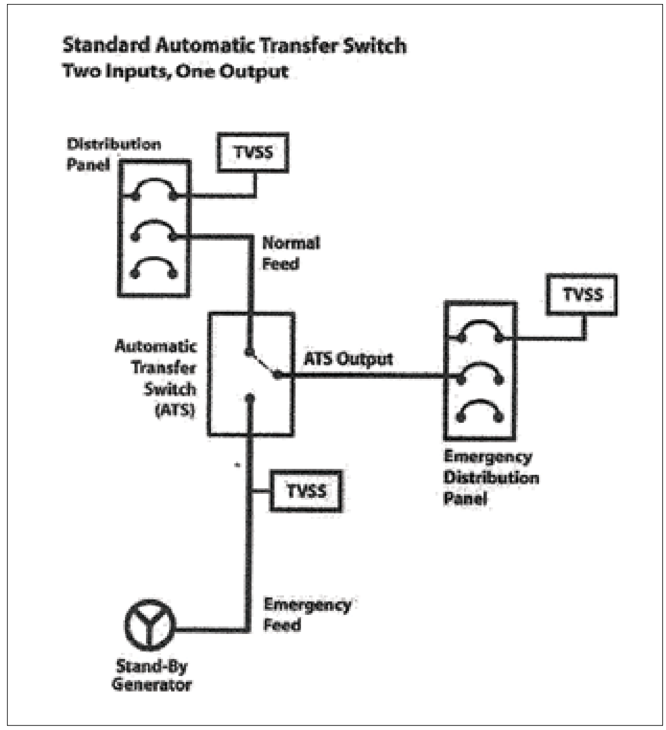

Figure 1. Location of SPD (TVSS) for Automatic Transfer Switch and Critical Load protection.

application, a control board was working fine for about six months and then suddenly it ceased to function. The control assembly was visually inspected and no damage was observed. Closer electronic inspection and troubleshooting revealed that two integrated circuits had shorted out. Not only did the two components cease to operate, they dragged down the entire DC bus leaving the other surviving components without sufficient power to perform vital functions.

Such a scenario is a costly predicament because the assembly has to be replaced and, until such time, the switch will not operate. It is of note that this event occurred in a part of California where lightning activity is not that common. The cause of the failure was attributed to utility switching surges, which occur on a daily basis. A utility switching surge may be caused by actual utility company switching or the operation of and powering up/down of heavy machinery (e.g. foundries, presses, cranes, and conveyors) from your grid-connected neighbors. A new control board costs $4,000.00, excluding installation. Add downtime costs at the businesses serviced by the Automatic Transfer Switch and the real cost of surge damage emerges. And, unless surge protection is applied, odds are that the replacement board with fail just as the original board did. Unlike the occasional lightning occurrence in this geographical area, utility surges are repetitive and will show up on a regular basis. Less visual drama, but more insidious damage.

To put it into perspective, think about ESD (Electrostatic Discharge). ESD is a form of surge, albeit a lower energy one. However, many components are sensitive to ESD and can be damaged by virtue of improper handling alone. For example, someone carrying an integrated circuit picks up an ESD charge then hands the component to someone else. A tiny spark occurs which is caused by both subjects being at a different voltage potential — possibly even as much as a 15 to 30kV difference. The energy in this spark is sufficient to cause damage to integrated circuits and other sensitive semiconductor devices before the component is even put into the assembly and powered up. During a surge event, a powered component already carrying the load of its nominal voltages and currents is now required to handle superimposed surge voltages and currents that it was not designed to address. Thus, it does not take much energy to cause damage and render equipment nonoperational.

The ATS is the gateway of power to the facility and all power to critical loads flows through it. The ATS passes both utility (normal) power and generator (emergency) power and automatically switches from utility to generator power should the utility power go off. If the ATS goes down, the facility power feed will be disrupted. Given the cost to replace such an assembly as well as loss of revenue caused by the damaged switch, it's imperative to protect this critical piece of hardware. See Figure 1.

Equipment failure is common but can be prevented by making a onetime, appropriate surge protection device (SPD) purchase. Use an AC protector on the ATS's Normal input with a surge current rating of 160,000 Amps per phase minimum. Depending on service size and lightning frequency, a heftier unit may be required due to the higher surge energy it will experience. Smaller capacity protectors are required on the Emergency Panel and the Emergency

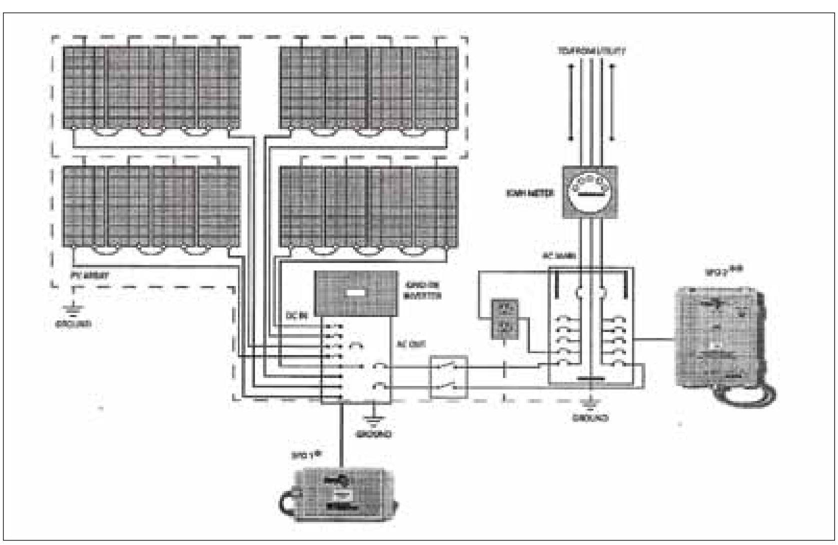

Figure 2. Protector locations for protection of inverter and AC panel loads.
*SPD 1 protects inverter's DC Input
**SPD 2 protects inverter's AC Output and Panel Loads

feed to protect those areas as well. Doing so eliminates loss of revenue and ongoing replacement of damaged hardware. Easy to install, quality surge protection equipment is designed to outlast the very equipment it is protecting. It is not uncommon for a properly designed surge protective device to last more than 20 years. Whether your equipment is subject to dramatic nearby lightning events or the insidious repetitive surges, employing appropriately-rated SPDs will ensure that your equipment realizes its design life and functions reliably for many productive years. "Appropriately-rated" means that the protector is designed to repeatedly handle the surges at a given location for decades. Avoid using poor quality or under-rated surge protectors as this will result in poor results and higher costs in the long run. Correctly choosing a protector is easily achieved by contacting a surge protection applications engineer.

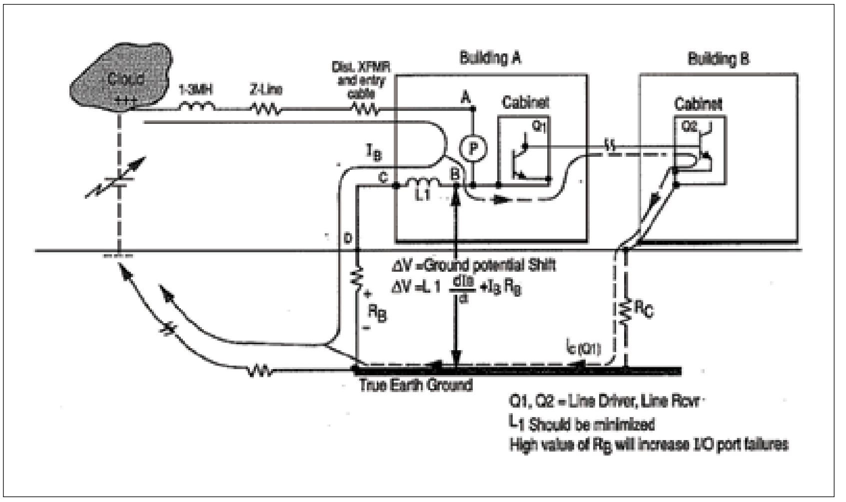

Figure 3. Ground potentional shift due to lightning current I1B.

Like an ATS, an inverter is also the gateway of power, but for solar power or photovoltaic systems. Solar generated power flows into the inverter and is converted from DC voltage to AC voltage. To protect this device, a DC surge protector on the inverter's input is required and an AC surge protector on its output, especially if it is a Grid Tie inverter since they are always exposed to surges from the utility grid. Figure 2 shows is an example of how to protect a Grid Tie inverter. Note that the AC protector's function is two-fold as it also protects the AC loads wired to the panel.

DON'T FORGET DATA LINE PROTECTION

Figure 3 shows a typical example of damage caused by surges on data lines. A network switch is seemingly operating smoothly, until it's not. The culprits are high-speed transients caused by differences in ground potential between the ports, represented by transistors Q1 and Q2.

To address this problem, adding data line surge protection at the equipment at each end of the connecting cable protects the equipment at both locations. These protectors typically use RJ45 connectors, so installation is five minutes or less. Some installations may require protectors with screw terminals or IDC (insulation displacement connectors) like an IDC110 block, which are readily available. Installing data line protection prevents an entire network-connected department from sitting idle because it cannot connect to the Internet.

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Extend Your PI, SI and EMC Requirements to Enable Profound Modular Mechatronic Designs

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MECHATRONICS means: mechanics combined with electronics. The amount of electronics involved in mechatronic systems is constantly increasing. The required precision, speed and stability of mechatronic systems is co-determined by the reliability of all kind of sensors with electronics, embedded controllers and pulse width modulated (PWM) motion drives with increasing performance and bandwidth.

To ensure a correct and safe operation of the electronics involved, parameters like: power integrity (PI), signal integrity (SI) and electromagnetic compatibility (EMC) need to be addressed. When building modular mechatronic designs, 'inter-system' EMC is usually specified whereas PI and SI are normally not addressed at all. However, when building modular mechatronic sub-systems, intra-system PI, SI and EMC requirements have to be addressed to ensure reliable operation at the required performance level. When mechatronic systems are built together in such a way that their AC or DC supplies are situated far away from where it is needed by the loads, PI and SI will be affected quite easily. An example is the on-switching of 'green' (more energy efficient) electronic driven power relays (see figure 1), which draws instant current of tens of amps over tens of microseconds (see figure 2).

Though the initial charge required is limited, the supply voltage will collapse shortly. To sustain the relay in its closed position, a hold current of just a few tens to a hundred mA is drawn, resulting in less energy being consumed. Operationally, the relay contacts are switched much faster (thus resulting in less arcing on the contacts) but leading to much higher voltage and current transients: dV/dt or di/dt's, at the load side [1, 2]. With conventional electro-mechanical relays, the current through the relay coil inductance increases smoothly when it is connected to its supply. A freewheel diode, transient voltage suppressor (TVS) or snubber (RC-network) is used to clamp the coil's reverse voltage when switched off (see figure 3.) Similar measures are internally applied with the electronic driven power relays. Mechatronic relays are used over solid-state relays as they can handle higher currents and they suit electrical safety with respect to the required insulation over open contacts.

Instant transients occurring on an AC distribution system couple onto the DC distribution network which supplies: active sensors, embedded controllers and motion

Figure 1. Example of an electronically driven power relay.

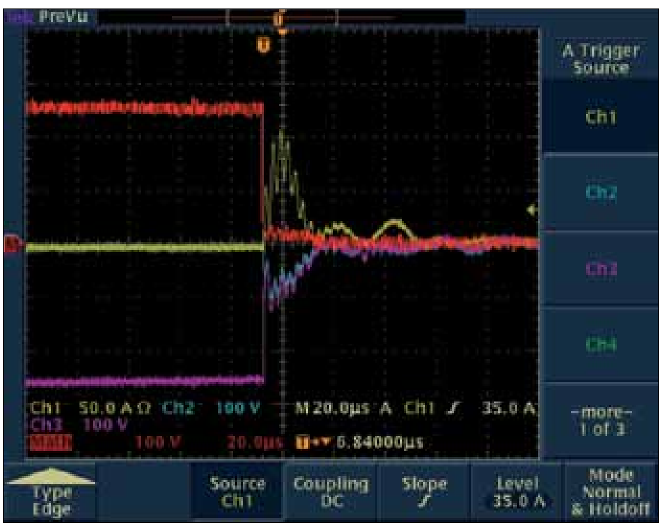


Figure 2. Peak start-up current of electronic driven power relay [yellow curve].

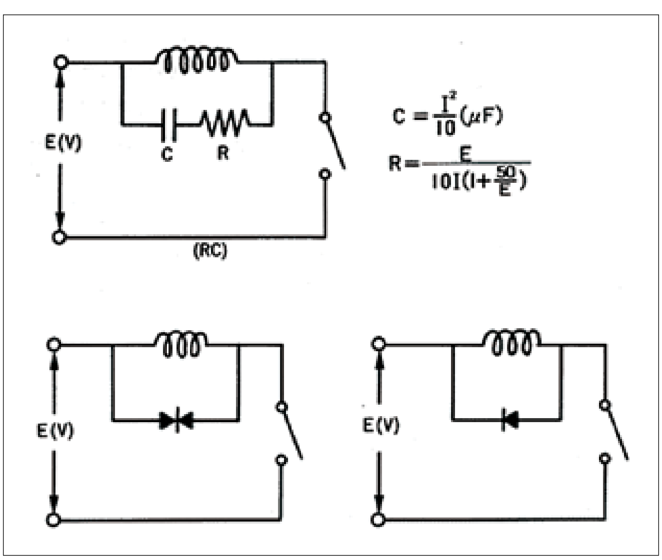


Figure 3. Different voltage clamping techniques.

drives. Depending on the AC/DC converter(s) used for supplying these active sensors, the noise suppression i.e. attenuation from AC-input to DC-output is not specified by the AC/DC converter supplier (as there is no international standard describing the required test methods and its requirements yet). With most electrical safety Class II (= double or reinforced insulated without PE connection) AC/DC converters or poorly grounded Class I converters (= basic insulation with PE connection), these transients are nearly 1:1 coupled from the AC input onto the DC output, due to the internal filtering components used (necessary to satisfy inter-system compliance of the converter itself). From well-designed AC/DC converters, either Class I or II, an RF attenuation of 60 dB (a factor of 1000) or more between input and output can be expected. But even in these design cases, transients of 1000 Volt on the AC-mains are still passed onto the DC-output at a level of 1 Volt. In accordance with the specification of an AC/DC converter manufacturer only an AC ripple in the order of 10 - 200 mV is specified [7], when measured in a 20 MHz bandwidth. Measurements of voltages and currents transients with less bandwidth won't be able to show these levels.

When a sensor system gets these 1 Volt transients on its supply, differentially or in common-mode, it will be determined by the power supply rejection ratio (PSRR) and the inner front-end design of the sensor (where often μV's or less are obtained from a physical transducer, which requires 10^6 - 10^9 (120 - 180 dB) or more attenuation from signals occurring elsewhere in the system) how it will react. If it is a single switching event, filtering by hardware or software can help to suppress the false data that is coming out of the sensor system. When using PWM driven applications, either at low-voltage DC or driven from the AC mains level, the resulting noise induced on the low voltage DC supply distribution network will be repetitive (see figure 4). When non-shielded or falsely applied shielded cables are partly routed in the same cable trays, the induced voltages may even be higher. At the motor i.e. load side, often non-filtered PWM switching voltages and currents occur. With a single phase AC-supplied PWM drive system, the internal DC-bus voltage becomes 360 Volt and the peak-peak voltage at the load may exceed 1000 Volt by cable reflections occurring, see figure 4. These repetitive PWM signals also couple onto the rotor shaft, rotating in its grease insulated bearings, which then couples onto the encoder. One of the mechanical aspects of these high voltage transients occurring is bearing corrosion due to arcing through the grease film in the bearings (see figure 5).

The coupling from cables onto other cables is determined by the electrical and magnetic fields stemming from these cables. Solutions to reduce coupling can serve both ways, as cables are passive networks and as such reciprocal. When the sum of all signal currents are confined to the inner wires, the resulting external magnetic fields will be low. Fulfillment of this condition can be easily measured as the common-mode current on such cables as a whole will be 'zero'. Electric fields can easily be minimized by connecting

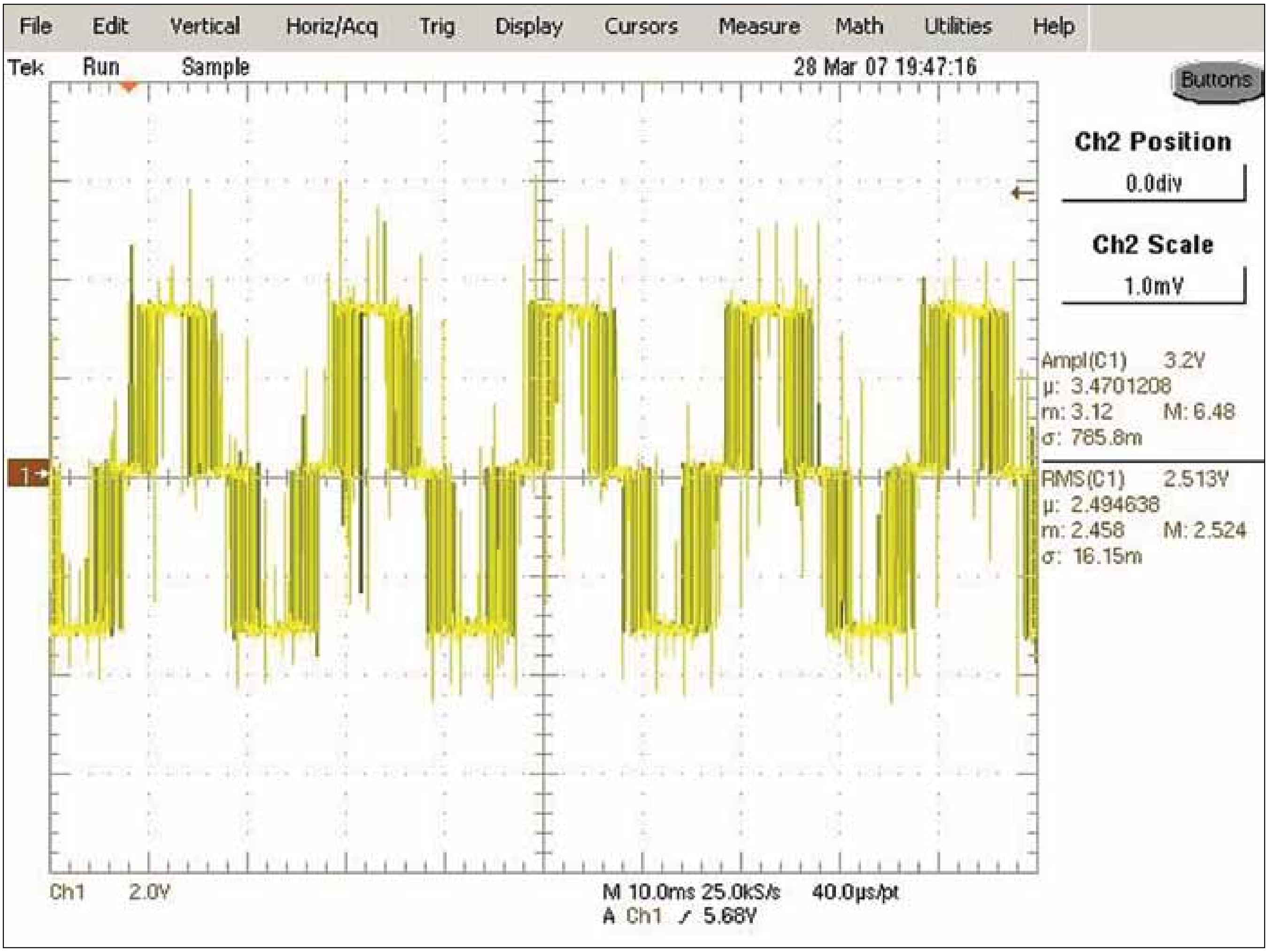


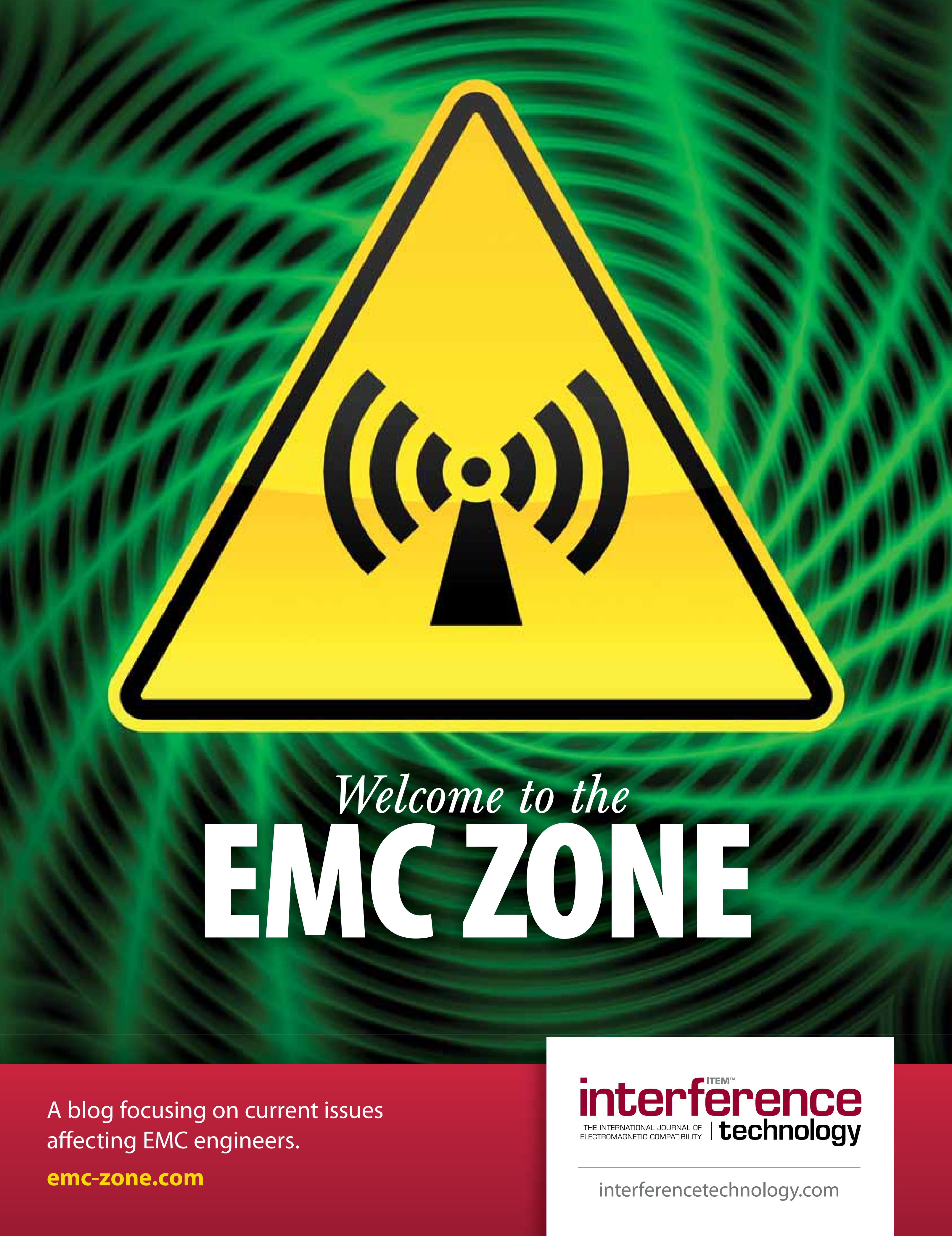
Figure 4. Example of voltages occurring on a PWM driven motor, measured against PE using an external 1:100 differential probe [9].

the cable shield to the reference terminals belonging with the circuit, which often is not the ground or protective earth (PE) terminal of the (sub-)system's enclosure.

Cable screens shall be electrically connected through their connector shells to the enclosure connected to. This electrical connectivity is determined by the various surface treatment of the metals used. Powder coatings, anodized aluminum, commonly used from a mechanical and/or an esthetic point of view, are providing one of the best electrical insulators. Using stainless steel thread inserts, which are glued into an aluminum frame, extends this non-conductivity.

Most, if not all, of the AC/DC converters, PWM motion drive systems are switching in the frequency range of 2 – 150 kHz as being an free zone for RF emission in EMC legislation. Most active inductive or capacitive sensors operate in the same frequency domain, also to avoid any formal legislative EMC immunity requirements. Even temperature and strain gauge sensors have a front-end sensor bandwidth over 20 kHz and often suffer intra-system immunity issues, though being inter-system compliant. The likelihood in having unintended interaction in a modular mechatronic system design is increasing progressively. Unintended cou-

Figure 5. Example of bearing corrosion as a result of transient arcing.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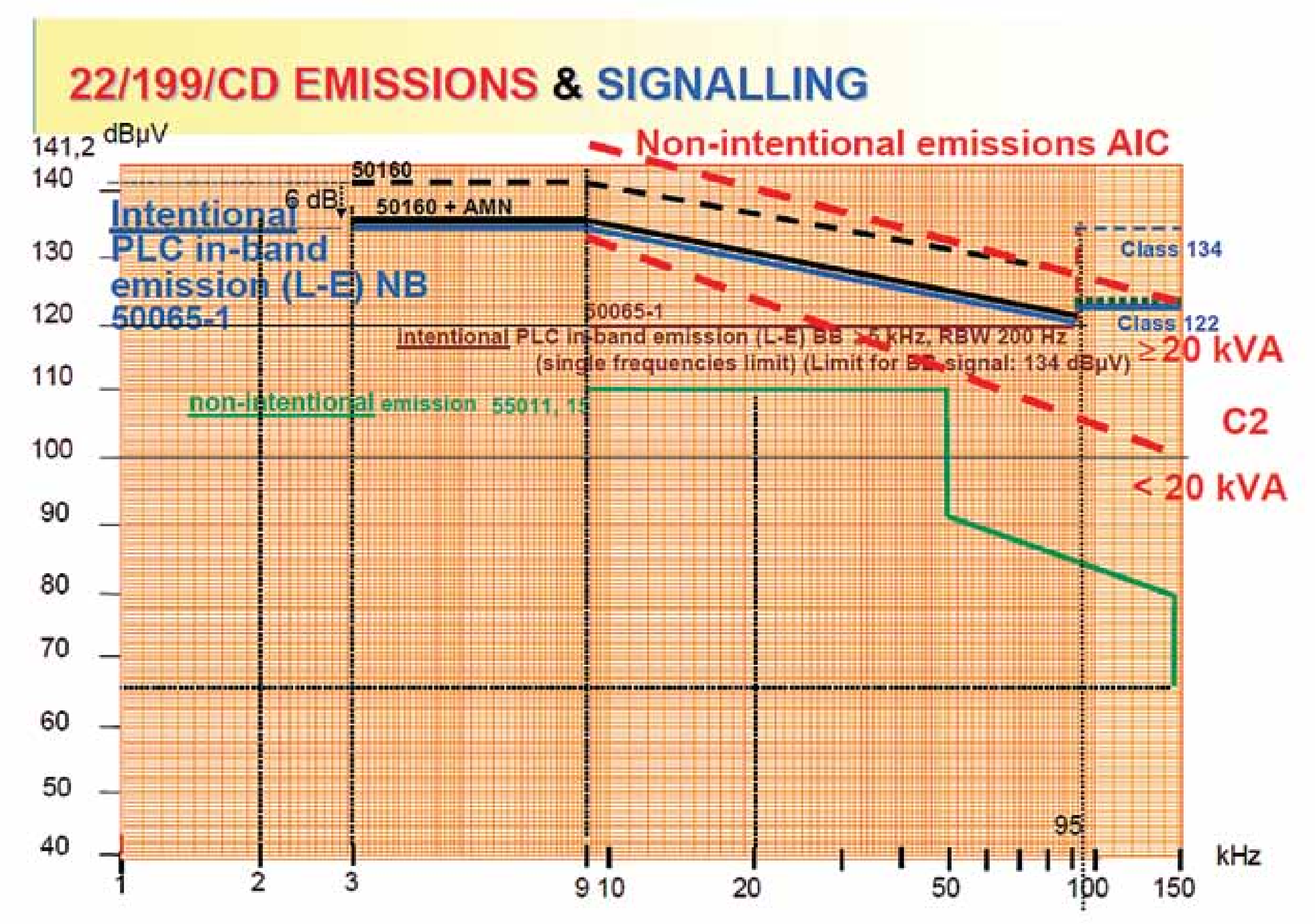

Figure 6. Summary of observed LF differential voltages on mains wires in industrial installations (excerpt from a working group document IEC 22/199/cd).

pling may occur through: air (E/H-fields), via mechanical frames (common-impedances) or result from cables running in parallel (crosstalk) which cannot be resolved by simply adding an opto-coupler somewhere along the signal path. It is unpleasant when your car's motor management system can't detect or recognize the contactless key anymore when the roof of your convertible is closing while driving.

All this requires an extended conceptual approach, with additional specifications, to anticipate to such interaction by 'selection' and/or 'design', A CE-mark on a sensor system or PWM drive product doesn't add anything to the avoidance of intra-system issues. These considerations shall be extended beyond the boundaries of the sub-system, in particular when the sub-system is part of an even larger system which adds additional constraints (and should be made clear to all parties/suppliers involved).

International standardization, work is progressing to close the non-regulated gap between 2 and 150 kHz. The mains harmonic disturbances up to 2 kHz are legally covered by reference 3 (up to 16 A/phase) and by reference 4 (up to 75 A/phase). Recently, an inventory document has been written with respect to the many signals that appear most severely in this frequency band, see figure 6 [1, 2]. In parallel, work is already progressing in CENELEC's sub-committee 205 and IEC TC77A by writ-

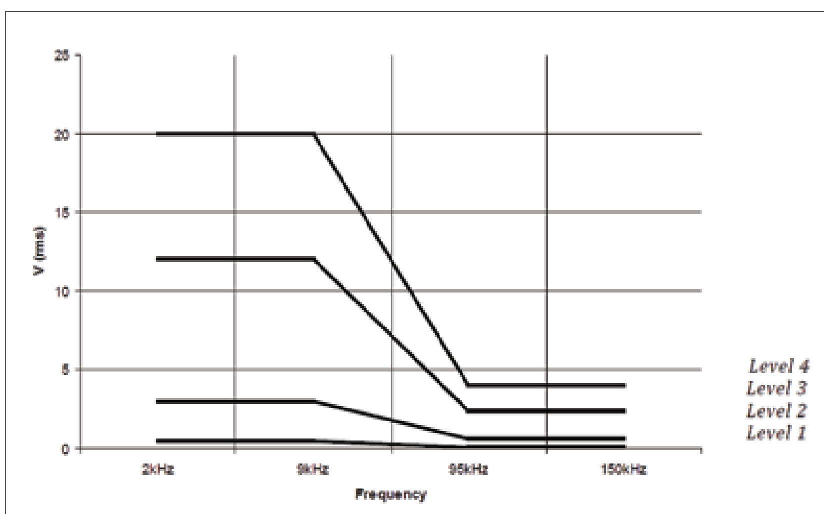

Figure 7. Proposed LF immunity requirements to conducted, differential mode disturbances in the frequency range from 2 - 150 kHz at AC mains ports [7].

ing new proposals on how to perform and apply immunity tests uniformly, see figure 7 [5, 6, 8]. The levels are taken again with some margin over those given in figure 6. Care shall however be taken with these out coming documents as again only inter-system issues are being addressed while intra-system effects are being ignored and left over to the modular mechatronic system designers.

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- [9] Private correspondence with Block Transformatoren GmbH, Verden, Germany

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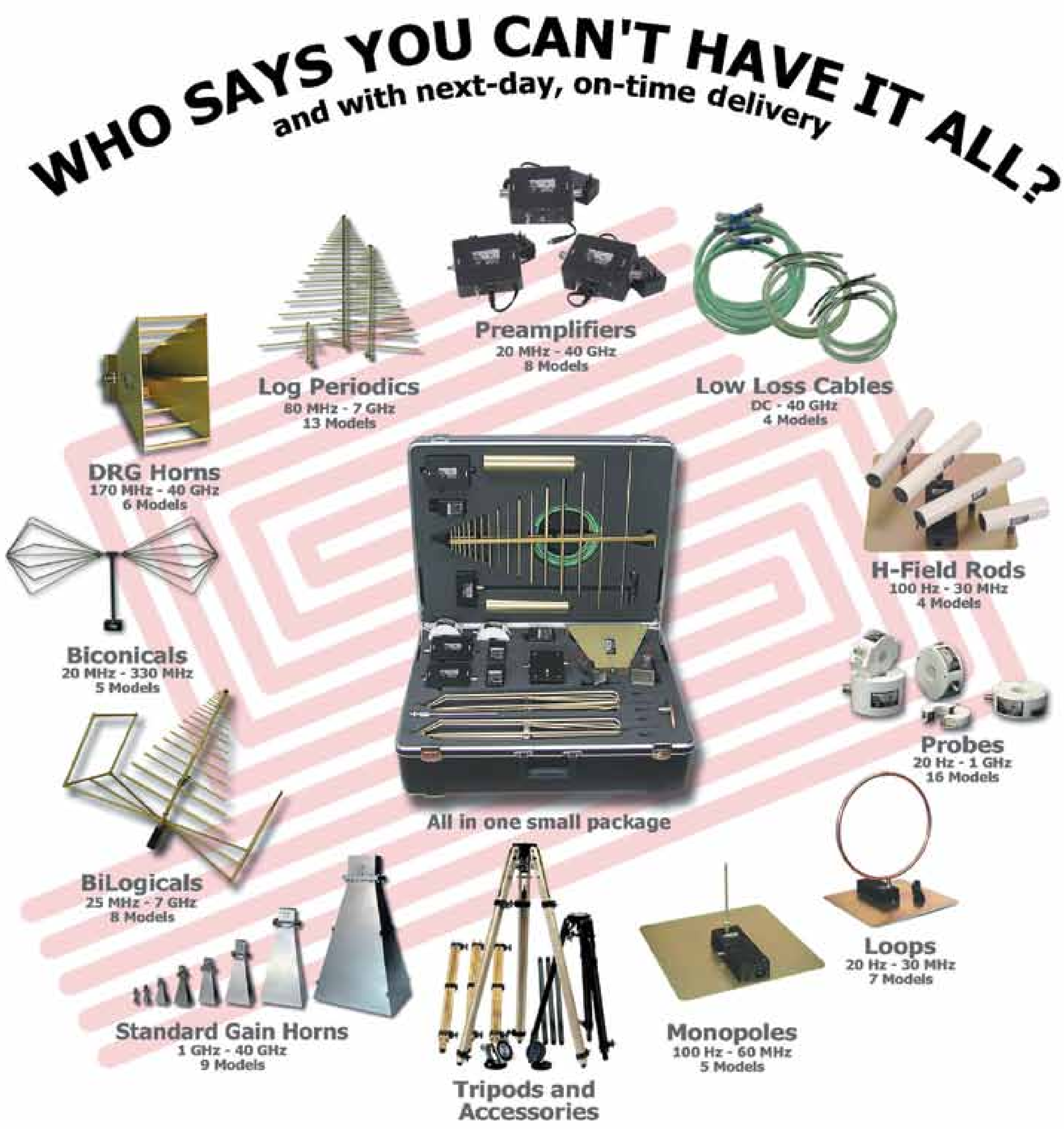
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