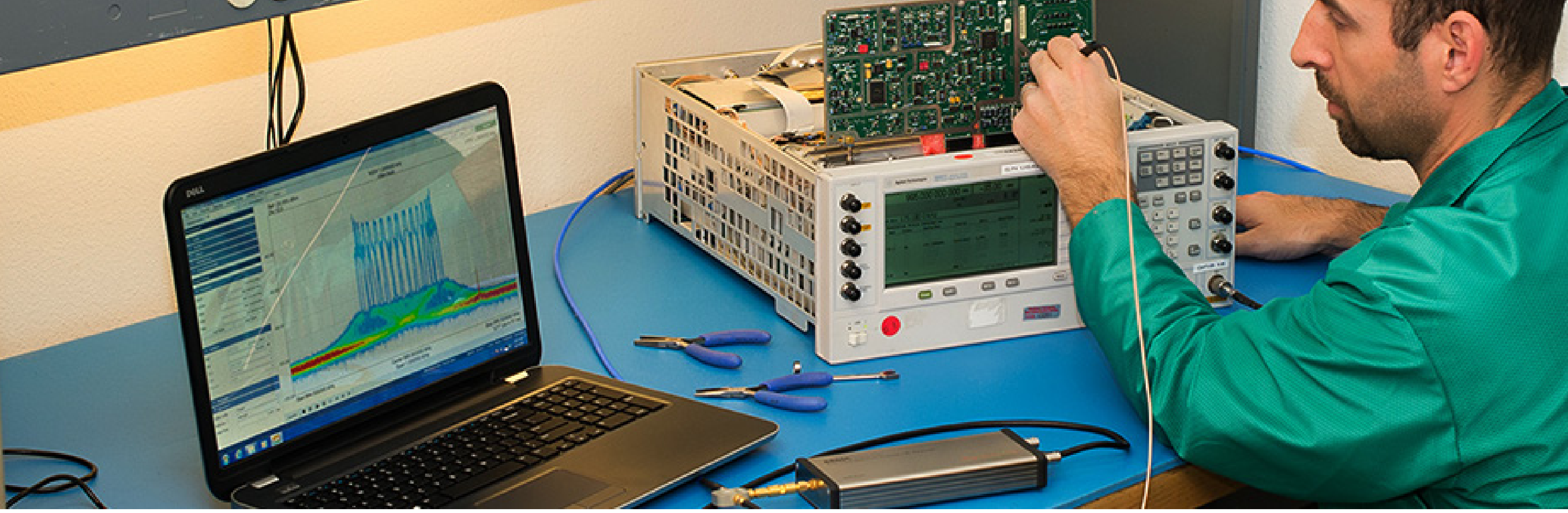

An Introduction to Practical Real-Time Spectrum Analysis

The electromagnetic spectrum (EM) is filled with complex continuous wave (CW) and modulated RF/Microwave signals, with many of these signals carrying important information such as digital information or location signals (radar). The ability to sense and analyze these signals aids in identifying interference causes and deducing component, device, and system behavior. Real-time spectrum analyzers enable on-the-go sensing and analysis of these signals and can put powerful software analysis tools at an engineer's fingertips.

Real-time spectrum analyzers (RTSAs) deliver the information contained in RF/Microwave signals in a convenient format for engineers to view and interpret. Backed by powerful software analysis tools, the frequency-based spectrum information gathered by a RTSA can reveal important information about the performance of RF/Microwave components, track down sources of interference, and monitor the spectrum for activity and security threats. If a RTSA is used in product development or security operations, understanding the EM spectrum and the methods used in RTSAs can provide a valuable perspective in the strengths and limitations of one of the key test and measurement equipment tools in an RF/Microwave engineers arsenal.

A **Technical Brief** from Signal Hound®

What is the EM Spectrum and Why Is Spectrum Analysis Helpful?

Radio Frequency (RF) technology leverages photonic, or electromagnetic (EM), energy from hundreds of kilohertz to tens of gigahertz in frequency for carrying information as analog or digital data. The EM energy acts as a carrier for the information, which is used to modulate the carrier signal. Methods have been devised to modulate and demodulate this information on RF carrier waves, so that security, military, commercial, or consumer data can be cost-effectively conveyed. This could be over short or long distances, and at high data rates or at low data rates with energy efficient transmission.

Figure 1—RF and microwave signals carrying useful communication information

As the components, devices, and systems that enable the transmission and reception of communication technology signals require several design, prototyping, production, verification, and maintenance stages, equipment that can measure the RF signal energy and provide tools to analyze these RF carrier waves and their modulated signals is extremely valuable. Test and measurement equipment, such as RTSAs, are necessary in characterizing components, verifying device behavior during manufacturing, and ensuring proper performance when operating in the field. For instance, security and interference hunting applications also make use of RTSAs for locating disruptive devices and phenomenon. Otherwise, these factors could pose a security threat or hinder the operation of normal communications traffic in protected frequency bands.

How Does Spectrum Analysis Work?

A spectrum analyzer leverages RF energy capture technology that digitizes the frequency domain and modulation information of a RF signal and prepares the digital data for further analysis. As a spectrum analyzer is composed of non-perfect devices, there are limitations on the range of frequencies, bandwidth, power levels, and complexity of RF signals that any given spectrum analyzer can effectively capture and analyze.

The signal chain of a spectrum analyzer generally consists of an antenna or RF input, a RF attenuator, a pre-selector or low-pass filter (LPF), a mixer, an IF gain amp, and an IF filter. Then, the conditioned signal reaches an analog-to-digital (ADC) converter that digitizes captured signal (see Figure 2). Once the RF signal is digitized, time slices of the RF signal are processed by Fast Fourier Transform (FFT) calculators—the time slices of RF signals prepared for FFT analysis are also known as FFT bins—and converted into concatenated frequency domain sweeps.

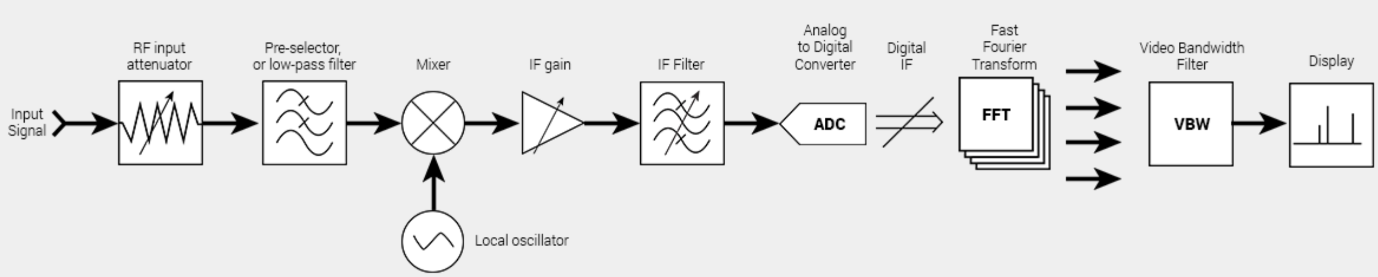

Figure 2—Simplified Spectrum Analyzer Block Diagram

How is a Spectrum Analyzer Configured To Measure?

As spectrum analyzers can sweep a finite minimum and maximum number of frequencies, an initial range of frequencies should be identified. The greater the sweep frequency range, the longer a measurement may take, and the harder it will be to discern and analyze details in the frequency range. So, the minimum sweep frequency should be chosen. The sweep frequency is selected through start and stop frequencies, or the center frequency and span bandwidth.

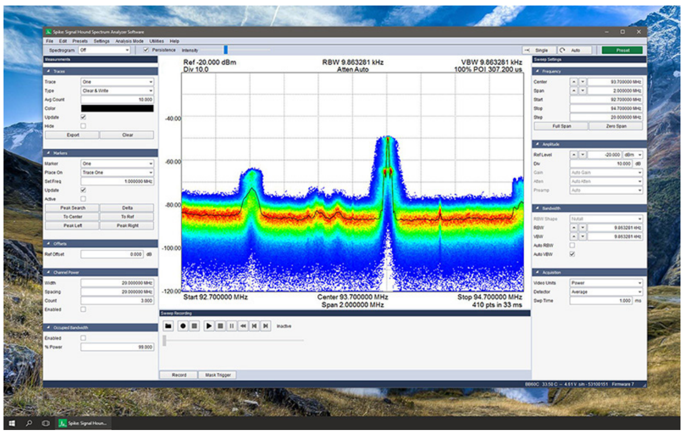

Figure 3—Spectrum analyzer software running on a PC

Additionally, the bandwidth of frequencies an ADC can convert at a given time is finite—also known as the instantaneous bandwidth— and the smaller conversion bandwidth may provide greater measurement accuracy at the cost of viewable spectrum. However, if a measurement sweep range is beyond the instantaneous bandwidth, there will be a delay in updating each section of the sweep. For CW signals that are constant and unvarying this may not be an issue. Yet, this may pose a challenge for modulated communication signals, random signals, or pulsed signals.

What is Resolution and Video Bandwidth and How Do They Impact Spectrum Analyzer Measurements?

The size of the FFT bins in the frequency domain, or the bandwidth of the resolution bandwidth (RBW), determines the frequency resolution of the signals that can be discerned and analyzed by the spectrum analyzer. For instance, if larger FFT bins, or a smaller RBW range, is used, greater signal detail can be observed and analyzed by the spectrum analyzer (see Figure 4). On the other hand, decreasing the RBW also reduces the speed of each frequency sweep. So, there is a trade-off between the resolution of the frequency sweep and the speed of test.

In addition to the RBW, the video bandwidth (VBW) filter provides a smoothing of the amplitude of the signals by digitally filtering and processing the signal output from the FFT engine. The VBW can provide log, power, or voltage detection signal processing that can, for example, act as a power detector and smooth the frequency sweep without affecting the channel power. The log detector emulates a traditional spectrum analyzer output, while the voltage detector

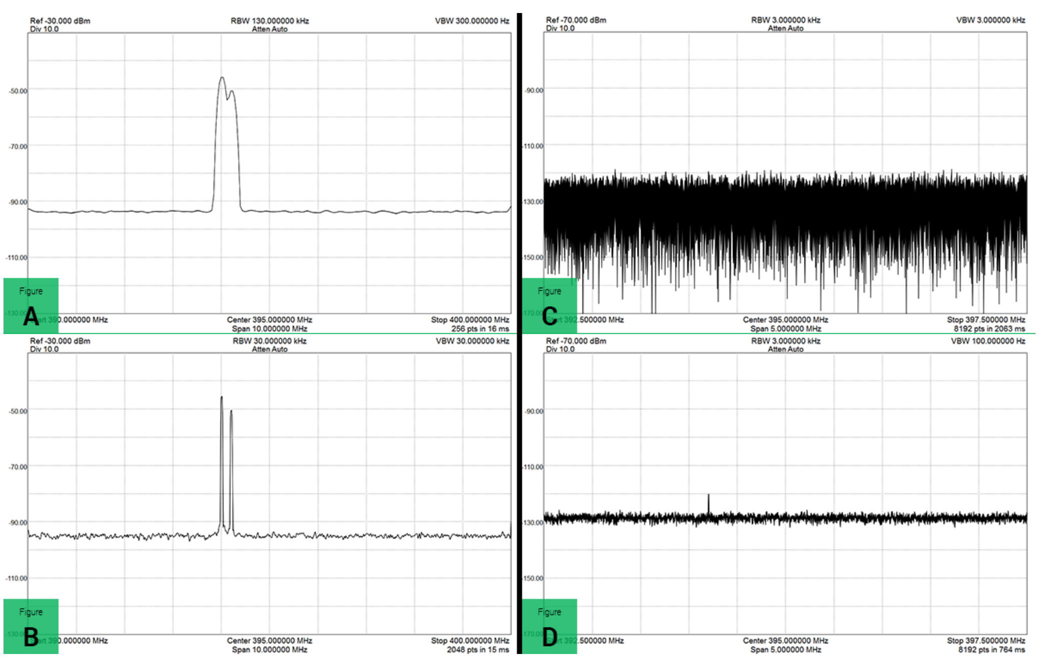

Figure 4—A: Large RBW does not reveal two distinct tones. B: Lowering the RBW reveals two distinct tones. C: Noise floor with VBW equals RBW. D: Lowering VBW reduces the peak-to-peak noise revealing tone.

function can aid in deciphering certain amplitude modulated signal information. The VBW filter can also provide video averaging, that averages several frequency sweeps to reduce random noise factors, or peak-to-peak noise.

Lowering the VBW, or increasing the resolution of the VBW, also increases test times, similar to decreasing RBW. In cases when low-level continuous wave (CW) signals are being measured in close frequency proximity to large signal powers, slower sweep times may be a necessary sacrifice for measurement fidelity. For instance, if spurs from a phase-locked-loop (PLL) or intermodulation distortion products could overpower a signal of interest, and reducing the RBW would lower the noise floor and lowering the VBW would further smooth out the remaining noise, the spectrum analyzer could then reveal an accurate measurement of the previously hidden signal.

What is Spectrum Analyzer RF Gain, IF Gain, RF Attenuation, and Power Level?

The power level of the RF signal to be measured may influence the settings of the RF attenuation, IF gain, RF gain, and displayed power level. The RF attenuation level can be increased to enable high power RF signals to be measured with better linearity, or reduced to enable low-level signals to be measured with sensitivity. As some noise generators tend to scale with RF input power level, minimizing the RF input power level to the maximum signal power of interest is often recommended.

If a signal is of such low power, that it may not be adequately processed by the ADC after pre-selecting, or the IF filter, increasing the RF preamplifier gain may enable adequate signal levels. Nevertheless, increasing the RF gain will also reduce the linearity. Also, after downconversion by the mixer, the IF signal strength can be manipulated with the IF gain amplifier setting.

As balancing the various attenuator and gain stages may be confusing and time consuming, many spectrum analyzers enable automated optimization of the sensitivity and linearity based on the reference level of a signal. Depending upon the complexity of the measurement and the experience of the user, many spectrum analyzers provide manual override options for these automatically controlled settings.

What Else Can a Spectrum Analyzer Do?

Generally, a user is interpreting the data from a spectrum analyzer, which has led the software developers of spectrum analyzer interfaces to incorporate many software tools, both simple and complex. Being able to customize frequency sweep trace colors, develop frequency markers, and manipulate triggers aid in solving many of the basic measurement challenges (see Figure 5). Traces can be analyzed, averaged, and customized for better viewing and understanding of the EM energy in the frequency range being monitored. Markers can be placed as several frequencies of interest and

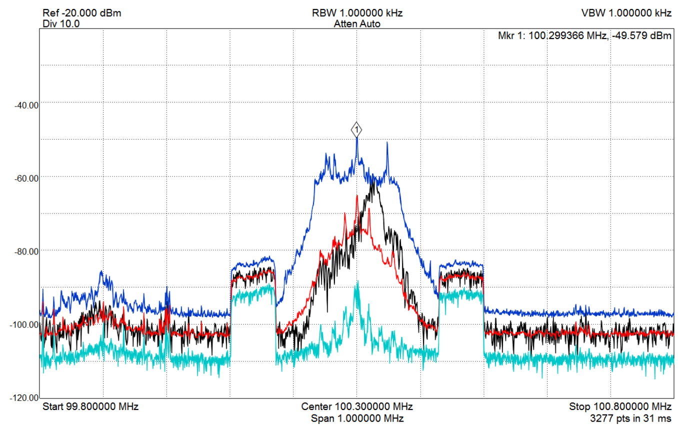

Figure 5—Configuring multiple traces to monitor an FM broadcast transmission

marker data can be algebraically manipulated with other marker data to give greater comparisons and insight.

As triggers may also change the method in which data is collected, there are many more features capable with trigger solutions. The concept of a trigger is that the trigger conditions are applied to incoming signals and will “trigger” a data capture even—or any other programmable actions—if EM energy follows the trigger conditions. For example, if a trigger is based at 0 dB and a signal is increasing in strength and crosses the 0 dB threshold, a trigger event can be programmed for that instance.

Additionally, some triggers, such as a configurable limit lines, can be used to create a boundary condition at each frequency point, where an event can be programmed based on any signal energy violating that boundary. Lastly, an external trigger can also be provided through the trigger input. These triggers can be initiated by external software routines or other equipment triggers to create synchronized testing systems.

What’s the Difference Between Real-Time Spectrum Analysis and Spectrum Analysis?

Real-world signals, especially for communications and radar technology, are not as easily interpreted and measured as CW signals. The majority are modulated signals with signal energy that is non-recurring, sporadic, or even random. Simple spectrum analysis cannot capture and analyze these signals, unless a user happens to be lucky enough to trigger on the event. Capturing and interpreting these modulated signals requires a real-time analyzer, which use modern signal processing technology such as overlapping FFTs and

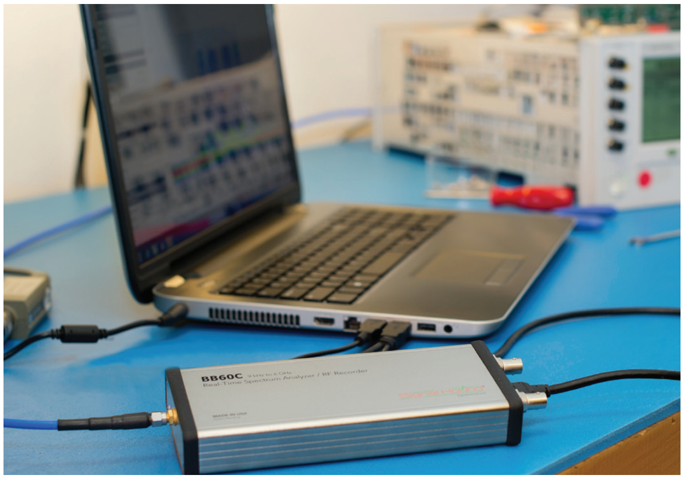

Figure 6—USB-powered real-time spectrum analyzer connected to a PC

high-speed memory storage. These analyzers are capable of capturing any signal that is within the instantaneous bandwidth of the ADC, and that has a duration long enough to be correctly measured.

Another advantage of RTSAs over standard spectrum analyzers, is that the signal information in an RTSA is already digitized and the information can be digitally controlled, filtered, and further analyzed readily. Having digitized frequency data also enables rapid storage and playback features without missing slices of time, so deep analysis and security features are enabled.

What Limitations for RTSAs Exist?

Ultimately, a user will need to be able to see and engage with the signal data provided by an RTSA. As a user cannot necessarily make decisions and observe data at the rate that it happens, RTSAs have built in display and analysis functions to aid a user in observing trends and even record/playback functions for analysis at a later time.

Modern communications applications, such as Wi-Fi, Bluetooth, Zigbee, GPS, and cellular technologies, all leverage techniques that produce non-CW signals that are difficult to observe. Some even hop around or operate in a wide range of frequency bands. Moreover, military and defense applications— especially for electronic signal intelligence (ELINT) and electronic warfare (EW) applications—are often observing and relying upon complex pulse signals to carry important tactical information. Intentionally, these signals are inconsistent and of very short duration, so that they are essentially impossible to observe in real time. Hence, capture, record, and playback technology can be used to later analyze these signals with advanced signal processing and computational engines.

A RTSA has finite limits in the length of duration that can be accurately captured. This feature is known as probability of intercept (POI), and is rated as a percentage and a length of time of an event that can be captured at that percentage of probability. For example, some modern PC-Driven RTSAs can capture RF events with 100% probability as short as 1µs of duration.

POI is dictated by the window bandwidth of the RTSA. For 50% overlapping FFT RTSAs with a window bandwidth of about 2, the length of duration at 100% probability of intercept can be calculated by 3.0/RBW. For instance, for an RBW of 300 kHz, or ~150 KHz FFT bins, a signal of 10µs, or more, can be captured successfully with adequate resolution. For signals that are shorter than 10µs, the signal energy from the event may be captured in more than one FFT bin. This would lead to a misrepresentation of the signal amplitude at any given frequency in which that signal contains energy.

As the instantaneous bandwidth, frequency range, and RBW of an RTSA is limited, the speed and complexity of signals that can be observed by a given RTSA will also be limited. Furthermore, there may be commerce regulations and security regulations that limit the performance of RTSAs in terms of instantaneous bandwidth and the length of signal duration with 100% POI.

How Are Modern Signal Modulation Techniques and Infrequent/Inconsistent Signals Observed by RTSA?

For communications signals that leverage frequency hopping, spread spectrum techniques, are low-duty cycle, or are inconsistent, being able to visually observe and make judgements on these signals can be challenging in a rapidly changing display. Moreover, military/defense, ELINT, EW, interference hunting, and security applications may need to observe minute trends and changes in the spectrum over a long length of time to hone in on signals of inter-

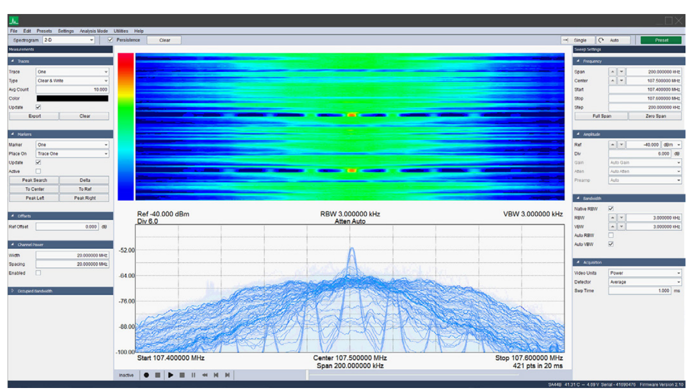

Figure 7—A persistent waterfall display in spectrum analyzer software

est. A method to enable this with a RTSA, is a display technique that combines the signal energy at any given power and frequency point on the analysis display with color coded variations with persistence (see Figure 7).

Known as persistent displays, this technology enables a user to see the time domain variations of fast moving signals. Furthermore, this persistent display can be reconfigured for showing captures of the display as time slices that steadily stack to create a "waterfall" of successive frequency sweeps with intensity color differentiation. Especially useful for analyzing disruptive signals and signals that rapidly change frequency, a persistent display can provide a large amount of insight into the dynamic environment of the spectrum being observed.

An added benefit of a RTSA, is that the frequency sweep data, as it is already digitized, can be recorded in high speed memory and further analysis can be performed when greater computational resources are available. So, for a test done in the field, full analysis and troubleshooting may not be available. Instead of having to share limited value screenshots, an RTSA with RF Recording capability can play back the measured signal information.

Though these abilities enable direct observation of the spectrum in highly useful ways, just like a security video, panning through time to search for a specific event can be time consuming and error prone. Another RTSA feature that enhances a user's ability to capture events of interest are configurable limit lines. Limit lines allow the user to create a trigger based upon frequency power invading a boundary that can be configured for each frequency point at different power levels. When spectral energy violates the high/low limit, or logic event, a trigger can be activated that captures the event, or even begins recording for deeper analysis over time.

Further Reading

Learn more about Signal Hound's robust, real-time USB-powered spectrum analyzers at www.SignalHound.com.

About Signal Hound

The Signal Hound® company started as Test Equipment Plus (TEP) in 1996 with the belief that providing quality used test equipment, at affordable prices to every customer, would drive growth and foster loyal customers. It did. Then in 2006, TEP expanded their focus by designing and manufacturing a color LCD display retrofit kit to answer the need for CRTs that were no longer available for the aging HP® 8566A, 8566B, 8568A, and 8568B spectrum analyzers. TEP also began offering a repair service for HP/Agilent® step attenuators. In 2007 TEP designed and began manufacturing another color LCD display retrofit kit to support the HP/Agilent 8560 series spectrum analyzers. At the same time, TEP also decided to play to their strengths, and began offering test equipment repair services for Agilent spectrum analyzers, network analyzers, and signal generators. The repair segment of TEP is now recognized in the RF and microwave test equipment industry as a world class operation.

The LCD kits were so well received that in 2009, TEP decided to design a compact, lightweight, and inexpensive spectrum analyzer. The goal was to provide an economical spectrum analyzer with unparalleled value compared to anything else on the market. TEP achieved that goal with the USB-SA44 spectrum analyzer which was introduced in February 2010, marking the birth of the Signal Hound line of test equipment. In April of 2014, Test Equipment Plus began officially doing business as Signal Hound. Signal Hound's latest innovation is the Signal Hound BB60C spectrum analyzer, introduced June 2014, which is an enhanced version of its well-received predecessor, the BB60A.

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