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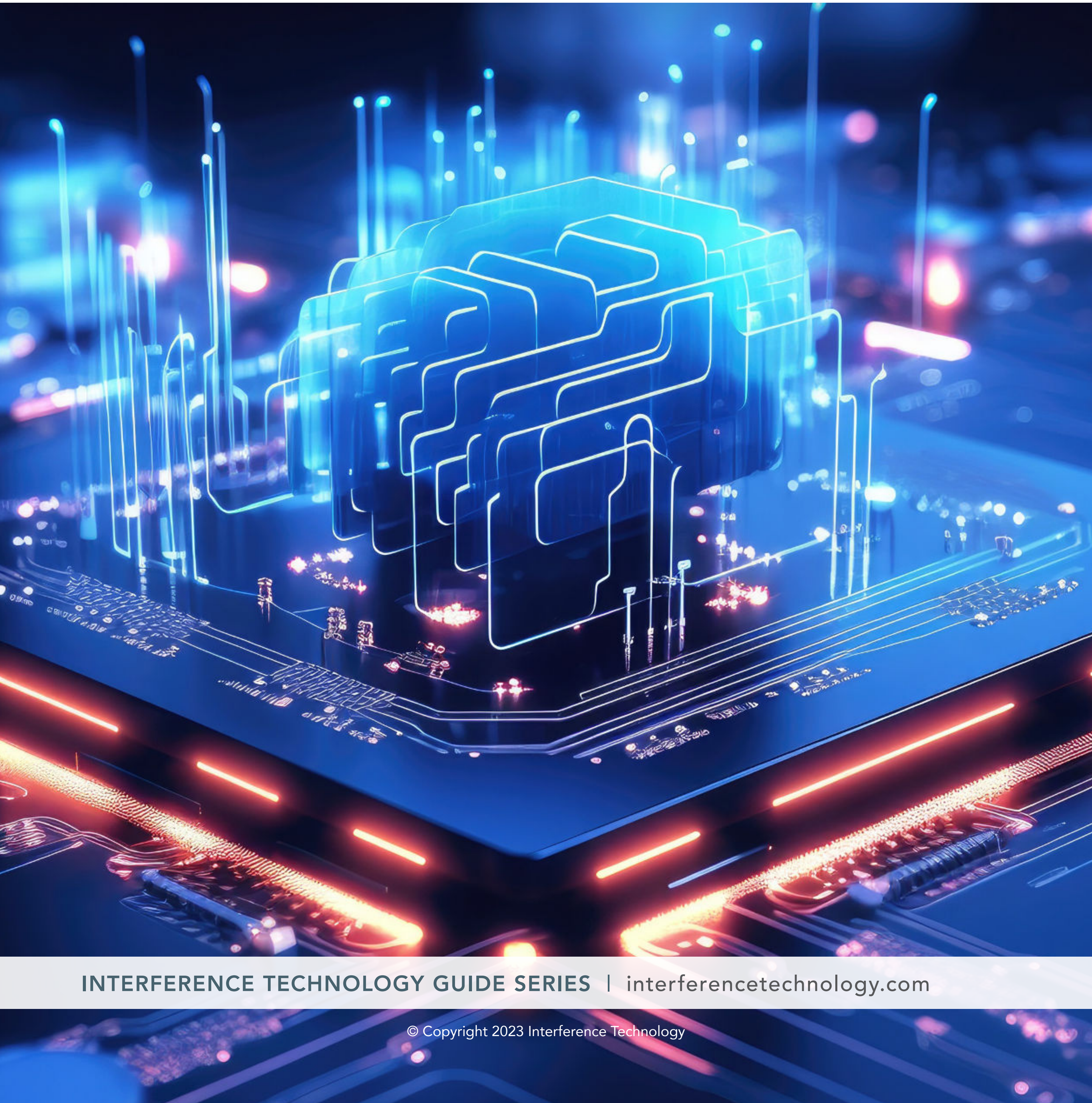
2023
IoT, WIRELESS, 5G EMC GUIDE



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REFERENCE GUIDE
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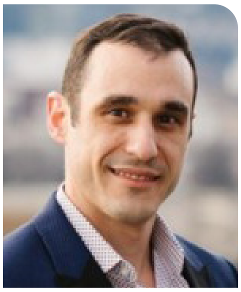
TECHNICAL EDITORIAL BOARD MEMBERS

Meet the 2023 Editorial Board

GHERY PETTIT | PRESIDENT, PETTIT EMC CONSULTING LLC

Ghery S. Pettit received the BSEE degree from Washington State University in 1975. He has worked in the areas of TEMPEST and EMC for the past 47 years. Employers were the US Navy, Martin Marietta Denver Aerospace, Tandem Computers and Intel Corporation, prior to retiring from industry in 2015 and becoming an independent consultant.

Mr. Pettit is presently serving as Chair of CISPR SC I and is one of CISPR's representatives on the Advisory Council on EMC (ACEC) within the IEC. He has been involved in CISPR activities since 1998, both as a member of the US Technical Advisory Groups to CISPR SC G and CISPR SC I and as an active member of CISPR SC I and its maintenance teams, CISPR SC I MT7 (CISPR 32 maintenance) and CISPR SC I MT8 (CISPR 35 maintenance). He is also a member of the working groups preparing the next editions of ANSI C63.4, C63.9 and C63.16.



ZACHARIAH PETERSON | NORTHWEST ENGINEERING SOLUTIONS

Zachariah Peterson received multiple degrees in physics from Southern Oregon University and Portland State University, and he received his MBA from Adams State University. In 2011, he began teaching at Portland State University while working towards his Ph.D. in Applied Physics. His research work originally focused on topics in random lasers, electromagnetics in random materials, metal oxide semiconductors, sensors, and select topics in laser physics; he has also published over a dozen peer reviewed papers and proceedings. Following his time in academia, he began working in the PCB industry as a designer and technical content creator. As a designer, his experience focuses on high-speed digital systems and RF systems for commercial and mil-aero applications. His company also produces technical content for major CAD vendors and consults on technology strategies for these clients. In total, he has produced over 2,000 technical articles on PCB design, manufacturing, simulation, modeling, and analysis. Most recently, he began working as CTO of Thintronics, an innovative PCB materials startup focusing on high-speed, high-density systems.

He is a member of IEEE Photonics Society, IEEE Electronics Packaging Society, American Physical Society, and the Printed Circuit Engineering Association (PCEA). He previously served as a voting member on the INCITS Quantum Computing Technical Advisory Committee working on technical standards for quantum computing and quantum electronics. He now sits on the IEEE P3186 Working Group focused on Port Interface Representing Photonic Signals Using SPICE-class Circuit Simulators.

TECHNICAL EDITORIAL BOARD MEMBERS

Meet the 2023 Editorial Board

MIKE VIOLETTE | iNARTE CERTIFIED EMC ENGINEER

Mike is President of Washington Laboratories and Director of American Certification Body. He has over 35 years of experience in the field of EMC evaluation and product approvals and has overseen the development of engineering services companies in the US, Europe and Asia. Mike is currently on the Board of Directors of the IEEE EMC Society.

He is a Professional Engineer, registered in the State of Virginia. He has given numerous presentations on compliance topics and is a regular contributor to technical and trade magazines.

DAVID A. WESTON | iNARTE EMC ENGINEER

David A. Weston is an electromagnetic compatibility (EMC) consultant and certified National Association of Radio and Telecommunications Engineers (iNARTE) EMC engineer at EMC Consulting Inc. Merrickville, Ontario, Canada. A life member of the Institute of Electrical and Electronics Engineers, Weston has worked in electronic design for 55 years, specializing in the control, prediction, measurements, problem solving, analysis, and design aspects of EMC for the last 44 years.

He is the author of the third edition of the 1,157-page book Electromagnetic Compatibility, Methods, Analysis, Circuits, and Measurement published by CRC press in 2017, as well as numerous papers of a practical nature.

WIRELESS & IoT EMC SUPPLIERS MATRIX

INTRODUCTION

There are two main categories of equipment in this handy supplier guide: EMI troubleshooting & measurement equipment and direction finding equipment.

EMI troubleshooting and measurement equipment includes spectrum analyzers, near field probes, current probes, antennas, and other pre-compliance equipment.

Direction finding (or DFing) equipment usually includes specialized portable, mobile, or base station spectrum analyzers with custom antennas and mapping software especially designed for locating interfering sources.

Wireless & IoT EMC Supplier Matrix		Type of Equipment								
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Current Probes	Fixed DF Systems	Mobile DF Systems	Near Field Probes	Portable DF Systems	Pre-Compliance Test	Spectrum Analyzers / Receivers
360Compliance	www.360compliance.co/								X	
Aaronia AG	www.aaronia.com	X	X		X	X		X	X	X
Alaris Antennas	www.alarisantennas.com		X							
Anritsu Company	www.anritsu.com		X							X
Avalon Test Equipment Corp	www.avalontest.com	X	X	X		X	X		X	X
CommsAudit	www.commsaudit.com/products/		X		X	X				X
Doppler Systems	www.dopsys.com		X		X	X		X		
The EMC Shop	www.theemcshop.com	X	X	X			X		X	X
Gauss Instruments	www.gauss-instruments.com/en/									X
Intertek	www.intertek.com								X	
Kent Electronics	www.wa5vjb.com		X							

Wireless & IoT EMC Supplier Matrix		Type of Equipment								
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Current Probes	Fixed DF Systems	Mobile DF Systems	Near Field Probes	Portable DF Systems	Pre-Compliance Test	Spectrum Analyzers / Receivers
Keysight Technologies	www.keysight.com						X		X	X
Morcom International	www.morcom.com/direction_finding_systems.html							X		X
MPB srl	www.gruppompb.uk.com		X	X					X	X
MVG, Inc	www.mvg-world.com/en		X				X		X	
Narda/PMM	www.narda-sts.it	X	X						X	X
Pearson Electronics	www.pearsonelectronics.com			X						
RDF Antennas	www.rdfantennas.com							X		
RDF Products	www.rdfproducts.com				X	X				X
Rhotheta America	www.rhothetaint.com				X	X		X		
Rigol Technologies	www.rigolna.com			X			X		X	X
R&K Company Limited	www.rk-microwave.com	X								
Rohde & Schwarz USA, Inc.	www.rohde-schwarz.com/us/	X	X	X	X	X	X	X	X	X
Siglent Technologies	www.siglentna.com						X			X
Signal Hound	www.signalhound.com			X						X
SPX/TCI	www.spx.com		X		X	X		X		X
SteppIR Communication Systems	www.steppir.com		X							
TechComm	www.techcommdf.com		X		X	X		X		X
Tektronix	www.tek.com					X	X	X	X	X
Teseq	www.teseq.com/en/index.php	X		X					X	
Thurlby Thandar (AIM-TTi)	www.aimtti.us								X	X
TMD Technologies	www.tmd.co.uk	X								
UST	www.unmannedsystemstechnology.com/company/marshall-radio-telemetry/							X		X

A SHORT PERSPECTIVE ON OUR INDUSTRY: IoT, WIRELESS AND SECURITY

Mike Violette, P.E
President, American Certification Body and Washington Labs

Progress works out to be about 20 dB/decade, a familiar slope in our trade.[1]

INTRODUCTION

The term "The Internet of Things" is a concept that went from a novel (like Bitcoin or Streaming or something similar) to a phrase that is as household as a Spying Siri or an Alert Alexa.

Way back, when I was a green engineer, the nominal upper frequency for testing of PCs and the like was 1 GHz. System clocks ticked along at a blistering 25 MHz. Jump a generation and the talk is in the THz, which is a nominal 1000-fold increase in frequency, or to the logarithmically inclined, an increase in 60dBGHz which works out, throughout my career, an increase of about 20dB/decade indicating an exponential increase in operating frequencies, which goes with a plethora of design challenges, ever higher data rates, spectrum expansion and the potential for interference, not to mention the need to making measurements of this stuff.

Staring at the green pre-LED phosphor-painted wiggles on our trusty HP 8568 spectrum analyzer, we didn't see much "up there" as most of the mush from the early machines of the x86 family of microprocessors petered out above a few hundreds of MHz. (Historical note, initial versions of Intel's offerings appeared as 8086 and 8088.

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[1] For the mathematically pure, this is not a correct use of the decibel. The next decade, in years, is 10X the current year or about the year 20220, but what the hey, mixing meanings here, is the author's prerogative.

The 4044 being the first commercially-available 4-bit µP As the speeds/densities increased, Intel released models numbered 80286, 80386 and 80486 and finally said "Heck with it, let's stop at '5' and call it PENTIUM.) Of course, this was about 26 dByears ago (refer to previous footnote regards liberal use of the dB acronym), as many advances in processor technology have occurred. Currently, the Pentium product is nominally an entry- to mid-range processor—Intel's "Core" offerings are the current high-end data workhorses.

Now, embedded designs, agile software-defined radios, multi-function chipsets and networked solutions are the norm.

Interference Technology's **IoT, Wireless, 5G EMC Guide**, at it's surface covers a few topics, namely some thoughts on the Internet of Things, Wireless, and Security—all things that designers, test houses/compliance professional/systems planner have to contend with. The convergence of these ideas and notions has happened amazingly quickly.

The current generation of IoT consists of numerous applications, from asset-tracking to inventory control, Earth sensing and geo-location. We have a client that uses low-data rate array of sensors to communicate with a Low Earth Orbit (LEO) satellite constellation. The ground-based sensors use Ground Penetrating Radar (GPR) to image the dirt underneath. These data are relayed to the satellite to provide the image data to geo-physicists for research and exploration (beats digging up the planet, I guess, and is nominally less intrusive than explosive-based seismic monitoring or brute-force prospecting). This particular application uses a very low bit rate and burst communications to the satellites, a good example of "Internet of Space" and the application of sensing to IoT.

On the opposite end of the "spectrum of use" so-to-speak are the SATCOM networks used for broad-access broadband internet communications, useful in our busy e-commerce environment and appealing to Tik-Tokers the world-over (and yes, I am guilty of hours of "swiping up" to the next silly video). Various contenders use LEO and GEO orbits for data delivery.

IoT is a medium of many forms and, really, has been around for many decades. Expect more…

Wireless Applications are proliferating profusely. 5G is pretty common nowadays and rapidly spreading. 6G is next (and being adopted in various guises)—the "G" having nothing to do with frequency, but about performance metrics, data delivery and access, and marketing. The exciting part of this area of technology is the upper-push into the GHz+ space. Various stakeholders are working and competing in this arena are across the industry and government. One common link to these activities is the mmWave Coalition https://mmwavecoalition.org/ which is an advocacy group for spectrum access for industry and academia. Incumbents include government users and space-exploration advocates. Careful accommodation of the various users of the spectrum is a key goal.

The tricky part of these frequencies are the milli-meter wave measurements that need to be quantified (for performance and regulatory purposes). As a test lab, we are continuously challenged to make the most-accurate measurements possible. The real tricky part of these measurements are the very fine-beamwidths that are affiliated with the physics of the propagation of small-wavelength signals (and noise). Tiny displacements of device arrangement and measurement probes make a huge difference in performance and quantification. I think of these subtleties as the precision needed to focus a magnifying glass to a fine point to scorch a leaf or burn a piece of paper. Millimeters matter.

Layered atop these implementations of IoT and wireless application are the real concerns about security. The actions of bad-actors, state-sponsored and sophisticated bandits, lays a heavy cold blanket atop the promise of more access and functionality of our data-driven world.

For device suppliers with a European market (CE Marking, UKCA), a cyber-requirement is emerging under the Radio Equipment Directive (RED). The implementation of cyber-protections is emerging and will require compliance with Article 3.3(d), (e) and (f). A useful guide can be found here: https://ec.europa.eu/docsroom/documents/33162.

CONCLUSION

EMC, in its traditional sense, has morphed to cover layers of the physical and software world. As the world becomes more complex and intertwined, the EMC engineer needs to be a "Swiss-Army" engineer with multiple tools to assist clients and maintain proficiency in our fast-changing industry.

TECHNIQUES FOR MITIGATING INTRAPAIR SKEW-INDUCED EMI WITH SHIELDED CONNECTORS

Zachariah Peterson
Owner, Northwest Engineering Solutions LLC

INTRODUCTION

EMI stands for electromagnetic interference. There are several methods of EMI transmission from the source to the victim. Two of them are radiated EMI and conducted EMI. Radiated EMI happens when an electrical device produces an RF signal that is picked up and causes unwanted effects. Conducted EMI is unintentional energy carried out of the source via signal cables or PCB traces. Common sources include antennas, RFICs, power supplies, and transmission lines.

Adverse effects of EMI include passing or failing regulatory emissions tests and neighboring antenna sensitivity. Common solutions include shield coverings, EMI absorbing materials, ferrite chokes, and grounding clips. The disadvantages of these solutions include cost, space, and increased time on labor and assembly.

Over the past 40 years, EMC requirements have evolved. In 1985, Cray made the world’s most powerful supercomputer. Today, that computing power resides in today’s smartphones, tablets, and portable computers. In 1985, system-level shielding for a typical desktop computer was sufficient. Today, that computing power resides in your hand. External cables have been cut and radiating structures, like antennas, have been added. In 1985, we did not see much need for component-level shielding for interconnects. Today, many devices require fully shielded solutions to isolate radiating sub-sections from one another.

CABLE ASSEMBLIES

How do cable assemblies specifically affect EMI? To answer that question, we will need to investigate the components of the cable assembly, namely the cable construction and the connectors on the ends. There are two common types of unshielded cables, discrete wire and twisted pair. Since neither has shielding around the conductors, the EMI radiation is unhindered.

Shielded cables mitigate EMI by wrapping a shield around the conductors. Two common examples are Micro-Coaxial Cable and shielded twisted pair. Shielding the cable helps with direct radiated emissions from the cable, but mismatches in differential pairs also exacerbate EMI. This is referred to as intrapair skew.

Intrapair skew is the timing difference between the positive and negative signal lines within a differential pair. It is caused by mismatches in electrical length or unequal propagation delays. Shown in *Figure 1* are E-field plots of a cable assembly. The left has a match differential pair and the right has a four millimeter mismatch within the pair. The length mismatch causes intrapair skew and a much larger electric field.

ZENSHIELD CONNECTOR

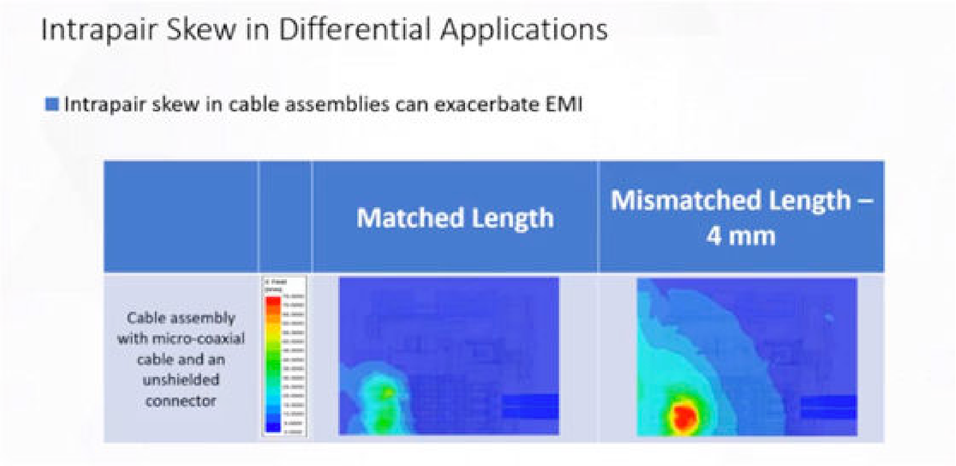
What is the solution? Using a fully-shielded connector. Not all connectors that have a shell or shield will work. The shield needs to completely surround the signal contacts in order to contain the electric fields.

At I-PEX, this type of connector is called a ZenShield connector. A connector is only rated as ZenShield if it has the following three characteristics. One, the entire connector is covered by 360 degree shielding for both the plug and the receptacle. Two, the shield-to-shield interface between the plug and receptacle is effectively connected at multiple points. Three, the connector shield-to-board interface is properly grounded at multiple points on the board.

Shielded connectors block EMI generated by intrapair skew from leaking outside of the connector. As you can see on the left of *Figure 2,* EMI radiates freely without the aid of a shield. The shielded connector on the right blocks unwanted radiation from the signal contacts.

We simulated the effect of length mismatch within a differential pair on EMI. We also compared the use of unshielded connectors in one assembly and shielded connectors in another assembly. We ran several side-by-side comparisons of shielded versus unshielded

Figure 1

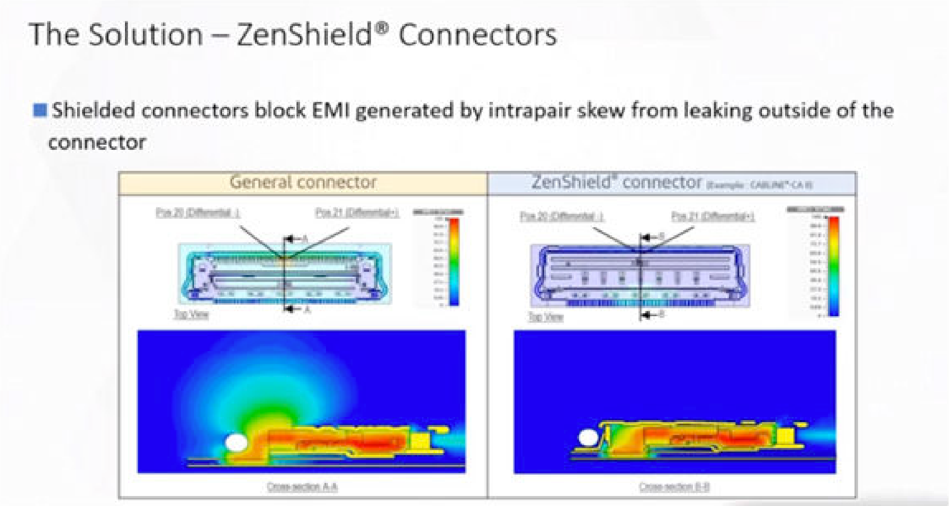


Intrapair Skew in Differential Applications

- Intrapair skew in cable assemblies can exacerbate EMI

	Matched Length	Mismatched Length – 4 mm
Cable assembly with micro-coaxial cable and an unshielded connector		

Figure 2



The Solution – ZenShield® Connectors

- Shielded connectors block EMI generated by intrapair skew from leaking outside of the connector

General connector	ZenShield® connector (Example: CABLINE®-CA II)

connectors. We compared matched lengths, a slight mismatch of one millimeter, and a larger mismatch of four millimeters.

The simulated effective intrapair skew values for the three conditions are as follows. Matched length, 0.2 picoseconds. Mismatched length of one millimeter, 3.5 picoseconds. And mismatched length of four millimeters of 16.6 picoseconds. As we can see from the mode conversion simulation, the more mismatches we have, the worse the mode conversion results. This is expected as the differential pair is no longer balanced.

To illustrate the E-fields, we looked at the top view, 0.5 millimeters above the connector. Here we see larger E-fields as the mismatch increases. However, the shielded connector in the bottom row has significantly less emissions compared to the unshielded connector in the top row. We also looked at the E-fields from the side view or cross-section of the connector. You can see that in the shielded connector, all of the E-fields remain contained within the connector. Whereas in the unshielded connector, some of the E-fields leak from the area where the signal contact is soldered to the PCD. This shows that shielded connectors provide an additional margin for assembly tolerances as EMI from intrapair skew can be mitigated.

CONCLUSION

I-PEX offers various types of fully shielded wire-to-board connectors. We offer vertical or horizontal options along with multiple pin counts and pitches. ZenShield connectors give board designers more flexibility for designing the board by allowing the connectors to be placed close to sensitive subsystems, such as transmit receive antennas commonly found in high-performance wireless communication systems. I-PEX also provides ZenShield connectors for other applications like antennas or board-to-board and FFC-to-board connections.

For more information, please visit https://www.i-pex.com/.

REFERENCES

1. https://www.i-pex.com/

IoT, WIRELESS, 5G EMC STANDARDS

ETSI STANDARDS

https://www.etsi.org

Document Number	Title
ETSI EN 300 220	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1,000 MHz frequency range with power levels ranging up to 500 mW
ETSI EN 300 328	Electromagnetic compatibility and Radio Spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques; Harmonized EN covering essential requirements under article 3.2 of the R&TTE Directive
ETSI EN 300 330	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 9 kHz to 25 MHz frequency range and inductive loop systems in the 9 kHz to 30 MHz frequency range
ETSI EN 300 440	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 1 GHz to 40 GHz frequency range
ETSI EN 301 489-3	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 3: Specific conditions for Short Range Devices (SRD) operating on frequencies between 9 kHz and 40 GHz
ETSI EN 301 489-17	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 17: Specific conditions for Wideband data and HIPERLAN equipment
ETSI EN 301 893	Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering essential requirements of article 3.2 of the R&TTE Directive
ETSI EN 303 413	GPS receivers
ETSI EN 303 417	Wireless Power Transfer

IoT, WIRELESS, 5G EMC GROUPS & ORGANIZATIONS

MAJOR WIRELESS/5G/IoT LINKEDIN GROUPS

- Wireless Telecommunications Worldwide
- Cellular, Wireless & Mobile Professionals
- Wireless Communications & Mobile Networks
- 802.11 Wireless Professionals
- Wireless Consultant
- Telecom & Wireless World

MAJOR IoT, WIRELESS, 5G EMC ASSOCIATIONS AND ORGANIZATIONS

APCO International
https://www.apcointl.org
APCO International is the world's oldest and largest organization of public safety communications professionals and supports the largest U.S. membership base of any public safety association. It serves the needs of public safety communications practitioners worldwide–and the welfare of the general public as a whole–by providing complete expertise, professional development, technical assistance, advocacy and outreach.

ATIS
http://www.atis.org
In a rapidly changing industry, innovation needs a home. ATIS is a forum where the information and communications technology (ICT) companies convene to find solutions to their most pressing shared challenges.

Bluetooth Special Interest Group
https://www.bluetooth.com
Join thousands of the world's most innovative companies already developing and influencing Bluetooth technology.

CTIA - The Wireless Association
http://www.ctia.org
CTIA is an international nonprofit membership organization that has represented the wireless communications industry since 1984. The association's members include wireless carriers, device manufacturers, suppliers as well as apps and content companies.

ETSI - European Telecommunications Standards Institute
http://www.etsi.org
We produce globally applicable standards for Information & Communications Technologies including fixed, mobile, radio, broadcast, internet, aeronautical, and other areas.

NAB - National Association of Broadcasters
http://nab.org
The National Association of Broadcasters is the voice for the nation's radio and television broadcasters. As the premier trade association for broadcasters, NAB advances the interests of our members in federal government, industry and public affairs; improves the quality and profitability of broadcasting; encourages content and technology innovation; and spotlights the important and unique ways stations serve their communities.

Satellite Industry Association
http://www.sia.org
The Satellite Industry Association (SIA) is a Washington D.C. based trade association representing the leading global satellite operators, service providers, manufacturers, launch services providers, and ground equipment suppliers.

Telecommunications Industry Association
http://www.tiaonline.org
The Telecommunications Industry Association (TIA) is the leading trade association representing the global information and communications technology (ICT) industry through standards development, policy initiatives, business opportunities, market intelligence and networking events. With support from hundreds of members, TIA enhances the business environment for companies involved in telecom, broadband, mobile wireless, information technology, networks, cable, satellite, unified communications, emergency communications, and the greening of technology.

IoT, WIRELESS, 5G EMC GROUPS & ORGANIZATIONS (CONTINUED)

Wireless Infrastructure Association (WIA)
http://wia.org
The Wireless Infrastructure Association represents the businesses that develop, build, own, and operate the nation's wireless infrastructure.

Wireless Innovation Forum
http://www.wirelessinnovation.org
WInnForum members are dedicated to advocating for the innovative use of spectrum and advancing radio technologies that support essential or critical communications worldwide. Through events, committee projects, and initiatives the Forum acts as the premier venue for its members to collaborate to achieve these objectives, providing opportunities to network with customers, partners and competitors, educate decision makers, develop, and expand markets, and advance relevant technologies.

WiMax Forum
http://wimaxforum.org
The WiMAX Forum® is an industry-led, not-for-profit organization that certifies and promotes the compatibility and interoperability of broadband wireless products based upon IEEE Standard 802.16. The WiMAX Forum's primary goal is to accelerate the adoption, deployment, and expansion of WiMAX, AeroMACS, and WiGRID technologies across the globe, while facilitating roaming agreements, sharing best practices within our membership and certifying products.

ZigBee Alliance
http://www.zigbee.org
Our innovative standards are custom-designed by industry experts to meet the specific market needs of businesses and consumers. These market leading standards give product manufacturers a straightforward way to help their customers gain greater control of, and even improve, everyday activities.

USEFUL WIRELESS REFERENCES

WIRELESS WORKING GROUPS

802.11 Working Group
The 802.11 Working Group is responsible for developing wireless LAN standards that provide the basis for Wi-Fi.
http://grouper.ieee.org/groups/802/11/

802.15 Working Group
The 802.15 Working Group is responsible for developing wireless PAN standards that provide the basis for Bluetooth and ZigBee.
http://www.ieee802.org/15/

802.16 Working Group
The 802.16 Working Group is responsible for developing wireless MAN standards that provide the basis for WiMAX.
http://grouper.ieee.org/groups/802/16/

Bluetooth SIG
The Bluetooth SIG is responsible for developing wireless PAN specifications.
https://www.bluetooth.com

Cellular Telecommunications and Internet Association (CTIA)
The CTIA represents cellular, personal communication services, mobile radio, and mobile satellite services over wireless WANs for service providers and manufacturers.
http://www.ctia.org

Federal Communications Commission (FCC)
The FCC provides regulatory for RF systems in the U.S.
https://www.fcc.gov

GSM Association
The GSM Association participates in the development of development of the GSM platform–holds the annual 3GSM World Congress.
http://www.gsmworld.com

Wi-Fi Alliance
The Wi-Fi Alliance develops wireless LAN ("Wi-Fi") specifications based on IEEE 802.11 standards and provides compliance testing of Wi-Fi products.
http://www.wi-fi.org

WiMAX Forum
The WiMAX Forum develops wireless MAN standards based on IEEE 802.16 standards and provides compliance testing of WiMAX products.
http://wimaxforum.org

ZigBee Alliance
The ZigBee Alliance develops standards for low-power wireless monitoring and control products.
http://www.zigbee.org

USEFUL WEBSITES

ARRL RFI Information
http://www.arrl.org/radio-frequency-interference-rfi

Jim Brown has several very good articles on RFI, including: A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing.
www.audiosystemsgroup.com

FCC
http://www.fcc.gov

FCC, Interference with Radio, TV and Telephone Signals
http://www.fcc.gov/guides/interference-defining-source

IWCE Urgent Communications
http://urgentcomm.com has multiple articles on RFI

Jackman, Robin, Measure Interference in Crowded Spectrum, Microwaves & RF Magazine, Sept. 2014.
https://www.mwrf.com/technologies/test-measurement-analyzers/article/21845885/measure-interference-in-crowded-spectrum

RFI Services (Marv Loftness) has some good information on RFI hunting techniques
www.rfiservices.com

TJ Nelson, Identifying Source of Radio Interference Around the Home, 10/2007
http://randombio.com/interference.html

USEFUL BOOKS

Interference Technology Engineer's Master (ITEM) 2023
A complete guide full of invaluable EMC directories, standards, formulas, calculators, lists, and "how-to" articles, compiled in easy-to-find formats.
https://learn.interferencetechnology.com/item-2023/

The ARRL RFI Book (3rd edition)
Gruber, Michael
ARRL, 2010.

USEFUL WIRELESS REFERENCES

USEFUL BOOKS (CONTINUED)

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Percival Publishing, 2001.

Transmitter Hunting: Radio Direction Finding Simplified
Moell, Joseph and Curlee, Thomas
TAB Books, 1987.

Interference Handbook
Nelson, William
Radio Publications, 1981.

Electromagnetic Compatibility Engineering
Ott, Henry W.
John Wiley & Sons, 2009.

Platform Interference in Wireless Systems - Models, Measurement, and Mitigation
Slattery, Kevin, and Skinner, Harry
Newnes, 2008.

Spectrum and Network Measurements, (2nd Edition)
Witte, Robert
SciTech Publishing, 2014.

Radio Frequency Interference (RFI) Pocket Guide
Wyatt and Gruber
SciTech Publishing, 2015.

USEFUL FORMULAS AND REFERENCE TABLES

E-Field Levels versus Transmitter Pout			
Pout (W)	**V/m at 1m**	**V/m at 3m**	**V/m at 10m**
1	5.5	1.8	0.6
5	12.3	4.1	1.2
10	17.4	5.8	1.7
25	27.5	9.2	2.8
50	38.9	13.0	3.9
100	55.0	18.3	5.5
1,000	173.9	58.0	17.4

Assuming the antenna gain is numerically 1, or isotropic, and the measurement is in the far field and greater than 100 MHz.

Using Decibels (dB)

The decibel is always a ratio…

- Gain = P_{out}/P_{in}, where P = power
- Gain(dB) = $10\log(P_{out} / P_{in})$, where P = power
- Gain(dB) = $20\log(V_{out}/V_{in})$, where V = voltage
- Gain(dB) = $20\log(I_{out}/I_{in})$, where I = current

Power Ratios

3 dB = double (or half) the power
10 dB = 10X (or /10) the power

Voltage/Current Ratios

6 dB = double (or half) the voltage/current
20 dB - 10X (or /10) the voltage/current
Multiplying power by a factor of 2 corresponds to a 3 dB increase in power. This also corresponds to a 6 dB increase in voltage or current.

Commonly Used Power Ratios (dB)		
Ratio	**Power**	**Voltage or Current**
0.1	-10 dB	-20 dB
0.2	-7.0 dB	-14.0 dB
0.3	-5.2 dB	-10.5 dB
0.5	-3.0 dB	-6.0 dB
1	0 dB	0 dB
2	3.0 dB	6.0 dB
3	4.8 dB	9.5 dB
5	7.0 dB	14.0 dB
7	8.5 dB	16.9 dB
8	9.0 dB	18.1 dB
9	9.5 dB	19.1 dB
10	10 dB	20 dB
20	13.0 dB	26.0 dB
30	14.8 dB	29.5 dB
50	17.0 dB	34.0 dB
100	20 dB	40 dB
1,000	30 dB	60 dB
1,000,000	60 dB	120 dB

Multiplying power by a factor of 10 corresponds to a 10 dB increase in power. Multiplying a voltage or current by 10 is a 20 dB increase. Dividing by a factor of 10 corresponds to a 10 dB reduction in power, or 20 dB for voltage and current.

USEFUL WIRELESS REFERENCES

COMMON WIRELESS FREQUENCY BANDS (LINKS)

GSM Bands:
https://en.wikipedia.org/wiki/GSM_frequency_bands

UMTS Bands:
https://en.wikipedia.org/wiki/UMTS_frequency_bands

LTE Bands:
https://en.wikipedia.org/wiki/LTE_frequency_bands

MMDS:
https://en.wikipedia.org/wiki/Multichannel_Multipoint_Distribution_Service

V Band (40 to 75 GHz):
https://en.wikipedia.org/wiki/V_band

DECT and DECT 6.0 (wireless phones and baby monitors):
https://en.wikipedia.org/wiki/Digital_Enhanced_Cordless_Telecommunications

Comparison of wireless internet standards:
https://en.wikipedia.org/wiki/Comparison_of_mobile_phone_standards

Wi-Fi Protocols (From Intel):
http://www.intel.com/content/www/us/en/support/network-and-i-o/wireless-networking/000005725.html

LINKS TO MANUFACTURER'S WHITE PAPERS

VIDEO / Handheld Interference Hunting for Network Operators (Rohde & Schwarz):
https://www.rohde-schwarz.com/us/solutions/wireless-communications/gsm_gprs_edge_evo_vamos/webinars-videos/video-handheld-interference-hunting_229255.html

Interference Hunting With The R&S FSH (Rohde & Schwarz):
https://www.rohde-schwarz.com/us/applications/interference-hunting-with-r-s-fsh-application-note_56280-77764.html

Interference Hunting / Part 1 (Tektronix):
http://www.tek.com/blog/interference-hunting-part-1-4-get-insight-you-need-see-interference-crowded-spectrum

Interference Hunting / Part 2 (Tektronix):
https://in.tek.com/blog/interference-hunting-part-2-4-how-often-interference-happening

Interference Hunting / Part 3 (Tektronix):
http://www.tek.com/blog/interference-hunting-part-3-4-use-mask-search-automatically-discover-when-interference-happenin

Interference Hunting / Part 4 (Tektronix):
https://www.tek.com/blog/interference-hunting-part-4-4-storing-and-sharing-captures-interference-hunter%E2%80%99s-safety-net

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