Using Spectrum Analyzers For Signal Monitoring

Presented by:

Agilent Technologies
At the completion of this module you will have an understanding of how commercially available spectrum analyzers can be used for very specific frequency management and signal surveillance applications.

**Agenda**
- Basic Equipment
- Enhancements
- Pulse Measurements
- Modulation Measurements
- Wideband Application
- Connectivity
- Conclusion
Signal Monitoring Applications

– Frequency management:
  • Monitor RF bands to determine compliance with local laws and regulations
  • Monitor assigned frequencies to look for interfering signals or to determine if your transmitters are working properly
  • Manage RF assets on large industrial/government sites, like airports, missile launch facilities, and test ranges
  • Look for RF sources that might be causing out of band interference to other equipment such as medical equipment
  • Perform site surveys prior to installation of a repeater or cellular base station.

– Signal surveillance:
  • Law enforcement or other government agencies could monitor other people’s transmissions to extract intelligence
  • Sweep rooms or buildings for bugs or other RF emitters
Basic Equipment

- For the most basic spectrum monitoring tasks a receiver and antenna are required.
  - Suggested equipment could include:
    - Spectrum Analyzer (receiver)
    - Antenna
    - Antenna transmission lines
    - Preamplifier
    - Graphics output device (printer or plotter)
    - Specialized software

Signal monitoring systems can range from extremely simple to very complex fixed-site systems. This paper will review some of the basic components that can be used to assemble a signal monitoring system. The most basic of signal monitoring systems could simply be a radio and an antenna. To learn more about the signal it is necessary to measure frequency and amplitude of the signal. These requirements suggest that the spectrum analyzer can be the foundation of many signal monitoring systems.
Receiver Requirements

- Surveillance/monitoring receivers should provide the following features:
  - Broad frequency range
  - Fast tuning speed
  - Graphical display to aid in signal identification
  - Good sensitivity
  - Good selectivity
  - IF output and or video output
  - Remote or computer control.

The receiver is really the heart of the signal monitoring system. As mentioned previously, signal monitoring systems can range from simple to complex. For general signal monitoring requirements, the spectrum analyzer is a very attractive receiver choice. The spectrum analyzer’s extremely broad frequency coverage and excellent dynamic range make it a logical building block for signal monitoring systems.

In some applications that require 100% probability of intercept (POI) the swept tuned spectrum analyzer may not be the best tool. In these cases specialized receiving equipment may be required. However, for narrow spans, less than 10 MHz, the Agilent PSA series spectrum analyzer can be used in FFT mode to improve POI.
The Agilent PSA Series Spectrum Analyzer

- The Agilent PSA series spectrum analyzer as a signal monitoring receiver.
  - Broad frequency range 3 Hz to 50 GHz
  - State of the art all digital IF with 160 resolution bandwidth filters
  - Digital filters provide excellent selectivity
  - Interface with Agilent 89601A software for signal demodulation.
  - Wideband IF and video outputs to improve signal analysis

The PSA series spectrum analyzers are well suited for signal monitoring applications. The PSA is offered in five models covering the following frequency ranges: 3 Hz to 6.7 GHz, 3 Hz to 13.2 GHz, 3 Hz to 26.5 GHz, 3 Hz to 44 GHz, and 3 Hz to 50 GHz. The PSA family is unique, in that it incorporates a revolutionary 100% digital IF. All of the traditional analog filters and IF signal processing have been replaced with a custom ASIC that performs these through DSP.

The PSA’s digital IF provides improved IF filtering and greatly improved measurement accuracy. In addition, the PSA’s DSP provides a host of detector choices to aid signal characterization. The PSA family features many single button measurements to simplify modern RF measurements. Some of these measurements that are of interest in a signal monitoring environment are occupied bandwidth, integrated channel power, adjacent channel power, spectrum masks.

The PSA also provides an amplitude correction function. Amplitude correction allows the user to specify amplitude correction table to apply to measurement data. In a signal analysis role amplitude correction can be used to correct measured data for antenna gain, transmission line losses, and preamplifier gain. In addition to amplitude correction, the PSA includes a set of measurement limit lines. The limit lines can be programmed to generate an alarm when a signal’s amplitude exceeds the limit setting in a specific frequency range. Following our discussion of antennas and preamplifiers we will discuss the use of limit lines and amplitude correction.
Many factors will influence your choice of antennas. Generally, most signal monitoring applications require portable operation, which limits the practical size and weight of antennas. However, if very small signals must be analyzed larger antennas will be required. Antenna polarization is another important consideration. If the polarization of received signal is unknown, a circular polarized antenna may be the best choice, since it works equally well for both horizontal and vertical polarization.

Line of bearing of the measured signal may be determined by various techniques. One simple method is to use a spinning receive antenna. By correlating the signal with the direction the antenna was pointed when the signal was received, the signal's line of bearing may be determined.

Another very important antenna parameter is bandwidth. If you are only looking over a narrow communications band, simple narrow-band antennas will provide an economical solution. However, if you must survey a broad frequency spectrum, a broadband antenna will be required. Associated with bandwidth is dispersion. Some antennas, while broadband, will induce different time delays to different frequencies. These changes in delay can greatly distort very short pulses.

Generally, antennas designed for Electromagnetic interference (EMI) and electromagnetic compatibility (EMC) applications work very well for signal monitoring applications.
This table reviews some of the characteristics of basic antennas that may be used for signal monitoring. Other antennas are suitable, as required by specific signal collection requirements. Antennas can range in physical size from small patch antennas to HF antennas that may be larger than a football field.

<table>
<thead>
<tr>
<th>Type</th>
<th>Gain</th>
<th>Polarization</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whip/Monopole</td>
<td>Low (small size)</td>
<td>Linear V or H</td>
<td>Narrow</td>
</tr>
<tr>
<td>Biconicle</td>
<td>Low</td>
<td>Linear V or H</td>
<td>Decade</td>
</tr>
<tr>
<td>Discone</td>
<td>Low</td>
<td>Linear V</td>
<td>Decade</td>
</tr>
<tr>
<td>Standard Gain Horn</td>
<td>Medium (Gain is traceable)</td>
<td>Linear V or H</td>
<td>Octave</td>
</tr>
<tr>
<td>Ridged Horn</td>
<td>Medium</td>
<td>Linear V or H</td>
<td>Decade</td>
</tr>
<tr>
<td>Conical Log Spiral</td>
<td>Low</td>
<td>Circular</td>
<td>Decade</td>
</tr>
<tr>
<td>Cavity Backed Spiral</td>
<td>Low (small size)</td>
<td>Circular</td>
<td>Decade</td>
</tr>
<tr>
<td>Log Periodic</td>
<td>Medium</td>
<td>Linear V or H</td>
<td>Decade</td>
</tr>
</tbody>
</table>
Antenna Gain

- Several factors relate the antenna’s output voltage or power to incident field strength and power density. The antenna gain $G$, effective area $A_e$, antenna factor $AF$, and beamwidth can be related mathematically.

\[
G = \eta G_D
\]

\[
G_D = \frac{4\pi}{\theta\phi(\text{radians})^2} = \frac{41,253}{\theta\phi(\text{deg})^2}
\]

\[
A_e = \frac{G\lambda^2}{4\pi}
\]

The directive gain of an antenna is a measure of its ability to concentrate energy in one direction. Mathematically, directive gain can be defined as the antenna’s maximum radiation intensity divided by its average radiation intensity. Since the average radiation intensity over a solid angle of $4\pi$ radians is equal to the total power radiated divided by $4\pi$, directive gain can be expressed as:

\[
G_D = \frac{4\pi(\text{maximum power radiated/unit solid angle})}{\text{total power radiated}} = \frac{4\pi}{B}
\]

Where $B$ is the beam area of the antenna. This is the solid angle through which all of the antenna’s power passes. If $\theta$ and $\phi$ are the half power beamwidths in two orthogonal planes then $B$ is approximately equal to $\theta\phi$. This results in a directive gain of:

\[
G_D = \frac{4\pi}{\theta\phi(\text{radians})^2} = \frac{41,253}{\theta\phi(\text{deg})^2}
\]

Since our antenna is non ideal, its actual power gain will be somewhat less than its directive gain. The ratio of power gain ($G$) divided by directive gain ($G_D$) is the antenna efficiency factor $\eta$. Another useful antenna parameter related to gain is the effective aperture or area $A_e$ presented by the antenna to the incident wave. The gain $G$ and effective area of a loss less antenna are related by:

\[
A_e = \frac{G\lambda^2}{4\pi}
\]
Determining Field Strength

- The antenna’s measured output signal power can be used to determine the power density of the incident wave that is intercepted by the antenna.

\[
\rho = \frac{4\pi S}{G_R \lambda^2} \quad \text{(Watts per square meter)}
\]

Where: 
- \( S \) = Received signal power (watts)
- \( G_R \) = Receive antenna gain
- \( \lambda \) = wavelength in meters

- Similarly, the peak intensity of the signal’s electric field strength can be determined

\[
E_{\text{peak}} = \sqrt{\frac{8S\pi Z_0}{G_R \lambda^2}}
\]

Where: 
- \( Z_0 \) = Characteristic Impedance of free space = 377Ω

The antenna’s output signal power (\( S \)) is simply the product of the antenna’s effective aperture \( A_e \) multiplied by the power density of the incident wave. Assuming the signal’s source is an isotropic radiator and multipath and fading are not considered, the free space power density will be the source’s output power divided by the surface area of a sphere with radius \( R \).

\[
S = \rho A_e = \frac{P_I G_T A_e}{4\pi R^2}
\]

Substituting the relationship for antenna gain and effective aperture, the the antenna’s output power becomes:

\[
S = \rho G_R \lambda^2 = \frac{P_I G_T G_R \lambda^2}{(4\pi)^2 R^2}
\]

With these equations we can relate the received signal power to the incident power density or to the source’s output power, assuming we know its transmit antenna gain and range. Since we can relate the peak intensity of the signal’s electric-field strength to its power density, we can substitute this into the above equation and determine the peak field strength of our measured signal.

\[
\rho = \frac{|E|^2}{2Z_0} \quad \text{Therefore:} \quad E_{\text{peak}} = \sqrt{\frac{8S\pi Z_0}{G_R \lambda^2}}
\]

Another useful term is the so called antenna factor (AF) that relates the incident electric field to the antenna’s output voltage. \( AF = E/ V_o \) Many EMI antennas will be provided with calibrated antenna factor curves.
A preamplifier can be used to improve the spectrum analyzer's sensitivity. A preamplifier can be used to improve the spectrum analyzer's sensitivity.

- The spectrum analyzer's sensitivity is the displayed average noise level (DANL) = kTBF
- The analyzer's sensitivity can be improved by lowering the system noise figure with a preamp.
- Receiver's output signal is increased by the amp's gain, So = GPA Si
- Analyzer noise floor is only increased by: F_eq + GPA – FSA – 2.5 dB

The sensitivity of a spectrum analyzer is specified as displayed average noise level (DANL). For signal monitoring applications the smallest signal that can be displayed is one equal in amplitude to DANL. Another common way to specify the sensitivity of a receiver is by its noise figure F. Noise figure can be defined as the ratio of output to input signal to noise ratio or F = (S_i/N_i) / (S_o/N_o), where S_i and N_i are the input signal and noise and S_o and N_o are the output signal and noise. In the special case of a spectrum analyzer, the output signal is equal to the input signal times the gain of the analyzer, which is unity because the output signal on the display is the same amplitude as the input level at the RF connector. Therefore, the expression for noise figure can be simplified to F = No/N_i. To determine F we simply divide the DANL by the available noise power at the input, or by KTB. Expressed in dB the resulting noise figure would be:

F(dB) = 10*Log(F) = DANL - (-174 dBm/Hz) - 10*Log(B)

For the lower trace we see that F_SA = -83.9 dBm + 174 - 62.6 = 27.5 dB

A noise figure of 27.5 dB is pretty good for a spectrum analyzer with 10 dB input attenuation, but somewhat poor for a signal monitoring receiver. The upper trace shows the same signal after being amplified by a preamplifier with a gain of 25 dB and a noise figure of 7.77 dB. The new DANL with the preamplifier is:

DANL_2 = KTB F_eq G_2 - 2.5 dB = -174 dBm + 62.6 + 8.9 + 25 - 2.5 = -80 dBm

Where F_eq is the system noise figure of the analyzer and preamp combined and the 2.5 dB term is a correction term for noise signals (see Agilent Application Note 150).
Amplitude corrections are necessary for most signal monitoring applications. Generally, not only is the frequency and bandwidth of a signal important, but the amplitude of the measured signal is also important. The PSA series spectrum analyzers provide four amplitude correction tables that are defined as: antenna, cable, other, and user. Each of these corrections can be turned on or off independently of the others. In addition a separate key labeled “Apply Corrections” must be pressed to invoke the corrections. Antenna, cable, other, and user corrections are generally entered as positive values, which indicate a loss in the external device. Negative values would be used to represent gain in the external device. Correction tables can be entered manually from the front panel of the spectrum analyzer or they can be downloaded from an external computer.

Correction factors can also be used to provide more complex corrections to measured data. For example, if the user desires to correct screen data to free space power density a suitable correction table can be calculated based on antenna gain and frequency. Modifying our equation for power density on Slide 10 to replace wavelength with frequency yields a correction factor in dB of:

\[ 10 \times \log(4\pi) - 20 \times \log(c) + 20 \log(F) - G_R = 20 \log(F) - G_R - 159 \text{ dB} \]

Assuming we are measuring a signal at 2.4 GHz with an antenna whose gain is 10 dB, we would apply a correction factor of 18.6 dB. If we leave the spectrum analyzer in its preset mode, of displaying power in dBm, our display would now be calibrated for dBm/ m², for this specific antenna. By changing the amplitude display to display in Watts we would be able to directly read power density in Watts/ m².
Generating Alarms With Limit Lines

- Another convenient feature of using a spectrum analyzer for signal monitoring is limit lines.
  - Limit lines are easily generated by editing a table or are downloadable from an external computer.
  - Will generate an alarm (fail indication) when a measured signal exceeds the specified limit.
  - Both upper and lower limit lines are available.

In many signal monitoring applications it is desirable to provide notification when a signal at a specific frequency appears. Generally alarming criterion are based on some amplitude threshold over a frequency band of interest. Most software packages developed for signal monitoring provide some sort of alarm capability. For simple applications the limit line capability of the PSA series spectrum analyzers can be used to provide an indication if a signal’s amplitude crosses a threshold.

The PSA provides two limit lines that can be programmed from the front panel or via an external computer. Each limit line provides both an upper and lower threshold. The user may enter up to 200 points frequency and amplitude pairs to define the limit line.

Limit lines were designed for manufacturing test applications and provide a “Pass/ Fail” indication on the screen. If the signal’s amplitude exceeds the threshold the fail indicator will appear on the spectrum analyzer’s screen. For signal monitoring we can use this feature to let us know when a signal in a band of interest appears, but the indication we will receive is a test fail notice on the screen.
Time Domain Analysis

- In addition to frequency domain analysis, the spectrum analyzer can be used to analyze time characteristics of pulsed RF signals to measure:
  - Pulse width
  - Pulse repetition time (PRT)
  - Pulse amplitude droop
  - AM modulation on pulse

In addition to the frequency characteristics of RF signals, the spectrum analyzer can be used to measure the time domain characteristics of signals. One classic example of this is analysis of RF pulsed signals such as radar and bursted communications signals. To perform this analysis the analyzer is tuned to the correct frequency and then placed in the zero-span mode (span is set to 0 Hz). In zero span mode the analyzer provides an oscilloscope like display of the signal, with amplitude in the Y axis and time on the X axis. Similar to an oscilloscope, the spectrum analyzer provides trigger and sweep controls to assist setting up the display. Once the signal is properly displayed, markers can be used to measure such parameters as pulse width and PRF.

When using the zero-span mode to view RF pulsed signals it should be remembered that the signal’s rise time and other pulse characteristics are dependant on the resolution bandwidth (RBW) filter used to process the signal. The rise time of spectrum analyzer RBW filters is approximately 0.67/RBW. Generally the wider (> 1 MHz) RBW settings will be required for good pulse characterization. In some circumstances the maximum RBW of 8 MHz may be insufficient to pass the fast transitions of the pulse. In this case you will be measuring the rise time of the spectrum analyzer, not your signal.

If shorter rise time measurements are desired the PSA provides a fast rise time video output option, Option H7L.
PSA Options:  
For Signal Monitoring

- **1DS**: Internal 3 GHz preamplifier  
- **H26**: Internal 26 GHz preamplifier  
- **B7J**: Digital demodulation hardware  
- **H7L**: Fast rise-time video output  
- **H70**: 70 MHz IF output  
- **HN8**: 250 MHz IF bandwidth for RF > 3 GHz  
- **HN9**: 100 MHz IF bandwidth for RF < 3 GHz  
- **HNQ**: Wideband IQ outputs and calibration software

The PSA series spectrum analyzers have several options that are beneficial in signal monitoring applications. As discussed previously a preamplifier is an essential element of a signal monitoring system. Option 1DS for the PSA is an internal preamplifier that is intended to improve the system noise figure for RF frequencies less than 3 GHz. This internal preamplifier is fully calibrated and its performance is specified in the PSA specifications. Option H26 is available in 26, 44 and 50 GHz versions for the E4440A, E4446A, and E4448A PSAs. This amplifier is also intended to lower system noise figure; however, it is not fully calibrated.

Option B7J is a high speed electronic step attenuator that is used for analysis and demodulation of digital communications signals. This option supports internal demodulation firmware as well as the Agilent 89601A vector signal analyzer (VSA) software.

Option H7L is a fast rise time video output option designed to provide video to an external oscilloscope for short RF pulse analysis. This option is primarily used to analyze radar and electronic warfare signals.

Option H70 provides a 70 MHz IF output signal for use with the Agilent 89611A VSA. This configuration provides up to 36 MHz of analysis bandwidth for analysis and demodulation of digital communications and wide band analog signals.

Options HN8 and HN9 provide wide band IF signals which can be digitized by Agilent’s Infiniium oscilloscopes and analyzed using the 89601A VSA software.

Option HNQ provides wideband IQ outputs and calibration software to be used in conjunction with a dual channel 89600 system. The calibration software requires the ESG (E4438C) or the PSG (E8267C). When used in conjunction with the 896102A, the system provides nominal performance and flatness correction across 78 MHz of IF bandwidth on the order of <0.2dB.
Characterizing Pulsed RF Signals with PSA Option H7L

- Provides fast rise time video output for characterization of radar and EW RF pulses
- PSA typically used in zero-span mode
- Video output viewed on O-scope

- Pulsed RF signal
  - PW=100 ns
  - Amplitude = -10 dBm

If your signal monitoring requirements involve analysis of pulsed RF sources such as radar and electronic warfare systems, the 8 MHz resolution bandwidth of the PSA’s digital IF may be insufficient for complete analysis. In these cases Agilent offers a wide bandwidth log-video detector that provides excellent dynamic range and fast rise time. Option H7L uses the 40 MHz wide 321.4 MHz IF output of the PSA to drive the video circuitry. This results in great improvements in signal rise time. If even better rise time performance is required, Option H7L can be coupled with Options HN8 and or HN9. In these configurations Option H7L can provide down to 15 ns rise times.

The output of Option H7L is log-video with a slope of 25 mV/ dB. By setting up your external oscilloscope with a deflection factor of 250 mV/ division your scope will be calibrated to read RF power with a deflection factor of 10 dB/ division.
Many times simply looking at the spectrum of intercepted signals is not enough. Additional signal analysis capability can be added to a signal monitoring system by using vector signal analysis (VSA) capability. Since the PSA utilizes an all digital IF, the IF signals are already in a digital format and can be exported over a LAN or GPIB to an external computer running the Agilent 89601A VSA software. The 89601A software will allow you to measure AM modulation depth, peak FM deviation, and many other signal parameters.

The 89601A software provides both analog and digital signal demodulation and analysis in a user friendly signal processing workstation.
The above slide shows a 4-level frequency shift keyed (FSK) signal with a center frequency of 1 GHz. The four frequency states of the FSK signal can clearly be seen on the upper left quadrant of the display. The lower left quadrant shows the frequency spectrum of the signal. The upper right quadrant of the display shows the frequency error of the signal on a per symbol basis. The bottom right quadrant provides tabular data that describes the signal’s characteristics. These include: FSK error (average and peak), magnitude error, carrier offset, and deviation.

In addition to demodulating AM, FM, PM, and FSK signals; the 89601A VSA can demodulate the data formats listed on slide above.
If you are required to analyze and demodulate signals with greater bandwidth than the PSA’s 10 MHz digital IF can support, an Agilent Infiniium oscilloscope can be used as a high-speed digitizer to provide digital data to the 89601A software. The above slide illustrates using the PSA as a wide-band down converter to translate the RF signal to an IF frequency of 321.4 MHz. PSA Option HN8 provides 250 MHz of IF bandwidth that can be analyzed using the 89601 software. This capability is a very powerful tool for demodulation of wideband digitally modulated signals, Barker coded radar pulses, chirped radar pulses, and for analysis of frequency hopping radios.
This slide shows the demodulation of a $1 \mu s$ RF pulse with 80 MHz of linear FM chirp. The upper left quadrant of the display shows the frequency spectrum of an individual pulse. The upper right quadrant shows the FM demodulation of the pulse. Here we see that the pulse has greater than 80 MHz of chirp in approximately $1 \mu s$. The lower right quadrant of the display shows the signal’s phase as a function of time. Since the time derivative of phase is frequency, we know that if we take the derivative of a ramp we will get a parabolic curve. This can be clearly seen in the phase display above.
The above slide shows spectrogram display of a frequency hopping radio as viewed on the 89601A VSA. As in the previous slide, the PSA was used as a down converter and the Infinium oscilloscope was used as a digitizer for the VSA. The top panel of the display shows the spectrogram display, which shows frequency in the X-axis, time in the Y-axis and the signal’s amplitude is shown as changes in color. The bottom panel is the instantaneous spectrum of the signal. This spectrum represents a bottom raster line of the spectrogram.
BenchLink WebRemote (Option 230)

Capabilities:
- LAN connectivity to PSA (Control PSA over internet or intranet)
- Enhanced visualization and analysis capability: user definable color mapping, graphic zooming, continuous tracing, and display lines
- Variety of displays: SA standard, waterfall, spectrogram, persistence displays

Many times in signal monitoring applications it is desirable to site the spectrum analyzer in a remote location. In these situations the signal monitoring system must be remote controlled or controlled by a computer without operator intervention. Agilent’s WebRemote software (PSA Option 230) provides a convenient way to remote control a PSA spectrum analyzer using a web browser, such as Netscape or Microsoft Internet Explorer. The WebRemote software runs on a local server, which controls the spectrum analyzer and generates graphic images that are served to a remote browser. The connection between the server and user terminals can be a corporate intranet or the World Wide Web. Most of the standard spectrum analyzer control functions have soft keys on the remote browser window.

The WebRemote software allows multiple users to operate and view the signal monitoring system.
BenchLink Web Remote

• Supported Functions:
  • Start / Stop Frequency
  • Center Freq / Span / Zero-span
  • Reference Level
  • Attenuator
  • Resolution BW / Video BW
  • Video & power averaging
  • Sweep time & number of sweep points
  • Factory & user presets
  • Preferences: Auto Align ON/OFF, Auto Ranging ON/OFF
  • Markers

The Web Remote software provides controls for all the important basic analyzer controls as shown here. However, it does not offer full control of ALL front panel buttons that would be available if you were physically located in front of the analyzer. Additional functions can be accessed through a dialog box that allows you to send SCPI commands directly to the instrument.
Conclusion

- Commercially available spectrum analyzers are an excellent foundation for signal monitoring applications such as frequency management and signal surveillance.

- Recent enhancements to the Agilent PSA series of spectrum analyzers, coupled with appropriate accessories, can provide excellent capability and flexibility to system designers, integrators, and users.

- Additional Agilent products contribute to a robust signal monitoring solution:
  - 89601A VSA software
  - WebRemote software
  - E8257C PSG signal generator
  - 5485xA Infiniium series oscilloscope