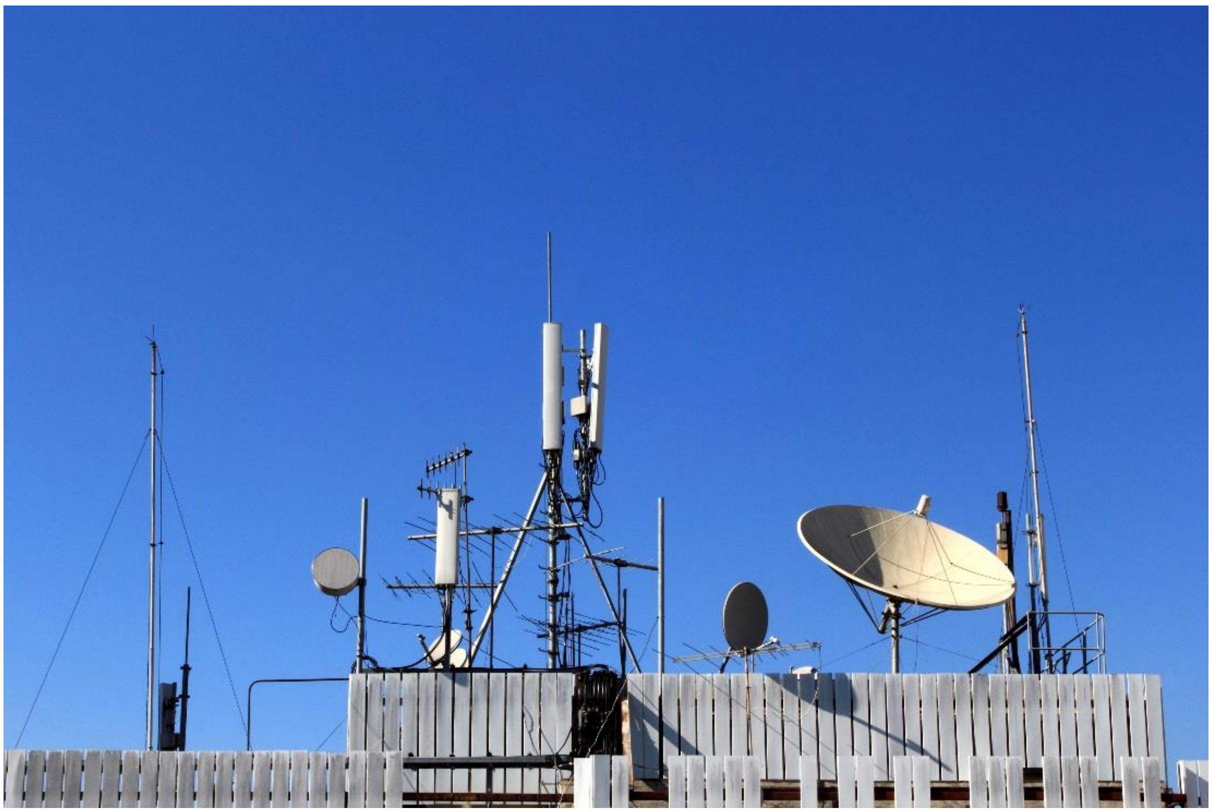
Modern Co-Site RF Interference Issues and Mitigation Techniques

A General Educational White Paper for Business Professionals and Technical Staff



Benjamin A. Culver
President, Southwest Antennas, Inc.

RF co-site interference has been around since the advent of wireless communications equipment and the problem is getting worse as the need for new RF/Microwave communication systems grow. It is not uncommon to find ten or more individual wireless systems installed within close proximity of one another on a single roof top. It has become more important than ever to have an understanding of RF co-site interference, what the terms mean and what tools are available to address the problem. One thing is certain; RF co-site interference is not going away and will become worse over time as new wireless systems proliferate the environment.

This white paper is written from a practical perspective for those using or specifying new RF wireless systems about what RF co-site interference is, where it comes from and some of the most common techniques and tools that are available in today's market place to solve these RF co-site interference problems. This paper will not delve into the math and science behind this RF co-site interference phenomenon but will serve as a general educational guide to business professionals, marketers and technical staff who are involved with the installation and use of these RF wireless systems.

Introduction to RF Co-Site Interference

RF co-site interference occurs when two or more co-located RF systems affect one another negatively. This normally occurs when two or more RF systems are operating physically close to one another (within several feet to hundreds of feet) and they are operating in such a way that one of the system transmitters negatively impacts one or more system receivers.

Chasing and resolving these RF co-site interference problems often becomes a "reactive" endeavor instead of a "pro-active" exercise. Up-front study is strongly recommended to determine potential sources of RF co-site interference before wireless equipment is deployed.

When considering or discussing the potential for RF co-site interference one should ask themselves two fundamental questions:

1.) Will the new RF wireless system that I am fielding potentially cause other co-located or nearby RF systems any problems?

2.) Will other fielded RF wireless systems that are nearby or co-located negatively affect my new RF system?

The first step in examining the potential for RF Co-site interference is conducting a study of the specifications of the RF wireless equipment being fielded. Common questions are:

1.) Where am I installing this equipment and how "RF congested" is the local environment?

2.) Is this a fixed site or mobile application?

3.) What kind of antennas are being used at or near the site? Are these omni or directional antennas and what are the antenna properties and specifications?

4.) What is the frequency range of my RF wireless system and how close am I in both frequency and location to other RF wireless systems operating nearby?

5.) What transmit power level(s) is my RF wireless system transmitting and what modulation schemes am I employing?

6.) What is my RF wireless system's receiver sensitivity level and what kind of RF filtering do I need?

7.) Does my transmitter have the ability to desensitize or jam my receiver or other collocated RF receivers that are close by?

These are but a few of the important questions to ask when fielding a new RF wireless system. The answers to these questions will help you focus on the issues at hand and will bring attention to potential weaknesses in the RF wireless system design.

Licensed vs. Unlicensed Transmitters

When it comes to RF co-site interference there are a few factors working in our favor. One of these is *The Federal Communications Commission (FCC)* and other similar government bodies around the world that define critical operational specifications for both licensed and unlicensed transmitters. The FCC's mantra: "my device shall not cause any harmful interference" and "my device shall accept any harmful interference" establishes the precedent under which system designers operate when specifying and designing new RF wireless systems.

Often it is much easier to deal with licensed transmitter issues in that they have a higher level of federal regulations that reduces the risk of RF co-site interference. Conversely, unlicensed transmitter regulations are specified and designed in such a way to allow many users to occupy the same Industrial, scientific and medical (ISM) bands such as popular ISM bands operating in the 900MHz, 2.4GHz and 5.8GHz frequency ranges.

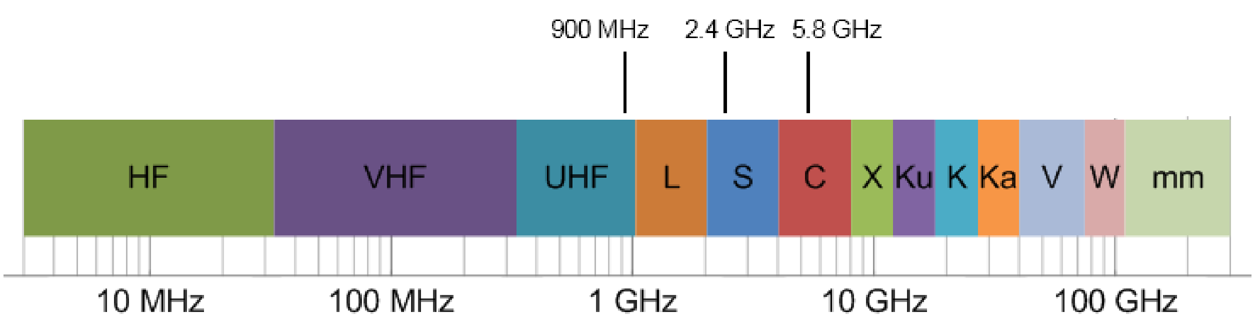


Figure 1: Example of common ISM bands within the IEEE frequency band chart. (Graphic based on "Frequency Band Comparison" by Treinkvist licensed under CC BY-SA 4.0)

Unlicensed ISM band transmitters are usually low power (1Watt / +30dBm or under when using an omni antenna) and they use complex frequency hopping algorithms and spread spectrum modulation schemes to allow many users to share frequency bandwidth simultaneously.

However, this is not normally the case with licensed radio spectrum. Licensed radios are typically higher in RF power level and they can transmit and receive over a much longer distances. RF co-site interference is very important when planning a new RF wireless system operating on a licensed frequency. For the purposes of this white paper, we will not discuss the process to apply to the FCC or other regulating government body for a licensed radio frequency or channel. This process can be complex and cumbersome and should be completed prior to studying RF co-site interference issues. The official www.fcc.gov website is a good resource to learn about licensing requirements.

Collecting Information via RF Site Survey

Working in our favor to overcome RF co-site Interference is the use of an information gathering technique called an "RF Site Survey". This is one of the best methods for establishing the "RF environment" at a fixed site location. For the purposes of this white paper, an RF site survey is defined as "a process used to gather pertinent and critical information on a particular RF environment in order to do proper RF system planning to minimize the potential for RF co-site Interference".

Important points in an RF "site survey" include:

1.) Understanding the geography of a site location including:

a.) Are we dealing with urban, suburban or a rural area?

b.) What is the topography of the area? Are we dealing with a flat, hilly or mountainous area?

c.) What type of foliage are we dealing with and what is the general description of this foliage?

d.) What type of buildings, houses and other structures are we dealing with at the site and what kind of building density and building heights are we dealing with?

e.) Are there other RF systems located nearby? If so, what are they, what are they being used for and who do they belong to? How close are these other RF wireless systems to my new RF wireless system? ***Note: this is often the most difficult and the most important information to obtain.***

f.) How high off the ground will my system be located and what is the elevation of the antenna my system will use?

2.) What type of equipment will I be employing at the site? Is this point-to-point wireless equipment or point to multi-point wireless equipment?

a.) What antenna type are we using for the RF wireless systems? Are these omni or directional antennas? What type of antennas are used on the other ends of the wireless link?

b.) Does my system employ complex antenna set-ups like multiple-in-multiple-out (MIMO) where multiple antennas are involved?

c.) What is my antenna gain and beamwidth (both azimuth and elevation)?

d.) What type of RF cabling am I using and how much insertion loss does it have at the highest frequency of operation?

e.) What is my RF transmit and receive frequency range?

f.) What type of modulation and data rates does my system use?

g.) What is my transmit RF power level and duty cycle?

h.) What is my receiver sensitivity?

Once much of this information is collected (and any other information that could be critical to the RF site survey), it is best to go to the actual site and bring a good quality RF spectrum analyzer and a broadband omni antenna (broadband directional antennas can also come in very handy for pinpointing specific sources of RF interference) along with all of the required hand tools used for testing set-up and other RF accessories needed to do the job.

Figure 2: Example of an omnidirectional antenna (left) and a directional panel antenna (right).

Some forethought needs to go into how you will conduct the RF site survey before going to the actual site. It is important to note that some excellent small form factor battery powered RF spectrum analyzers are now available on the market for this purpose.

The Anritsu "Site Master"™ line of small form factor spectrum analyzers is an excellent choice. You will want to set-up the spectrum analyzer and antennas as close as possible to how the actual system antenna will be used in the field. This will ensure the data you collect during the RF site survey will match as closely as possible to what your RF wireless systems will experience when deployed.

Using the same RF cabling that you will use in the deployed wireless system is always a good idea. By doing this you can see the impact from using the actual RF cables that your system will use when deployed and you can then determine if any improvements or changes need to be made to these RF cables prior to system deployment.

Setting up the RF spectrum analyzer with a wide frequency bandwidth which includes the frequency band you are operating within plus a wider frequency range on both ends is best practice (several hundred MHz of extra bandwidth on each end should be sufficient). Setting the sweep speed of the RF spectrum analyzer to a very low setting while using a high resolution bandwidth and video bandwidth is important so that you can capture highly accurate and high resolution RF spectrum data.

Get an initial wide band sweep of the RF spectrum. Use a maximum hold (Max Hold) feature of the RF spectrum analyzer to capture several hours of spectrum activity to ensure you do not miss any collocated systems that operate intermittently.

This RF site survey data will show where local transmitters are operating in the area and will highlight specific frequencies of interest along with their associated signal amplitudes. All of this RF spectrum data should be recorded and saved for future reference. Saving this RF spectrum sweep data as a "baseline" data set is very important. It can be referred back to at a later date if problems come up at the site in question and you need to go back to the site to conduct a secondary site survey to see what has changed in the RF environment. Being able to compare the before and after baseline RF sweep data with the new RF sweep data can be very revealing in terms of determining new sources of RF interference and summarizing the changing RF landscape.

After the initial base line wide band RF sweep is completed with the RF spectrum analyzer the site surveyor can then focus in on specific sources of RF interference that operate close to the system's operating frequency. By collecting this narrow band sweep data, the user can determine how close other transmitters are to their RF system's operational frequency range and how high the RF power levels are of these close-in signals. Recording frequency and amplitude data from the site is important and will reveal how "noisy the neighbors are". Once this RF spectrum measurement data is collected and examined the site surveyor can then identify specific areas of interest where sources of potential RF interference can be filtered out or negated by relocating antennas, changing antenna types, or using other common interference mitigation methods such as employing RF filters to eliminate or reduce sources of RF co-site interference.

Sources of RF Co-Site Interference

Sources of RF co-site interference can be classified into two primary areas:

1.) Receiver front-end overload

2.) Receiver desensitization ("desense")

We begin with receiver front-end overload as this is the most detrimental source of RF co-site interference. Receiver front-end overload occurs when a co-located transmitter is getting into the wireless system's receiver front-end. This interference causes all kinds of problems with the receiver system, but the majority of these problems come from ***overdriving the receiver's first stage LNA*** (low noise amplifier).

This is especially true in low power ISM band receiver systems that do not employ RF filters ***prior*** to the first stage LNA. Low power ISM band receiver manufacturers specify and advertise their system noise figure specification as a very important selling point of their products. The better the noise figure specified by the manufacturer the better the receiver looks to potential customers! The noise figure can look great in a perfect operating environment without localized sources of RF interference, but in an environment with high levels of interference the receiver will not work at all.

This means that the receiver manufacturer leaves out the first stage RF filter in the design, leaving the receiver front-end literally "wide open" and prone to the ingress of out-of-band RF interference. The first stage RF filter has in band insertion loss associated with its design and therefore this in band insertion loss adds directly to the total system noise figure on a dB for dB basis. The receiver manufacturer has the advantage of saying their receiver noise figure is amazingly low, but in reality their receiver is actually very susceptible to out-of-band RF interference because there is no first stage RF filter installed prior to the first stage LNA.

The receiver manufacture leaves it up to the wireless system designer to install their own RF filters in their wireless systems, and rightly so because not all wireless systems will require the same type or amount of RF filtering. Receiver manufactures can also offer the market better prices for their products if they leave out the first stage RF filter which can be and often is the most expensive component of their receiver design.

This is also attractive to system designers because they will add their own RF filter to their wireless system design anyway and they do not want to contend with duplicate system component costs, added noise figure and insertion loss. Novices to the industry often miss this point. They assume that the receiver is well protected (by design) when in reality it is not protected at all as the receiver front-end is unfiltered, wide open and highly susceptible to out of band interference and sources of noise. ***The main point here is to always understand the receiver's technical specifications and make sure you know what type of RF filtering is employed in the receiver design that you are fielding.***

When high power level out-of-band or in-band RF signals get into the receiver front-end they can overdrive the first stage LNA and cause receiver distortion problems. LNA designs in today's market have a wide range of available maximum input power specifications and they can be degraded, damaged and even blown out due to being overdriven by large input signal levels.

***This can happen to the LNA even by high level <u>out-of-band</u> RF power that is outside the LNA's stated operational frequency range*!** Understanding and adhering to the specifications of your first stage LNA is one of the most critical aspects to defeating RF co-site interference. If you keep the first stage LNA well protected from interference sources in terms of both out of band frequencies and high input power levels, then your receiver will work well.

Another unwanted condition that happens during front-end overload is called inter-modulation distortion (IMD) This is due to the wanted received signal mixing with the unwanted interfering signals leading to the generation of what is called intermodulation distortion products within the receiver.

IMD generation is a process of non-linear diode junction mixing within the low noise amplifier. This can vastly degrade and interfere with the receiver's intended performance. The intermodulation distortion products cause all kinds of strange problems in the system from intermittent and total loss of service to slow data rates and even damaged equipment. Although this white paper will not cover the specifics of intermodulation distortion, the reader should understand the basic premise of this interference condition and further study should be done to gain an in-depth knowledge of this critical area of RF system design.

The best tool available for solving receiver front-end overload conditions is a good RF filter. You will not always have the luxury of being able to add RF filters to local transmitters operating in the area. Since these transmitters do not belong to you, you will likely not have direct access to them and you may not even be able to determine who these transmit systems belongs to.

From this writer's experience, it is often difficult to convince the owner / operator of a co-site RF transmitter system to add an in-line RF filter to their transmitter system front-end as this can limit their transmitter's RF performance in terms of the maximum RF communications range their system can achieve, and furthermore the addition of the RF filter itself is often expensive. During your RF site survey you can determine where the local RF transmitters are operating, what frequencies they are using and what signal levels your receiver will likely see. You can then work towards selecting the proper RF filter or RF filters for your receiver equipment to eliminate the potential sources of RF co-site interference.

There are a number of different RF filters types available. These RF filter types range from very expensive and often large cavity filters that can reject just about everything from above and below your receivers operating frequency band to relatively inexpensive in-line bandpass RF filters which have much less out-of-band rejection than cavity filters have but have enough out-of-band rejection to do the job adequately. There are also notch filters which can be used by themselves or with other types of RF filters. These notch filters can be used to eliminate or "notch" out sources of specific troublesome interference.

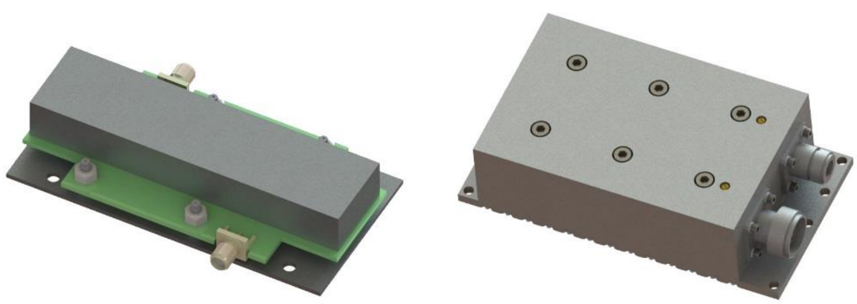


Figure 3: Examples of Band Pass Filters that can be added to a system.

Receiver desensitization or "desense" as it is commonly referred to in the RF / microwave industry is another important phenomenon to understand when examining RF co-site interference problems.

Receiver desense is defined as "a measured value of receiver degradation from a receiver's best case specified receive sensitivity level". All RF / microwave receivers have a specified receiver sensitivity level which is a value expressed in dBm and is commonly within the -80dBm to -115dBm range. -80dBm would be indicative of a low cost moderate performance receiver sensitivity value (like a common ISM band radio receiver) while -115dBm would be associated with a much higher cost high performance receiver (like a military radar receiver).

This receiver sensitivity value is the level at which a receiver no longer operates within its advertised specifications. This is generally the value used to describe when a receiver loses lock on its desired received signal. Often, this is expressed in terms of a bit error rate (BER) and is always expressed as the "best case" value the receiver can achieve while operating in ideal laboratory conditions. Ideal laboratory conditions are almost always RF cabled test conditions and not over-the-air test conditions.

This term of "receiver sensitivity" can be easily described as the point at which an RF / microwave receiver can no longer "hear" or "discern" the desired received signal from the transmitter. The term "MDS" is often used to describe the minimum discernible signal a receiver can "hear".

An adequate receiver sensitivity requires the wanted received signal to have an amplitude that is a minimum number of dB above the noise floor. In classic super heterodyne receiver design this number was 12dB SINAD (signal to noise and distortion).

The term of SINAD came from the days of Bell Laboratories and it was an actual measured value of when the human ear could discern intelligible speech above the noise floor. It turns out that the average human being at the time could differentiate the intelligible speech from the noise floor when the signal level was 12dB above the noise floor. 12dB seems like a large value, but when considering the human ear cannot tell the difference in a 3dB increase or decrease in signal level (double or half the power) it does not seem out of the question.

12dB SINAD is often expressed in terms of signal-to-noise ratio (SNR). This is another way of looking at the desired received signal level height above the noise floor measured in dB. It is important to note that the bandwidth and the resolution of the receiver measurement system can change this SNR measurement dramatically. The narrower the bandwidth and the higher the resolution of the measurement will result in better SNR numbers. When making comparison measurements, it is best practice to define the frequency span, resolution bandwidth and video bandwidth of the RF spectrum analyzer or measurement receiver making the SNR measurements.

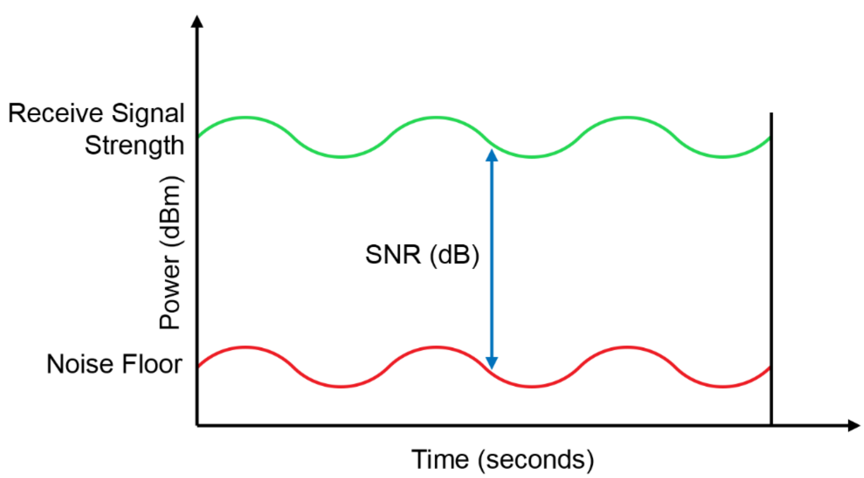


Figure 4: Illustrating Signal-to-noise ratio as the decibel measurement difference between the received signal strength and noise floor.

Receiver sensitivity, signal-to-noise ratio and SINAD are all important points of background information that the reader should be familiar with when considering RF co-site interference and specifically receiver desense topics in general. Receiver "desense" is defined as an additive noise phenomenon which degrades the receiver sensitivity measured in dB.

To understand what receiver desensitization is, imagine the case of a common modern 4G hand held cellular phone. Not only do you have the cell phone receiver and transmitter that are collocated where the transmitter itself adds noise into to the receiver but you also have all the other collocated high frequency baseband circuitry, switching power supplies, system clocks and other noise generating sources. They sit right next to the receiver and they often share a common system ground plane and mechanical enclosure. These cause common mode noise degradation in the receiver.

In this case you can determine receiver desense by first measuring the worst case receiver sensitivity of the system in its fully operational state. Once you have this baseline worst case receiver sensitivity measurement you can then compare it to the receiver sensitivity measurement of the receiver measured in its best case operating conditions which is when the receiver is properly instrumented and isolated from all of the other collocated electronics and being measured within a common laboratory bench top equipment set-up. It is not unusual for these collocated electronics to desense the receiver by 10dB or more. Remember, 10dB is an order of magnitude or a 10X degradation in system performance.

Combating receiver desense can be accomplished using the following techniques:

1.) Proper system frequency planning, understanding the design first and for most!

2.) Minimizing sources of local radiation interference using: shielding, RF chokes, ferrite beads and RF absorbing materials.

3.) Using high quality RF cables and RF adapters - ***the writer cannot emphasize enough how poor quality RF cables, RF connectors and RF adapters (especially with 90 degree right angles) have caused desense issues in the past***. Poor RF cabling, RF connectors and RF adapters can literally "leak" RF energy that can find its way into the receiver by many conduits. High standing waves (VSWR) within these devices can also create just the right ingredients for raising the noise floor in the receiver dramatically.

4.) Proper antenna type selection – selecting the right antenna can have a profound impact on receiver desense. Eliminating Omni antennas where they are not required can remove local RF interference sources emanating from certain directions. Using directional antennas with high front-to-back ratios can also reduce unwanted RF energy and noise coming from undesired locations.

5.) Proper antenna placement – Omni antennas often transmit in-band and out-of-band signals back into receiver electronics causing sources of common mode noise. Proper antenna placement, spacing, orientation, polarization and height above ground can make a large difference in reducing noise sources getting into the receiver.

Generally speaking receiver "desense" can be viewed as a process of system noise mitigation. First, you find the source of the undesired noise that is desensitizing the receiver. Often this noise source is a harmonic of a lower frequency operating within the system like a 10MHz master clock or high frequency digital video lines. Once you locate the source of the receiver desense, you must find the ***mechanism*** that is causing the desense problem. This mechanism can be either conducted or radiated.

Conducted noise is very common in complex and highly integrated RF wireless systems. Often this conducted noise can be minimized or reduced by incorporating a simple component value change on one of the system circuit boards or it can be killed all together by adding RF chokes or Ferrite Beads to the design in the right locations.

Radiated sources of receiver desense either come directly from the antenna and feed back into the receiver or it comes from unintentional antennas in the system like circuit traces on the boards, ground planes, DC power cables, etc. Radiated desense problems are often solved by using RF shields in the right locations in the system design.

There are many papers written on receiver desensitization and there are many practical tools and techniques available to the system design engineer to eliminate or minimize desense problems. It comes down to how much desense your system can tolerate, while still meeting its operational objectives.

Conclusion

This white paper discussed the basics of RF co-site interference and its various mechanisms. There are many aspects to understanding and resolving RF co-site interference problems. Good RF site surveying information gathering techniques is key to gaining an understanding of the RF landscape you are dealing with.

There are many tools and techniques available to the system designer to solve complex RF co-site interference problems in the field. This paper provides a basic understanding of these issues. It is important for those involved in the operation and deployment of RF wireless systems to continue to gain a more advanced understanding of the issues surrounding this topic to ensure that their RF wireless systems continue to meet the ever increasing challenges that are coming towards this industry at an ever increasing rate.

About Southwest Antennas

Southwest Antennas specializes in the design and manufacture of rugged, high-performance RF and Microwave antennas, accessory products, and customized antenna solutions built for today's demanding communication environments. Founded in 2005 and headquartered in San Diego, California, Southwest Antennas offers a full range of technical services from initial product concept to final manufacturing for broadcast video, military / defense, law enforcement, homeland security, surveillance, aerospace, oil and gas, and M2M/IoT markets. For more about Southwest Antennas, visit their website at http://www.southwestantennas.com.