RF Measurements You Didn't Know Your Oscilloscope Could Make

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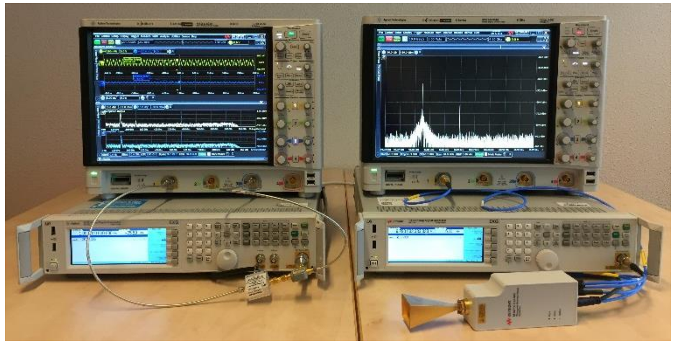
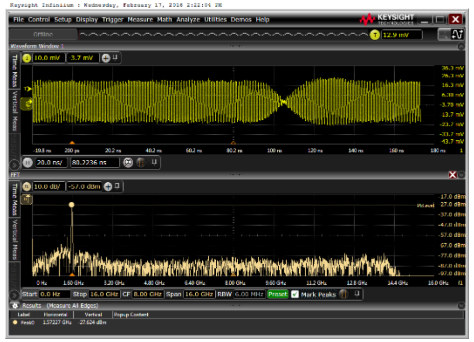




KEYSIGHT TECHNOLOGIES

HARDWARE + SOFTWARE + PEOPLE = INSIGHTS

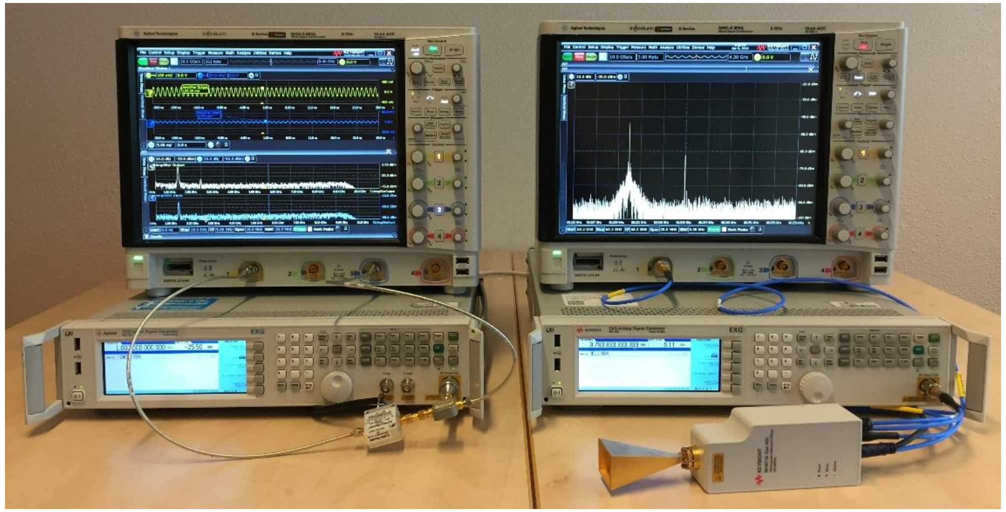
Introduction

– Keysight oscilloscopes do measure very well RF signals.

– Consider Keysight RF oscilloscopes for measuring Amplifier AM/PM, AM/AM & Gain Compression on complex modulated (WLAN, LTE etc.) signals.

– Consider economic RF scope solution for E band measurements (60 to 90 GHz) using 4 GHz scope and E-band mixer.

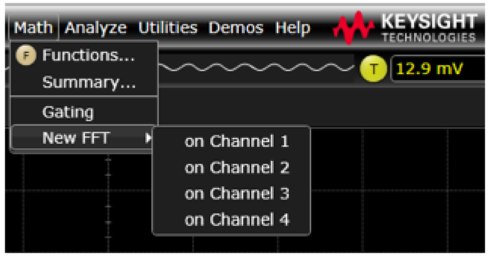
– Consider OMNIRADAR Timofey.Savelyev@omniradar.com



Agenda

- Oscilloscope as Spectrum Analyzer
  - RF specifications for Oscilloscopes: Noise floor, Signal to Noise, phase noise
- Demonstration measuring Amplifier AM/PM, AM/AM & gain compression
  - using complex modulated (WLAN, LTE etc.) signals and 2 channel oscilloscope
- Demonstration 60 GHz OMNIRADAR measurement using 4 GHz oscilloscope

Agenda



- **Oscilloscope as Spectrum Analyzer**
  - **RF specifications for Oscilloscopes: Noise floor, Signal to Noise, phase noise**
- Demonstration measuring Amplifier AM/PM, AM/AM & gain compression
  - using complex modulated (WLAN, LTE etc.) signals and 2 channel oscilloscope
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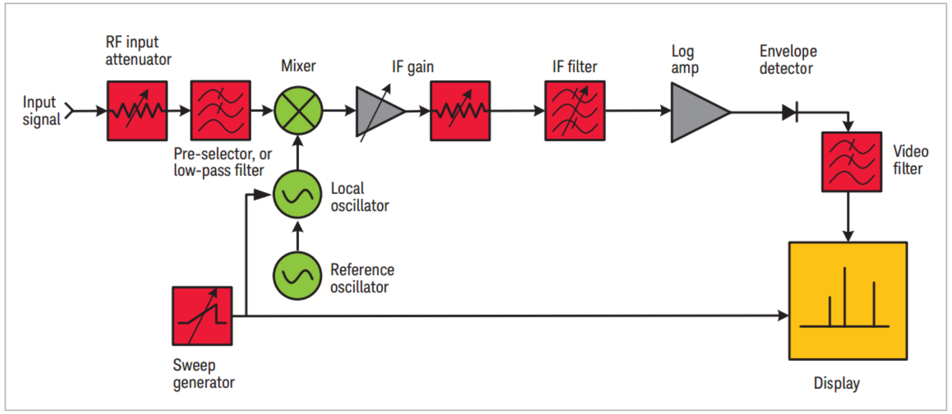
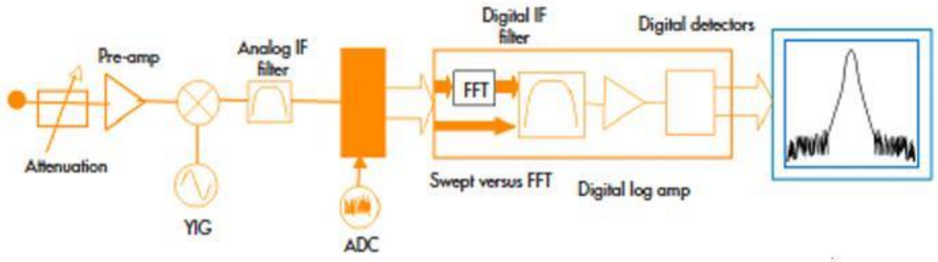
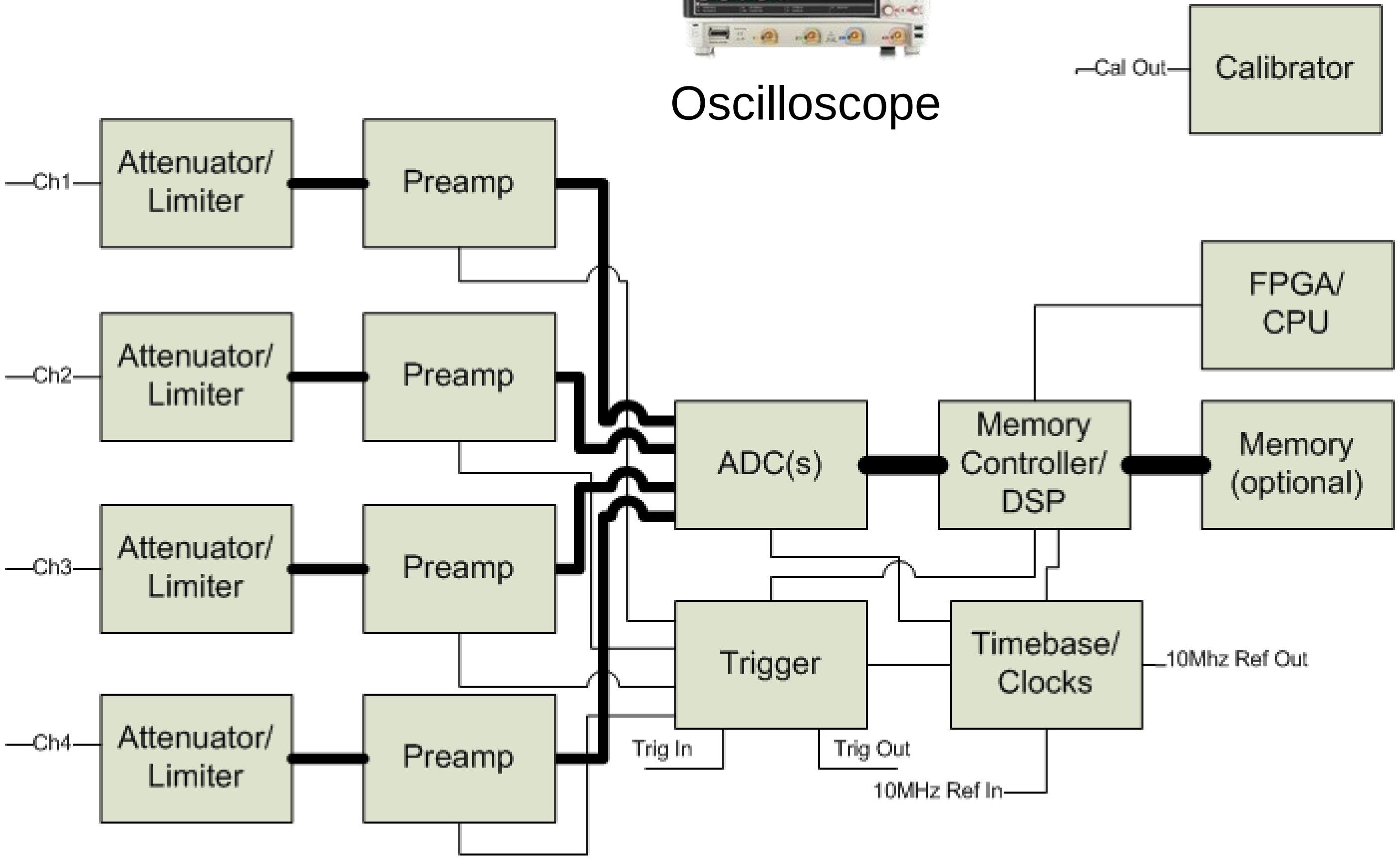
Block Diagram: Spectrum Analyzer vs Real-Time Oscilloscope

Spectrum Analyzer





Oscilloscope



Oscilloscope Noise Floor: Getting Noise Density from Data Sheet V_{rms} Noise

From S-Series Data (8 GHz model)

50 mV/div and 8 GHz BW →

S-804A	V/div	dBm Ref Level	dBm/Hz Noise
260 uV	1mV/div	-28 dBm	-158 dBm/Hz **
260 uV	2mV/div	-28 dBm	-158 dBm/Hz
320 uV	5mV/div	-24 dBm	-156 dBm/Hz
390 uV	10mV/div	-18 dBm	-154 dBm/Hz
620 uV	20mV/div	-12 dBm	-150 dBm/Hz
1.4 mV	50mV/div	-4 dBm	-143 dBm/Hz
3.1 mV	100mV/div	+2 dBm	-136 dBm/Hz
6.4 mV	200mV/div	+6 dBm	-130 dBm/Hz
13.3 mV	500mV/div	+16 dBm	-124 dBm/Hz
24.1 mV	1V/div	+22 dBm	-118 dBm/Hz

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

1.4mV rms noise:
(1.4mV x 1.4 mV) / 50 = 0.000392 mW
10*log(0.000392) = -44 dBm

-44dBm spread/divided over 8GHz bandwidth
-44dBm – 10log(8E09) =
-143dBm/Hz noise density

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Oscilloscope Noise Density (dBm/Hz) from Vrms Noise

Example S series oscilloscopes (20 Gsample/sec, 10 bit)

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 uV	90 uV	120 uV	130 uV	153 uV	195 uV	260 uV
2 mV/div	74 uV	90 uV	120 uV	130 uV	153 uV	195 uV	260 uV
5 mV/div	77 uV	94 uV	129 uV	135 uV	173 uV	205 uV	320 uV
10 mV/div	87 uV	110 uV	163 uV	172 uV	220 uV	256 uV	390 uV
20 mV/div	125 uV	163 uV	233 uV	254 uV	330 uV	446 uV	620 uV
50 mV/div	372 uV	456 uV	610 uV	650 uV	768 uV	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.
4mV rms noise = -44dBm @ 8GHz = -143dBm/Hz

Oscilloscope Noise Density (dBm/Hz) from Vrms Noise

Example V series oscilloscopes (80 Gsample/sec, 8 bit)

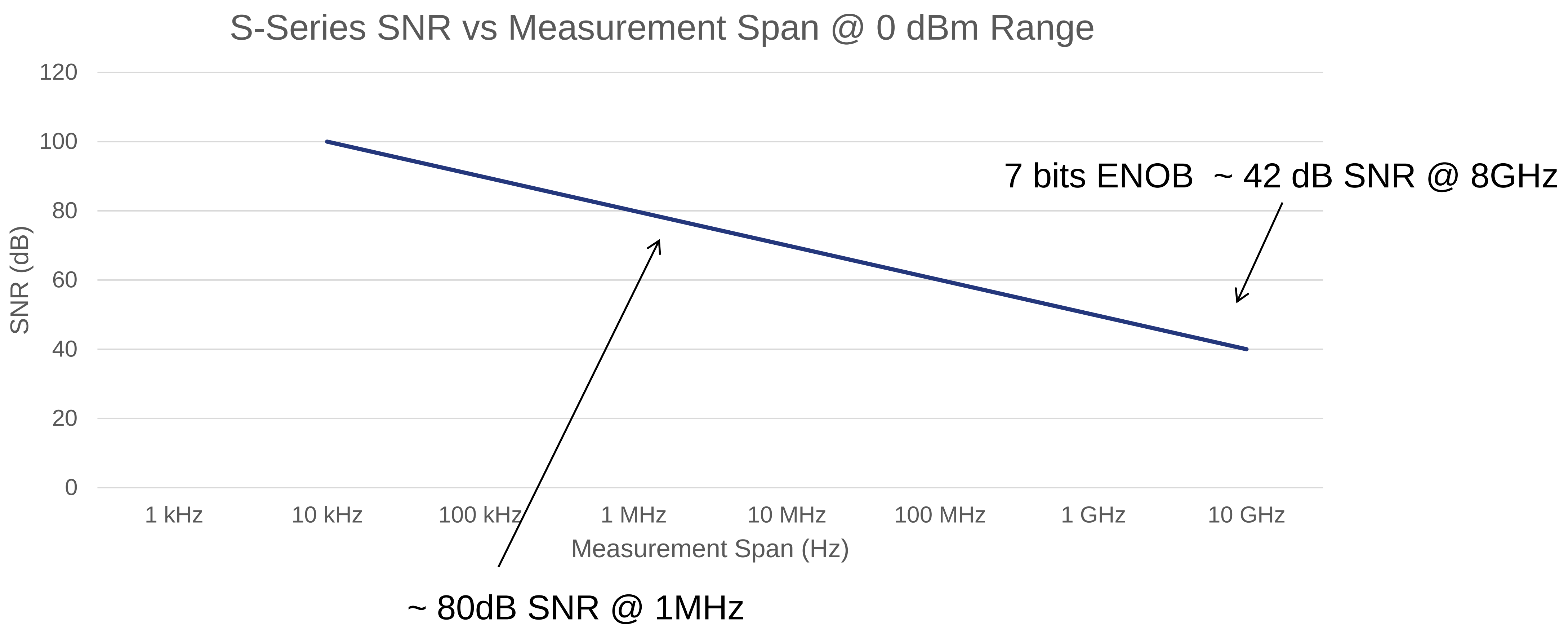
Translated (calculated) to RF-terms
(33 GHz Model Only)

From V-Series Datasheet.

RMS noise floor (oscilloscope only) Vertical setting (mVrms)	V084A 8 GHz	V134A 13 GHz	V164A 16 GHz	V204A 20 GHz	V254A 25 GHz	V334A 33 GHz	dBm Ref Level	dBm/Hz Noise
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

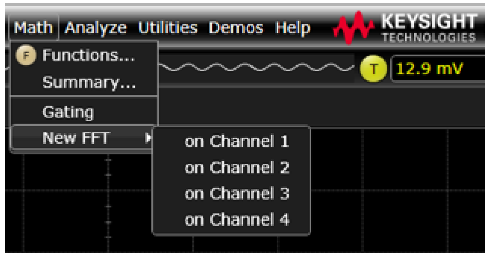
50mV/div = 400mV full scale (Vpp) = -4dBm range.
2.09 mV rms noise = -40.6 dBm - 10log(33e9) = -146 dBm/Hz

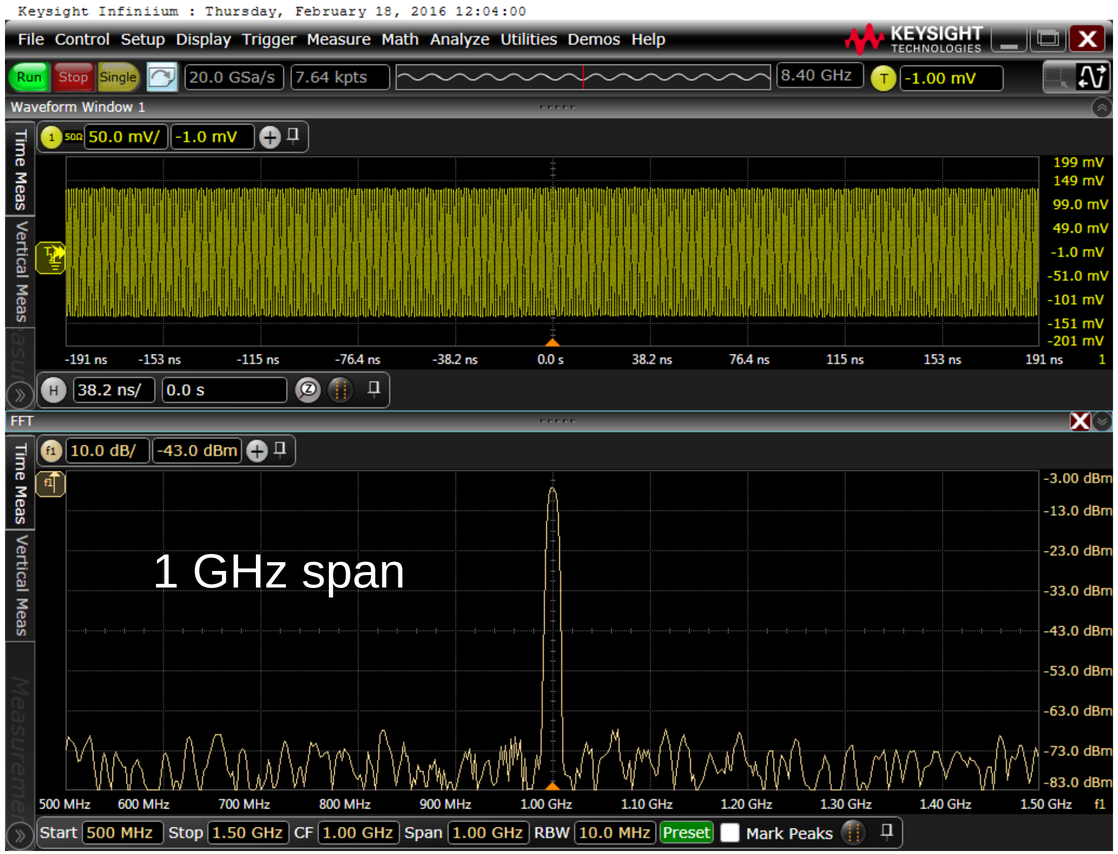
Signal to Noise Ratio: Dependent on Measurement Span

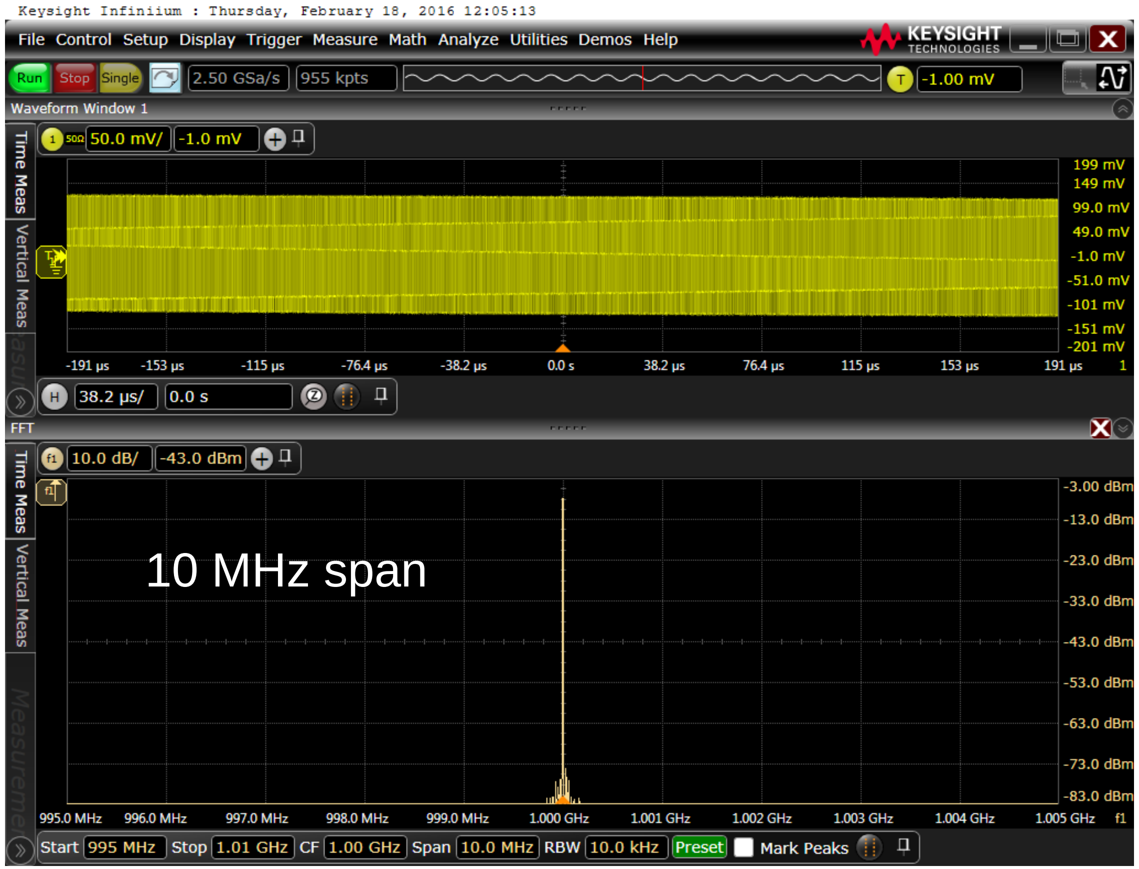


Screenshots Signal to Noise Ratio on S series scope

Measurements on a 1 GHz sinewave. Notice different spans & rbw

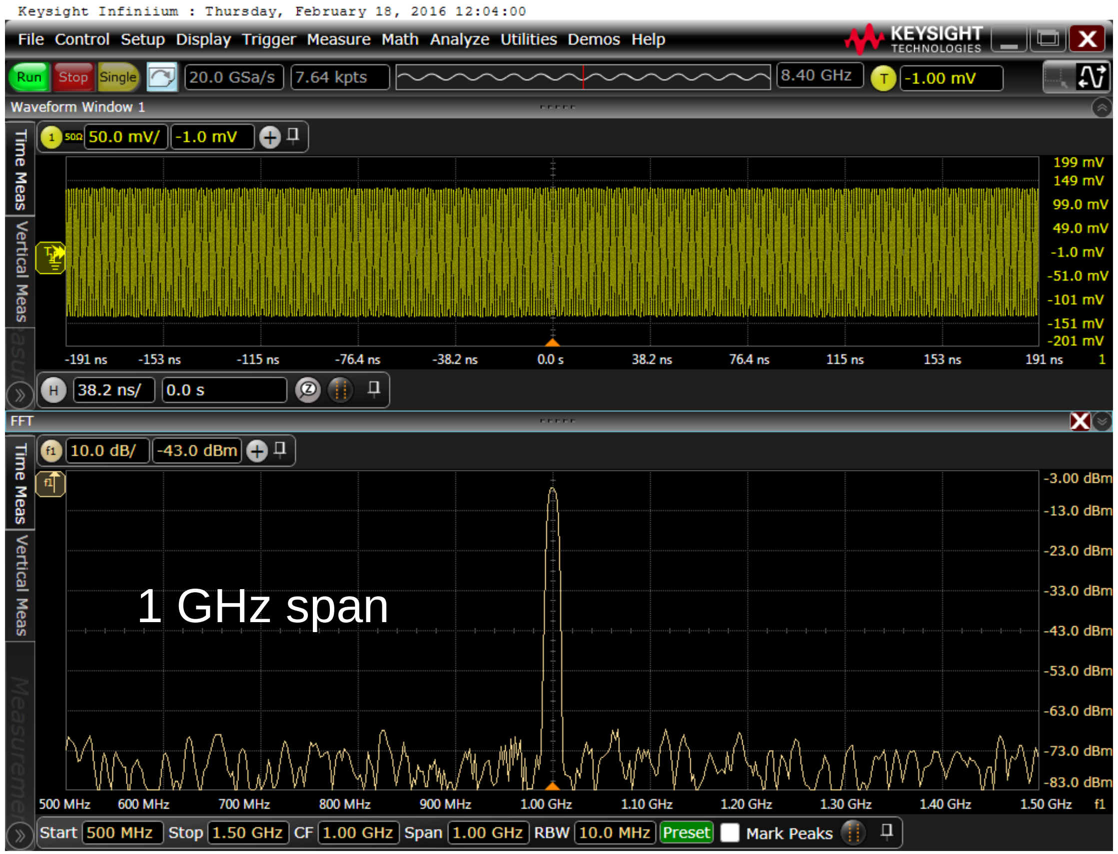


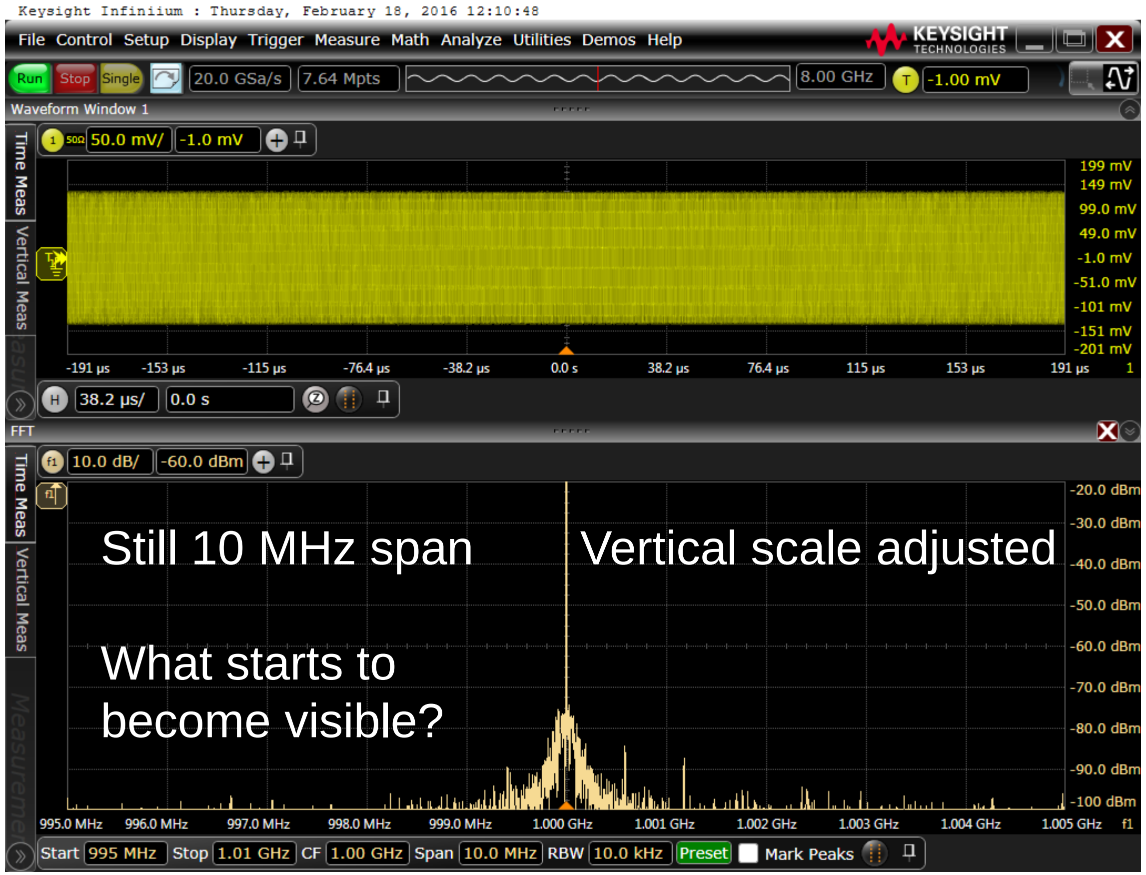




Screenshots Signal to Noise Ratio on S series scope

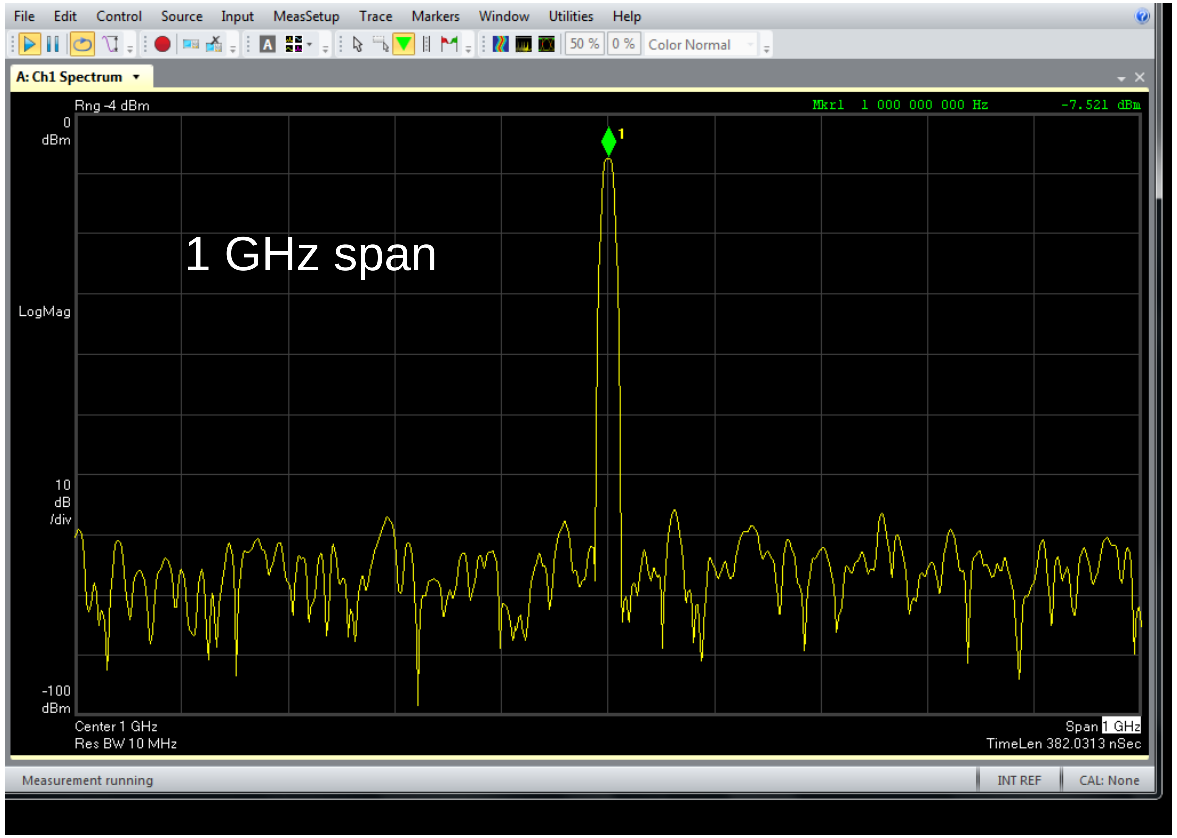
Measurements on a 1 GHz sinewave. Notice different spans & rbw

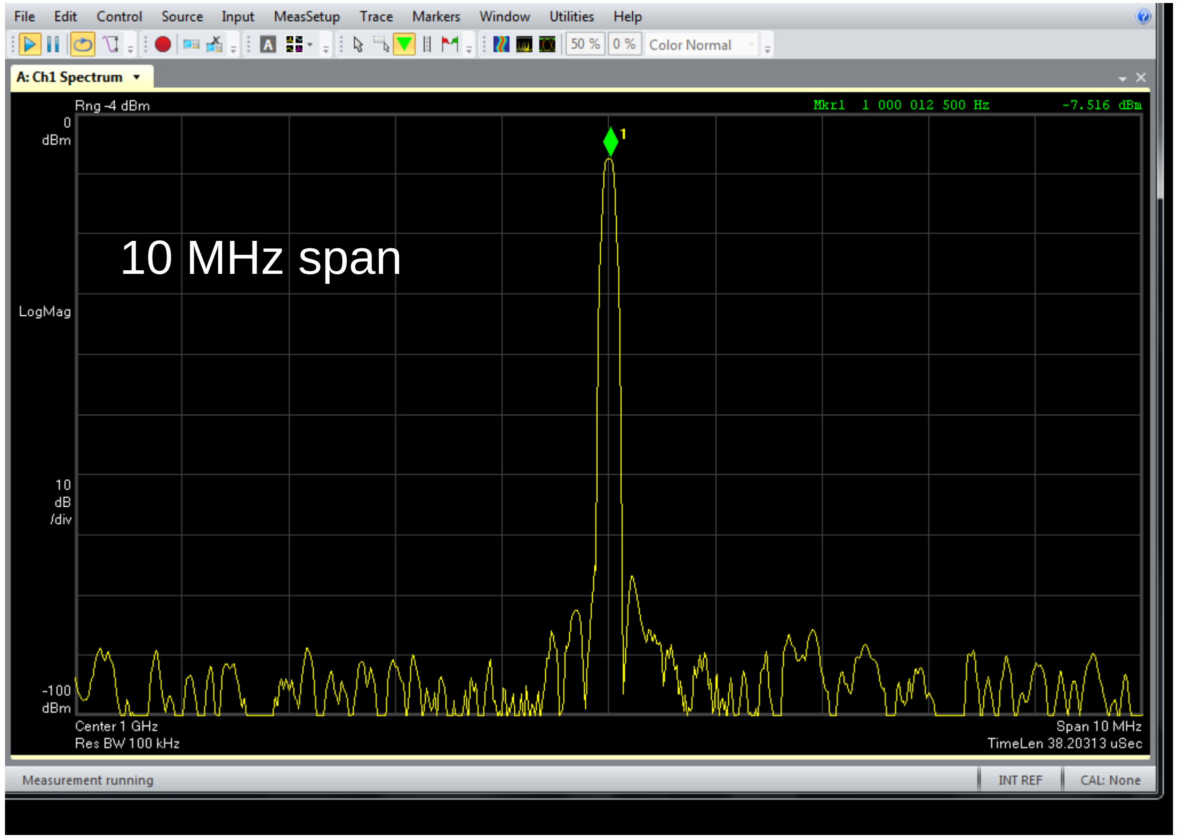




VSA 89601B Screenshots: Signal to Noise Ratio on S series scope

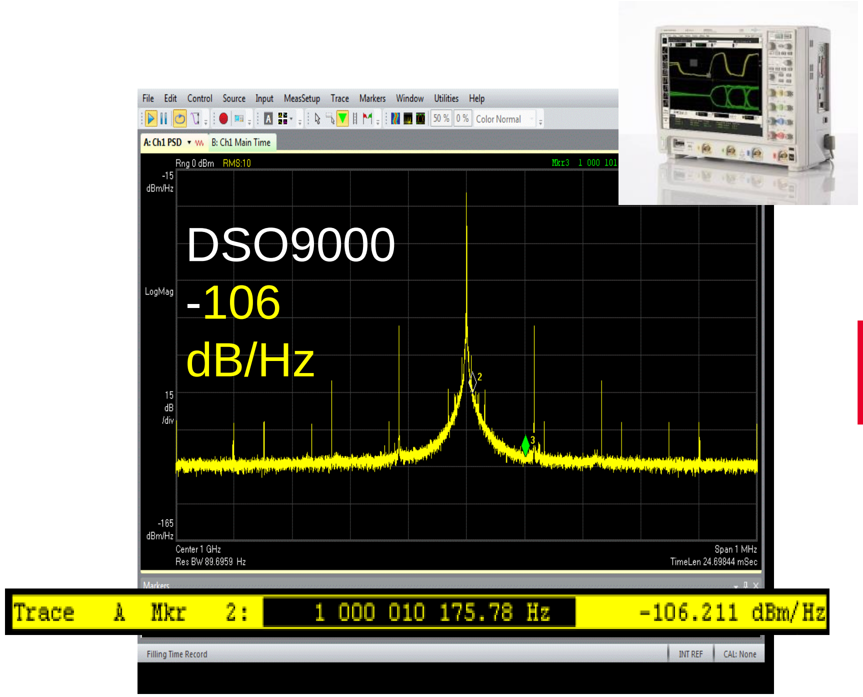
Same measurements on a 1 GHz sinewave. Using 89601B + Oscilloscope





Oscilloscope Phase Noise: Improvements over 1 Generation

Phase Noise Example



RF specifications listed in oscilloscope datasheet

Page 14 datasheet Keysight Infiniium S-Series

Oscilloscope Overview - Frequency Domain

Trying to interpret traditional oscilloscope time-domain specifications can be challenging in determining if a specific scope can be recommended for RF/uW/mmW measurements. With correction filters, low-noise front end, and the 10-bit ADC, S-Series oscilloscopes can be used for wideband RF applications. Typical RF characteristics for the S-Series are listed below with graphs showing characterization results shown at the bottom of the page.

Typical RF characteristic values from measured results on an 8-GHz S-Series oscilloscope	
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)	± 1 dB
Deviation from linear phase (0 to 7.5 GHz)	± 7 deg
Phase noise (at 1 GHz) 10 KHz offset 100 KHz offset	 -121 dBc/Hz -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 (TOI) distortion 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, 0-7 GHz) (>= 50 mV/div, 0-7 GHz)	 -15 dB; 1.4 VSWR -19 dB; 1.25 VSWR

"Spectrum analyzer RF language" in an Oscilloscope time domain environment

Oscilloscope portfolio 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

Refer to respective data sheets for measurement conditions.

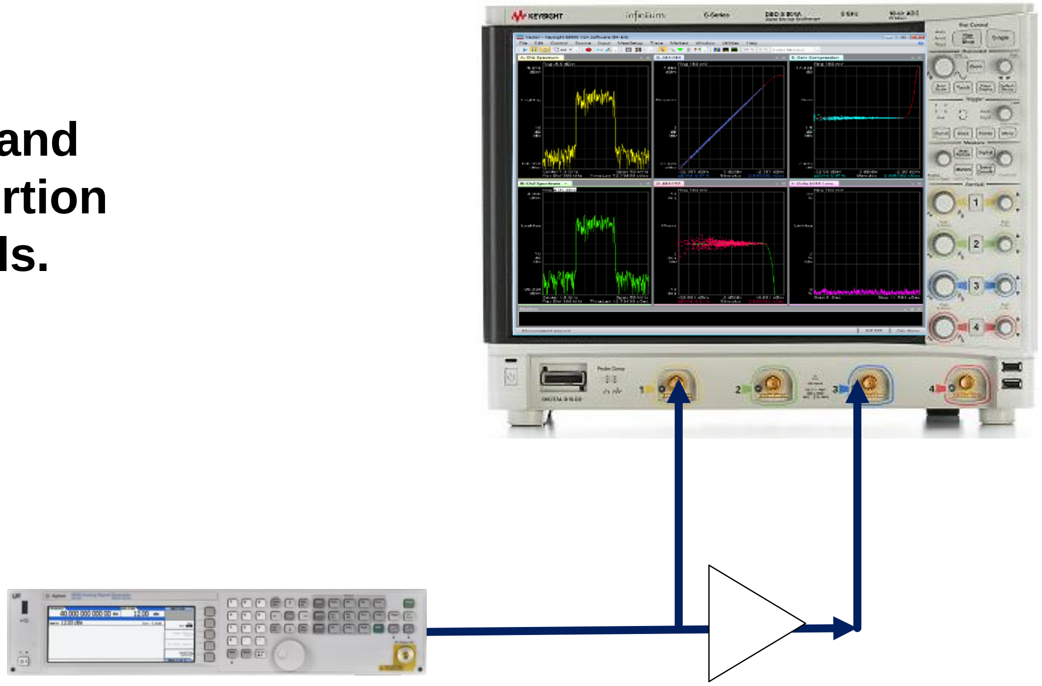
Agenda

- Oscilloscope as Spectrum Analyzer
  - RF specifications for Oscilloscopes: Noise floor, Signal to Noise, phase noise
- **Demonstration measuring Amplifier**
  - **Spectrum**
  - **AM/PM, AM/AM & gain compression using complex modulated (WLAN, LTE etc.) signals and 2 channel oscilloscope**
- Demonstration 60 GHz OMNIRADAR measurement using 4 GHz oscilloscope

Power Amplifier Distortion Analysis

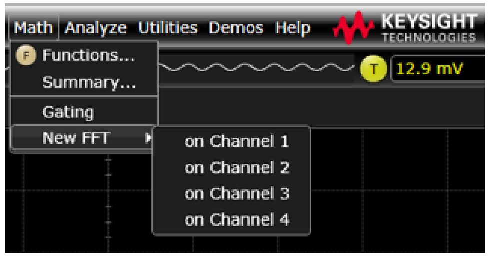
– Generate and measure the same signals that are going to be used with the DUT

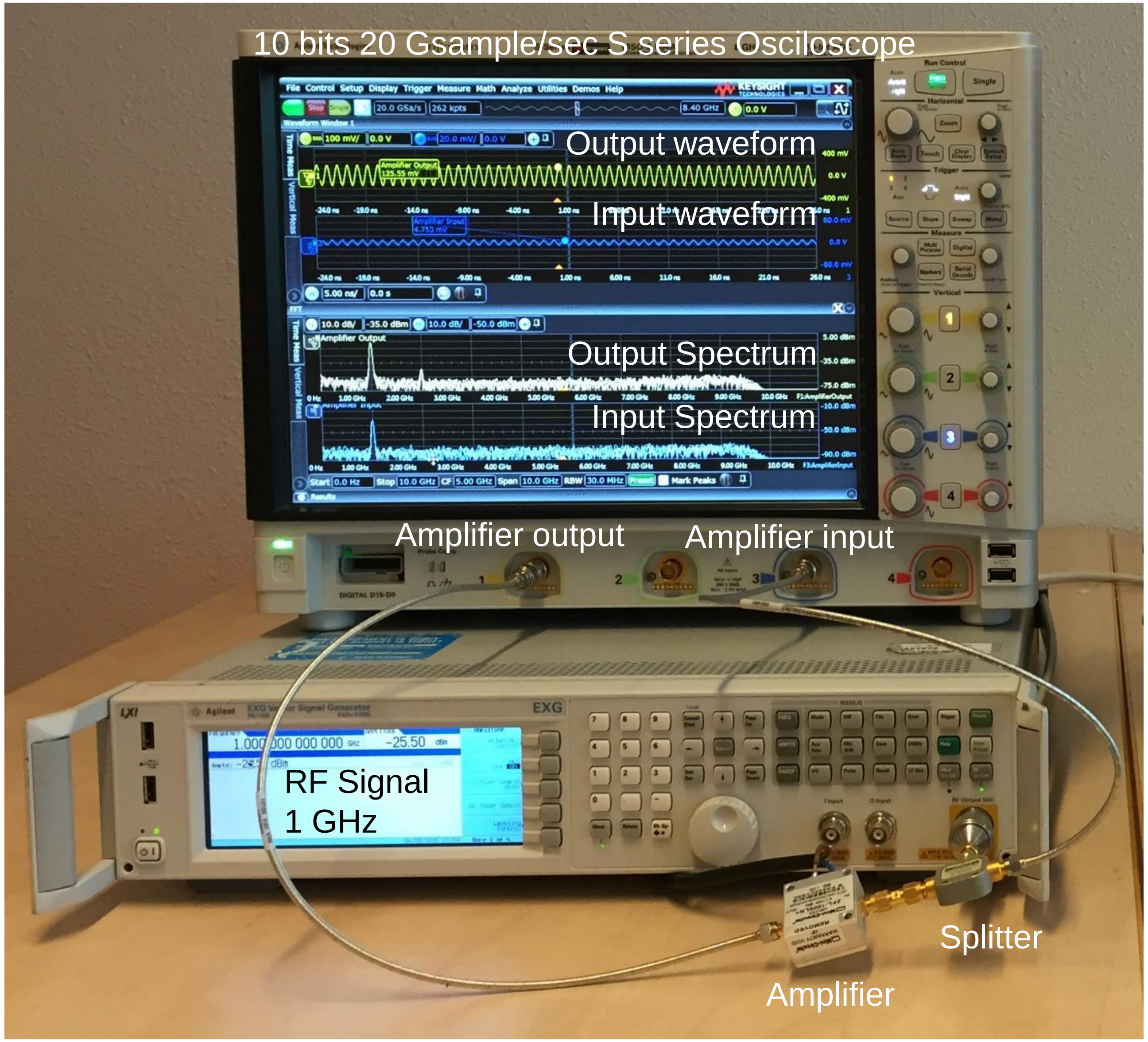
– **A scope can monitor modulated input and output waveforms to provide live distortion measurements using real- world signals.**



Customer PA/DUT for analysis

Demonstration Amplifier Distortion



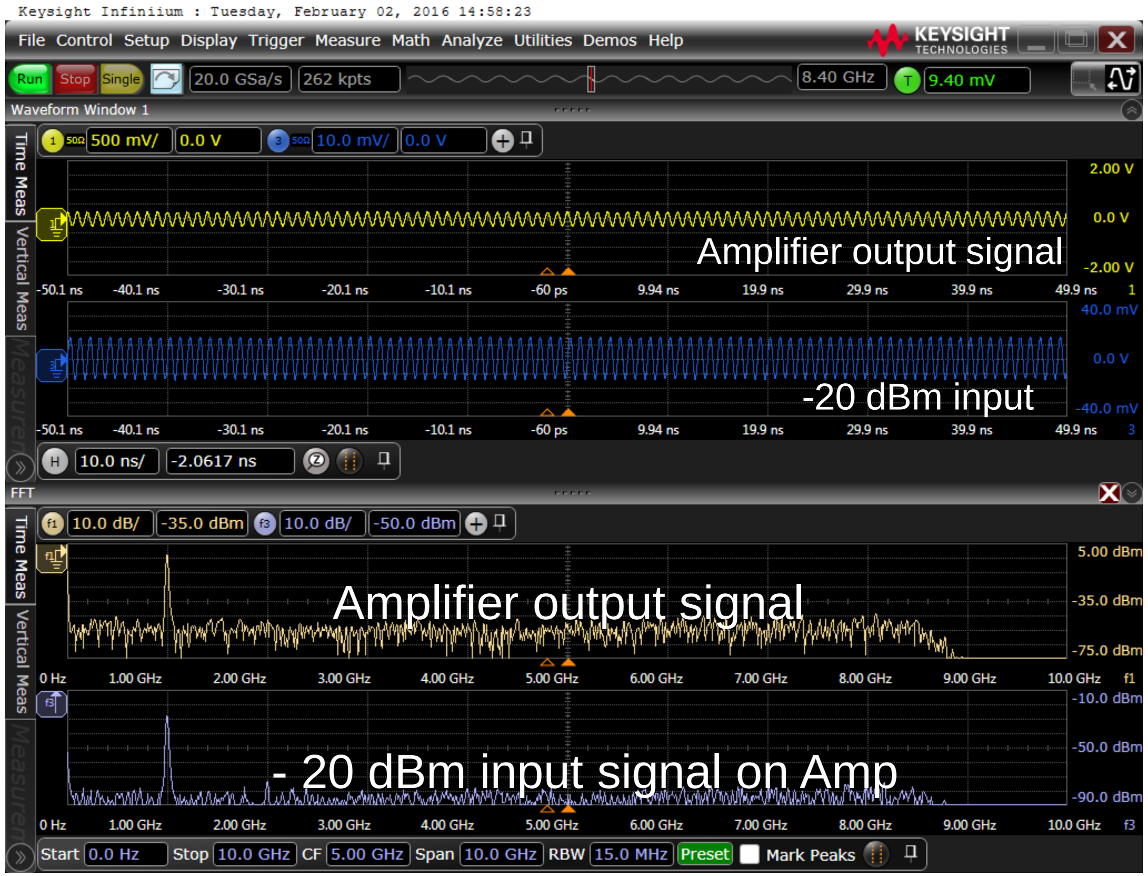


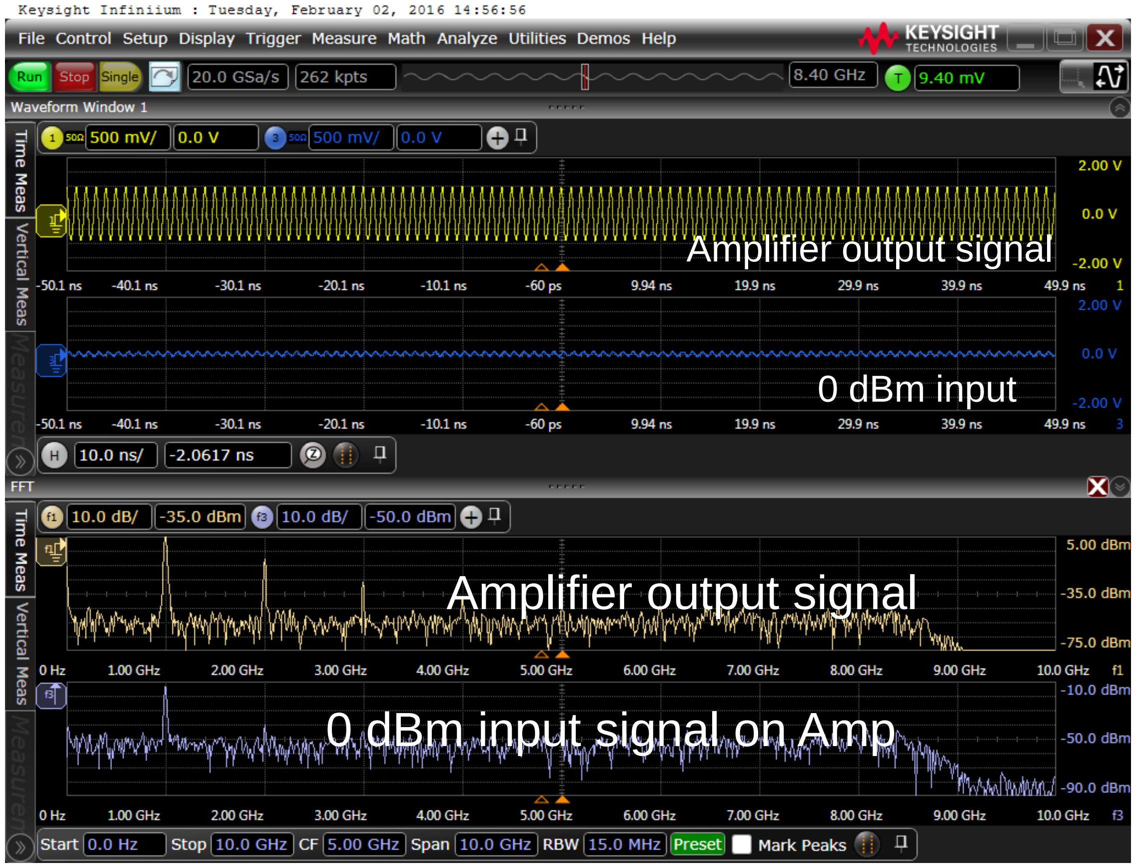
Amplifier Distortion

in the frequency Domain

Demo Amplifier Distortion: 1 GHz sinewave

Distortion Test using Scope only

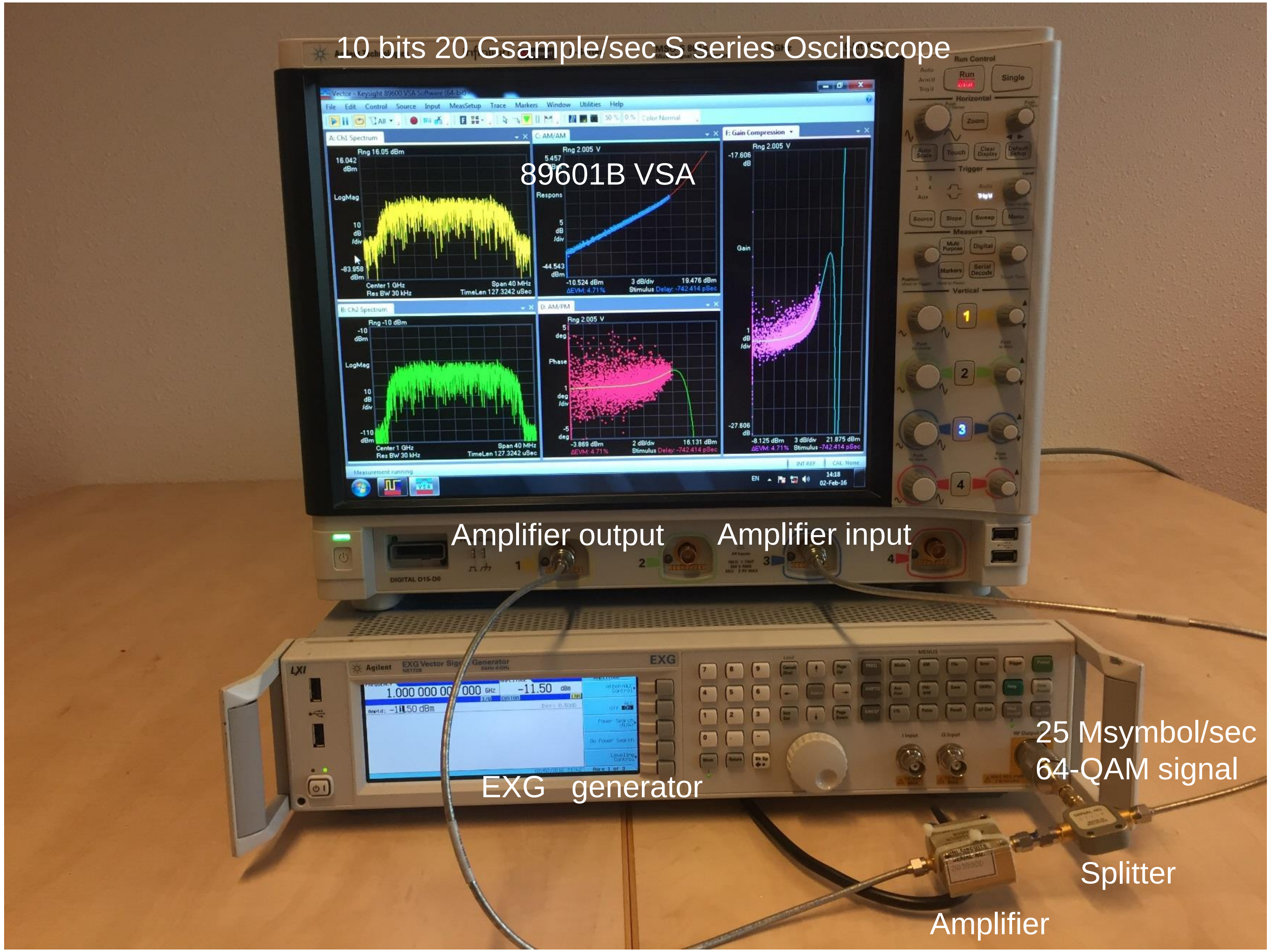




Demonstration Amplifier Distortion

Amplifier Distortion Test

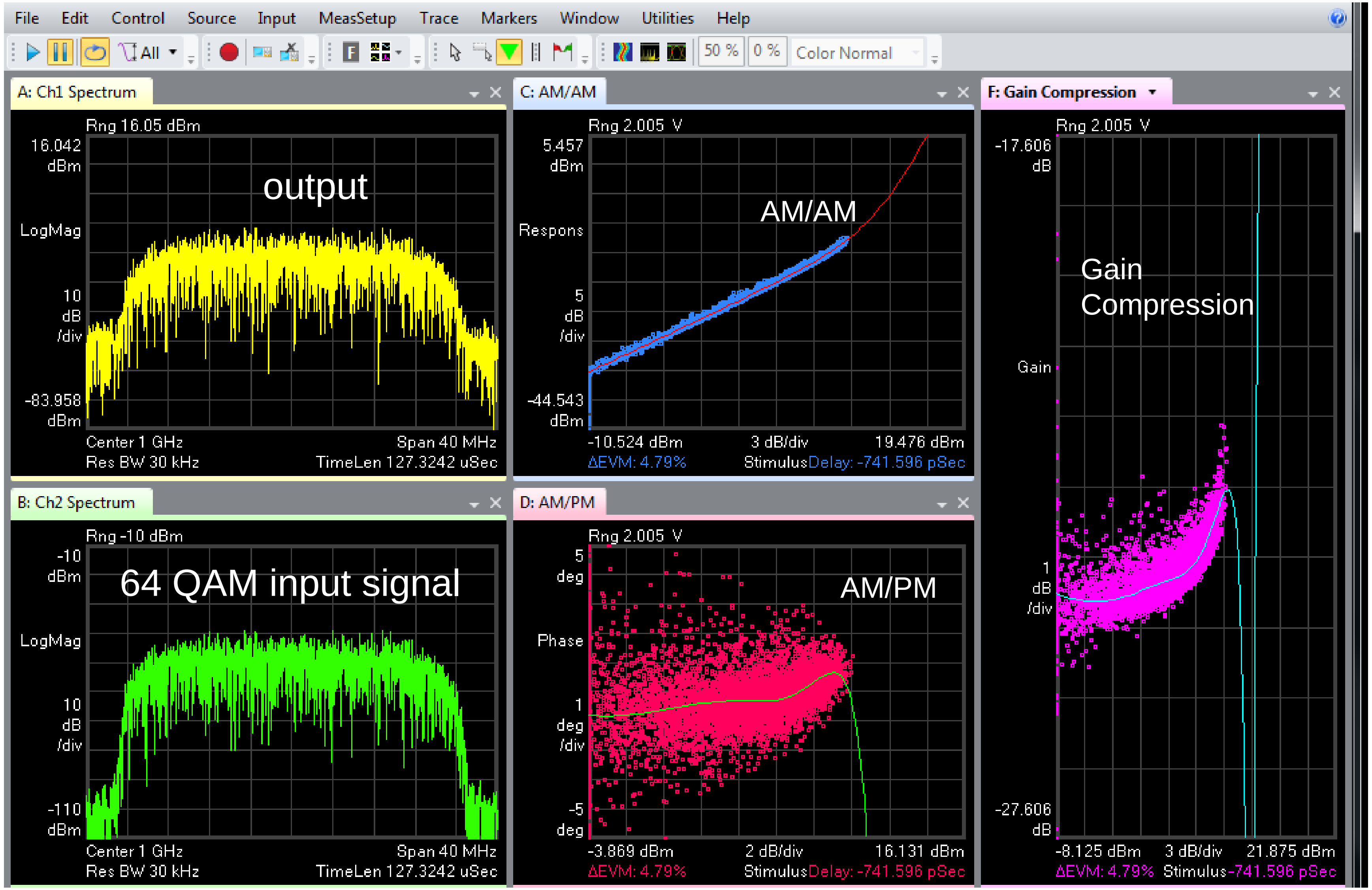
using VSA+ Scope



KEYSIGHT TECHNOLOGIES

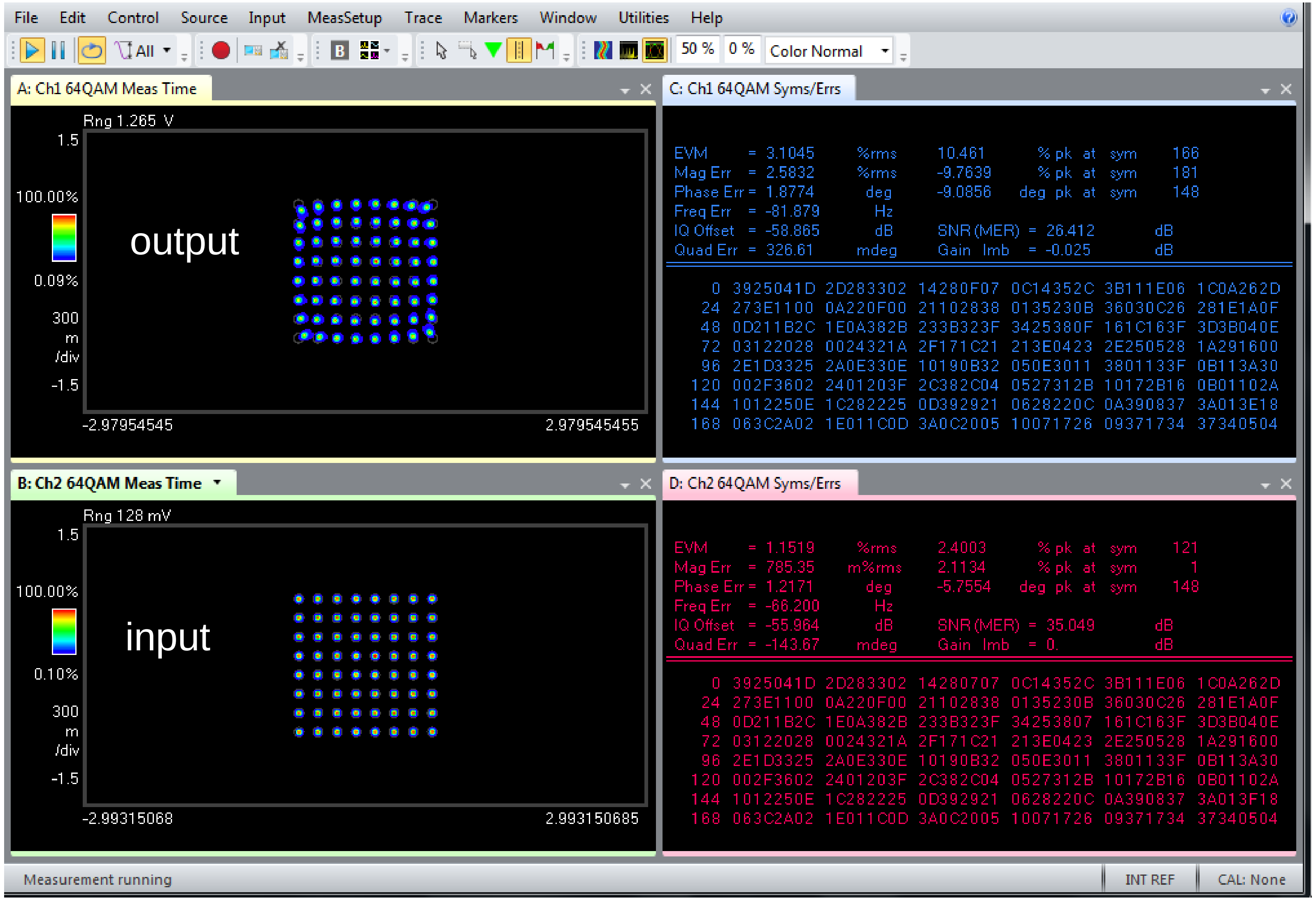
Demo Amplifier Distortion: 64-QAM signal

Distortion Test using Oscilloscope + 89601B VSA software



Amplifier Compression visible in constellation plane

1 GHz RF carrier with 64-QAM 25 Msymbols/sec on Amplifier input



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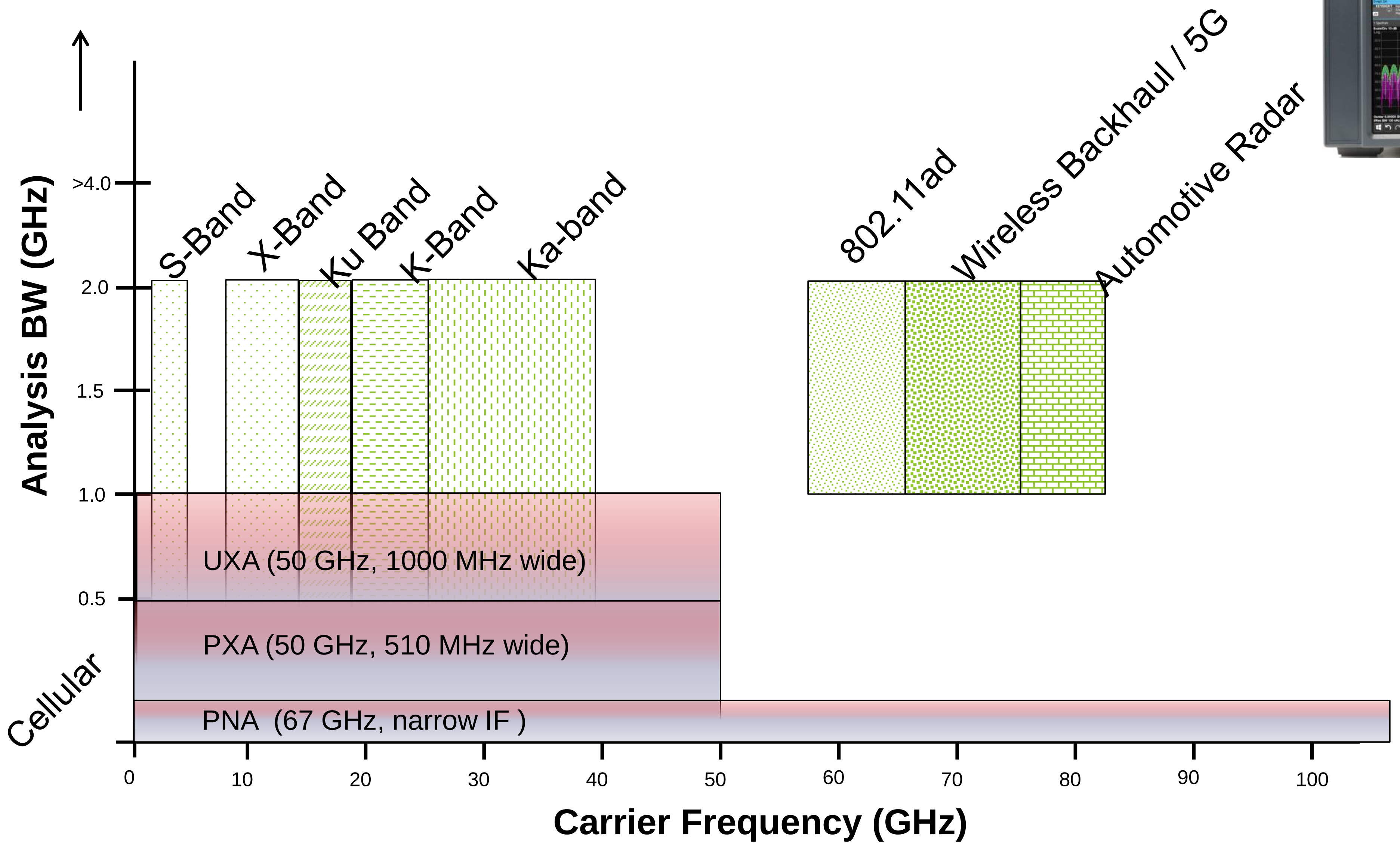
- **Demonstration 60 GHz OMNIRADAR band measurement using 4 GHz oscilloscope**

Wideband Applications & Spectrum Analyzers

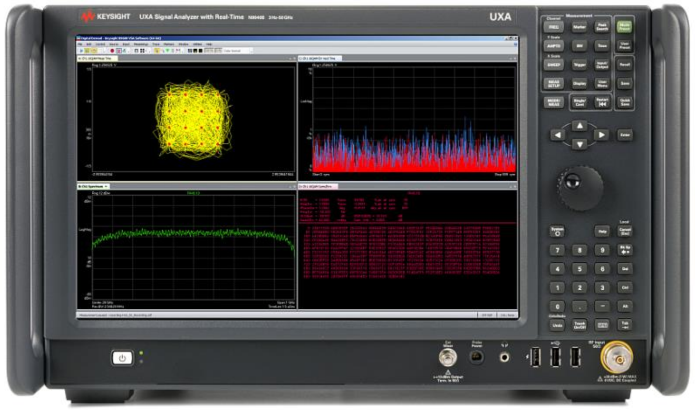


Wider Signals With Spectrum Analyzers

Simplifying analysis of the latest wideband signals

– **New: 1 GHz analysis bandwidth on 50 GHz UXA**

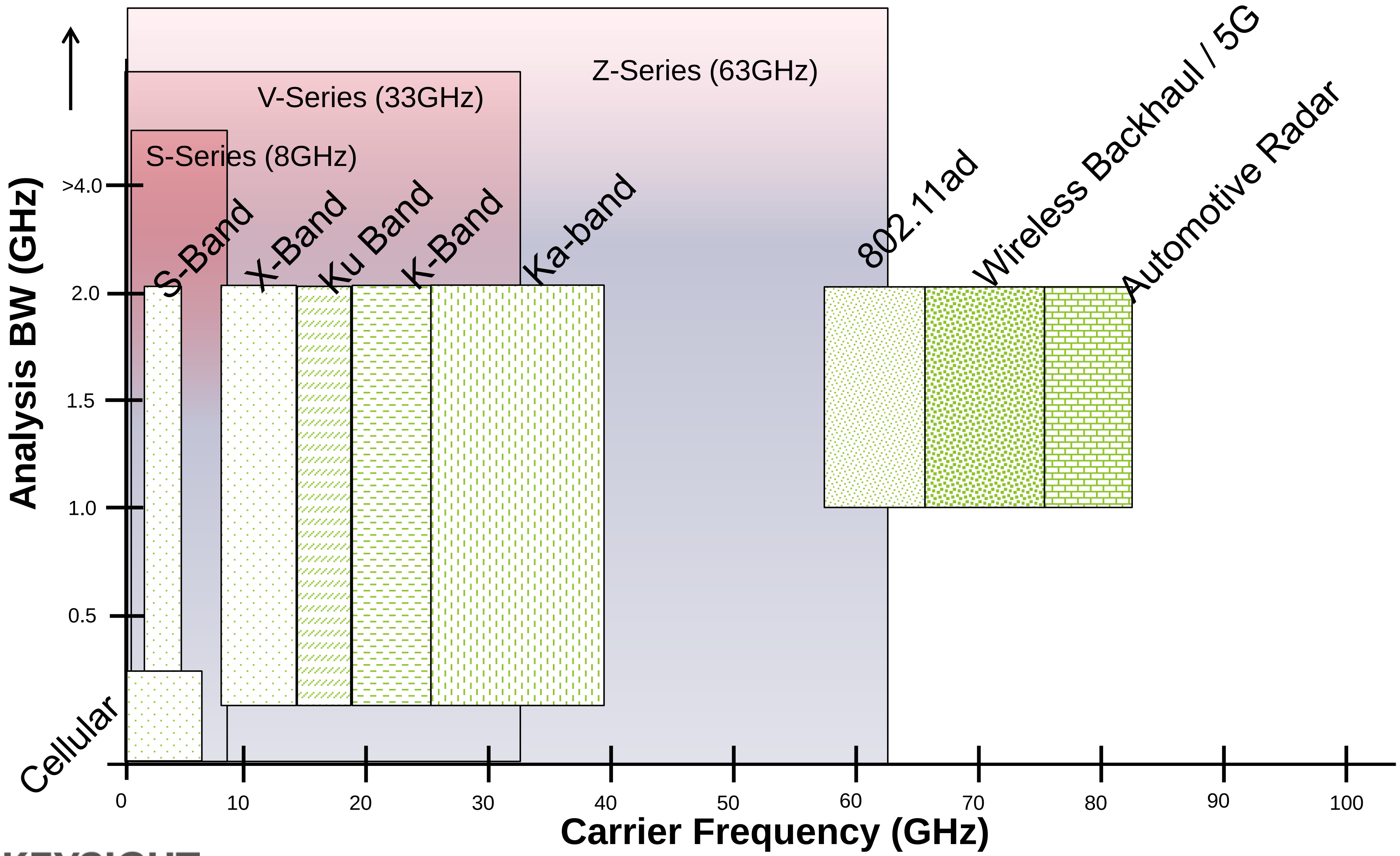
- Widest signal analyzer BW on market
- Fully integrated to minimize setup complexity and footprint
- Factory-calibrated IF phase & magnitude for better EVM measurements



– **New**: **255 and 510 MHz analysis bandwidth on 50 GHz PXA**

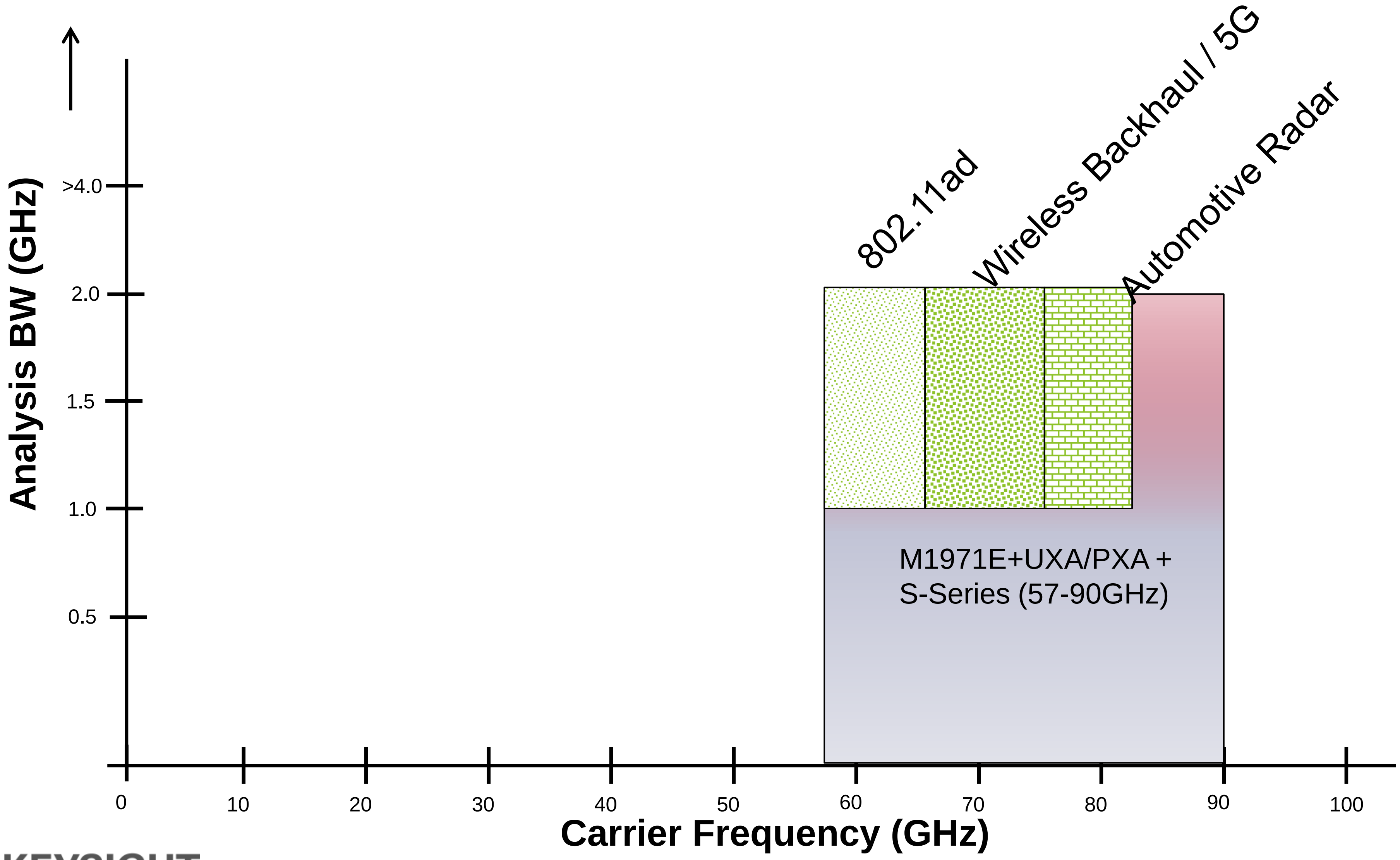
- Widest bandwidth in compact classic 4U form-factor for drop-in legacy replacement

Wideband Applications & Oscilloscopes



Note: Keysight is working on 10 bit 100 GHz oscilloscopes to be released in 2017

Wideband Applications & Smart Mixers



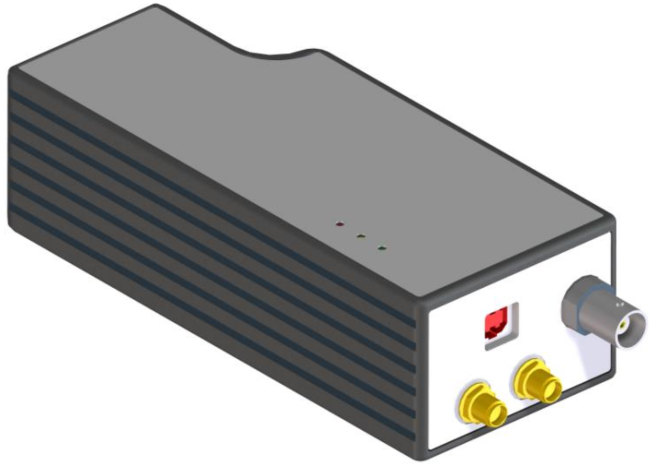
E-Band WB smart mixers

Short uWave cable = less cable loss

Model #: M1971E

To complete wide bandwidth mm- Wave analysis

E-band Extended Bandwidth "Smart" USB Mixers

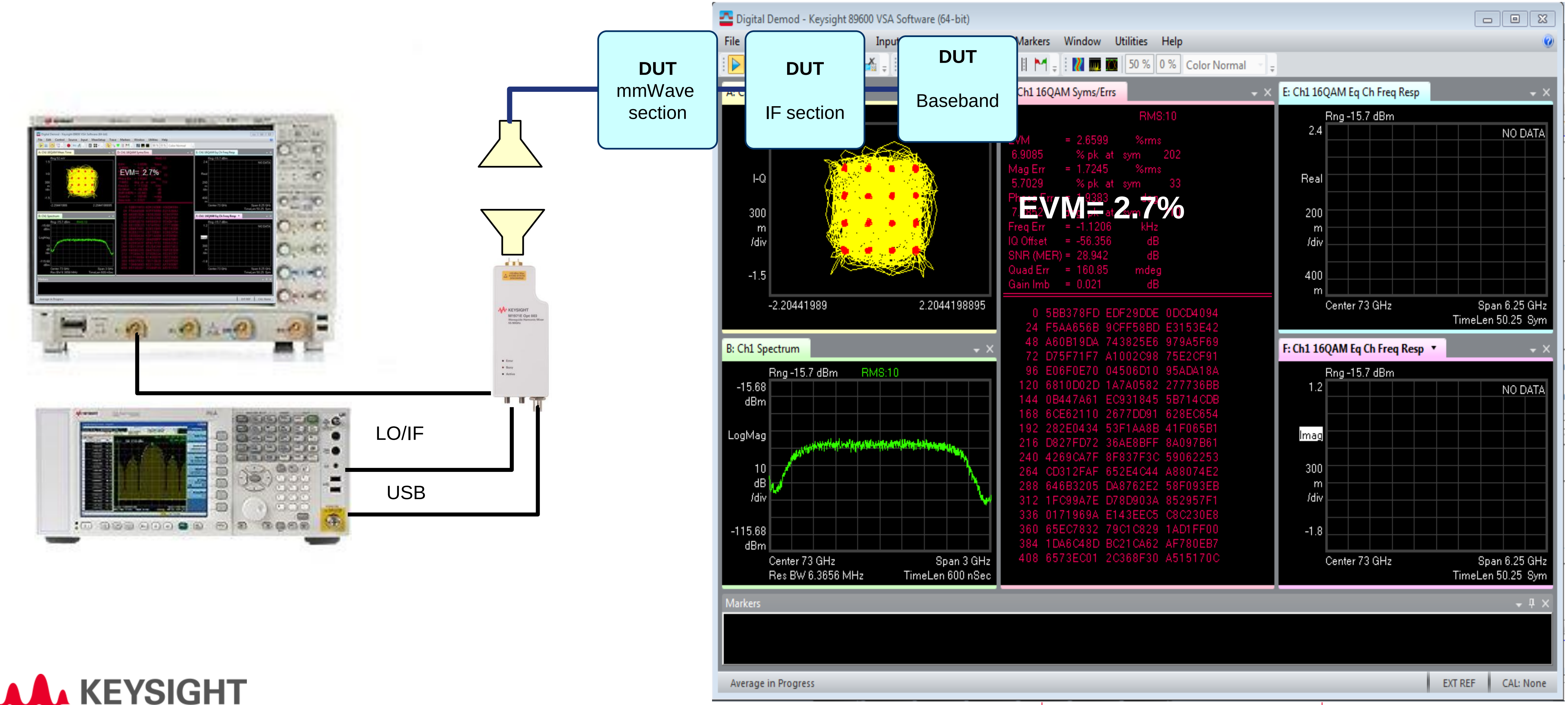


Application: Wide bandwidth (2 GHz) modulation for the following segments :

- **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**

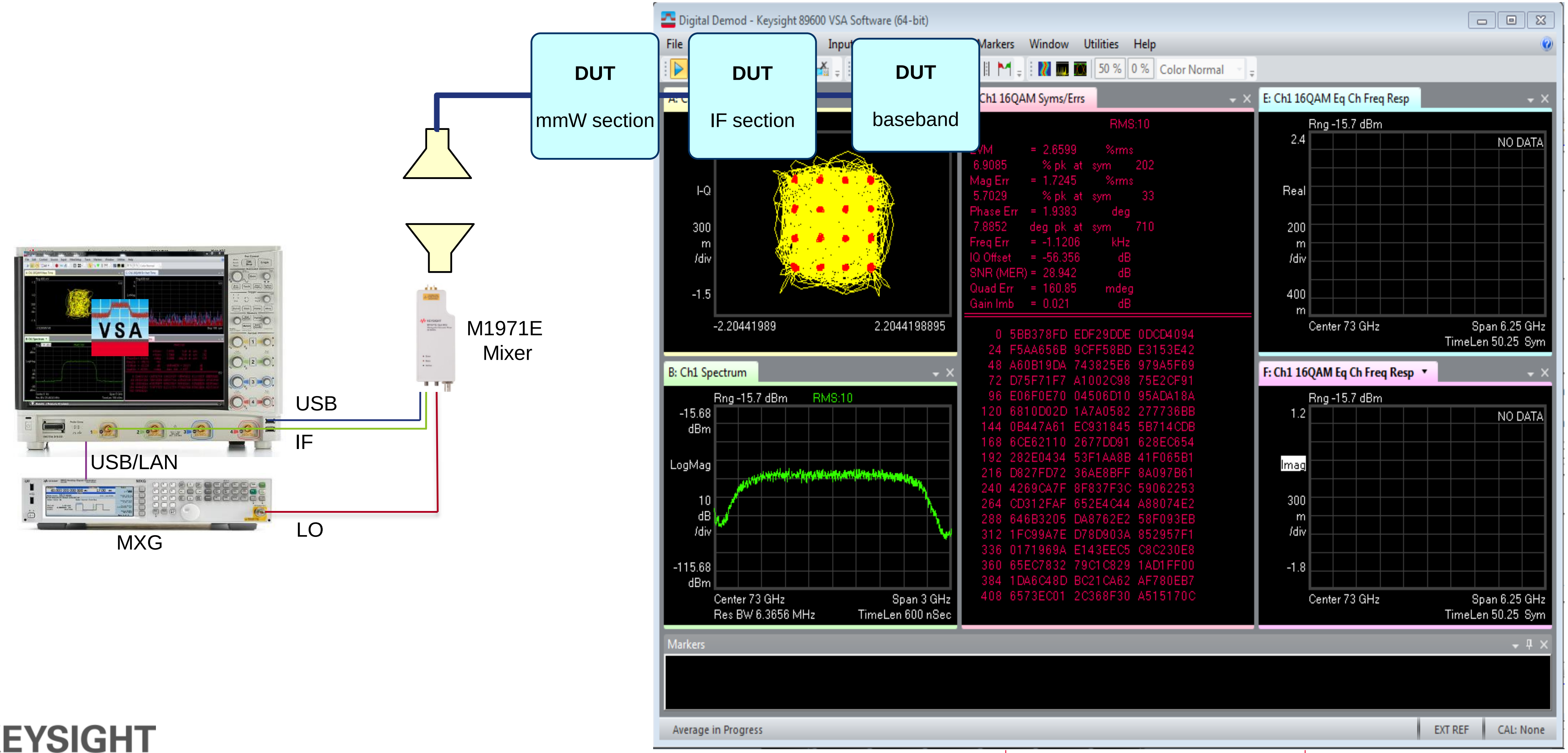
Configuration1: Mixer + SA + Scope for E-Band 60-90 GHz

73 GHz Measurements

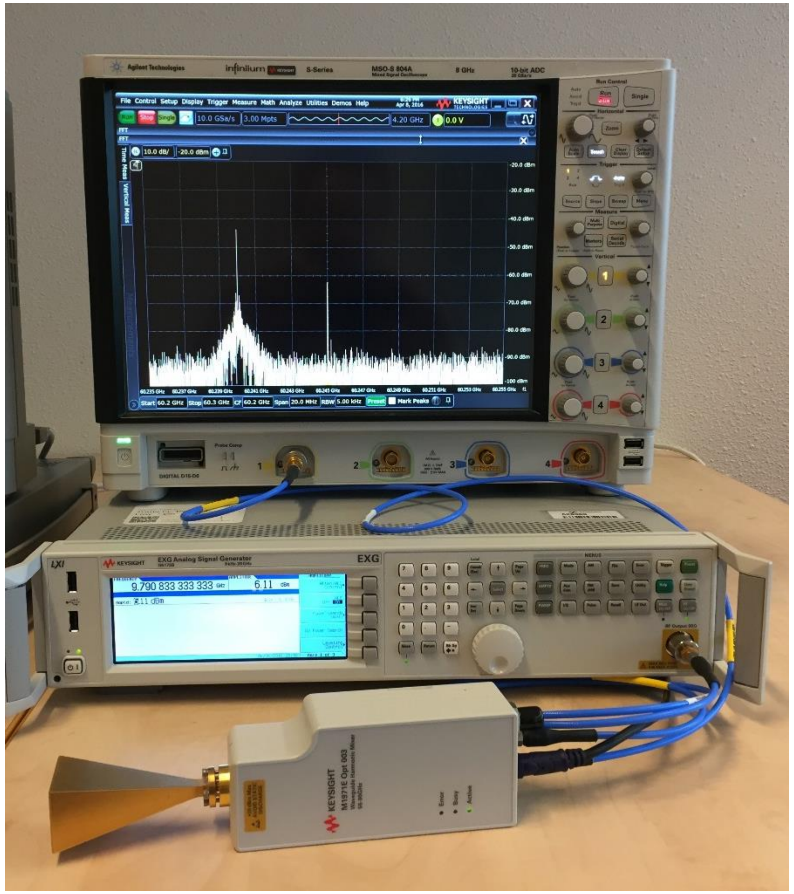


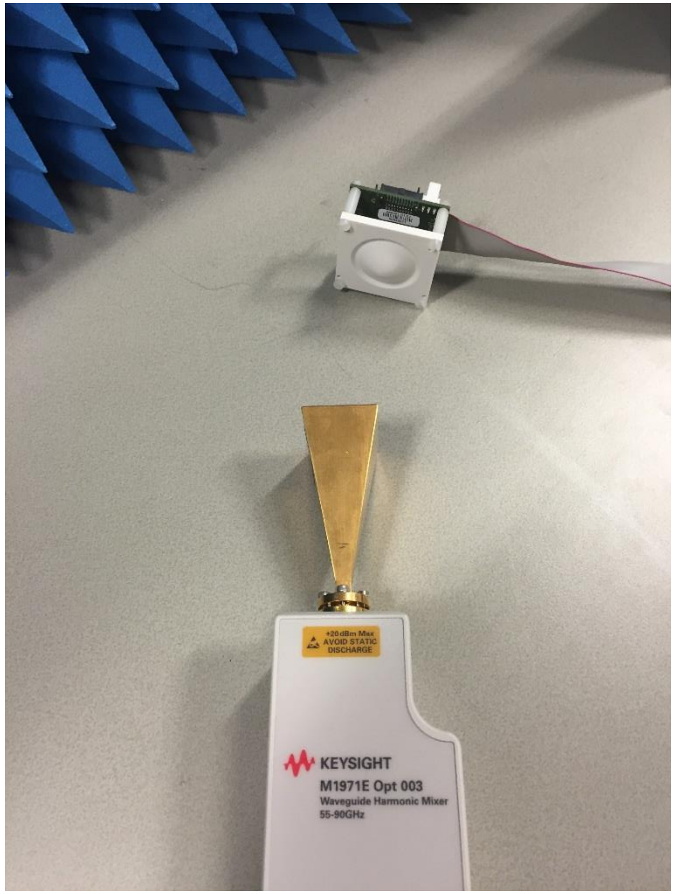
Configuration2: Mixer + Sig gen + Scope for E-Band 60-90 GHz

73 GHz Measurements



Demonstration 60 GHz OMNIRADAR radar measurement





OMNIRADAR evaluation kit

Operated by Timofey Savelyev

Radar System Architect

Omniradar Eindhoven office

Timofey.Savelyev@omniradar.com

Conclusion

- Keysight oscilloscopes do measure very well RF signals.
- Keysight RF oscilloscopes do measure Amplifier AM/PM, AM/AM & gain compression on complex modulated (WLAN, LTE etc.) signals.
- For E band measurements (60 to 90 GHz) an 4 GHz scope and a E-band mixer provides an economic solution.
- OMNIRADAR has good FMCW and Doppler radar solutions Timofey.Savelyev@omniradar.com