Keysight Technologies
Infiniium Oscilloscopes Used for Wideband RF Measurements

Application Note

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Introduction

Both digital and RF designers are discovering that the FFT function in oscilloscopes can be very helpful when used in conjunction with the time domain view to validate and debug their prototypes. For example, an FFT view of the noise riding on a power supply rail can quickly isolate and identify an unwanted, coupled signal so that the source of the coupling can be determined.

Also, a growing number of RF oriented designs are driving spectral widths greater than 510 MHz or 1 GHz, the limit of real-time signal analyzer analysis bandwidth capabilities. Designers are finding that to achieve this greater analysis bandwidth, a digitizing oscilloscope has become an important tool for such applications. In essence, the oscilloscope becomes a wideband RF receiver.

This application note will outline how the Infiniium S-Series, V-Series and Z-Series oscilloscopes can be used to make a variety of FFT and wideband RF measurements to speed designs to market.

High-Level Tool Choice Considerations

Signal carrier frequency and modulation frequency spectral width are key drivers for what bandwidth oscilloscope is appropriate for an application. An S-Series 8 GHz bandwidth oscilloscope being used together with 89600 Vector Signal Analysis (VSA) software is shown in Figure 1 and will be considered in a variety of applications where carrier plus modulation is within its 8 GHz bandwidth. The scope is being driven by an M8190A arbitrary waveform generator. A V-Series 33 GHz oscilloscope is shown in Figure 2, capturing a 15 GHz carrier RF pulse with wideband chirp modulation and processing the captured signal with VSA software. The V-Series will have application for wide bandwidth signals where carrier plus modulation is within its 33 GHz bandwidth.

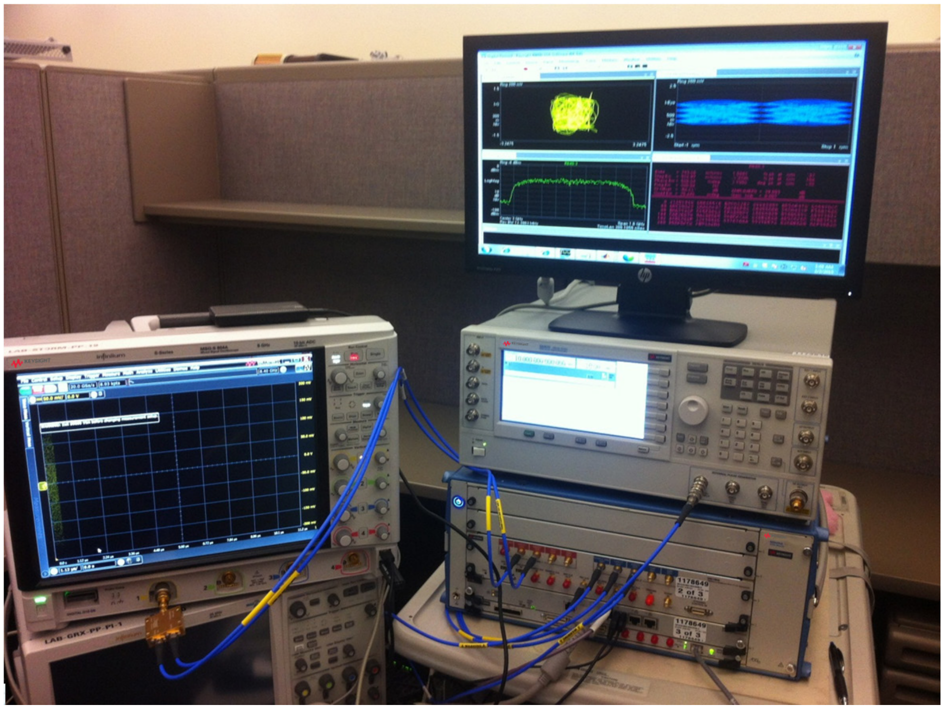


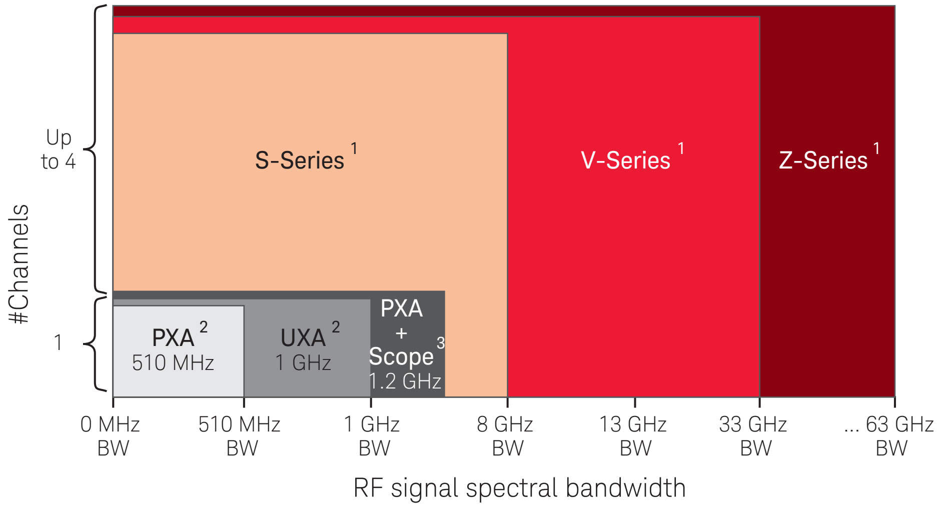
Figure 1. S-Series 8 GHz oscilloscope driven by an M8190A arbitrary waveform generator and showing captured signals processed with the 89600 Vector Signal Analysis (VSA) software.

Figure 2. V-Series 33 GHz oscilloscope receiving a 15 GHz carrier pulsed RF signal with wideband chirp modulation processed with the 89600 VSA software running on the oscilloscope PC.

The key tool choices available as a function of input channels and analysis bandwidth are shown in Figure 3. The PXA and UXA signal analyzers allow for single channel measurements with real-time signal analysis bandwidth capabilities of 510 MHz and 1 GHz respectively. These products can analyze signals with high carrier frequencies by down converting those signals to IF where baseband signals can then be re-sampled and analyzed.

A PXA or UXA can also be used as a down converter in front of a Keysight oscilloscope and achieve up to around 1.2 GHz of analysis bandwidth. Such a configuration loses some of the real-time signal analyzer capabilities, like frequency domain triggering, that are offered in a vector signal analyzer being used as a stand-alone instrument, since the PXA or UXA are only being used as a down converter.

Oscilloscopes can also be used stand-alone for RF measurements and are limited to the bandwidth rating of the oscilloscope. For example, an S-Series 8 GHz bandwidth Infiniium scope could handle signals whose carrier plus modulation above the carrier frequency did not exceed 8 GHz. A signal with a 7 GHz carrier and 1 GHz wide modulation would fit within the bandwidth of the scope.



1. S, V and Z-Series 2 ch full bandwidth, 4 ch half bandwidth.
2. Up to 50 GHz carrier.
3. 3.6 GHz to 50 GHz carrier.

Figure 3. Channel count and analysis bandwidth capabilities of various solutions.

Another way of viewing tool choices can be drawn by plotting carrier frequency of the signal of interest vs. the spectral width of that signal, and then showing which tools apply for the carrier/spectral width combination. Such a view is shown in Figure 4.

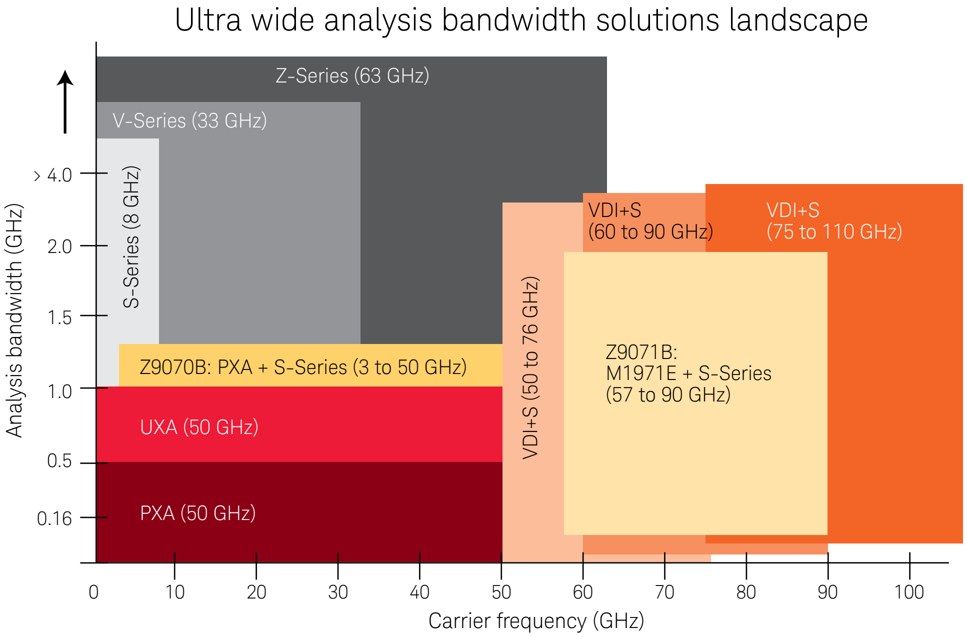


Figure 4. Applicable tools as a function of signal carrier frequency and spectral width.

The PXA signal analyzer can measure signals with carrier frequencies up to 50 GHz and offers up to 510 MHz analysis bandwidth on one input channel. The UXA signal analyzer can input carrier frequencies up to 50 GHz and has up to 1 GHz analysis bandwidth. Multiple PXAs or UXAs can be ganged together to get higher channel count.

The S-Series oscilloscope can be used by itself to offer two channels with 8 GHz bandwidth or four channels with 4 GHz bandwidth. The oscilloscope can handle signals with spectral widths nearly up to the bandwidth of the oscilloscope. But the carrier plus modulation must be sampled with enough bandwidth to capture both. For example, a signal with a 6 GHz carrier and a 2 GHz wide modulation would fit within the 8 GHz bandwidth of an S-Series oscilloscope and could be evaluated.

The V-Series oscilloscope offers two channels with 33 GHz bandwidth or four channels with 16.6 GHz bandwidth. The Z-Series oscilloscope offers two channels with 63 GHz bandwidth or four channels with 32 GHz bandwidth.

The Z9070B wideband signal analysis bundle places a PXA as a down converter in front of the S-Series oscilloscope to handle carrier frequencies from 3 to 50 GHz and has up to 1.2 GHz of analysis bandwidth. If a signal had a 20 GHz carrier and 1 GHz wide modulation, then the Z9070B bundle could make the measurement. An alternative for this signal would be to use a V-Series oscilloscope by itself, a more accurate but more expensive alternative, since the V-Series has up to 33 GHz bandwidth. If this 20 GHz carrier signal instead had a 2 GHz wide modulation, then a V-Series oscilloscope would need to be used instead of the Z9070B bundle since the bundle is limited to 1.1 GHz analysis bandwidth.

If an application had a 55 GHz carrier and 2 GHz wide modulation, then a Virginia Diode Inc. (VDI) mixer could be placed in front of an S-Series oscilloscope to make a measurement. VDI mixers are available to handle carriers up to 110 GHz with up to around a 3 to 4 GHz analysis bandwidth.

Another bundle called the Z9071B combines an M1971E Waveguide Harminic Mixer (Smart Mixer) as a down converter with an S-Series oscilloscope to make 2 GHz wide measurements on carriers between 57 and 90 GHz.

So depending on the application, a variety of solutions are offered to make required measurements.

RF Characteristics of the Infiniium S-Series, V-Series, and Z-Series Oscilloscopes

Before making FFT or wideband RF measurements with an oscilloscope or oscilloscope combined with the 89600 VSA software, it is helpful to evaluate the RF characteristics of the oscilloscope as this can have a major influence upon the result of such measurements.

The Infiniium oscilloscopes incorporate amplitude and phase correction with the result of excellent absolute amplitude accuracy and low deviation from linear phase across the oscilloscopes frequency range, which in turn contributes to high quality RF measurements. These oscilloscopes also offer excellent noise densities, in the vicinity of –160 dBm per hertz, and high dynamic range and signal-to-noise ratios, considering the wide bandwidth capability they offer. This enables a designer to be able to look at very small wideband signals adjacent to large signals, or to be able to boost scope sensitivity to measure isolated, low power signals. The time base circuitry in these oscilloscopes also results in good, close-in phase noise, which corresponds to low jitter in very deep memory traces.

The three main series of Infiniium oscilloscopes, the S-Series, V-Series and Z-Series, and their typical RF characteristics, are shown in Table 1. Details of measurement conditions can be found in the appendix in Tables 3 through 5. Plots of typical amplitude response over frequency for various oscilloscopes can be seen in the appendix in Graphs 1 through 5.

Table 1. S-Series, V-Series, and Z-Series typical RF characteristics compared (note measurement conditions listed within individual scope tables in Tables 3 through 5 in appendix).

	S-Series	**V-Series**	**Z-Series**
Bandwidth	DC to 8 GHz	DC to 33 GHz	DC to 63 GHz (measurements on 33 GHz ch.)
Sensitivity (dBm/Hz) 3 kHz Res BW	–161 dBm/Hz	–158 dBm/Hz	–160 dBm/Hz
Signal to noise (dB) 1 GHz 0 dBm input, 1 kHz RBW	–109 dB	–111 dB	–112 dB
Spur Free Dynamic Range (dB) 550 MHz span	–74 dB	–67 dB	–73 dB
Absolute amplitude accuracy across the frequency range (typical worse case)	± 1 dB	± 0.5 dB	± 0.5 dB
Deviation from linear phase across the frequency range (typical worse case)	± 7 degrees	± 3 degrees	± 3 degrees
Third Order Intercept (dB) 2 MHz separation	21.5 dB	28 dB	26 dB
2nd harmonic (dB)	–66 dB	-51 dB	–60 dB
3rd harmonic (dB)	–66 dB	-51 dB	–54 dB
Phase noise (10 kHz) (dBm/Hz)	–121 dBm/Hz	–125 dBm/Hz	–122 dBm/Hz
Phase noise (100 kHz) (dBm/Hz)	–122 dBm/Hz	–131 dBm/Hz	–126 dBm/Hz
EVM (%)	0.47%	0.47%	0.37%
EVM (dB)	–47 dB	–47 dB	–49 dB

Basic FFT Measurement Example

In a first example, a basic sine wave signal is captured and analyzed with an FFT in the frequency domain with a V-Series 33 GHz oscilloscope. An E8267D PSG vector signal generator is used to create a 10 GHz, highly pure, sine wave with 0 dBm (1 mW into 50 Ω) power. The measurement setup is shown in Figure 5 (M8190A arbitrary waveform generator also pictured but not used for this measurement).

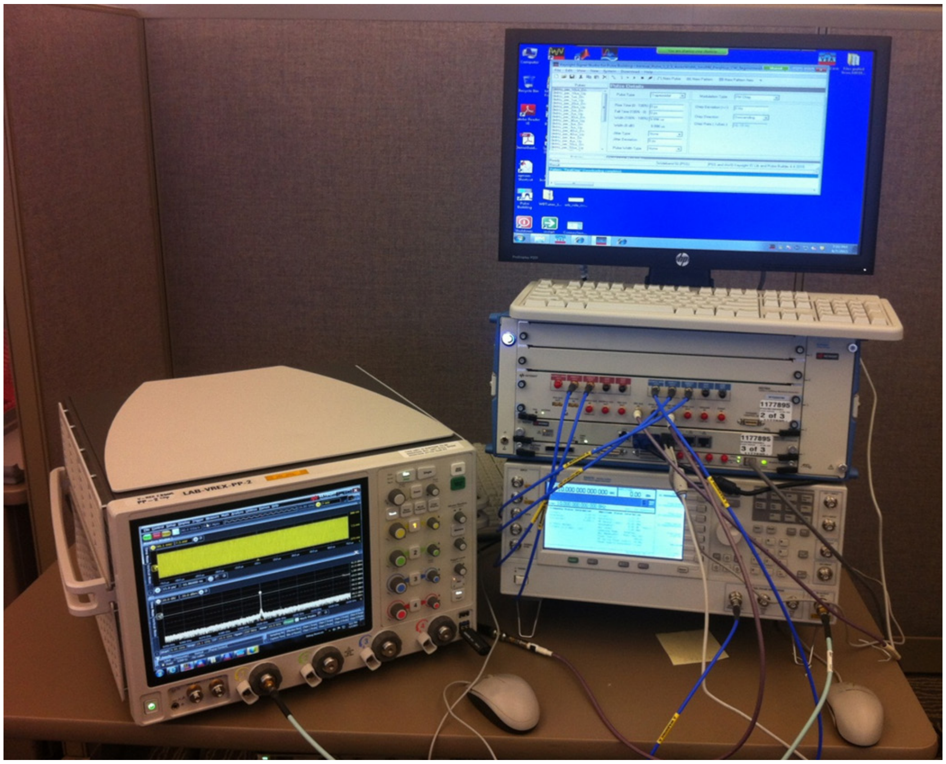
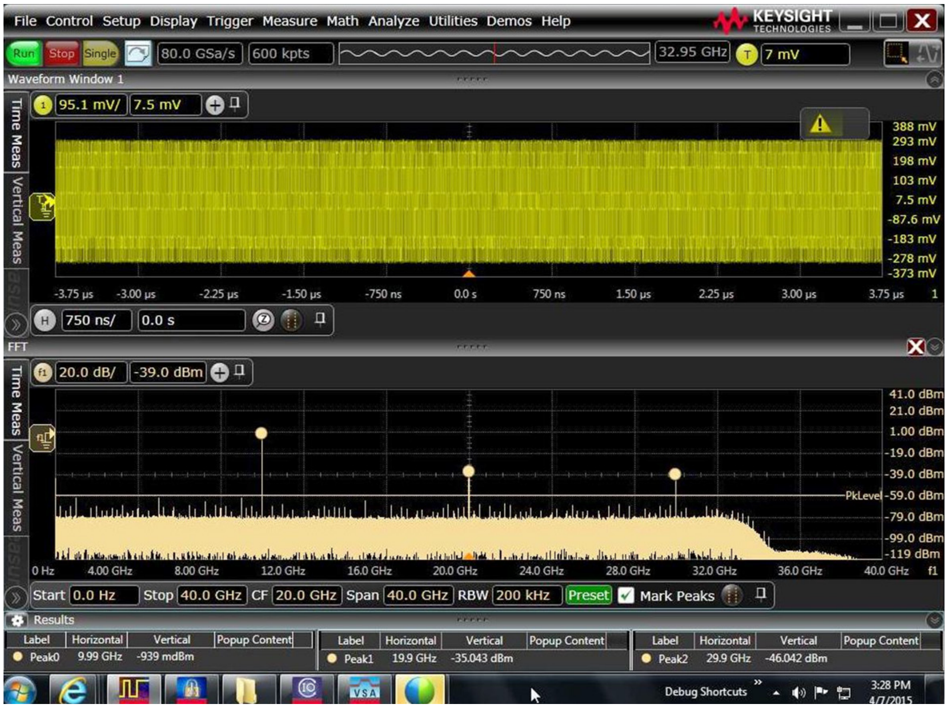


Figure 5. 10 GHz pure sine wave capture with a V-Series oscilloscope.

An FFT measurement is available as a Waveform Math function, and it is used to create a frequency domain view of the input signal as shown in Figure 6. For this measurement 16 averages were selected for the time domain capture, and an FFT resolution bandwidth (ResBW, RBW) of 200 kHz was chosen.

With this kind of resolution, the 2nd and 3rd harmonics are seen at –35 dBm and –40 dBm respectively. These are artifacts of the oscilloscope sampling process and are noted in the evaluation of the 10 GHz input sine signal. The E8267D PSG vector signal generator is specified to have 2nd and 3rd harmonic distortion less than 80 dB down from the carrier, so this allows for the determination of oscilloscope 2nd and 3rd harmonic distortion for this particular signal example.



Start 0.0 Hz Stop 40.0 GHz CF 20.0 GHz Span 40.0 GHz RBW 200 kHz Preset ☑ Mark Peaks

Results

Label	Horizontal	Vertical	Popup Content
Peak0	9.99 GHz	-939 mdBm	
Peak1	19.9 GHz	-35.043 dBm	
Peak2	29.9 GHz	-46.042 dBm	

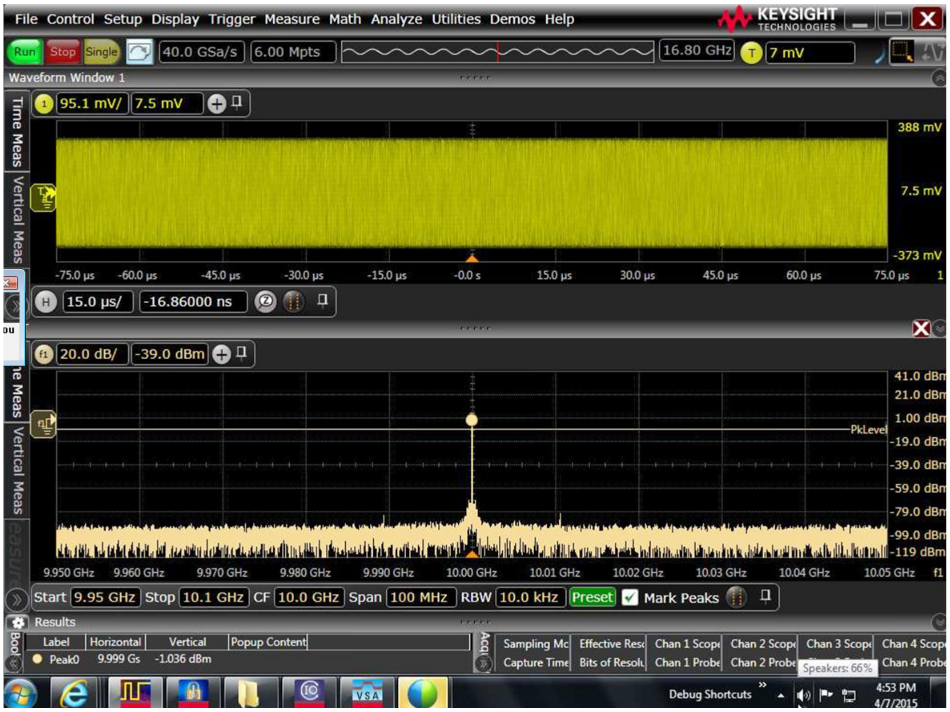
Figure 6. Addition of FFT amplitude math function to see 2nd and 3rd harmonics (–35 dBm, –40 dBm).

Just for a frame of reference, when a similar measurement was taken with a 4 GHz input sine wave, the 2nd and 3rd harmonics seen were at –45 dBm and –49 dBm respectively.

Many times it is important to zoom in to a frequency of interest with a much more narrow frequency span. With the oscilloscope FFT, even with a narrower span selected around a chosen center frequency, the analysis bandwidth for a measurement is still “DC to the selected oscilloscope bandwidth”. In the case of this last measurement, the analysis bandwidth was 33 GHz wide. Later, the use of the 89600 Vector Signal Analysis (VSA) software package will be discussed where the selected VSA FFT span becomes the analysis bandwidth for a measurement, which in turn will decrease the noise level in the measurement.

By setting the FFT frequency “Center” to 10 GHz and “Span” to 1 GHz, decreasing the sample rate to 40 Gsa/sec, and narrowing down the RBW even further, a much more close up view of the 10 GHz spike can be seen, and is shown in Figure 7.

With these settings, there is now a tradeoff between resolution and throughput. An update happens every few seconds because 6 Msamples of memory depth are required at 40 Gsa/sec to place 150 usec of time across the main time record to support the 10 kHz RBW (using a Hanning FFT window where the time required equals 1.5/RBW = 1.5/10E04 = 150 usec).



40.0 GSa/s | 6.00 Mpts | 16.80 GHz | T 7 mV

1 95.1 mV/ 7.5 mV

H 15.0 µs/ -16.86000 ns

f1 20.0 dB/ -39.0 dBm

Start 9.95 GHz Stop 10.1 GHz CF 10.0 GHz Span 100 MHz RBW 10.0 kHz Preset ☑ Mark Peaks

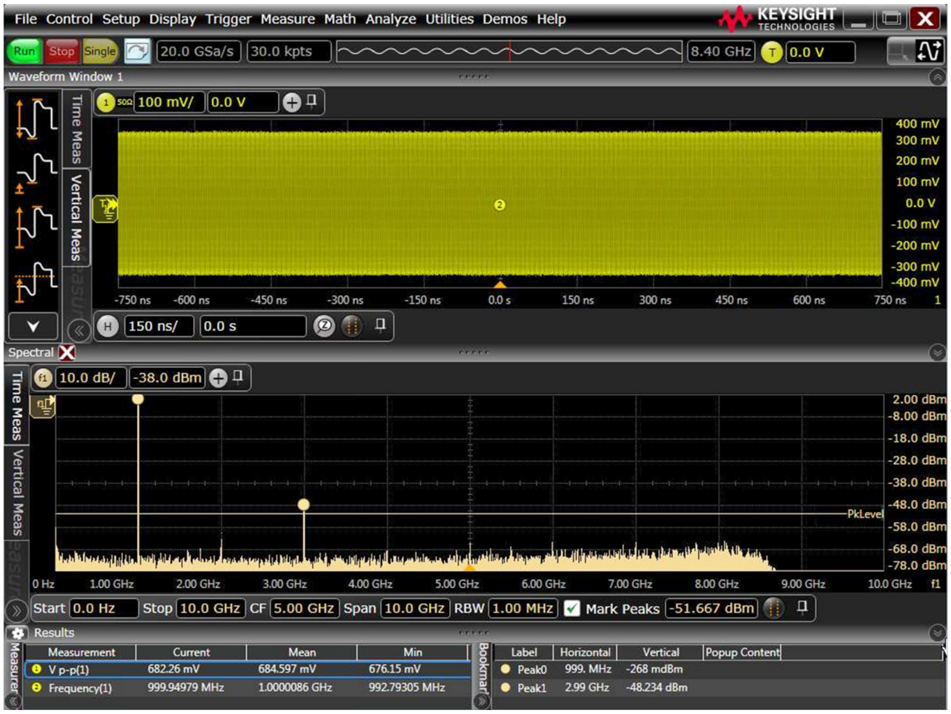
Results

Label	Horizontal	Vertical	Popup Content
● Peak0	9.999 Gs	-1.036 dBm	

Figure 7. Frequency center set to 10 GHz, span to 100 MHz and 10 kHz RBW, some throughput tradeoff.

Notice that each time the RBW was made finer, the level of the noise dropped. This is because the same amount of broadband noise is now being spread across smaller frequency buckets.

A similar measurement can be made on the S-Series Infiniium oscilloscopes that have up to 8 GHz of bandwidth. An example capture and FFT, with a 0 dBm, 1 GHz clean sine wave input, is shown in Figure 8 with 2nd and 3rd harmonics of –65 dBm and –48 dBm respectively, and a spur free dynamic range, ignoring 2nd and 3rd harmonics, of around –68 dBm in a 1 MHz RBW.



20.0 GSa/s | 30.0 kpts | 8.40 GHz | T 0.0 V

1 50Ω 100 mV/ 0.0 V

H 150 ns/ 0.0 s

f1 10.0 dB/ -38.0 dBm

Start 0.0 Hz Stop 10.0 GHz CF 5.00 GHz Span 10.0 GHz RBW 1.00 MHz ☑ Mark Peaks -51.667 dBm

Results

Measurement	Current	Mean	Min
● V p-p(1)	682.26 mV	684.597 mV	676.15 mV
● Frequency(1)	999.94979 MHz	1.0000086 GHz	992.79305 MHz

Label	Horizontal	Vertical	Popup Content
● Peak0	999. MHz	-268 mdBm	
● Peak1	2.99 GHz	-48.234 dBm	

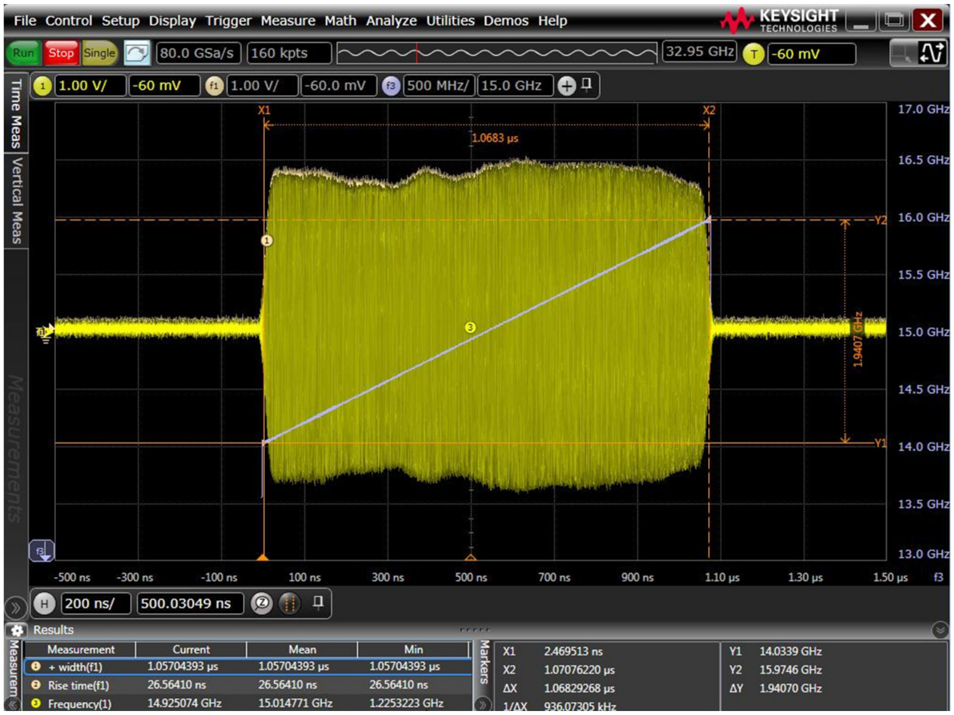
Figure 8. S-Series 8 GHz bandwidth oscilloscope capture and FFT of a 1 GHz clean sine input with 1 MHz RBW.

Wideband Pulsed RF Time Domain Measurements of Envelope, Frequency and Phase Chirp

The next topic to consider is the time domain measurement and analysis of wideband pulsed RF signals with Infiniium oscilloscopes. The choice of S, V or Z-Series depends on the maximum frequency content of the carrier plus modulation. The signal under test is supposed to have 1 usec wide pulses, with a pulse repetition interval of 100 usec, an RF carrier frequency of 15 GHz, and linear FM chirping that is 2 GHz wide.

The signal is being produced with the M8190A arbitrary waveform generator running IQTools signal generation software and driving wideband I/Q inputs on an E8267D PSG vector signal generator.

A view of a variety of measurements on a single RF pulse, including envelope parameters and the frequency chirp across the pulse can be seen in Figure 9. Stable triggering on this pulse is accomplished with trigger “holdoff” set to a value slightly longer than the RF pulse width.



Measurement	Current	Mean	Min
❶ + width(f1)	1.05704393 µs	1.05704393 µs	1.05704393 µs
❷ Rise time(f1)	26.56410 ns	26.56410 ns	26.56410 ns
❸ Frequency(1)	14.925074 GHz	15.014771 GHz	1.2253223 GHz

X1	2.469513 ns	Y1	14.0339 GHz
X2	1.07076220 µs	Y2	15.9746 GHz
ΔX	1.06829268 µs	ΔY	1.94070 GHz
1/ΔX	936.07305 kHz		

Figure 9. Time domain measurements on 15 GHz carrier, 2 GHz wide linear FM chirped RF pulse with V-Series oscilloscope.

To make these measurements the “Envelope” math function is used and then pulse measurements are dropped down onto the visible RF pulse envelope. Also, a frequency measurement is dropped down onto the RF pulse (not onto the envelope), and a “Measurement Trend” is defined with a data source of the frequency measurement, and a smoothing math function is defined with a data source of the measurement trend, with the resultant linear ramp display of the linear FM chirp modulation that was shown in Figure 9. The oscilloscope magnitude linearity over the frequency span of interest has a direct upon the quality of the magnitude linearity of the device under test. Magnitude plots over frequency of typical RF performance of the S, V and Z-Series Infiniium scopes are shown in the Appendix (IV through VI).

Wideband Pulsed RF Gated FFT Measurement of Spectrum

Another important set of measurements includes wideband FFTs and time gated FFTs. A wideband FFT can be created by defining an “FFT Magnitude” math function with “Rectangular” windowing.

A new waveform window appears that displays a wideband FFT of the captured RF pulse as shown in Figure 10.

80.0 GSa/s | 160 kpts | 32.95 GHz | T -60 mV

1 1.00 V/ -60 mV | f1 1.00 V/ -60.0 mV | f3 500 MHz/ 15.0 GHz

H 200 ns/ 500.03049 ns

f4 10.0 dB/ -18.0 dBm

Start 0.0 Hz Stop 40.0 GHz CF 20.0 GHz Span 40.0 GHz RBW 500 kHz

Measurement	Current	Mean	Min
❶ + width(f1)	1.05753967 µs	1.05753967 µs	1.05753967 µs
❷ Rise time(f1)	26.00130 ns	26.00130 ns	26.00130 ns
❸ Frequency(1)	14.910981 GHz	15.014738 GHz	1.1677625 GHz

X1	2.469512 ns	Y1	14.0339 GHz
X2	1.07076220 µs	Y2	15.9746 GHz
ΔX	1.06829269 µs	ΔY	1.94070 GHz
1/ΔX	936.07305 kHz		

Figure 10. Wideband FFT measurement on 15 GHz carrier, 2 GHz wide linear FM chirped RF pulse with V-Series oscilloscope.

A better view of the spectrum can be seen by changing the center frequency of the FFT display to 15 GHz and the frequency span to 5 GHz. The result is seen in Figure 11. Clearly, the RF pulse has a 14 GHz to 16 GHz chirp, with uniform power across the 2 GHz modulation bandwidth.

80.0 GSa/s | 160 kpts | 32.95 GHz | T -60 mV

1 1.00 V/ -60 mV | f1 1.00 V/ -60.0 mV | f3 500 MHz/ 15.0 GHz

H 200 ns/ 500.03049 ns

f4 10.0 dB/ -18.0 dBm

Start 12.5 GHz Stop 17.5 GHz CF 15.0 GHz Span 5.00 GHz RBW 500 kHz Preset ☐ Mark Peaks

Measurement	Current	Mean	Min
① + width(f1)	1.05753967 µs	1.05753967 µs	1.05753967 µs
② Rise time(f1)	26.00130 ns	26.00130 ns	26.00130 ns
③ Frequency(1)	14.910981 GHz	15.014738 GHz	1.1677625 GHz

X1	2.469512 ns	Y1	14.0339 GHz
X2	1.07076220 µs	Y2	15.9746 GHz
ΔX	1.06829269 µs	ΔY	1.94070 GHz
1/ΔX	936.07305 kHz		

Figure 11. FFT set to a 15 GHz center frequency and to a 5 GHz frequency span.

A time gated FFT is also possible through the use of the "Timing Gate" math function. First a time gating math function is defined with the result seen in the upper trace window in Figure 12, where the growing RF pulse can be more clearly seen in orange.

80.0 GSa/s | 160 kpts | 32.95 GHz | T -60 mV

1 1.00 V/ -60 mV | f1 1.00 V/ -60.0 mV | f3 500 MHz/ 15.0 GHz | f5 1.00 V/ -60.0 mV

H 150 ns/ 500.03049 ns

f4 10.0 dB/ -18.0 dBm

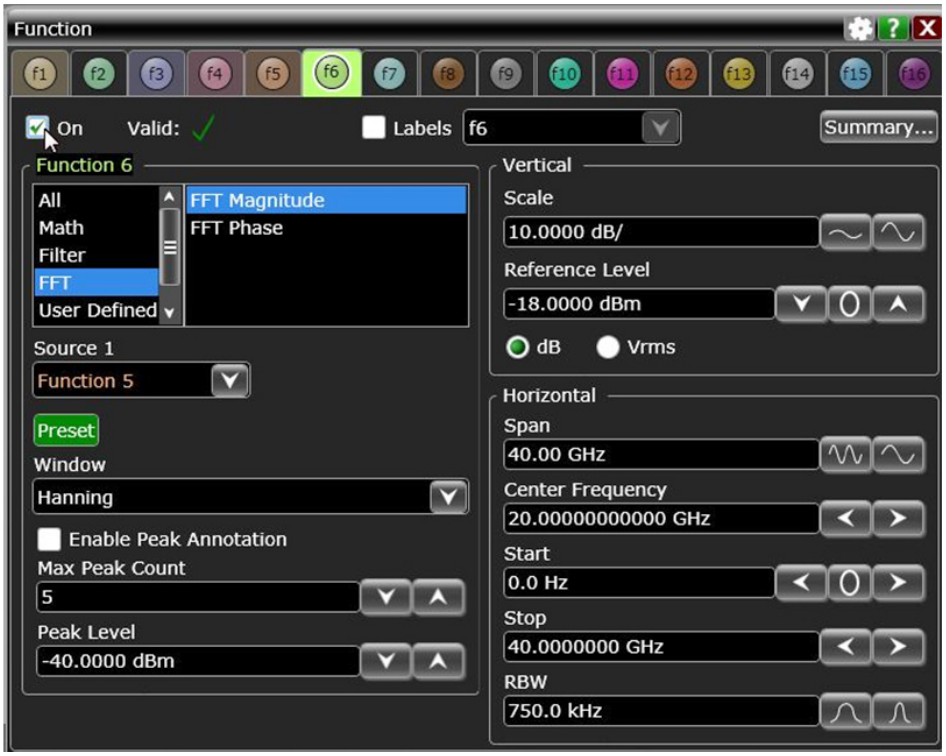
Start 12.5 GHz Stop 17.5 GHz CF 15.0 GHz Span 5.00 GHz RBW 667 kHz Preset ☐ Mark Peaks

Measurement	Current	Mean	Min
① + width(f1)	1.05753965 µs	1.05753965 µs	1.05753965 µs
② Rise time(f1)	26.00129 ns	26.00129 ns	26.00129 ns
③ Frequency(1)	14.910981 GHz	15.014738 GHz	1.1677625 GHz

X1	-1.636197 ns	Y1	14.0227 GHz
X2	1.05003049 µs	Y2	16.0227 GHz
ΔX	1.05166669 µs	ΔY	2.00000 GHz
1/ΔX	950.87160 kHz		

Figure 12. View of the time gate trace.

Then a second FFT math function can be defined to be the FFT of the signal present within this time gate (also called a “time gated FFT”). In this example the time gated FFT is math function number 6 and is operating on math function 5 as shown in Figure 13. A “Hanning” window for the FFT is chosen because a thin time slice of the pulsed RF signal is essentially a sine wave, and the Hanning window is a good choice for such a signal.



☑ On

Valid: ✓

☐ Labels f6

Function 6: FFT, FFT Magnitude

Source 1: Function 5

Window: Hanning

☐ Enable Peak Annotation

Max Peak Count: 5

Peak Level: -40.0000 dBm

Vertical

Scale: 10.0000 dB/

Reference Level: -18.0000 dBm

● dB ○ Vrms

Horizontal

Span: 40.00 GHz

Center Frequency: 20.00000000000 GHz

Start: 0.0 Hz

Stop: 40.0000000 GHz

RBW: 750.0 kHz

Figure 13. Definition of FFT magnitude math function on the signal present in the time gate.

After widening the time gate slightly to bring more cycles on screen, and adjusting the center frequency to 15 GHz and the span to 5 GHz to match the non-gated FFT, the time gated FFT result can be seen in Figure 14. “Mark Peaks” was also checked and the threshold placed just below the peak level to get a reading on the frequency of the chirped pulse at the beginning of the RF pulse.

80.0 GSa/s | 160 kpts | 32.95 GHz | T -60 mV

1: 1.00 V/ | -60 mV
f1: 1.00 V/ | -60.0 mV
f3: 500 MHz/ | 15.0 GHz
f5: 1.00 V/ | -60.0 mV

H: 150 ns/ | 500.03049 ns

f4: 10.0 dB/ | -18.0 dBm
f6: 10.0 dB/ | -18.0 dBm

Start 12.5 GHz Stop 17.5 GHz CF 15.0 GHz Span 5.00 GHz RBW 1.00 MHz Preset ☑ Mark Peaks

Measurement	Current	Mean
❶ + width(f1)	1.05753965 µs	1.05753965
❷ Rise time(f1)	26.00129 ns	26.00129 ns
❸ Frequency(1)	14.910981 GHz	15.014738 G

X1 2.469512 ns
X2 1.07076220 µs
ΔX 1.06829269 µs
1/ΔX 936.07305 kHz
Y1 14.0339 GHz
Y2 15.9746 GHz
ΔY 1.94070 GHz

Label	Horizontal	Vertical	Popup Content
● Peak0	14.0 GHz	15.552 dBm	

Figure 14. View of time gated FFT and display with time gate at the beginning of the RF pulse.

Then, by dragging the time gate to various points along the RF pulse, the frequency of the RF pulse at those time points can be observed in the time gated FFT display. The result of the gate placed at the end of the pulse can be seen in Figure 15.

Start 12.5 GHz Stop 17.5 GHz CF 15.0 GHz Span 5.00 GHz RBW 1.00 MHz Preset ☑ Mark Peaks

Results

Measurement	Current	Mean
+ width(f1)	1.05753965 µs	1.05753965
Rise time(f1)	26.00129 ns	26.00129 ns
Frequency(1)	14.910981 GHz	15.014738 G

Markers

X1	2.469510 ns	Y1	12.0000 V
X2	1.07076220 µs	Y2	12.0000 V
ΔX	1.06829269 µs	ΔY	0.0 V
1/ΔX	936.07305 kHz		

Bookmarks

Label	Horizontal	Vertical	Popup Content
Peak0	15.95 Gs	10.198 dBm	

Figure 15. View of time gated FFT and display with time gate at the end of the RF pulse.

A similar set of measurement was made with the 8 GHz bandwidth S-Series Infiniium scope, with a similar signal but where the carrier frequency is at 2 GHz. This set of measurements is shown in Figure 16.

Start 0.0 Hz Stop 10.0 GHz CF 5.00 GHz Span 10.0 GHz RBW 750 kHz ☑ Mark Peaks -40.000 dBm

Results

Measurement	Current	Mean
Frequency(1)	1.8553980 GHz	2.1491391 G
+ width(f1)	1.04091286 µs	1.04107472
Rise time(f1)	31.67823 ns	32.0832149

Markers

X1	9.707631 ns	Y2	3.01494 GHz
X2	1.06271965 µs	ΔY	1.95238 GHz
ΔX	1.05301201 µs		
1/ΔX	949.65677 kHz		
Y1	1.06256 GHz		

Bookmarks

Label	Horizontal	Vertical	Popup Content
Peak0	1.03 GHz	-10.832 dBm	

Figure 16. Time domain measurements and FFT on 4 GHz carrier, 2 GHz wide linear FM chirped RF pulse with S-Series oscilloscope.

The Role of Oscilloscope Segmented Memory to Achieve Long Target Time Capture in Pulsed RF Applications

So far, measurements have been taken on a single RF pulse from a pulse train. By extending the memory depth of the capture, multiple pulses can be captured and analyzed. At the full 80 Gsa/sec sample rate, using the full 2 Gsample memory depth, that corresponds to 25 msec of capture time:

(2 Gsa) / (80 Gsa/sec) = 25 msec

Given that this pulse train has a pulse repetition interval of 100 usec (a pulse repetition rate [PRI] of 10 kHz), that means that a capture would include around 250 pulses:

(25 msec) / (100 usec / pulse) = 250 pulses

By using an oscilloscope feature called segmented memory, the number of pulses captured can be increased dramatically. With segmented memory mode, the 2 Gsamples of memory depth can be broken up into smaller segments, where each segment gets filled with captured trace after a trigger condition is met. In this case, the trigger event is still the beginning of the RF pulse, and segments can be defined to be a little longer than the longest pulse captured. A 1.2 usec wide segment size can be used to capture the 1 usec wide pulses.

The segmented memory capture can be set up with 1.2 usec side segments where the memory depth was chosen to be 96 kpoints, and 32,768 segments as shown in Figure 17.

Acquisition

Sampling Mode
○ Real Time
○ Equivalent Time
● Segmented
○ Roll Mode

Sin(x)/x Interpolation
Auto

Segmented Memory
# of Segments
32768

Sampling Rate
○ Automatic ● Manual
80.0 GSa/s

Samples/Segment
○ Automatic ● Manual
96.000 kpts

Acquisition Mode
● Normal
○ Peak Detect
○ High Resolution
Automatic

Anti Alias Filter Bandwidth
● Automatic ○ High ○ Low

Display Status
☐ Enabled

Figure 17. Segmented memory setup to choose 1.2 usec wide segments for 1 usec wide pulse capture.

The calculation for the required segment memory depth is very simple, knowing the sample rate is 80 Gsa/sec, and that a 1.2 usec segment length is desired:

(80 Gsa/sec) x (1.2 usec) = 96,000 samples

With this choice, up to 32k segments can be selected. Now, by pressing the “Single” capture button, 32k pulses are captured and brought into 32k segments, which corresponds to 3.3 seconds of target activity time. This is not gapless capture, but it is capture that has focused on capturing RF pulses, and ignoring the time when no signal is present. This is in contrast to Real Time Sampling Mode that had 25 msec of gapless capture of 250 RF pulses.

The segmented capture can be seen in Figure 18. Notice, there is a “Play” button that allows a playback of the 32k segments. Notice also that statistics are calculated on the 32k pulses that were captured.

80.0 GSa/s | 96.0 kpts | 32.95 GHz | 32768 | T -60 mV

1 1.00 V/ -60 mV | f1 1.00 V/ -60.0 mV | f3 500 MHz/ 15.0 GHz

H 200 ns/ 500.03049 ns | 32768 of 32768 3.27670001 s | 100 ms | Segmented

f4 10.0 dB/ -18.0 dBm | f6 10.0 dB/ -18.0 dBm

Start 12.5 GHz Stop 17.5 GHz CF 15.0 GHz Span 5.00 GHz RBW 1.25 MHz Preset ☑ Mark Peaks

Measurement	Current	Mean
❶ + width(f1)	1.05733959 µs	1.05733959
❷ Rise time(f1)	26.63662 ns	26.63662 ns
❸ Frequency(1)	14.929664 GHz	15.015148 G

X1 2.469510 ns
X2 1.07076220 µs
ΔX 1.06829269 µs
1/ΔX 936.07305 kHz
Y1 12.0000 V
Y2 12.0000 V
ΔY 0.0 V

Label	Horizontal	Vertical	Popup Content
● Peak0	15.9 GHz	9.633 dBm	

Figure 18. V-Series segmented memory capture of 32k pulses into 32k segments, 1.2 usec per segment.

Similar measurements can be made with the S-Series scopes, with up to 8 GHz of bandwidth, 20 Gsa/sec sampling rate (on up to two channels, 4 GHz bandwidth and 10 Gsa/sec on 4 channels), and 800 Msamples of memory depth in “Single” capture that can be spread across multiple memory segments.

The Z-Series Infiniium oscilloscopes have up to 63 GHz of bandwidth on 4 channels, 160 Gsa/sec sampling rate on 4 channels, and 2 Gsamples of memory depth per channel.

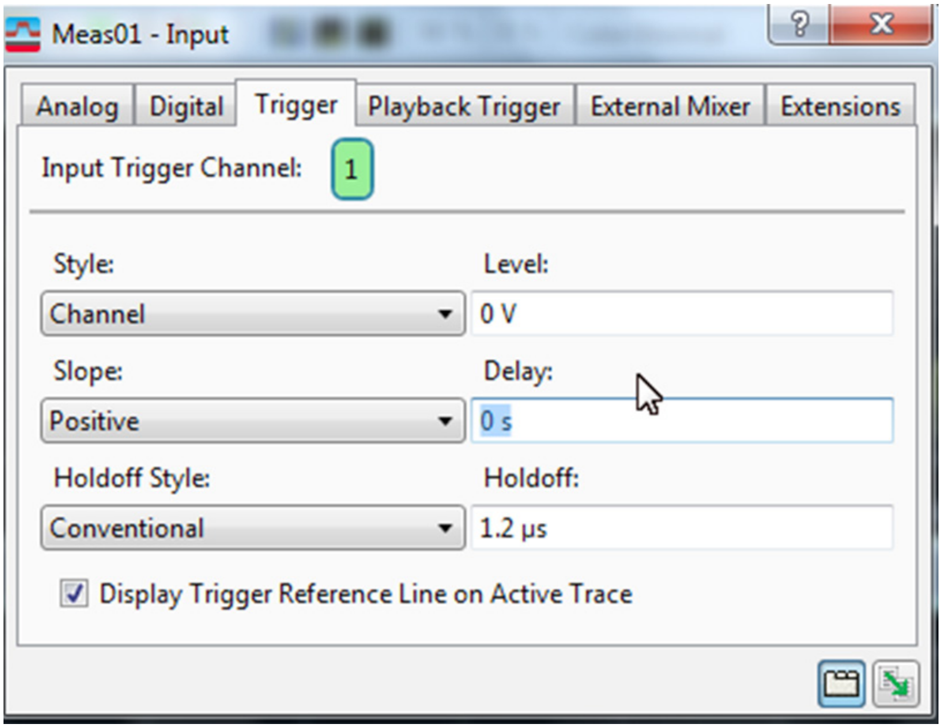
Wideband Pulsed RF Time and Frequency Domain Measurements with a Scope Plus VSA Software

RF and FFT measurements with Infiniium oscilloscopes can be further enhanced through the use of the 89600 Vector Signal Analysis (VSA) software. Some advantage of using the VSA software include:

- Host of built in RF measurements
- Ability to band pass filter scope input samples and decimate prior to FFT calculation to reduce noise and speed FFT calculation
- Variety of digital and analog demodulation options

The Keysight Connection Manager is used to establish a connection between the oscilloscope and the 89600 VSA software so that VSA can control the oscilloscope for the measurement.

From within the VSA software some requirements for setup include setting the center frequency to the 4 GHz carrier of the input signal, as well as setting a span a little wider than that of the modulation of the signal. A trigger also needs to be set to act upon the input signal with the right voltage threshold level and with a trigger holdoff a little wider than the input signal's pulse width as shown in Figure 19.



Input Trigger Channel: 1

Style: Channel

Level: 0 V

Slope: Positive

Delay: 0 s

Holdoff Style: Conventional

Holdoff: 1.2 µs

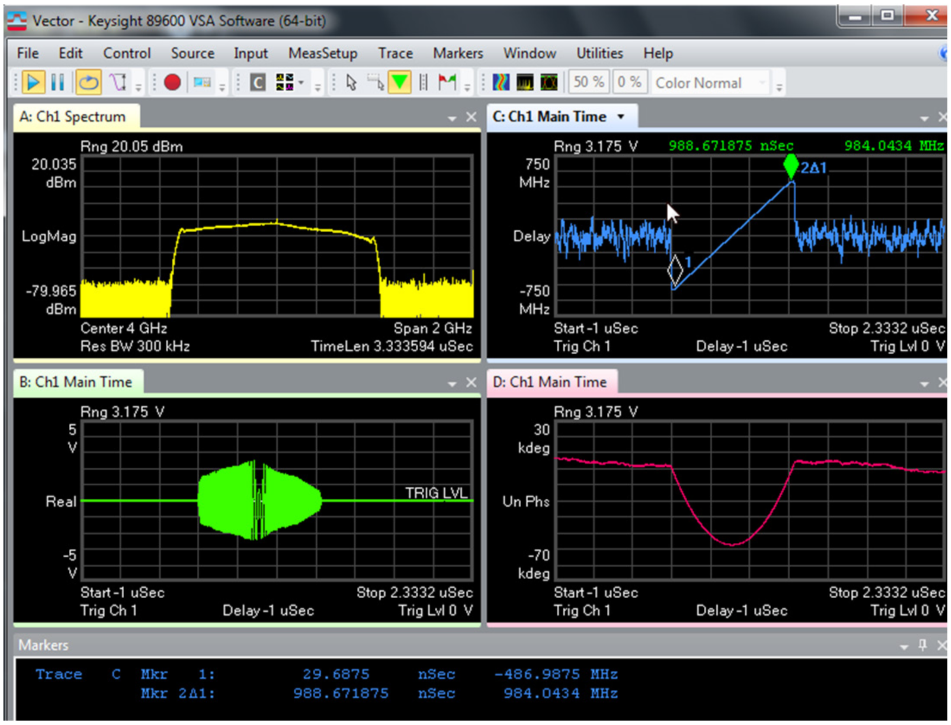
☑ Display Trigger Reference Line on Active Trace

Figure 19. Set trigger source to "Channel 1", and a 1.2 us trigger hold off.

The Range setting, which selects the oscilloscope volt/div sensitivity, also has to be adjusted so that the input signal is a little smaller than the full scale range of the oscilloscope. Rectangular FFT windowing is selected since the goal is to get a single RF pulse on screen, and a rectangular window can completely contain the pulse without adding any distortion through filtering. VSA software allows the choice of multiple windows, and a 2x2 window format is convenient to display

- An FFT spectral view
- Time domain baseband view of pulse
- The frequency shift across the pulse
- The phase shift across the pulse

as shown in Figure 20.



```
Trace   C  Mkr   1:       29.6875    nSec   -486.9875 MHz
           Mkr  2Δ1:     988.671875  nSec    984.0434 MHz
```

Figure 20. VSA FFT, pulse, frequency chirp, and phase change across the pulse.

For the FFT spectral view in the upper left hand window, “Ch1 Spectrum” is selected, “Ch1 Main Time” and “Real” scaling to view the pulse in the lower left window. To view the frequency change across the pulse, “Ch1 Main Time” is again chosen, but the vertical units setting is changed from LogMag to “Group Delay” as seen in the upper right hand window. This is a trick to take a calculation that normally takes the derivative of time and in this case takes the derivative of phase which is frequency. In effect, it is performing an FM demodulation to see the frequency chirp across the pulse. The VSA FM demodulator could also have been used to see the change of frequency across the pulse. To view the phase shift across the pulse “Unwrapped Phase” is chosen as the vertical scale as seen in the lower right hand window.

Markers can be placed on waveforms to make a variety of measurements such as delta frequency across the linear frequency chirp, or the delta phase from the start of the RF pulse to the center.

Increase in Pulsed RF Capture Dynamic Range Through Limiting the Analysis Bandwidth Via VSA

Another advantage using the 89600 VSA software in conjunction with an oscilloscope is that it can extend the measurement signal to noise ratio. VSA software has the capability to band pass filter the acquired oscilloscope data and resample the data at a lower sample rate resulting in lower noise, higher dynamic range, and a wider signal to noise ratio. In the following example, the S-Series oscilloscope captures a pulse train where a large pulse is immediately followed by a small pulse that is 50 dB down from the first pulse, which corresponds to being 100,000 times lower in power and ~316 times smaller in voltage (sqrt [100,000]) than the first pulse. The two-pulse sequence then repeats.

The large pulse had a +6 dBm power level (~1.4 mW) which results in a peak voltage of around 633 mV into 50 Ω. This can be represented as a –4 dBVpk level (20log 0.633). It also corresponds to a 1266 mV peak to peak signal into 50 Ω.

In contrast, the small pulse, being 316 times smaller in voltage, is only 4 mV peak to peak (–44 dBm, –54 dBVpk)

The VSA Range is set to +6 dBm (633 mV peak), which corresponds to an oscilloscope vertical range of 1266 mV. There are 8 vertical divisions, so this corresponds to a ~160 mV/div setting.

At the full 8 GHz bandwidth for this ~160 mV/div setting, the broadband rms noise for the S-Series is around 5 mV, interpolating from a noise chart in the data sheet, shown in Table 2. The 5 mV of noise roughly translates into a peak to peak noise that is 3x the rms noise (assuming Gaussian noise). So there is around 15 mV of p-p noise.

Table 2. S-Series oscilloscope RMS noise levels at various V/div settings.

	RMS noise floor (Vrms ac)						
Vertical setting (Volts/div)	**S-054A**	**S-104A**	**S-204A**	**S-254A**	**S-404A**	**S-604A**	**S-804A**
1 mV/div	74 µV	90 µV	120 µV	130 µV	153 µV	195 µV	260 µV
2 mV/div	74 µV	90 µV	120 µV	130 µV	153 µV	195 µV	260 µV
5 mV/div	77 µV	94 µV	129 µV	135 µV	173 µV	205 µV	320 µV
10 mV/div	87 µV	110 µV	163 µV	172 µV	220 µV	256 µV	390 µV
20 mV/div	125 µV	163 µV	233 µV	254 µV	330 µV	446 µV	620 µV
50 mV/div	372 µV	456 µV	610 µV	650 µV	768 µV	1.3 µV	1.4 µV
100 mV/div	0.78 mV	0.96 mV	1.2 mV	1.3 mV	1.6 mV	2.3 mV	3.1 mV
200 mV/div	1.6 mV	2.0 mV	2.6 mV	2.8 mV	3.4 mV	4.9 mV	6.4 mV
500 mV/div	3.5 mV	4.2 mV	5.5 mV	6 mV	7.3 mV	10.0 mV	13.3 mV
1 V/div	5.1 mV	6.8 mV	9.2 mV	10.1 mV	12.5 mV	17.6 mV	24.1 mV

So the small pulse (4 mV p-p) is masked by the noise in the measurement (15 mV p-p), and cannot be well discerned in the full 8 GHz measurement of the oscilloscope, with a linear scale and no averaging, as shown in Figure 21.

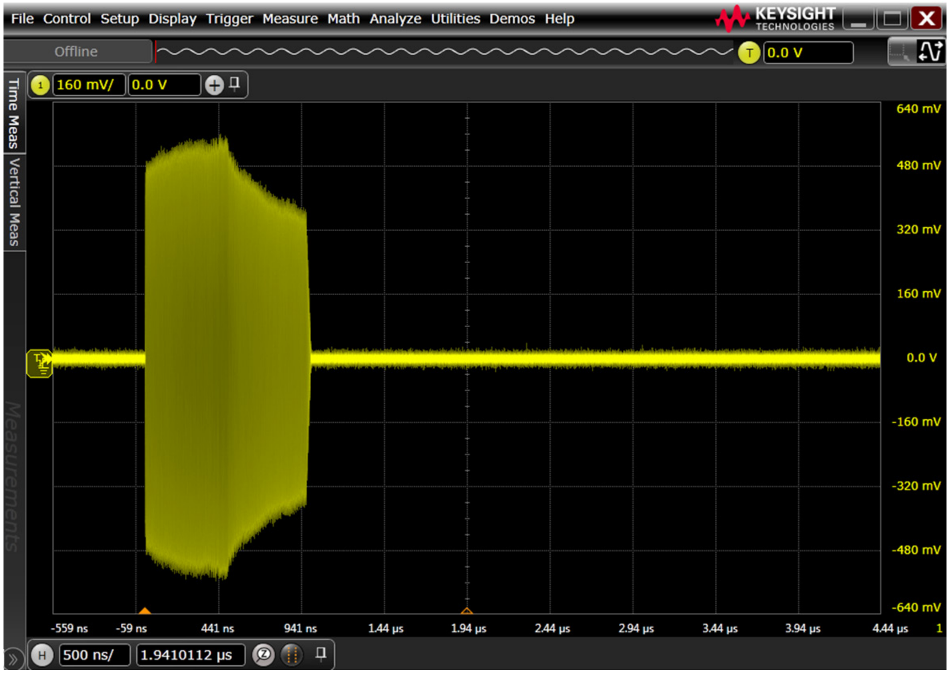


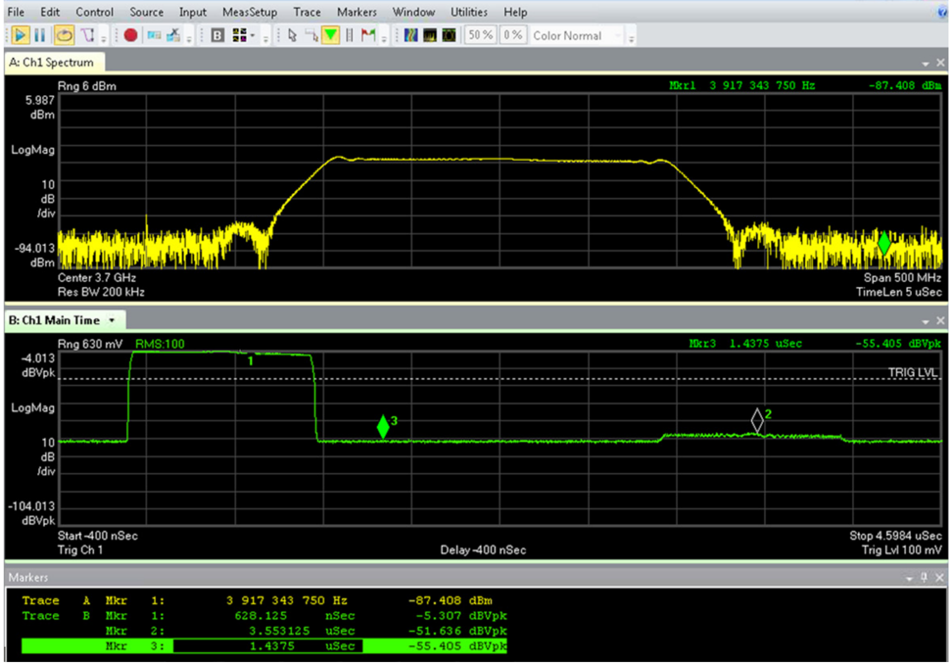
Figure 21. S-Series capture of +6 dBm pulse next to a 50 dB down pulse (2nd pulse cannot be seen).

If the oscilloscope captured data is imported to the 89600 Vector Signal Analysis (VSA) software, it can be digitally down converted into I and Q baseband data, bandpass filtered, and then resampled. This process can greatly decrease the amount of noise in the measurement. Essentially, the process is “tuning” to the center frequency of the signal, and “zooming” into the signal to analyze the modulation. This is also referred to “processing gain”.

In this example, the original 8 GHz wide measurement with the associated noise is reduced to a 500 MHz wide measurement, centered on the 3.7 GHz carrier with an instantaneous measurement bandwidth slightly wider than the width of the signal modulation. This corresponds to an improvement in signal to noise ratio of 10log*(ScopeBW/Span) = 10log*(8E+09/500E+6) = 12 dB

SNR is improved by 10log*(ScopeBW/Span)

Taking advantage of this processing gain, combined with VSA's ability to have a log magnitude scale, and using averaging, the 50 dB down pulse is now visible as shown in Figure 22.



```
Trace   A  Mkr   1:      3 917 343 750 Hz      -87.408 dBm
Trace   B  Mkr   1:       628.125     nSec      -5.307 dBVpk
           Mkr   2:         3.553125  uSec     -51.636 dBVpk
           Mkr   3:         1.4375    uSec     -55.405 dBVpk
```

Figure 22. 50 dB down pulse seen with 89600 VSA software "Center Frequency" and "Span" set.

The improvement in signal to noise ratio realized through narrowing down the span is depicted graphically in Figure 23.

This is an example graph excepted SNR for the scope 0 dBm sensitivity range.

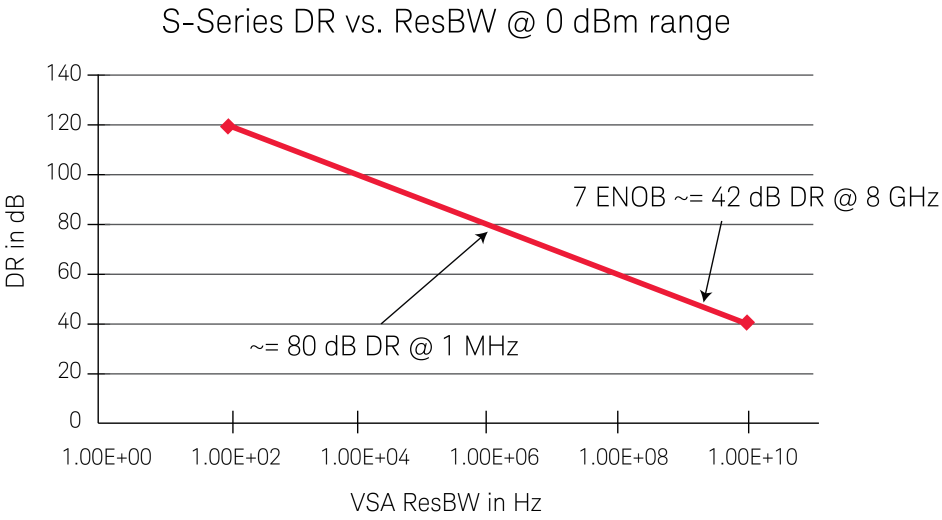


Figure 23. Plot of SNR achievable in time view verses span adjustment in VSA software.

A similar plot can be drawn to see improvement in dynamic range possible when measuring narrow band signals as shown in Figure 24.

This is an example graph excepted Dynamic Range for the scope 0 dBm sensitivity range (narrow signal).

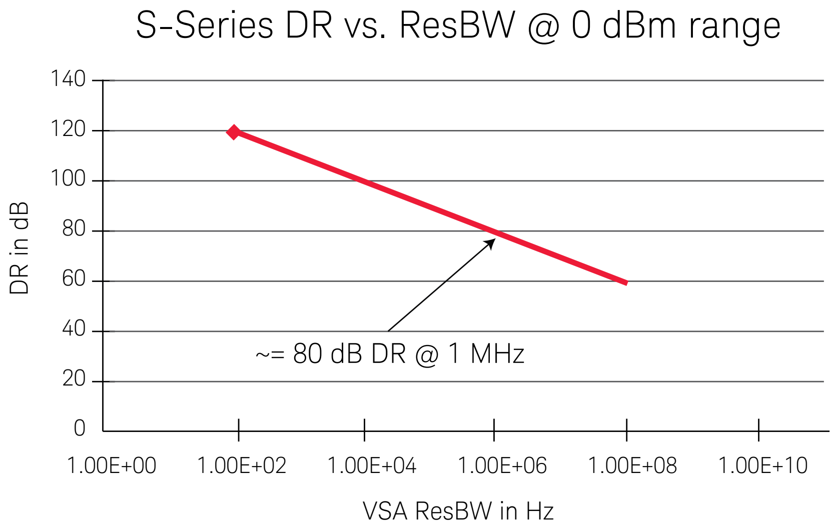


Figure 24. Plot of dynamic range in FFT vs. resolution BW setting in the vector signal analyzer software.

Here the dynamic range improvement when measuring narrowband signals in an FFT view is described as:

10log*(ScopeBW/RBW)

This does not describe the spur free dynamic range (SFDR) or harmonic distortion characteristics of the oscilloscope response, but it does give an idea of where the noise floor will be in an FFT measurement. As the resolution bandwidth is made more fine, and the noise present is divided among smaller time buckets, the noise floor drops.

This graph is not accounting for limitations due to various spurs, so the spur free dynamic range (SFDR) remains limited to around 50 dB.

Use of Oscilloscope Segmented Memory Together with VSA Pulse Option BHQ for Long Target Time Capture and Statistical Pulse Analysis

When an oscilloscope is used to sample a wideband RF signal, it must sample at a fast enough rate to accurately capture the carrier plus modulation. This means that often a very fast sample rate is required, which also means in a normal real time sampling mode, the oscilloscope memory will not allow for a very long capture period.

For example, to capture a signal with a 20 GHz carrier and 2 GHz wide modulation, an oscilloscope is needed that still has a flat response out to 21 GHz. A 25 GHz or 33 GHz model V-Series Infiniium oscilloscope, with up to 80 Gsa/sec sample rate, has the required performance. A good rule of thumb is that an oscilloscope should sample at a rate at least 2.5x the highest frequency content of interest in a signal being measured. That would correspond to around a 50 GHz sampling rate in this example (2.5 * 21 GHz).

In a measurement with the 33 GHz, 80 Gsa/sec V-Series model, even a full 2 Gsamples of memory depth only yields 25 msec of target capture time:

Target capture time = 2 Gsa * (1/80 Gsa/sec)= 1/40th sec = 25 msec

A method that can greatly increase the target activity time when there is a low duty cycle signal, like a common pulsed RF radar signal, is to use an oscilloscope feature called Segmented Memory. Here, the scope memory is divided into smaller segments, of fixed time width. The width of segments should be chosen to be a little wider than the widest RF pulse. The scope triggers on an event, such as the beginning of the RF pulse, and then places one RF pulse in a segment of memory. The scope then stops capturing data, rearms the trigger, and waits for the next RF pulse to occur. A second RF pulse is put into the 2nd segment of memory. This process continues until all the scope memory segments are used.

The 89600 VSA software's pulse analysis option BHQ can allow the user to takes advantage of the oscilloscope segmented memory. It allows the definition of segments, and also has many built in pulse measurements for pulsed RF signals. A capture of many RF pulses, through the use of segmented memory in the oscilloscope, combined with pulse parameter measurements built into the BHQ option, is shown in Figure 25.

Pulses = 10

Avg Power = 3.0512

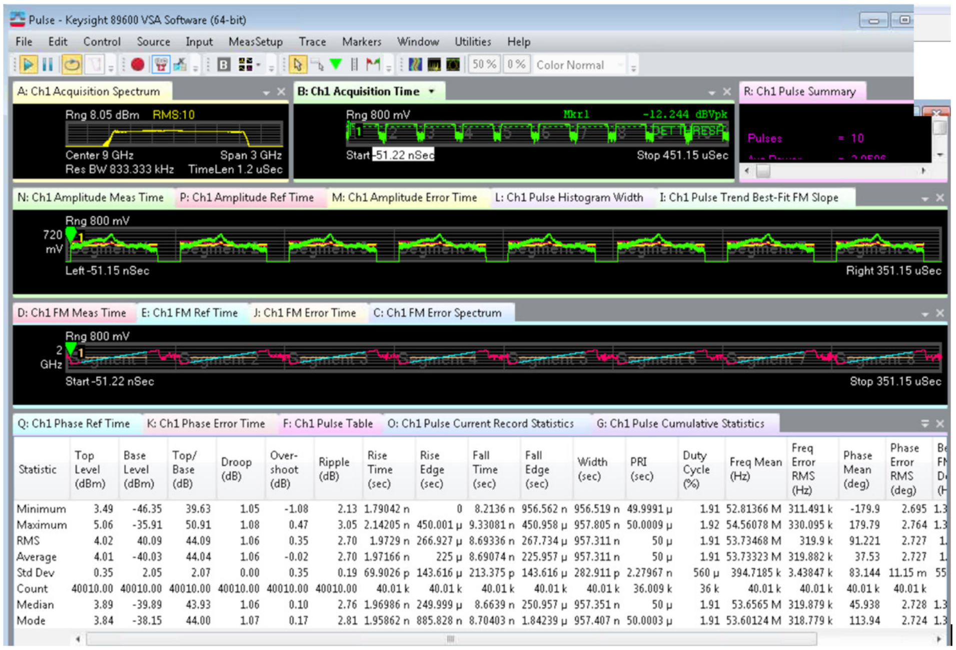
Pulse	Seg-ment	Modulation	ipple dB)	Rise Time (sec)	Rise Edge (sec)	Fall Time (sec)	Fall Edge (sec)	Width (sec)	PRI (sec)	Duty Cycle (%)	Freq Mean (Hz)	Freq Error RMS (Hz)	Phase Mean (deg)	Phase Error RMS (deg)	Best-Fit FM Pk-Pk Dev (Hz)	Best-Fit FM Slope (Hz/µs)	Best-Fit FM INL (%)
1	1	LinFM	2.81	1.85477 n	0	8.71872 n	956.983 n	956.983 n	49.9992 µ	1.91	54.04412 M	312.851 k	-104.02	2.718	1.367912 G	1.92315 G	0.080

Playback Measurement - recording bhq_rec_2GHz_wide_chirp_9GHz_carrier.sdf

Figure 25. 89600 VSA's pulse analysis option BHQ and pulse parameter measurements on oscilloscope segmented memory.

Notice the 2 GHz wide spectrum in the upper left hand side of the screen, a dB volt peak view of pulses in each scope segment at the top of the screen, and then a view of pulses in the middle of the screen with a linear voltage scale, comparing expected (red trace) to actual (green) and the delta (yellow), and finally a trace at the bottom of the screen showing the linear FM chirp in each scope memory segment, expected (blue) vs. measured (red) and the delta (yellow). It can be seen that the linear FM chirp is following an expected linear ramp very closely.

A full set of statistics is also possible by clicking on the "Ch1 Pulse Cumulative Statistics" tab and expanding the measurements window as shown in Figure 26.



Pulses = 10

Statistic	Top Level (dBm)	Base Level (dBm)	Top/ Base (dB)	Droop (dB)	Over-shoot (dB)	Ripple (dB)	Rise Time (sec)	Rise Edge (sec)	Fall Time (sec)	Fall Edge (sec)	Width (sec)	PRI (sec)	Duty Cycle (%)	Freq Mean (Hz)	Freq Error RMS (Hz)	Phase Mean (deg)	Phase Error RMS (deg)
Minimum	3.49	-46.35	39.63	1.05	-1.08	2.13	1.79042 n	0	8.2136 n	956.562 n	956.519 n	49.9991 µ	1.91	52.81366 M	311.491 k	-179.9	2.695
Maximum	5.06	-35.91	50.91	1.08	0.47	3.05	2.14205 n	450.001 µ	9.33081 n	450.958 µ	957.805 n	50.0009 µ	1.92	54.56078 M	330.095 k	179.79	2.764
RMS	4.02	40.09	44.09	1.06	0.35	2.70	1.9729 n	266.927 µ	8.69336 n	267.734 µ	957.311 n	50 µ	1.91	53.73468 M	319.9 k	91.221	2.727
Average	4.01	-40.03	44.04	1.06	-0.02	2.70	1.97166 n	225 µ	8.69074 n	225.957 µ	957.311 n	50 µ	1.91	53.73323 M	319.882 k	37.53	2.727
Std Dev	0.35	2.05	2.07	0.00	0.35	0.19	69.9026 p	143.616 µ	213.375 p	143.616 µ	282.911 p	2.27967 n	560 µ	394.7185 k	3.43847 k	83.144	11.15 m
Count	40010.00	40010.00	40010.00	40010.00	40010.00	40010.00	40.01 k	40.01 k	40.01 k	40.01 k	40.01 k	36.009 k	36 k	40.01 k	40.01 k	40.01 k	40.01 k
Median	3.89	-39.89	43.93	1.06	0.10	2.76	1.96986 n	249.999 µ	8.6639 n	250.957 µ	957.351 n	50 µ	1.91	53.6565 M	319.879 k	45.938	2.728
Mode	3.84	-38.15	44.00	1.07	0.17	2.81	1.95862 n	885.828 n	8.70403 n	1.84239 µ	957.407 n	50.0003 µ	1.91	53.60124 M	318.779 k	113.94	2.724

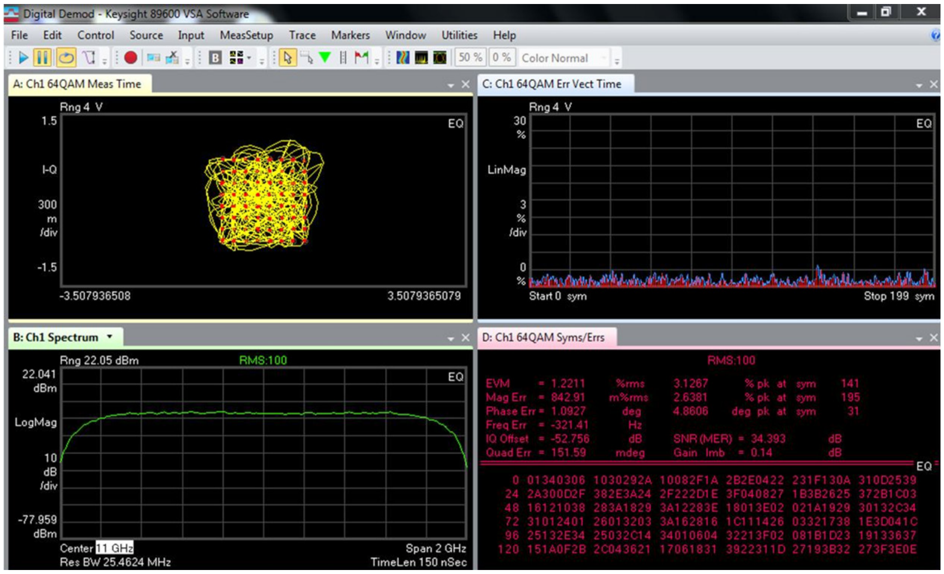
Figure 26. Statistical analysis with the pulse option BHQ in 89600 VSA software.

Wideband Communications Measurement with an Infiniium Oscilloscope and VSA

Communications signals are also getting wider in modulation bandwidth and/or incorporating multi-channel architectures like MIMO. This in turn is driving the use of oscilloscopes or wideband digitizers as front-end receivers, coupled with the 89600 VSA software for modulation analysis.

Take, for example, the 64QAM communications signal shown in Figure 27, with an 11 GHz carrier IF and 2 GHz wide modulation bandwidth, measured with the V-Series 33 GHz oscilloscope. The carrier plus modulation is captured and sampled by the 80 Gsa/sec oscilloscope front-end and ADC, and then the 89600 VSA application imports the samples, and performs a digital down conversion to baseband I and Q. This includes digital low pass filtering to a desired span, and digital down-sampling to significantly reduce the data set for FFT processing.

The VSA software can then perform analysis such as drawing out a constellation diagram of the baseband I/Q signals and computing the error vector magnitude (EVM).



```
EVM        =  1.2211      %rms       3.1267        % pk  at  sym    141
Mag Err    =  842.91     m%rms       2.6381        % pk  at  sym    195
Phase Err  =  1.0927       deg       4.8606      deg pk  at  sym     31
Freq Err   =  -321.41       Hz
IQ Offset  =  -52.756       dB       SNR (MER)  =  34.393        dB
Quad Err   =  151.59      mdeg       Gain  Imb  =  0.14          dB

  0  01340306  1030292A  10082F1A  2B2E0422  231F130A  310D2539
 24  2A300D2F  382E3A24  2F222D1E  3F040827  1B3B2625  372B1C03
 48  16121038  283A1829  3A12283E  18013E02  021A1929  30132C34
 72  31012401  26013203  3A162816  1C111426  03321738  1E3D041C
 96  25132E34  25032C14  34010604  32213F02  081B1D23  19133637
120  151A0F2B  2C043621  17061831  3922311D  27193B32  273F3E0E
```

Figure 27. Wideband V-Series oscilloscope plus VSA measurement of 64QAM digital communications 5G IF 2 GHz wide signal.

Summary

The number of designs is increasing that have modulation bandwidths greater than the 1 GHz of instantaneous measurement bandwidth currently available in Vector Signal Analyzers. This is driving designers to use digitizers and oscilloscopes that offer enough bandwidth and sample rate to directly sample the carrier plus modulation. Math functions like envelope, measurement trend, and FFT have all proven very helpful to understand target system operation and issues. Combining an oscilloscope with 89600 VSA software formed a powerful RF measurement suite to perform a wide range of measurements, including demodulation, extended signal to noise ratio time domain views, and statistical RF pulse analysis. Although there is a tradeoff between dynamic range/SNR and the instantaneous bandwidth available, many helpful wideband measurements are possible to assist an engineer in evaluating a prototype or production unit.

Related Literature

Publication title	**Publication number**
Infiniium Z-Series Oscilloscopes - Data Sheet	5991-3868EN
Infiniium S-Series High-Definition Oscilloscopes - Data Sheet	5991-3904EN
Infiniium V-Series Oscilloscopes - Data Sheet	5992-0425EN

Appendix

Table 3. S-Series 8 GHz oscilloscope and typical RF characteristics.

	S-Series typical values (tested at 8 GHz bandwidth, 1 channel on one scope unless noted)
Sensitivity/noise density (1 mV/div; –38 dBm range)	
Power spectral density measurement at 1.0001 GHz, 1.0001 GHz center frequency, 500 kHz span, and 3 kHz RBW	–160 dBm/Hz
Noise figure	
Derived from measurement above	14 dB
Signal to noise ratio/dynamic range	
(0 dBm, 1 GHz input carrier, 0 dBm scope input range) 1 GHz center frequency, 100 MHz span, 1 kHz RBW, measurement at +20 MHz from center	108 dB
Absolute amplitude accuracy	
(0 to 7.5 GHz) 5 scopes, 4 channels, worst case	± 1 dB
Deviation from linear phase	
0 to 7.5 GHz	± 7 deg
Phase noise (@ 1 GHz)	
10 kHz offset	–121 dBc/Hz
100 kHz offset	–122 dBc/Hz
EVM	
802.121 2.4 GHz carrier, 20 MHz wide, 64 QAM	–47 dB (0.47%)
Spurious responses (0 dBm signal; 0 dBm input range) **Spur Free Dynamic Range (SFDR)**	
1 GHz, 0 dBm signal present at input, FFT =5 GHz span, 3 GHz center, 100 kHz RBW	72 dB
2nd harmonic distortion	
1 GHz input, 0 dBm, 5 GHz span, 3 GHz center, 100 kHz RBW	–64 dBc
3rd harmonic distortion	
1 GHz input, 0 dBm, 5 GHz span, 3 GHz center, 100 kHz RBW	–46 dBc
Two-Tone Third-Order Intermodulation distortion (TOI)	
0 dBm input tones, 2.435 GHz and 2.439 GHz, 2 MHz separation, 2.437 GHz center frequency, 10 MHz span, 100 kHz RBW, 6 dBM input range	+21.5 dB
Input match	
< 50 mV/div, 0 to 7 GHz	‘–15 dB; 1.4 VSWR
>= 50 mV/div, 0 to 7 GHz	‘–19 dB; 1.25 VSWR

Table 4. V-Series 8 GHz oscilloscope and typical RF characteristics.

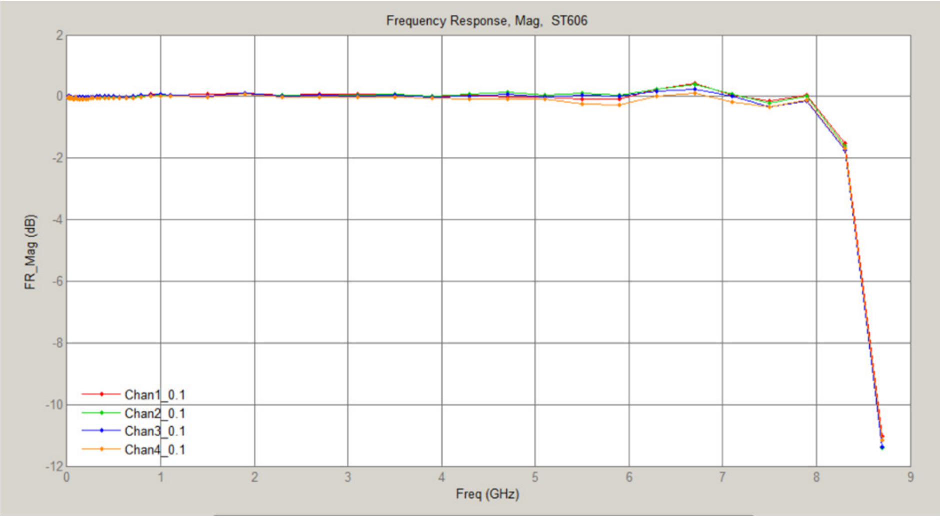
	V-Series typical values (tested at 33 GHz bandwidth, 1 channel on one scope unless noted)
Sensitivity/noise density (1 mV/div; –38 dBm range)	
Power spectral density measurement at 1.0001 GHz, 1.0001 GHz center frequency, 500 kHz span, and 3 kHz RBW	–159 dBm/Hz
Noise figure	
Derived from measurement above	+15 dB
Signal to noise ratio/dynamic range	
(–1 dBm, 1 GHz input carrier, 0 dBm scope input range) 1 GHz center frequency, 100 MHz span, 1 kHz RBW, measurement at +20 MHz from center	+111 dB
Absolute amplitude accuracy	
0 to 30 GHz	± 0.5 dB
Deviation from linear phase	
0 to 33 GHz	± 3 deg
Phase noise (@ 1 GHz)	
10 kHz offset	–125 dBc/Hz
100 kHz offset	–131 dBc/Hz
EVM	
802.121 2.4 GHz carrier, 20 MHz wide, 64 QAM	–47 dB (0.47%)
Spurious responses (–4.6 dBm input signal; –4 dBm input range) **Spur Free Dynamic Range (SFDR)**	
1 GHz, –4.6 dBm signal present at input, FFT =5 GHz span, 3 GHz center, 100 kHz RBW	+ 67 dB
2nd harmonic distortion	
1 GHz input, –4.6 dBm, 5 GHz span, 3 GHz center, 100 kHz RBW	–51 dBc
3rd harmonic distortion	
1 GHz input, –4.6 dBm, 5 GHz span, 3 GHz center, 100 kHz RBW	–51 dBc
Two-Tone Third-Order Intermodulation distortion (TOI)	
–6.6 dBm input tones, 2.435 GHz and 2.439 GHz, 2 MHz separation, 2.437 GHz center frequency, 10 MHz span, 100 kHz RBW, 8 dBm range	+28 dB
Input match (S_{11})	
< 50 mV/div, 0 to 30 GHz, no attenuation	‘–15 dB; 1.4 VSWR
>= 50 mV/div, 0 to 30 GHz, no attenuation	‘–21 dB; 1.2 VSWR

Typical frequency domain characteristics for the Infiniium V-Series (not guaranteed, subject to change).

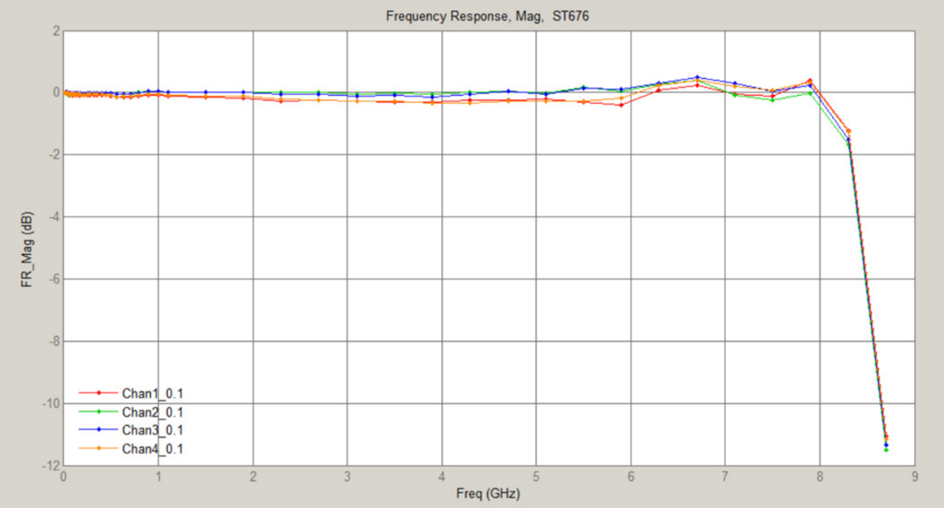
Table 5. Z-Series 63 GHz oscilloscope and typical RF characteristics.

	Z-Series typical values (tested at 33 GHz bandwidth on 33 GHz channel, 1 channel on one scope unless noted)
Sensitivity/noise density (1 mV/div; –38 dBm range)	
Power spectral density measurement at 1.0001 GHz, 1.0001 GHz center frequency, 500 kHz span, and 3 kHz RBW	–160 dBm/Hz
Noise figure	
Derived from measurement above	14 dB
Signal to noise ratio/dynamic range	
(0 dBm, 1 GHz input carrier, 0 dBm scope input range) 1 GHz center frequency, 100 MHz span, 1 kHz RBW, measurement at +13 MHz from center	112 dB
Absolute amplitude accuracy	
0 to 30 GHz	± 0.5 dB
Deviation from linear phase	
0 to 33 GHz	± 2 deg
Phase noise (@ 1 GHz)	
10 kHz offset	–122 dBc/Hz
100 kHz offset	–126 dBc/Hz
EVM	
802.11 2.4 GHz carrier, 20 MHz wide, 64 QAM	–49 dB (0.37%)
Spurious responses (–4.6 dBm input signal; –4 dBm input range) **Spur Free Dynamic Range (SFDR)**	
1 GHz, –4.6 dBm signal present at input, FFT =5 GHz span, 3 GHz center, 100 kHz RBW	73 dB
2nd harmonic distortion	
1 GHz input, –4.6 dBm, 5 GHz span, 3 GHz center, 100 kHz RBW	–60 dBc
3rd harmonic distortion	
1 GHz input, –4.6 dBm, 5 GHz span, 3 GHz center, 100 kHz RBW	–54 dBc
Two-Tone Third-Order Intermodulation distortion (TOI)	
–6.6 dBm input tones, 2.435 GHz and 2.439 GHz, 2 MHz separation, 2.437 GHz center frequency, 10 MHz span, 100 kHz RBW	+26 dB
Input match (S_{11})	
< 50 mV/div, 0 to 30 GHz	‘–15 dB; 1.4 VSWR
>= 50 mV/div, 0 to 30 GHz	‘–21 dB; 1.2 VSWR

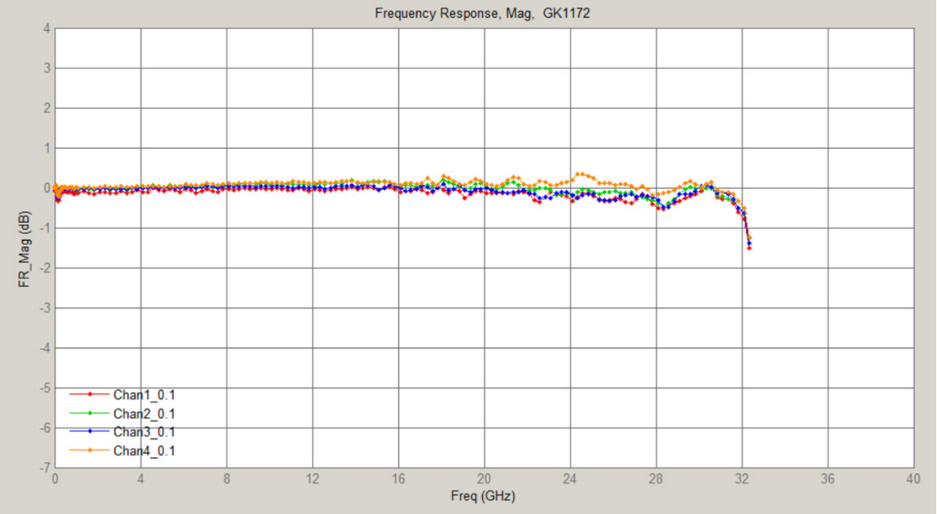
Typical frequency domain characteristics for the Infiniium Z-Series (not guaranteed, subject to change).



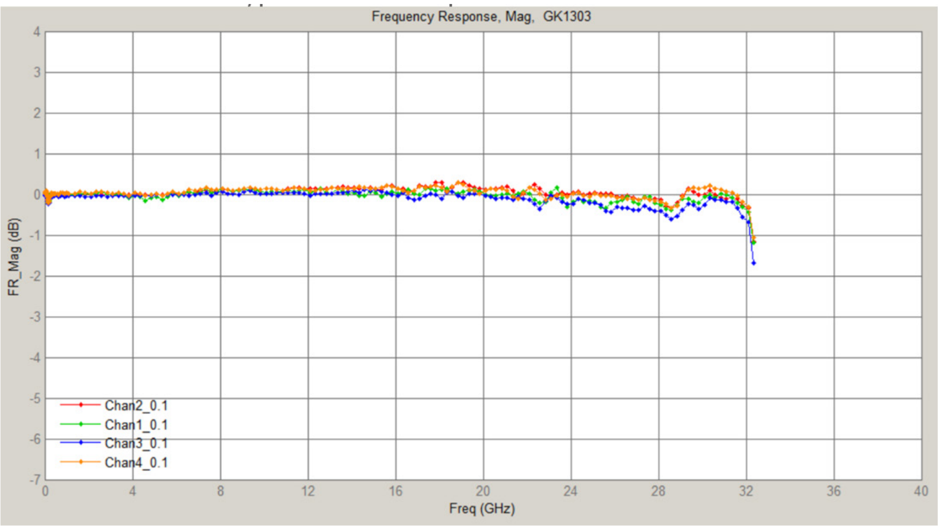
Graph 1. S-Series magnitude linearity typical RF performance (oscilloscope 1).



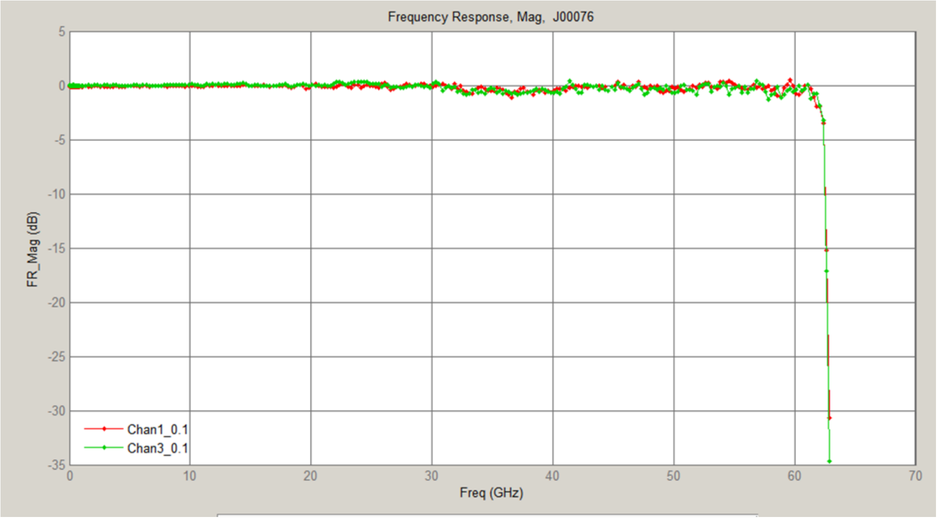
Graph 2. S-Series magnitude linearity typical RF performance (oscilloscope 2).



Graph 3. V-Series magnitude linearity typical RF performance (oscilloscope 1).



Graph 4. V-Series magnitude linearity typical RF performance (oscilloscope 2).



Graph 5. Z-Series magnitude linearity typical RF performance.

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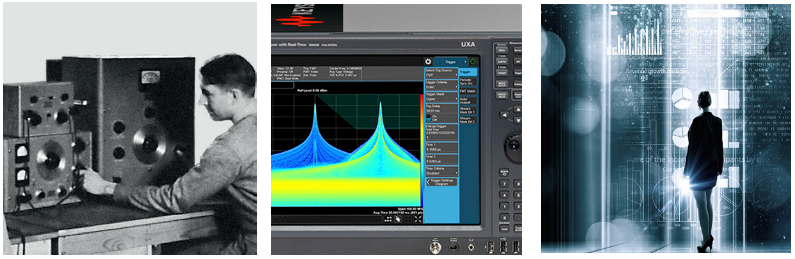

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