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2021 IoT, WIRELESS, 5G EMC GUIDE

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IoT, WIRELESS, 5G 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 Product/Service								
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Current Probes	Fixed DF Systems	Near Field Probes	Portable DF Systems	Pre-Compliance Test	Testing Services	Spectrum Analyzers / Receivers
360Compliance	www.360compliance.co/							X		
Aaronia AG	www.aaronia.com	X	X		X		X	X		X
Alaris Antennas	www.alarisantennas.com		X							
Anritsu Company	www.anritsu.com		X					X		X
Avalon Test Equipment Corp	www.avalontest.com	X	X	X		X	X	X		X
CommsAudit	www.commsaudit.com/products/direction-finding		X		X		X			X
Doppler Systems	www.dopsys.com		X		X		X			
The EMC Shop	www.theemcshop.com	X	X	X		X		X		X
Eurofins E&E North America	www.metlabs.com								X	
F2 Laboratories	www.f2labs.com							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 Product/Service								
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Current Probes	Fixed DF Systems	Near Field Probes	Portable DF Systems	Pre-Compliance Test	Testing Services	Spectrum Analyzers / Receivers
Keysight Technologies	www.keysight.com/main/home.jspx?cc=US&lc=eng					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/narda/default_en.asp	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.rhothetaamerica.com/index.html				X		X			
Rigol Technologies	www.rigolna.com	X		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
Siglent Technologies	wwwsignlentamerica.com					X		X		X
Signal Hound	www.signalhound.com			X		X		X		X
SPX/TCI	www.spx.com/en/our-businesses/detection-and-measurement/TCI/		X		X		X			X
SteppIR Communication Systems	www.steppir.com		X							
TechComm	www.techcommdf.com		X		X		X			X
Tektronix	www.tek.com					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

COST EFFECTIVELY ENSURE ELECTROMAGNETIC COMPATIBILITY IN THE AGE OF IoT

Matthew Maxwell
Rohde & Schwarz

Wireless/RF is ubiquitous, so implement a pre-compliance regimen with off-the-shelf equipment.

COST EFFECTIVELY ENSURE ELECTROMAGNETIC COMPATIBILITY IN THE AGE OF IoT

Every electronic product has to go through full electromagnetic compatibility (EMC) testing to get the much-coveted stamp of approval from the various regulatory bodies. This has traditionally been a costly undertaking with multiple trips to a distant testing facility, with multiple reworks required to get final approval. In the age of the Internet of things (IoT), this is not the way to go about it. There is a better approach.

The IoT has changed everything, with wirelessly connected devices creating the opportunity to gather data to perform analytics in order to improve device usability for consumers. For industry, IoT-enabled analytics are improving process, safety, and production outcomes for manufacturing facilities, while opening the possibility of new business models. However, for electronic system and consumer product designers, it has created a number of headaches; some obvious, some more subtle and insidious.

To start with, there's the ubiquitous demand for wireless connectivity, whether it be Wi-Fi, Bluetooth, Zigbee, cellular, or the various flavors of long-range, low-power options such as LoRaWAN, Sigfox, Narrowband-IoT (NB-IoT) or LTE Cat 1. It's common to have multiple RF interfaces in the same device. This is great for users, but is a nightmare for designers, many of whom are not RF experts. They may have mastered the art of ensuring power supplies no longer interfere with digital circuits, but wireless connectivity adds a whole new dimension of difficulty. From the antenna placement and routing, to the design of high-frequency circuits from 900 MHz to 5 GHz, the difficulties have affected many product delivery schedules, and the problem is only going to get worse with 5G emerging with millimeter-wave operation at 28 GHz and up.

Brave designers will "roll their own" RF circuits, but these tend to be large design teams with high-volume expectations. It seems easy enough, get a good RF integrated circuit (IC) from a reputable vendor, put some shielding around it, place and route the antenna wire, and they're off and running. Maybe. However, a few trends have altered the design landscape and have forced designers to rethink their approach.

The primary influences on designs are smaller form factors, higher integration, and electronic component densi-

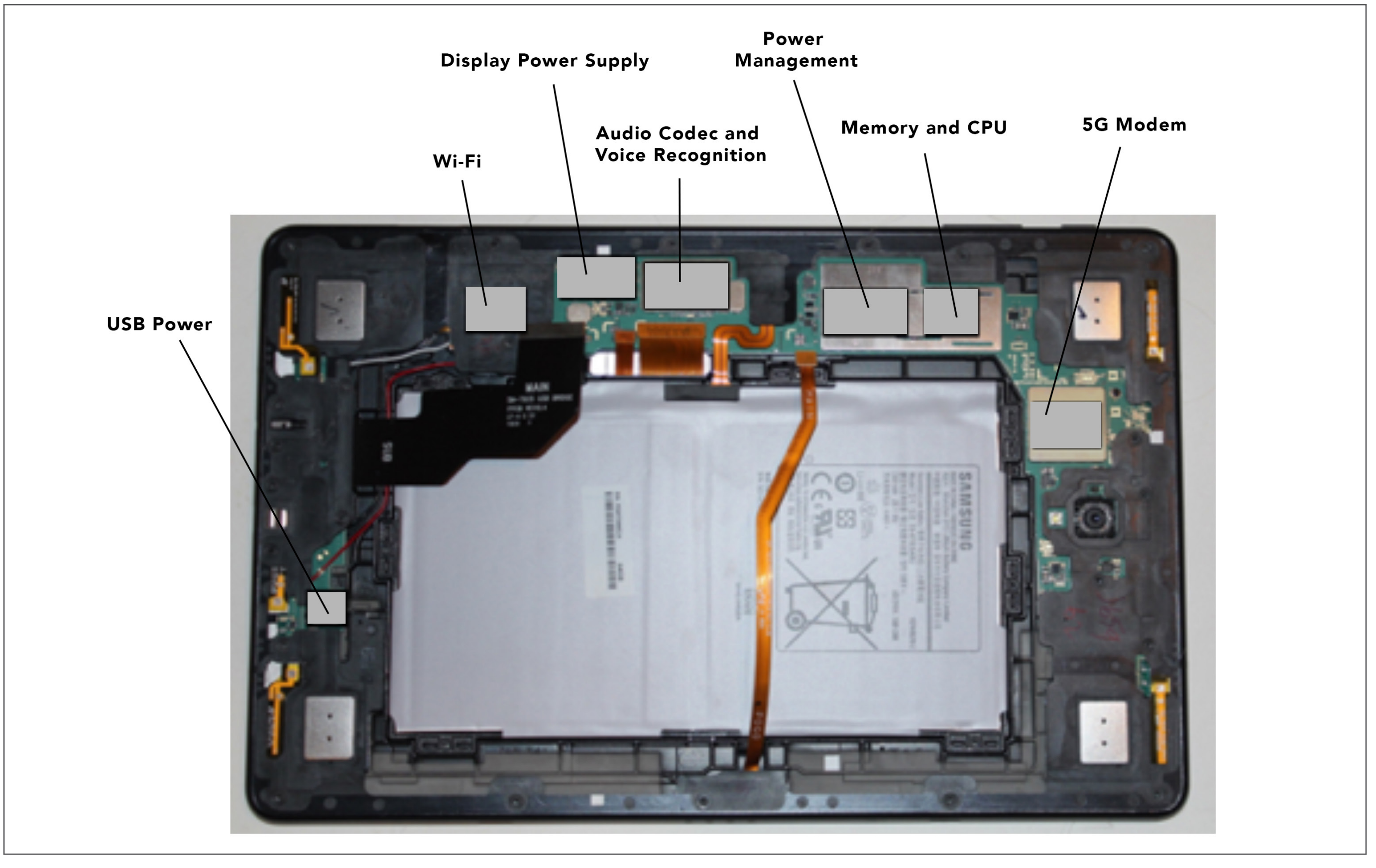

Figure 1: It used to be sufficient to shield a couple of key circuits, but the designers of the Samsung Tab S4 tablet shielded literally every circuit to ensure maximum EMC. The four rectangular silver elements on the corners are speakers, not circuits. (Image source: Rohde & Schwarz)

ty per inch squared of printed circuit board (PCB) space, system complexity, higher clock speeds, multiple and distributed power rails with fast-switching transients, LCD emissions as displays get integrated into IoT devices, and faster data transfer rates between central processing unit (CPU) and memory. These are the obvious and classic trends that create interesting challenges that designers actually enjoy solving, though time-to-market pressures and shrinking budgets can be a kill-joy for some, or an added challenge for others.

However, as mentioned, there are two more subtle trends, and these are the ones that are actually causing the most headaches, and the most opportunity for differentiation through innovative approaches to expediting the route to ensuring system EMC.

These trends, which are a direct result of the IoT, are the need to combine power supplies, high-performance digital circuits, and RF interfaces in compact form factors for products that are falling rapidly in price. So much so, that the complexity-to-price ratio is becoming untenable for high-quality, low-cost, smart-home-based systems that are the sweet-spot for IoT devices. Even mobile phone and tablet manufacturers, which have typically been able to charge a premium for higher margins, are getting squeezed as complexity increases and form factors shrink.

To address EMC and its associated electromagnetic interference (EMI) issues, it used to be sufficient to place shielding around key components, such as the RF circuits, to reduce their susceptibility to interference from high-speed digital clock and signal switching harmonics, and to prevent them from being an interferer. However, as density and complexity has increased, it's now not uncommon to shield literally everything, as in the case of the Samsung Tab S4, *Figure 1* (see page 8).

The Tab S4 is an extreme example of cutting-edge consumer-level design in terms of density, performance, and complexity, with a price to match ($649). However, most designs in the IoT space, from white goods and audio streaming systems with built-in voice assistants, to wearables, cost much less, forcing designers to find ways to lower development and test costs.

ACCELERATING EMC TESTING — WHILE LOWERING COST

It's possible to accelerate the design and test cycle when using power-supply and RF modules. These come pre-certified and do save time and resources. However, many designers falsely assume that buying a module means they're home free with respect to national and international compatibility and compliance regulations. Nothing could be further from the truth.

It's true that the RF module may remain fully Bluetooth certified and interoperable, but once the power supply, RF module, antenna, and digital circuits are laid out and connected all regulatory certification bets are off. The *full system* now needs to be certified to CE, FCC, or CISPR requirements, due to the many and varied interactions

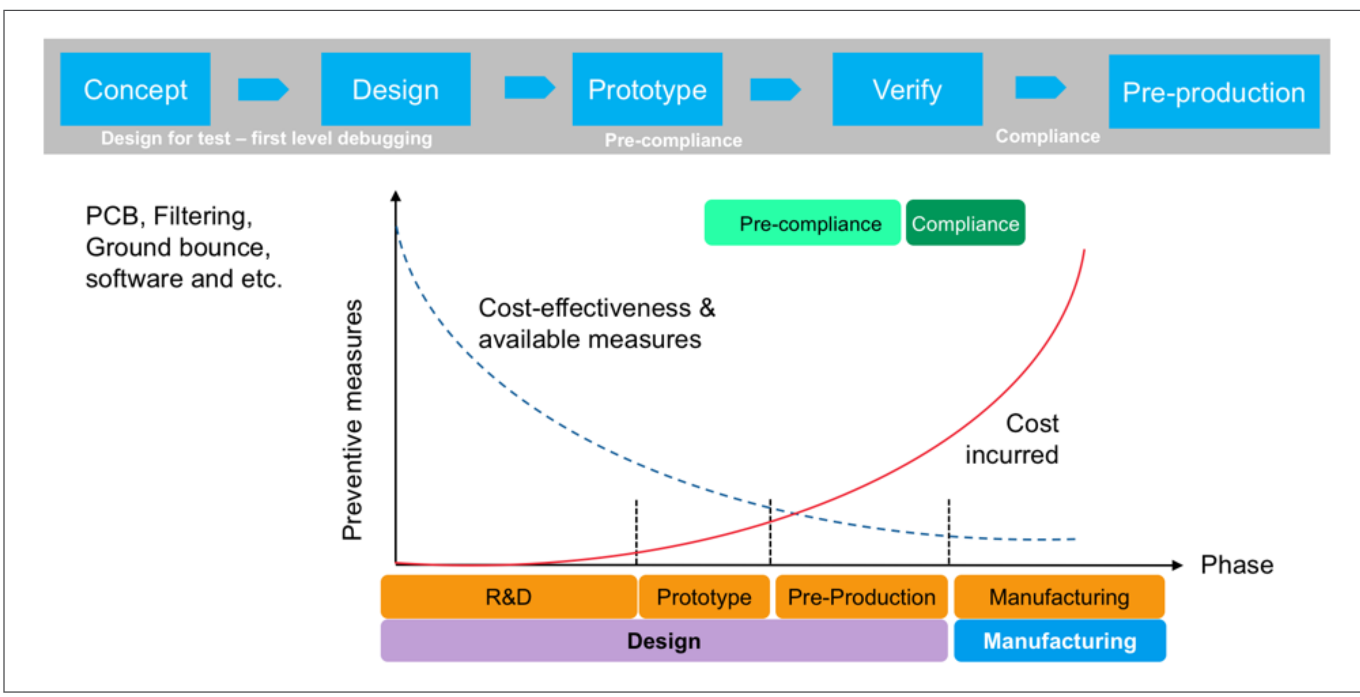

Figure 2: Implementing a regimen of pre-compliance checkpoint tests can greatly increase the chance of completing an IoT design on time and within budget. (Image source: Rohde & Schwarz)

between the subsystems. These include load transients, spurious power-supply emissions, various internal and ambient EMI sources, and RF harmonics.

The task for designers is to understand EMC and the effects and sources of EMI, and then performance pre-compliance testing on the system to identify and mitigate any issues — before sending it out to an external lab for certification. Along with the expense of time, the compliance tests themselves can cost up to $10,000 and up to 90 percent of devices fail the first time around, leading to rework and retesting, sometimes multiple times. The costs add up quickly, especially if the fix requires a full or partial redesign. It's critical to initiate preventative measures, such as design-cycle checkpoints, to help avoid costly project delays, *Figure 2* (see page 9).

Another important reason to perform pre-compliance testing is to avoid over-design of the device. Often, designers run the risk of adding additional shielding or other precautions, which adds weight, time, power consumption, and direct costs. The goal is to pass the test for full compliance without going overboard.

In order to minimize the chance of multiple rounds of compliance certification and rework, it helps to have some up-front education on EMC and EMI. Combined with off-the-shelf test equipment and some "tricks of the trade," it's possible to quickly identify and mitigate EMC issues before submitting a system for formal certification.

DEFINING EMC AND IDENTIFYING SOURCES OF EMI

EMC and EMI are often confused, but simply put, EMC is concerned with ensuring various pieces of electrical and electronic equipment can operate in the same electromagnetic environment. It requires the equipment to have minimal unwanted electromagnetic emissions and to also minimize its susceptibility to ambient electromagnetic energy, typically from nearby equipment or long-range radio transmitters.

EMI is the actual unwanted electromagnetic energy that designers need to suppress within their own designs, as well as protect their design from outside sources. These sources can be static electricity, other radios, sporadic emissions from motors or power supplies, mains hum, microwave ovens and the system's internal digital switching harmonics and sub-harmonics, and even audio signals. Their interference potential depends upon the operating frequency of the equipment under test (EUT) and they can manifest as continuous wave or pulsed EMI signals.

In EMC parlance, the system causing the interference is the source, and the system being affected is the victim. Between them are the four EMI coupling mechanisms: radiated, inductive, capacitive, and conductive, or any combination of the four, *Figure 3*. EMI can be viewed fractally in the sense that it applies between small or large systems that are near or far apart, as well as between subsystems, components, traces, and antenna within a system. Not that antennas are particularly interesting, as they not only transmit and receive intentional emissions, but also serve as perfect couplers of EMI into and out of a system.

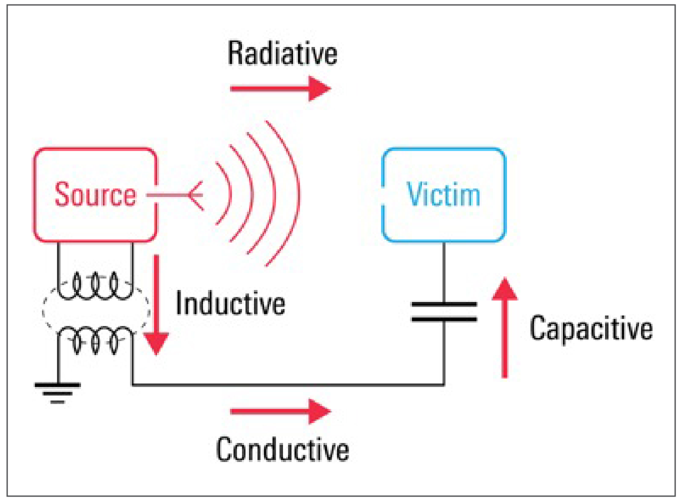

Figure 3: The four EMI coupling mechanisms are radiative, inductive, capacitive and conductive. (Image source: ipfs.io)

The EMI and EMC principles are similar for nearby and within systems. For the sake of simplicity, this article will focus on a single system and how to design for EMC, perform pre-compliance testing, and debug using an off-the-shelf, mid-range oscilloscope.

DESIGNING FOR EMC

Let's consider the following basic principles to demonstrate that EMC hasn't changed since EE 101:

- Be careful on trace routing
- Be aware that higher speeds mean more EMI issues
- PCB stacking makes EMI worse
- Avoid sharp corners in traces (reasonable design tools can match the maximum trace angle to the operating frequency)
- Have larger ground planes
- Use shielded cables and housings
- Avoid discontinuities and resonances in the transmission path

Unfortunately, EMI cannot be eliminated entirely. Thus the designer's job is to manage and mitigate it, applying fundamental principles in combination with experiential know-how.

PRE-COMPLIANCE TEST AND DEBUG

Once the design is in the prototype stage and pre-compliance checkpoints have been established, the next task is to either isolate the EUT completely from ambient EMI, or

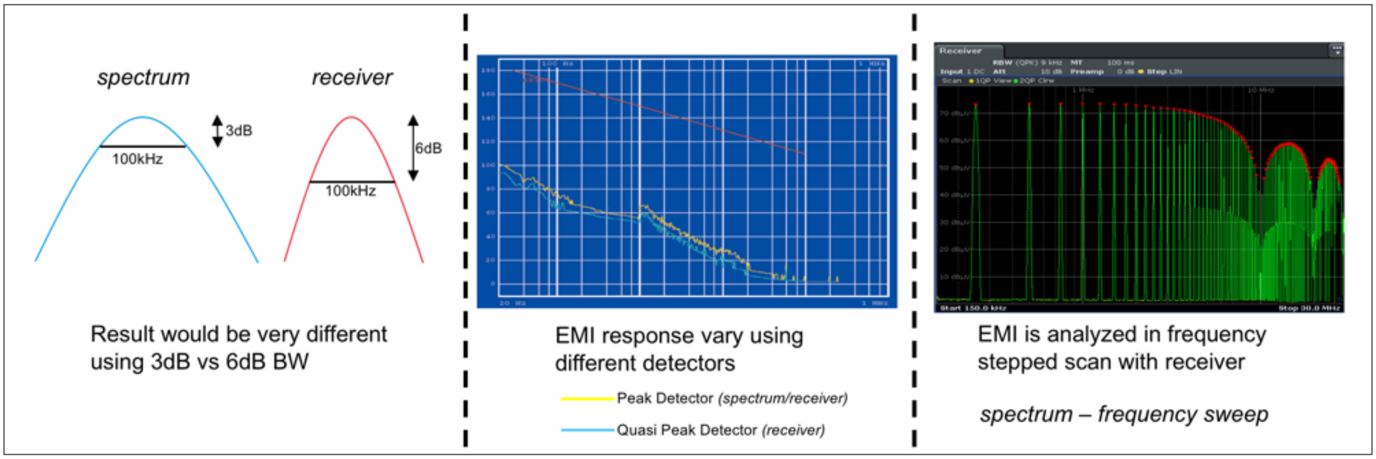

Figure 4: When in receive mode, spectrum analyzers can imitate higher cost EMI receivers, but make sure it has at least a quasi-peak (QP) detector with a directional antenna. (Image source: Rohde & Schwarz)

to characterize the environment and account for detected interferers during the test cycle. Again, interferers also cannot be eliminated, but the probability of interference can be determined and mitigated.

To scan a wide range of frequencies for interferers, a full EMI receiver with an array of filters and wide dynamic range is a good option, but can be expensive. Alternatively, a spectrum analyzer can come close to an EMI receiver's capabilities without breaking the bank. Start by getting a baseline and account for any present signals. Spectrum analyzers, such as the R&S®FPC1500, have optional PC EMI software (Elektra) that can set the compliance limits, or the user can do it manually, *Figure 4.*

The spectrum analyzer itself will need at least a quasi-peak (QP) detector with a directional antenna as part of the minimum viable feature sets to approximate a full EMI-compliant receiver. Look for an analyzer with a frequency range from 5 kHz to 5 GHz to detect sub-GHz signals and 5-GHz Wi-Fi network interferers. Also, a built-in vector network analyzer (VNA) is useful as it can be used to match the antenna impedance to the RF module if there isn't an RF antenna built in. Some spectrum analyzers also have an integrated signal generator that can be used to generate an additional signal in the presence of the intended transmitter signal. This "interferer" tests to make sure there is sufficient blocking at the receiver to allow the intended signal to get through.

To start pre-compliance testing, do a limit-line test, or max hold sweep, with a max hold detector, as that's a fast and easy test. Then, use the QP detector to do spot checks on any potential problem areas. Use electric field (E-field) and magnetic field (H-field) near-field probes, *Figure 5.* The magnetic field probe has a loop through which the magnetic field passes perpendicularly, inducing a detectable voltage.

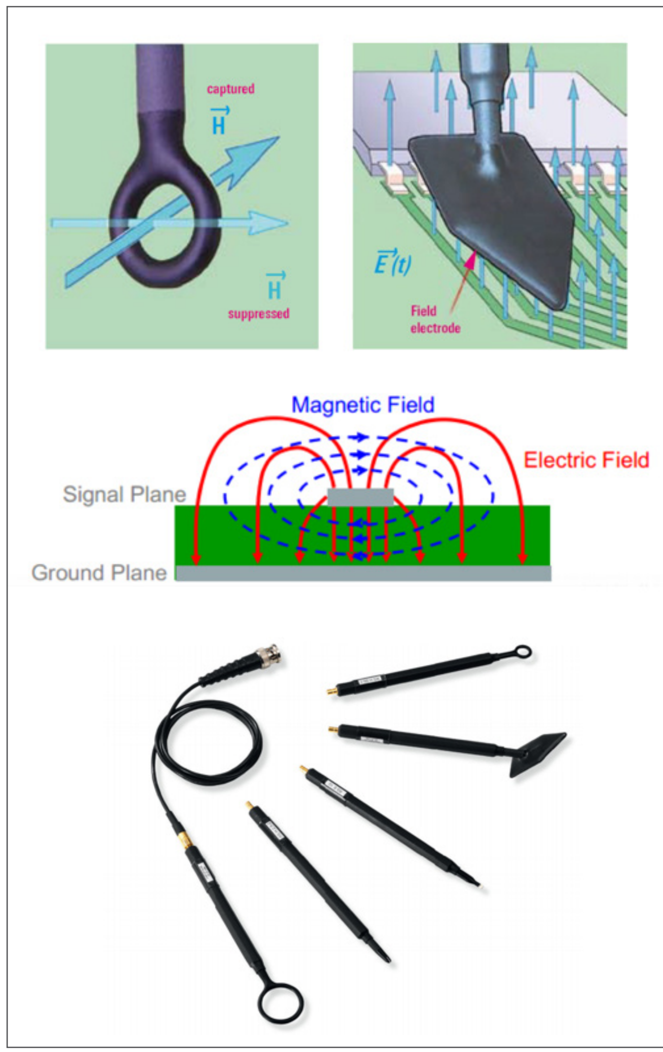

Figure 5: The larger the size of the E-field and H-field probes, the greater their sensitivity, at the cost of precision. It helps to zero in on the EMI source by reducing the size of the probe. (Image source: Rohde & Schwarz)

When using the probes, it's important to keep in mind that the output of the probe very much depends upon the orientation of the probe relative to the emitters. Also, there is a trade-off to be made: the larger the probe, the greater the sensitivity, but the precision decreases. So, as the source of EMI gets more clearly defined, reduce the size of the probe to zero in on the source and verify that the readings are below the maximum power levels allowed.

This requires having a solid knowledge of the design to know where these might be. Many EMI sources can be anticipated by factoring in the clock frequencies, the power supply's switching frequency, and the expected harmonics.

Knowing the layout is critical, as it helps to know when a clock line might be too close to an RF module. This becomes something to watch for as it might be what's coupling in and causing another spur that's in a different part of the spectrum.

However, no matter how good a designer's knowledge of the physical layout and the circuit's design parameters, nothing beats running the system software and time-correlating the EMI to the running code.

TIME-CORRELATED TEST AND DEBUG WITH OSCILLOSCOPES

Given the budget and resource constraints of many IoT developers, a spectrum analyzer may be out of reach. However, every bench has an oscilloscope, and the right digital oscilloscope can also perform EMI test. This was not always the case, as the fast Fourier transform (FFT) processing capability wasn't available. That has changed, with some digital oscilloscopes now implementing FFT digital down-conversion and overlapping FFTs in hardware.

Look for a digital oscilloscope with these key characteristics: enough capture memory (can hold greater than 500 Ksamples), 50-Ω coupling impedance to ensure sufficient bandwidth and a sample rate >2x the maximum frequency, start with 2.5 Gsamples/s for 0 to 1 GHz. If testing systems with 2.45-GHz or 5-GHz radios, the sample rate will need to be upgraded accordingly. Also look for low noise and good vertical sensitivity capable of being set to 500 μV/div to 5 mV/div for high sensitivity over the full bandwidth.

As the probe will be moving around the board or system, it's important that the scope's response time be fast so there's no delay when trying to correlate EMI back to the time domain. Some scopes do include FFTs in software, so be careful to ensure the time and frequency domain are seen in real time. As the source of the EMI becomes clearer, the time-domain view should allow the EMI source to be correlated to changes such as bus level switching, *Figure 6*.

Other features to look for on a scope include a color table and screen persistence to easily detect and distinguish continuous wave signals, burst signals, and signal zoom: *Figure 7* (see page 12).

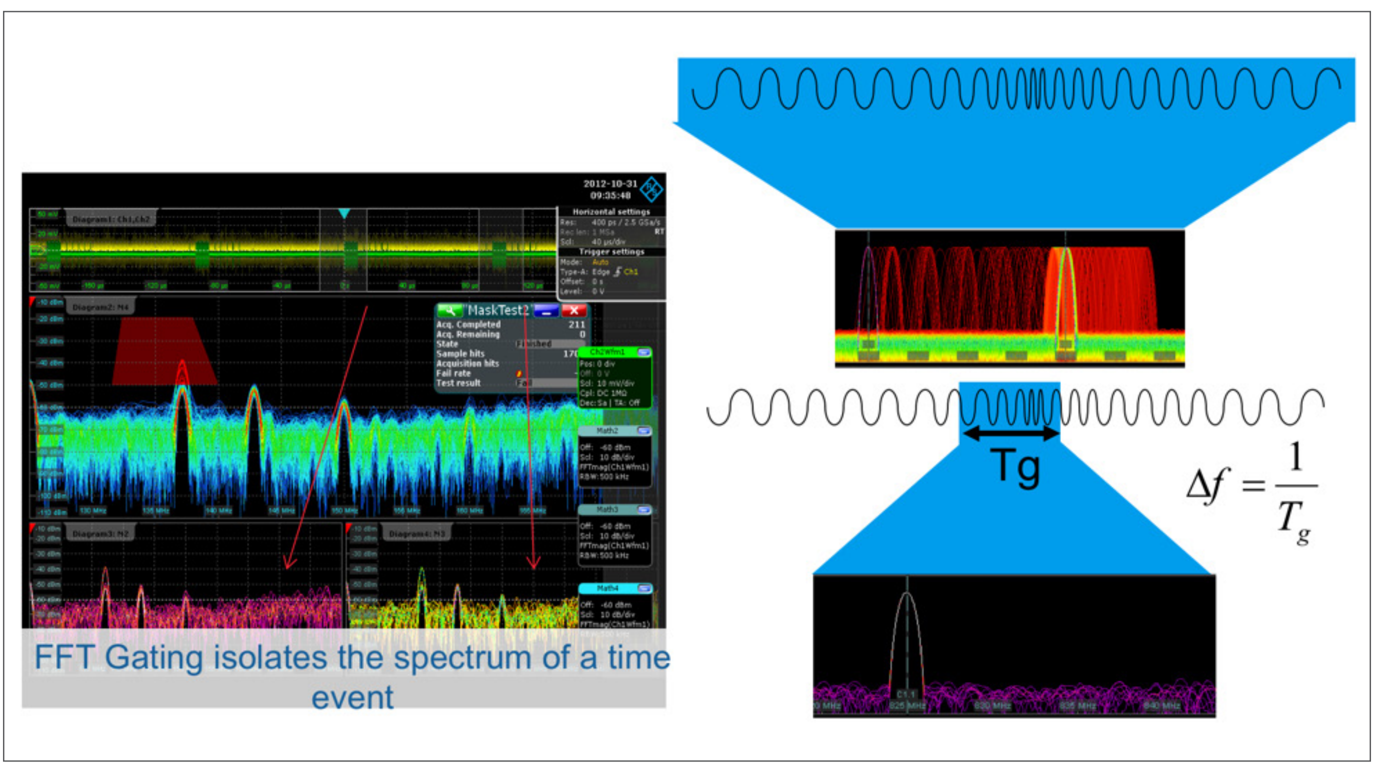

Figure 6: Multi-domain digital oscilloscopes with fast FFT capability and a gating feature help debug by allowing users to time-correlate EMI events and find their origin. (Image source: Rohde & Schwarz)

CONCLUSION

In the age of IoT, with ubiquitous wireless connectivity, meeting EMC requirements for any standard is becoming more difficult and time consuming. The problem is exacerbated by the falling cost of IoT devices, which puts pressure on designers to get it right the first time to avoid extra certification costs and rework. That said, implementing a strict pre-compliance test regimen and checkpoints combined with typical benchtop equipment, such as digital oscilloscopes, can help limit formal and expensive EMC certification testing to one round.

Figure 7: The R&S®RTO2000's 10.1-inch capacitive touchscreen allows users to quickly navigate pop-up menus and adjust scaling by zooming in or moving a waveform. (Image source: Rohde & Schwarz)

THE VITAL ROLE OF SIMULATION FOR VIRTUAL EMI AND EMC TEST ENVIRONMENTS

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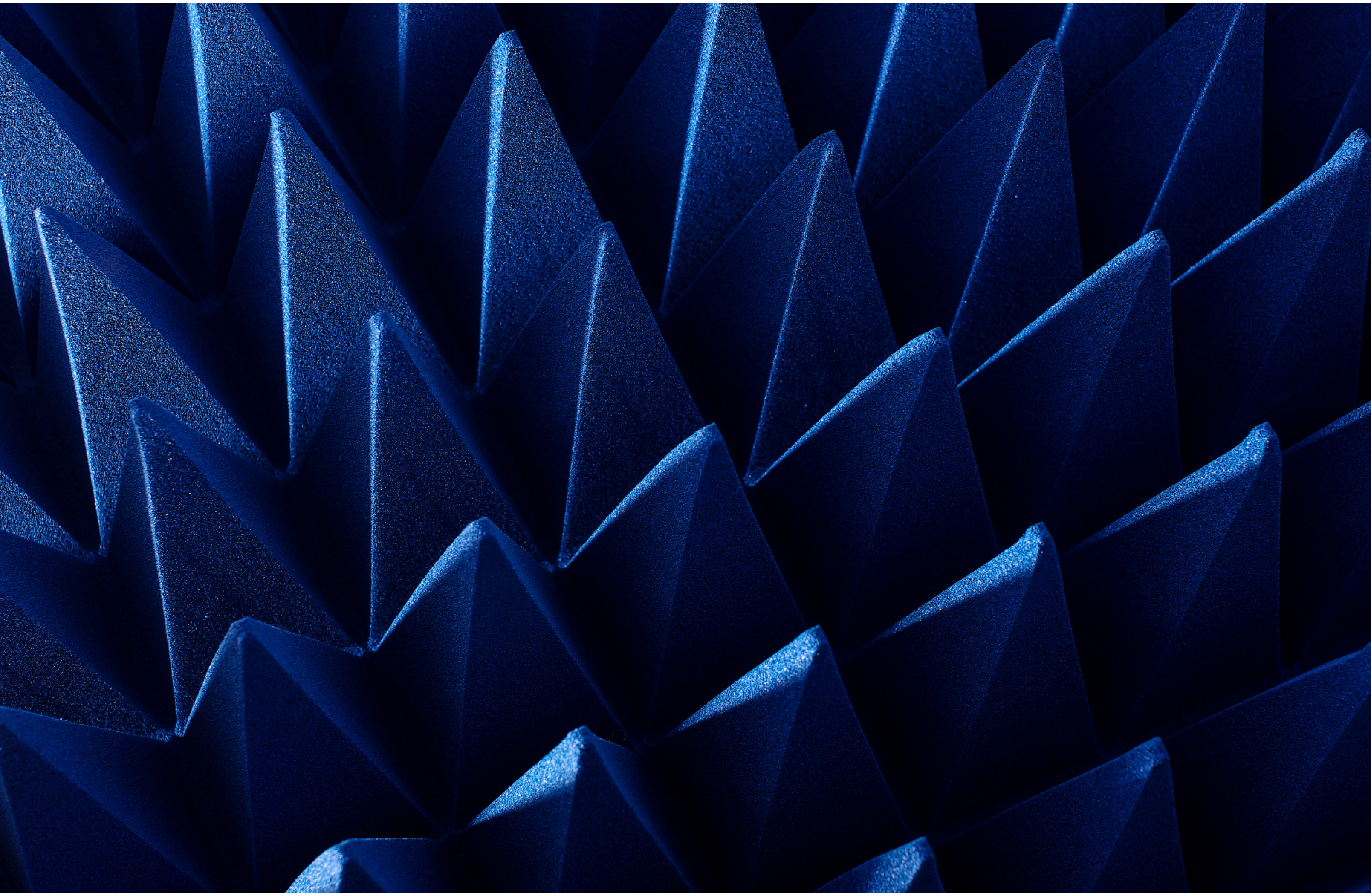


THE VIRTUAL ROLE OF SIMULATION FOR VIRTUAL EMI AND EMC TEST ENVIRONMENTS

Before deploying microwave and millimeter-wave devices and systems within 5G, the Internet of Things (IoT), and high-speed wireless communication, it is essential to predict their performance. This need has increased the demand for virtual test platforms through simulation software.

High carrier and system bus frequencies are necessary for high-data-rate communication between multiple devices present in such systems. However, increased operational frequencies may induce undesirable and troublesome electromagnetic compatibility (EMC) and electromagnetic interference (EMI) issues, especially when communication is congested. Moreover, the impact from other physics is no longer negligible in mmWave devices. Multiphysics phenomena, such as structural deformation caused by heat expansion, need to be a part of the design consideration as well. Fortunately, a wide range of EMC and EMI scenarios can be virtually emulated and tested without having to elaborately adapt test configurations to real-world environments.

Using electromagnetics simulation software for evaluating device functionality reduces time and costs during the development and production cycle. Virtual evaluations can be performed prior to fabrication, test, and manufacture, and are an important component in reliable quality control processes.

The goal of simulation is to describe the real world as closely as possible on the computer by using proven physics equations. Ideally, the numerical model is used to mimic multiple physical phenomena representing a great variety of operational conditions, which is hard to realize in a lab environment. Accurately analyzing real-world designs and conditions comes at a cost. The more complex the analysis, the more computational resources are needed. Therefore, engineering judgment is used for excluding unnecessary parts from the analysis and for configuring the simulation settings to ensure efficient computations.

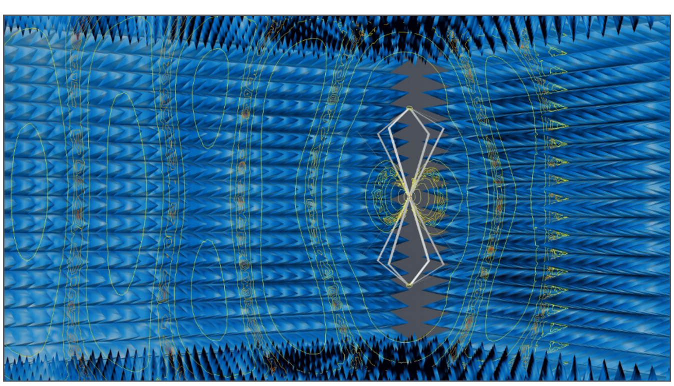


Figure 1: Contour plot of the logarithmic field distribution of a biconical antenna in a fully anechoic chamber.

When evaluating EMI and EMC performance of radiating devices, test engineers often perform measurements in a fully anechoic chamber. Simulation tools are used to set up a numerical environment that can reproduce such tests virtually (*Figure 1*) by using, for example, the finite element method (FEM). For instance, the pyramidal absorbers that are attached to the anechoic chamber walls contain lossy conductive carbon particles. The absorbers attenuate the incident electromagnetic waves gradually with only small amounts of unwanted reflections. For efficiency, instead of modeling the full-sized wall of absorbers, the simulation uses only a single pyramidal unit cell with periodic boundary conditions (*Figure 2*). This is an efficient way of estimating the performance of the complete set of absorbers to make sure the reflectivity is at a minimum. Even if the model consists of just a single unit cell, the periodic boundary conditions make it equivalent to an infinite array of pyramidal absorbers. The effective homogeneous material properties obtained from the unit cell simulation are then used for the entire anechoic chamber wall.

To validate the virtual version of the anechoic chamber, a wideband biconical antenna is placed inside the anechoic chamber. The performance of the antenna (for example, far-field radiation patterns and S-parameters) is computed to validate that there is no degradation of performance due to the incomplete absorber characterization.

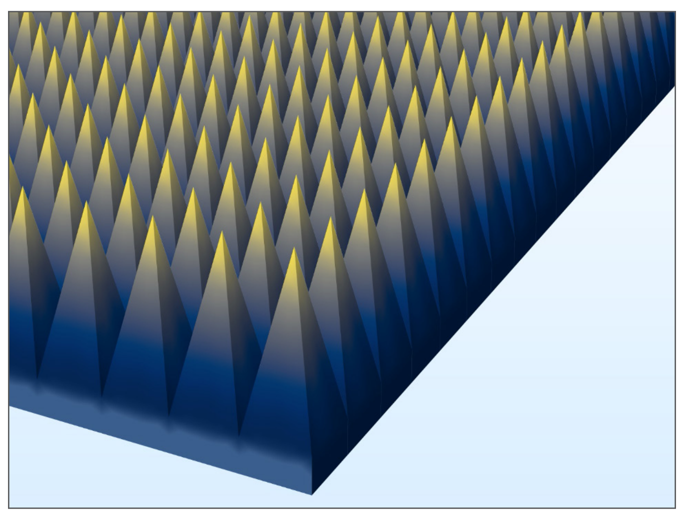


Figure 2: Microwave absorber simulation using Floquet periodic boundary conditions.

Although the real-world representation of the antenna inside the fully anechoic chamber in the simulation is visually quite appealing, as shown in *Figure 1*, its computational cost is unnecessarily high. The simulation can be made much faster and more efficient in terms of memory usage by using a numerical technique that is equivalent to the anechoic chamber walls. Such techniques involve using perfectly matched layer (PML) and absorbing boundary condition features. To efficiently study the near and far fields and other antenna parameters, it is sufficient to place the same biconical antenna in a much smaller surrounding air domain enclosed by a perfectly matched layer (*Figure 3*).

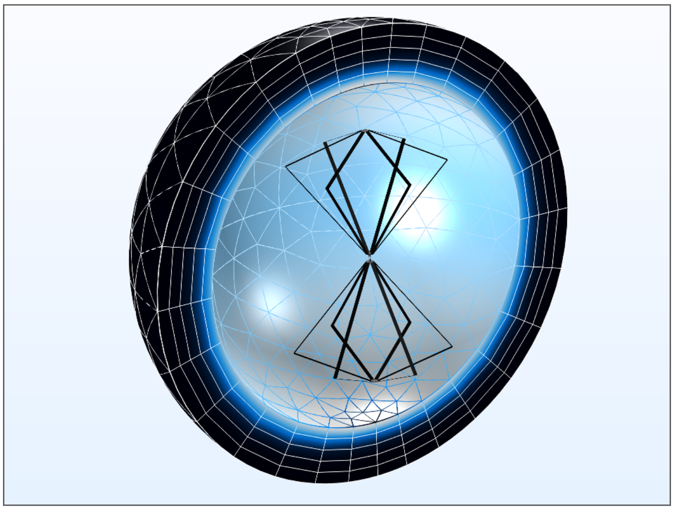


Figure 3: Biconical antenna enclosed by a PML. The PML at the front is removed from view to show the interior.

In order to simulate a large system efficiently, it is crucial to choose proper numerical boundary conditions. In addition, eliminating design details that are deemed to have negligible impact on the results, and just keeping the relevant components, can make further efficiency gains. By using PMLs, a large system can be simulated and not limited to just device-level modeling.

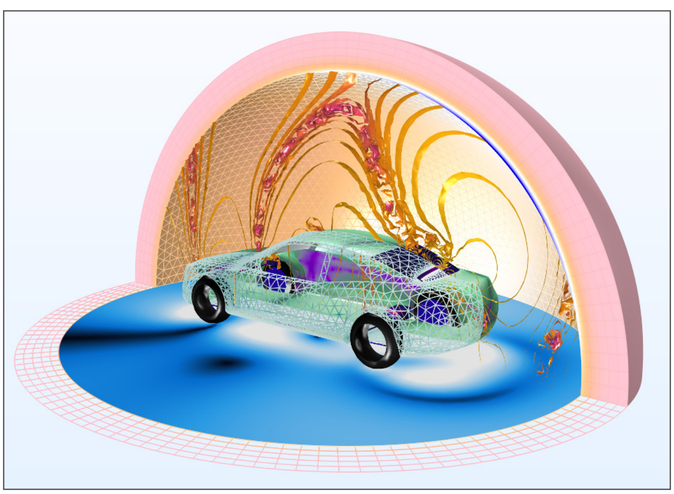


Figure 4: Impact on cable harness by the radiation from the rear windshield in the FM radio frequency band.

In *Figure 4*, the electric field transmitted from a fictitious radiating device on the rear windshield of a car is studied to see the radiated emission effect over the cable harness inside. The PML covers the upper half-space, absorbs all outgoing waves, and ensures that reflected waves do not bounce back onto the car. Meanwhile, the bottom ground and the car body generate reflection and multipath fading effects on the cable harness. The electromagnetic waves coupled to the cable are a source for unwanted conducted emission as well. In a real car system, it would be hard to access and relocate the source and victims for the EMI/EMC test. However, by using simulation, it is possible to analyze arbitrary configurations. In this way, by not being limited by physical testing, engineers can produce more robust system designs.

By using simulation, one can estimate the actual performance of devices for IoT applications when they are deployed in a real environment. IoT devices may be placed in a living room, a garage, or other spaces in a house. The electrical size of the problem in terms of the number of spanned wavelengths can easily exceed what can be addressed by so-called full-wave numerical methods. Full-wave methods include the finite element method (FEM), the finite difference time domain (FDTD) method, and the method of moments (MoM). There are alternative computational electromagnetics approaches available for approximating the performance of IoT devices without sacrificing too much accuracy. In addition, such approximate methods can produce useful results while still using limited computational resources. One such approach is the method of ray tracing. *Figure 5* shows multiscale simulation capabilities when ray tracing is employed together with FEM. The part of the simulation that uses FEM analyzes a small simulation domain surrounding the antenna of a wireless router that includes a truncated surrounding air domain. Rays are launched from the antenna location, and their initial strength is proportional to the directional intensity of the 3D far-field radiation pattern of the antenna. The antenna coverage inside a media room (*Figure 5*) can be approximated quickly without long simulation times or excessive memory usage. This multiscale electromagnetics modeling technique is a great alternative for overcoming the limitations of traditional computation methods for large EMI and EMC problems.

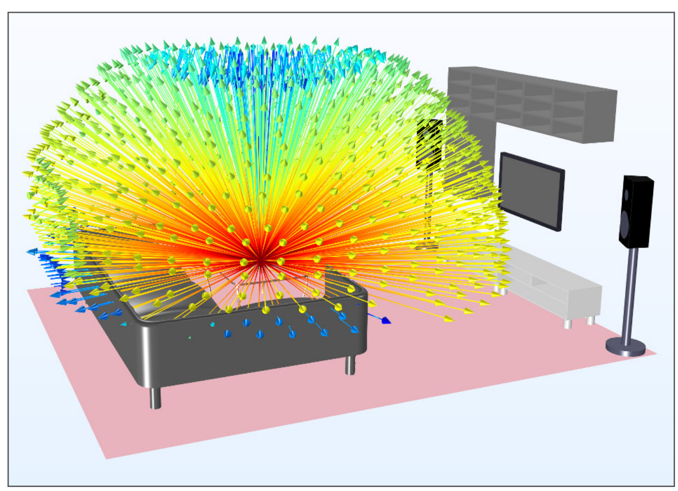


Figure 5: Multiscale electromagnetics simulation example. It combines the conventional finite element method for antenna analysis and ray tracing for describing indoor communication.

Simply combining existing computational methods can overcome the limitations of traditional numerical analysis. Two such situations are when you need to produce wideband results with high-frequency resolution, or when you need to analyze signal integrity and time-domain reflectometry (TDR) for a large device. Such simulations can be very time consuming. However, in both cases, the computational performance can be greatly boosted by conducting a fast Fourier transform (FFT), either from the time domain to the frequency domain or the other way around. For example, you can first perform a transient analysis and then run a time-to-frequency FFT to achieve a wideband S-parameter and far-field calculation in the frequency domain. Alternatively, you can first perform a frequency sweep and then run a frequency-to-time FFT for a time-domain bandpass impulse response. This is useful for time-domain reflectometry analysis, such as identifying a defective part of a transmission line, which results in impedance mismatch and signal quality degradation.

Simulation provides virtual analysis platforms for a wide range of test scenarios. However, learning how to use electromagnetics simulation software may not be the best use of time for everyone in an organization. Limited training and access to simulation software may restrict usage of electromagnetics simulation tools to a small set of expert users. Completed numerical EMI and EMC test models may frequently need new input parameters in order to adjust to a real-world test environment's variations. The need for updating boundary conditions, mesh, and postprocessing settings outside of the simulation group can cause unexpected delays in the development cycle. The good news is that simulation software has evolved to accommodate specialists who are not dedicated simulation engineers. The simulation models can be converted to easy-to-use apps (*Figure 6*). An app has a straightforward, specialized user interface (UI) and can be shared with colleagues and customers through existing web browsers or as a standalone executable file. Such standalone apps do not require purchasing extra software licenses and can run regardless of the operating system. A large number of people involved in EMI test projects can easily access the virtual test kit provided by an app and optimize the product without learning how to use the software behind the curtain.

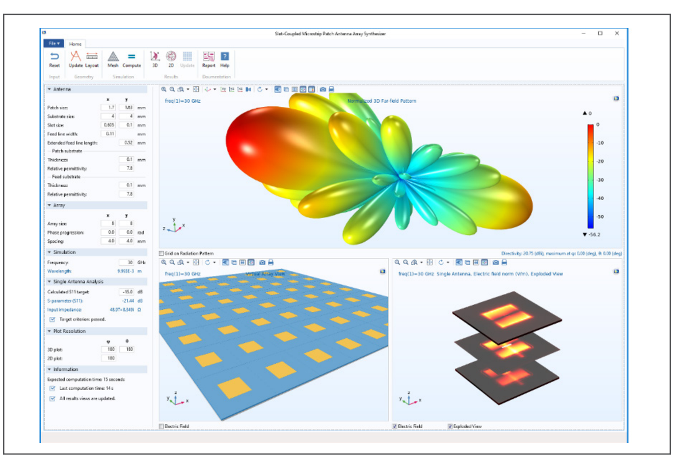
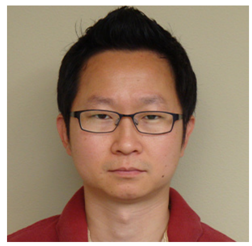


Figure 6: Simulation app for quickly estimating the far-field pattern of a phased array antenna using a full-wave single antenna simulation and array factor.

The variety of simulation tools that support multiple numerical methods within electromagnetics helps engineers and researchers not only to design conventional devices, such as filters, couplers, antennas, and waveguide structures, but also to test EMI and EMC problems in applications for 5G, IoT, and wireless communication. Conventional electromagnetics analyses can be extended to include multiple physical effects using multiphysics simulation. The simulation software industry is also evolving to meet the demands of the fast-paced market for emerging high-speed communication technologies and help more people benefit from simulation.



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Jiyoun Munn is the technical product manager for the RF Module at COMSOL, and a senior member of IEEE. He has two decades of experience in the RF industry, developing more than 150 antenna and microwave device prototypes. Munn also holds patents for antenna interrogation systems. He received his MS degree in electrical engineering from the University of Michigan.

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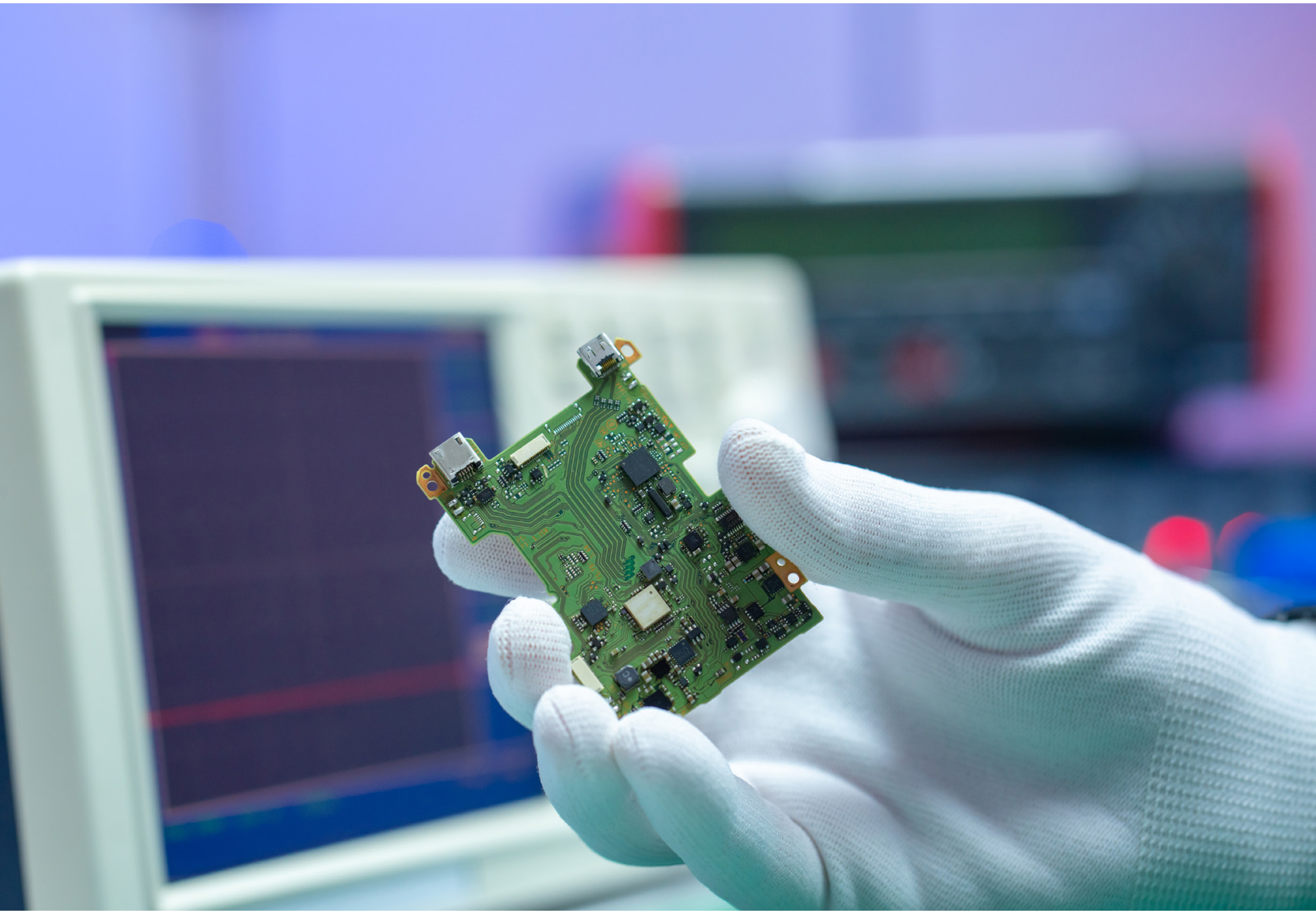


PC BOARD DESIGN FOR WIRELESS PRODUCTS

INTRODUCTION TO SELF-GENERATED EMI

It seems many manufacturers these days are developing products that incorporate wireless technologies — both in new and existing products. Many of these products are using LTE cellular connectivity and designers are finding that the on-board DC-DC converters and processor/memory bus noise are creating enough broadband electromagnetic interference (EMI) that the cellular receiver downlink channels are being desensed (decreased sensitivity) to a point where the product is non-compliant with the cellular provider's sensitivity requirements. Sometimes this broadband EMI even extends up to the GPS bands of 1575.42 MHz affecting navigational performance.

Cellular providers have strict receiver sensitivity requirements and the Total Isotropic Sensitivity (TIS) is one of the tests performed during CTIA compliance. If the receiver is not sensitive enough, the product will not be allowed onto the cellular system (*References 1* and *2*).

WHY PROPER PC BOARD DESIGN IS KEY

One factor that is always key to low-EMI designs is proper PC board design. If high-speed signals are not captured within transmission line structures, common mode current generation, EMI radiated leakage and crosstalk can result. Very often, I find clients use layer stack-up designs suggested in the 1990s for modern wireless designs of today and this is just asking for trouble, with associated schedule delays, debugging, and repeated compliance testing.

In order to understand why proper PC board design is a major key to success, let's first understand how highpeed signals move in circuit boards.

HOW SIGNALS MOVE IN PC BOARDS

I suspect many of us were taught in university or college that electric current was the flow of electrons in copper wires or circuit traces, and that signals travelled at near the speed of light. This is inaccurate. It was also unlikely we were taught much about how signals propagated in circuit board transmission lines during our fields and waves class.

Before you can understand how signals propagate in PC boards, you must first understand some physics (*References 3* and *4*).

This current flow is partially true, of course, for DC circuits (with exception of the initial battery connection transient). But for AC (or RF) circuits or for the switching transients from switch mode power supplies, we need to understand all connecting wires/traces must now be considered transmission lines.

First, let's consider how capacitors seemingly allow the "flow" of electrons. Referring to *Figure 1*, if we apply a battery to the capacitor, any positive charges applied to the top plate will repel positive charges on the bottom plate, leaving negative charges. If we apply an AC source to the capacitor, it might seem as if the current flows through the dielectric, which is impossible. James Clerk Maxwell called this "displacement current," where positive charges merely displace positive charges on the opposite plate leaving negative charges, and vice versa. This displacement current is defined as dE/dt (changing E-field with time).

Electrons and the positively-charged holes do not travel at near light speed in copper as was implied, but move at about 1 cm/sec, due to the very tight atomic bond of the copper molecules (*Reference 4*). There are certainly clouds of free electrons and holes, but these move slowly from molecule to molecule. This is called conduction current and is what we would measure with an ammeter. Conduction current is related to the tangential component of the B-field, that is the $curl\ B = J$.

The influence of one electron in the copper molecule to its neighbor (and on down the transmission line) propagates at the speed of the electromagnetic (EM) field in the dielectric material. In other words, jiggle one electron

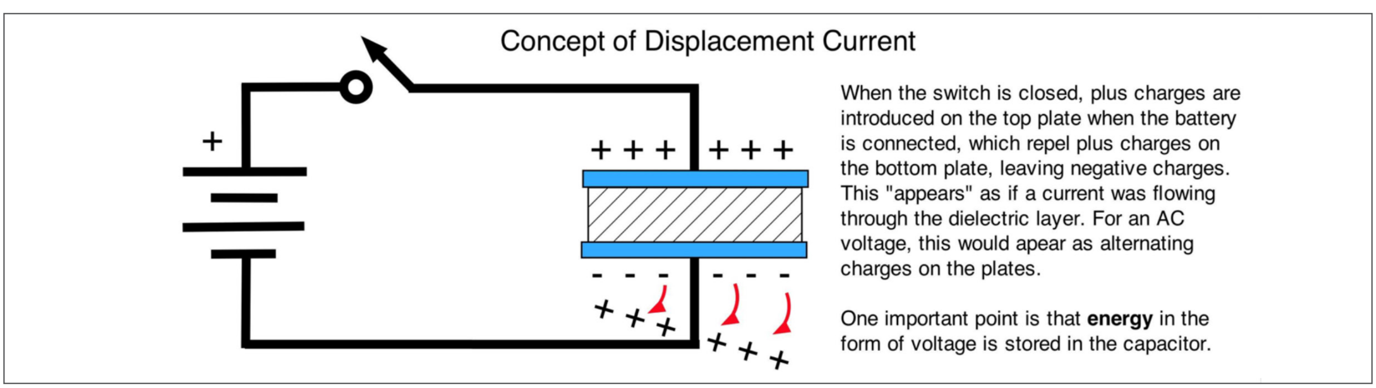


Figure 1. The concept of displacement current through a capacitor.

at one end of a microstrip and it jiggles the next, which jiggles the next, and so on, until it jiggles the last one at the load end of the transmission line. This jiggling is called a kink in the E-field and can be envisioned as the Newton's Cradle toy, a mechanical analogy, where the first ball hits the next and this eventually pops off the end ball (*Figure 2*).

Figure 2. Newton's Cradle is a good analogy to EM field signal propagation in the dielectric of a circuit board.

Let's now consider a digital signal with a wave front moving at about half light speed (about 6 in/ns in FR4 dielectric) along a simple microstrip over an adjacent ground return plane (GRP) as illustrated in *Figure 3*.

The next important point is that the **EM field of the digital signal travels in the dielectric space**—not the copper. The copper merely "guides" the EM wave (*References 4* and *5*).

When the signal (EM wave) is first applied between the microstrip and GRP, it starts to propagate along the transmission line formed by the microstrip over an adjacent GRP. There is a combination of conduction current and displacement current (across the dielectric).

EMI harmonics originate at the wave front as the EM wave propagates. The fast rise or fall times of the signal contain all the harmonic energy and this is what creates the EMI.

If the load impedance is equal to the characteristic impedance of the transmission line, then there will be no reflections of the EM wave back to the source. However, if there is a mismatch, there will be reflected EM fields propagating back to the source. In reality, most realistic digital signals will have multiple reflections moving back and forth through the transmission line simultaneously. The transition zone (rise time or fall time) of these propagating waves will potentially produce EMI.

PHYSICS-BASED RULES FOR TRANSMISSION LINES

With a better understanding of how signals move in circuit boards, there are two very important principles when

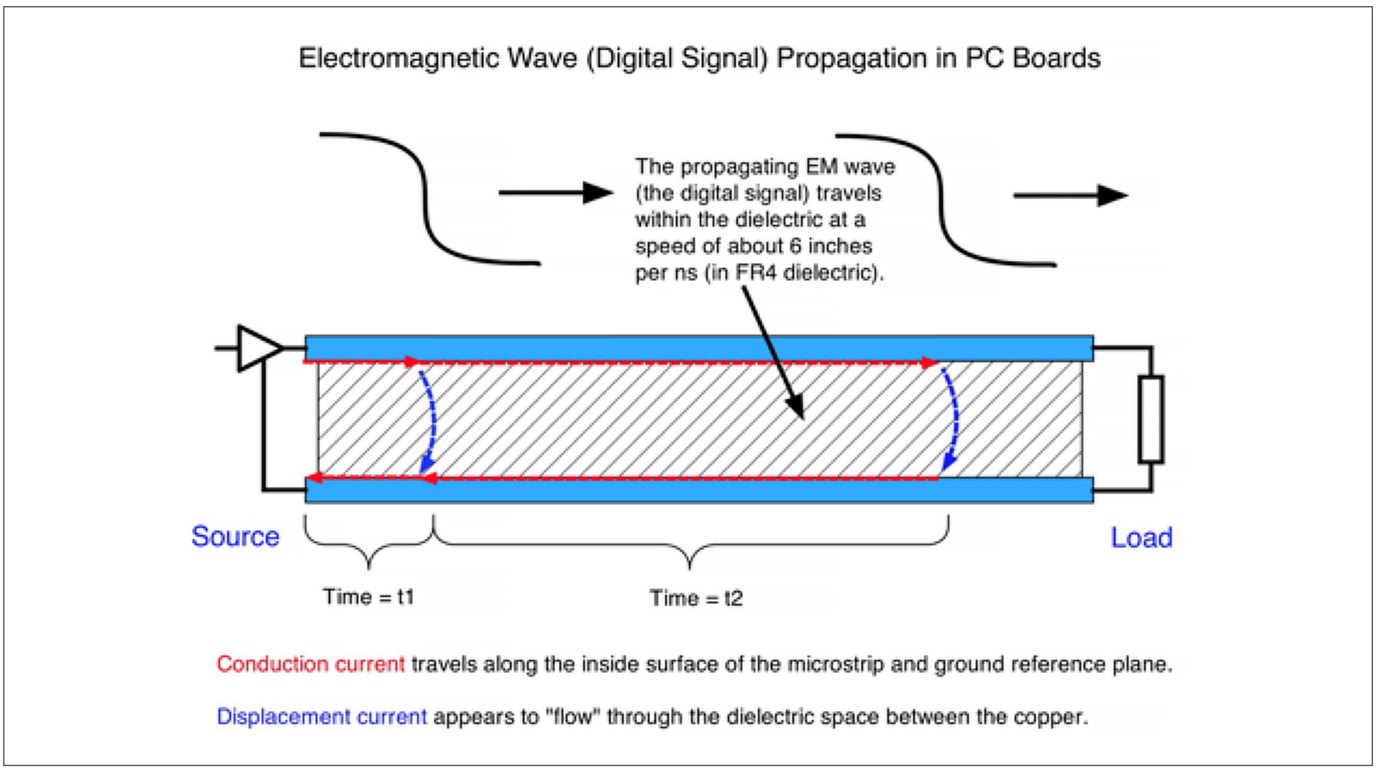


Figure 3. The digital signal (an electromagnetic wave) travels through the dielectric space between the microstrip and ground reference plane (GRP).

it comes to low EMI PC board design:

1. Every signal and power trace (or plane) on a PC board should be considered a transmission line.

2. Digital signal propagation in transmission lines is really the movement of electromagnetic fields in the space between the copper trace and GRP.

To construct a transmission line, you need two adjacent pieces of metal that capture or contain the field. Examples include a microstrip over an adjacent GRP or a stripline adjacent to a GRP or a power trace (or plane) adjacent to a GRP. Locating multiple signal layers between power and ground reference planes will lead to real EMI issues for fast signals.

IMPORTANT POINT #1 - In other words, every signal or power trace (routed power) must have an adjacent GRP and all power planes should have an adjacent GRP. Many products end up violating these two rules, with resulting EMI issues.

IMPORTANT POINT #2 - If you break the path of conduction current in the GRP through a gap or slot, we start to get "leakage" of the signal EM field throughout the dielectric space, which leads to edge radiation from the board and cross-coupling to other circuits through via-to-via coupling. This also occurs when we pass a signal through multiple ground reference or power planes if there is no nearby return path adjacent stitching via or stitching capacitor (to connect GRP to power planes). This self-generated EMI can easily conductively couple or radiate into sensitive cellular receivers. Please refer to the video demo explaining why gaps in the GRP are a disaster for EMI (*Reference 6*).

Via penetration: Very often, signals need to be run from the top side to the bottom side (or interior-to-interior layers), relying on vias to get there. If you only need to pass from one side of a GRP to the other, there's no issue, because the electromagnetic field of the signal is contained between a constant metallic transmission line along the entire path (*Figure 4).*

It's only when you need to pass through multiple planes that many designs fail to provide a continuous return path for the electromagnetic wave as it travels through the dielectric space of the board (*Figure 5)*.

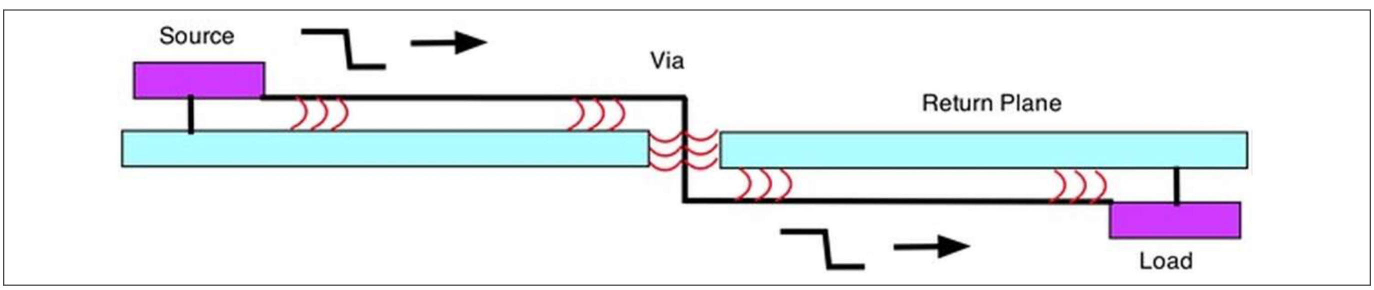


Figure 4. Passing a signal trace through a single GRP allows field propagation along the entire path. The dielectric layer is not shown for clarity and the field propagation is represented by the red "waves."

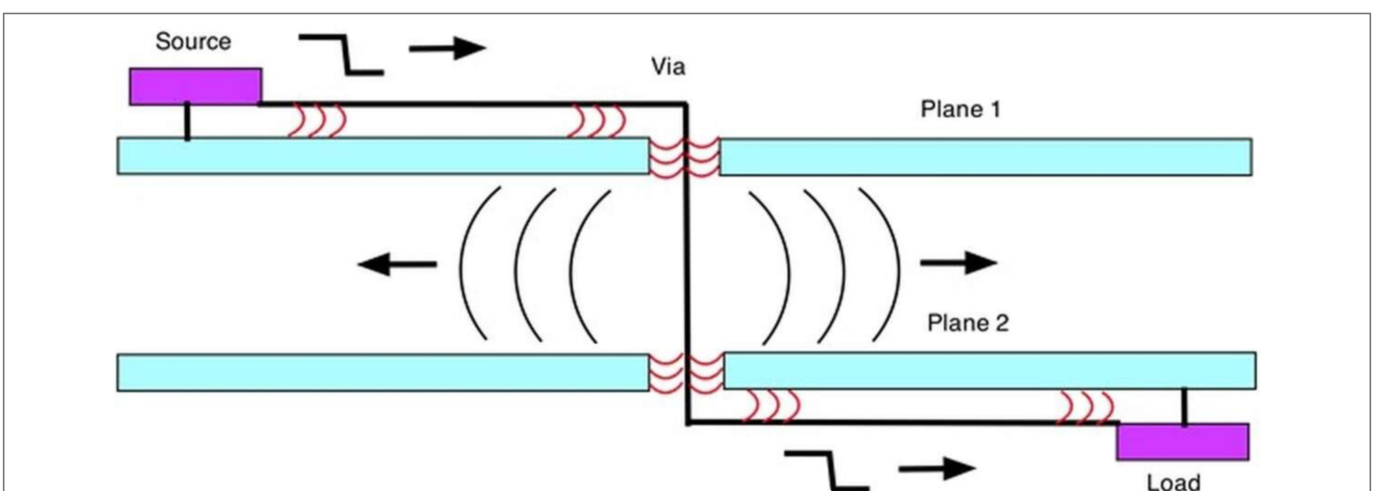


Figure 5. Passing a signal trace through two planes results in field leakage within the dielectric space, unless a defined path for return current is added. The dielectric layer is not shown for clarity and the field propagation is represented by the red "waves."

A lack of transmission-line continuity between the planes (using a stitching via or capacitor), will result in field leakage throughout the dielectric space as the signal tries to find a way back to the source. This field energy will couple to other vias, as well as propagate out as "edge radiation."

If the two planes are GRPs, then you need to merely stitch them together in at least one location near the signal via. This allows field propagation along the entire path. A matrix of ground vias is always a good practice and if they're located very close together (5 mm spacing is good), there's no need to specifically locate one at each penetration.

A challenge presents itself when the two planes are at different potentials, such as a GRP and power, then a stitching capacitor needs to be installed next to the signal via. If there are dozens of signal penetrations on such a board, it may be impractical to add a stitching capacitor for every signal penetration, so that's one reason to locate an even distribution of decoupling/stitching capacitors throughout the board. This will also help reduce "ground bounce" or simultaneous switching noise (SSN).

PROPER BOARD STACK-UP FOR LOW EMI

Observing these two important rules will dictate the layer stack-up. Following are some good and not so good EMI designs. More information on this topic may be found in *References 7* and *8*.

FOUR-LAYER BOARD: POOR (BUT TYPICAL) EXAMPLE

A typical four-layer board design I see often is (top to bottom): Signal - Ground Return Plane - Power Plane - Signal. This worked OK decades ago with relatively slow clock and signal frequencies, but is just asking for EMI issues in today's high frequency wireless technology. Let's show a couple four-layer examples that follow the rules. Note the lack of power planes.

FOUR-LAYER BOARD: GOOD DESIGN 1

Here is an example of a good four-layer board stack-up for improved EMI (*Figure 6*). Instead of a power plane, we use either routed or poured power, along with signals on layers 2 and 3. Thus, each signal/power trace is adjacent to a GRP. Also, it's easy to run simple vias between all layers, so long as the two GRPs are also connected

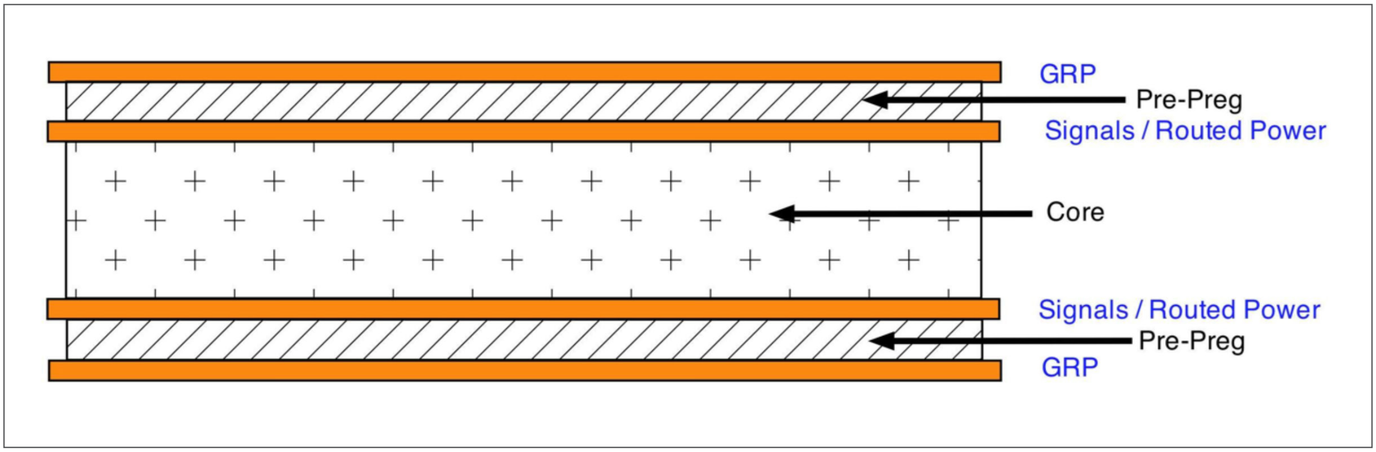


Figure 6. This good four-layer board stack-up for improved EMI keeps the signals and routed power near the ground reference planes.

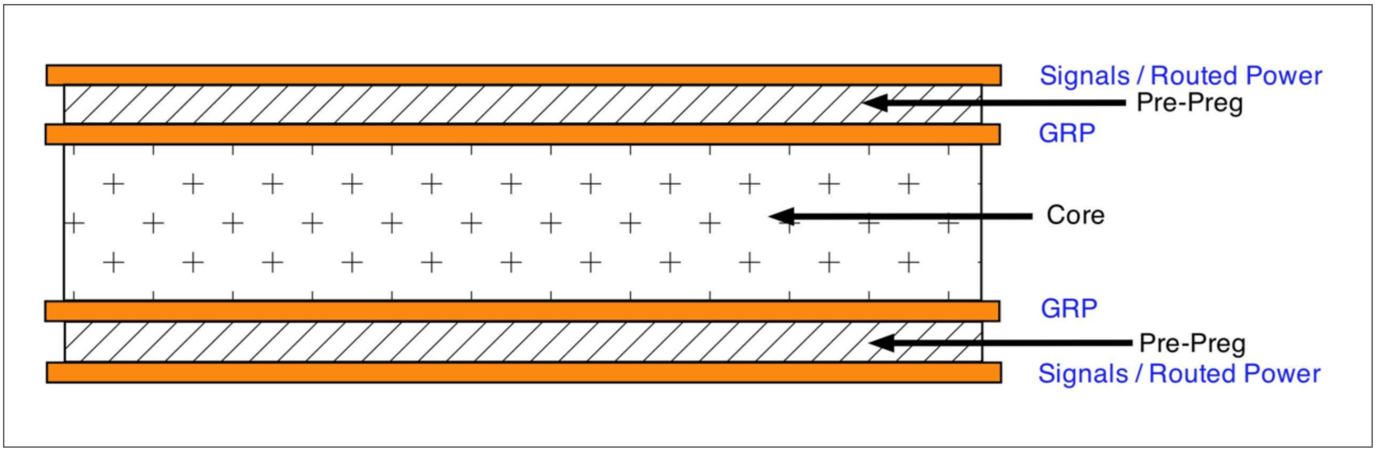
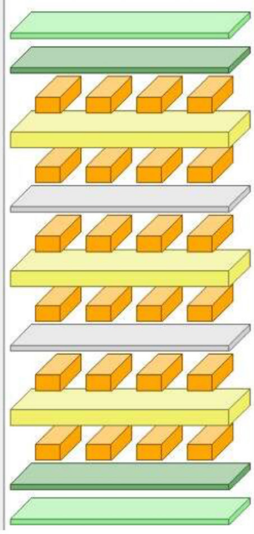


Figure 7. This good four-layer board stack-up for improved EMI places the ground reference planes inside the board.



Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant
Top Overlay	Overlay				
Top Solder	Solder Mask/Coverlay	Surface Material	0.4	Solder ...	3.5
Top Layer	Signal	Copper	1.4		
Dielectric	Dielectric	Core	7	FR-4	4.2
GND	Signal Gnd	Copper	1.4		
Dielectric 3	Dielectric	Prepreg	15	FR-4	4.2
Signal Layer 1	Signal	Copper	1.4		
Dielectric 5	Dielectric	Core	10	FR-4	4.2
Signal Layer 2	Signal	Copper	1.4		
Dielectric 4	Dielectric	Prepreg	15	FR-4	4.2
Power	Signal Power	Copper	1.4		
Dielectric 1	Dielectric	Core	7	FR-4	4.2
Bottom Layer	Signal	Copper	1.4		
Bottom Solder	Solder Mask/Coverlay	Surface Material	0.4	Solder ...	3.5
Bottom Overlay	Overlay				

Figure 8. A very common, but poor, EMI six-layer stack-up design.

together with a matrix of stitching vias. If you run a row of stitching vias along the perimeter (say, every 5 mm) you form a Faraday cage. This is an excellent option for critical wireless products.

FOUR-LAYER BOARD: GOOD DESIGN 2

If, on the other hand, you'd prefer to have access to the signal and routed/poured power traces, you may simply reverse the layer pairs, such that the two GRP layers are in the middle and the two signal layers are positioned at the top and bottom, with routed power and sufficient decoupling caps, rather than a power plane (*Figure 7,* see page 23).

For both four-layer designs, you want to run a 5-mm matrix pattern of stitching vias connecting the two GRPs.

For routed or poured power, every digital device will need 2-3 decoupling capacitors per power pin, or tight groupings of pins. In addition, rails (typically the main digital voltages) should have wider pours around any high *di/dt* devices, such as core voltage, drivers, ASICs, motor controllers, processors, etc. This will help serve as your high frequency decoupling.

TYPICAL SIX-LAYER DESIGN: POOR EXAMPLE

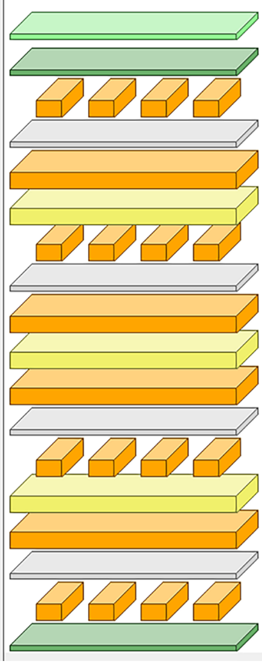
One stack-up I frequently see is this six-layer design (*Figure 8*). This probably worked well enough in the a decade or two ago, but like the poor four-layer design, is recipe for EMI disaster. There are two issues with this: the bottom two signal layers are referenced to the power plane and the power and ground return planes are non-adjacent and too far apart for best EMI decoupling.

With few exceptions (some DDR RAM power and signals, for example) currents want to return to their sources, which are referenced to the GRP. Referencing these signals to the power plane is very EMI-risky, because there is no clearly defined return path, except through plane-to-plane capacitance, which in this case, is relatively small. In addition, the indefinite return path can result in field leakage into other areas of the board's dielectric layers. That, in turn, leads to cross-coupling into wireless receivers and other circuitry and radiated EMI.

The second issue occurs when we have the power and GRP separated by two signal layers. Any power distribution network (PDN) transients will cross-couple to any signal traces on layers 3 and 4 within the dielectric layers. You also lose any plane-to-plane capacitance decoupling benefit if these planes are separated by more than 3-4 mils.

EIGHT-LAYER BOARD (GOOD EXAMPLE)

Both the four- and eight-layer board design examples (*Figures 6, 7,* and *9:* for *Figures 6* and *7*, see page 23, and for *Figure 9,* see page 25) follow the two fundamental rules (IMPORTANT POINT #1) that preserve good transmission line design and resulting low EMI. In addition, for the eight-layer design, the power and GRP planes are now 4 mils apart, providing good plane-to-plane capac-



Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant
TOP SILK	Overlay				
TOP MASK	Solder Mask/Cover	Surface Material	0.04	Solder ...	3.5
Top	Signal	Copper	1.417		
Dielectric1	Dielectric	Prepreg	5	FR-4	4.2
Layer02	Internal Plane Gnd	Copper	0.7		
Dielectric 10	Dielectric	Core	10		4.2
Layer03	Signal	Copper	0.7		
Dielectric 5	Dielectric	Prepreg	10		4.2
Layer04	Internal Plane Gnd	Copper	0.7		
Dielectric 3	Dielectric	Core	4		4.2
Layer05	Internal Plane Pwr	Copper	0.7		
Dielectric 2	Dielectric	Prepreg	10		4.2
Layer06	Signal	Copper	0.7		
Dielectric 8	Dielectric	Core	10		4.2
Layer07	Internal Plane Gnd	Copper	0.7		
Dielectric 9	Dielectric	Prepreg	5		4.2
Bottom	Signal	Copper	1.417		
BOT MASK	Solder Mask/Cover	Surface Material	0.04	Solder ...	3.5

Figure 9. A good EMI stack-up design (8-layer example). All signal layers are referenced to an adjacent GRP, while power is also referenced to an adjacent GRP.

itance. Closer spacing would be even better. For example, a spacing of 1 mil to 3 mils is ideal for minimizing EMI. Multiple GRPs should be stitched together with a 5-mm matrix pattern of vias.

Of course, there are many more iterations on creating proper transmission line pairs between signal and GRP or power and GRP.

PARTITIONING OF CIRCUIT FUNCTIONS

The next most important consideration when laying out the circuitry for your wireless board is partitioning of circuit functions, such as digital, analog, power conversion, RF, and motor control or other high-power circuits.

To avoid signal coupling and crosstalk, you must not allow the various return signals from intermixing within the same dielectric space. Thus, you need to partition major circuit functions. *Figure 10* (see page 26) demonstrates one example of partitioning. Of course, this gets more challenging as board size shrinks. Henry Ott also describes this concept in *Reference 9*.

Another way to separate noisy circuits, such as digital and power conversion, from analog and RF circuitry is to locate the digital on the bottom side of the stack-up and the analog and RF modules on the top side. For practical applications, this often assumes at least an eight layer design with one, or more, GRPs near the middle to isolate the top and bottom sides. Great care must be taken to avoid coupling noisy circuitry with sensitive receivers, in the case of wireless designs.

Because low frequency (less than 50 kHz) or audio signal return currents tend to spread out more, that circuitry must be separated from digital, power conversion, or motor controller circuits. Likewise, sensitive RF receiver circuits, such as GPS, cellular, or Wi-Fi devices must also be kept separate from noisy digital, power conversion, or motor controller circuitry.

While *Figure 10* implies routed power, it is very common to use 3.3V power planes under the digital circuitry for good EMI suppression. Power can also be routed as polygons under the appropriate circuit sections.

ADDITIONAL TIPS

Multiple ground vias: It's a good practice to create a matrix of ground vias connecting GRPs together using a spacing of about 5-mm. This will provide multiple return paths for signals penetrating more than one GRP layer. In addition, if you use multiple GRPs, you should design via stitching all around the periphery of the board to create a Faraday cage for those signal layers in between. This technique is especially useful when incorporating wireless technology in the design.

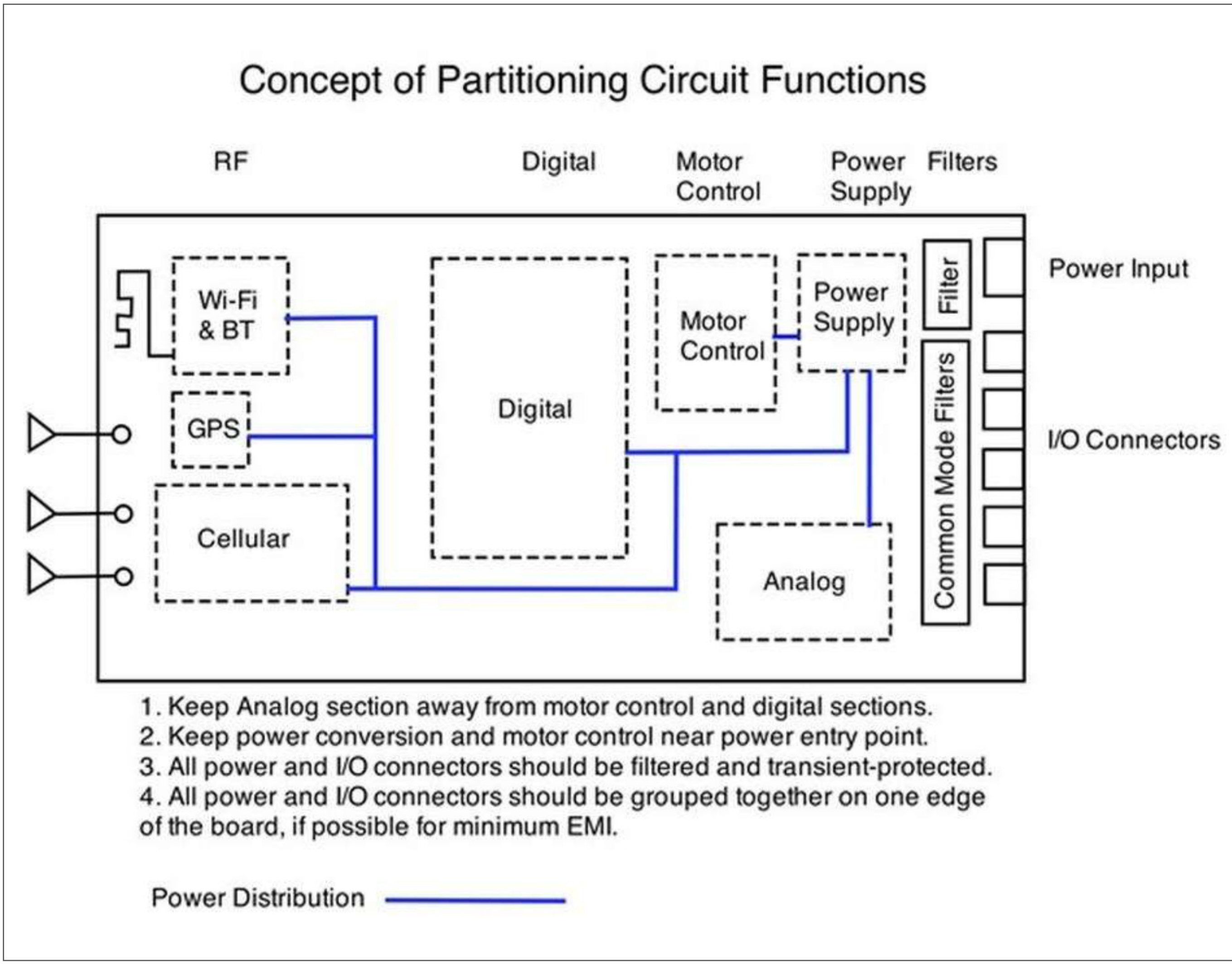


Figure 10. An example of how to partition circuit functions on a board.

Ground fills: While it seems to be a fairly common practice to fill in unused areas within each layer with ground fills, besides being unnecessary, they can lead to the issue of the "trace crossing a gap in the return" problem for dense boards where all the transmission line rules may be difficult to achieve. Eric Bogatin explains this a bit more in *Reference 10*.

Routed power versus power planes: The conventional method is to start with one or more (depending on the number of layers) power-ground "cores" and build the signal layers from there, usually equally on each side of the core for best manufacturability. Typically, digital ground return is used for this. Another big advantage is that when spaced very close together (less than 3 mils), the power-ground core becomes a good high-frequency decoupling capacitor. As the number of layers increase, it's often best to locate two or more power-ground cores closer to the top and bottom of the stack-up — generally on layers 2-3 and 6-7 (on eight-layer boards, for example).

CONCLUSION

Most wireless products, especially smaller portable/mobile devices, now require greater care in their overall system design. An important key to low EMI and consequently, optimum performance, is the design of the PC board. You can largely "throw out" the layout rules used in past years, because at the clock and signal speeds used today, all copper traces become transmission lines and require more care to avoid gaps in the signal path where the electromagnetic wave can "leak out" and couple to sensitive circuits.

The important points to remember are that all signal and power networks should now be considered as transmission lines, the signals and power transients travel at about half light speed within the dielectric space, the copper traces "guide" the signals along the GRP, and circuit functions need to be partitioned across the board real estate in order to reduce coupling. Maintaining these guidelines will help assure the lowest EMI and best performing wireless designs.

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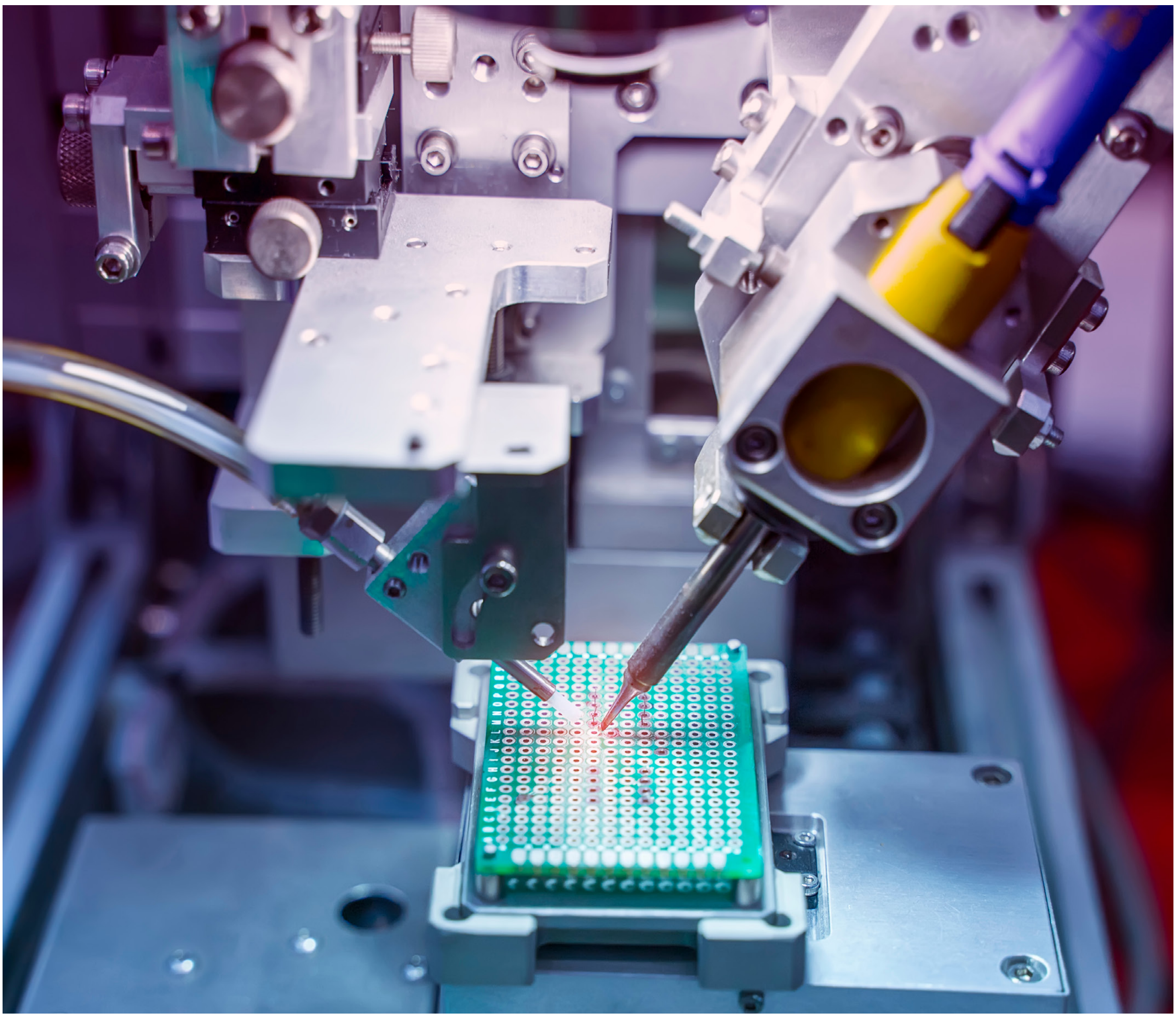

SECURING NEW 5G PHYSICAL ASSETS WITH ELECTRONIC ACCESS CONTROL

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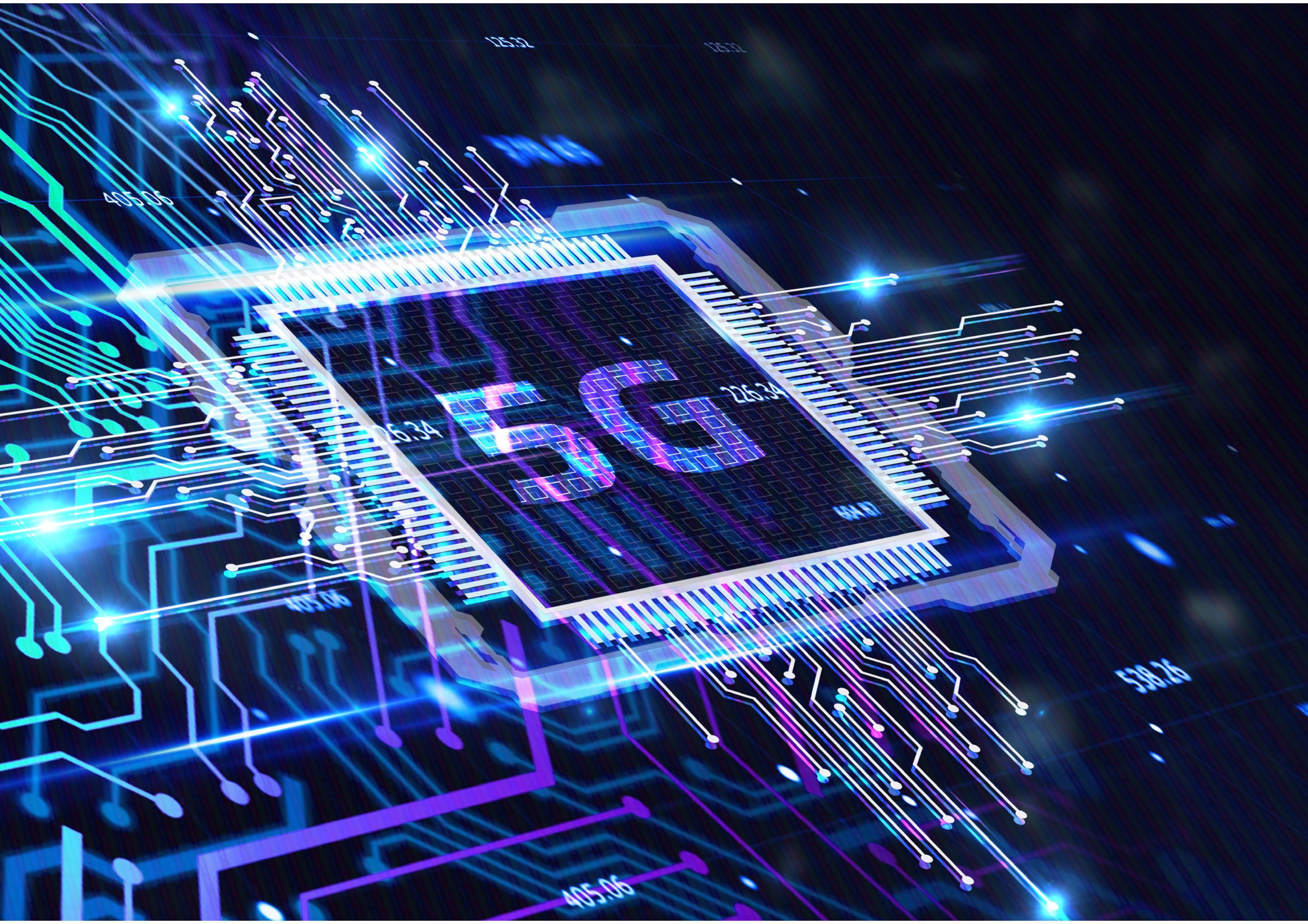

SECURING NEW 5G PHYSICAL ASSETS WITH ELECTRONIC ACCESS CONTROL

The 5G era of mobile computing and communications is rapidly moving forward. 5G stands for the fifth generation of wireless infrastructure—a massive upscale of network technology. It will provide data transfer rates faster than the blink of an eye, reducing latency for even the most data-hungry applications, high bandwidth and greater opportunities for connectivity and reliability.

Figure 1: With the introduction of 5G, networking equipment, storage and computing hardware, other valuable infrastructure will now be located closer to the end user, increasing the need for advanced physical security.

Within the next four years, global spending on 5G infrastructure will exceed $10 billion. A majority of leading telecommunications providers have committed to launching 5G commercially by 2020. Of the 15 largest providers worldwide, nine have public plans to launch 5G by this date, including all of the major providers in the United States, China, and Japan.

This high-value, cutting-edge, digital cell technology will be woven through and added to our existing physical telecommunications environment. However, it's not just a simple upgrade of existing cellular base stations and antennas.

5G cells are generally referred to as small cell wireless facilities (SWF). They are much smaller than typical enclosures, with dimensions that enable them to attach to walls and streetlight poles—or can even be integrated into the pole itself.

With the introduction of 5G, networking equipment, storage and computing hardware, and other valuable infrastructure will now be located closer to the end user, increasing the need for advanced, physical security.

Electronic access solutions (EAS) provide versatile security for small cells and other 5G equipment, as well as offering an intelligent way to efficiently and comprehensively manage physical access to these systems.

Electronic access systems consist of integrated electromechanical locks and latches that can be used to secure enclosures in remote locations. Networked electronic access control systems provide significant benefits for physical security management, providing simplified credential management, and audit trail monitoring for small cells.

SECURING DISTRIBUTED TECHNOLOGY

Like other utilities, such as cable companies and power companies, telecommunications companies have their equipment installed throughout our urban landscape, in cities and suburban housing developments, commercial and industrial locations, along roads and highways—even the most remote locations.

The physical components of our digital world share two common attributes:

- The remote equipment they deploy is secured in enclosures designed to protect the valuable technology that enables functional wireless networks.
- This remote equipment needs to be accessed by a variety of personnel performing routine maintenance and service tasks.

These enclosures are present throughout our world—ubiquitous and utilitarian; they almost disappear from view unless you are seeking them out.

5G small cells will be adding a whole new denser layer of equipment to our world. At their core, small cells are wireless transmitters and receivers designed to provide greater network capacity in smaller areas. While current high power "macro" towers send signals across an entire city, they lack the ability to support the data running through these networks. Global mobile data traffic will increase seven-fold by 2022 due to the continuing development of Internet of Things (IoT) technology.

As the number of devices connecting to the current networks increases, so does the demand for data. Current network infrastructure might provide coverage to all of these devices, but will lack the wireless density to support fast data transfer—ultimately slowing down devices. This explains why an individual might have full signal but still experience slow connection speeds. This is where small cells come in. Small cells multiply wireless density by only servicing a limited area, reducing the likelihood that a small cell will be overwhelmed. This enables networks to meet the data demands from multiple devices at the same time.

There are two key ways our environment will be affected by the launch 5G SWFs:

- These small cells are about the size of a picnic cooler or mini-fridge, with similar sized antennas.
- To provide the bandwidth and service performance the 5G network is designed to offer, they will typically be installed much closer together, which means there will be many more 5G SWFs installed.

Many of these smaller cells have already been deployed to support 4G network service. And many more will be installed as 5G is rolled out through 2020. Until recently, most small cells secured with a basic physical lock were accessed by a key—one that is easily duplicated, thus presenting a security risk.

These SWFs will need to be routinely accessed by service technicians, sometimes from several different companies or subcontractors. Many telecom enclosures use multiple padlocks with different keys assigned to different vendors, an inefficient and vulnerable method for securing the unit.

Securing these widely dispersed systems is crucial, especially since most are located within reach of the public, are (for the most part) unattended and are at significant risk for vandalism and theft. These enclosures are often targets for thieves seeking valuable materials, such as batteries, copper wire and other electronic components.

One further danger associated with vandalism and theft is downtime. When equipment in these enclosures is damaged due to theft or vandalism, that node on the network goes down. Bringing it back online requires emergency repair dispatch and new components, combined with the costs associated with downtime of any network segment. Investing in more secure locking systems, such as electromechanical locks and latches can save on these significant downtime costs.

Figure 2: Concealed electronic access solutions, like Southco's AC-EM-10 series provide an effective physical security solution for small cell enclosures. The sealed AC-EM-10 features a compact design that takes up minimal application space and facilitates the electronic actuation of mechanical latches.

UPGRADING ENCLOSURE SECURITY

Electronic access solutions provide an effective physical security solution for these new enclosures. Compared to mechanical locks, which must be accessed by a physical key, EAS provides a digital credential that can be easily issued, traced, and even revoked from anywhere in the world.

An electronic access solution is composed of three primary components: an access control reader or input device, an electromechanical lock and a controller for monitoring the status of the access point. When designing an EAS, choosing the appropriate electronic lock for the specific enclosure will provide the intelligence, flexibility, and security needed for the small cell.

The most basic type of electronic access credential is an RFID card, which is widely used in many building management and technician management operations today. Many telecom service providers and the contractor vendors who service them already use RFID cards for accessing central and local offices, data centers, and other operational locations.

Figure 3: Telecom providers are encouraging enclosure manufacturers to incorporate hardware that complements the industrial design of SWFs, like Southco's E6 Constant Torque Positioning Hinge series, which provides superior durability in harsh outdoor environments and improves aesthetics.

Another form of access credential is an electronic PIN code which can be changed on a recurring basis, with different codes assigned to each individual. This makes the credential more personal. The downside is that PINs are easily shared and lost or forgotten, which can complicate maintenance activities and add security risks.

The most secure access credential is one with more than one layer, and is unique to the individual and easily modified through cloud-based systems. For example, an EAS platform that supplies an electronic, time-based key via a mobile app on a technician's smartphone has the following layers of personalization:

- The phone and phone number are unique to the technician. Some smartphones today actually have biometric-type security that uses a thumbprint or facial recognition scans to unlock the phone.
- The smartphone app the technician uses to download the key from the cloud platform is secure and password protected.
- The electronic key loaded to the app is site- and event-specific. It can only be used to open a specific enclosure, and only for a scheduled period of time.

When combined with a robust, secure intelligent electronic lock, these cloud-based access controllers can provide simple solutions for providing time-based access control to 5G small cells.

Audit trails generated by electronic access solutions provide telecom management with an additional resource: They can track when a 5G small cell door is opened in order to monitor maintenance and service activity. If a 5G cell is scheduled for activity that should take an hour, but the audit trail shows the enclosure access panel was open for far longer, management can find out why the delay occurred and exercise better management of service personnel and costs for service.

EAS is a scalable solution that is applicable when needing to add electronic access to a large number of distributed enclosures. Some enclosure manufacturers and end users have a perception that these electronic access solutions require significant hardware, IT investment, and ongoing support. However, there are EAS platforms that can provide secure access and control without having to wire into a network or install additional hardware or software. As a result, electronic access solutions can be used to elevate the physical security of 5G enclosures with minimal cost and complexity.

ON THE POLE—OR IN THE POLE

Many new 5G SWFs will be attached to streetlights and utility poles, as they are already pre-equipped to meet the needs of 5G small cells. They have the proper height (no more than 50 feet), already have power and are often close to telecom fiber-optic lines, which is the backhaul network connectivity for the 5G cells.

At this juncture, most 5G SWFs are boxes attached to the light poles at sufficient height to provide line-of-sight connectivity to the surrounding cells. However, there is a growing trend to adapt the poles themselves as the enclosure. In some cases, this is done by building the enclosure into an ornamental base; in others, the solution is to install equipment up through the length of the pole.

For enclosure manufacturers, this presents an engineering and aesthetic challenge. Many municipalities have zoning regulations defining physical and visual characteristics of street fixtures like poles. These codes (particularly in historic locations, city centers, and commercial locations) set equipment design criteria to minimize the "intrusion" of network equipment into established settings.

The telecom providers seeking to install 5G networks are encouraging enclosure manufactures to design external elements, like access panels, hinges, and latches, to be more attractive by using hardware that's flush-mounted, concealed, and inconspicuous.

With equipment that is installed within the length of the pole, there may be a need to have two or more access panels tied to different pieces of cell equipment. Enclosure manufacturers can benefit from working with component suppliers who can supply or custom-modify hinges and electromechanical locks to have form factors that satisfy these requirements.

CONCLUSION

5G technology promises a major transformation in the way our networked, mobile computing world operates. Newly emerging concepts such as autonomous vehicles and smart cities will need the bandwidth and millisecond response time 5G offers to move from vision to reality. The IoT will also demand more bandwidth: It's estimated that there were 8.4 billion connected "things" in 2016, which is expected to grow to 20.4 billion connected elements by 2020.

As 5G equipment is deployed, it needs to be both fully secured and easily accessed on an ongoing basis. Electronic access solutions provide significant benefits for physical security management, providing simplified credential management and audit trail monitoring. By using EAS platforms to better secure these enclosures, valuable, and sensitive equipment can be better protected, and maintaining and servicing the equipment protected by these enclosures can be managed with efficiency, flexibility, and maximum security.

BIO

Mike Fahy is Commercial Product Manager for Southco's Electronic Access Solutions (EAS) division. He has over 27 years of experience working in various roles supporting Southco around the world. Fahy focuses on solutions for data center rack level security, from self-contained to fully-networked access control systems. He holds a Bachelors in Mechanical Engineering from Drexel University and is a member of AFCOM.

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
- Wireless and Telecom Industry Network
- 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) 2020
An exhaustive 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-2020/

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

USEFUL WIRELESS REFERENCES

USEFUL BOOKS (CONTINUED)

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.

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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