APPLICATION NOTE

# Real-Time Spectrum Analysis for Agile Signals

KEYSIGHT

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# Introduction

For the capable RF engineer, continuous-waveforms (CW) and predictably repeating signals are not the great challenge today's multi-signal environments and complex, agile signals are proving to be. To keep up with the evolving analysis needs of recent years, new types of signal analyzers and application software have emerged.

This application note discusses and compares the available tools and techniques for both discovering elusive signals and the vital next steps in RF engineering to complete the solution. The material presented will discuss approaches optimized for making precise and selective measurements of complex, demanding signals, and describe how to go beyond measurement to post-processing analysis, signal replay, and the transfer of captured signals to other analysis and simulation tools.

# Two Case Studies: Highlighting Tools and Techniques

The tasks of designing and troubleshooting agile signals are difficult. In diverse applications, from wireless communications to electromagnetic spectrum operations (EMSO), when these signals exist in an environment populated with similarly agile signals, this difficulty only grows.

Indeed, some engineering jobs where two or more of these technologies intersect must be performed. However, given the scope of the topic, there is not sufficient space in one application note to cover all aspects of finding and measuring these signals or determining their causes and finding fixes. Instead, this note will use two examples — along with brief discussion of the measurement tools and their corresponding architectures — to illustrate how the different approaches and tools complement each other.

Several measurement tools and techniques will be highlighted through the analysis of two distinct scenarios: an individual signal that is both complex and dynamic, and a dynamic signal environment containing several different signals and signal types. Together, these two examples will demonstrate an exploration of a variety of effective capabilities in the analysis of agile signals.

# Case Study #1: An Agile Radar Signal

The first case study focuses on an S-band acquisition radar, and a signal which receiving antennae would expect to see when a narrow-beam transmitter performs a scan. This signal is a repeating sequence of radar pulses, each with a width of 6 μs and a pulse repetition interval (PRI) of 600 μs. Each pulse group consists of seven pulses that step in 10 MHz increments from –30 MHz to +30 MHz relative to the 3 GHz center frequency. Figure 1 shows the scanning of this signal.

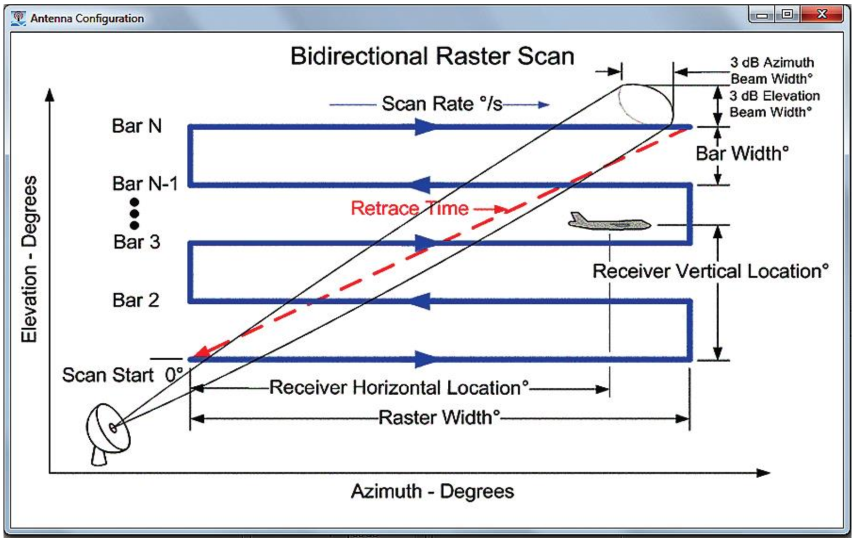


**Figure 1.** The scan pattern of an S-band acquisition radar

The signal at the receiver varies widely in amplitude over a period of several seconds; this long-duration characteristic, combined with the short-duration characteristics of its pulse length and PRI, define a short duty cycle, making the signal agile and difficult to measure well.

## Beyond max hold: density and persistence displays

Performing a basic spectrum analysis of the signal with a swept spectrum analyzer, as shown in Figure 2, reveals the measurement difficulty posed by this complex signal.

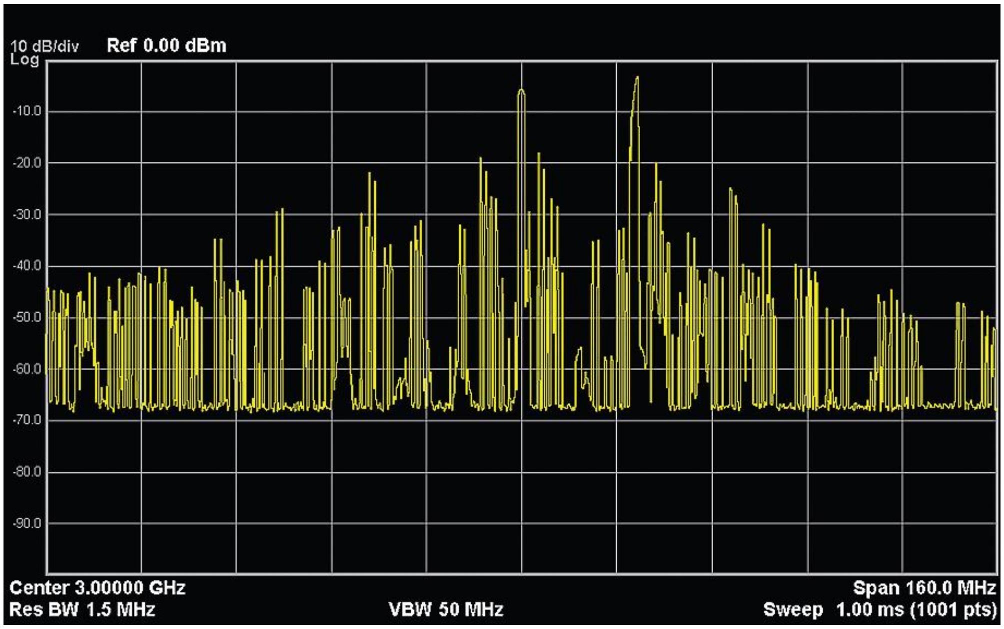


**Figure 2.** Even when using fast sweeps and max hold over a period of many seconds, the swept spectrum analyzer view of the radar signal is not informative.

Even after several sweeps and the use of a max-hold function, the signal is not clearly represented. In fact, due to the max-hold function and the single-valued spectrum trace, the scanning (amplitude) dynamics of the signal are not represented in the trace at all. While some level of limited signal analysis is certainly possible in this mode, it requires a considerable amount of interpretation and assumptions. One additional measurement technique for signals such as this would be a zero-span measurement that uses a wide resolution bandwidth (RBW) filter and tuning of the analyzer to one of the signal peaks discovered in this display.

In contrast with the swept spectrum display, the density display from the Keysight Technologies, Inc. PXA and MXA real-time spectrum analyzers (RTSAs) readily show the main characteristics of the signal as pictured in Figure 3. The coupling of real-time analyzer mode and density display provide a fast, insight-producing view of this wideband, dynamic, and agile signal.

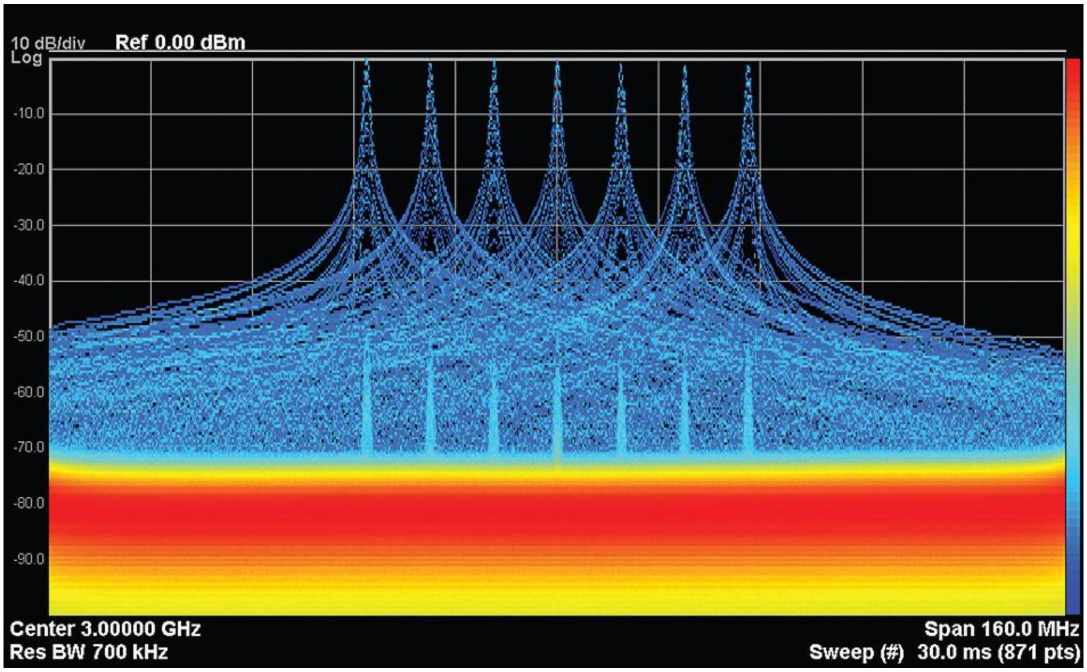


**Figure 3.** The density or histogram display collects a large amount of real time spectrum data into a single display that shows both rare and frequent events, with an indication of relative frequency of occurrence.

The blue color of all but the noise floor indicates that the pulses, while prominent, have a very low frequency of occurrence. This is the principal characteristic that makes the signal difficult to measure — or even rapidly and reliably find — with a swept spectrum analyzer. It is of note that due to the directionality of the antenna, the signal is often below the displayed noise floor of the analyzer.

Because this signal exhibits very narrow duration peaking of amplitude every few seconds, it is most effectively measured with the real-time analyzer when the persistence parameter is set to a value of seconds or more. However, even a very short persistence value will show the signal clearly and provide a more responsive display of the signal dynamics during scanning.

# Changes over time: Spectogram displays

While the density display itself can be observed over a period of time with an appropriate persistence value or range of persistence settings, the display lacks information indicating signal behavior over time. Fortunately, real-time analyzers also provide spectrogram displays to take advantage of real-time spectral data, presenting spectrum vs. time vs. power rather than spectrum vs. density vs. power. An example spectrogram of the radar signal is shown in Figure 4.

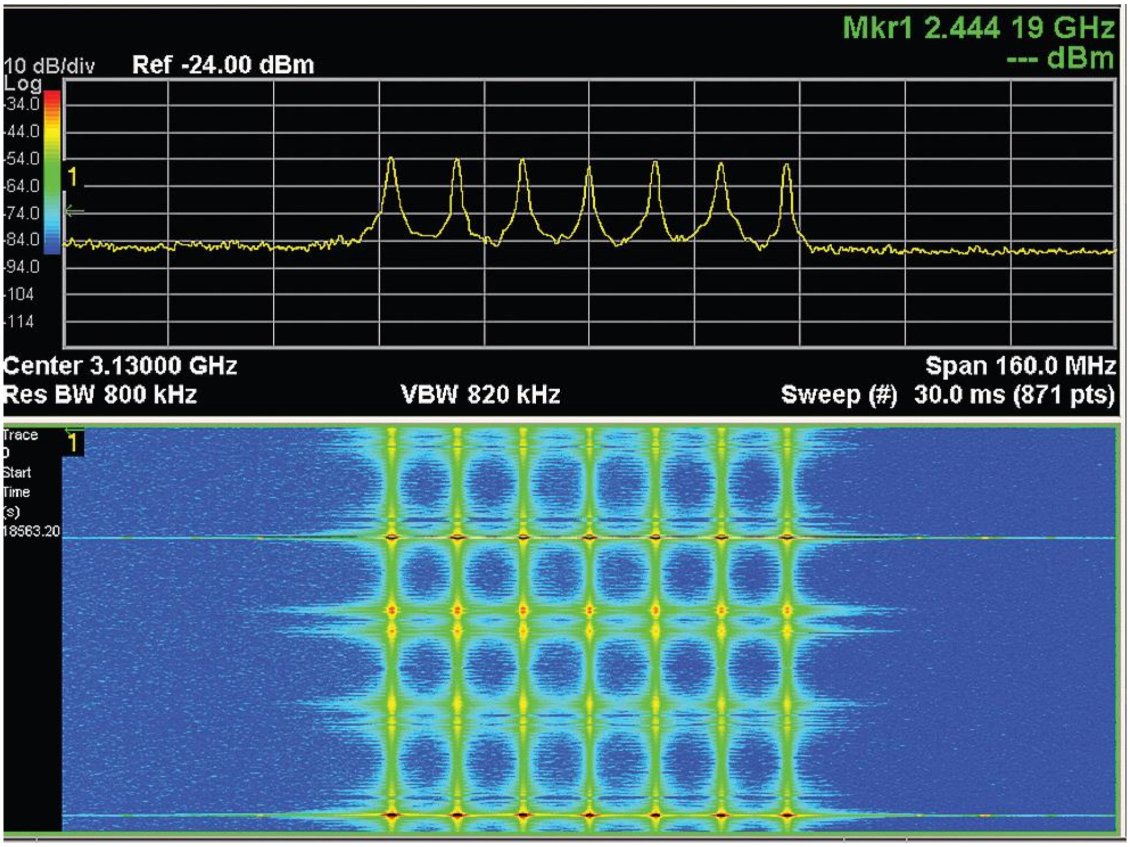


**Figure 4**. The spectrogram view of real-time data displays time information instead of density providing a clear indication of signal behavior over time.

Spectrogram displays are increasingly common in mainstream signal analysis applications because they add a time dimension to the spectrum display. Similarly, in real-time analyzers, spectrogram displays serve as a complement to the density display. The display in Figure 4 is a real-time spectrogram which stacks individual real-time spectra (shown at the top of the screen) vertically, while amplitude is represented by color (shown at the left of the top display). The individual spectrum lines are real-time but in most cases are formed from a number of individual FFT calculations (as controlled by the analyzer's detector setting). In this configuration, each line represents about 10,000 FFT spectrum calculations.

# Optimizing acquisition and persistence values

To optimize the spectrogram view over a period of seconds, the display in Figure 4 is configured for a long acquisition time and long persistence. This creates an identifiable, distinct pattern including medium-amplitude double peaks and higher-amplitude single peaks. However, a long persistence value in this display causes signals to be blurred or smeared somewhat along the vertical time axis.

It is also important to note that each spectral line is composed of many spectra, limiting the time resolution but increasing the time coverage of a single screen or spectrogram trace buffer. This characteristic result of measurement and display settings provides signal visibility at the cost of reduced time specificity. Thus, this display is more suited for observing signal behavior over a period of seconds rather than showing any individual pulses or pulse groups that characterize the signal behavior on the millisecond scale. Because we may also want to observe — and perhaps verify — the pulse group behavior in the signal, it's useful to shorten the acquisition and persistence values. The display shown in Figure 5 has been optimized for viewing the pulses on an exclusively short time scale. For brevity, some intermediate steps have been omitted.

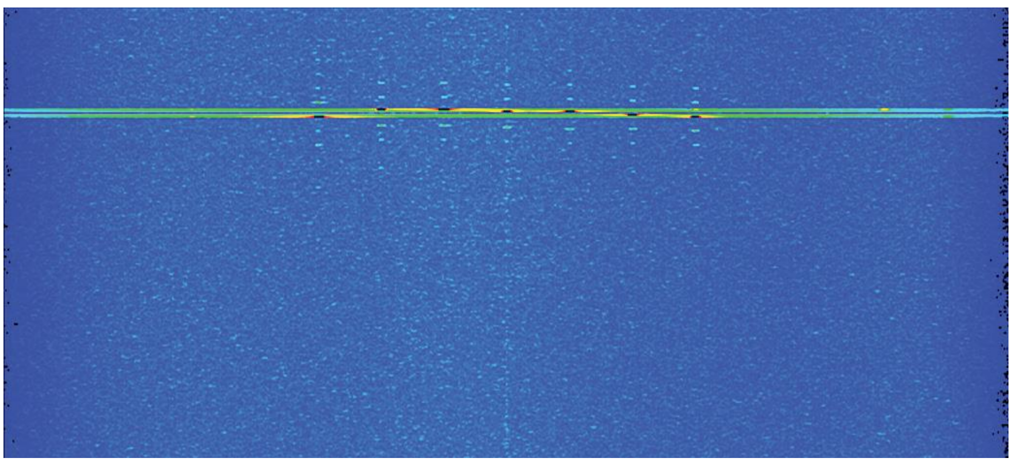

**Figure 5.** Large reductions in acquisition time and persistence optimize the real-time spectrogram view for time resolution and display of brief events such as the pulse trains.

With a short acquisition time, each screen or spectrogram buffer — which is up to 10,000 traces in the Keysight RTSAs — provides a significantly higher time resolution and proportionally shorter coverage interval. Some amplitude variations related to antenna scanning can be seen near the signal peaks; however, the time scale of the signal changes is too long for this brief view and would be better shown with acquisition-time and persistence values in an intermediate range between those of Figures 4 and 5.

The greater time resolution of Figure 5 brings visibility into both individual pulses and sets of pulses. The use of a spectrogram slice marker might be useful in this case, but because each spectrogram trace still represents multiple spectrum calculations, the relative timing would be difficult to see and could not be accurately measured. However, the view of the signal is much more detailed than previous ones. Somewhat longer time periods could be seen by viewing multiple spectrogram screens or scrolling through the large spectrogram buffer.

Shortening acquisition time is a good next step in understanding how signals behave over time, but it may not be enough for complete analysis of fast-changing signals such as this one. In addition, a shorter acquisition time does not provide controllable overlap for precise timing analysis. In many cases, including this one, each real-time spectrum display update or spectrogram line combines many individual spectral measurements, limiting the accessible time resolution.

## Next steps: Vector signal analyzer time capture

The 89600 vector signal analyzer (VSA) software and its gap-free time capture are the natural next step for getting a detailed understanding of this signal. Taking advantage of the same general RF and signal-processing architecture as real-time PXA and MXA signal analyzers, the 89600 VSA adds signal-capture and vector processing capabilities such as analog and digital demodulation. These added capabilities from the 89600 VSA software to signal analyzer hardware enable forward progress: from signal discovery and basic power measurements of agile signals to full understanding and engineering of solutions to difficult problems.

In the 89600 VSA, experiment or formula may optimize parameters for capturing a contiguous block of signal data, including resolution and the desired time/frequency coverage. However, in most cases the center/span/amplitude settings for a suitable spectrum measurement, along with the default capture settings, will provide a successful starting point. The typical process is to simply start a capture with the red “record” button and press the “play” button when the capture is complete. See Figure 6 for an example of a time capture and measurement in post-processing, including a real-time spectrogram (heavily overlapped) and an IF time-domain display of one pulse.

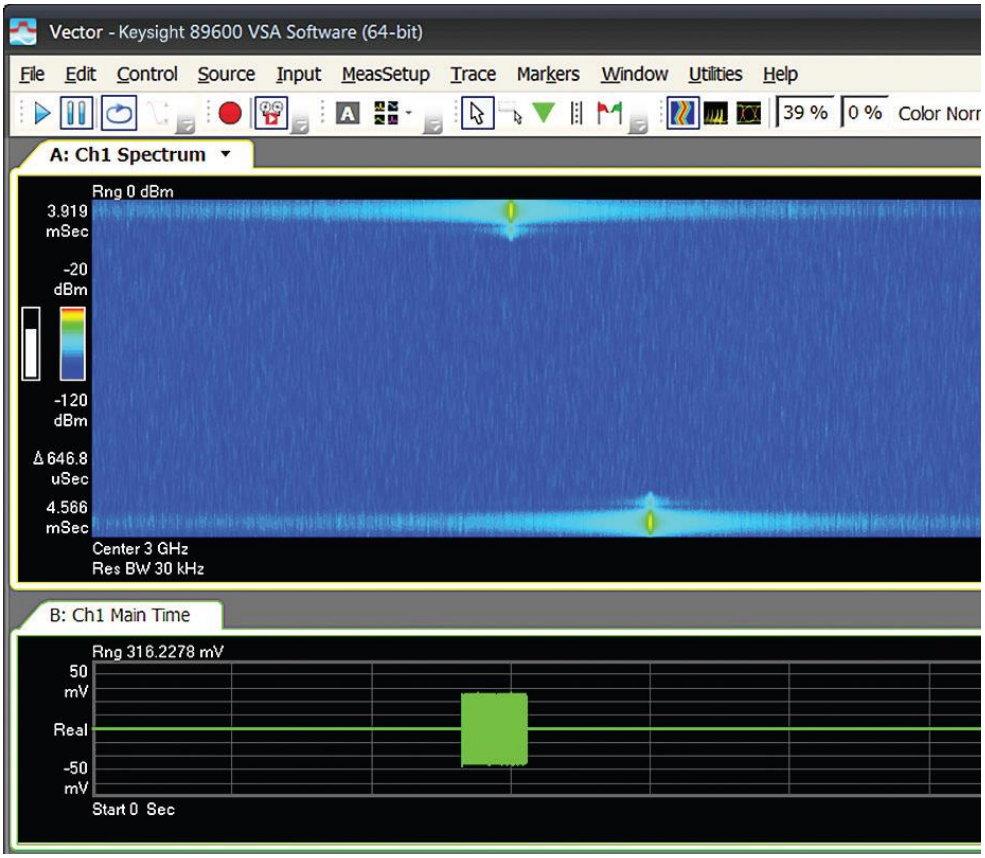


**Figure 6.** Time-capture operations and post-processing in the 89600 VSA produce a spectrogram in which individual pulses are clearly shown and easily measurable in time and frequency. In the spectrogram trace, the vertical axis is time and two pulses are shown with the inter-pulse interval.

The combination of capture and overlap processing with a spectrogram display clearly reveals two of the individual pulses and their timing and spectra. The use of time capture, signal playback and a variety of post-processing operations (including triggering and demodulation) enables detailed analysis of individual pulses.

The real-time and heavily overlapped measurements of time capture and post-processing in the 89600 VSA provide flexibility to view the individual pulse groups in this radar signal, revealing the signal anomaly that has not appeared thus far. The spectrogram in Figure 7 clearly shows the pulse sequence versus frequency.

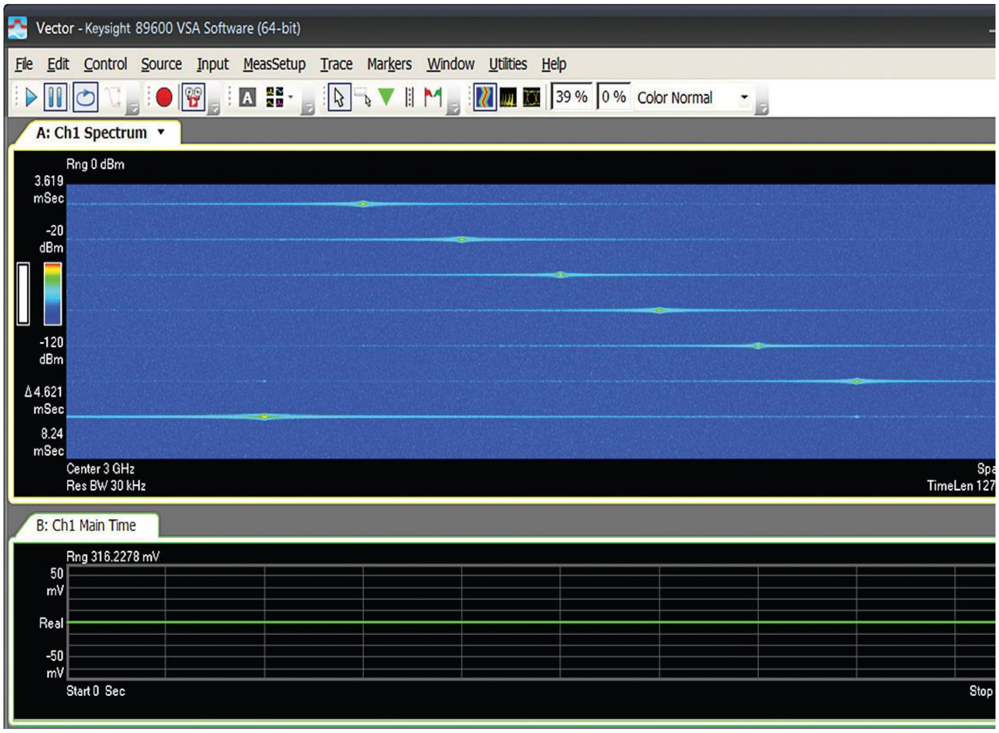


**Figure 7.** Using the same capture bugger and adjusting the FFT length and overlap to show the full pulse group reveals an anomaly in the signal: the pulse set does not begin with the -30 MHz pulse but instead ends with this pulse.

Adjusting overlap to show an entire pulse train in a single spectrogram quickly reveals an anomaly in this signal. The original intent was to step from –30 MHz to +30 MHz in seven steps with a long gap before the next pulse repetition cycle; however, it is obvious from the spectrogram that the pulses start at –20 MHz and proceed through +30 MHz before ending at –30 MHz.

It is logical to suspect that when constructing the sets of pulses, the inter-set interval was placed after the first pulse instead of before the first pulse. This sort of error is obvious when viewed with the right tool (89600 VSA with time capture) and display (spectrogram) but might otherwise be exceedingly difficult to detect or measure.

The progression from RTSA to 89600 VSA in analyzing this challenging signal provides comprehensive knowledge of the signal with confidence that important aspects of its behavior are not going undetected. All this analysis can be performed in any PXA and MXA signal analyzers equipped with the RTSA and 89600 VSA applications.

# Post-capture changes in center frequency and span

The ability to select portions of a capture buffer for detailed analysis in both the time and frequency domains can be very useful. The traditional spectrum analyzer approach for RF engineers examining individual signals is to set the center frequency to the signal of interest and narrow the frequency span, often referred to as “tune and zoom.” An example of this process and the result on the captured radar signal is shown in Figure 8.

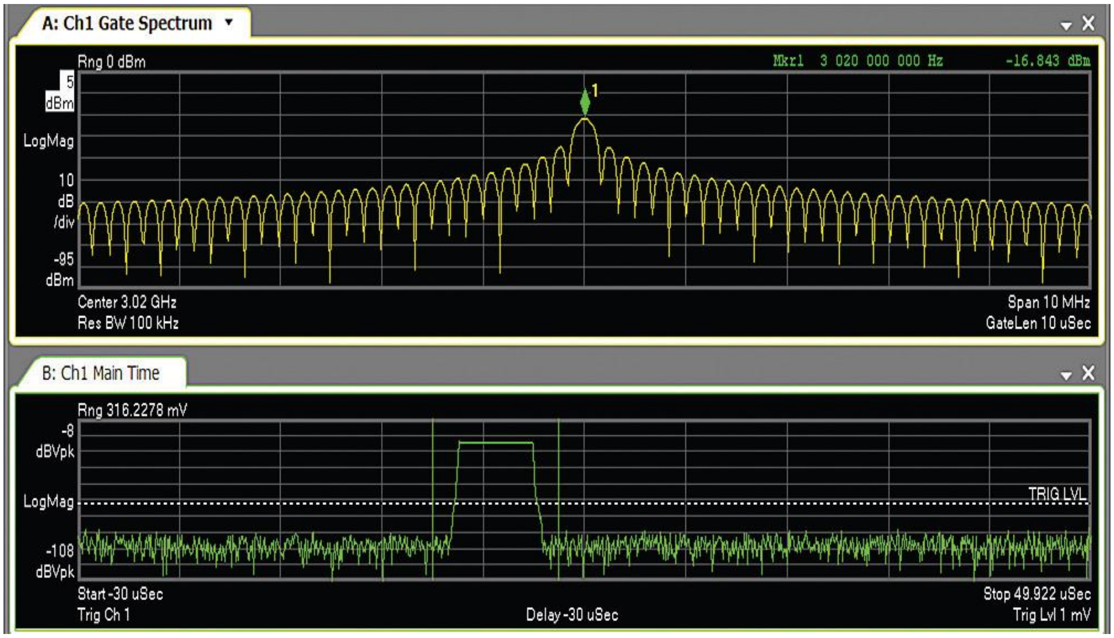


**Figure 8.** The same capture bugger is re-processed to focus analysis on a specific time and frequency region. In this measurement the center frequency is changed to match the +20 MHz pulse and the frequency span is reduced to 10 MHz. Gated sweep and a uniform window (for this self-windowing pulse) provide high-resolution analysis of a single selected pulse.

This example analyzes a single pulse from the capture buffer for analysis. A larger time-record length of 50 μs has been selected with gated spectrum (the vertical green bars in the lower trace) and uniform window (RBW). These selections have been made since the pulse signal is self-windowing. The upper trace shows the result.

By using DSP techniques (e.g. resampling) and a digital local oscillator, the 89600 VSA is capable of changing the post-capture center frequency and span. This ability to perform the analysis on already captured data eliminates the need to retune the 89600 VSA and perform another capture. Resampling data via DSP techniques — in combination with decimation — provides a near-infinite selection of effective sample rates from the original samples. Changing sample rates combined with digital filtering provides the desired reduced frequency. The result is analysis of the selected 10 MHz span around the signal of interest, with all signals outside of this span filtered out.

Because the digital LO applied to the sampled data changed the analysis center frequency, the new center frequency will apply to all measurements, allowing its use for operations such as analog or digital demodulation and changes in frequency resolution or RBW.

It is important to note that this “post-capture tune and zoom” capability is much more flexible and powerful than simply re-scaling or re-centering the spectrum data. Simply re-scaling spectrum display data would only change the display, rather than providing other analysis capabilities such as demodulation or changes in resolution or filtering.

# Case Study #2: A Dynamic Signal Environment

Complex signal environments, even those with less agile signals, provide another class of measurement challenges. As is the focus of case study #2.

Around the world, the industrial, scientific and medical (ISM) band at 2.45 GHz is perhaps the most varied and dynamic frequency band. In many locations it is lightly regulated and heavily used; it has become especially popular for WLANs, Bluetooth® PANs, cordless phones, and RF heating devices such as high-power microwave ovens.

The band covers 100 MHz in many countries and often require spread spectrum techniques of some sort for communications equipment. The two most popular techniques in the band are orthogonal frequency-division multiplexing (OFDM, used by 802.11g/n) and frequency hopping (Bluetooth). Some cordless phones use a simple form of code-division multiple access (CDMA).

Because the transmissions in this band are not generally coordinated, there are many opportunities for collisions, interference, and some complex interactions due to activities such as retransmissions. Fortunately, the modulation schemes and protocols used with these signals are designed to be somewhat tolerant of collisions and interference.

The dynamics of the band are thus important for the objective of keeping data payloads moving, and some behaviors such as channel scanning may be a combination of brief (small fraction of a second), wideband (tens of MHz), and rare (occurring only every few seconds to minutes) — and this makes them difficult to see with traditional swept or FFT analyzer technologies. In these situations, real-time analyzers can be very useful.

When unregulated bands become crowded and mutual interference increases significantly, there can be a rather sudden drop-off in total channel throughput, sometimes referred to as a cliff effect. At a certain channel loading, collisions and the increase in channel occupancy due to retransmissions can cause a cascade in which effective channel throughput is seriously impaired.

## Beyond peak hold: Density displays

As stated in the previous section, the 2.45 GHz ISM band is thus both dynamic and complex, and a good example of the challenges of agile signal analysis. Traditional swept spectrum analysis is not a very effective tool for understanding the activity in this band, as shown in Figure 9.

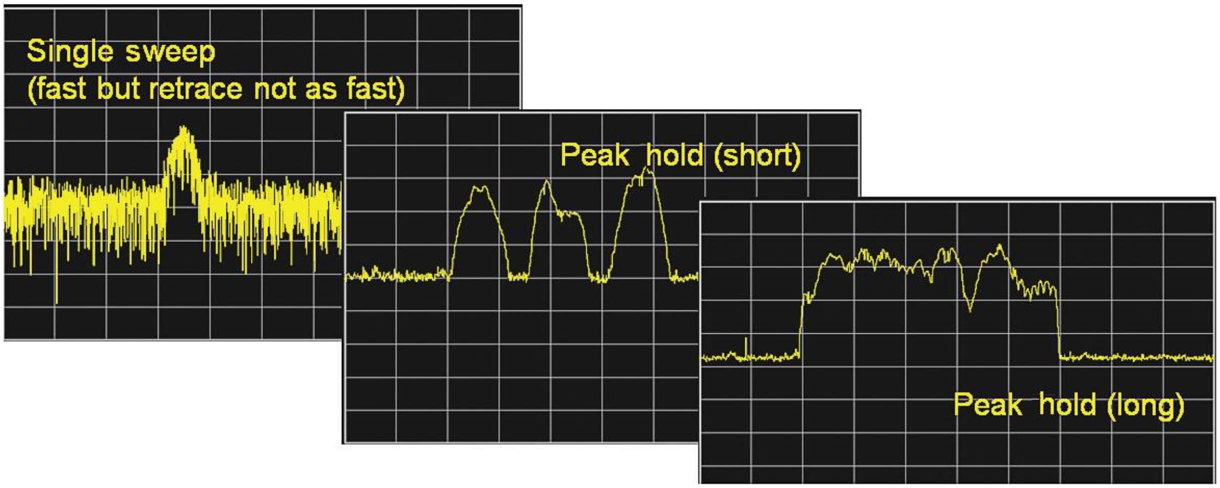


**Figure 9.** With multiple agile signals sharing a 100 MHz frequency band, it can be difficult to understand signal behavior using a swept spectrum analyzer. Using the peak-hold function over a period of time can catch some signal activity but subsequent activity can also obscure it.

Depending on the degree of spectrum/time occupancy, a single sweep from a spectrum analyzer may show either nothing or only a portion of one or more signal bursts. It can be very difficult to interpret such a measurement, especially because the dynamics of the analyzer's sweeping RBW filter interact with the dynamics of the signal itself.

Peak hold is a useful tool for understanding some aspects of the signal environment, and a long measurement with peak hold will eventually catch most of the signals in the band. However, long peak-hold measurements often result in some signals in the band obscuring others as shown at the right in Figure 9.

While swept spectrum analysis is not a productive way to understand the activity in this band, the fast processing and advanced displays of real-time analyzers make them a good fit for exploring this dynamic signal environment, as shown in Figure 10.

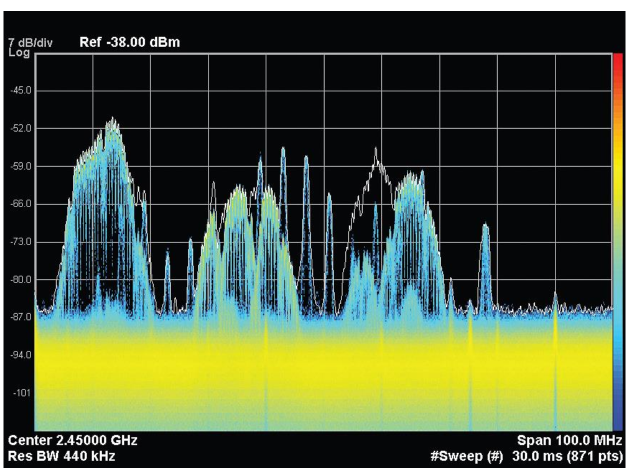


**Figure 10.** With a similar setup to the swept spectrum analysis approach (Figure 9) the real-time density display quickly reveals detail about the spectral occupancy of this band.

This density display from a real-time analyzer provides a good, immediate understanding of the ISM band and the signals in it. Because the measurements are gap-free and all signal samples are represented in the display in some fashion, it is possible to see most of the signals in the band over a short measurement time.

The density or spectrogram display is very data-dense and quite dynamic, updating about 30 times per second, with some (adjustable) amount of persistence applied to fade older data. With an FFT rate of almost 300,000 per second, each display update represents about 10,000 spectra. The result is a responsive display that does a good job keeping up with the dynamics of the in-band signals and showing subtle detail such as signals inside of other signals and small signals near the noise floor of the analyzer.

It is worth noting, however, that the action of combining 10,000 spectra into one display update can cause signals present at different times to be displayed in the same spectrum update. The signals that appear to be multi-tone in Figure 10 are actually Bluetooth frequency-hop patterns. The signal is never actually transmitted on multiple frequencies at once.

## Variations versus time: real-time spectogram displays

An alternative way to understand the signal behavior in this frequency band is to use a real-time spectrogram display, as described in Case Study #1, Figure 4. Figure 11 shows the result of using this real-time spectrogram display on the 2.45 GHz ISM band. With default settings, the spectrogram is an effective way to view signal or environment behavior over a period of seconds. The combination of multiple spectra to form one spectrum update, thus one horizontal line of the spectrogram, causes repeated Bluetooth hops over a limited channel pattern to form a set of vertical lines in the spectrogram display.

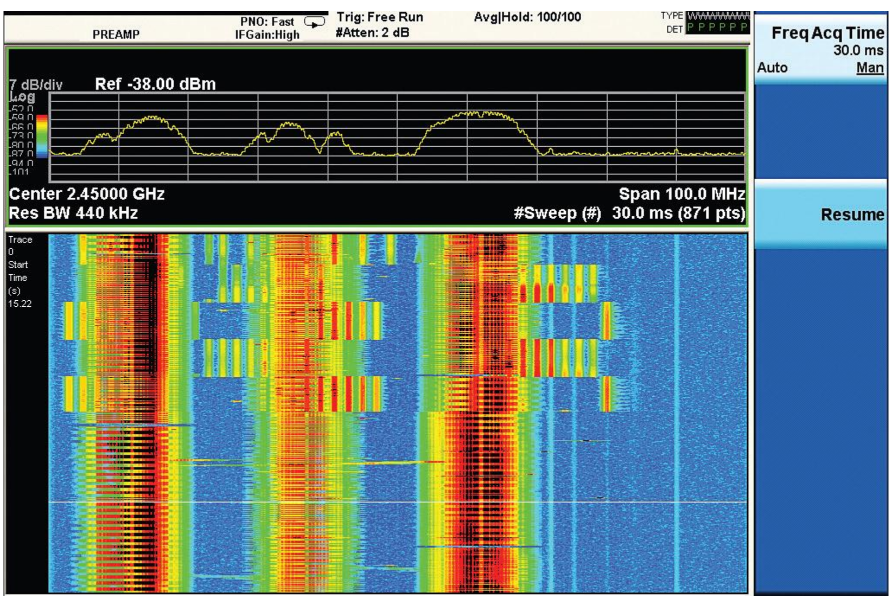


**Figure 11.** The spectogram display of the ISM band summarizes signal behavior over a period of seconds, revealing mostly WLAN and Bluetooth signals.

The time element (vertical axis) of the spectrogram can reveal important aspects of signal behavior in the spectral environment as well. Note that many Bluetooth hops form a repeating pattern (vertical lines) and other bursts appear to be isolated (mostly in the top half of the spectrogram). Also note the diagonal bars that move between the wide WLAN channels in the bottom half of the spectrogram. These appear to be from some sort of channel scanning and are occasionally, over intervals of seconds, visible in the density displays.

The acquisition-time setting at the upper right of the display controls the combination of individual spectra into spectrum updates (as shown in the top trace) and into individual spectrum lines to form the spectrogram display. A longer acquisition combines more spectra to form a spectrum update, causing the spectrogram to update slower. This allows a single spectrogram display to represent a longer time period.

Because coverage of a long period is a tradeoff for the spectrogram, selection of a much shorter acquisition time for each update — for spectrum display or spectrogram line — provides a much better time resolution, as shown in Figure 12. The short acquisition time can have a large effect on the appearance and content of the spectrogram display or buffer. Although the buffer and display will cover a proportionally shorter span of time — therefore not showing some longer-term phenomena — the additional time resolution can reveal important spectral behavior that would otherwise be obscured.

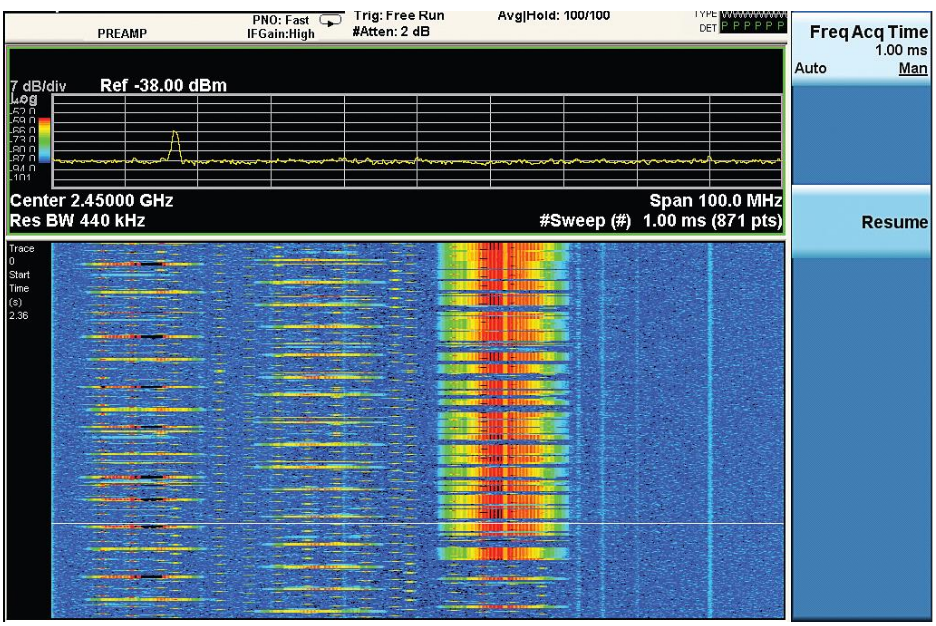


**Figure 12.** Selecting a shorter acquisition time period of 1 ms rather than 30 ms provides increased time resolution, revealing more about the structure of the WLAN bursts and Bluetooth hops. The spectogram now represents a much shorter interval in time.

In this case, increased time resolution allows the individual WLAN bursts and Bluetooth hops to be resolved better. As a result, two things become clear: even the Bluetooth hops that overlap the WLAN bursts in frequency often do not overlap in time, and collisions are not as frequent as the previous display would suggest. Note, however, that each spectrum line in the spectrogram and trace still represents hundreds of individual FFT results from the real-time measurement engine.

## Additional resolution: Power versus time displays

Another display type available in the real-time analyzer can clarify agile signals in a complex environment: the power versus time (PVT) display. A real-time display of the total RF power in the signal environment, the PVT display can provide additional time resolution, as shown in Figure 13. This display is also useful for understanding pulse or burst duration directly. In this ISM band the WLAN bursts or frames are comparatively long while the Bluetooth hops are much shorter.

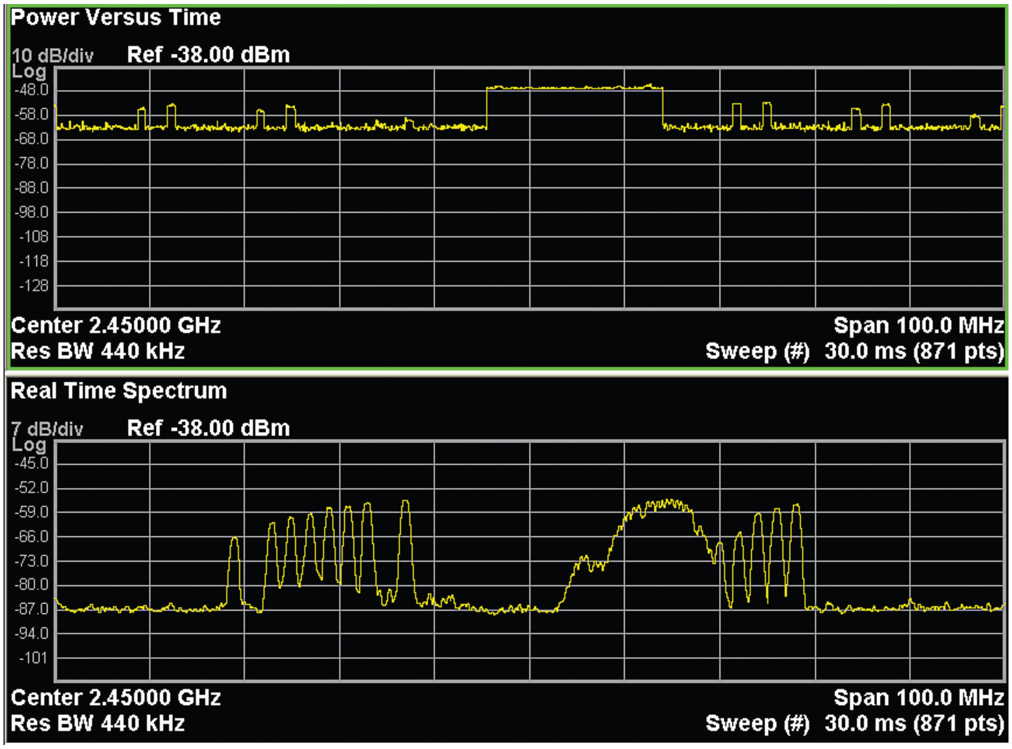


**Figure 13.** The real-time display of RF power vs. time (top) shows the total power in the ISM band, including a longer WLAN burst and short Bluetooth hops.

## Extending signal analysis with a vector signal analyzer

As described so far, the real-time analyzer architecture, processing, and displays are very powerful in detecting elusive signals or agile signal behavior and in understanding complex and dynamic signal environments. This is particularly true if the phenomenon in question is unknown or unexpected.

Of course, finding an elusive signal or event is often just one step in finding and solving problems, or in optimizing performance. In these cases, 89600 VSA software is a logical and powerful complement to a real-time analyzer solution.

As in Case Study #1, the 89600 VSA solution utilizes the same general RF and signal-processing architecture, adding signal-capture and vector-processing capabilities such as analog and digital demodulation, as shown in Figure 14.

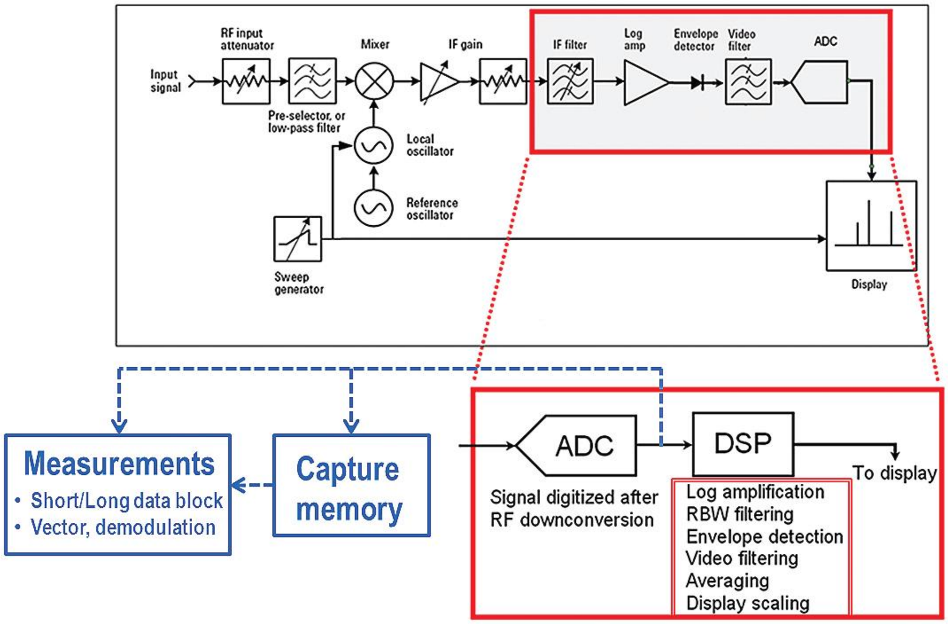


**Figure 14.** The signal-processsing architecture of a vector signal analyzer is primarily a software extension of that used in a spectrum/signal analyzer with a digital IF. This architecture may be consistent with that of a real-time analyzer as well, as in the case of the Keysight PXA or MXA.

Vector signal analysis often begins with FFT analysis of a digitized IF signal. For agile signals or dynamic environments, FFT analysis has the benefit of removing one source of measurement variability or uncertainty: the sweeping RBW filter.

Because a block or “time record” of the digitized IF signal is used to calculate the entire spectrum measurement, the data from which the spectrum is computed can be viewed and is well understood. In 89600 VSA software, the data used for the FFT can be further refined using time gating, through which any portion of the time record can be selected for analysis. In addition, a window function for the gated spectrum can be independently selected to optimize the measurement.

In general, the default time record used in most analyzers is fairly short at about 1000 time samples; this is similar to the longest time records used in real-time analyzers. The top of Figure 15 shows the resulting spectrum.

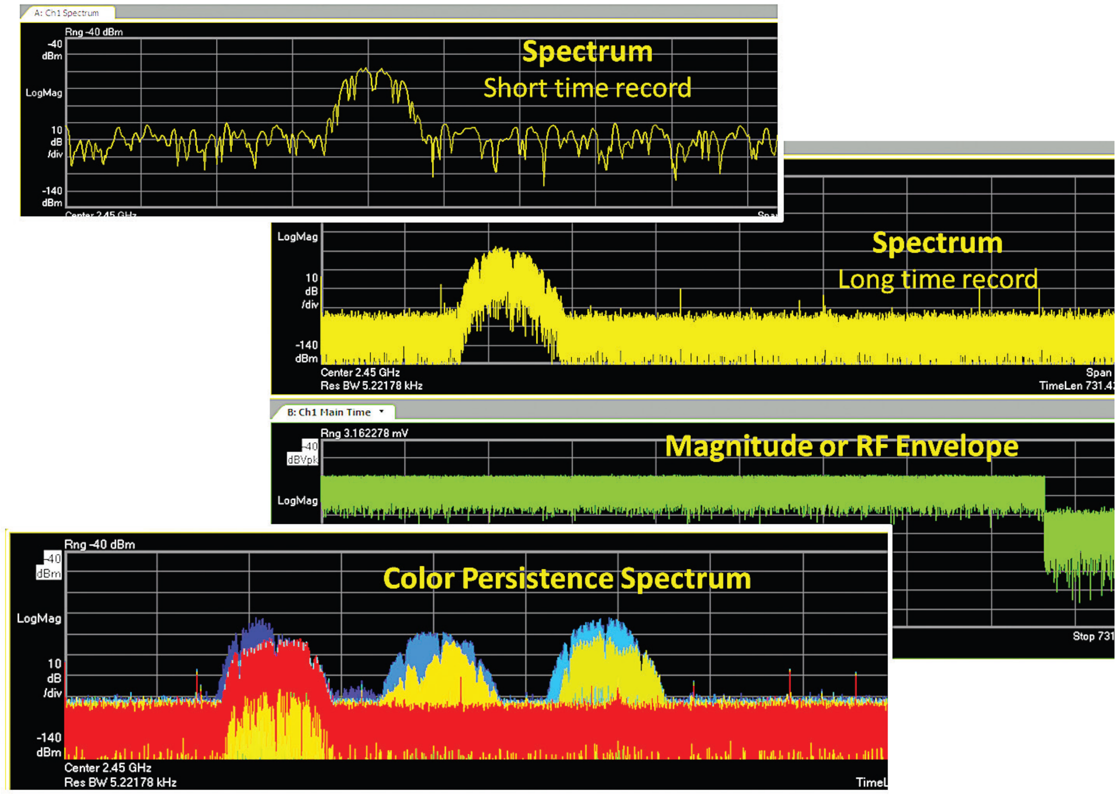


**Figure 15.** FFT analysis of a short time record (top) avoids the problem of the swept spectrum analyzer's moving RBW filter but POI is likely to be very low. For most agile signals, a more comprehensive view — and higher POI — is obtained through the use of a much longer time record (middle) and enhanced displays such as color persistence (bottom).

Fortunately, the time records in the 89600 VSA can be quite long. These longer time records provide a better view of many signals and a higher effective probability of intercept (POI), also shown in Figure 15. Using a longer time record and enhanced displays such as persistence and density can result in signal views that are much more informative and significantly closer to real time, even though they are well short of genuine real-time analysis.

Using a long FFT time record (via the "# frequency points" setting in the 89600 VSA) results in significantly bigger contiguous blocks of analyzed time and increases the probability of intercept. In the 89600 VSA, users can specify time-record length in terms of time or number of points depending on preference.

Using persistence mode for displaying spectrum analysis results — either monochrome or color — allows information to remain on the display long enough for observation and evaluation. Max-hold settings could achieve some of the same benefits; however, in many cases the accumulation of display results without discarding any can cause obscured data and limit the display's responsiveness as the signal changes.

# FFT analyzer settings to improve POI

As discussed earlier, the swept spectrum analyzer may not be the best way to characterize agile signals or dynamic signal environments. Fortunately, the adjustment of some basic 89600 VSA measurement settings can dramatically improve POI.

## Use longer time records

Time-record length can be set in terms of seconds or frequency points. Because of overhead processing such as that involved in display updates, the spectrum update rate of the 89600 VSA generally decreases more slowly than the time-record length increases, so a higher percentage of ADC samples are processed with longer result lengths. One side benefit is that longer time records include more signal dynamics. Those dynamics can be explored with gated sweep, which enables specific time portions of a signal to be later selected for spectrum analysis.

## Reduce the frequency span

Because the effective ADC sample rate varies directly with frequency span, the POI increases as span is reduced. Thus, it is useful to reduce the measured frequency span — perhaps after the signal has been explored at a wider span — to the minimum necessary to measure the signal or frequency region in question.

## Measure in a triggered mode

For some signals and signal environments, there are periods during which no signal (or no significant signal) is present. In such cases it is practical to set a magnitude threshold below which no time records are acquired and no measurement is made. The 89600 VSA's magnitude trigger can easily accomplish this task, with the potential to dramatically improve POI simply by ensuring that no measurements are made when no signal is present. The negative trigger delay feature included in the 89600 VSA's IF magnitude and frequency-mask triggers can be used to ensure that signals occurring before the trigger is satisfied are measurable as well. Of course, the use of the frequency-mask trigger (FMT) available with the real-time PXA and MXA along with the 89600 VSA combination can perform more sophisticated testing to ensure that only the desired signals are caught and measured. The FMT functionality will be described later in this note.

## Use advanced, data-dense displays

Another approach to improving practical POI is to ensure that events that show up in even a single display update are not missed. In the 89600 VSA, the digital-persistence and cumulative-history display enhancements can readily provide this benefit, and can be customized as needed to highlight rare or frequent events or to differentiate between recent or older events.

These measurement settings and techniques may not provide the 100 percent POI that is available in a real-time analyzer; however, they can dramatically increase effective POI and allow the 89600 VSA to bring its wide range of sophisticated analysis capabilities to bear on difficult signals and measurements.

## Triggering: Applying IF Magnitude & Frequency Mask to Case Study #2

So far, FMT (spectral) and magnitude trigger types have only been briefly discussed. The following section will cover these in more detail, primarily in the context of the signal environment measurement covered in Case Study #2.

Both frequency-mask and IF-magnitude triggers operate on digital samples from the analyzer IF. Real-time analyzers typically implement FMT while vector signal analyzers have generally offered IF-magnitude triggering. With Keysight's real-time PXA and MXA signal analyzers, the 89600 VSA can be used with the RTSA option to provide both FMT and IF-magnitude triggering.

Both trigger types employ ASICs, FPGAs, or both, to perform the real-time calculations required for triggering. IF-magnitude triggering has been available for RF signals in vector signal analyzers for quite some time, beginning with the 89400 VSA instruments (c.1993). As with current signal analyzers such as the PXA and MXA, ASICs or FPGAs are used to calculate, in real time, the signal magnitude by taking the square root of the I2 + Q2 combination. These calculations are performed in real time on a sample-by-sample basis with time alignment, allowing triggers to be aligned with specific samples of the IF signal. In contrast, the FMT requires more processing power because the triggering is calculated on the basis of a spectrum result, which is transformed from a block of samples (as previously described).

In the 89600 VSA software, either type of trigger can be used to initiate an individual measurement or a time capture of a large block of samples that can be post-processed as desired. Positive and negative trigger delays can be applied to either trigger type to ensure that a complete signal event is available for measurement or post-processing.

## FMT and the ISM band

When dealing with dynamic scenarios such as the ISM band, the FMT capability can be a very useful tool in finding signals — either expected or unexpected — and improving POI. For example, the FMT is a powerful way to take advantage of the very fast spectrum calculations inherent in real-time analyzers. As previously mentioned, the spectra are calculated much too rapidly to be viewed by users but it is not difficult for high-speed DSP to evaluate them individually against one or more spectral masks and against behavior criteria such as enter-then-leavemask, etc. When the result of the evaluation is a measurement trigger, this provides an effective way to sort through millions or billions of spectra to find specific signals or events or circuit behavior (Figure 16).

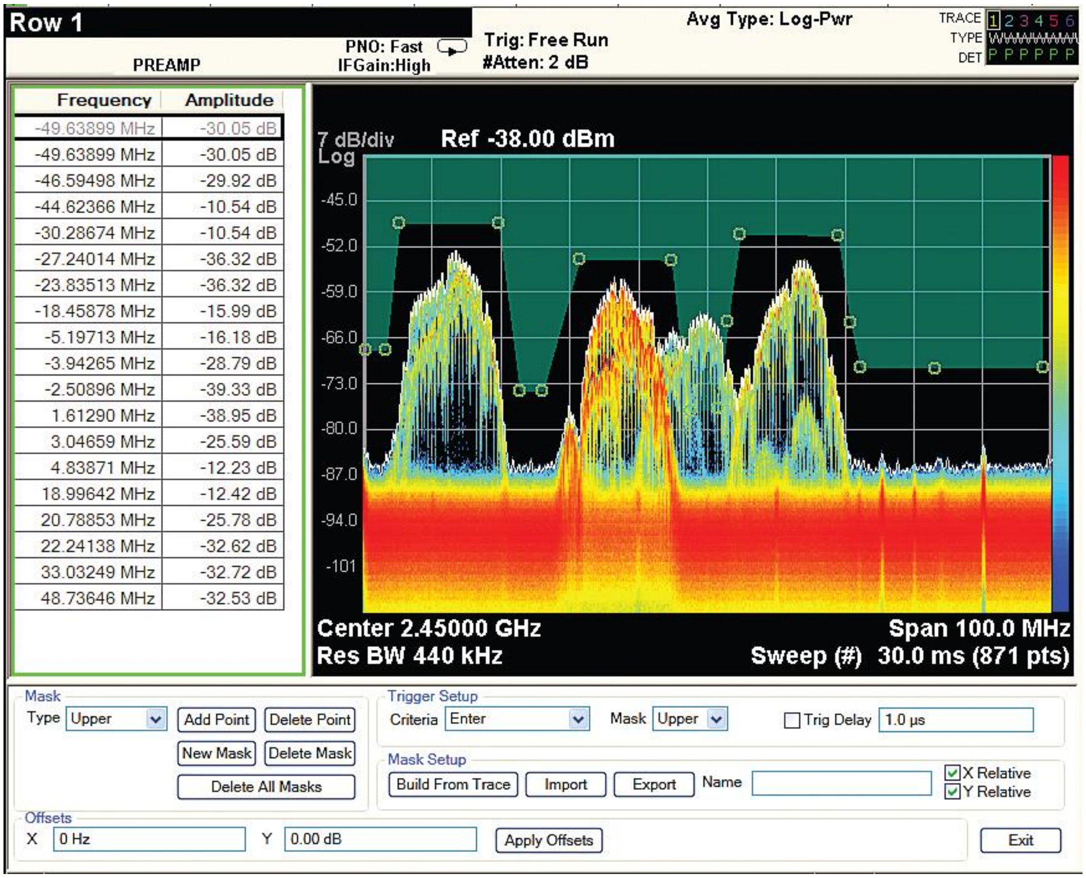


**Figure 16.** A frequency mask constructed around three WLAN channels is violated when one WLAN transmitter switches to a frequency that is between channels currently in use.

In the example shown in Figure 16, the FMT is set up to detect when the WLAN radios are switching between channels or when another signal (such as a Bluetooth hop) appears between the WLAN channels. Normally, the WLAN signals stay within their typical three channels; however, as becomes apparent when watched for several seconds or longer, channel scanning may occur, especially when the ISM band is crowded. It is of note that an RF pulse or magnitude trigger would not work in this case because the scanning has a distinctive spectral shape but not a large magnitude (e.g., not larger than the rest of the signals in the analysis bandwidth).

Untriggered time capture and playback with the 89600 VSA might capture this event. However, because it happens comparatively rarely (e.g., every few seconds to tens of seconds) it could be missed or would be very tedious and time-consuming to find. For example, it might be quite tiresome to review a time capture of long enough duration to ensure a high probability of including the scanning event (high POI).

Because the trigger is generated from FFT power spectrum results, the basic trigger timing resolution is 1/FFT period (in units of time). In some cases it might be possible to further refine the timing; however, it is important to note that the trigger is asynchronous with the signal and not time-aligned with the signal’s RF envelope.

The frequency-mask trigger can be used in several different ways, the most common being the initiation of a spectrum measurement or group of measurements. The trigger can also be used, in concert with 89600 VSA software, for vector measurements such as analog or digital demodulation. Also with the VSA software, the trigger can be used to start a time-capture operation to record a signal event (including the time before the trigger) for a wide range of post-processing operations including demodulation.

## Selecting signals from the ISM band for analysis and demodulation

The combination of the real-time analyzer's FMT and the 89600 VSA's time-capture mode is especially useful for analyzing one or more of the abundant signals and events present in the ISM band. Because the content of the band is continuously changing, a significant benefit of time capture and post-processing is that analysis parameters, displays and analysis types can be changed while analyzing the same event over and over. This avoids situations with ambiguous interpretations in which the engineer cannot be sure if inconsistent analysis results are due to different analysis settings or to a change in the signal itself.

In the 89600 VSA, graphic tools simplify navigation of timecapture buffers and the selection of which portions to analyze. Playback begins at the start time and ends or repeats at the stop time, and the current analysis position in the buffer is shown both numerically and graphically. These parameters can be entered numerically or graphically.

One convenient approach is to drag the analysis position indicator while watching the analysis displays to find the signal of interest and identify the desired start/stop times: the displays are updated continuously as the position is changed. The start/stop time sliders can then be moved to select the appropriate analysis region.

The spectrogram display is an excellent tool for understanding behavior in the ISM band and then selecting the signals and analysis region of interest. The crowded and complex character of the ISM band is shown in Figure 17: a capture lasting about 26 ms and covering the entire band was occupied by energy from WLAN bursts, Bluetooth hops and microwave ovens.

Gap-free playback with adjustable overlap provides a detailed look at all activity in the band over time. Virtually any activity can be seen and measured and the horizontal spectrogram or slice markers can be used with a relative time marker to understand signal timing (see red ellipse, upper right of Figure 17). The 16.7 ms indicated time interval of repeating microwave oven bursts (the narrow curving lines) shows that they are operating on a 60-Hz cycle.

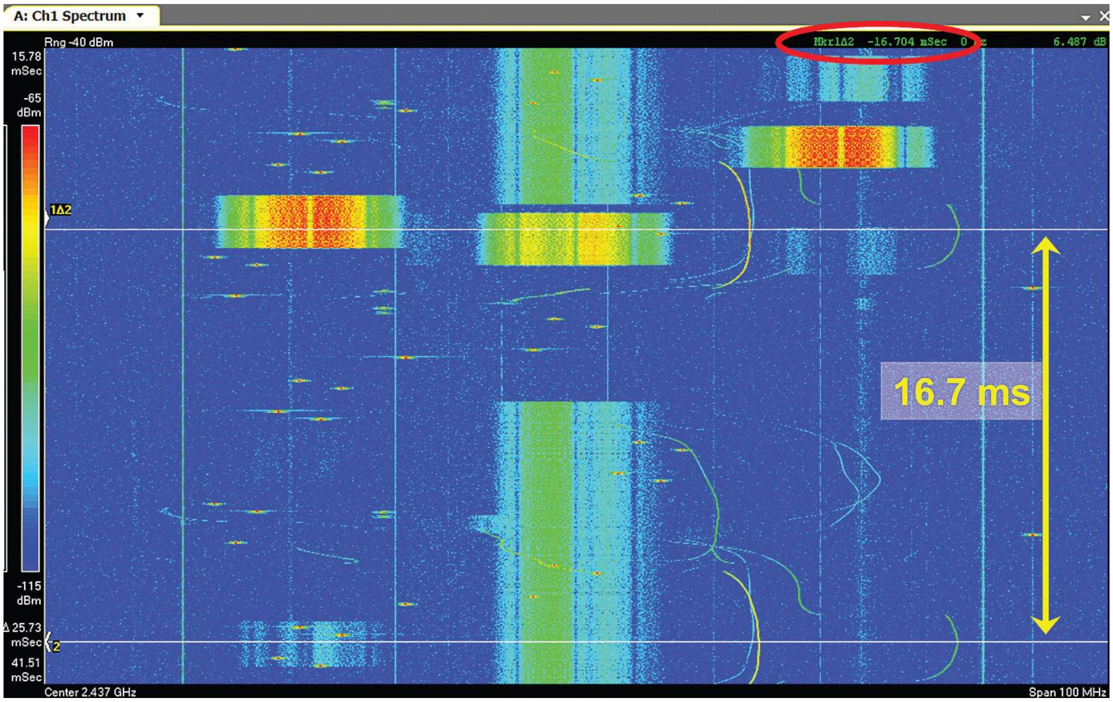


**Figure 17.** This spectrogram display provides an overview of signals and behavior in the 2.45GHz ISM band over an interval of about 26 ms. The highly-overlapped real time measurement produces a detailed view of WLAN bursts, Bluetooth hops and microwave oven leakage.

The fine time resolution of the spectra in the spectrogram reveals some instances of interference and many of effective spectrum sharing. Note that, within this timeframe, two WLANS are successfully sharing the center channel. Also note that most Bluetooth hops are clear of WLAN bursts and oven activity.

Sharing of this band by multiple users appears to be successful, though one could imagine problems as the band gets busier. At some point, interference could cause excessive retransmissions and those additional bursts could lead to even more interference and retransmissions. This positive feedback situation could lead to another cliff effect: small increments in band activity could cause large problems with effective throughput. The density and spectrogram displays of real-time analyzers would be useful in spotting this phenomenon and capture/playback and spectrogram displays from an 89600 VSA would be very useful in diagnosing problems and testing potential solutions.

Once a signal of interest has been identified in the capture buffer in terms of frequency and time, it can be isolated for analysis and demodulation. As discussed in Case Study #1, the 89600 VSA uses a digital LO, resampling and digital filtering to allow changes to the analysis center frequency and span for further analysis without the need to re-capture the signal. An example is shown in Figure 18.

In Figure 18, the multiple types of post-processing capabilities available in the 89600 VSA come together to support selection and detailed analysis of a specific element of the signal environment. Here, a portion of the buffer is selected to include a specific Bluetooth hop. The hop is then isolated from other occupants of the band by centering it in a reduced analysis span.

After these operations have been performed, the hop can be examined in detail with other signals filtered out.

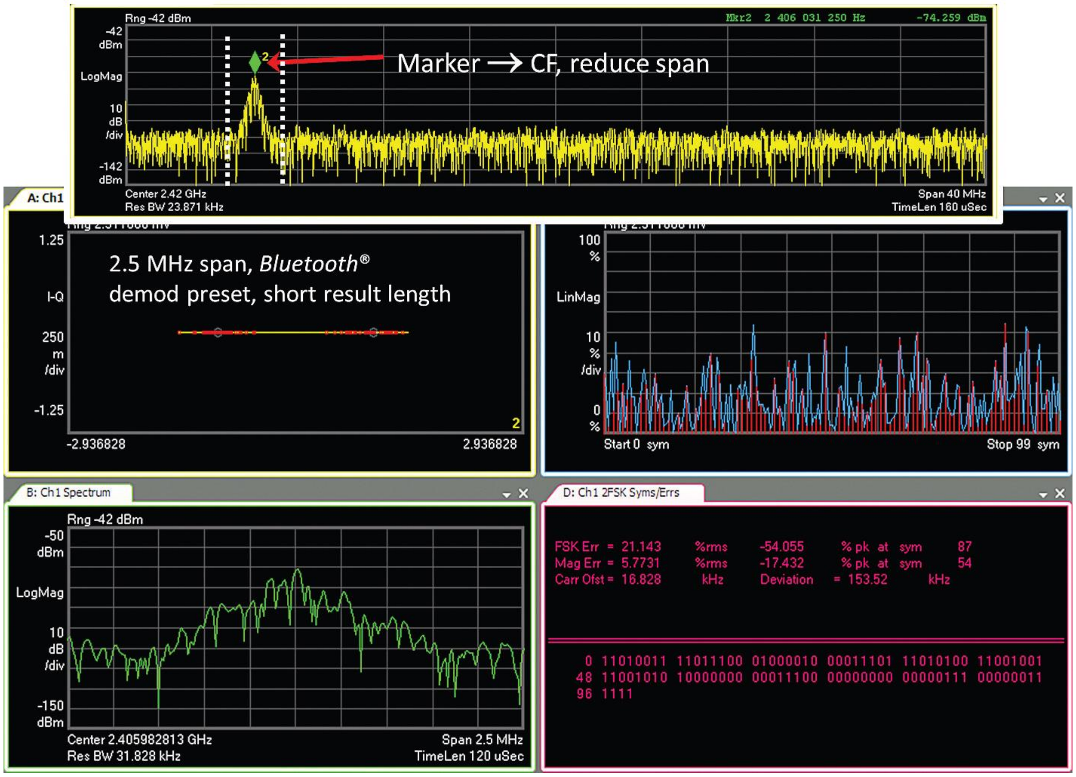


**Figure 18.** By selecting a portion of the capture bugger, reducing frequency span, and changing the center frequency to match (top), post-processing in the 89600 VSA provides isolation and analysis of any signal in the capture bugger including demodulation of this single Bluetooth hop (bottom).

In this case, a Bluetooth hop without interference has been selected and the demodulation results are shown. The Bluetooth demodulation was performed with the 89600 VSA's presets for this modulation type. Many different displays are available, including the constellation, spectrum, EVM and error summaries shown here. The physical-layer data is also provided in the display at the lower right.

It may also be useful to select other hops or WLAN bursts that include interference to evaluate the effects of that interference.The spectrum and power vs. time displays (above) would be good tools for this selection, along with the spectrogram shown previously. All of these display and analysis tools could be used on the same signal if desired.

## Selecting and saving sampled data for RF output or other analysis

A major benefit of the ability to find and measure agile signals is the potential for re-using them, either as real-world RF stimulus signals or as inputs to another process such as simulation or mathematics tools. This allows real-world signals, including their defects or impairments, to be used in other design and test processes.

In the 89600 VSA, selecting and saving time and frequency segments of captured data is straightforward, as shown in Figure 19. In the software, the sampled data from a measurement or time capture can be saved either as-is or in a modified form. For example, the data can be saved at an altered center frequency and span, after the operations of resampling and mixing with a digital LO, as described previously.

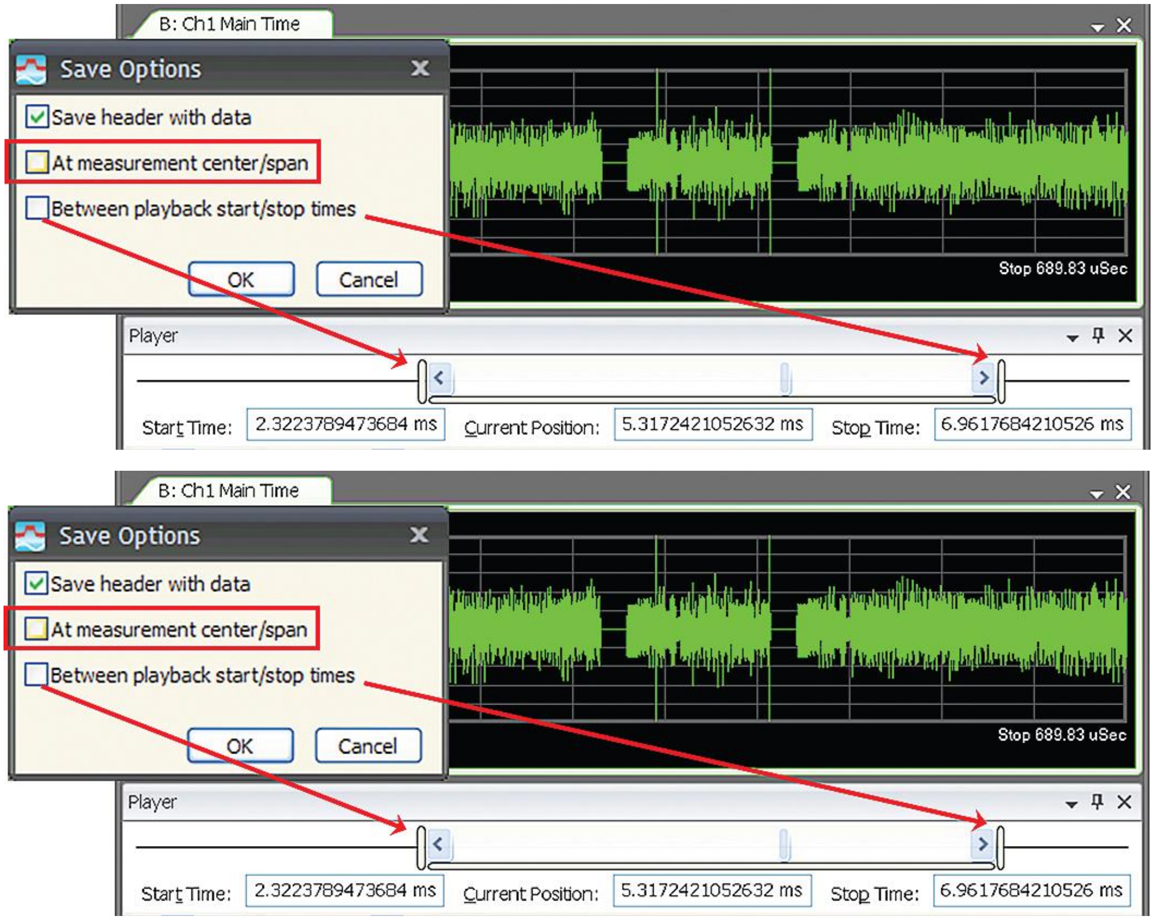


**Figure 19.** When storing a time-capture recording in the 89600 VSA, options are provided to save selected data between start/stop times, and to save data at center and span frequencies different than the original capture. These processing options make it easier to re-use sampled data in other instruments, tools or processes.

In addition, a particular time portion of the sampled data can be selected for saving, and this selection can be combined with the frequency conversion operations. In the Figure 19 example, a shortened burst has been found, and the data portion has been measured with gated sweep. The shortened burst itself can be selectively saved or passed along to other processes for analysis or used as an RF stimulus signal.

# Summary

In real-time analyzers and vector signal analyzers, the combination of real-time analysis and density displays is especially useful for agile signals and dynamic spectral environments. When the signal or behavior in question is short in duration, infrequent in occurrence, or simply unexpected, the large amount of data that can be processed and represented by a real-time analyzer can provide the best chance of detection.

While a real-time analyzer and its display capabilities are very useful, there are limits to its diagnostic or troubleshooting power. For example, the large amount of spectrum results compared to the limited rate of display updates means that each update typically combines many spectra. As a result, it may be hard to see, in any detail, those phenomena that have a rate of change much faster than the display update or acquisition time.

Vector signal analyzers are the logical complement and extension of the signal discovery functions of real-time analyzers. As shown in the examples here, the two analyzer types work together to take engineers from signal discovery and analysis of the most agile and challenging signals through the process of analysis, troubleshooting and optimization.

Both real-time analyzers and the 89600 VSA can operate on the hardware platform of swept analyzers such as the Keysight PXA and MXA, building on the performance, flexibility, and familiar user interface of this fundamental RF analysis tool.

# Appendix: Comparing Triggering Techniques and Benefits

In many challenging situations, choosing and using a triggering approach from one of the several available can dramatically improve the effectiveness of your measurements. It can be used to focus your attention on the signals or time intervals that matter the most or are most likely to reveal troublesome signals. For example, selection of an appropriate trigger type and setting can ensure that the analyzer is not measuring when no signal is present and is therefore more likely to be armed and ready to measure or capture when significant signals appear.

Triggering can be especially helpful when examining long time periods for either expected or unexpected signals. The two trigger types discussed below both involve real-time calculations performed on the digitized signal and therefore can monitor signals or signal environments exhaustively in ways that are impractical for analyzer operators to duplicate visually.

For real-time analyzers and vector signal analyzers, the two most useful trigger types for agile RF signals are frequency-mask triggering and IF-magnitude triggering. Their benefits are summarized and compared in Table 1, below.

**Table 1. Comparing IF magnitude and frequency-mask triggering techniques**

| IF Magnitude | FMT |
|---|---|
| Real-time calculation of magnitude in selected span | Real-time calculation of spectrum & test against spectral mask |
| Precise, repeatable time alignment | Upper and lower limits |
| Negative & positive trigger displays | Build from trace & adjust, or enter parameters manually |
| Selectable level & polarity | Trigger timing ambiguity ± 1 FFT period |
| Selectable holdoff, holdoff type | Logic: Enter/leave, in/out,<br>enter → leave, leave → enter |
| Playback IF magnitude trigger | Negative & positive trigger delays |

These triggering techniques are most effective when combined with specific knowledge of your signals or systems and with your insights into phenomena or behavior that are of most interest or concern. Be sure to consider all you know about important signal levels and transitions as well as relative timing of the signal of interest versus others. When using vector signal analyzers such as the 89600 VSA, be sure to consider positive and negative trigger delays and trigger holdoff as ways to measure a signal of interest, even if it is not the signal that initiates the trigger.

## Considering time capture as alternative to triggering

When triggering is impractical or difficult, the time-capture and post-capture signal-selection capabilities of the 89600 VSA may be a useful alternative. For repeating signals, it may be practical to simply record a signal long enough to ensure that a full cycle, full pulse, or complete frame is captured, and then select the appropriate measurement position or interval in post-processing.

The main element of this approach is to set the capture to an adequate length. For repeating pulsed or bursted signals, a general rule for the minimum is to set the capture length to a time equal to the sum of the inter-burst interval plus twice the burst length. This [“off time” + 2x “on time”] calculation would be the same for analyzing a digitally modulated burst or frame when you want the search time to always include the beginning, middle and end of a frame.

As described previously, the analysis region can be selected graphically or numerically to focus on the signal of interest. In a similar way, if a problem is repetitive and not especially rare, one may simply capture a segment of sufficient length and look for the signal or event of interest during playback. In some cases, this approach is easier than setting up other trigger types. It may also be useful when spectral characteristics of interest are not known, either as spectrum shape or behavior over time. Note that because this approach is simply a form of time capture, the results are always gap-free and analysis types and parameters can be freely changed in post-processing.