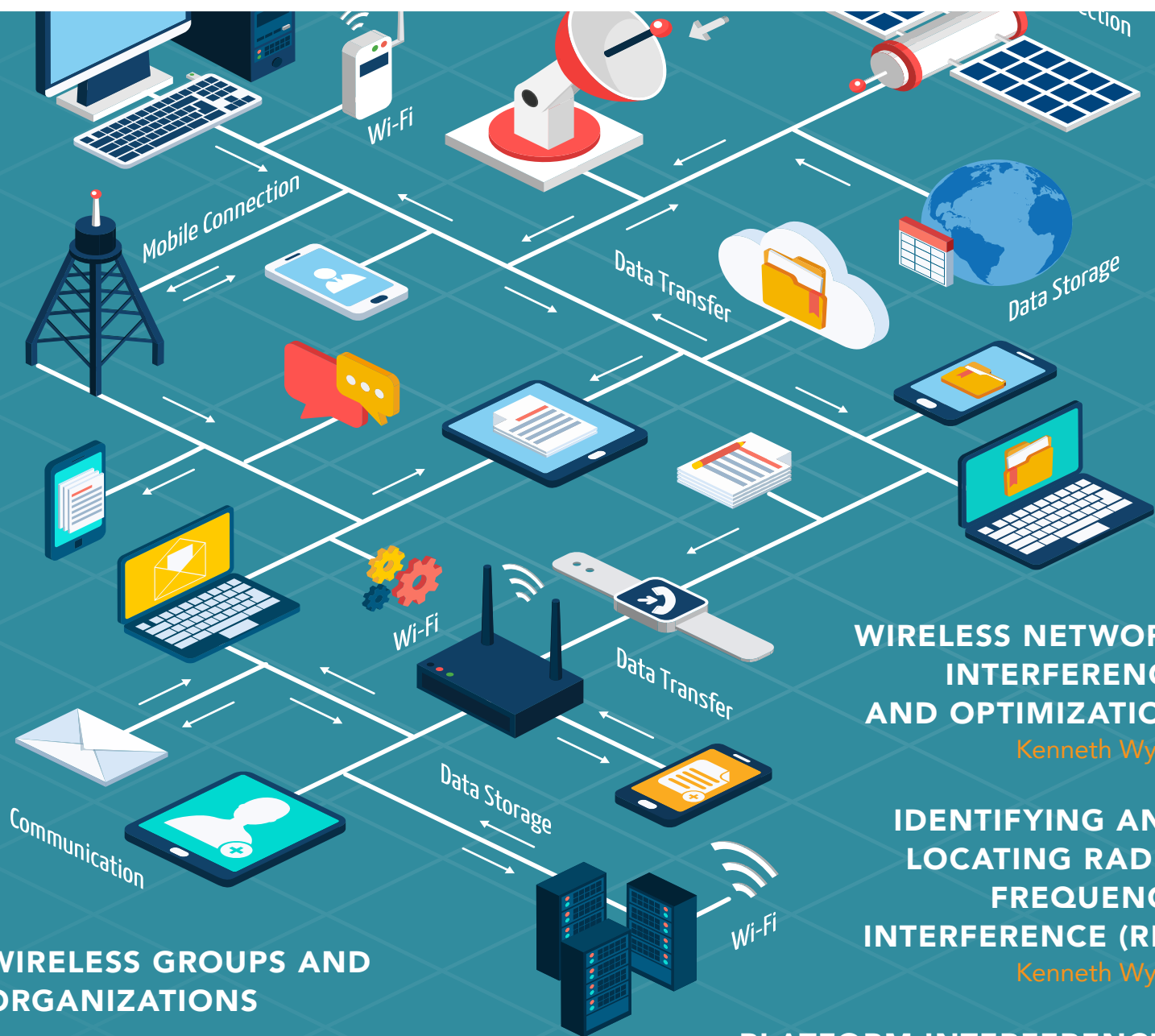


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2017 WIRELESS INTERFERENCE & RFI GUIDE



**WIRELESS NETWORK
INTERFERENCE
AND OPTIMIZATION**

Kenneth Wyatt

**IDENTIFYING AND
LOCATING RADIO
FREQUENCY
INTERFERENCE (RFI)**

Kenneth Wyatt

**PLATFORM INTERFERENCE -
MEASUREMENT AND
MITIGATION**

Kenneth Wyatt

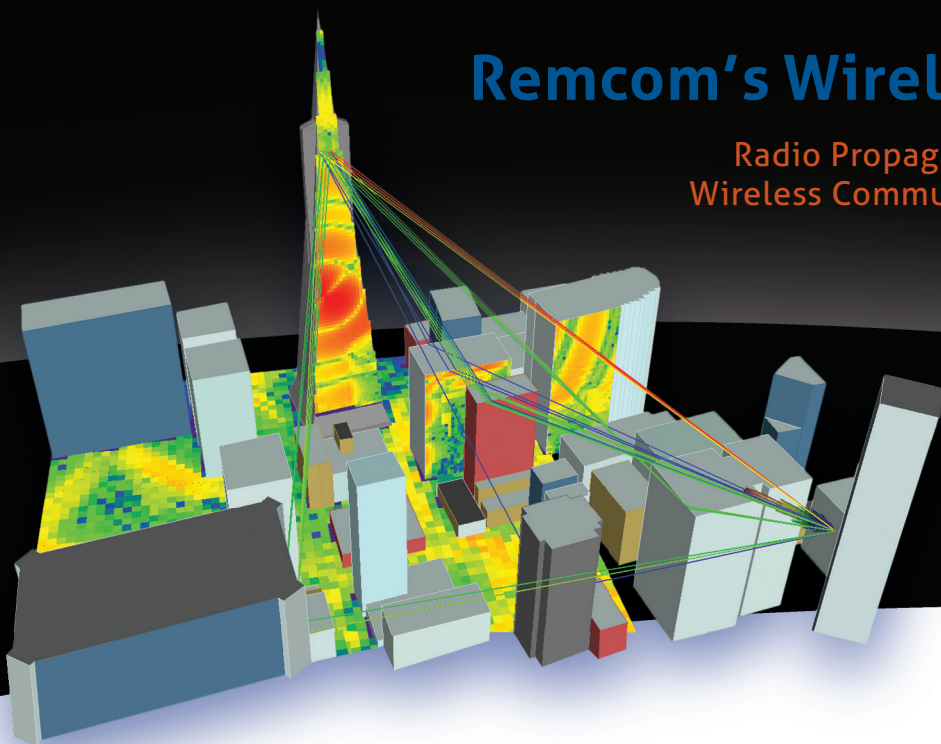
**WIRELESS GROUPS AND
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WIRELESS CONFERENCES 2017

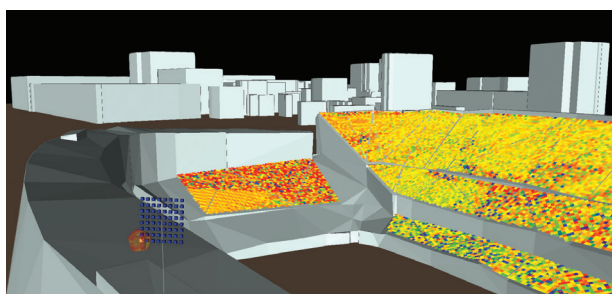
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INTRODUCTION

Wireless and radio frequency interference (RFI) has reared up as much more of an issue as we've moved more to a mobile society. The proliferation of current and developing wireless systems, broadcast, two-way communications, and "Internet of Things" (IoT) systems only make the risk of interference greater. The fact that most of the wireless systems are relegated to rather narrow ISM (Industrial, Scientific, and Medical) frequency bands makes for an increasingly crowded spectrum.

This new 2017 Wireless Interference and RFI Guide will include content and reference material in three primary areas:

- Interference to wireless systems, resulting in spectrum congestion and resulting data slowdown.
- Interference Hunting - finding and mitigating sources of interference to wireless, broadcast, and communications systems.
- Platform Interference - that is, self-interference to on-board telephone and wireless modules from noise sources, such as DC-DC converters and other high frequency sources that degrade cellular telephone receiver sensitivity.

In addition, we include a reference section with a host of useful information on wireless networks, protocols, frequencies, bands, organizations and pertinent conferences and trade shows.

We're hoping this will be of value to those who are installing or managing wireless networks, as well as those in the communications and broadcast industry that are designing and installing systems. Tools and techniques are described for identifying, locating, and mitigating sources of interference, including those within the product itself.





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WIRELESS INTERFERENCE & RFI SUPPLIER GUIDE

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 & RFI Supplier Guide		Type of Equipment								
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Current Probes	Fixed DF Systems	Mobile DF Systems	Near Field Probes	Portable DF Systems	Pre-Compliance Test	Spectrum Analyzers / Receivers
Aaronia AG	http://www.aaronia.com	X	X		X	X		X	X	X
Alaris Antennas	http://www.alarisantennas.com	X								
Anritsu	http://anritsu17-px.rtrk.com/en-US/test-measurement/industries/automotive/								X	X
CommsAudit	https://www.commsaudit.com/products/direction-finding	X			X	X				X
Doppler Systems	http://www.dopsys.com	X			X	X		X		
Emscan	http://www.emscan.com								X	
Gauss Instruments	https://www.gauss-instruments.com/en/									X
Kent Electronics	http://www.wa5vjb.com	X								
Keysight Technologies	http://www.keysight.com/main/home.jsp?cc=US&lc=eng						X		X	X
Morcom International	http://www.morcom.com/direction_finding_systems.html							X		X
Narda/PMM	http://www.narda-sts.it/narda/default_en.asp	X	X						X	X
Pearson Electronics	http://www.pearsonelectronics.com			X						
RDF Antennas	http://www.rdfantennas.com/bc-121-5.php							X		
RDF Products	http://www.rdfproducts.com				X	X				X
Rhotheta America	http://www.rhothetaamerica.com/index.html				X	X		X		
Rigol Technologies	https://www.rigolna.com			X			X		X	X
Rohde & Schwarz	https://www.rohde-schwarz.com/us/home_48230.html	X	X	X	X	X	X	X	X	X
Siglent Technologies	http://siglentamerica.com						X		X	X
Signal Hound	https://signalhound.com						X		X	X
SPX/TCI	http://www.spx.com/en/our-businesses/detection-and-measurement/TCI/	X			X	X		X		X
TechComm	http://www.techcommdf.com	X			X	X		X		X
TekBox Technologies	https://www.tekbox.net		X				X		X	
Tektronix	http://www.tek.com					X	X	X	X	X
Teseq	http://www.teseq.com/en/index.php		X	X					X	
Thurlby Thandar (AIM-TTi)	http://www.aimtti.us								X	X
UST	http://www.unmannedsystemstechnology.com/company/marshall-radio-telemetry/							X		X

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WIRELESS NETWORK INTERFERENCE AND OPTIMIZATION

Kenneth Wyatt

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Introduction

With the proliferation of embedded wireless systems in all imaginable products, comes the risk of increasing interference and resulting slowdown in data transfer. As we transition to a more mobile and connected society, the number of Wi-Fi (home appliances and control) and Bluetooth-enabled devices (speakers, headset, watches, etc.) is rapidly increasing. Add to that the increasing number of, so-called Internet of Things, (lighting control, thermostats, and security systems), all utilizing wireless technology, and can only imaging the congestion and resulting interference issues.

This article discusses some of the interference issues with wireless networks, describes some useful tools to help evaluate and optimize your networks for minimum interference and maximum data throughput.



WIRELESS NETWORK INTERFERENCE AND OPTIMIZATION

If you live or work in the city, it's not unusual to have a dozen, or more, separate 2.4 GHz Wi-Fi access points (APs) or "hot spots" within range of your own system. Fortunately, I live out in the country, but my system can still "see" a half-dozen APs nearby. If two, or more, nearby APs are using adjacent overlapping channels, the result can be a massive slowdown in data transfer for both systems. Add to this many wireless phones, baby monitors, and microwave ovens, all operating in this same 2.4 GHz Industrial, Scientific, and Medical (ISM) band and you can imagine the resulting interference issues possible.

The above are only the most common sources of interference in the 2.4 GHz ISM band. Here is a more complete list:

- Wi-Fi (IEEE 802.11b, 802.11g, and 802.11n)
- Bluetooth (IEEE 802.15.1)
- ZigBee (IEEE 802.15.4)
- Microwave ovens (2.450 GHz center frequency)
- Cordless telephones and baby monitors
- Custom FCC Part 15 devices (Internet of Things)
- Licensed users (Amateur radio at 2.39 to 2.45 GHz)

In this article, we'll briefly cover the two major wireless protocols (Wi-Fi and BT), provide some frequency, band plans, interference issues, and optimization methods.

Wi-Fi

While Wi-Fi is allocated to two different bands (2.4 and 5 GHz), predominantly, most APs, computers, and mobile devices, still operate in the 2.4 GHz band. Here's the worldwide channel allocations for Wi-Fi in this band ("ETSI" is the European channel plan).

Channel	Center Frequency	USA Canada	ETSI	Japan
1	2412 MHz	X	X	X
2	2417 MHz	X	X	X
3	2422 MHz	X	X	X
4	2427 MHz	X	X	X
5	2432 MHz	X	X	X
6	2437 MHz	X	X	X
7	2442 MHz	X	X	X
8	2447 MHz	X	X	X
9	2452 MHz	X	X	X
10	2457 MHz	X	X	X
11	2462 MHz	X	X	X
12	2467 MHz	-	X	X
13	2472 MHz	-	X	X
14	2484 MHz	-	-	X

Figure 1. Wi-Fi channel worldwide allocations. Figure, courtesy Robert Morrow.

Wi-Fi uses Orthogonal Frequency Division Multiplexing (OFDM) for 802-11a, g and n, and variations of Direct Se-

quence Spread Spectrum (DSSS) for 802-11b. Wi-Fi also uses a "listen-before-talk" scheme called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to avoid collisions with other APs on the same channel. Of course, the more APs there are on a given channel, the more likely the data throughput will be slowed due to the forced CSMA/CA activity and repeated data packets.

The number of channels is rather limited, unfortunately. But, even worse, these channels are overlapping in order to fit within the limited ISM band. In the U.S., there are 11 channels on 5 MHz spacing with just three non-overlapping channels; 1, 6, and 11 (in Europe; channels 1, 7, and 13). When two APs operate on the same channel, collisions are reduced because they both use CSMA/CA and each can sense a transmission from the other. Rather than jam each other, they instead coordinate their transmissions so both can support a reasonable throughput - roughly sharing the bandwidth equally. For example, for a 10 Mb/s throughput, two APs would share about 5 Mb/s, three APs would share about 3.3 Mb/s, and so forth.

Fortunately, most AP manufacturers set the default channel to one of these channels, so the chances are pretty good your own AP will not be clashing too badly with your neighbor's AP. However, if any nearby APs are set to one of these non-overlapping "rogue" channels they will create havoc to the "standardized" channels on either side, because adjacent channels are not recognized as valid APs and most of the time will be spent with data packet collisions and resends, greatly reducing the throughput. Therefore, it's best to stick with channels 1, 6, or 11.

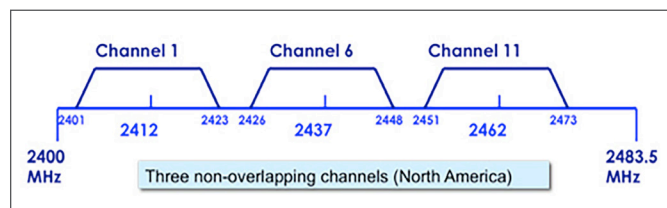


Figure 2. There are only three non-overlapping Wi-Fi channels in the U.S. 2.4 GHz ISM band. Figure, courtesy Robert Morrow.

Bluetooth

Bluetooth (BT) devices operate in the same 2.4 GHz ISM band as Wi-Fi, with channels starting at 2402 and ending at 2480 MHz, with 1 MHz channel spacing. BT uses a Frequency Hopping Spread Spectrum (FHSS) protocol and has a moderate data rate of 1, 2, and 3 Mb/s. The range is generally limited to about 10m. Recently, BT Low Energy has been developed and uses a similar protocol and channel scheme, except the data rate is nominally 1 Mb/s.

In the meantime, the Bluetooth 5 standard has been released and products are due to hit the market within the next six months. You can expect up to four times the range, twice the speed, and eight times the amount of data in broadcast messages.

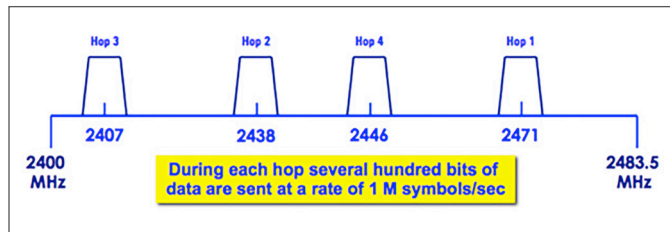


Figure 3. Example of a few hop-channels for Bluetooth. Figure, courtesy Robert Morrow.

Wi-Fi and Bluetooth Coexistence

You may wonder how BT avoids interfering with Wi-Fi, and visa versa. The earliest BT devices indeed had an issue with collisions, but later 802.15.1 standards included the concept of Adaptive Frequency Hopping (AFH). BT devices now evaluate interference on a particular hop channel and if it senses a Wi-Fi channel in use, will automatically avoid that channel.

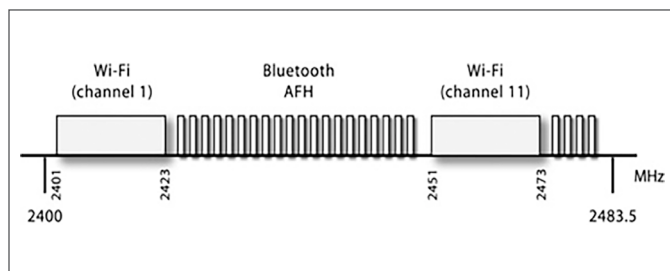


Figure 4. Graphical example of Wi-Fi channels with Bluetooth adaptive frequency hopping (AFH) used to avoid collisions. Figure, courtesy Robert Morrow.

By using a real-time spectrum analyzer, we can see this adaptive frequency hopping and resulting BT/Wi-Fi coexistence clearly. For example, using the Tektronix RSA306 USB-based real-time spectrum analyzer, it's possible to see three different APs on the same channel, along with several BT hop frequencies (*Figure 5*). Persistence is turned on, so the latent image of past BT hops and Wi-Fi bursts may be observed.

Interference Issues

While multiple Wi-Fi APs can degrade the data throughput of systems set up on the same, or adjacent, channels. What happens when we add other interfering devices? For example, many older wireless telephones operate using FHSS in the same 2.4 GHz ISM band (*Figure 6*). These phones do not have anti-collision protocols and will transmit over the top of existing Wi-Fi and BT devices, thereby causing multiple “resends” of the packetized data streams. Obviously, placing your wireless phone near your AP would compromise the data throughput whenever the phone was in use.

Fortunately, newer wireless phones use the Digital Enhanced Cordless Telecommunications (DECT, or DECT 6.0 in the U.S.) standard that uses the general frequency band of 1880 to 1930 MHz (with variations in frequency limits depending on the country), so interference with 2.4 GHz Wi-Fi is no longer the issue it once was.

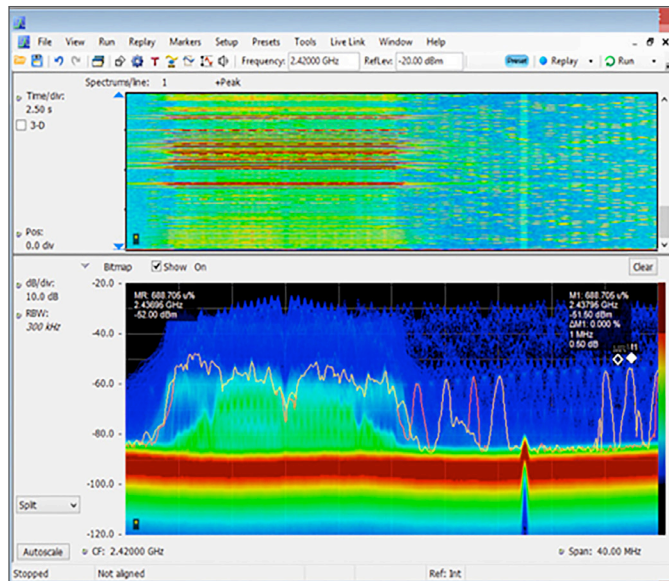


Figure 5. A real-time spectral plot with spectrogram display (upper plot) showing a Wi-Fi channel with Bluetooth hopping while avoiding the Wi-Fi signal. Note that because of the extremely fast capture rate, you can observe three separate Wi-Fi APs on the same channel (lower plot). This would be impossible to see on a normal swept frequency spectrum analyzer.

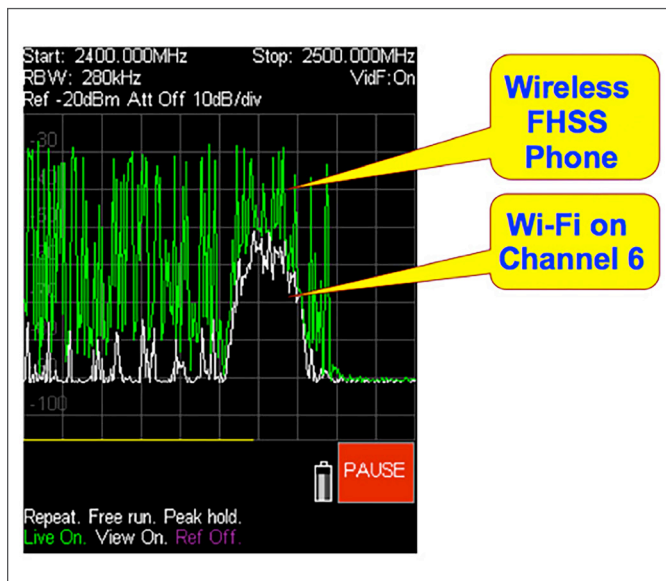


Figure 6. An example of wireless telephone interference to Wi-Fi channel 6.

How about microwave ovens? The magnetron operates at a (nominal) center frequency of 2.450 GHz - right in the middle of the 2.4 GHz ISM band.

In the example shown in *Figure 7*, microwave oven emissions were captured with the Tektronix RSA306 real-time spectrum analyzer. You can see that the analyzer is fast enough to have captured a couple of the microwave pulses, which occur every 16 ms. These pulses are derived from the half-wave rectifier in the magnetron power supply.

This view includes the maximum (40 MHz) real-time bandwidth of the RSA306, which is less than half the

total bandwidth of the 2.4 GHz band. Note, however, nearly the entire 40 MHz is unusable due to the level of interference. If your AP channel was anywhere near, your data throughput would likely be extremely degraded. The only saving grace is that microwave ovens are only used briefly.

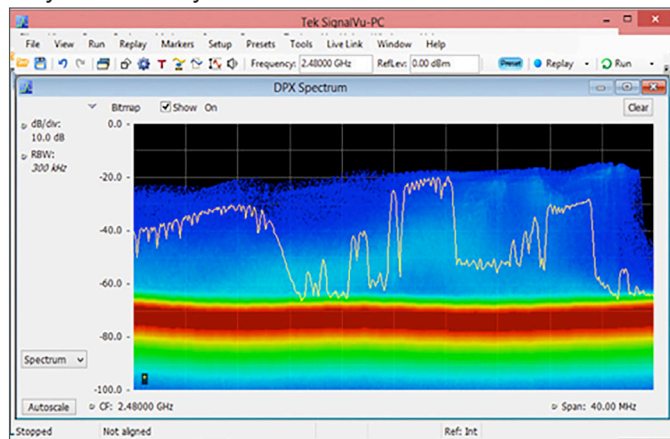


Figure 7. A real-time spectral plot showing the signal from a microwave oven. The blue persistence zone is a picture of the actual interference, while the orange line is an instantaneous capture of the magnetron signal. Note the pulsed 16 ms periodicity, due to the half-wave rectifier in the magnetron power supply.

Solutions

Obviously, we should avoid deploying APs near interfering devices and appliances when depending on Wi-Fi systems for fast throughput, like streaming video. As for multiple Wi-Fi systems located close together, the best route is channel management and possibly moving your APs to the 5 GHz ISM band (802.11ac or 802.11n), where there are far fewer interference sources. Another advantage is that the 5 GHz ISM band has 23 non-overlapping channels from which to select.

There are a number of Wi-Fi network evaluation software packages for both Windows and Mac operating systems that can help you evaluate both 2.4 and 5 GHz wireless networks. I use the “Wi-Fi Explorer” from Adrian Grenados (*Figure 8*) for the Mac in the example.

The advantage is that the software can utilize the built-in Wi-Fi 2.4 and 5 GHz receivers built into the laptop to capture all the nearby APs, including signal strength, network names, and Service Set Identifiers (SSIDs). Equivalent Windows software would include Kismet (www.kismetwireless.net) or inSSIDer (www.inssider.com). There are likely several other choices.

Also useful in managing your Wi-Fi network is “heat-mapping” software, such as the Mac-based “Wi-Fi Scanner” from www.netspotapp.com. Equivalent Windows software might include Ekahau (www.ekahau.com).

By creating a simple floorplan of your home or facility using the built-in drawing tool and then walking around with your laptop in hand, you can map out the signal strength

of a particular Wi-Fi system. By observing “dead zones”, you can relocate the AP to a more suitable spot or add “slave” APs to fill in the gaps.

In addition, for best system performance when designing a large system of multiple APs, be sure to set their channels to 1, 6, or 11 in an alternating selection of channels and in patterns of slightly overlapping reception ranges. For example, the first set of four APs could be set to channel 1, 6, 11, then back to 6 or 1, etc. In other words, be sure there are no two adjacent APs set to the same channel by maximizing the distance between any two APs on the same channel.



Figure 8. “Wi-Fi Explorer” screen capture showing how the software can identify all the nearby access points, along with system names, SSIDs and signal strength. to that most APs are located in one of the three non-overlapping channels. Notice one AP is set to a “rogue” channel 10 and so will cause extreme data slowing to those APs on channel 11.

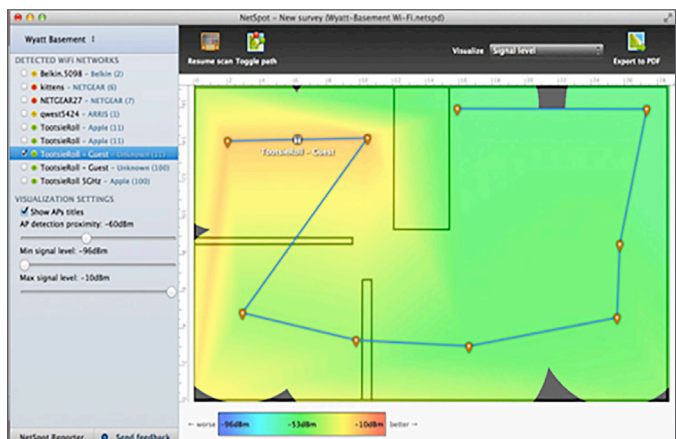


Figure 11. An example of a Wi-Fi “heat map” of my own system. Mapping out the signal strength is useful in managing and optimizing Wi-Fi networks.

Conclusion

With the proliferation of wireless devices and networking systems, the risk of decreased data throughput will only increase. By using low cost spectrum analysis tools or software-based Wi-Fi network analyzers and mapping tools, interference sources may be identified and wireless networks managed and optimized.

More information on spectrum analyzers:

Real-Time Spectrum Analyzers Guide (2016) from Interference Technology <http://learn.interferencetechnology.com/2016-real-time-spectrum-analyzer-guide/>

Tektronix RSA306 Review in The EMC Blog, hosted by EDN (Part 1 and Part 2).

Another affordable real-time spectrum analyzer would include the Signal Hound BB60C. See the review in The EMC Blog, hosted by EDN (Part 1 and Part 2).

Swept frequency spectrum analyzer mentioned: Thurlby Thandar PSA2702T spectrum analyzer review in The EMC Blog, hosted by EDN.

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1. How-To Geek, How You and Your Neighbor Are Making Each Other's W-Fi Worse.
2. How-To Geek, How To Get a Better Wireless Signal and Reduce Wireless Network Interference.
3. Robert Morrow, public and in-house wireless and Bluetooth seminars. www.wireless-seminars.com.
4. Robert Morrow, Bluetooth Operation and Use, McGraw-Hill, 2002.
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IDENTIFYING AND LOCATING RADIO FREQUENCY INTERFERENCE (RFI)

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Introduction

With the plethora of wireless devices, increasing broadcast, communications, and other RF sources all competing for radio spectrum, the chances of radio frequency interference (RFI) will only increase. This article explains how to identify, characterize, and locate typical interfering sources.



IDENTIFYING AND LOCATING RADIO FREQUENCY INTERFERENCE (RFI)

CATEGORIES OF INTERFERENCE

There are two broad categories of interference; narrow band and broadband (Figure 1).

Narrow Band – this would include continuous wave (CW) or modulated CW signals. Examples might include clock harmonics from digital devices, co-channel transmissions, adjacent-channel transmissions, intermodulation products, etc. On a spectrum analyzer, this would appear to be narrow vertical lines or slightly wider modulated vertical bands associated with specific frequencies.

Broadband – this would primarily include switch-mode power supply harmonics, arcing in overhead power lines (power line noise), wireless digitally-modulated systems (such as Wi-Fi or Bluetooth), or digital television. On a spectrum analyzer, this would appear to be broad ranges of signals or an increase in the noise floor. Power line noise or switch-mode power supplies are the most common sources.

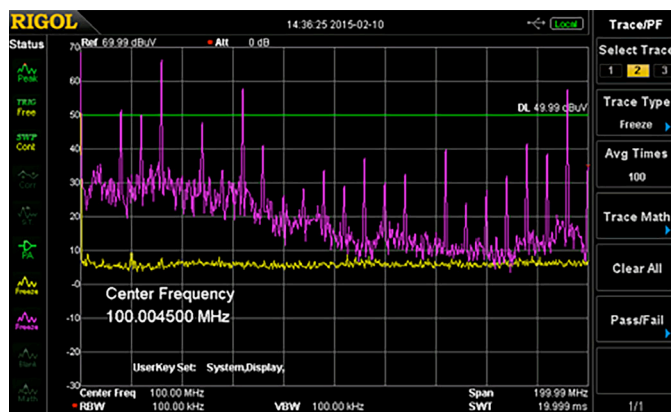


Figure 1. An example spectral plot from 9 kHz to 200 MHz of narrow band harmonics (vertical spikes) riding on top of broadband interference (broad area of increased noise floor). The yellow trace is the baseline system noise.

TYPES OF INTERFERENCE

Some of the most common types of interference are described below.

Co-Channel Interference – more than one transmitter (or digital harmonic) using, or falling into, the same receive channel.

Adjacent-Channel Interference – a transmitter operating on an adjacent frequency whose energy spills over into the desired receive channel.

Intermodulation-Based Interference – occurs when energy from two, or more, transmitters mix together to produce spurious frequencies that land in the desired receive channel.

Third-order mixing products are the most common and usually, this occurs from nearby transmitters. An example of potential intermodulation might occur in a strong signal area for FM broadcast.

Fundamental Receiver Overload – this is normally caused by a strong, nearby, transmitter simply overloading the receiver front-end or other circuitry, causing interference or even suppression of the normal received signal. A common example is VHF paging transmitters interfering with receivers.

Power Line Noise (PLN) – This is a relatively common broadband interference problem that is typically caused by arcing on electric power lines and associated utility hardware. It sounds like a harsh raspy buzz in an AM receiver. The interference can extend from very low frequencies below the AM broadcast band, and depending on proximity to the source, into the HF spectrum. If close enough to the source, it can extend up through the UHF spectrum.

Switch-Mode Power Supplies – Switch-mode power supplies are very common and are used for a variety of consumer or commercial products and are a common source of broadband interference. Lighting devices, such as the newer LED-based lights or commercial agricultural “grow” lights, are another strong source of interference.

Other Transmitters – There are several transmitter types that commonly cause RFI:

- **Two-Way or Land Mobile Radio** - Strong interfering FM signals may result in “capture effect”, or over-riding of the desired received signal.
- **Paging Transmitters** - Paging transmitters are generally very powerful FM or digitally modulated transmissions that can overload receiver circuits. Digital paging will sound very raspy, like a power saw or buzzing, and may interfere with a wide range of receive frequencies. Fortunately, most of the VHF paging transmitters moved to the 929/931 MHz frequency pairs, so this is not the issue it once was.
- **Broadcast Transmitters** - Broadcast transmitter interference will have modulation characteristics similar to their broadcasts – AM, FM, video carriers, or digital signals.

Cable Television - Signal leakage from cable television systems will generally occur on their prescribed channel assignments. Many of these channels overlap existing over-the-air radio communications channels. If the leaking signal is a digital channel, interference will be similar to wideband noise (a digital cable channel is almost 6 MHz wide).

Wireless Network Interference - Interference to wireless networks (Wi-Fi, Bluetooth, etc.) is increasingly common,

and with the proliferation of mobile, household (IoT), and medical devices incorporating Wi-Fi and other wireless modes, this issue is likely to get worse. More details on wireless interference will be found in the companion article, Wireless Network Interference and Optimization.

LOCATING RFI

SIMPLE DIRECTION FINDING (DFING)

DF Techniques - There are two primary methods for DFing. (1) "Pan 'N Scan" where you "pan" a directional antenna and "scan" for the interfering signal, recording the direction on a map, while keeping note of intersecting lines. (2) "Hot and Cold" where an omni-directional antenna is used while watching the signal strength. In this method, the rule of thumb is for every 6 dB change you've either doubled or halved the distance to the interfering source. For example, if the signal strength was -30 dBm at one mile from the source, traveling to within a half-mile should read about -24 dBm on the spectrum analyzer.

DF Systems - Radio direction-finding (RDFing) equipment can be installed into a vehicle or used portable. For vehicular use, there are several automated Doppler direction-finding systems available. Some examples include:

- Antenna Authority (mobile, fixed and portable)
www.antennaauthorityinc.com
- Doppler Systems (mobile and fixed)
www.dopsys.com
- Rohde & Schwarz (mobile, fixed, and portable)
<http://www.rohde-schwarz.com>

Step Attenuator - You'll also find a step attenuator quite valuable during the process of DFing. This allows control over the signal strength indication (and receiver overload) as you approach the interference source. The best models come in steps of 10 dB and have a range of at least 80 dB, or more. Step attenuators may be purchased through electronics distributors, such as DigiKey, etc. Commercial sources would include Narda Microwave, Fairview Microwave, Arrow, and others.

LOCATING POWER LINE INTERFERENCE

For Low Frequency Interference - particularly power line noise (PLN) - the interference path can include radiation due to conducted emissions along power lines. Therefore, when using the "Hot and Cold" method you'll need to be mindful that the radiated noise will generally follow the route of the power lines, peaking and dipping along the route. The maximum peak usually indicates the actual noise source. As a complication, there may be several noise sources - some possibly long distances away.

Antennas - For simply listening to power line noise, the built-in "loopstick" antenna on an AM broadcast band

radio or telescoping antenna on a shortwave radio may work well. However, for tracking down power line noise to the source pole, and typically for DFing other interfering sources, you'll want to use higher frequencies. A simple directional Yagi, such as the Arrow 146-4 II (Figure 1) with three piece boom (www.arrowantennas.com) can be assembled quickly and attached to a short length of pipe and works well to receive this type of broadband RFI.

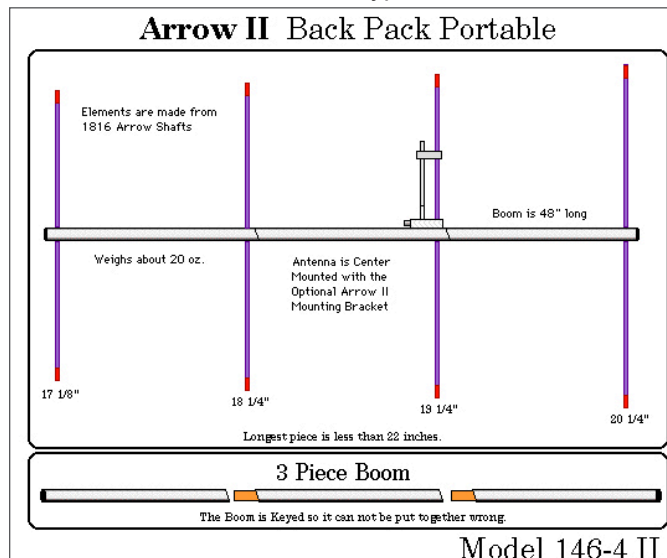


Figure 1 - The Arrow Antenna Model 146-4 II antenna may be used as a low cost directional antenna for locating power line interference.

Use of VHF Receivers - Whenever possible, you'll generally want to use VHF or higher frequencies for DFing. The shorter wavelengths not only help in pinpointing the source, they also make smaller handheld antennas more practical.

Signature Analyzers - These are time-domain interference-locating instruments that produce a distinct "signature" of an interfering signal. This would include instruments produced by Radar Engineers (Figure 2). They are the best solution for tracking down power line noise and consumer devices that produce repetitive noise bursts with known periodicity.



Figure 2. A signature analyzer from Radar Engineers that tunes from 500 kHz to 1 GHz and which displays an electronic "signature" of a specific interference source. Receivers such as this are used by professional investigators to track down power line noise (photo courtesy, Radar Engineers).

LOCATING NARROW BAND INTERFERENCE

For most narrow band interference sources, such as co-channel, adjacent channel, and intermodulation interference, the recommended tool is the spectrum analyzer, as this allows you to focus on particular frequency channels or bands and see the big picture of what's occurring. Once the interfering signal is identified, the analyzer can then be used to DF the signal.

USING SPECTRUM ANALYZERS

Spectrum analyzers display frequency versus amplitude of RF signals. They can be helpful in determining the type and frequencies of interfering signals, especially for narrow band interference. There are two types of analyzers; swept-tuned and real time.

Swept-tuned analyzers are based on a superheterodyne principle using a tunable local oscillator and can display a desired bandwidth from start to stop frequencies. They are useful for displaying constant, or near constant, signals, but have trouble capturing brief intermittent signals, due to the lengthy sweep time.

A real-time analyzer samples a portion of the spectrum using digital signal processing techniques to analyze the captured spectrum. They are able to capture brief intermittent signals and are ideal for identifying and locating signals that may not even show up on swept analyzers. Most real-time bandwidths are limited to 27 to 500 MHz, maximum. The Signal Hound BB60C and Tektronix RSA306 are both relatively inexpensive real-time spectrum analyzers that are USB-powered and use a PC for control and display.

One important point to keep in mind regarding the use of spectrum analyzers is that because they have an un-tuned front end, they are particularly susceptible to high-powered nearby transmitters off frequency from where you may be looking. This can create internal intermodulation products (spurious responses) or erroneous amplitude measurements that are very misleading. When using spectrum analyzers in an "RF rich" environment, it's important to use bandpass filters or tuned cavities (duplexers, for example) at the frequency of interest.

Spectrum analyzers are also useful to characterize commercial broadcast, wireless, and land mobile communications systems. For wireless or intermittent interference, real-time analyzers work best. If used for tracking PLN, it's best to place the analyzer in "zero-span" mode to observe the amplitude variation. Placing the analyzer in "Line Sync" may also be helpful.

COMMERCIAL INTERFERENCE HUNTING SYSTEMS

There are several manufacturers of interference hunting or direction-finding systems. I'd like to describe four of

these, Aaronia, Narda, Rhode & Schwarz, and Tektronix.

As mentioned previously, for intermittent interference (particularly for commercial communications installations) or digitally-modulated signals, a real-time spectrum analyzer is the best tool and has the ability to capture brief, intermittent, signals; some as short as a few microseconds. Examples might include the Aaronia Spectran V5 series. Tektronix RSA-series, or Narda IDA2.

Aaronia - Aaronia not only has the lightest portable system for Dfing, but the biggest and heaviest-looking. Their Spectran V5 Handheld is the smallest real time analyzer. Mapping is not an option on this model, but the larger Spectran V5 XFR PRO is a ruggedized laptop that can use open-source maps and has triangulation features. Aaronia also has a variety of affordable directional antennas and a combination GPS/compass may be mounted on some models.



Figure 3. The Aaronia Spectran V5 handheld real-time analyzer is the smallest self-contained unit and tunes from 9 kHz to 6 GHz. Other models have upper frequencies of 12 and 18 GHz.

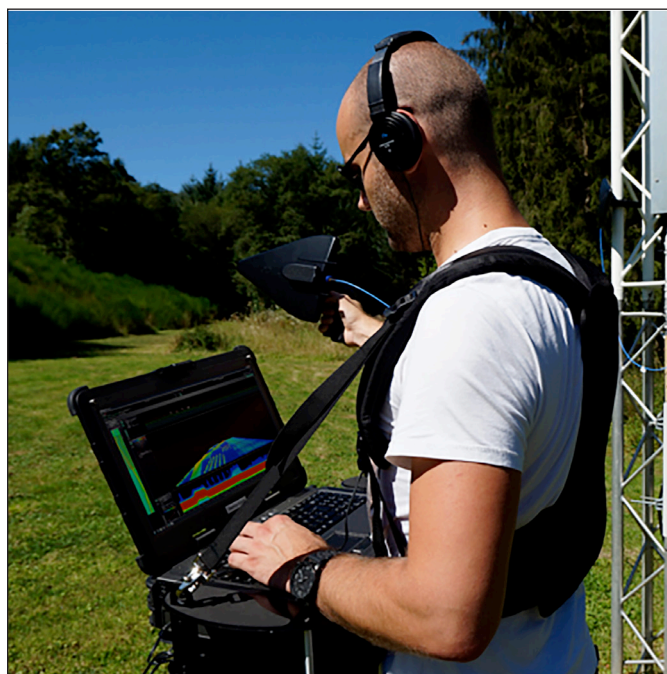


Figure 4. The Aaronia Spectran V5 XFR PRO in the field portable configuration.



Figure 5. The Narda IDA2 spectrum analyzer and interference hunting system. The frequency range is 9 kHz to 6 GHz. Photo, courtesy Narda STS.

Narda Safety Test Solutions - Narda has a similar interference analyzer, the Model IDA2 with a real-time bandwidth of 32 MHz and frequency range of 9 kHz to 6 GHz. There are a variety of directional antennas available with built-in GPS and compass. This system also relies on open-source mapping tools, such as Open Street Maps (<http://www.openstreetmaps.org>). It is battery-operated for easy portable use.

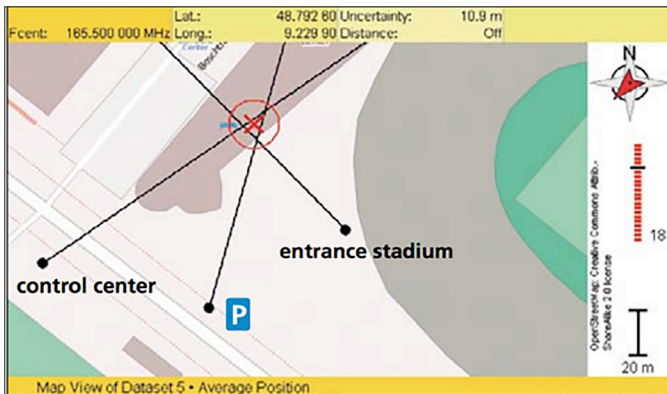


Figure 6. The mapping software with bearing lines drawn showing triangulation of an interference source. Photo, courtesy Narda STS.



Figure 7. The Rohde & Schwarz R&S®PR100 custom spectrum analyzer with mapping and triangulation and R&S®HE300 antenna. The R&S® FSH analyzer may also be used. Photo courtesy, Rohde & Schwarz.

Tektronix - Tektronix also has a means of Dfing and mapping with their real time DSA-series spectrum analyzers. The USB-controlled RSA507A is noteworthy due to it's built-in battery and portable capability. It also offers 40 MHz real-time bandwidth. By connecting it to a tablet PC, such as the Panasonic Toughpad model FG-Z1 and with the Alaris DR-A0047 antenna, you have a self-contained portable DF hunting tool (Figure 9). This system also relies on open-source mapping tools, such as Open Street Maps (<http://www.openstreetmaps.org>).



Figure 8. The mapping application for the R&S® FSH analyzer. Photo courtesy, Rohde & Schwarz



Figure 9. The Tektronix spectrum analyzer with mapping/triangulation and Alaris DR-A0047 antenna. Photo, courtesy Tektronix.

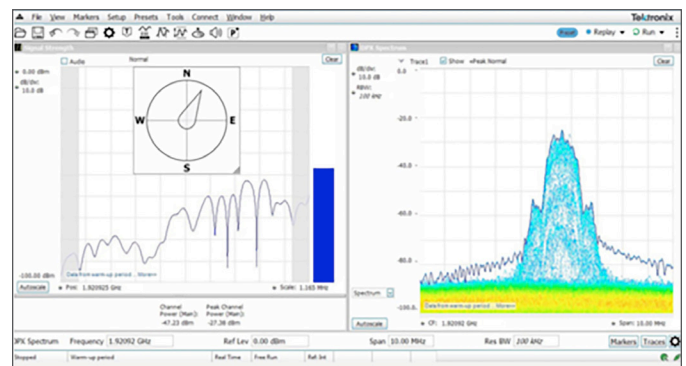


Figure 10. When the SignalVu-PC software with mapping option is connected to one of their RSA-series real time spectrum analyzers and Alaris directional antenna, the compass direction is automatically shown, along with the spectral display of the signal in question. Photo, courtesy Tektronix.

Tektronix provides their SignalVu-PC with Mapping option to help identify and capture interfering signals. The mapping option allows bearing lines to be marked on the map to triangulate the source of interference.

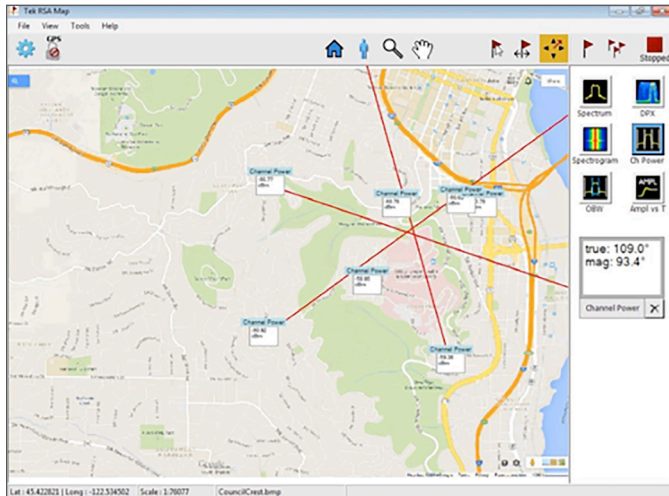


Figure 11. Flipping over to the mapping option of SignalVu-PC, allows you to record bearing lines to the interfering source, with the triangulation showing the approximate location of the source. Photo, courtesy Tektronix.

Summary

With today's increasing use of wireless devices, broadcast, communications, military and other RF sources all competing for radio spectrum, the chances of radio frequency interference (RFI) will only increase. With the proper tools, broadcast and communications engineers are able to quickly identify and eliminate sources of interference as they are detected. The latest real-time spectrum analyzers make the job even more efficient.

Manufacturers Mentioned

Aaronia AG
<http://www.aaronia.com>

Narda Safety Test Solutions
<https://www.narda-sts.com/en/>

Radare Engineers
<http://www.radarengineers.com>

Rohde & Schwarz
https://www.rohde-schwarz.com/us/home_48230.html

Tektronix
<http://www.tek.com>

References

- Handheld Interference Hunting (R&S video)
- Automated Interference Hunting in Multipath Environments (R&S video)
- Advanced Interference Hunting and Emitter Location (R&S)
- Interference Hunting with R&S®FSH (R&S)
- Locating A Signal Source (R&S)
- Interference Hunting (Tektronix)
- Hunting Interference with the Tektronix RF Scout (Tektronix)
- Finding, Classifying, and Analyzing Interfering Signals (Tektronix)
- Clock Radio Disrupts VHF Reception (Narda STS)
- Analysis of Jamming Systems for Mobile Phone (Narda STS)
- Drone Detection System (Aaronia)



PLATFORM INTERFERENCE - MEASUREMENT AND MITIGATION

Kenneth Wyatt

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Introduction

As a consultant, I'm seeing an increasing number of manufacturers wanting to add or retrofit wireless into new or existing products. Products typically include mobile, household, industrial, scientific, and medical devices. Also, the trend toward the "Internet of Things" (IoT) or the Industrial Internet of Things (IIoT) adds to the problem. This transition towards "everything wireless" is in full swing and with it comes problems with EMI. That is, EMI from the product itself interfering with sensitive on-board telephone, GPS/GNSS, and Wi-Fi/Bluetooth receivers. This is called "platform" or self-interference and it's a big problem for manufacturers.



PLATFORM INTERFERENCE - MEASUREMENT AND MITIGATION

Most digital-based products create a host of on-board radio frequency “noise” (electromagnetic interference, or EMI), that usually won’t bother the digital circuitry itself, but the harmonic energy from digital clocks, high-speed data buses, and on-board switch-mode power supplies can easily create interference well into the 700 to 950 MHz and higher mobile phone bands, causing receiver “desense” (reduced receiver sensitivity).

In order to use the various mobile phone services (Verizon, ATT, Sprint, T-Mobile, and others in the U.S.), manufacturers must pass very stringent receiver sensitivity and transmitter power compliance tests, as described above, according to CTIA standards. This on-board digital noise often delays product introductions for weeks or months. Cellular and wireless providers require a certain receiver sensitivity in dBm called Total Isotropic Sensitivity, or TIS.

For example, this might typically be a sensitivity of -108 dBm, and must include the effect of antenna efficiency used in the mobile device. Because mobile device antennas typically operate in close proximity to human hands or head, this tends to reduce the sensitivity further (-99 dBm might be typical, depending on the antenna).

More information on this, as well as the test methods, are described in “Test Plan for Mobile Station Over the Air Performance: Method of Measurement for Radiated RF Power and Receiver Performance”, by the CTIA (Cellular Telephone Industries Association), now known as “CTIA - The Wireless Association”. See *Reference 1*. Cellular radio manufacturer, Broadcom, also has some information in their white paper, Compliance with TIS and TRP Requirements (*Reference 2*).

Several recent clients all had platform interference issues that kept their products off the market for weeks or months until major product redesigns were done. In this article, I’ll show what this noise looks like, how to measure it, and will list common problem areas and suggest some mitigations.

Characterizing On-Board Noise (Platform Interference)

First, let’s take a look at a typical product. Specific details will remain general for confidentiality purposes. This board includes a USB port whose data ultimately gets transmitted via various mobile phone systems, depending upon the factory configuration.

There are generally two primary areas of focus where on-board noise can couple to the receiver antenna and cause receiver degradation:

- On-board sources, such as DC-DC converters, address

and data buses, and other fast-edged digital signals

- Attached cables that act as “radiating structures” (antennas), such as I/O and power cables

There are two measurement techniques I commonly use to characterize platform interference

- High frequency current probes are best used for measuring small RF currents on cables
- Near field magnetic or electric field probes for locating noise sources

In *Figure 1* below, a current probe is used to measure the common mode harmonic currents flowing on the outside of a shielded USB cable. How these currents are formed and why they tend to couple onto cables is explained more completely in *References 2 and 3*. Let’s just say that noise currents generated on the PC board can easily couple to attached I/O and power cables, which can then re-radiate into the radio module.

The spectrum analyzer is the most useful tool for these measurements, as entire frequency spectrums may be observed. *Figure 1* shows the general test setup.

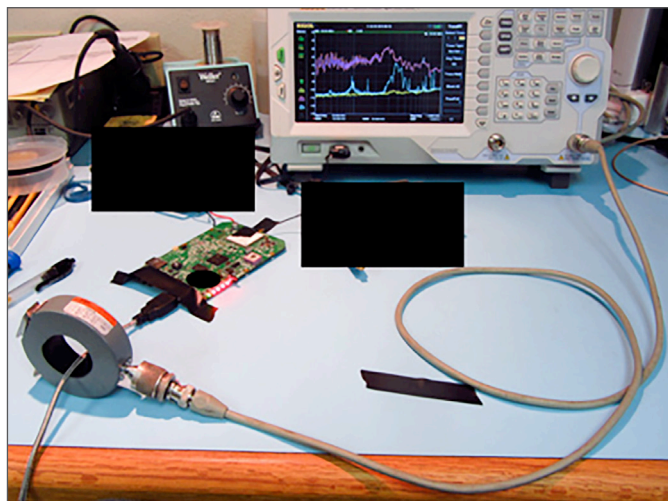


Figure 1. The measurement setup for general PC board noise characterization. Near field probes are used to narrow down the areas of noise generation and to characterize the type of noise produced at the board. In this case, a high frequency current probe is being used to measure the USB cable harmonic currents coupled to the outside of the shielded cable.

There are two common types of high frequency harmonic plots; narrow band and broadband. *Figure 2* shows the difference as we’re looking from 9 kHz to 1.5 GHz.

Typically, DC-DC converters or data/address bus data will appear as a very broad signal with several resonant peaks (violet trace in *Figure 2*), while crystal oscillators or high speed clocks will appear as a series of narrow spikes (aqua trace in *Figure 2*). Unless the product is designed for EMC compliance, both these types of signals can radiate or conduct high frequency energy well into the mobile phone bands.

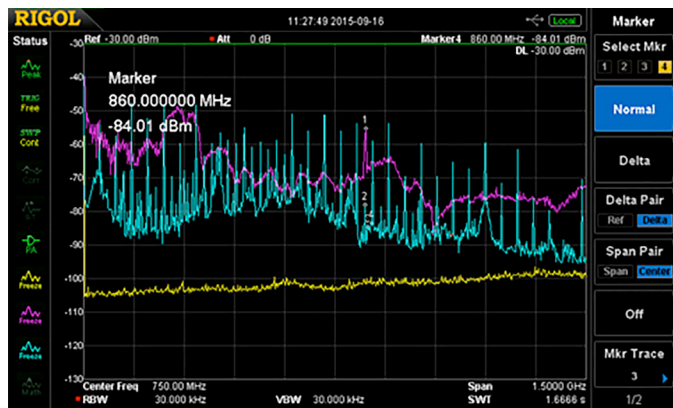


Figure 2. There are two common types of high frequency harmonics; narrow band (in the aqua trace) and broadband (violet trace). The yellow trace is the ambient noise level of the measurement system and is always a good idea to document a measurement system baseline.

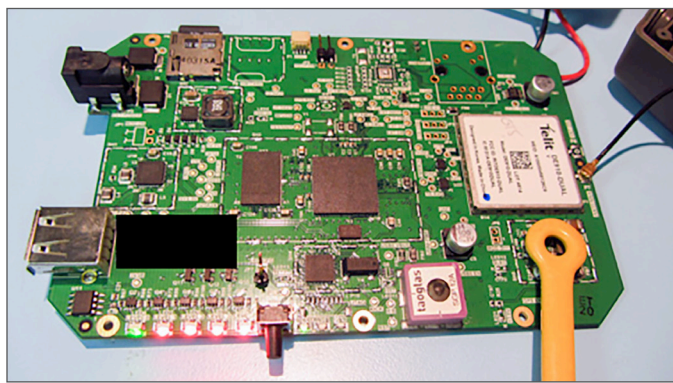


Figure 3. Measuring the noise from a DC-DC power converter located adjacent to the radio module.

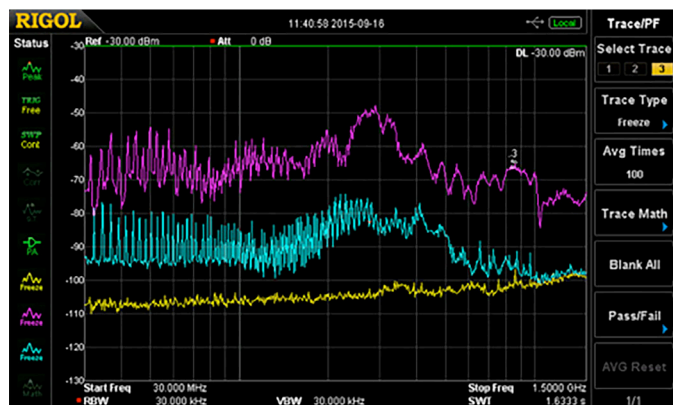


Figure 4. In this example, we're looking from 30 MHz to 1.5 GHz to generally characterize the spectral emissions profile of a couple of on-board DC-DC converters. Both will potentially cause interference to mobile phone bands in the 700 to 950 MHz region. The one with the violet trace is over 30 dB above the ambient noise level.

Types of Measurements

There are generally two types of measurements I suggest performing. The first helps characterize the general profile of noise sources, such as DC-DC converters, clock buses, processors, RAM, and any other potential high frequency device. This measurement is taken from least 1 to 1000 MHz, in order to characterize the general spectral

profile and to see whether any energy extends into the receiver passband of concern (Figure 4). For other mobile phone and/or GPS/GNSS, you'll need to look as high as 2 GHz. For Wi-Fi, you'll need to look as high as 2.5 or 5.4 GHz. Placing the spectrum analyzer in "Max Hold" mode is used to build up a maximum spectral amplitude.

Once the various noise sources on the board are identified, the next measurement I suggest is to look at just the receiver (downlink) band. In the case of Verizon in the U.S., for example, this would be "Band 13" of the FCC allocation from 746 to 756 MHz. You'll probably need an external broadband preamplifier of at least 20 to 30 dB gain in order to clearly observe the noise, if any. I generally turn on the 20 dB built-in preamplifier in the analyzer, as well. The Beehive Electronics Model 150A external amplifier, with frequency range of 100 kHz to 6 GHz, works well, but there are many other companies, such as Aaronia, TekBox, Com-Power, Rohde & Schwarz, and Keysight that sell high-gain broadband preamplifiers with low noise figure. You'll probably need to make these measurements inside a shielded room in order to exclude other mobile phone transmissions from disrupting your measurements. Examples are shown in Figure 5.

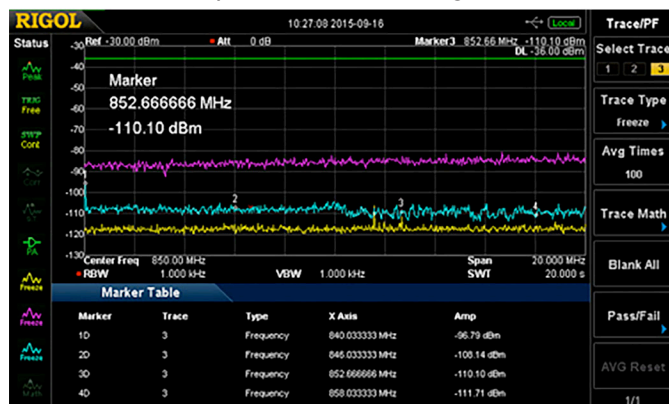


Figure 5. Measurement of two noisy sources (aqua and violet traces) within the receiver passband of a mobile phone band. Note the broadband noise in the violet trace is about 30 dB above the ambient noise floor. The yellow trace is the ambient system noise floor measurement.

Remediation Checklist

As I mentioned, the product design must be developed with EMC in mind and no corners should be cut. This will consist of:

- A near perfect PC board layout
- Filtering of DC-DC converters
- Filtering of any other high frequency device
- Filtering at the radio module
- Local shielding around high noise areas
- Possibly shielding the entire product
- Proper antenna placement

The PC board layout is critical and is where most of your effort should be spent. An eight or ten layer stack-up will provide the most flexibility in segregating the power sup-

ply, analog, digital, and radio sections and provide multiple ground return planes, which may be stitched together around the board edge to form a Faraday cage. Care must be taken to avoid return current contamination between sections (common impedance coupling). According to *Reference 5*, isolating the power plane for the radio section from the digital power plane (except for a narrow bridge) can provide up to 40 dB of isolation between the digital circuitry and radio.

It is vital that the power and ground return planes be on adjacent layers, and 3-4 mils apart, at the most. This will provide the best high frequency decoupling. Clocks, or other high speed traces, should avoid passing through too many vias and should not change reference planes.

DC-DC power supply sections should be well isolated from sensitive analog or radio circuitry (including antennas). Be aware of primary and secondary current loops and their return currents. These return currents should not share the same return plane paths as digital, analog, or radio circuits. remember that return currents above about 50 kHz want to return directly under the source trace.

For general product design guidelines, the books, *EMI Troubleshooting Cookbook for Product Designers*, by Patrick André and Kenneth Wyatt and *Electromagnetic Compatibility Engineering*, by Henry Ott (*References 3 and 4*), describe several basic design concepts to reduce

EMI. *Platform Interference in Wireless Systems*, by Intel engineers, Kevin Slattery and Harry Skinner, is very useful in providing ideas for measurement and remediation (*Reference 5*).

Summary

Platform interference has quickly become one of the most challenging issues for manufacturers building in wireless technology into new or existing products. Success depends on carefully designing the entire product to ensure minimal EMI. Proper circuit board layout and stack-up is a key factor for success. Cutting corners by simply “bolting on” a cellular modem to an existing product is a recipe for disaster.

References

1. CTIA, Test Plan for Mobile Station Over the Air Performance: Method of Measurement for Radiated RF Power and Receiver Performance, http://files.ctia.org/pdf/CTIA_OTA_Test_Plan_Rev_3.1.pdf
2. Broadcom, Compliance with TIS and TRP Requirements, <https://www.broadcom.com/collateral/wp/21XX-WP100-R.pdf>
3. André and Wyatt, *EMI Troubleshooting Cookbook for Product Designers*, SciTech Publishing, 2014.
4. Ott, *Electromagnetic Compatibility Engineering*, Wiley, 2009.
5. Slattery and Skinner, *Platform Interference in Wireless Systems - Models, Measurement, and Mitigation*, Newness Press, 2008.



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

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/main.asp>

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.

Mobility Development Group

<http://mobilitydg.org>

To serve as an objective and agenda-neutral forum for information exchange and harmonization among legacy CDMA stakeholders, through CDMA end-of-life.

Our specific goals are:

- Facilitate ecosystem visibility for all members
- Promote technical clarity, and harmonization when viable
- Assist in intelligent and aware planning of transitions to newer technologies
- Serve as liaison to standards groups on CDMA topics

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.

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 GROUPS & ORGANIZATIONS

CONTINUED

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 Life Sciences Alliance

<http://wirelesslifesciences.org>

WLSA envisions a future in which healthcare is connected, consumer centric, distributed and integrated seamlessly across all providers irrespective of the venue. Digital and wireless technologies enable this vision. It will be the integration of medicine, science, technology, engineering and big data analytics that will deliver improved wellness and cost effective health care and outcomes.

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.

WIRELESS CONFERENCES 2017

Consumer Technology Association (CES)

January 5 - 8, 2017

Las Vegas, Nevada

<http://www.ces.tech>

International Workshop on Internet of Things and TV White Spaces

January 12 - 13, 2017

Pune, India

<http://www.mitpune.com/wiot2017/>

IOT Evolution Developers Conference

February 7 - 10, 2017

Ft. Lauderdale, Florida

<http://www.iotevolutionexpo.com/developers-conference/east/>

Mobile World Congress

Feb 27 to Mar 2, 2017

Barcelona, Spain

<https://www.mobileworldcongress.com>

IEEE Wireless Communications and Networking Conference

March 19 - 22, 2017

San Francisco, Calif.

<http://wcnc2017.ieee-wcnc.org>

International Wireless Communications Expo

March 27 - 31, 2017

Las Vegas, Nevada

<http://www.iwceexpo.com/iwce17/Public/Enter.aspx>

Wireless Telecommunications Symposium (IEEE)

April 26 to 28, 2017

Chicago

<http://www.cpp.edu/~wtsti/>

International Conference on Telecommunication (IEEE)

May 3 to 5, 2017

Limassol, Cyprus

<http://ict-2017.org>

Internet of Things World

May 16 - 18, 2017

Santa Clara, Calif.

<https://tmt.knect365.com/iot-world/>

International Symposium on Networks, Computers, and Communications (IEEE)

May 17 to 19, 2017

Marrakech, Morocco

<http://www.isncc-conf.org>

WIRELESS CONFERENCES 2017

CONTINUED

European Wireless 2017

May 17 - 19, 2017

Dresden, Germany

<http://ew2017.european-wireless.org>

IEEE International Conference on Communications

May 21 - 25, 2017

Paris, France

<http://icc2017.ieee-icc.org>

Wireless Infrastructure Show

May 22 - 25, 2017

Orlando, Florida

<https://wirelessinfrastructureshow.com>

Global IoT Summit

June 6 - 9, 2017

Geneva, Switzerland

<http://iot.committees.comsoc.org/global-iot-summit-2017/>

IEEE International Conference on Sensing, Communication and Networking

June 12 - 14, 2017

San Diego, Calif.

<http://secon2017.ieee-secon.org>

International Conference on Mobile and Wireless Technology

June 26 - 29, 2017

Kuala Lumpur, Malaysia

<http://icatse.org/icmwt2017/>

International Conference & Business Expo on Wireless & Telecommunication

July 2 - 21, 2017

Munich, Germany

<http://wirelesscommunication.conferenceseries.com>

IEEE International Workshop on Signal Processing Advances in Wireless Communications

July 3 - 6, 2017

Sapporo, Japan

<http://www.spawc2017.org/public.asp?page=home.html>

International Conference on Wireless and Optical Communications

July 7 - 9, 2017

Singapore

<http://www.icwoc.org>

IEEE International Symposium on EMC, Signal and Power Integrity

August 7 - 11, 2017

Washington D.C.

<http://www.emc2017.emcss.org>

Association of Public Safety Communications Officials (APCO)

August 13 - 16, 2017

Denver, Colorado

<http://www.apco2017.org>

Mobile World Congress Americas

September 7 - 9, 2017

Las Vegas, Nevada

<http://www.ctiasupermobility2016.com/exhibit/index.cfm/2017-show-information>

IEEE Vehicular Technology Conference

September 24 - 27, 2017

Toronto, Canada

<http://www.ieeevtc.org/vtc2017fall/>

IEEE International Symposium on Personal, Indoor and Mobile Radio Communications

October 8 - 13, 2017

Montreal, Quebec

<http://pimrc2017.ieee-pimrc.org/>

IEEE Conference on Communications and Network Security

October 9 - 11, 2017

Las Vegas, Nevada

<http://cns2017.ieee-cns.org>

MILCOM

October 23 - 25, 2017

Baltimore, Maryland

<http://events.afcea.org/milcom17/public/enter.aspx>

IEEE International Conference on Microwaves, Communications, Antennas and Electronic Systems

November 13 - 15, 2017

Tel Aviv, Israel

<http://www.comcas.org>

WIRELESS TECHNOLOGIES

Dr. Robert Morrow
dr.bob@wireless-seminars.com

Short Range Wireless Technologies					
Name	Purpose	Network Type	Frequency Bands	Modulation Method	Website
6LoWPAN	IoT using IPv6 addressing	Mesh	<1 GHz and 2.4 GHz ISM	DSSS-PSK	http://datatracker.ietf.org/wg/6lowpan
Bluetooth	PAN data, multimedia streaming, two-way voice	Point-to-point ad-hoc	2.4 GHz ISM	FHSS-GFSK and FHSS-PSK	http://www.bluetooth.com
Insteon	Home automation	Mesh	131.65 kHz (over power line), 900 MHz ISM (RF)	PSK (over power line), FSK (RF)	http://www.insteon.com
IrDA	Short-range optical data	Point-to-point (predominately)	Infrared optical	OOK (predominately)	http://www.irda.org
NFC	Very short range data	Point-to-point	13.56 MHz	Backscatter ASK	http://nearfieldcommunication.org
RuBee	Product tagging and tracking	Point-to-multipoint	131 kHz inductively coupled	ASK and PSK	http://www.ru-bee.com
Wi-Fi	LAN data, multimedia streaming, two-way voice	Point-to-multipoint	2.4 GHz and 5 GHz ISM (predominately)	OFDM	http://www.wi-fi.org
ZigBee	Low power control and monitoring	Mesh	2.4 GHz ISM (predominately)	DSSS-PSK	http://www.zigbee.org
Z-Wave	Home automation	Mesh	900 MHz ISM	GFSK	http://z-wavealliance.org

USEFUL WIRELESS REFERENCES

(GROUPS, WEBSITES, BOOKS, FORMULAS & TABLES)

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 WIRELESS REFERENCES

(GROUPS, WEBSITES, BOOKS, FORMULAS & TABLES) 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...

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

(LINKS & WHITEPAPERS)

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

1. Several direction-finding application notes (Narda) - <https://www.narda-sts.com/en/spectrum-analysis-and-receiver/ida-2-handheld-portable-interference-and-direction-analyzer/>
2. 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
3. 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
4. Interference Hunting / Part 1 (Tektronix) - <http://www.tek.com/blog/interference-hunting-part-1-4-get-insight-you-need-see-interference-crowded-spectrum>
5. Interference Hunting / Part 2 (Tektronix) - <http://www.tek.com/blog/interference-hunting-part-2-4-how-often-interference-happening>
6. Interference Hunting / Part 3 (Tektronix) - <http://www.tek.com/blog/interference-hunting-part-3-4-use-mask-search-automatically-discover-when-interference-happenin>
7. Interference Hunting / Part 4 (Tektronix) - <http://www.tek.com/blog/interference-hunting-part-4-4-storing-and-sharing-captures-interference-hunter's-safety-net>



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