Technical White Paper
Microwave Fundamentals Series
Spectrum Analysis for Interference Detection and Interpretation

Abstract

This technical paper describes in detail the tools and techniques used to conduct proper spectrum analysis in advance of terrestrial microwave radio system deployments. Radio operators, engineers and installation professionals can use this document as an on-site guideline for conducting spectrum analysis to identify potential sources of interference.

Introduction

Operation in the license-exempt bands presents the risk of encountering interference. Fortunately, the risk is easily managed with proper planning and analysis. In order to perform such analysis, a spectrum analyzer is required. Spectrum analyzers may be unfamiliar to those that deploy microwave radio equipment. In some cases, spectrum analyzer measurements may be misinterpreted by the operator. The purpose of this document is to provide a brief overview of spectrum analyzer functionality, guidelines for purchasing a spectrum analyzer and instructions for use. Most importantly, the document will provide information on how to interpret the information gathered with a spectrum analyzer.

The Spectrum Analyzer

Spectrum analyzers are used to effectively “sniff” the air for interference at a particular frequency or across a range of frequencies. They have many other uses and functions but for the sake of this discussion, interference identification is of the highest concern. Generally speaking, spectrum analyzers are wideband receivers that are capable of displaying the relationship of frequency and amplitude on a graphical interface. Often, a range of frequencies is defined for display on the screen. The amplitude of any noise or interference is represented by a line across the bandwidth of the signal. The shape of the line, or envelope, is often referred to as the signal’s footprint. Depending on the radio technology in use, these footprints vary. The footprint of a signal isn’t as pertinent as its individual components: frequency, amplitude and occupied bandwidth.

Equipment Selection

Spectrum analyzers come in various shapes, sizes and prices. It is important to find a device that meets the criteria for the job (size, price, and functionality). Bench-top devices are great for bench-top applications, however, the majority of uses for a spectrum analyzer in this context require some degree of portability. Precision accuracy is less important. Cost-effective, portable spectrum analyzers are often feature limited compared to their more expensive counterparts, though the features found in higher-end lab-quality spectrum analyzers are not necessarily required for measurements in the field. As a result, the work required of a portable spectrum analyzer can often be accomplished with a cost-effective, portable unit. Comparing technical specifications for various spectrum analyzers can be daunting. Here are a few guidelines:

1. Frequency coverage: cover the bands of interest (e.g. 2.4-2.4835, 5.25-5.85 GHz);
2. Resolution bandwidth: support 1MHz or higher;
3. Sensitivity: sensitive to the lowest supported receiver threshold of a typical microwave radio, plus any compensation for resolution bandwidth (see below for additional information regarding compensation for resolution bandwidth (RBW);
4. Peak hold or max hold capabilities;
5. Screenshot storage;
6. Battery power;
7. Network or serial interface for screenshot recovery.

Vendors in the cost-effective, portable category include:

- XL Microwave (Analyze-R) – www.xlmicrowave.com
- Avcom of Virginia (PSA-1727) – www.avcomofva.com
- Bantam Instruments (425A) – www.bantaminstruments.com

Vendors in the full-featured, portable category include:

- Anritsu (Spectrum Master or Site Master) – www.anritsu.com
- Rohde & Schwarz (FSH6) – www.rsd.de

Operation

There are two typical scenarios that demand spectrum analysis. The first scenario is a pre-installation site survey. In this case, the information obtained from the site survey will determine how much interference exists and it will provide some insight into how the radio system will need to be configured for optimum operation. The second scenario is diagnostic in nature and typically occurs during a troubleshooting process. In this case, interference has been suspected and now needs to be confirmed and quantified. In either application, the primary area of concern for a directional wireless system will be in the main beamwidth pattern of the antenna mounted and aligned at the location that it is deployed (or planned to be deployed). Off-axis interference is important to note but the directional properties of the antennas used will attenuate these signals to some degree. Therefore, the testing should be concentrated in the direction of the radio path. In the case of the installed system (second application), the existing antennas and transmission line system should be utilized for the spectrum analysis.

The following equipment is required to properly identify interference:

- Spectrum analyzer, with “peak hold” or “max hold” functionality
- 50Ω coax jumper approximately 6’ in length (3/8”, 1/2”, or equivalent)
- Flat panel or small dish antenna (14 to 29 dBi for 2.4GHz, 18 to 24 dBi for 5GHz)

A spectrum analyzer that has the ability to store a waveform on its screen as it sweeps through the specified frequencies allows the user to identify signals that do not have a constant carrier or continuous wave (CW). This feature is usually called “peak hold” or “max hold”. Examples of some transmitters that do not appear to be constant or continuous on a spectrum analyzer are 802.11b direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS) signals. Without this feature, the user will only see small slices of the signal as the spectrum analyzer sweeps through the defined frequencies, making them difficult to discern. Signals that are CW in nature will be easy to view on a spectrum analyzer. Non-CW signals that are under heavy load (almost 100% duty cycle) will also be easy to identify. It is important to make note of the insertion loss (dB) of the coax and connectors and the gain of the antenna (dBi) used for the interference testing.

Procedures

All interference studies should take place at the location of the new or existing antenna of interest. This provides the greatest accuracy in determining the impact of interference. Likewise, measurements should be taken in the direction of the intended or existing radio link.

1. If necessary, calibrate the spectrum analyzer as outlined in the user manual;
2. Verify and record the insertion loss (dB) of the coax and connectors;
3. Observe and note the gain (dBi) of the antenna being used to perform the spectrum analysis (usually on a spec sheet);
4. To start, adjust the spectrum analyzer for maximum receive sensitivity (the greatest negative number), sometimes referred to as Amplitude or Reference Level;
5. Set the center frequency and span of the analyzer to cover the entire frequency band of interest. To sweep a set of frequencies the analyzer can typically be set one of two ways, using either a start and stop frequency (Table 1) or a center frequency and span (Table 2). The tables below show the appropriate parameters for sweeping several of the unlicensed bands.

Note: Depending on the amplitude of the signal, the sensitivity of the spectrum analyzer may need to be decreased in order to get an accurate amplitude reading. Strong signals may be distorted if outside the dynamic range of the analyzer. Make adjustments to the analyzer, as necessary.

Table 1			Table 2		
Frequency Band	Start Frequency	Stop Frequency	Frequency Band	Start Frequency	Stop Frequency
900 MHz ISM	902MHz	928MHz	900 MHz ISM	915MHz	30MHz
2.4GHz ISM	2400MHz	2483MHz	2.4GHz ISM	2442MHz	84MHz
5.7-5.8GHz ISM	5725MHz	5850MHz	5.7-5.8GHz ISM	5788MHz	125MHz
5.2-5.3GHz U-NII	5250MHz	5350MHz	5.2-5.3GHz U-NII	5300MHz	100MHz
5.7-5.8GHz ISM	5725MHz	5825MHz	5.7-5.8GHz ISM	5775MHz	100MHz

6. Set the RBW (Resolution Bandwidth) of the spectrum analyzer to 1MHz (if it is variable). This may not be the optimal setting if a higher RBW is available but it is a good starting point. The RBW of a spectrum analyzer has a significant impact on the amplitude of the signals that are detected. It is critical to know the RBW of the spectrum analyzer in order to properly interpret the information gathered;
7. Set the Sweep Rate or Sweep Time to the slowest speed. A slower sweep will generally allow for easier identification of non-CW signals. Increase the sweep rate as determined appropriate by the signal being detected. You may attempt multiple sweep rates if the interference activity is intermittent in nature;
8. With the antenna connected to the spectrum analyzer and using vertical polarization, point it in the direction of the intended path while watching the display of the spectrum analyzer for any spikes or waveforms. If an existing link is being tested, connect the spectrum analyzer to the transmission line available at the RF port of the radio or by using a short jumper cable to the antenna;
9. Rotate the orientation of the antenna by 90° to horizontal polarization and perform the same test. Note which polarization shows the highest amount of interference;
10. Record any interfering signals in the band of interest in Table 3 below.

Table 3	1	2	3	4	5	6	7
Center Frequency (GHz)							
Bandwidth (MHz)*							
Antenna Azimuth (°)							
Spectrum Analyzer							
Amplitude (dBm)							
Antenna Polarity (V or H)							

**Bandwidth, or Occupied Bandwidth (OBW) is typically measured at –3dB from the peak*

11. Adjust recorded amplitudes (in Table 3) to account for the RBW of the spectrum analyzer.

Calculate the actual amplitude of the interference using the obtained value from the spectrum analyzer and the RBW correction factor. In order to do this you need to know the Resolution Bandwidth (RBW) of the spectrum analyzer and the Occupied Bandwidth (OBW) of the received signal from Table 3. Many spectrum analyzers have variable RBW's (100 kHz – 5 MHz), while some have fixed. Using the RBW value for the spectrum analyzer and the OBW of each interferer, calculate the correction factor using the following formula:

RBW Correction Factor = 10 x log(OBW/RBW) [Eq. 1]

Once the correction factor has been calculated, it needs to be applied to the amplitude recorded in the Spectrum Analyzer Amplitude field for each interferer. The formula below should be used:

Interferer Amplitude = Spectrum Analyzer Amplitude + RBW Correction Factor [Eq. 2]

Use Table 4 below to record corrected amplitude figures. Notice that the corrected amplitude is actually higher in amplitude than the value obtained from the spectrum analyzer, demonstrating the importance of taking RBW into account.

Table 4	1	2	3	4	5	6	7
Amplitude with RBW correction factor (dBm)							

12. Normalize amplitudes (in Table 4) to the receiver bandwidth of the affected radio, accounting for any differences in OBW of the interferer and intended radio receiver.

    If the interferer(s) perfectly overlap the intended signal (i.e. same occupied bandwidth and center frequency), the amplitude manipulation ends here and this step can be skipped. If the interferer(s) only occupies a portion of the intended signal or the occupied bandwidth of the interferer is different than that of the intended signal, additional work is required.

    The amplitude of each interferer needs to be normalized to the receive bandwidth of the intended receiver. Interferers that are tuned outside of the receive bandwidth of the radio can be generally disregarded unless they are extremely strong signals that are very close to the receiver frequency. The impact of the interferer decreases when it occupies only a portion of the receiver's bandwidth versus the entire bandwidth. The formula below can be used to calculate the impact of the interferer based on partial spectral overlap and received power density.

Normalized interference amplitude = Amplitude with RBW correction factor +

10log(overlapping spectrum / interferer's total bandwidth) +

10log(overlapping spectrum / receiver's bandwidth) [Eq. 5]

Complete Table 5 with the normalized interference amplitude.

Table 5	1	2	3	4	5	6	7
Normalized interference amplitude (dBm)							

13. Make any adjustments in the amplitude values to account for the difference in coax and antennas used between the spectrum analysis and actual system deployment.

If the spectrum analyzer was connected directly to an existing system at the radio's RF port, skip this step. For instance, if the spectrum analysis consisted of a coax jumper with 1 dB insertion loss and antenna gain of 23 dBi, the net gain is 22 dB (23 dBi – 1 dB). If the actual installed system will consist of a coax run with 5 dB insertion loss and an antenna gain of 28 dBi the net gain is 23 dB. Therefore, 1 dB (23 dB – 22dB) should be added to the measured interference amplitude to compensate for the difference between the test setup and the actual deployed system.

Complete Table 6 with the Amplitude at the RF port, which includes adjustments for any discrepancies in net gain. This should match Table 5 if the spectrum analysis was done at the RF port of an installed system.

Table 6	1	2	3	4	5	6	7
Amplitude at the RF port (dBm)							

Making Sense of It All

At this point, the appropriate information has been gathered and manipulated to reflect the parameters of the installed system (i.e. receiver bandwidth of the affected radio). Now it is necessary to use this information to determine the impact of the interference on the local (or proposed) system. In order to assess the impact or the potential for impact, the intended receive signal level (RSL) of the installed (or proposed) system needs to be considered. A link budget calculation will indicate the anticipated RSL of the system. The anticipated RSL should be very close to the actual RSL in the case of an existing system. In the event they aren't exactly the same, use the RSL indicated by the radio system.

The RSL (intended or realized, depending on whether or not the system is installed) should be compared to the amplitude of the interference at the RF port of the radio (as defined in Table 6). Clearly, any interferer that exceeds the RSL of the system will indicate that mitigation efforts need to be undertaken. However, the amplitude of the interference doesn't necessarily need to exceed the RSL in order to cause problems.

There is a performance specification related to microwave radios known as C/I (carrier-to-interference) that is a function of several factors of the radio design. The C/I value is the carrier to interference relationship that the receiver requires in order to properly demodulate the intended signal. If the amplitude of the interference approaches the RSL within the C/I requirement, the radio will experience bit errors and, eventually, the link will fail.

Therefore, it is necessary to know the radio's C/I value at the modulation and occupied bandwidth that the radio is utilizing. Any interference that approaches the RSL of the radio minus the C/I is suspect and appropriate mitigation measures should be taken to provide the desired fade margin (typically, at least 15 dB) beyond the RSL minus C/I.

> *Example*
> Assume that the designed and/or actual RSL of the system is -65 dBm. If the C/I of the radio is 10 dB, any interference signal with an impact level greater than -75 dBm will cause errors in the system. Also, if interference exists at this (normalized) level, there is effectively ZERO margin for the -65 dBm signal to experience atmospheric fading. As a result, unless the antennas can be re-oriented, the RSL improved or the interference level further reduced through other means, this link will be extremely unstable. Typically, it is desirable to design the link to accommodate adequate fade margin ABOVE the interference level as well as the C/I requirement. In this example, that level is -65 dBm (interference level of -75 dBm plus the C/I requirement of 10 dB), therefore the desired RSL may be in the range of -50 dBm.

Conclusion

An Interference Analysis Form is available at the end of this document to use at each location a spectrum analysis is performed. Using this form along with the directions provided above, an accurate spectrum and interference analysis can be completed. The risks associated with microwave radio deployments in the license-exempt frequencies are manageable when equipped with the proper knowledge and test equipment.

The staff at Exalt collectively has hundreds of years of RF knowledge and experience in this specific area. You are encouraged to leverage Exalt expertise to assist with complex system designs and interference analysis where Exalt radios are implemented or planned.

For more information regarding various interference mitigation techniques, please see the Exalt Technical White Paper, *Interference Mitigation in License-exempt Bands*.

Appendix A: Interference Analysis Form

Site Name:

Site Address:

GPS Coordinates: Datum:

Antenna gain: Coax loss: Net gain (antenna gain - coax loss):

Interferer	1	2	3	4	5	6	7
Center Frequency (GHz)							
Bandwidth (MHz)							
Azimuth (°)							
Spectrum Analyzer							
Amplitude (dBm)							
Antenna Polarity (V or H)							
Amplitude with RBW correction factor (dBm)							
Normalized interference amplitude (dBm)							
Amplitude at the RF port (dBm)							

Existing co-located wireless equipment:

Interferer Comments:

1.

2.

3.

4.

5.

6.

7.

Site Considerations: