Spectrum Monitoring and Interference Analysis

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"It is not a lack of spectrum. It is an issue of efficient use of the available spectrum" - ***Conclusions of the FCC Spectrum Policy Task Force***[1]

Abstract

Interference analysis has become an important part of deploying new wireless services. The increasing density of wireless service delivery requires careful site planning and analysis of existing transmitters. A process will be described to identify and eliminate intermodulation (IM) and non-IM sources of interference. The sources and types of IM and non-IM interference will be described. The process entails monitoring the radio frequency (RF) spectrum, identifying transmitters in the area, calculating potential IM sources and eliminating the interference.

Overview

With the increasing number of transmitters coming on the air, interference is becoming more prevalent in the wireless community. Wireless service providers have used spectrum analyzers to monitor their channels/frequencies and the adjacent spectrum. Unfortunately, the best a spectrum analyzer can do is show the interfering signal to the user; leaving the user to determine the source of the interference. Eliminating interference requires an understanding of transmitters in an area as well as any applicable communication standards. Compliant signals in licensed spectrum and compliant signals in unlicensed spectrum are potential components of an interfering signal.

In the United States, the FCC maintains various databases that describe all commercially licensed transmitters. The Universal Licensing System (ULS) database houses multiple databases from the FCC including cellular, land mobile radio, paging and microwave. The Consolidated Database System (CDBS) houses FCC Media Bureau data related to AM, FM, TV, & Digital TV. Depending on the network or the nature of the interference, it may be necessary to consult a variety of other databases in the process of resolving interference problems

Solving the Interference Problem

Solving interference problems in the past was very much an art. Some of the time was spent direction finding, gathering data as to what transmitters were near by (usually the most time consuming) and spending time calculating the possible intermodulation products that could affect a transmitter. All of these actions were usually repeated several times in order to identify a suspect, wasting valuable time and money. Today, with the increased number of transmitters, a general decline in the number of skilled RF personnel, and an increasing cost of time in the field, an organized process to find interference is required. The economics of the modern wireless network cannot tolerate haphazard, inefficient approaches to finding and resolving interference.

Finding interference can be broken down into three major steps which lead toward the identification of an interference source. First, characterize the local environment with respect to neighboring transmitters. Second, perform an IM analysis based on transmitters in the area. Lastly, locate the source of the interference and identify the problem.

Indications of Interference

Interference occurs when unwanted signals are received at signal strengths that desensitize the receiver. Many modern radio systems have reporting capabilities describing the operation of the radio system. A common example of this may be the types of reports generated by a cellular network's switch. The switch is the integrated hardware/software system that controls the operational aspect of the cellular network's operations. It is the switch that is the eyes, ears and brain for the network. In addition to the information coming from the radio system, customers or users may also be able to identify 'unwanted' problems.

Typically, there are several indications that a particular network or system is being impacted by interference:

- Switch Data
  - Idle Channel Squelch Opening
  - Noise floor data
  - Dropped calls
  - Access/Setup failures
  - Reverse Power Control
- Customer Complaints
  - Noise
  - Dropped Calls
  - Poor Voice Quality

Unfortunately, the cause of the problem is not reported by these systems. A deliberate examination of the circumstances and characteristics of the interference is required.

Sources of Interference

Intermodulation Interference

Intermodulation interference is a consequence of the increasing numbers of transmitters in the wireless spectrum. The intermodulation is created when two or more signals combine to generate new signals. This type of interference may look different than normal emissions in band due to either modulation format or bandwidth. Some of the characteristics include:

- Not a clearly defined bandwidth, may have "fuzzy" RF envelope
- Bandwidth may shift as the fundamental FM transmitter deviates
- May be intermittent as one or more of the contributing transmitters turns on and off
- May cover up entire protected band if IM product is of higher order or protected band is narrow

Intermodulation arises as a result of transmitter harmonics or the mixing of two or more signals. The mixing product from two or more signals can include fundamental frequencies and/or harmonic frequencies. Since intermodulation products are mathematically related to their parent signals, intermodulation signal products can be easily calculated. The IM order denotes the number of operations required to calculate the mixing product.

Assume that you have several RF signals present in an area and transmitting at frequencies F1, F2, and F3. Some of the potential IM products that can be produced include:

Second Order IM (IM2): 2*F1, F1 ± F2, 2*F2

Third Order IM (IM3): 3*F1,
2 * F1 ± F2,
F1 ± 2 * F2,
F1 + F2 + F3,
F1 – F2 + F3,
F1 + F2 – F3,
F1 – F2 –F3

IM5, IM7, etc would follow the same variation in arithmetic combinations.

The IM suspect will not be a single frequency but will cover a frequency band that corresponds to the frequency bandwidths of the components. Assume that you have two signals F1 and F2 both with a bandwidth of X. The resulting signal will range from (F1+F2)-X to (F1+F2)+X. The bandwidth of the IM generated will be wider than the component signals and the power level will never exceed the power level of any component signal. Figure 1 illustrates the mixing behavior.

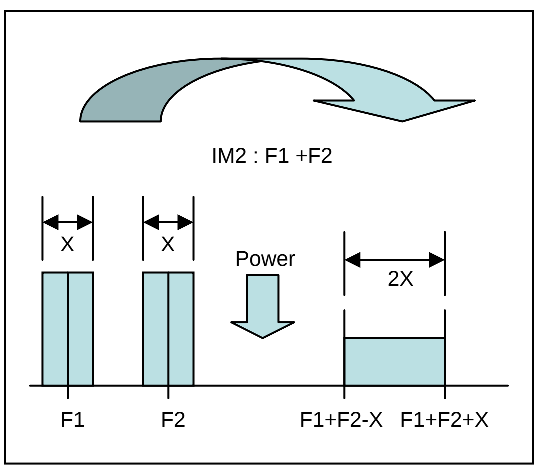

Figure 1 – IM2 Mixing Example

Further, the low-odd-order mixing products may fall particularly near (in frequency) to either or both of the fundamental signal(s) to be transmitted, or the fundamental signals to be received. Depending on the mechanism and spacing of the components, this type of intermodulation can be therefore very difficult to deal with in practice because it generally cannot be filtered out of either signal path without adversely impacting the primary signals of interest.

The key goal with eliminating an IM signal is determining the constituent parts. The signals that make up an IM product could be generated by combinations of internal sources transmitted, internal sources received, and external sources.

Passive Intermodulation Interference

Any passive component in the high power path from the amplifier output to the air is susceptible to generating passive IM interference. Example components:

- Filters
- Duplexers
- Couplers
- Lightening Arrestors
- Cables
- Connectors
- Antennas

The components may have inherent problems not discovered during manufacturing, may have degraded after installation, or were improperly installed. Some causes of passive IM include:

- Semi-Conducting Junctions
- Poor alignment of parts
- Inadequately torqued screws and fasteners
- Bad solder joints
- Plating related problems

- Non-Linear Characteristics of Materials
- Any Ferrite Material, e.g. nickel
- Degradation Due to Environment:
- Contaminated conductors and interfaces (Dirt, Dust, Moisture)
- Wind induced vibrations
- Temperature cycles

Sources of Non-IM Interference

Unauthorized Fundamental Frequency Transmissions

One common type of non-IM interference is a fundamental transmitter. A fundamental transmitter is a signal that is not mixed with another signal. Some examples of this type include:

- Off frequency transmitters
- Improperly tuned transmitters
- Abandoned transmitters that drift
- Defective cell phones
- Illegal transmitters

Co-Channel Interference

Co-Channel interference occurs when a distant base station signal is too strong. Co-Channel interference should be minimized by proper system deployment and design using tools that calculate propagation loss at the given site. This type of interference can be identified by using a spectrum analyzer or receiver that can decode the base station ID.

Equipment Issues

Interference may also be created by problems with equipment. The interference may manifest in several ways.

- Spectral regrowth (excessive sideband lobes) could be created by defective components or using components outside of the design limits.
- Broadband noise generated by defective components or poor design of equipment in the area.
- Power fluctuations of the signal cause non-compliance with standards or exceed design limits of the system.
- Sub-carrier signals embedded within the primary signal are not compliant with the standards.

Adjacent Channel Interference

Adjacent Channel Interference is caused by “bleed through” from transmitters operating at adjacent frequencies (channels). In Figure 2, signal F1 has overlapped signal F2. The overlap has degraded F2.

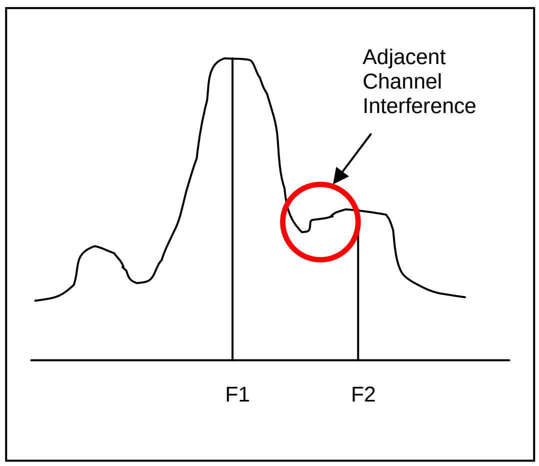

Figure 2 – Adjacent Channel Interference

Troubleshooting Process

1. Evaluate the Protected Band First

A channel or band of spectrum that is affected by interference can be considered the 'Protected Band.' The first step in troubleshooting is to monitor the protected band using a spectrum analyzer and determine whether the interference is present. A good rule of thumb would be to examine 3-10 times the bandwidth of the protected band. Adjacent Channel Interference can be identified in this step.

Once the interference is identified, the characteristics of the interference should be noted. The signal's duration, bandwidth, strength, sub-carriers, and time of occurrence will help begin the process of eliminating interference suspects in the area. The characteristics of the interference signal will also prioritize our search for the source of the interference.

Careful examination of the site and inspection of the antenna system is also recommended. New equipment installed at a location should be given a close examination but don't allow that to be the exclusive focus of the search. New equipment might be a tempting starting place for interference consideration, but it is possible that the new equipment may not even transmit signals on a frequency that could mix to create an emission that lands in the protected band.

2. Peak Hold Monitoring

The next step in troubleshooting is to make a broadband peak hold measurement of the local RF environment. The measurements are best conducted using a spectrum analyzer that can store the data or use commercially available software that stores the sweep data. A fine resolution bandwidth should be used (30kHZ or smaller is recommended) in combination with a suitable broadband antenna to enable the proper demarcation of signals for a variety of cellular and wireless technologies.

The broadband measurements should be conducted over a time period that includes when the suspected interference is occurring.

3. Transmitter Identification

Each peak that is measured by the spectrum analyzer should be identified and evaluated. The evaluation should include:

- Comparison of the signal to the characteristics of the interfering signal.
- Verification of compliance of the signal with the license and/or applicable standard.

The highest priority should be given to peaks with characteristics that match the characteristics of the interference signal. IM suspects calculated in the next step that include similar, unknown or non-compliant emissions should be flagged for closer examination

4. IM Suspect Calculation

As noted earlier, IM interference frequency ranges should be calculated using the start and stop frequencies of the measured peaks. The IM suspect will not be a single frequency but will be a frequency range that corresponds to the frequency ranges of the components. Any IM interference range that overlaps the Protected Band will be a suspect. Calculation of low order IM products is recommended for most applications. However, high power broadcast transmitters may cause IM products of the 13th order or higher to be present.

5. Interference Categorization

Now that the characteristics of the interference have been noted and the spectrum monitored to calculate IM suspect combinations. The interference needs to be categorized as either IM or non-IM.

Fundamental transmitters will closely match the characteristics of the interference. The bandwidth of the signal, presence of sub-carriers and ability to demodulate and 'listen' to the signal will provide clues to the source of the signal.

Signal Type	**Bandwidth**
Paging FM	15 to 30kHz
FM Broadcast	250 kHz
CDMA	1.25 MHz
GSM	200 kHz
SMR	12.5 to 30 KHz
IEEE 802.11	22 MHz
Bluetooth	1 MHz

Table 1 – Signal Bandwidths

IM interference mixing may prevent demodulating the signal. Each IM suspect should be evaluated with respect to duration and bandwidth. An interfering signal that is continuous implies that all of the components of the signal are continuous. An intermittent interfering signal implies that at least one component is intermittent. An interfering signal that is 60 kHz wide could not be created by 1 MHz wide components.

A spectrum analyzer should be used to monitor the protected band and each frequency range of each of the transmitters suspected of contributing to the interference. An ideal test setup would include multiple spectrum analyzers or the use of a spectrum analyzer that supports multiple sweeps.

If the interference is intermittent, simultaneous examination of the protected band and the component signals could reveal a relationship. If any component signal of the IM suspect turns off, then the interference should also turn off. A history spectrogram view of the sweeps over time is recommended. On/Off correlation provides the easiest way to identify what signals are combining to create the IM suspect.

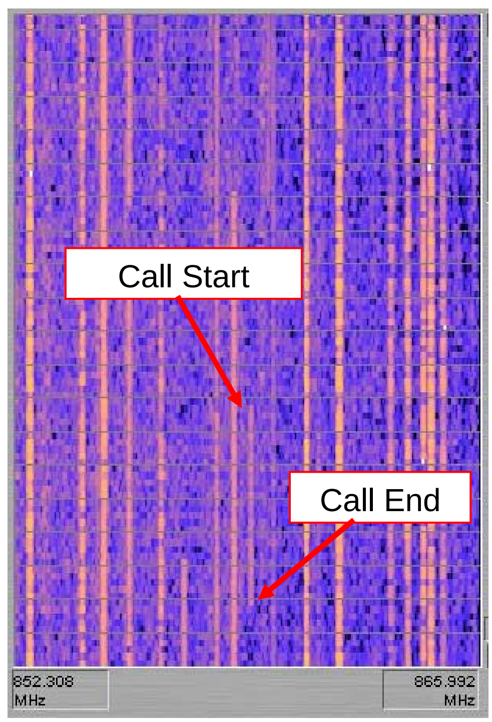

Figure 2 – Sweep History Spectrogram

In Figure 2, the sweep history spectrogram could show that the interference coincided with the call start and call end.

If the interference is continuous, the source of the IM suspect needs to be identified using a directional antenna. Direction Finding (DF) involves taking peak signal strength readings and bearings from several locations to find signals within the protected band. A Yagi type antenna is typically used in conjunction with a spectrum analyzer.

DF searching will reveal the locations of signals within the protected band. The IM suspect can be internally or externally generated. Internally generated IM can usually be attributed to a component failure or system design problem. Externally generated IM can be due to IM generated in another system or may be due to environmental factors.

It is important to note, that in areas of strong adjacent band or in-band signals the use of a front end filter or pre-selector may be necessary to prevent generating IM signals within the measurement instrument itself. The person making the measurements should test their measurement set-up before and during their investigation for the presence of internally generated interference. This can be easily determined by inserting a low value (3 or 10 dB) attenuator between the input of the instrument and the antenna. If the value of the interference drops by the value of the attenuation placed in line (or within 1 dB or so) then the interference is 'real' and the user can continue with the process. If the interference magnitude drops by more than the value of the attenuation (i.e. if a 3dB attenuator is used and the value of the interference drops 9 dB), then the user should consider the measurement set-up suspect to erroneous results and should consider using a front-end filter or suitable pre-selector.

6. Remediation

Once the location is determined, the root cause of the problem can be troubleshot. Common solutions for interference include:

- Defective component replacement
- Addition of filters to eliminate IM component signals.
- Relocation of antenna system components
- Modification and inspection of wireless system
- Change the channel plan

Illustrative Examples

Case 1

A RF link 'A to AA' was experiencing poor signal quality. A broadband scan was conducted but no transmitters were found to be in the area that could create a possible IM suspect that could affect the link. The technician examined the protected band with the spectrum analyzer and found a peak on the edge of Link A's licensed frequency.

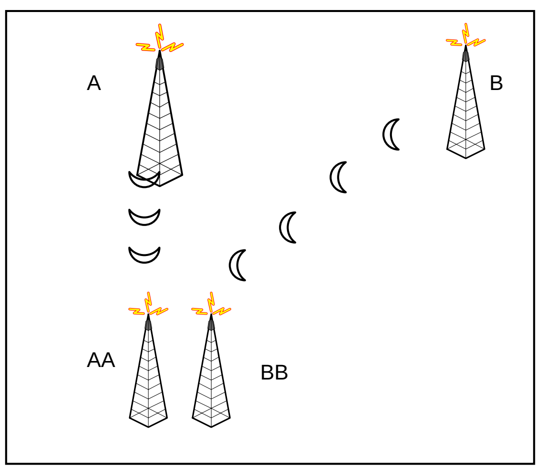

Figure 4 - Defective Transmitter

The technician performed a directional search and discovered that another RF link 'B to BB' was using the frequency. The FCC database was consulted and it was discovered that Link 'B to BB' was not using the correct frequency. Link 'B' was examined and the transmitter was found to be defective.

Case 2

A cellular provider 'A' had mounted an antenna on the rooftop of a building in a downtown area. The cellular provider had intermittent interference. A broadband scan of the RF environment was conducted and a suspect list was generated. It was calculated that a paging antenna system 'B' on another building across the street could create an IM suspect in the protected band in combination with the cellular carriers own signals. The technician performed a directional search and discovered a signal in the protected band that was emanating from a metal shed located on the roof top of the cellular provider's building.

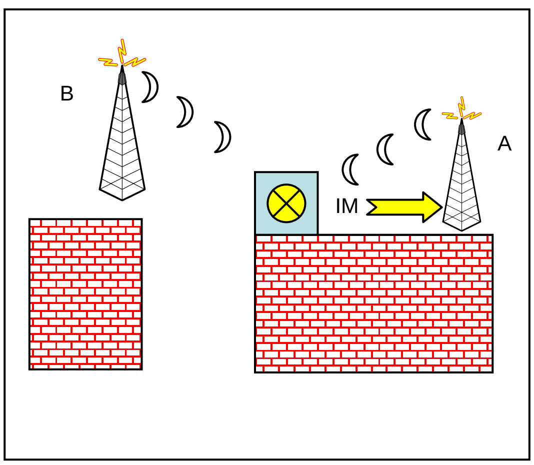

Figure 5 – Metal Shed Example

It was determined that both the cellular provider and the paging system antennas illuminated the metal shed. The metal shed acted as a mixing source and created an IM signal that was received by the cellular antenna. The cellular provider moved the placement of his antenna to eliminate illuminating the metal shed and the interference disappeared.

Case 3

A cellular provider was experiencing poor voice quality and dropped calls on a base station receiver. A broadband scan was conducted and a suspect list was generated. It was determined that certain active cellular channels on nearby towers could create IM suspects. The technician performed a directional search for the IM signal and discovered that the only signal in the protected band was emanating from the base station antenna.

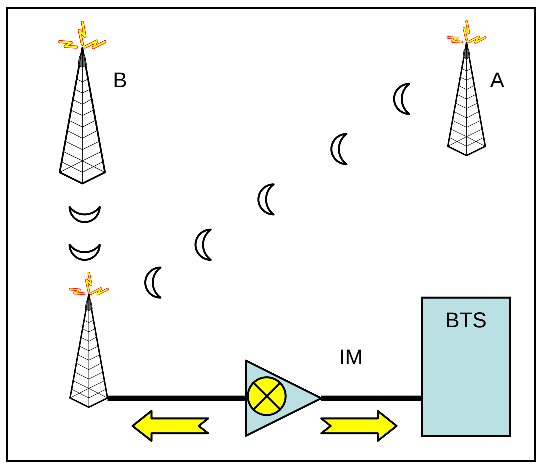

Figure 6 – LNA Overload

The IM suspect was being generated by one of the components within the Base Station antenna path. A visual inspection of the system was performed and showed no problems. Using a spectrum analyzer and a 10 dB pad, the attenuator was inserted between each element along the receive path of the signal. It was discovered placing the pad just prior to the LNA caused the interference signal level to drop much more than the pad's 10 dB value. Further investigation revealed that the combined power from transmitters 'A' and 'B' overloaded the LNA. This produced an IM signal which was re-radiated by the receive antenna. A filter was used to eliminate 'A' signal components and the interference was eliminated.

Summary

Interference issues can be resolved with a careful deliberate process. Searching for interference using a spectrum analyzer requires an understanding of wireless communication standards and the operating environment. The process presented in this paper describes how to identify signals in the area, calculate IM suspects and isolate the interference signals. The characteristics of the interference signal provide a way to prioritize the search for the source of the interference. The mechanisms of IM and non-IM interference were discussed along with illustrative examples of how interference was eliminated.

References

1. FCC Spectrum Policy Task Force, Report ET Docket No. 02-135, 2002

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