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2024
IoT, WIRELESS, 5G
EMC GUIDE

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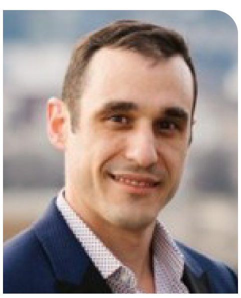
TECHNICAL EDITORIAL BOARD MEMBERS
Meet the 2024 Editorial Board

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.



ZACHARIAH PETERSON
PCB Design Expert & Electronics Design Consultant

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.

MIKE VIOLETTE

iNARTE Certified EMC Engineer

Mike is CEO 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.

TOM BRAXTON

iNARTE-Certified EMC Engineer and an iNARTE-Certified ESD Engineer

Tom Braxton has worked in the EMC industry since 1981, with experience at Lucent Technologies / AT&T Bell Laboratories, Shure Incorporated, and as an independent consultant.

Tom is an IEEE Life Senior Member, a past EMC Society Director at Large, and is the author of EMC-awareness articles for online and print publications. He chairs Technical Committee TC1 on EMC Management and was General Chair of the 2005 IEEE International EMC Symposium and Vice-Chair in 1994, both in Chicago. He is also the Vice-Chair and Program Chair of the EMC Society Chicago Chapter.

An iNARTE-Certified EMC Engineer and an iNARTE-Certified ESD Engineer, Tom holds a BSEET from Purdue University, an MSEE from the Illinois Institute of Technology, and Amateur Radio license WB9VRW.

DEAN LANDERS

E3 Engineer

Dean Landers is an Electromagnetic Environmental Effects (E3) engineer for a major defense contractor, working with the testing, simulations, and program management of all things involving E3 amongst several programs. Previously, he was the Supervisor of Applications Engineering for AR RF/ Microwave Instrumentation. He was actively engaged in new application and product development, system development and integration, customer support, and training with hardware demonstrations for both customers and AR personnel. Prior to working at Amplifier Research, Dean spent 9 years as an EMC Test Engineer at Retlif Testing Laboratories, managing military, commercial aviation, and commercial test programs, writing customer test procedures, and working with customers to help them understand their compliance needs and requirements. He also serves on the IEEE EMC Society Executive Committee.

EDITORIAL

Zachariah Peterson
Owner, Northwest Engineering Solutions LLC

Technology development cycles often begin with hype, but ultimately produce results outside the technological spotlight. As wireless, 5G, and IoT systems continue to advance, the challenges facing today's electronics engineers are more demanding and more intriguing than ever, and yet 5G does not occupy the same spotlight as in recent years. Still, the rollout of 5G has brought a level of connectivity that drives nearly every sector, revealing the need for faster, more reliable, and more secure networks. Engineers are tasked with designing systems that meet these high standards while ensuring they're resilient to interference, reliable under varying environmental conditions, and capable of seamless integration into existing infrastructure.

The fast-evolving IoT landscape adds another layer of complexity. The sheer number of connected devices poses unique challenges in terms of bandwidth, signal integrity, and device security. As we push toward 6G, designers face the additional task of addressing extreme data demands across huge networks, ultra-low latency, and robust security, all while maintaining energy efficiency and compliance with regulatory standards.

In this issue, we've curated articles to help you navigate these evolving demands. We explore the advantages of pre-certified RF modules in IoT applications, discuss the crucial role of electromagnetic pulse (EMP) protection for ensuring operational security, and examine how 5G sites can affect aircraft radar altimeters. Our guide offers a view into the major challenges in today's high-stakes wireless and IoT environments.

As always, we editors welcome your feedback and invite you to submit your own article to be included in a future issue.

COLUMN

DRAG RACES, A CASHLESS SOCIETY, AND THE THREAT OF EMP

Dean Landers
E3 Engineer

About a month ago, my 12-year-old son and I made his first-ever trip to the NHRA Drag Races near our home. It's something that I always did with my dad, and I have looked forward to taking him ever since he was born. It's a typical father-and-son day, wrought with loud, fast cars, terrible food, and the occasional waft of nitromethane fuel in the air.

The drive is about an hour from our house, so the discussions on the way were mostly racing focused. Since it was his first time there, I insisted we arrive early to tour the pits, look around, and let him get a feel for the atmosphere. Drag racing is unique from other events he's attended, like baseball, hockey, and basketball games. He seemed to have an interest in racing, so this was an opportunity to show him something different.

We arrived early. With the event kicking off around 10:30, we pulled into the track area around 9 am.

What evaded me from research on the event was that only cash was accepted in the parking lots. Being a moderately young-ish person (45 is the new 25, and don't you forget it), I rarely carry cash. I rolled up to an attendant and asked, "What if I don't have cash?"

"There's a gas station about five miles from here."

Uh oh.

So off we went, out of the track location, traversing through the hills of the rural Reading, PA, vicinity to find an ATM. Fifteen minutes later, a local Sunoco saved the day. I took out $100, plus the $6.50 ATM fee, and headed back to the track.

We arrived with some time to spare, enjoyed a long, hot day of racing, seeing cars routinely eclipse 300 MPH with no major accidents, ate terrible food, and breathed a bit of nitromethane (it's a requirement).

Incidentally, inside the venue, MOST of the vendors accepted ZERO cash transactions, except for the track concession itself. The food trucks, merchandise tents, etc. were all cashless.

Most other events I've attended since the pandemic have been cashless — including the aforementioned baseball, hockey, and basketball games. It's a convenient new deal with Apple and Google Pay options, card readers with RFID chips, paying with a smartwatch at a vending machine, and the list goes on.

The more I see this, the more I become increasingly concerned of cyber threats and an instantaneously broken economy with the threat of EMP (electromagnetic pulse). The threat looms large for financial institutions, with JP Morgan Chase, Bank of America, and Citigroup having combined assets of over $9.8 TRILLION. The likelihood of you having some sort of stake in one of those banks is a near certainty.

An EMP is a burst of electromagnetic energy that can damage or upset electrical devices, telecommunications networks, and large-scale infrastructure like the power grid. An EMP can be natural or man-made, with the natural phenomenon coming from solar flares. A man-made EMP, however, usually comes from a nuclear bomb, which ionizes air molecules, creating a large and powerful electromagnetic field.

With the lack of cash and reliance on digital payments in society today, the threat of an attack on these institutions is a sobering thought. A cyberattack — typically

coming from an EMP to literally shut down the infrastructure of a major financial institution — is real and closer than you think.

And it's not just money. Each week, 140 million American citizens get their groceries from Walmart. An attack on the infrastructure of the largest grocery chain in the United States would be devastating, crippling not only the retailer itself, but the grocery markets that are local to Walmart stores across the country, which would become overloaded, running out of food or struggling to deliver goods.

An EMP, detonated high above the ground, could affect electronic devices with a several thousand-mile radius. A powerful enough EMP event above a midwestern state like Kansas could affect the entire United States.

And this doesn't necessarily have to come from a nuclear bomb or explosion. Obviously, if nuclear war is in effect, ordering your Lucky Charms from Amazon isn't your highest priority. However, a non-nuclear EMP (NNEMP), which is the more likely scenario, could be utilized in a more localized fashion. Strategic placement of these smaller yet still effective weapons would be just as devastating.

So, what's the solution? Take all your money out of the banks and hide it under the mattress? Invest in a safe and anchor it to the floor of your basement and hope nobody ever finds it (or hope you never forget the combination)? Give all your money to me, the author, in the hopes that I have some great plan?

No. None of these are viable options.

In reality, our financial institutions, military installations, and companies that keep the heartbeat of our nation pumping are all protected against this. Shielded cabinets (LOTS of them), surge suppression, filter banks, and shielded buildings are a small part of the mitigation efforts performed by these companies, which generally yield solid results against this type of situation. However, if you were walking down the street with your laptop, a wallet full of credit and debit cards, a smartphone, and a smartwatch, and an EMP does detonate (let's assume a non-nuclear type), there's a good chance that one of your devices would fail. However, your money and assets are still likely safe.

Ideally, all the major institutions mentioned above utilize some sort of compliance testing and analysis regarding the threat of EMP. From the filters to the cabinet structure to the overall data center assembly and architecture, the most critical path through all of this is actual testing. One test is worth a thousand analyses, and the risk is lowered through full compliance testing.

We never want to wake up in a world where the threats have become realized. However, if the right tactics are used to mitigate the risks, we can rest assured that our money is there when we need it.

Because we always want to be able to order our Lucky Charms from Amazon when we run out.

ADVANTAGES OF USING A PRE-CERTIFIED RADIO FREQUENCY MODULE IN AN IoT APPLICATION

Ignacio de Mendizabal
Hardware Engineer & EMC Expert

Learn the benefits of using a pre-certified radio frequency (RF) module in the design phase when building a new IoT application, and learn the implications in EMC and Radio certifications.

The Internet of Things (IoT) is revolutionizing the quantity and manner in which we exchange and store information. Historically, people exchanged information through reading and speaking. Today and in the future, machines will increasingly handle information management. The size of these machines has been drastically reduced, from room-sized computers to pocket-sized devices with even greater computing power.

The future is promising with the widespread adoption of 5G technology, which enables high data transfer rates and low latency. Additionally, shifting processing capacity closer to data sources, such as sensors, enhances real-time applications and supports increasingly advanced use cases.

Some IoT nodes use wired communication mediums like Ethernet or CAN. However, scalability and adaptability necessitate low-cost deployment and maintenance solutions. Therefore, wireless communications are the most cost-effective option for IoT networks. Compared to wired networks, wireless systems are easier to install, access, and monitor, and they are also simpler to scale, making them ideal for rapidly expanding networks.

When designing a new IoT electronic system, system architects must choose a radio protocol from options like ZigBee, Wi-Fi, Bluetooth, and LoRa. The choice depends on factors such as the coverage area, number of nodes, speed, latency, transmission power, and the battery life of the IoT nodes.

Once the protocol is chosen, the second big question is: should I develop all the electronics by myself? Or should I use a preexisting module that seems to be plug-and-play? This article aims to clarify the advantages and disadvantages of using existing RF modules and their impact on the development and certification roadmaps.

REGULATORY COMPLIANCE

Every product entering a new market, such as the EU or USA, must comply with various regulations, including chemical safety and electromagnetic interference (EMI). These requirements depend on the geographic regions where the products are sold, their regulatory agencies, and the product type. Each country has its regulatory framework governing RF technologies to avoid interference and ensure safe operation. In the United States, the Federal Communications Commission (FCC) oversees this, while Europe follows the Radio Equipment Directive (RED).

Manufacturers need to take care of three aspects related to the electronics of their products:

- **Safety:** manufacturers need to guarantee the health and safety of people, animals, and properties.
- **Electromagnetic Compatibility (EMC):** electronic products must not generate electromagnetic disturbances above the limit, and they must allow other equipment to operate properly.
- **Efficient use of the spectrum:** electronic products using radio communications must make an efficient use of the radio spectrum, respecting the designated frequency bands.

The requirements related to Radio Frequency are very strict, so manufacturers will not get approval if the device transmits energy “just a little bit” over the limits. They need to prove that the new product is clearly not emitting in unexpected bands, that the emissions are within the accepted transmission power, and that the product is not a hazard for the user.

USING AN EXISTING RF MODULE OR BUILDING A NEW ONE

Designers building a new application need to face the decision of using an existing module or designing a new one. Considering just the design stage, using an existing module brings the advantages of:

- Fast development of software, since the hardware platform is available at an early stage
- The hardware is validated, so fewer hardware re-spins are needed
- Support from an existing community, making development easier

On the other hand, using an existing module has disadvantages. Naming some of them:

- Limited customization, which means the modules are not suitable for all kinds of applications
- Modules are big, taking up considerable amount of the board space
- The modules might have more functionalities than needed, provoking excessive power consumption.

For most of the applications like industrial or home automations, space and power are not a limiting factor, so the disadvantages of using an existing module are less important than the benefits. It is then the most convenient approach to make a fast development. Small companies or startups do not have in-house knowledge of antenna engineering or specialized equipment such as vector network analyzers (VNA), spectrum analyzers (SA) or RF design and simulation software tools. Using a module reduces the need for all of them, giving manufacturers the chance of launching and validating new applications fast.

SELECTING A MODULE — CERTIFICATES

There are many existing modules in the market and not all of them have gone through the same levels of quality control and development stages. Pre-certified RF modules are wireless communication modules that have passed some regulation tests before being sold to manufacturers. To reduce the development time, it is better to choose a module that has gone through an intensive certification process like those in reference 1. While this is an advantage compared to building everything from scratch, manufacturers still need to do their work to have a complete certificated product.

Manufacturers should check all the documentation provided by the module manufacturer to avoid possible surprises. Certificates are linked to specific components such as the hardware version, software version, or the test conditions. Therefore, if any of those changes, the validity of the performed tests is at risk. Here is a non-exhaustive list of things to consider when selecting a module:

- **Market certification:** EU (CE), US (FCC)… the certification should be aligned with the intended manufacturer market. For example, FCC certifications are not valid in the EU market.
- **Hardware version:** the hardware version that has been certified should be the same as the one that will be installed in the new product during the whole lifecycle of the product.
- **Software version:** during the certification tests, the modules run a specific version of software (firmware). Changes in this software should not impact the result of the tests.

Having these certificates is very useful to have a baseline of some key metrics such as output power, frequency bands, and distance to the limits for new tests. So, even if they do not exempt manufacturers from testing their products, these certificates are useful to interpret results and build the technical file of them.

COMPLIANCE WITH A PRE-CERTIFIED MODULE

While using products that are already certified brings benefits in the product development phases, that does not mean that certification efforts are eliminated. The responsibility for the final product lies with the product manufacturer. Electronic products are complex, with power supplies, analog and digital circuits, and integrating communication capabilities with RF modules. Then, manufacturers cannot underestimate the steps needed to comply with the legal requirements and need to consider compliance of the whole product in the planning phase.

There are many factors that can affect the results of the EMC and radiation tests, provoking that the emissions and the radio measurements measured on the full product differ from the ones obtained by the module manufacturer. Manufacturers should take care of the following aspects:

Mechanical Enclosures

Metallic enclosures can have resonant effects at certain frequencies due to their physical dimensions, shape, and openings. If these resonances overlap with the frequency band of the RF module, it can modify the radiation pattern of the module.

Antenna Type and Position

Some of the RF modules have an external antenna that can be customized, changing its gain and direction depending on the application. Furthermore, the properties of the RF link can be affected by the position of the antenna in relation to other board components or conductive surfaces.

Printed Circuit Board (PCB) Design

The board stackup, the ground planes position and extension, and the position of other board components in relation to the RF module can significantly impact the behavior of the radiation pattern. When the RF modules are certified, they are being tested with the minimum number of components, so the two boards will significantly differ from each other.

Software

Software configuration related to output power, frequency, modulation schemes, and bandwidth selection will affect the radio frequency behavior. Manufacturers need a careful development of software, both for production and for the certification tests, to ensure that the emissions are within the limits.

CONCLUSION

Using a pre-certified module to build a new IoT electronic system reduces development time and the need for highly experienced designers or advanced design and simulation tools. However, it does not exempt manufacturers from meeting legal requirements. The new system often differs significantly from the unit certified by the module manufacturer, necessitating full testing to ensure compliance.

REFERENCES

1. ESP32 certificates (https://www.espressif.com/en/support/documents/certificates)

2. Modular Transmitter Integration Guide Guidance for Host Product Manufacturers (https://apps.fcc.gov/kdb/GetAttachment.html?id=bNCiEdkFEKnHsZF9GHCNdg%3D%3D&desc=996369%20D04%20Module%20Integration%20Guide%20V02&tracking_number=44637)

CAN 5G SITES BE GOOD NEIGHBORS?

Tom Braxton
iNARTE-Certified EMC Engineer and iNARTE-Certified ESD Engineer

Baseball Hall of Famer Yogi Berra was notable for his skill on the field and was equally notable for many of his quotes. "Yogi-isms" were things he often said that were both amusing and insightful. Referring to a popular restaurant, he said, "Nobody goes there anymore; it's too crowded." Sounds like a contradiction, but it's easy to follow his meaning. Customers chose not to go there because it's difficult to get through the crowds.

Technology can be like that, too — sometimes with troubling consequences. The introduction of 5G wireless brought new features to our online wonderland: higher speeds, lower latency, greater capacity, and wider bandwidth. And more became possible in 5G-equipped networks. Technology does not stand still, and it certainly has not in wireless telecom applications.

Near airports, new 5G wireless sites have been unwelcome neighbors due to the potential for electromagnetic interference (EMI) to aircraft radar altimeters (RAs). Radar altimeters used in aircraft are safety-critical for planes making their final approach. A safe landing depends on an experienced pilot knowing exactly the altitude in the seconds before the wheels meet the runway. New 5G devices operate within the C-Band between 3.7 and 4.2 GHz, a frequency range close to the altimeters, which have operated between 4.2 and 4.4 GHz for many years. Wireless services shoulder-to-shoulder in frequency create an interference risk.

Though those spectrum segments don't directly share frequencies, their proximity can be a danger. Any transmitted signal, no matter how clean or precise, generates harmonics that appear as multiples of the fundamental frequency beyond the original. The RA is especially vulnerable, since it relies on minute radar signals processed critically as the aircraft is making its final approach. Corruption of that signal can make the difference between a graceful landing and a tragic crash.

Aircraft navigation safety clearly is a paramount concern. In December 2023, the Federal Aviation Administration (FAA) updated its guidance on the effects of 5G C-Band interference on RAs. The agency recommended that aircraft operators install bandpass filters to minimize the interference from 5G sites operating in the C-Band between 3.7 and 4.2 GHz.

Electromagnetic compatibility (EMC) engineers have at their disposal an array of tools to minimize or eliminate EMI. Bandpass filters are among those on the tool kit's top shelf. Filters capable of blocking or diverting unwanted signals are effective solutions but are added after-the-fact to devices that are interference victims.

Radar altimeters most often see use when a plane makes its approach in limited visibility. Landing in a fog requires precise altitude readings before the wheels hit the tarmac. Aircraft are capable of operating without RAs most of the time in clear weather using barometric altimeters, but not having the use of the RA restricts some approaches. In the US, there are airports that rely on RA readings for safe approaches because of geography or other factors. Pilots are given lists of those landing sites that require the use of the RA as the aircraft approaches the field.

A fundamental part of good EMC practice is to prevent an interference problem from happening, whether through design choices or application restrictions. The door swings both ways in EMC. Devices and systems can be built to minimize emissions and the interference those emissions might cause. Those devices can also be designed to be immune from reasonable levels of external radiofrequency (RF) energy.

One of the choices to be made in system planning is spectrum management, where frequencies are chosen to minimize both the risk of causing interference and the risk of being victimized by it. A product would not be expected to function properly if it's known that there will be disruption of signals at certain frequencies. But regarding 5G's altimeter interference potential, the network carriers, the aviation industry, the FAA, and the Federal Communications Commission (FCC) did not coordinate their plans. Concerns were raised in recent years as plans for new 5G deployment near airports proceeded.

Initial 5G services launched in the 3.5 GHz band for most networks but more spectrum slices will be needed as 5G usage increases. Low- and mid-band (<1 GHz – 2.6 GHz), and high band (24 GHz – 40 GHz) spectrum are also being deployed to support the full range of 5G uses. The 5G mid-band range (3.7 GHz – 4.2 GHz) remains problematic for the network carriers as they work to resolve potential altimeter interference.

On October 12, 2023, the FAA published SAFO (Safety Alert for Operators) 21007, which provided guidance "regarding the risk of potential adverse effects on RAs when operating in the presence of 5G C-Band wireless broadband signals." It explained that telecommunication companies agreed to coordinate their transmitter information to the FAA around specific airports, but there remain other safety systems relying on RA data that could be affected by 5G signals.

The FAA is especially concerned about missing or erroneous RA input signals that could disrupt systems in other flight phases. Systems that integrate RA input as part of their function include Traffic Alert and Collision Avoidance (TCAS), Terrain Awareness Warning Systems (TAWS-A and HTAWS), windshear detection, auto-flight systems, and more. The FAA warned that 5G

C-Band systems are being deployed throughout the contiguous U.S. and that all operators and pilots should assume that transmitters are anywhere in a flight path. Aircraft not equipped with a 5G C-Band-tolerant RA will be subject to harmful interference.

The FAA concludes SAFO 21007 by encouraging all operators to equip their aircraft with 5G C-Band-tolerant RAs and reminds the industry to remain aware of RA-reliant system degradation. Higher speed technology operating in an increasingly crowded frequency spectrum brings EMC design into sharp relief. Bandpass filters and other technical fixes work after the fact but managing the spectrum to reduce the initial risk of adjacent-signal interference is preferred. Yogi's observation holds true for radio-spectrum space: if it's too crowded, nobody will go there. That's not a solution, either for aviation or for the telecommunications industry.

WIRELESS GROUPS & ORGANIZATIONS

MAJOR WIRELESS LINKEDIN GROUPS

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

WIRELESS ASSOCIATIONS AND ORGANIZATIONS

ALLIANCE FOR TELECOMMUNICATIONS INDUSTRY SOLUTIONS

https://www.atis.org/

As a leading technology and solutions development organization, the Alliance for Telecommunications Industry Solutions (ATIS) brings together the top global ICT companies to advance the industry's business priorities.

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.

ALLIANCE FOR TELECOMMUNICATIONS INDUSTRY SOLUTIONS (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.

BROADBAND FORUM

https://www.broadband-forum.org/

The Broadband Forum is an industry-driven global standards development organization helping operators, application providers, and vendors deliver better, services-led broadband.

COMPETITIVE CARRIERS ASSOCIATION (CCA)

https://www.ccamobile.org/

CCA advocates on behalf of its members' interests and works to educate policymakers on the key issues that impact its members' ability to compete, survive, and thrive.

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.

EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE (ETSI)

http://www.etsi.org

We produce globally applicable standards for Information & Communications Technologies including fixed, mobile, radio, broadcast, internet, aeronautical, and other areas.

GLOBAL MOBILE SUPPLIERS ASSOCIATION (GSA)

https://gsacom.com/about-gsa/

GSA is a not-for-profit industry organization representing companies across the worldwide mobile ecosystem who are engaged in the supply of infrastructure, semiconductors, test equipment, devices, applications and mobile support services.

IEEE STANDARDS ASSOCIATION

https://standards.ieee.org/

IEEE Standards Association (IEEE SA) is a leading consensus building organization that nurtures, develops and advances global technologies, through IEEE. It brings together a broad range of individuals and organizations from a wide range of technical and geographic points of origin to facilitate standards development and standards related collaboration.

INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

https://www.iec.ch/homepage

Founded in 1906, the IEC is the world's leading organization for the preparation and publication of international standards for all electrical, electronic and related technologies. These are known collectively as "electrotechnology."

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

https://iso.org/home.html

ISO, the International Organization for Standardization, brings global experts together to agree on the best way of doing things – for anything from making a product to managing a process. As one of the oldest non-governmental international organizations, ISO has enabled trade and cooperation between people and companies the world over since 1946. The International Standards published by ISO serve to make lives easier, safer and better.

INTERNATIONAL TELECOMMUNICATION UNION (ITU)

https://www.itu.int/en/Pages/default.aspx

ITU is the United Nations specialized agency for information and communication technologies (ICTs). The Organization is made up of a membership of 193 Member States and more than 1000 companies, universities and international and regional organizations. Headquartered in Geneva, Switzerland, and with regional offices on every continent, ITU is the oldest agency in the UN family – connecting the world since the dawn of the telegraph in 1865.

INTERNET ENGINEERING TASK FORCE (IETF)

https://www.ietf.org/

IETF, founded in 1986, is the premier standards development organization (SDO) for the Internet. The IETF makes voluntary standards that are often adopted by Internet users, network operators, and equipment vendors, and it thus helps shape the trajectory of the development of the Internet. But in no way does the IETF control, or even patrol, the Internet.

NATIONAL ASSOCIATION OF BROADCASTERS (NAB)

http://nab.org

NAB 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.

NATIONAL ASSOCIATION OF TOWER ERECTORS (NATE)

https://natehome.com/

NATE is a non-profit trade association providing a unified voice for tower erection, maintenance and service companies. NATE is headquartered in Watertown, South Dakota with a staff of fourteen people who administer to the day-to-day operations of the association. As a member driven association, NATE is led by its Board of Directors. These individuals come from all types and sizes of companies located throughout the United States.

RURAL WIRELESS ASSOCIATION (RWA)

https://ruralwireless.org/

RWA is a trade association representing rural wireless carriers who each serve fewer than 100,000 subscribers. RWA's members have joined together to speed delivery of new, efficient, and innovative wireless technologies to the populations of remote and underserved sections of the country.

SATELLITE INDUSTRY ASSOCIATION (SIA)

http://www.sia.org

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 (TIA)

http://www.tiaonline.org

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.

Wi-Fi ALLIANCE

https://www.wi-fi.org/

Wi-Fi Alliance drives global Wi-Fi adoption and evolution through thought leadership, spectrum advocacy, and industry-wide collaboration. Their work includes the development of innovative technologies, requirements, and test programs that help ensure Wi-Fi provides users the interoperability, security, and reliability they have come to expect.

WIRELESS BROADBAND ALLIANCE (WBA)

https://wballiance.com/

WBA is the global organization that connects people with the latest Wi-Fi initiatives. Founded in 2003, the vision of the WBA is to drive seamless, interoperable service experiences via Wi-Fi within the global wireless ecosystem. WBA's mission is to enable collaboration between service providers, technology companies, cities, regulators and organizations to achieve that vision.

WIRELESS COMMUNICATIONS ALLIANCE (WCA)

https://wca.org/

WCA exists to enable collaboration between technology companies, solution and service providers, early adopters, and academia to drive the successful implementation of wireless products and services within the global wireless ecosystem.

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.

WIRELESS INTERNET SERVICE PROVIDERS ASSOCIATION (WISPA)

https://www.wispa.org/

WISPA – Broadband Without Boundaries was founded in 2004 to promote the development, advancement, and unification of the WISP industry, with WISP defined as "an Internet service provider that utilizes wireless, fiber optics, or other technologies to distribute broadband or related Internet Protocol-derived services."

WiMAX FORUM

https://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 its membership and certifying products.

WTA

https://w-t-a.org/

WTA is a member-driven association strengthening the ability of its members to provide affordable, advanced broadband and communications services in rural America through advocacy and education.

ZIGBEE ALLIANCE

csa-iot.org/all-solutions/zigbee/

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.
http://mwrf.com/test-measurement-analyzers/measure-interference-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

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

AC Power Interference Handbook (2nd edition)
Loftness, Marv
Percival Publishing, 2001.

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

USEFUL BOOKS (CONTINUED)

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
1000	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.

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

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/en/blog/interference-hunting-part-4-4-storing-and-sharing-captures-interference-hunter%E2%80%99s-safety-net

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