

Advanced RF Measurements You Didn't Know Your Oscilloscope Could Make

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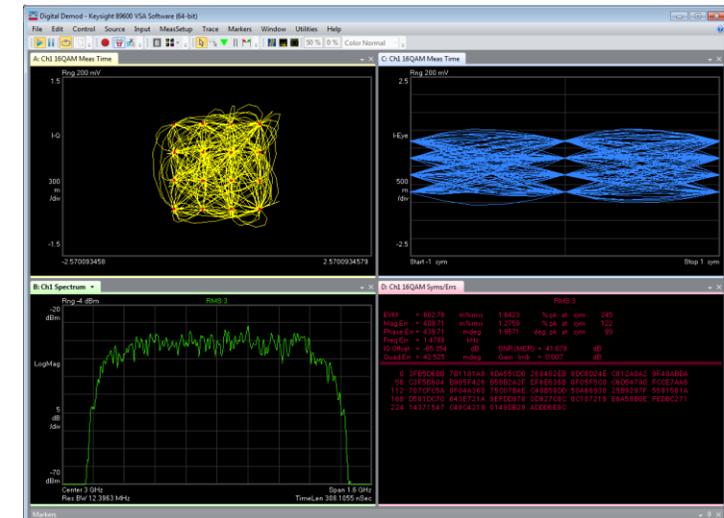
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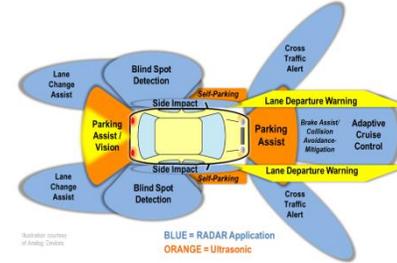
Agenda

- RF measurement challenges
- Oscilloscope platform overview
 - Typical “RF” characteristics
 - Bandwidth vs. frequency range
- Infiniium scope measurements
 - Radar “chirp”
 - Gated FFT
- Infiniium scopes plus 89600 VSA measurements
 - Radar “chirp”, MIMO cellular, Wideband Comms and more!

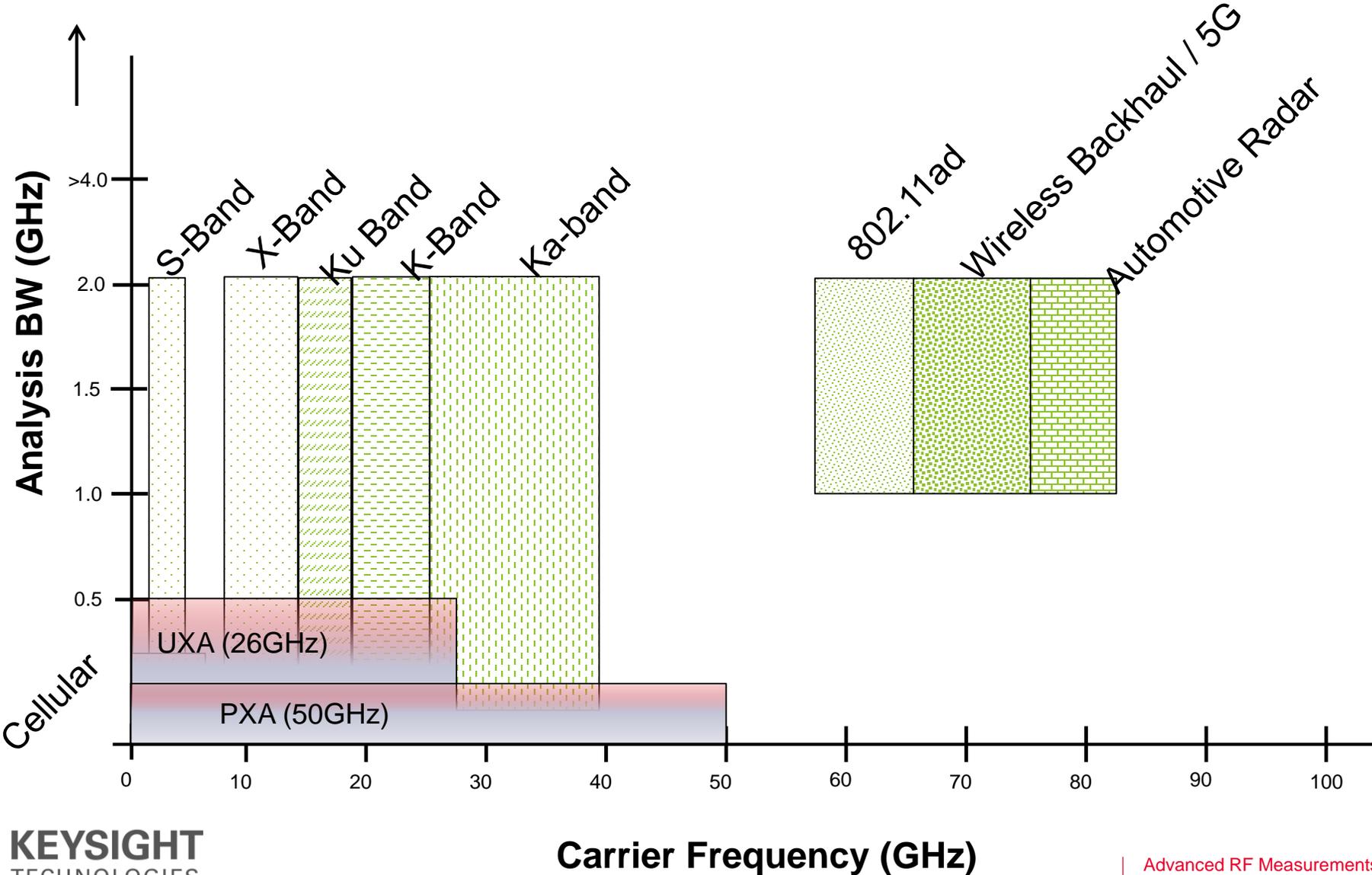


RF challenges for designers

- More RF designs now have modulation bandwidths wider than 510 MHz
- Seeing in radar/EW as well as communications systems
- Cannot use signal/spectrum analyzers for >510 MHz bandwidth signals
- Also seeing applications where have more than one signal (phased array antenna, MIMO)
- Designers needing good, wideband, multi-channel RF receivers for measurement front end

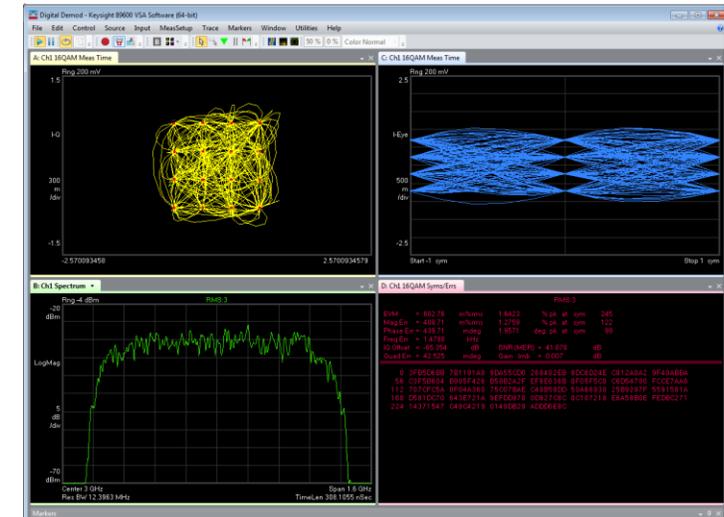


Wideband Applications that only Oscilloscopes Can Address



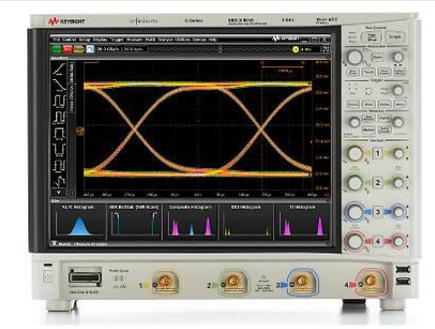
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Infiniium Oscilloscope Platform Overview

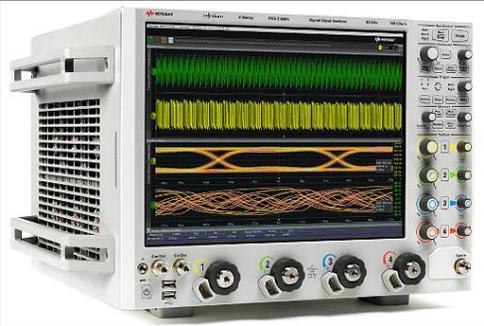
10 Bit ADC



S-Series



V-Series



Z-Series

500 MHz

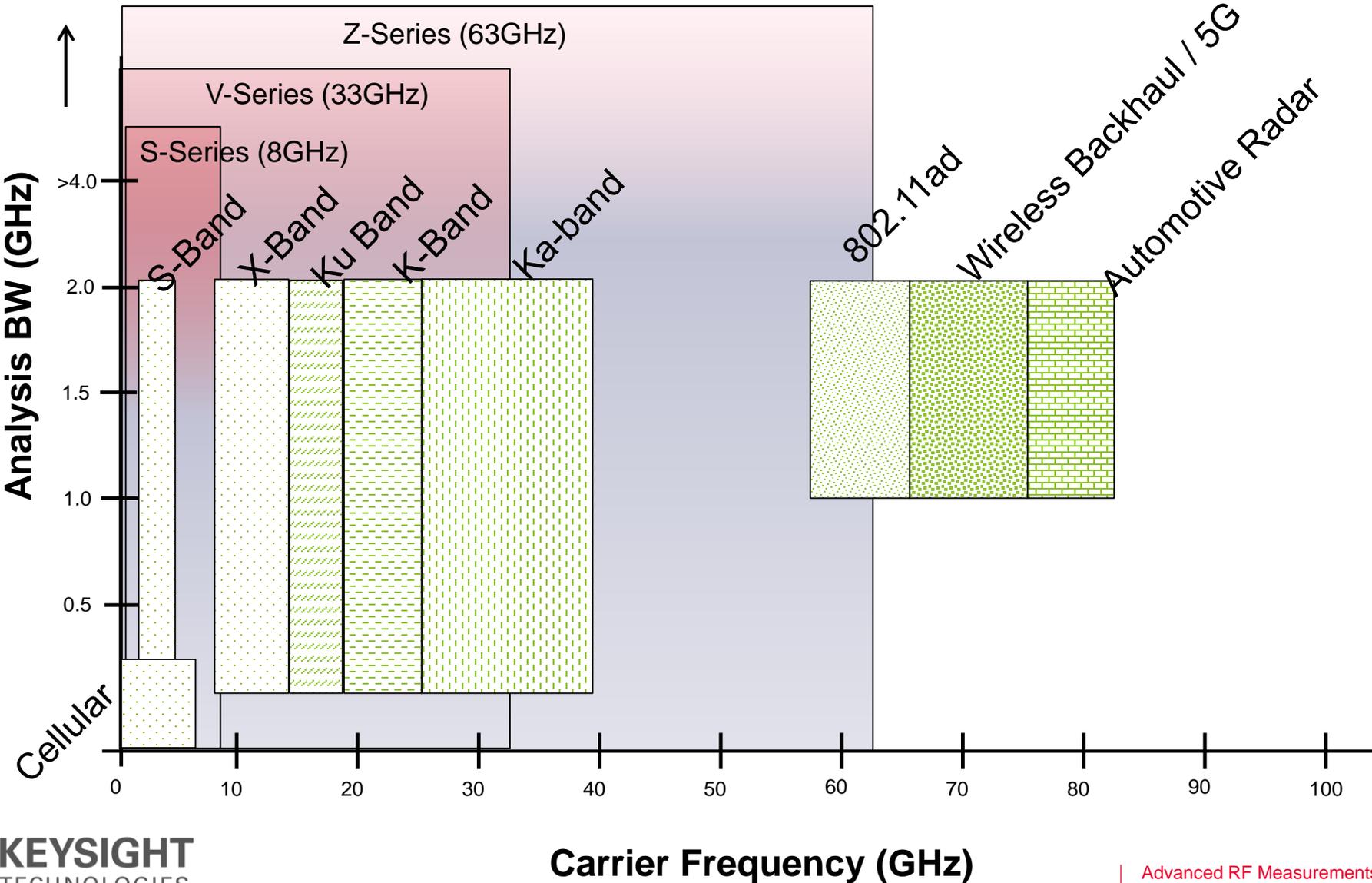
8 GHz

33 GHz

63 GHz

Bandwidth

Wideband Applications that only Oscilloscopes Can Address



Oscilloscope RF Performance

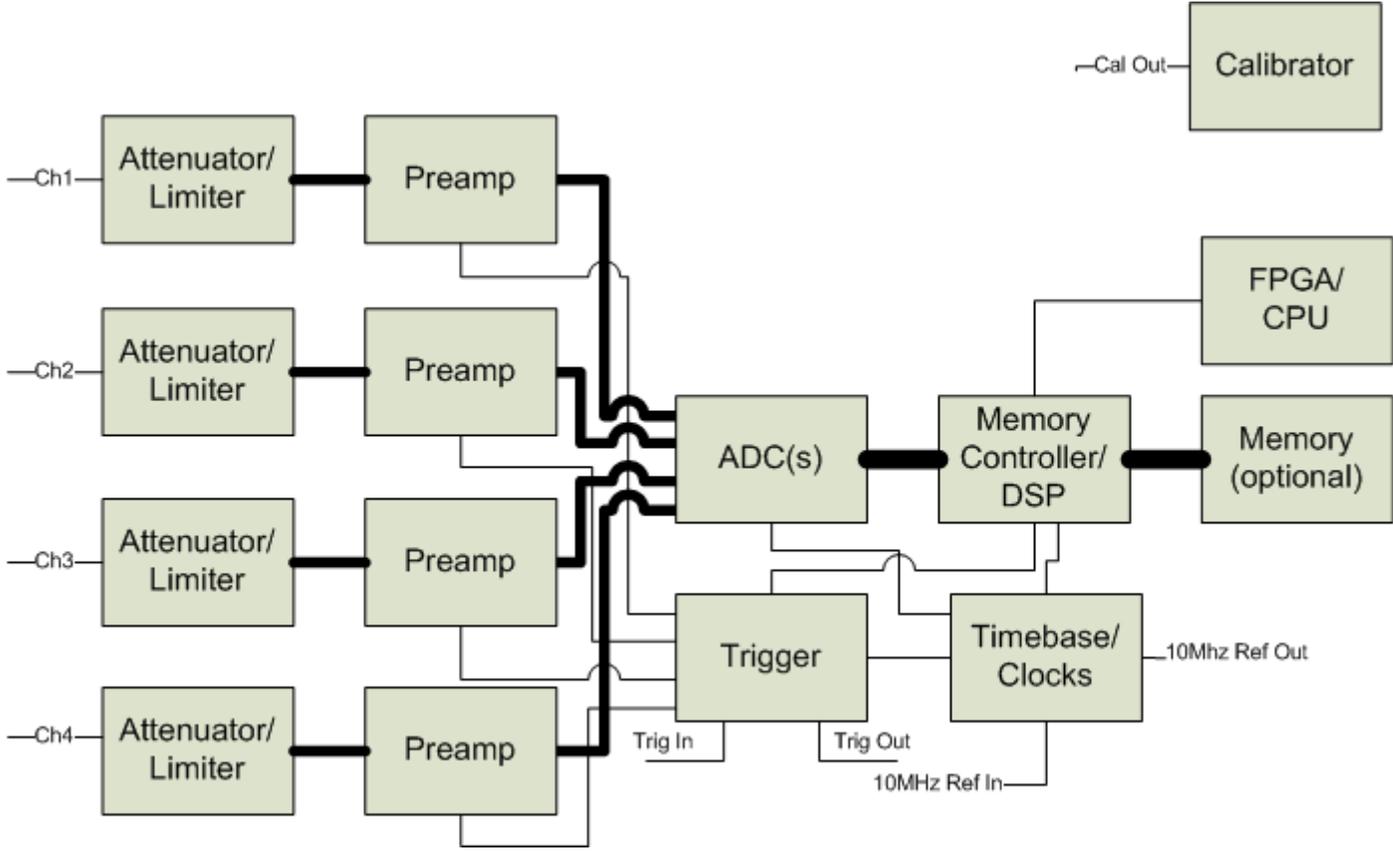
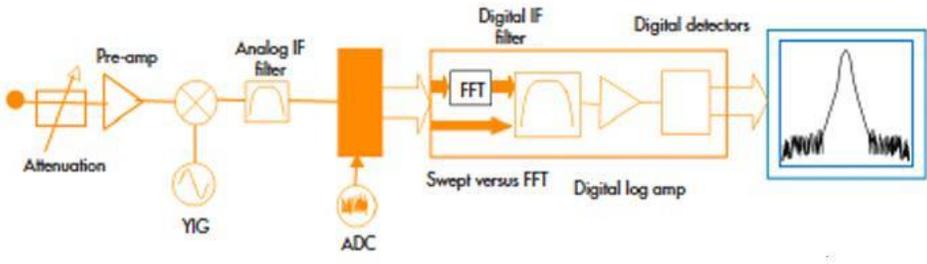
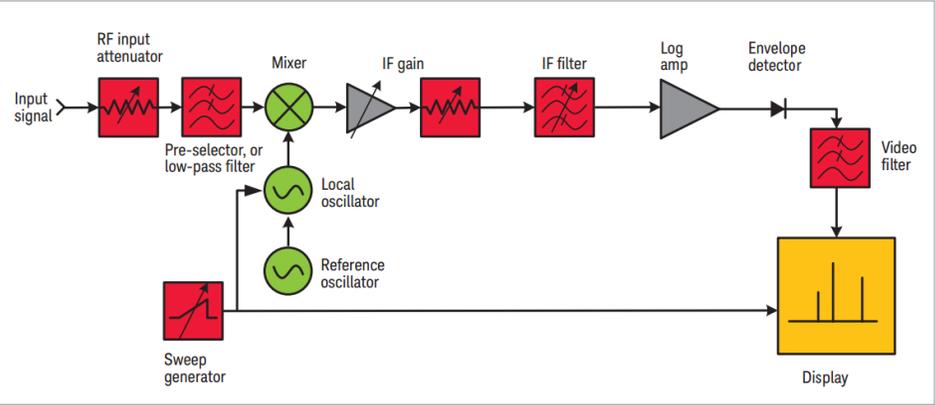
| | S-Series Typical Values | V-Series Typical Values | Z-Series Typical Values |
|--|----------------------------|-----------------------------|----------------------------|
| Noise Density / DANL* | -160 dBm/Hz | -159 dBm/Hz | -160 dBm/Hz |
| Signal to Noise Ratio / Dynamic Range | 108 dB | 111 dB | 112 dB |
| Absolute amplitude accuracy | +/- 1 dB (0 to 7.5 GHz) | +/- 0.5 dB (0 to 30 GHz) | |
| Third Order Intercept | +21.5 dBm | +28 dBm | +26 dBm |
| Phase noise (@ 1 GHz) | | | |
| 10 KHz offset | -121 dBc/Hz | -125 dBc/Hz | -122 dBm/Hz |
| 100 KHz offset | -122 dBc/Hz | -131 dBc/Hz | -126 dBm/Hz |
| Spur Free Dynamic Range (SFDR) | -72 dBc | -67 dBc | -73 dBc |

Oscilloscope RF Performance

| | S-Series Typical Values | V-Series Typical Values | Z-Series Typical Values | PXA | UXA |
|--|----------------------------|-----------------------------|----------------------------|--------------|--------------|
| Noise Density / DANL* | -160 dBm/Hz | -159 dBm/Hz | -160 dBm/Hz | -171 dBm/Hz* | -171 dBm/Hz* |
| Signal to Noise Ratio / Dynamic Range | 108 dB | 111 dB | 112 dB | 119 dB | 119 dB |
| Absolute amplitude accuracy | +/- 1 dB (0 to 7.5 GHz) | +/- 0.5 dB (0 to 30 GHz) | | +/- 0.19 dB | +/- 0.16 dB |
| Third Order Intercept | +21.5 dBm | +28 dBm | +26 dBm | +22 dBm | +22 dBm |
| Phase noise (@ 1 GHz) | | | | | |
| 10 KHz offset | -121 dBc/Hz | -125 dBc/Hz | -122 dBm/Hz | -132 dBm/Hz | -136 dBm/Hz |
| 100 KHz offset | -122 dBc/Hz | -131 dBc/Hz | -126 dBm/Hz | -131 dBm/Hz | -142 dBc/Hz |
| Spur Free Dynamic Range (SFDR) | -72 dBc | -67 dBc | -73 dBc | -79 dBc | -79 dBc |

Spectrum Analyzer vs Real-Time Oscilloscope

Block Diagrams



Getting Noise Density from Vrms Noise

Scope design driven by time domain constraints.

From S-Series Datasheet.

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 μ V | 90 μ V | 120 μ V | 130 μ V | 153 μ V | 195 μ V | 260 μ V |
| 2 mV/div | 74 μ V | 90 μ V | 120 μ V | 130 μ V | 153 μ V | 195 μ V | 260 μ V |
| 5 mV/div | 77 μ V | 94 μ V | 129 μ V | 135 μ V | 173 μ V | 205 μ V | 320 μ V |
| 10 mV/div | 87 μ V | 110 μ V | 163 μ V | 172 μ V | 220 μ V | 256 μ V | 390 μ V |
| 20 mV/div | 125 μ V | 163 μ V | 233 μ V | 254 μ V | 330 μ V | 446 μ V | 620 μ V |
| 50 mV/div | 372 μ V | 456 μ V | 610 μ V | 650 μ V | 768 μ V | 1.3 mV | 1.4 mV |
| 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 |

Translated (calculated) to RF-Speak!
(8GHz Model Only)

| V/div | dBm Ref Level | dBm/Hz Noise |
|-----------|---------------|--------------|
| 1mV/div | -28 dBm | -158 dBm/Hz |
| 2mV/div | -28 dBm | -158 dBm/Hz |
| 5mV/div | -24 dBm | -156 dBm/Hz |
| 10mV/div | -18 dBm | -154 dBm/Hz |
| 20mV/div | -12 dBm | -150 dBm/Hz |
| 50mV/div | -4 dBm | -143 dBm/Hz |
| 100mV/div | +2 dBm | -136 dBm/Hz |
| 200mV/div | +6 dBm | -130 dBm/Hz |
| 500mV/div | +16 dBm | -124 dBm/Hz |
| 1V/div | +22 dBm | -118 dBm/Hz |

50mV/div = 400mV full scale (Vpp) = -4dBm range.
1.4mV rms noise = -44dBm @ 8GHz = -143dBm/Hz

Getting Noise Density from Vrms Noise

Scope design driven by time domain constraints.

Translated (calculated) to RF-terms
(33 GHz Model Only)

From V-Series Datasheet.

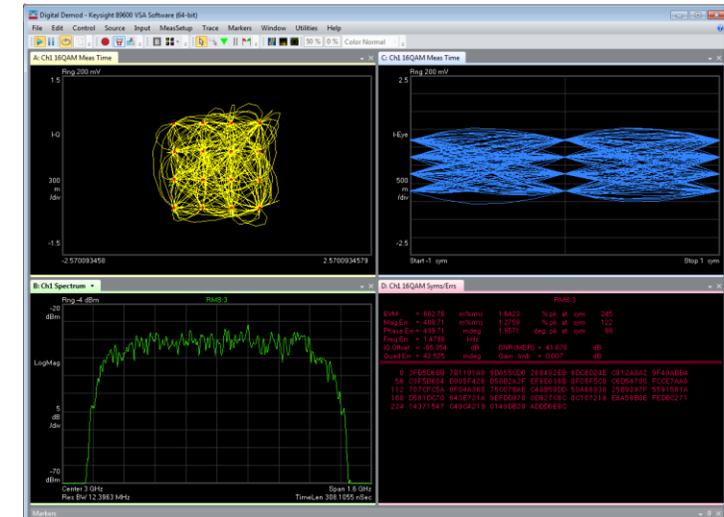
| RMS noise floor (oscilloscope only) | V084A | V134A | V164A | V204A | V254A | V334A | dBm Ref Level | dBm/Hz Noise |
|-------------------------------------|----------|----------|----------|----------|----------|----------|---------------|--------------|
| Vertical setting (mVrms) | 8 GHz | 13 GHz | 16 GHz | 20 GHz | 25 GHz | 33 GHz | | |
| 5 mV/div | 0.21 mV | 0.27 mV | 0.31 mV | 0.37 mV | 0.45 mV | 0.58 mV | -24 dBm | -157 dBm/Hz |
| 10 mV/div | 0.23 mV | 0.28 mV | 0.36 mV | 0.42 mV | 0.49 mV | 0.60 mV | -18 dBm | -157 dBm/Hz |
| 20 mV/div | 0.46 mV | 0.57 mV | 0.65 mV | 0.74 mV | 0.83 mV | 1.04 mV | -12 dBm | -152 dBm/Hz |
| 50 mV/div | 1.04 mV | 1.09 mV | 1.32 mV | 1.54 mV | 1.73 mV | 2.09 mV | -4 dBm | -146 dBm/Hz |
| 100 mV/div | 1.92 mV | 2.30 mV | 2.63 mV | 3.02 mV | 3.39 mV | 3.98 mV | +2 dBm | -140 dBm/Hz |
| 200 mV/div | 4.39 mV | 5.52 mV | 6.14 mV | 6.92 mV | 8.16 mV | 9.88 mV | +6 dBm | -132 dBm/Hz |
| 500mV/div | 10.07 mV | 12.42 mV | 13.68 mV | 15.05 mV | 17.08 mV | 20.25 mV | +16 dBm | -126 dBm/Hz |
| 1 V/div | 18.47 mV | 21.36 mV | 26.12 mV | 30.15 mV | 34.36 mV | 39.35 mV | +22 dBm | -120 dBm/Hz |

50mV/div = 400mV full scale (Vpp) = -4dBm range.

2.09 mV rms noise = -40.6 dBm - 10log(33e9) = -146 dBm/Hz

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Use Functions for Advance RF Measurements

1 GHz Wide Chirp Example using 5 scope functions



- “Meas Trend” of Clock TIE to see inverse of phase shift
- Time view of single RF pulse in pulse train
- “Meas Trend” of Frequency to see frequency shift across the RF pulse (1 GHz linear shift)
- FFT of an RF pulse (variety of FFT window options)

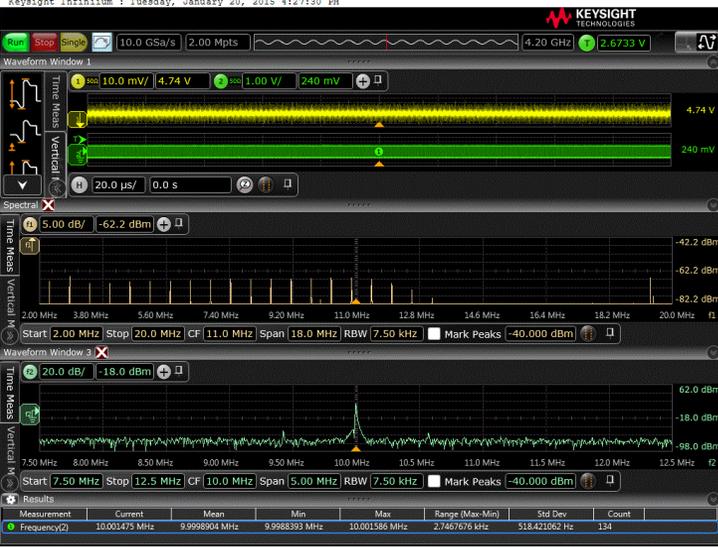
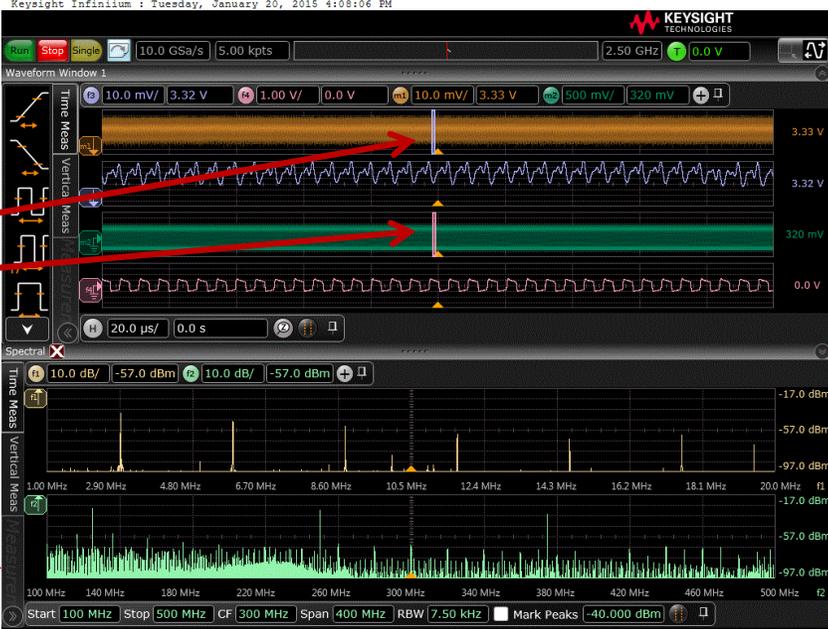
Example: 1 usec wide RF pulses, linear FM 3.5 GHz to 4.5 GHz, 10 usec PRI

Multiple FFTs

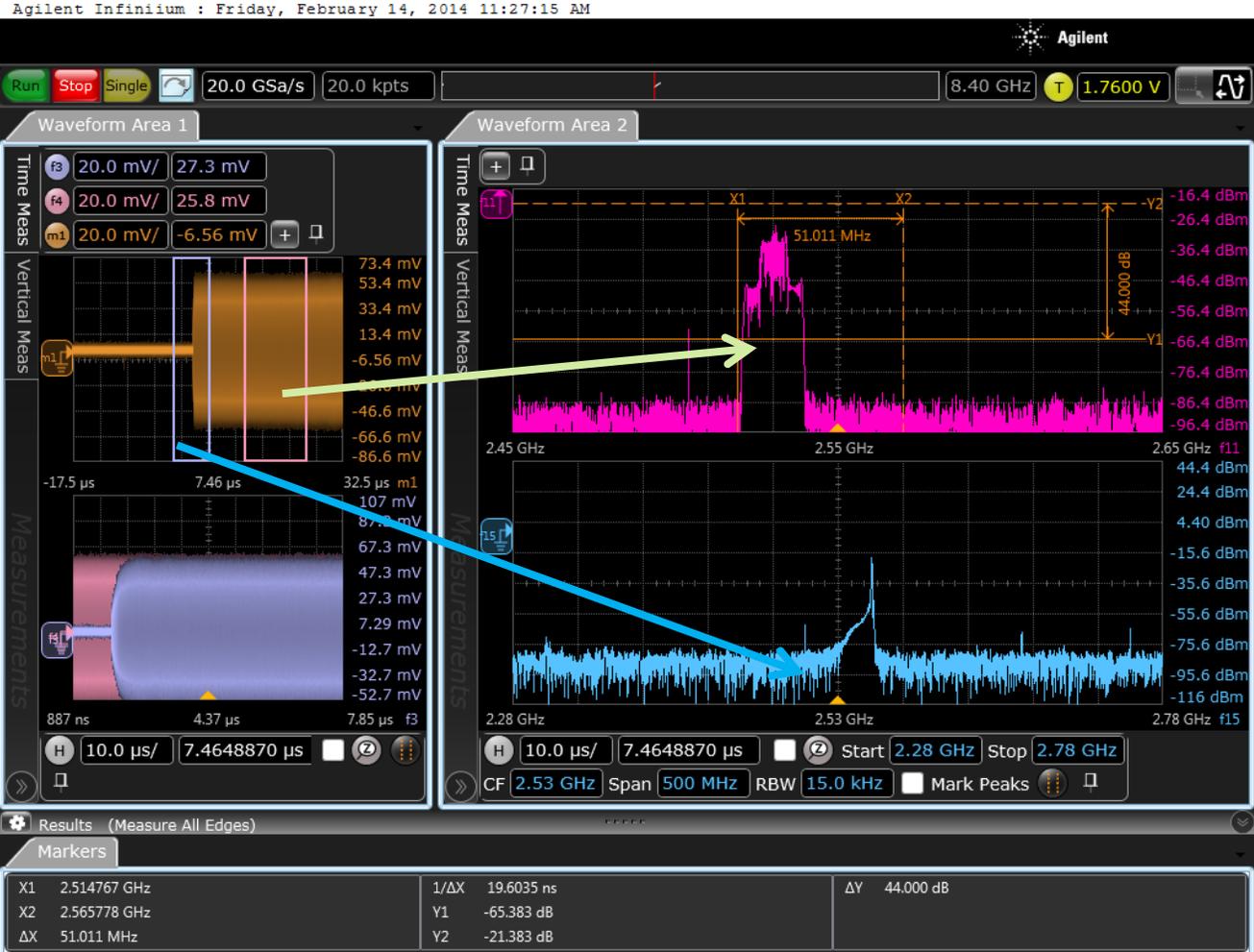
– Multiple gates

– Multiple FFTs on same waveform with different Start/Stops

– FFT per input channel

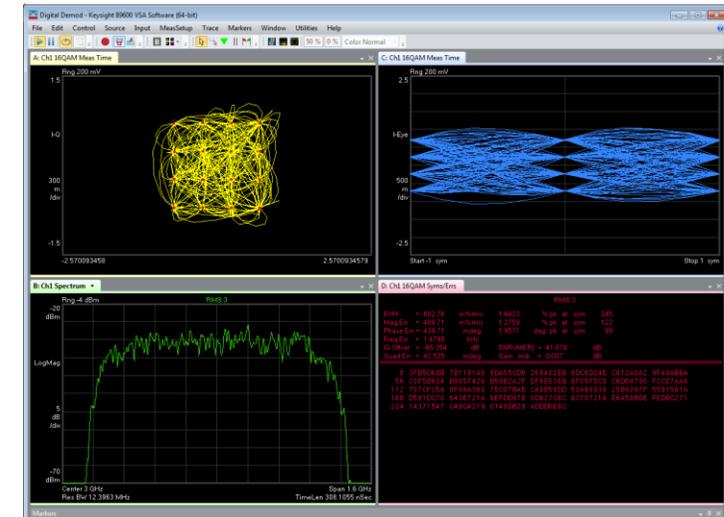


Gated FFTs for Time/Frequency Correlation



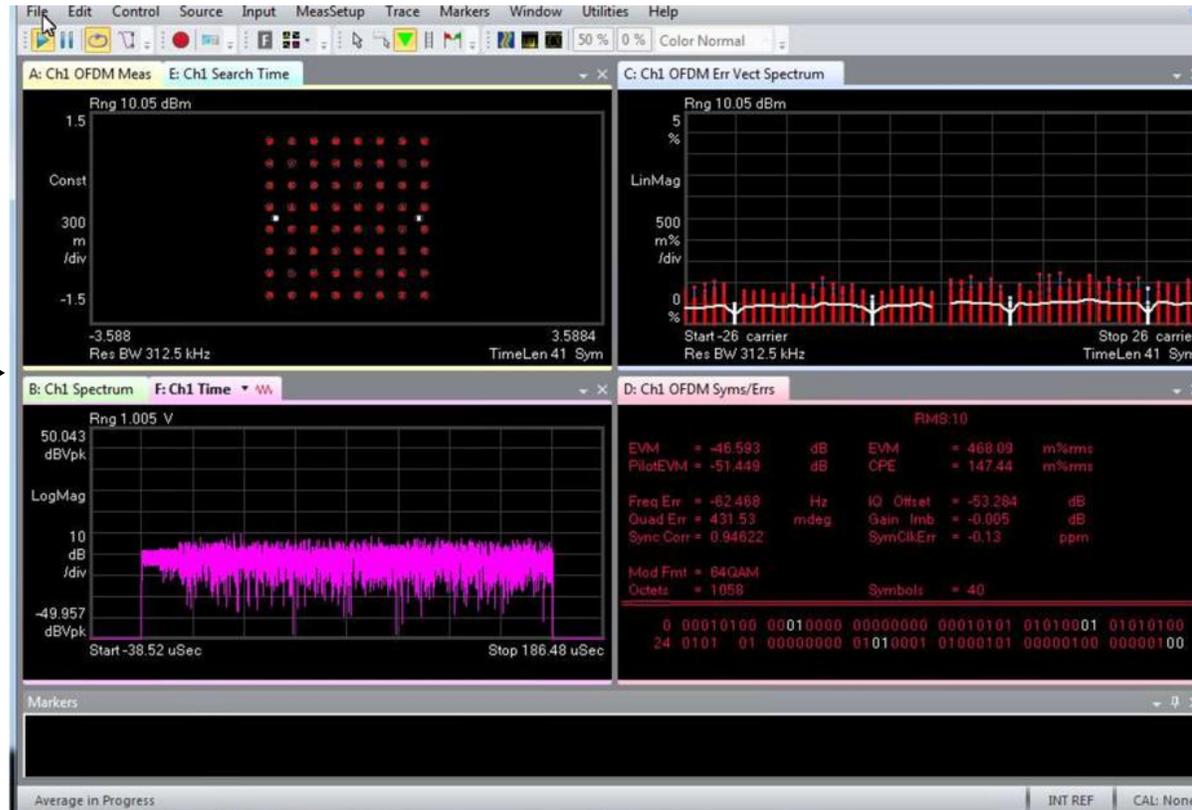
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Additional Analysis

VSA (Vector Signal Analysis) App can run on the scope, or on a PC



Spectrum Analysis

- Channel power
- PSD
- ACP
- OBW

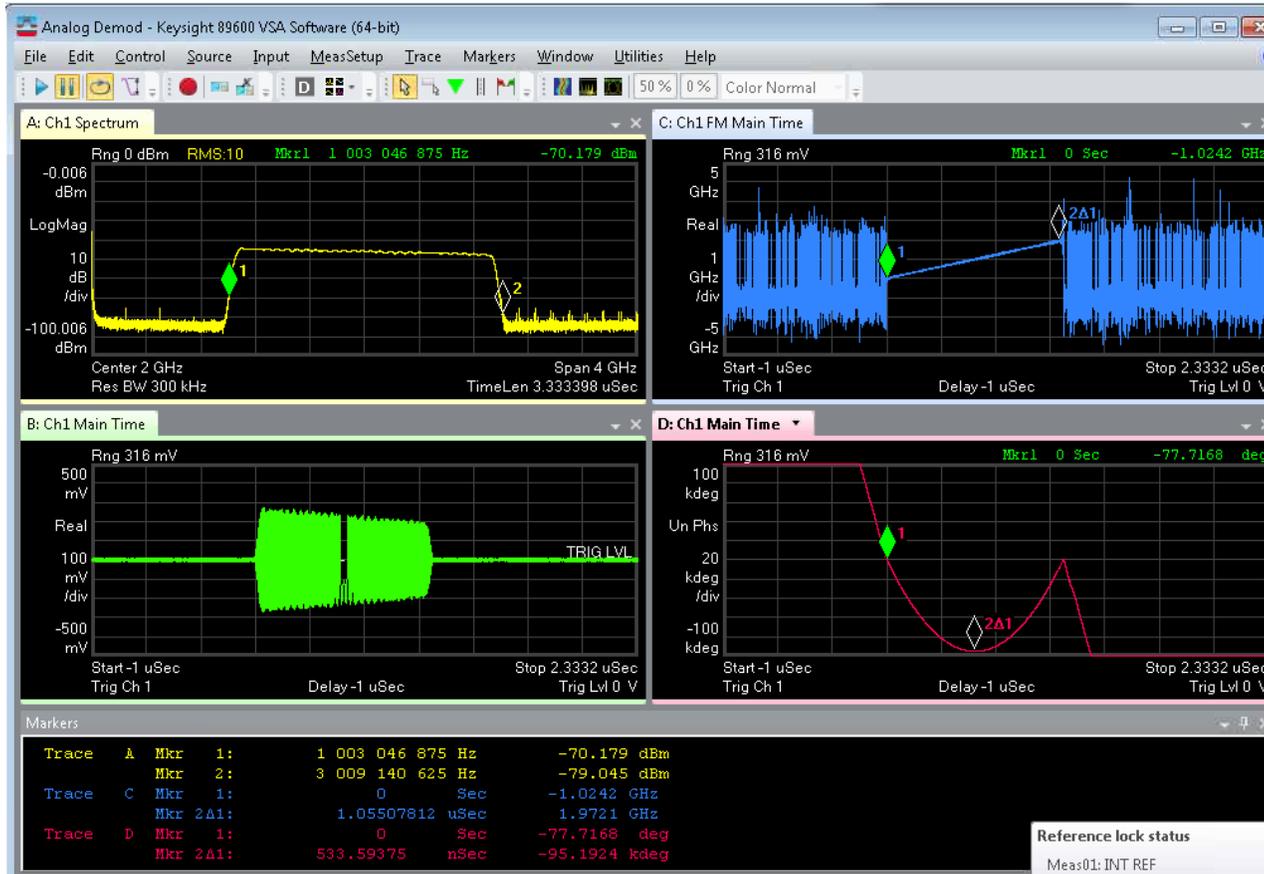
Demodulation Analysis

- Constellation diagrams
- EVM

Advanced Pulse Analysis

- P2P frequency, phase, amplitude
- FMCW

Chirp Radar analysis --- 2 GHz wide



2 GHz linear FM chirp

Measure of:

- Spectral content
- Pulse "Real"
- Frequency across pulse
- Unwrapped phase across pulse

VSA 19 pulse option BHQ

Use segmented memory in scopes for long captures

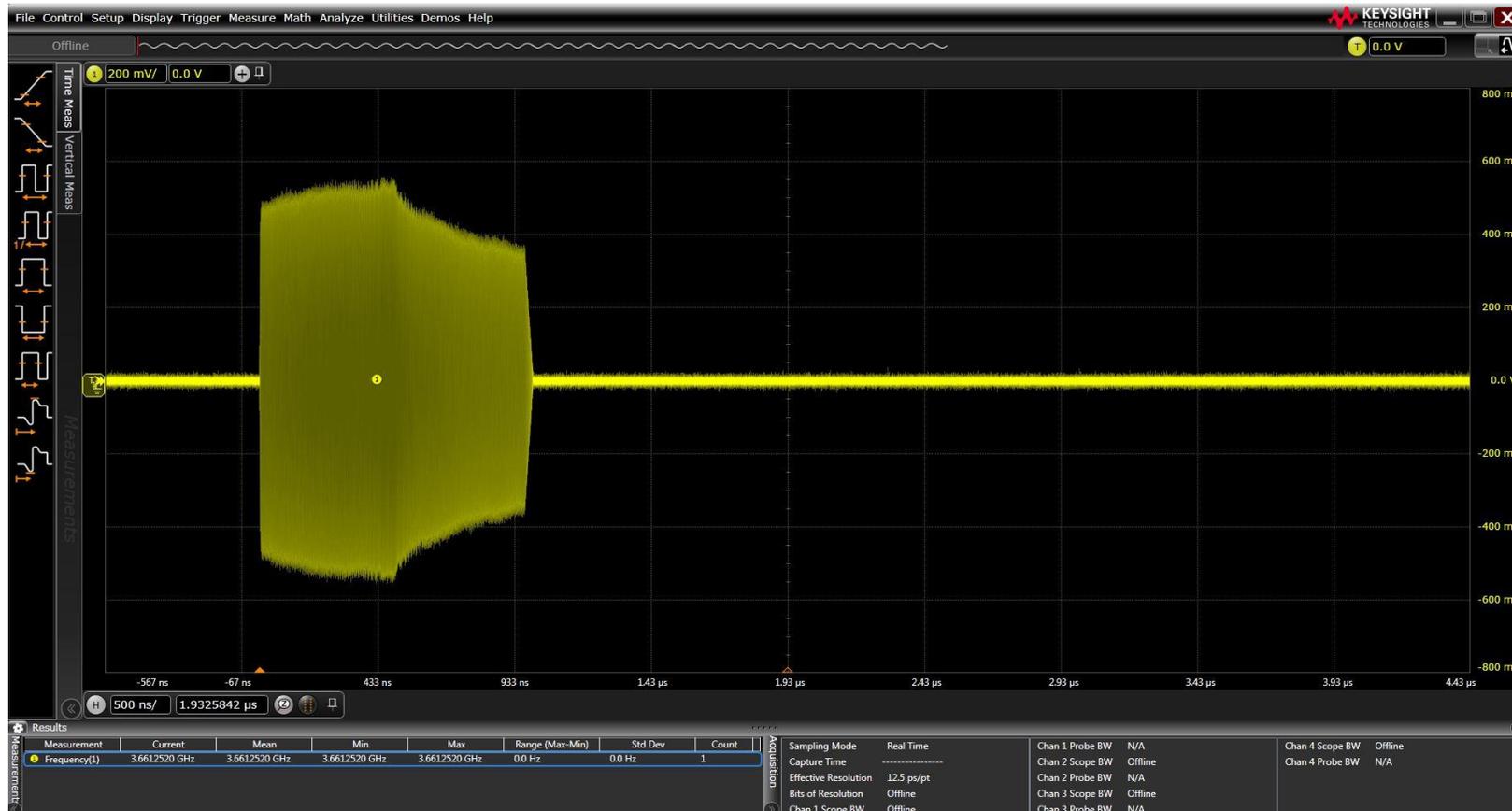


Up to 64k segments

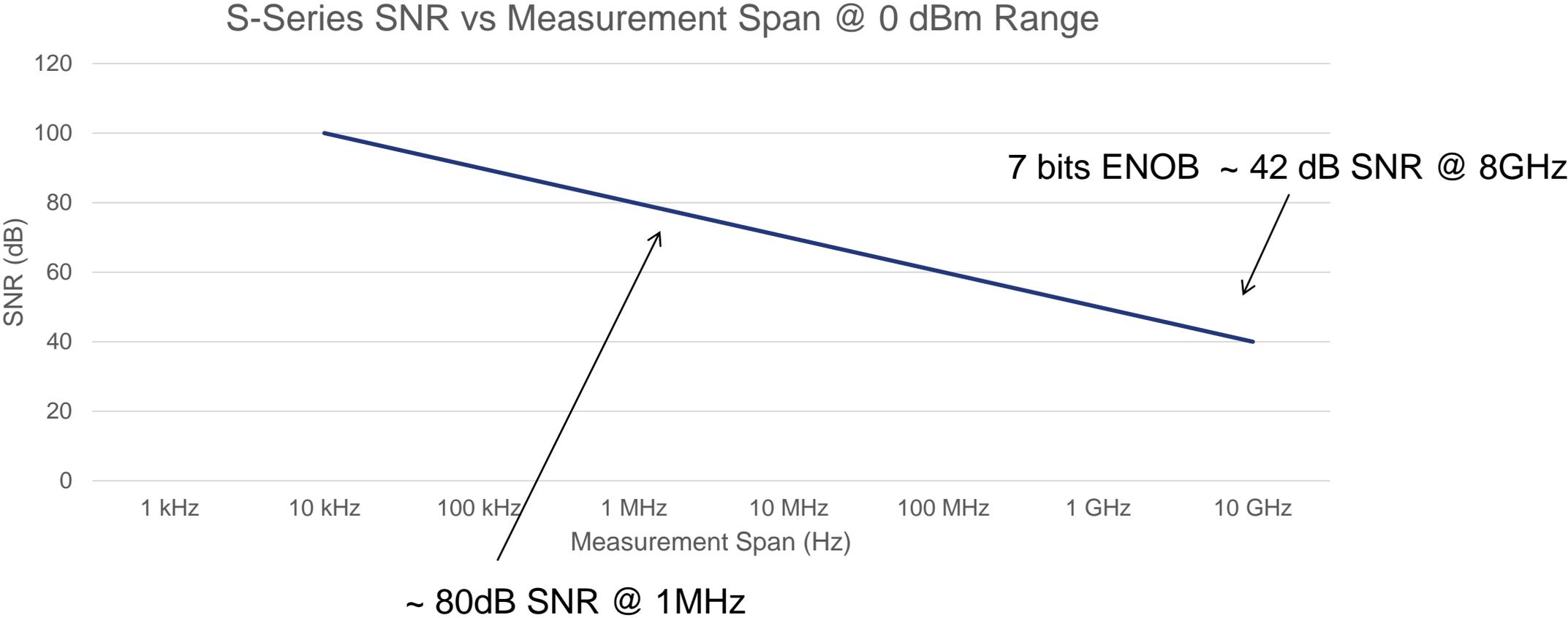
Full suite of RF pulse measurements

Statistical analysis

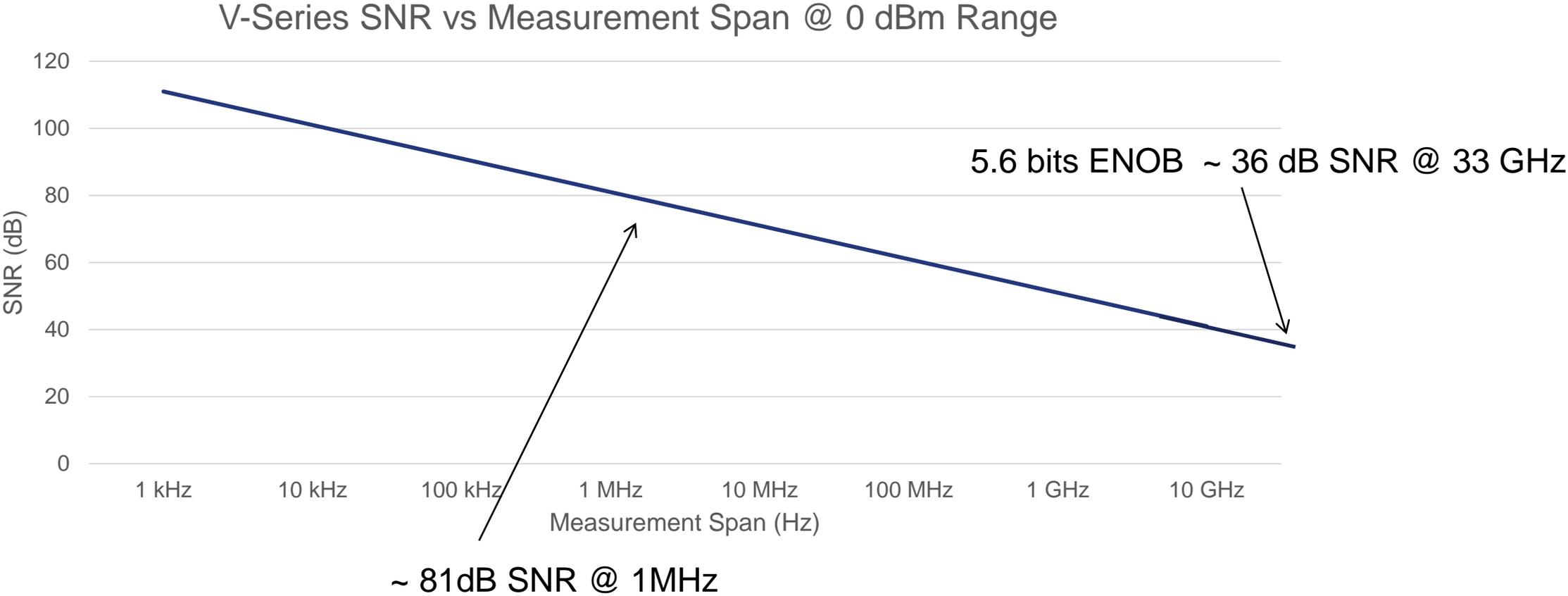
Can't see 50 dB down pulse next to large pulse



Optimize SNR by Reducing Measurement Span in VSA

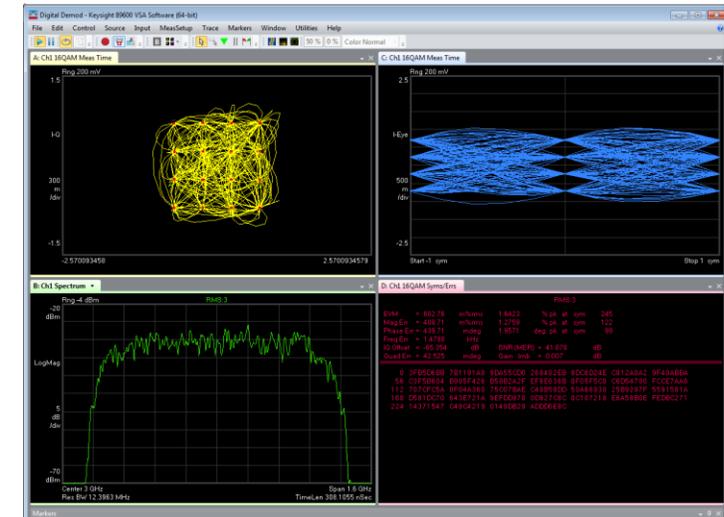
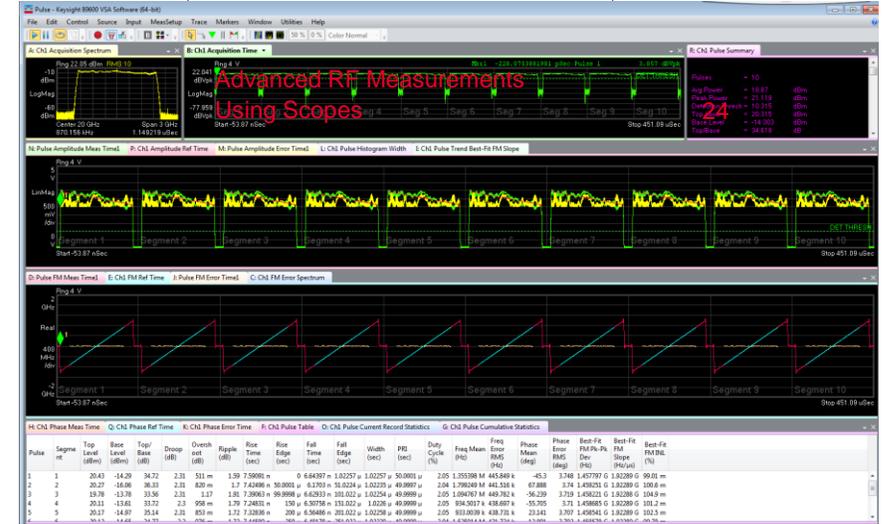


Optimize SNR by Reducing Measurement Span in VSA



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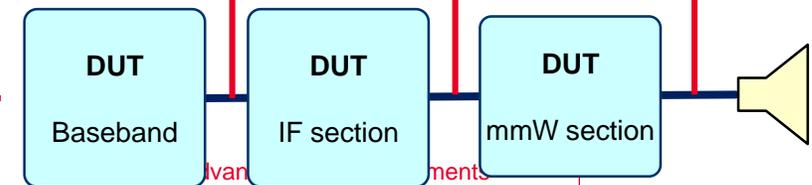
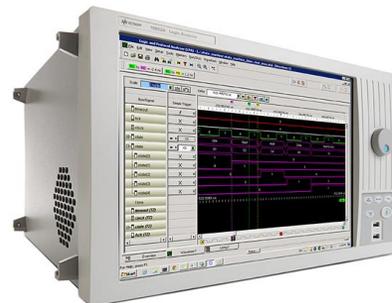
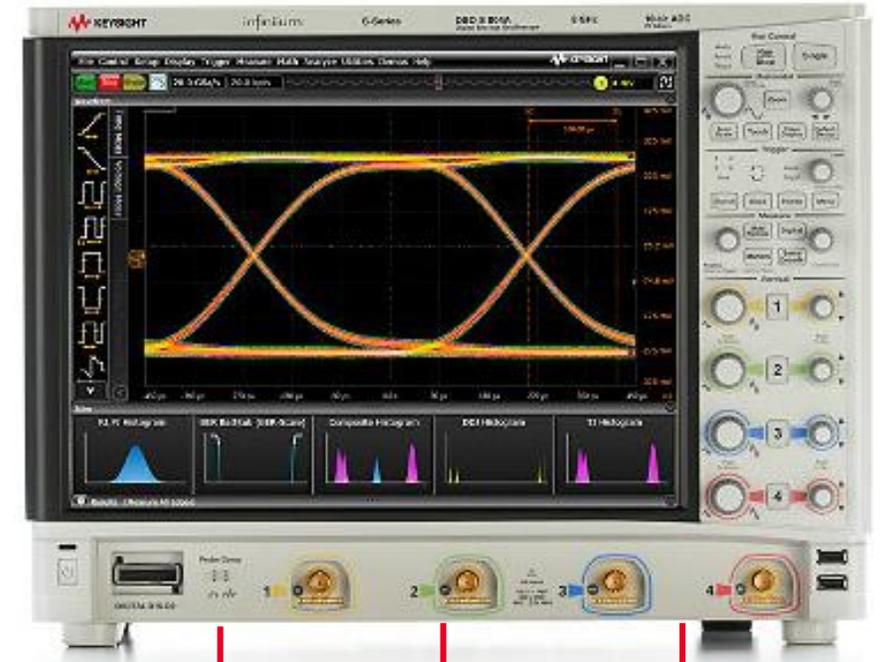


Wideband Communications Testing

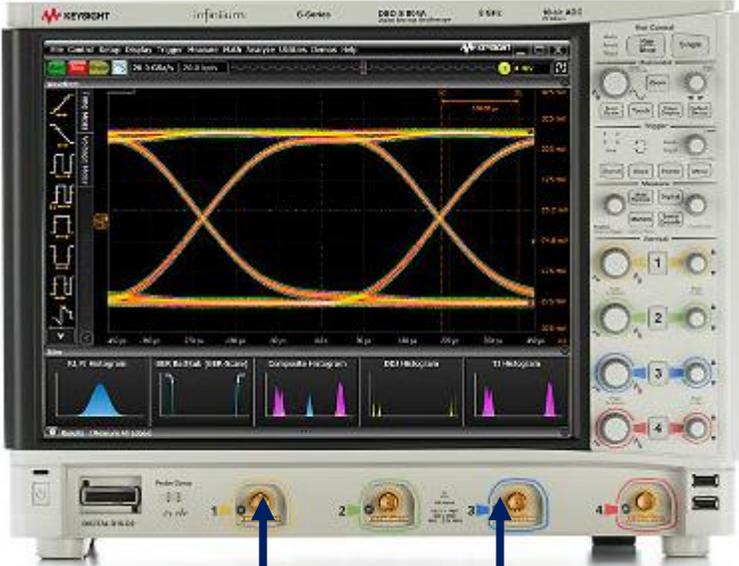
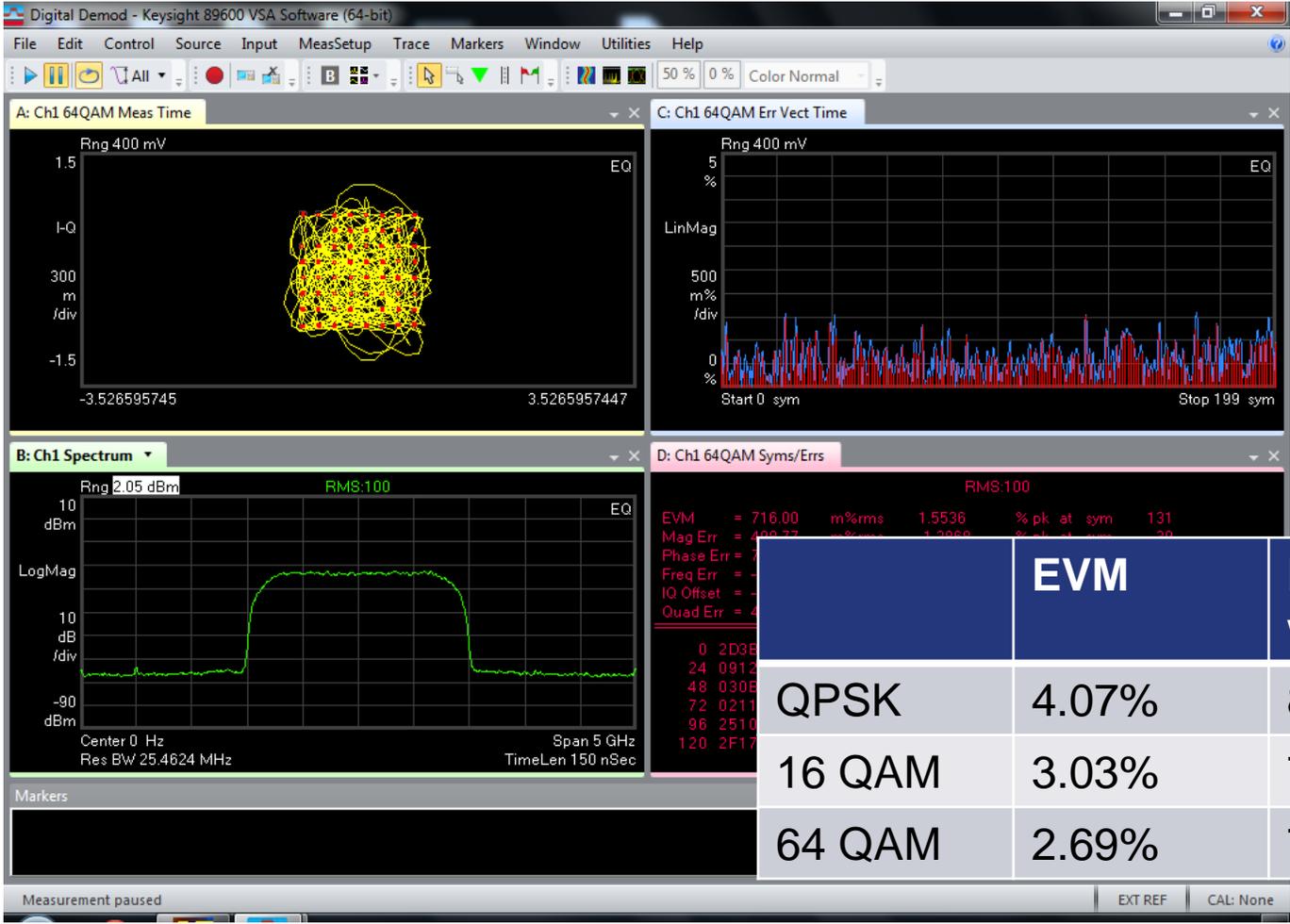
5G, WiGig, Automotive Radar

Wideband communication testing can be broken into at least 3 categories

- Logic Analyzers for digital baseband analysis
- Analog Baseband analysis
- RF/IF signal analysis
- mmW/RF signal analysis in E-band (60-90 GHz)

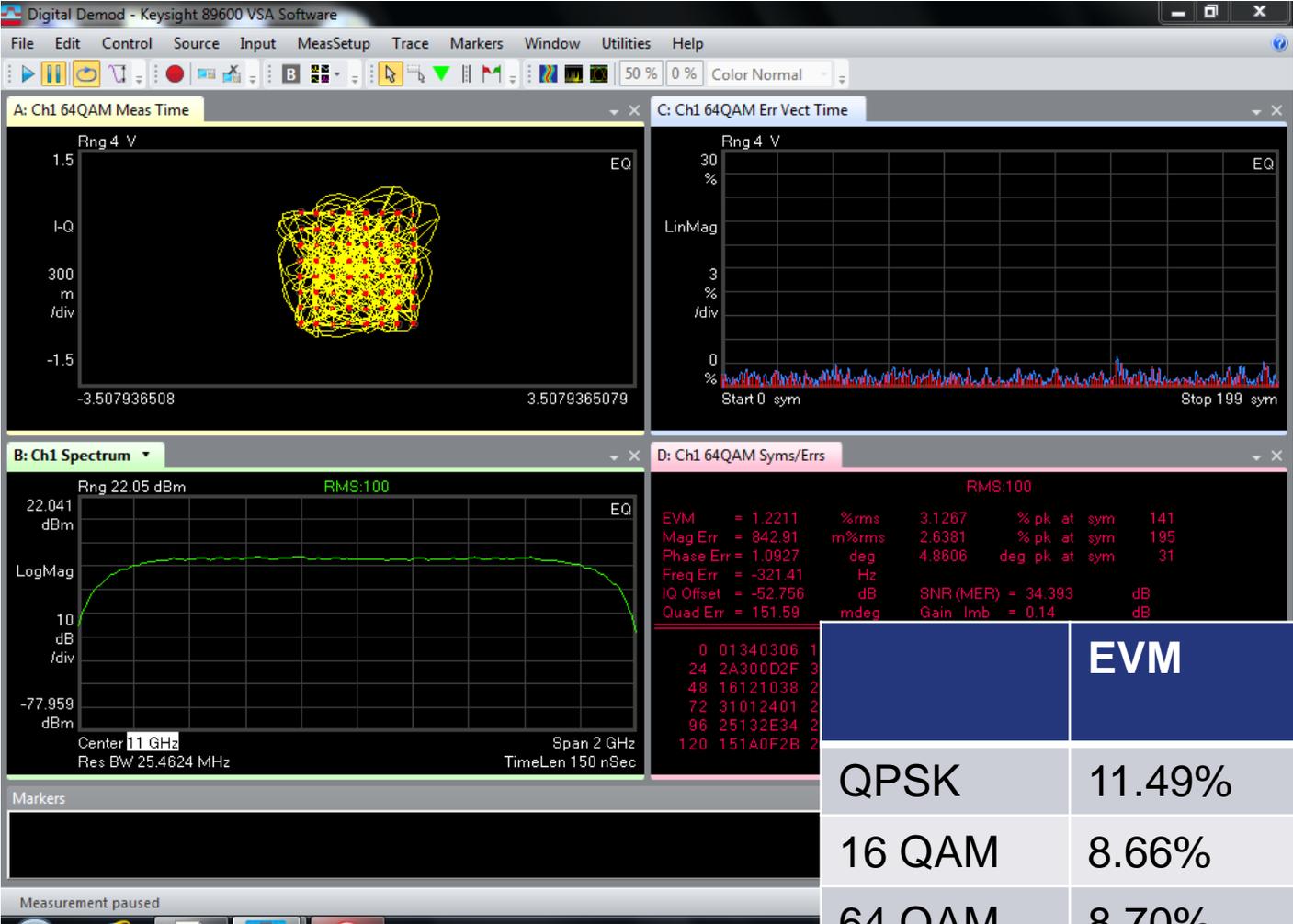


Baseband Analysis

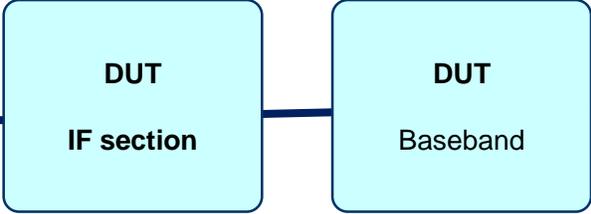


DUT
Baseband

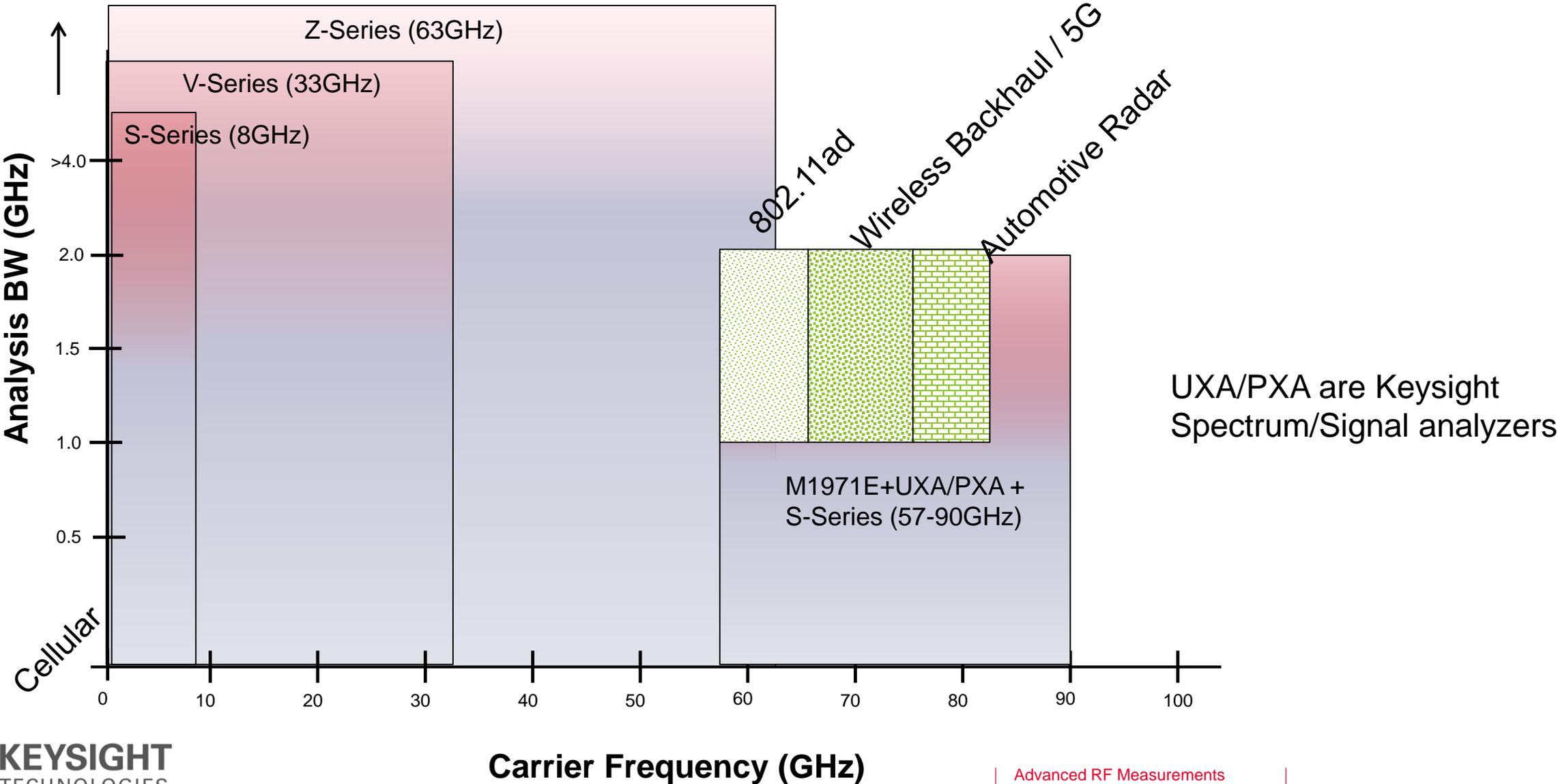
IF Signal Analysis



| | EVM | EVM w/EQ |
|--------|--------|----------|
| QPSK | 11.49% | 1.77% |
| 16 QAM | 8.66% | 1.37% |
| 64 QAM | 8.70% | 1.22% |



Wideband Applications that only Oscilloscopes Can Address



Introducing new E-Band WB smart mixers

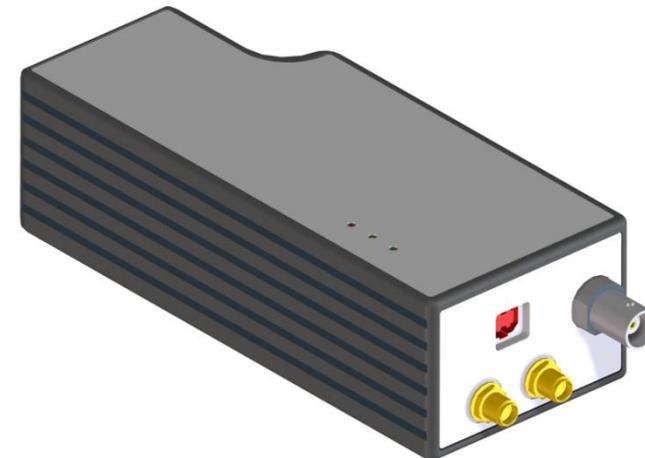
Model #: M1971E

E-band Extended Bandwidth “Smart” USB Mixers

Application: Wide bandwidth (2 GHz) modulation for the following segments :

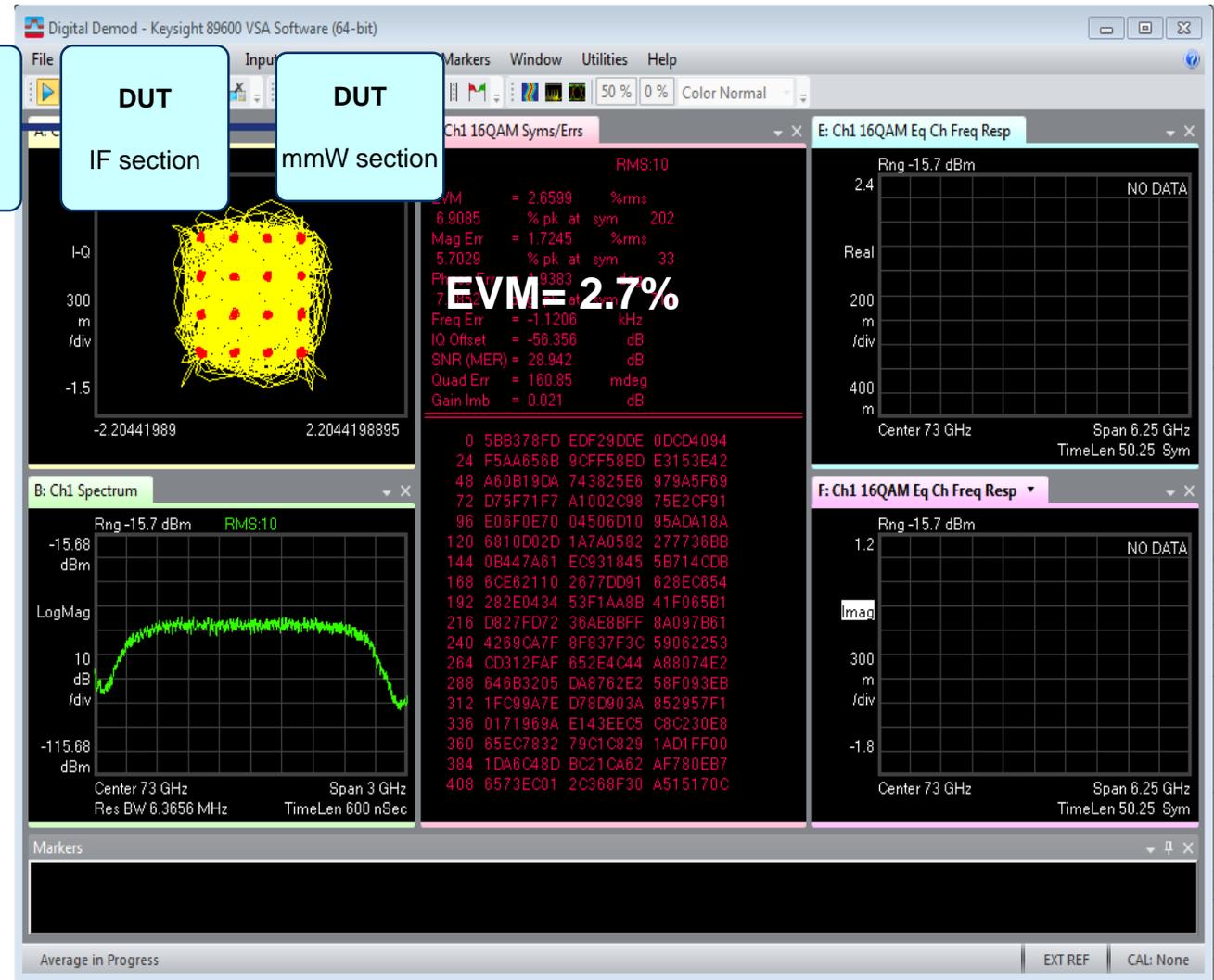
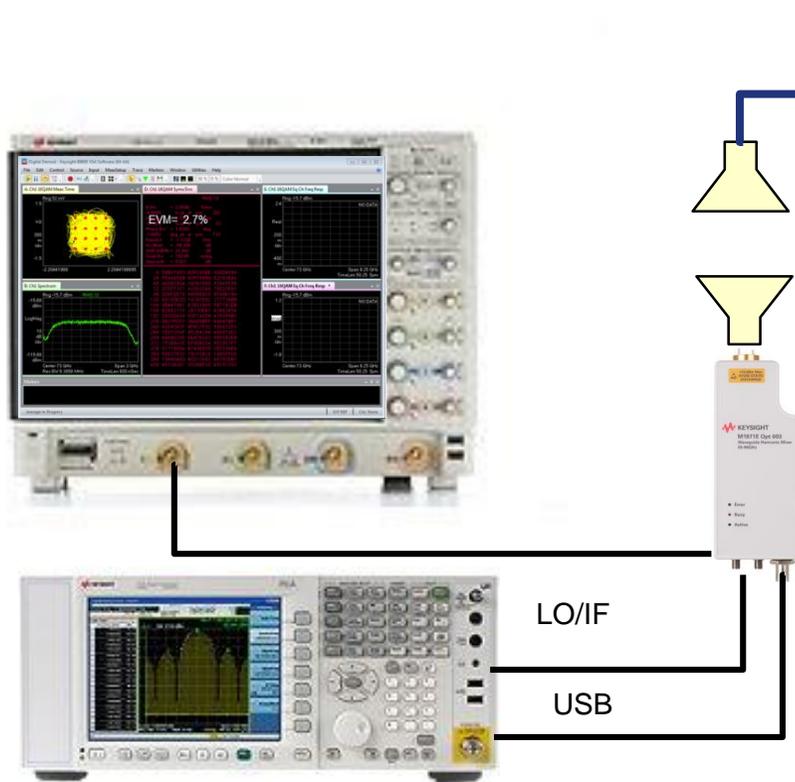
- 57-66 GHz 802.11ad / WiGig
- 60 GHz Unlicensed Wireless Backhaul
- 71-76 GHz, 81-86 GHz Licensed Wireless Backhaul
- 76-81 GHz Automotive Radar

***To complete wide
bandwidth
mm- Wave analysis***



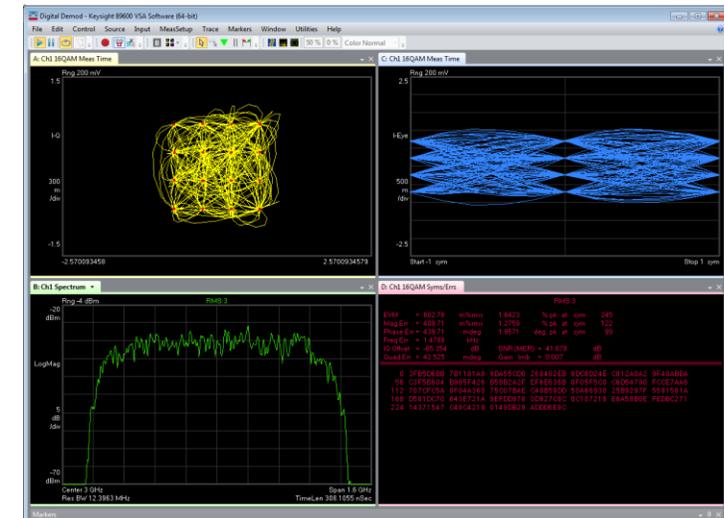
mmW/RF Signal Analysis, E-Band 60-90 GHz

73 GHz Measurements



Agenda

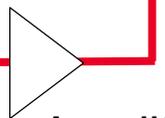
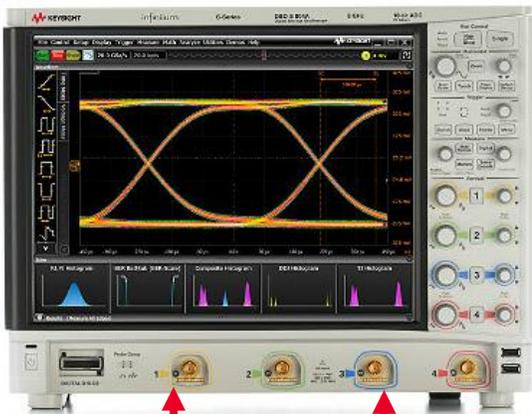
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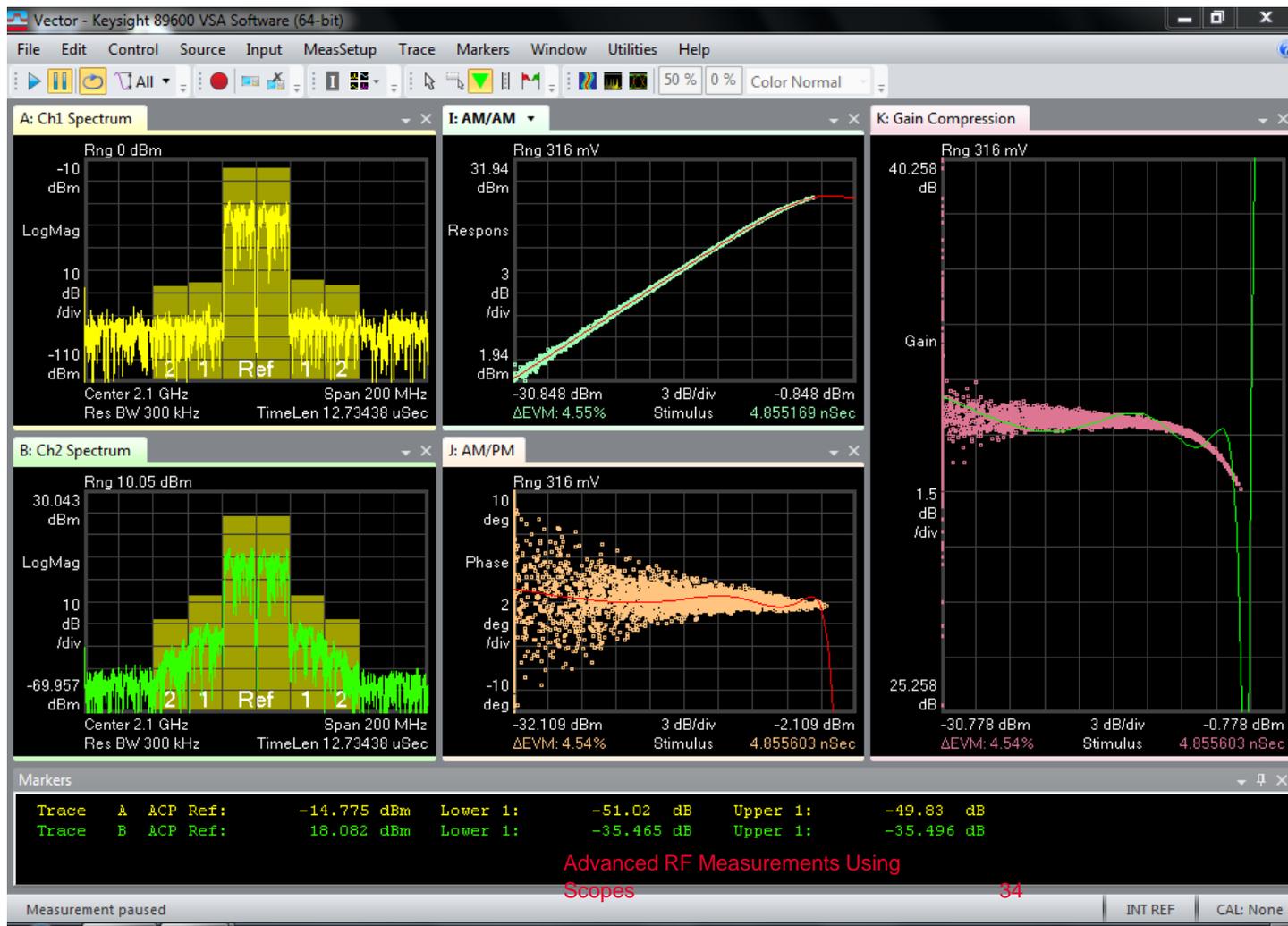
PA test driven into compression

2x20 MHz LTE R10 CC 2100MHz / S-Series

S-Series Oscilloscope



Amplifier



SatCom Wideband Channel Quality

1.4 GHz bandwidth satellite channel

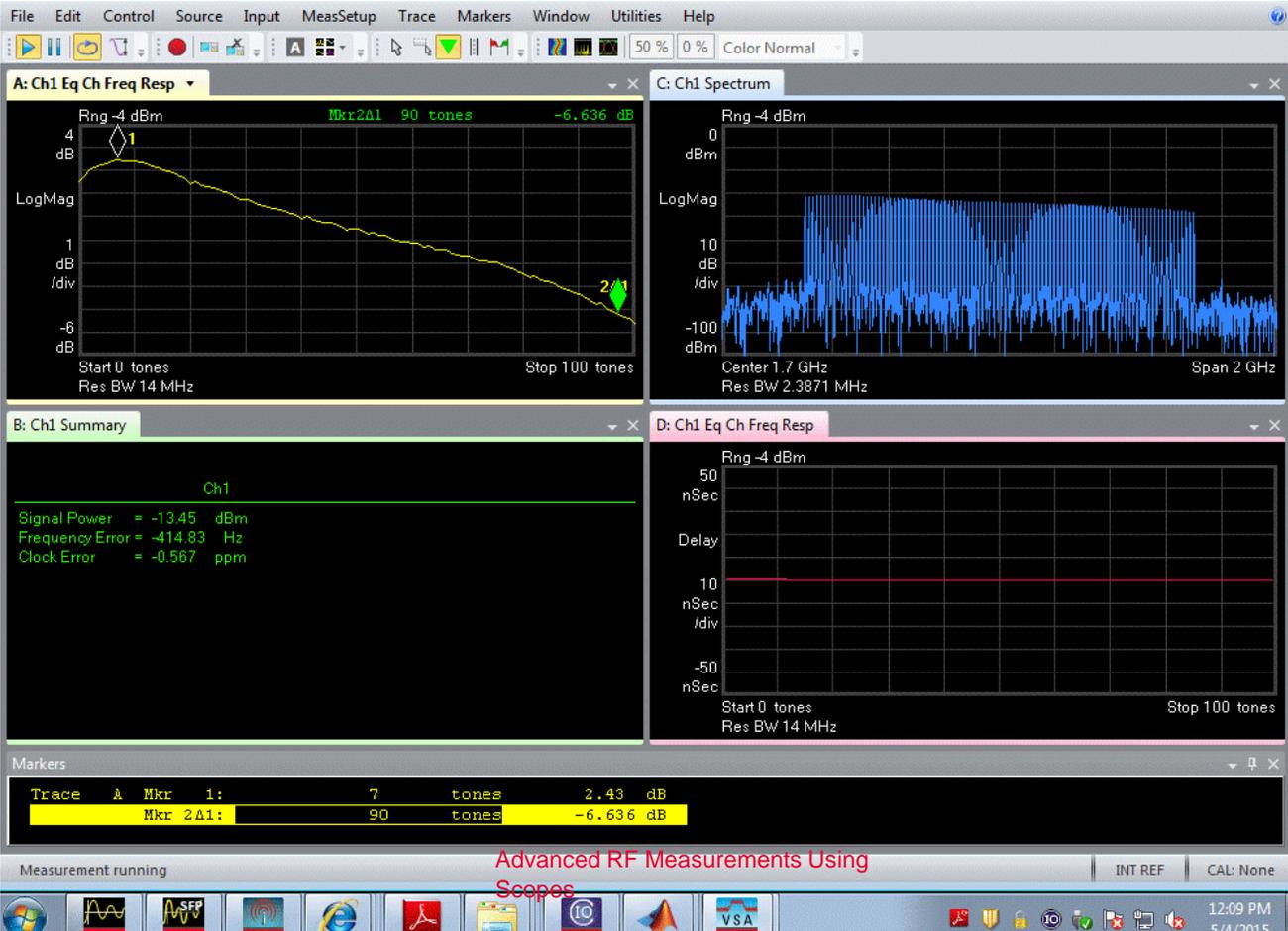
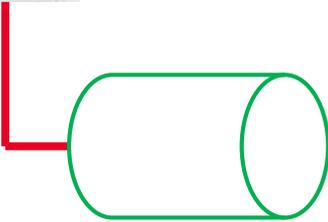
Calibrated wideband signal generator



V-Series Oscilloscope



Channel of interest



802.11ac 5.18 GHz 160 MHz 2x2 -10dBm MCS 8

-40.78 dB EVM / S-Series



| Modulation | Required EVM | With 10 dB margin |
|------------|--------------|-------------------|
| 256 QAM | -32 dB | -42 dB |
| 64 QAM | -27 dB | -37 dB |

| | S-Series 20GSa/s | V-Series 20 GSa/s | V-Series 80 GSa/s |
|----------|---------------------|----------------------|----------------------|
| EVM (dB) | -40.78 | -41.308 | -44.667 |



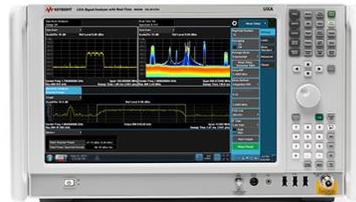
What have we seen?

Scopes for RF measurements

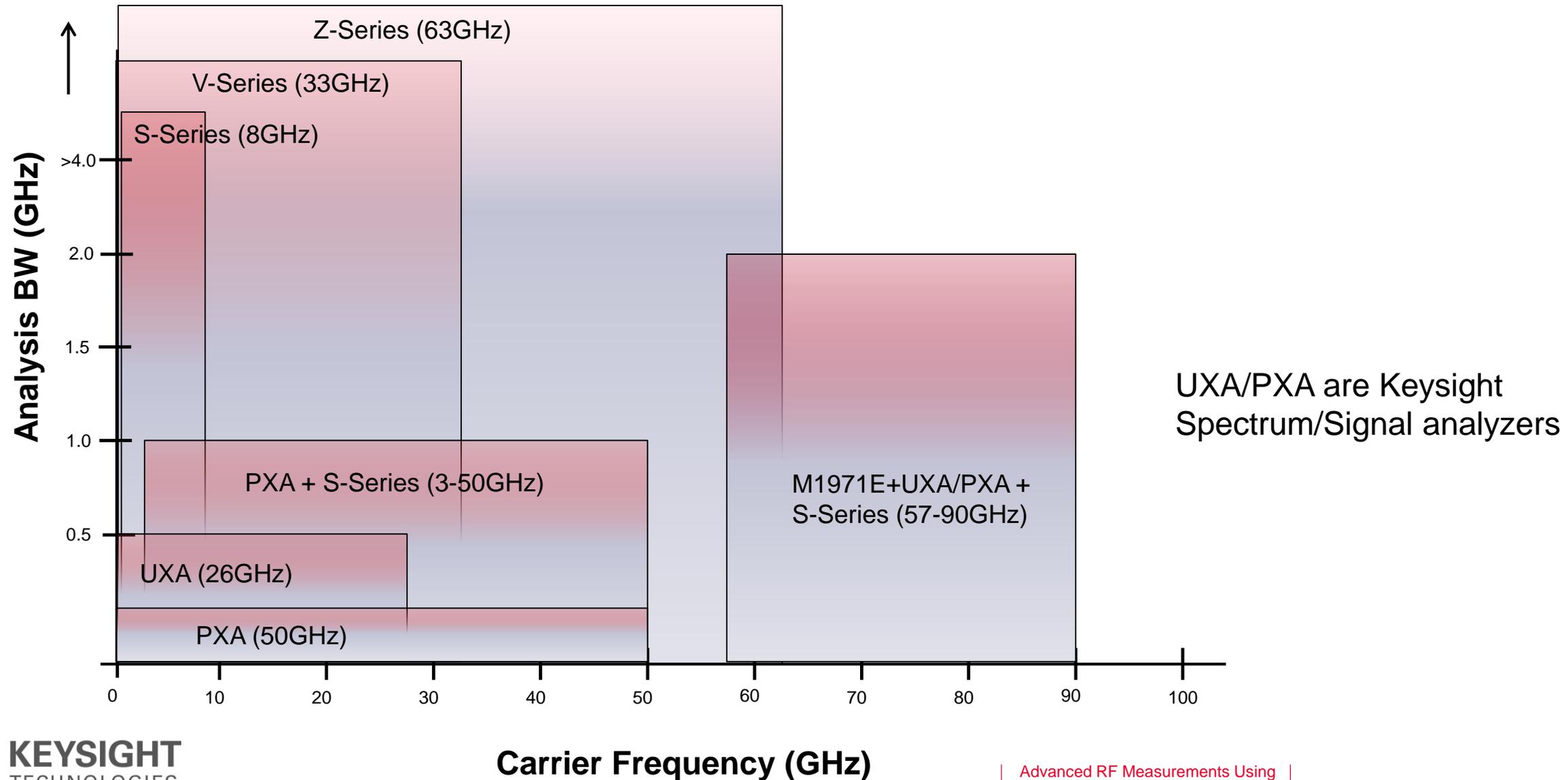
- New scopes make great, wideband RF receivers, that translate into excellent in-band RF measurements
- Oscilloscopes offer the widest analysis bandwidth to address the latest pulse and communications oriented applications
- The noise density of new scopes is better than you might have realized, making them applicable to small signal applications
- Scopes and Spectrum/Signal Analyzers each have their strengths for RF measurements
- Scopes combined with VSA software become a powerful wideband RF measurement suite

Keysight Oscilloscopes for High-Quality RF Measurements

- S-Series with up to 8 GHz bandwidth (2-ch)
- V-Series with up to 33 GHz bandwidth (2ch)
- Z-Series with up to 63 GHz bandwidth (2ch)
- Multi-instrument Reference solutions
 - Scope + PXA or UXA as down converter yields up to 1.1 GHz analysis bandwidth



Wideband Applications that only Oscilloscopes Can Address



Keysight's Oscilloscope Portfolio

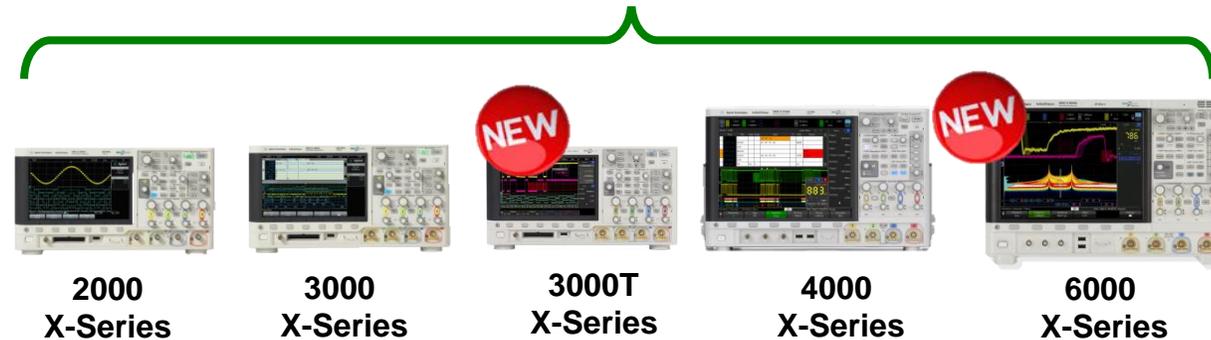
Extreme Value to Extreme Performance

Infiniium- Signal Integrity and Analysis

- 500 MHz to 63 GHz
- Detailed Analysis
- Deep memory
- Win7 OS

InfiniiVision – Designed for Value

- 70 MHz to 6 GHz
- Optimized for visualization
- Debug
- Embedded OS



Questions?

