5G Boot Camp

PART ONE:
7 KEY MEASUREMENT CHALLENGES AND CASE STUDIES

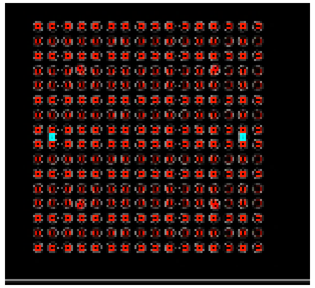
Keysight Technologies

Brian Su / Sr. Project Manager

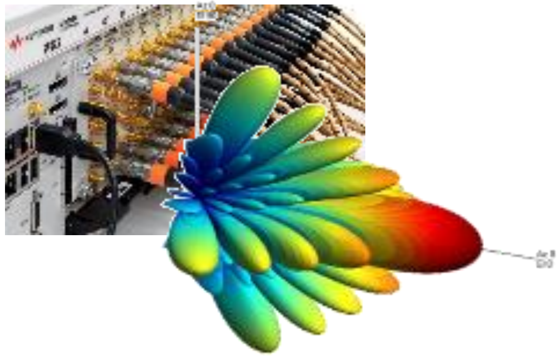
NOV. 2019

7 Key Measurement Challenges

Signal Quality
mmW, Waveform, Fidelity



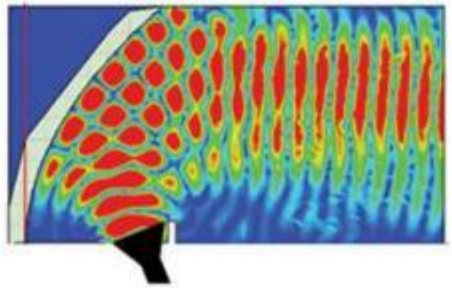
Lots of Channels
MIMO/Beamforming



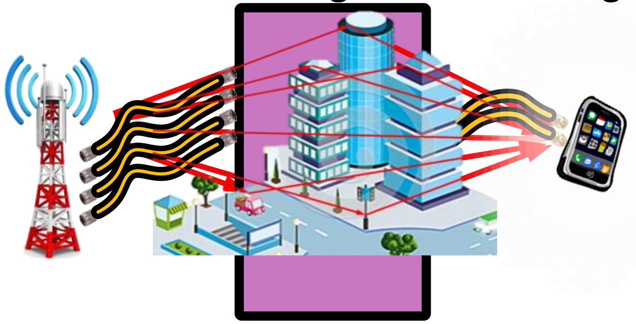
Connect Design & Test
Components, Systems

Design
Simulate
Validate
Connect
Test

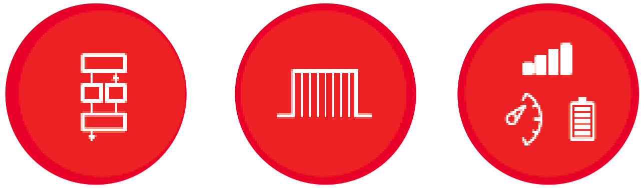
Life Beyond Connectors
Over-the-Air



Channel
Characterizing & Emulating



Performance on the Network
Network Emulation



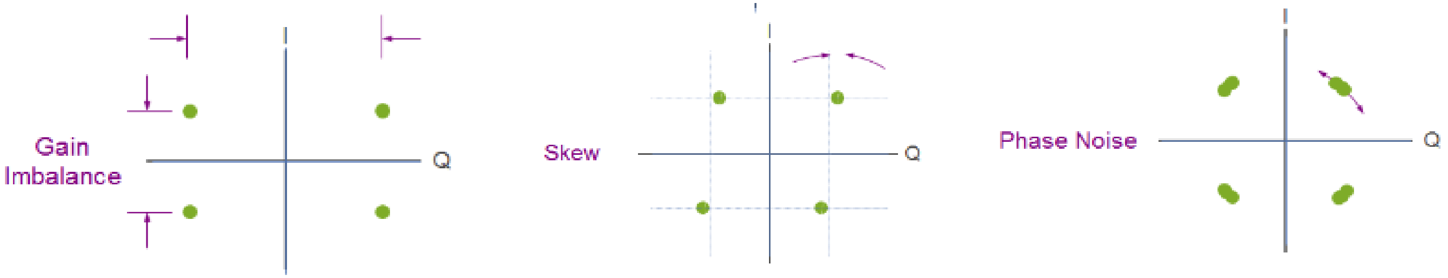
Protocol R&D
RF / RRM DVT
Functional KPI

Field Testing and Drive Test

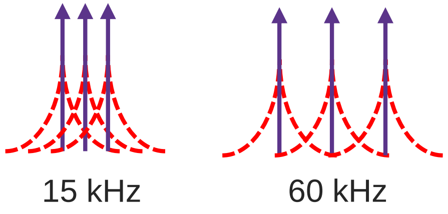
Challenge: Signal Quality and mmWave

CHALLENGES WITH MMWAVE AND BANDWIDTH

- IQ modulator errors

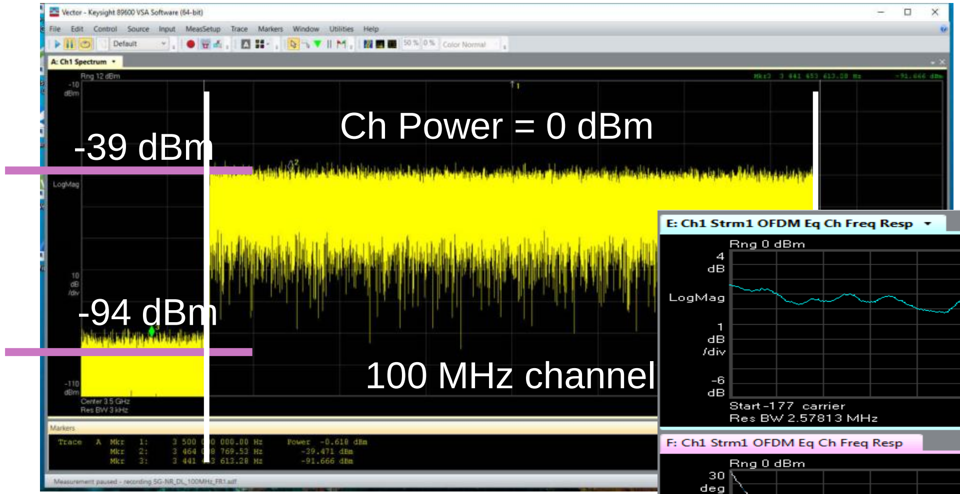


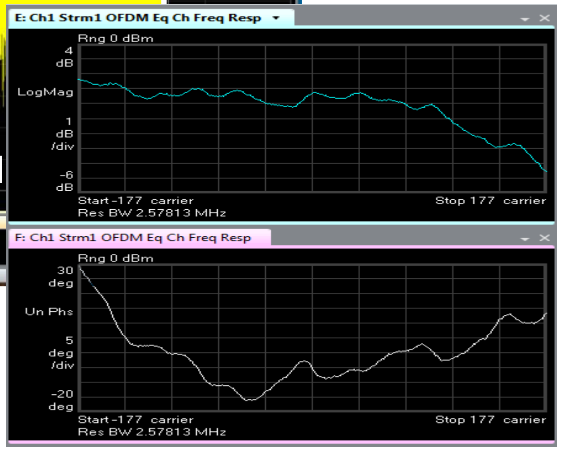
- Phase noise
  - OFDM close subcarrier spacing



- Distortion
  - Overdriving causes compression and distortion
- Signal-to-noise ratio
  - Wide BW systems with high noise figure coupled with low RF power levels
- Amplitude flatness and phase linearity
  - Frequency response of cables, gain horn, amplifiers, filters, signal generator, signal analyzer, etc.

10xLog[30 kHz/(273 PRB x 12 SC/PRB x 30 kHz)] = -35 dB





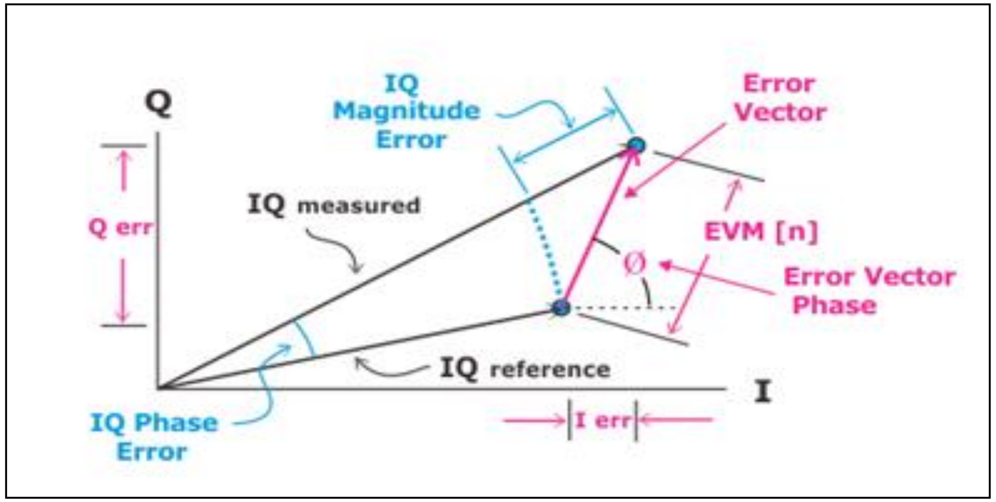
Nt = k T B (Watts) = -124 dBW

k = Boltzmann's constant = 1.38E-23 J/˚K
T = temperature in degrees Kelvin = 290 (room)
B = overall bandwidth = example 100 MHz

How Do You Know If the Signal Is Good?

EVM IS THE STANDARD MEASURE OF SIGNAL QUALITY

EVM (Error Vector Magnitude): *The normalized ratio of the difference between two vectors: IQ measured signal & IQ reference (IQ reference is calculated value)*

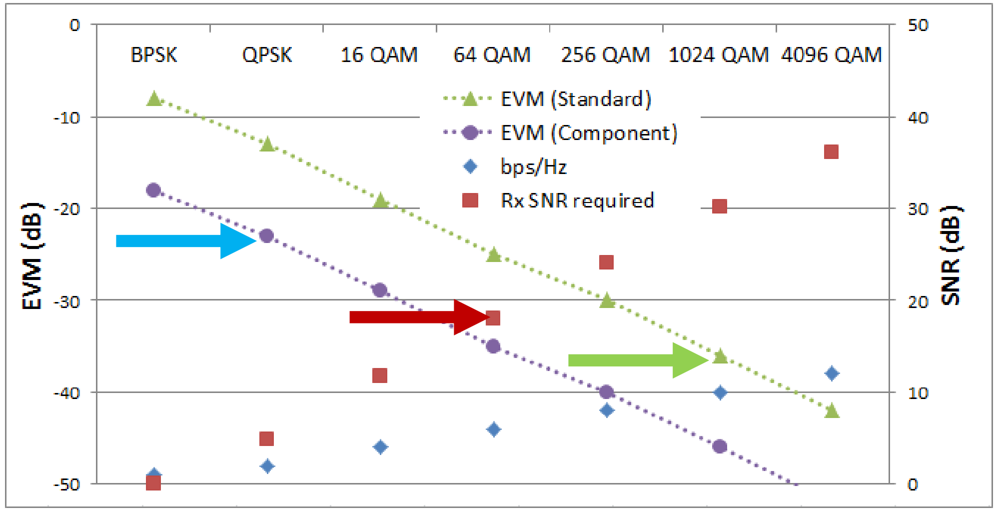


What's considered Good?

- For the link to work: "At the limit for the scenario"
- For component test: "10 dB better than the system as a whole"
- For system test: "3 dB better than the source from radio standard"

5G NR Release 15 EVM Requirements

Mod	Required EVM
Pi/2 BPSK	30% (-5.2 dB)
QPSK	17.5 % (-15.1 dB)
16QAM	12.5 % (-18.1 dB)
64QAM	8 % (-21.9 dB)
256QAM	3.5 % (-29.1 dB)



Signal Quality at mmWave Frequencies

CHALLENGES AND TIPS

- IQ modulator errors
- Phase noise
  - OFDM close subcarrier spacing
- Distortion
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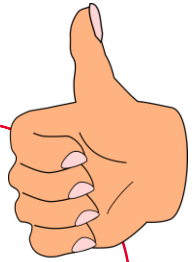


Tips for mmWave Measurements

✓ Minimize signal generation impairments correcting for IQ modulation, phase noise, flatness, and linearity errors

✓ Ensure adequate antenna gain

✓ Select test equipment with EVM and Signal-to-noise ratio better than your DUT

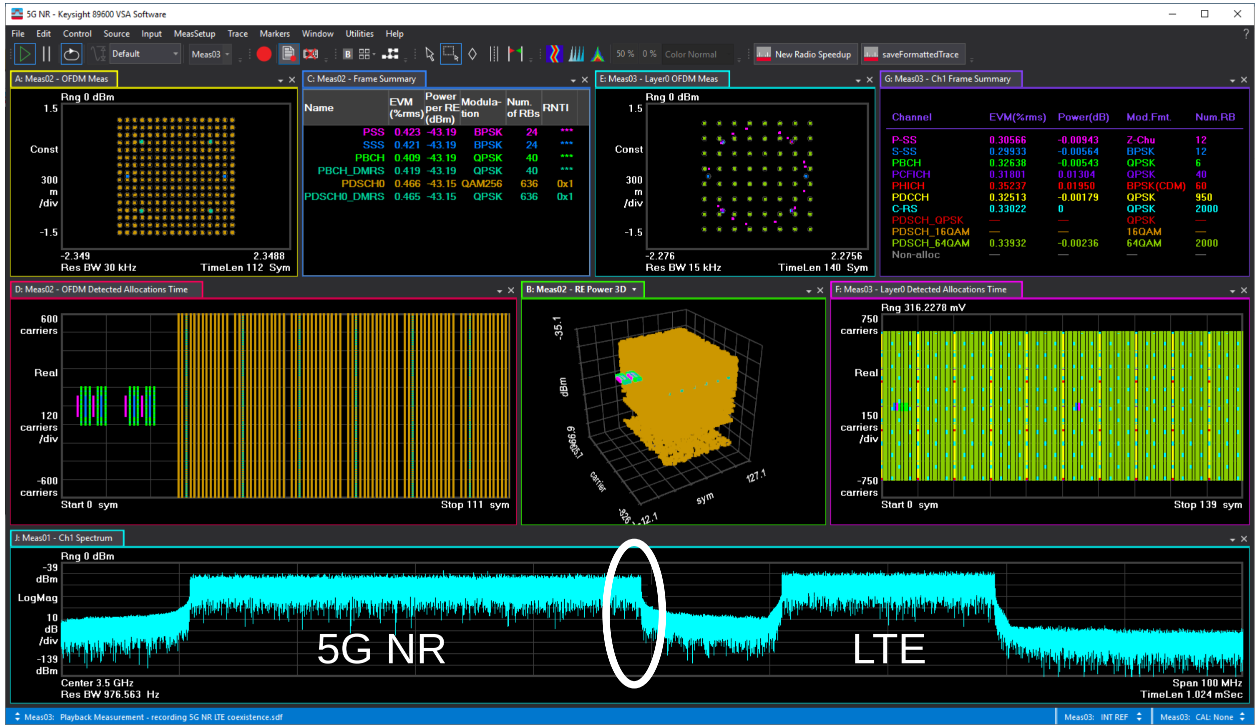
✓ Ensure proper use of cables and connectors for the given frequency

✓ Perform system-level calibration to ensure measurement is at DUT plane

Case Study: Testing for Coexistence

Challenge: Dual-mode operation. Verify performance in- and out-of-band to reduce interference

- How will the waveforms interact?
- How much out-of-band suppressions will be required?
- How much guard band will be required?
- How can different scenarios be explored?

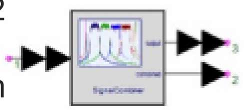


Solution:

Simulate

Waveform 1
Waveform 2
.
Waveform n

"SignalCombiner" Element

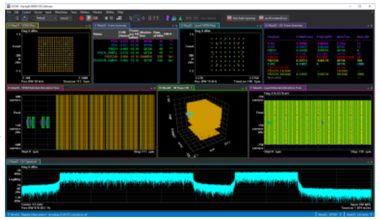


Wideband Source M9384B

Wideband Analyzer

N9040B

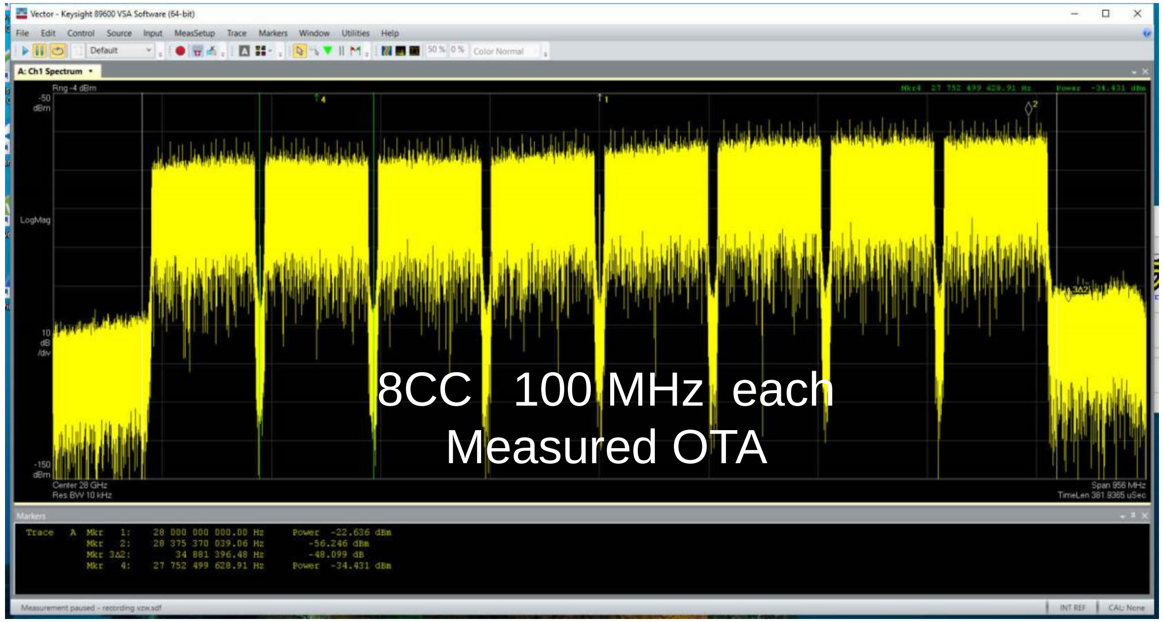
Analysis

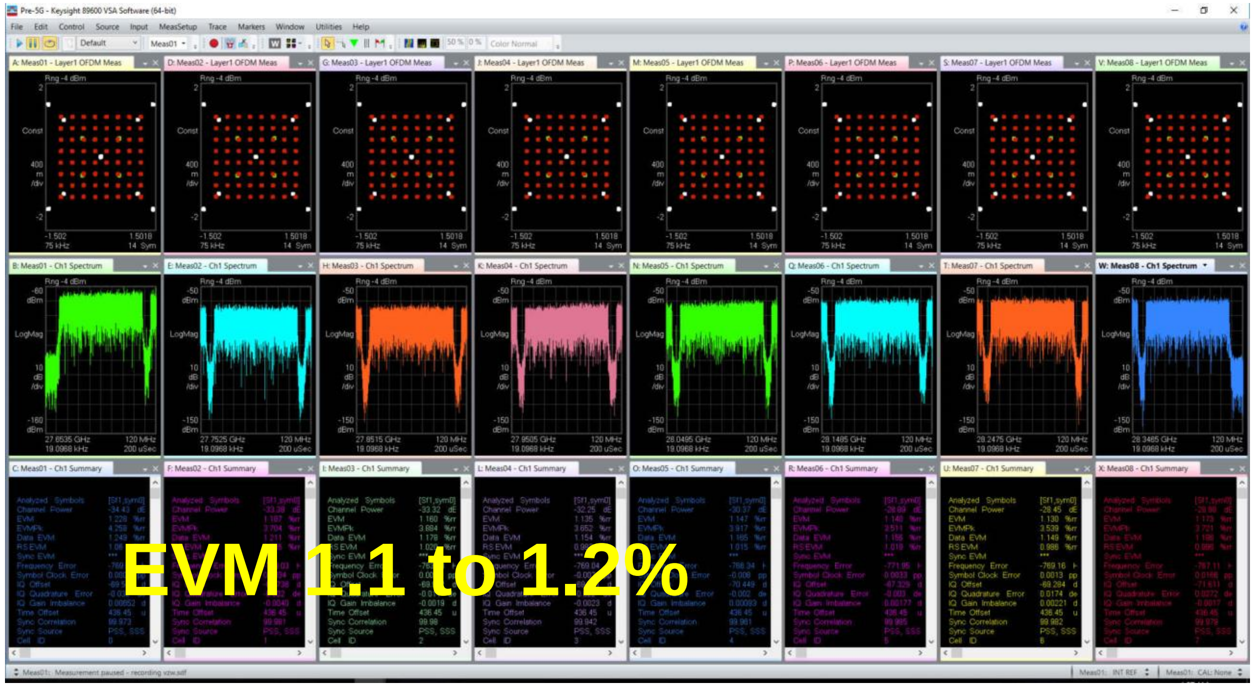


Multiple LTE, 5G measurements from 1 acquisition

Case Study: 8CC Signal Generation and Analysis

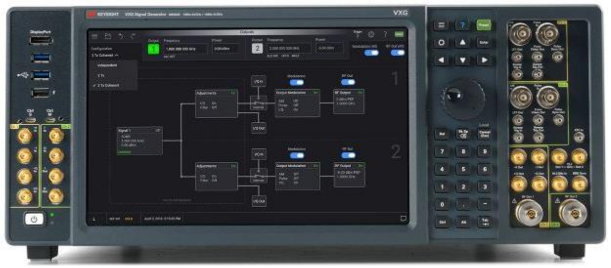
Spectrum – ***956 MHz*** Span centered at ***28 GHz***

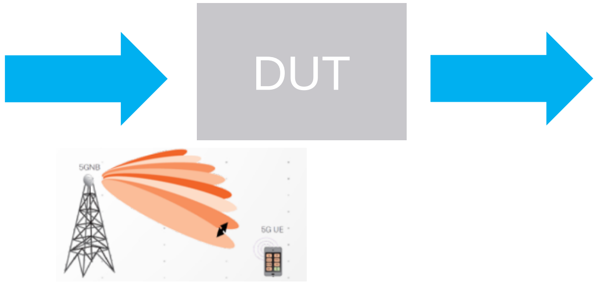




Modulation analysis of each 100 MHz carrier

Signal creation





Signal analysis

Challenge: EVM Optimization @ mmWave

OPTIMIZE EVM USING X-APPS AND VSA

Amplifier EVM performance:

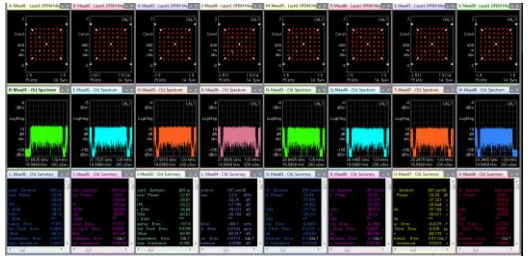
- 5G NR DL 1CC/8CC, 64/256 QAM (high crest factor), 100 MHz bandwidth, 28 GHz & 39 GHz (FR2)

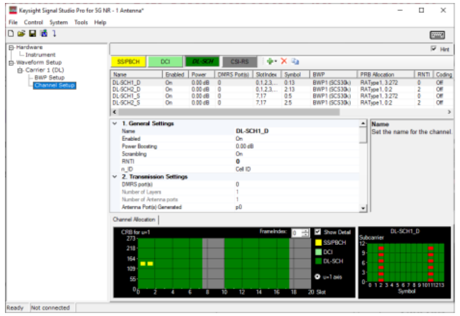
1 Generate 5G NR waveform and playback on wideband vector source

2 Export VSA setup file from Signal Studio or use Signal Studio .SCP file to configure 5G NR EVM measurement in VSA/X-Apps

3 X-Apps or VSA: ***Optimize*** and measure EVM before and after AUT

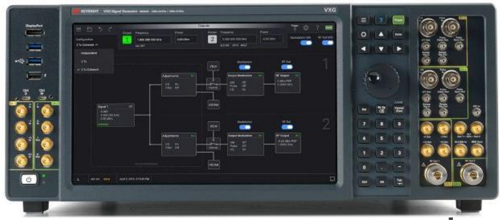
89601BHNC VSA 5G NR



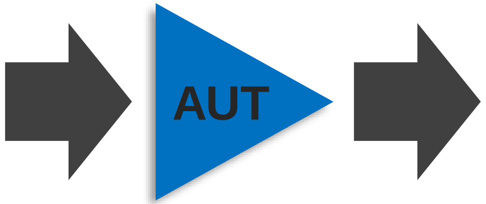


N7631C Signal Studio

Wideband Source



M9383/84B



Wideband Analyzer

N9040B

Trigger

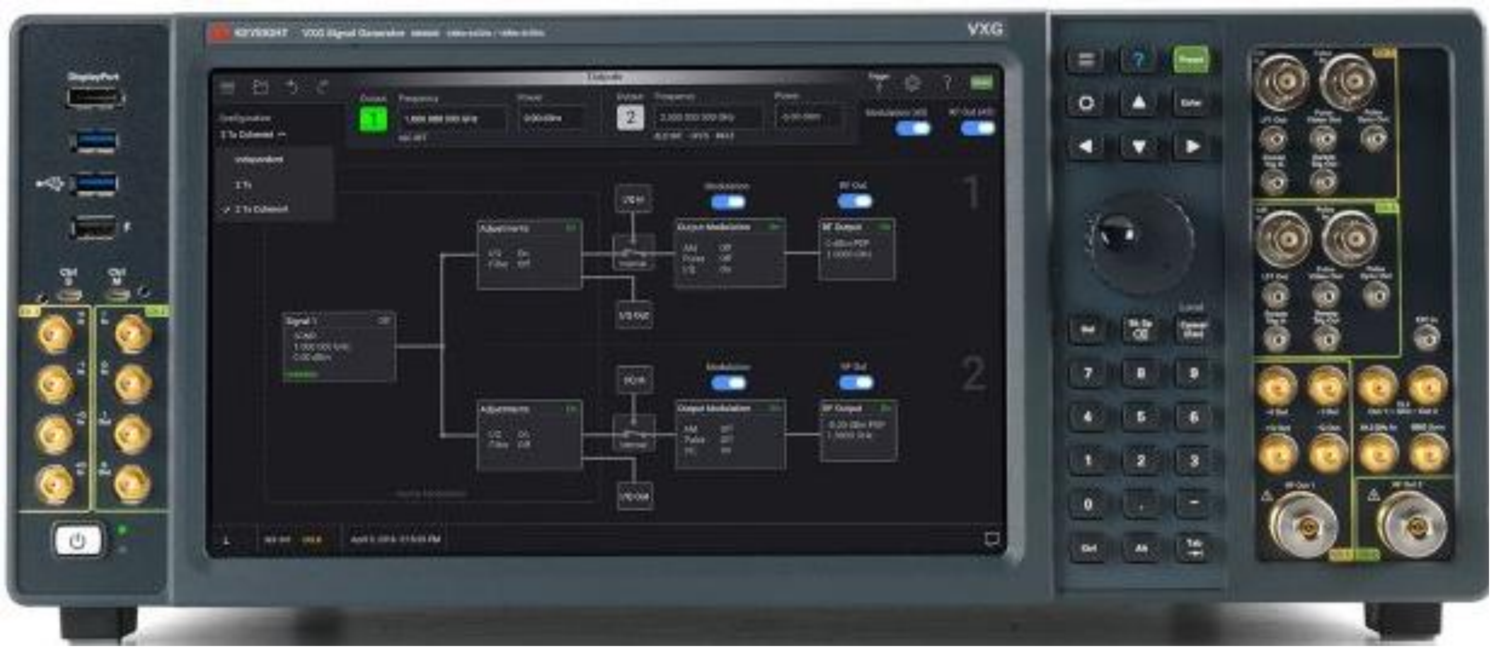
N9085EM0E X-Series measurement application

EVM Optimization @ mmWave

M9383B/M9384B VXG PXI VECTOR SOURCE

VXG PXI vector signal generators are optimized by default. Simply do the following:

- Set frequency
- Set amplitude
- Set ALC:
  - Freq < 20 GHz: Turn off
  - Freq > 20 GHz: Set to very slow
- Select waveform
- Turn ARB & RF on



M9383B VXG-m and M9384B are optimized right out of the box!

Note: you can also use the waveform markers to trigger the PXA or UXA, which greatly speeds up the demodulation measurements.

EVM Optimization @ mmWave

N9040B X-SERIES ANALYZER

Several things you can do to optimize EVM:

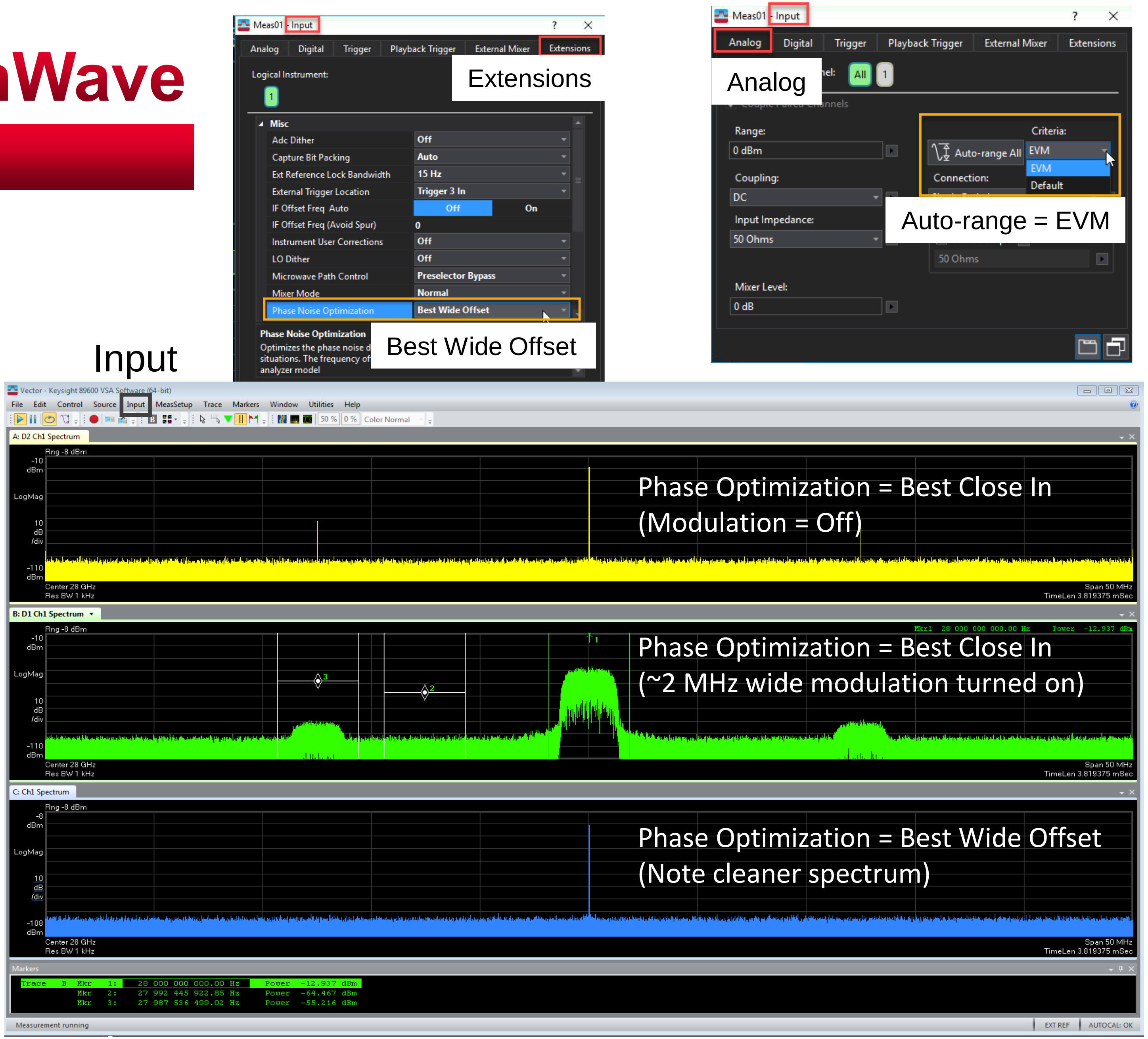
- Select *frequency span* that closely captures signal bandwidth
- Optimum phase noise method for wide bandwidth signals: *Best Wide Offset*
- Optimize front end path: if available, use *Full Bypass Mode* (particularly at higher frequencies around 28 and 39 GHz) – for EVM only
- Optimize attenuator: find best level at signal analyzer ***mixer input*** for optimum EVM (same for ACLR)
- Optimize attenuator & IF gain: use "Optimize EVM" auto range in the 5G NR application to get the best combination of both

EVM Optimization @ mmWave

89601C VSA

For wide bandwidth signals, optimize EVM performance by:

- Setting phase noise optimization method to ***Best Wide Offset;***
  - Input → Extensions → Phase Noise Optimization
- Optimizing IF gain and attenuation values using the Auto-range criteria for EVM optimization
  - Input → Analog → Auto-range All Criteria



KEYSIGHT TECHNOLOGIES

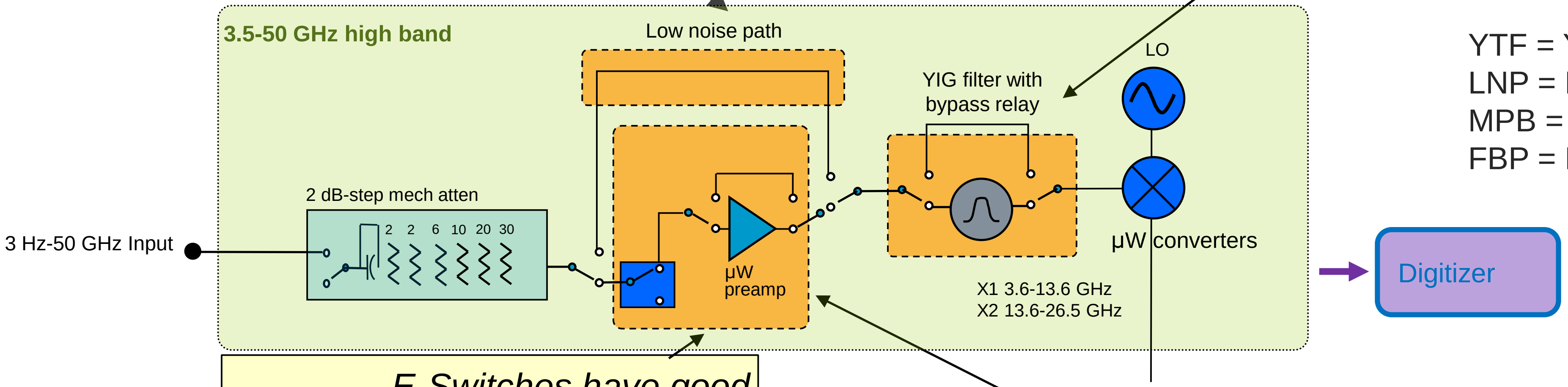
EVM Optimization @ mmWave

OPTIMIZE FRONT END PATH

Things you ***should*** do to optimize signal path and improve EVM at mmWave; MPB, LNP, and FBP

YTF loss at 40 GHz is ~10 dB.

YTF BW is ~40-60 MHz, must bypass for wide-BW EVM measurements. Don't bypass for ACLR



YTF = YIG tuned filter
LNP = Low Noise Path
MPB = Microwave Preselector Bypass
FBP = Full Bypass Path (LNP + MPB)

E-Switches have good performance at <6 GHz, but degrade SNR and limit EVM at 28 and 39 GHz.

When measuring EVM, distortion in uW Pre-Amp will limit EVM floor.

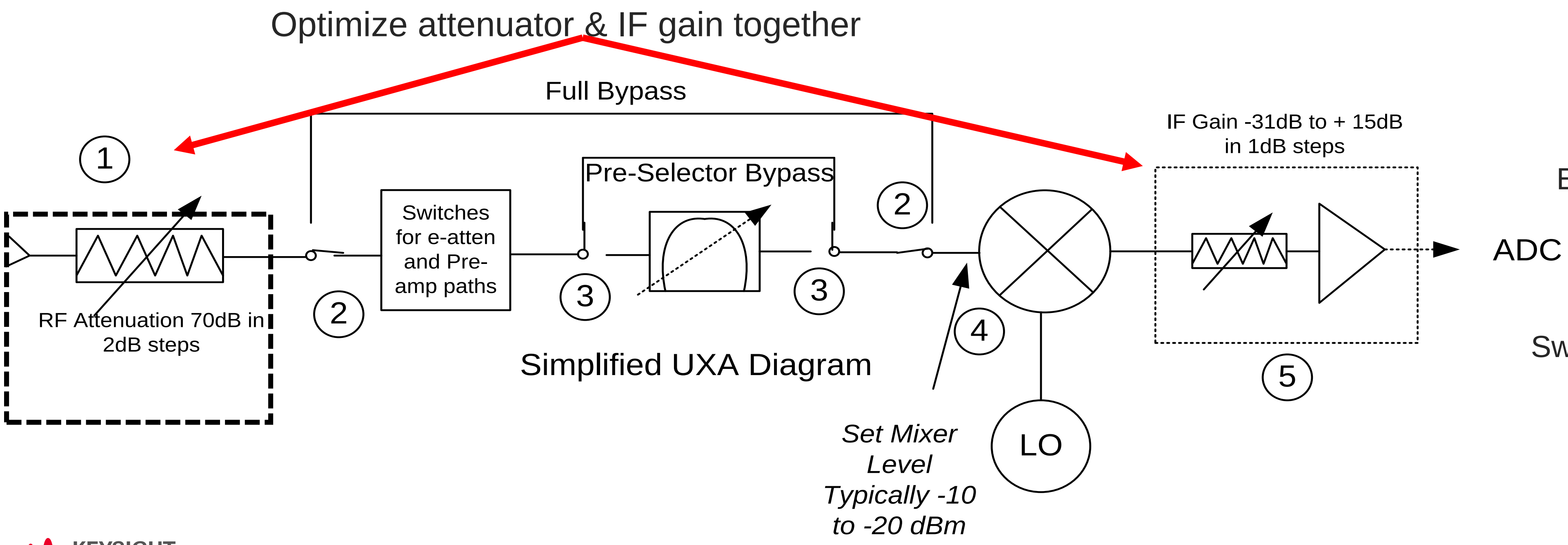
Note: use uWave pre-amp only if signal is low in power **and** improves EVM

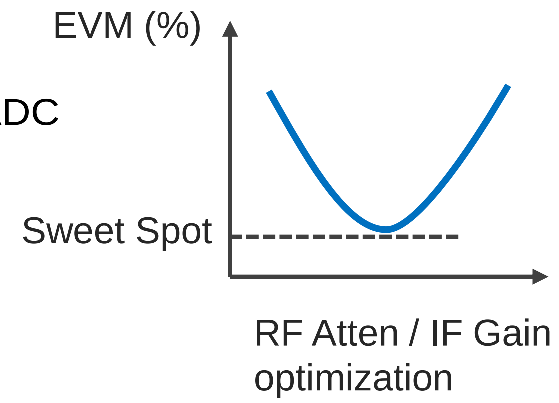
***FBP** allows bypassing both LNP and MPB at same time.*
Cal data is applied for this new path.
UXA with #550 & #H1G only

EVM Optimization @ mmWave

UXA FRONT END - SIMPLIFIED VIEW

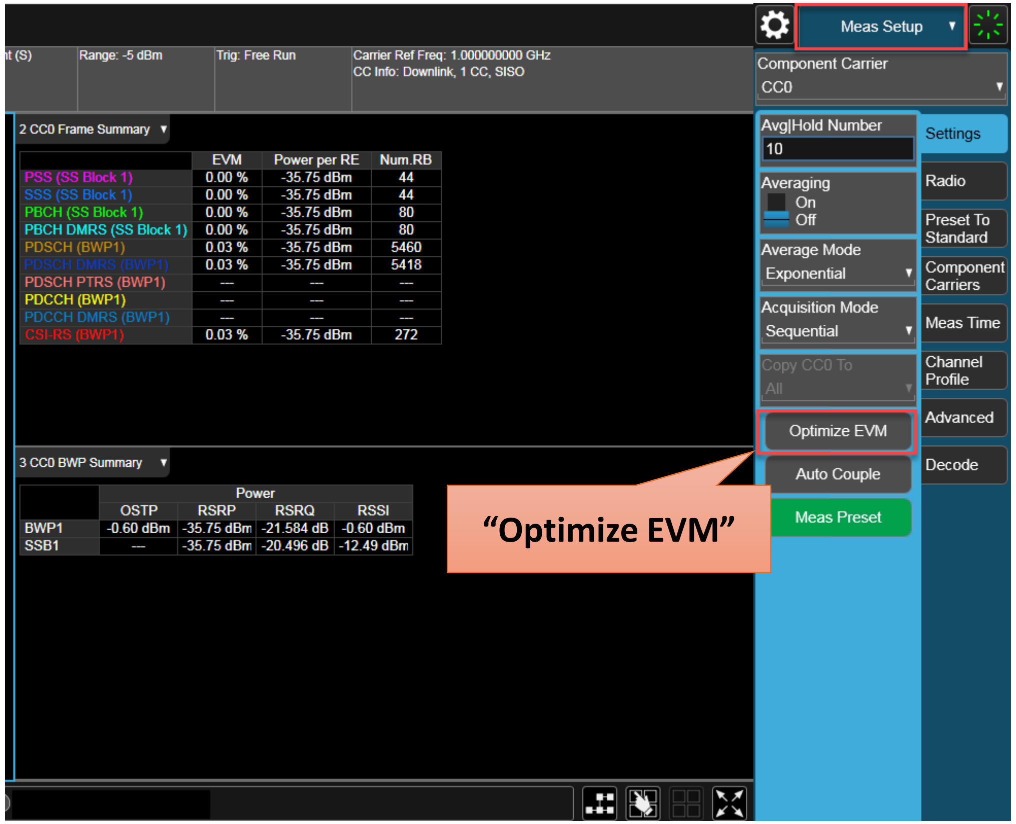
- Normally, wide BW measurements are noise limited, hence, bypassing both pre-selector & path for electronic attenuator/preamp (Low Noise Path) can improve EVM
- Normally, analyzer selects IF gain depending on other analyzer settings, including the selected RF attenuation. For a given signal BW and crest factor, adjusting both the RF attenuator and IF gain improves EVM.
  - 5G NR application has “Optimize EVM” feature that adjusts preamp, IF gain, and attenuation based on measured peak power to improve EVM.





EVM Optimizing Auto Range

- "Optimize EVM" auto range is available to optimize hardware settings for best EVM performance
- Optimized EVM result is achieved by:
  - Adjusting preamp (on or off), IF gain, and attenuation based on measured peak power
  - Mech attenuation could be set below 6 dB after Optimize EVM is pressed, to get better noise floor

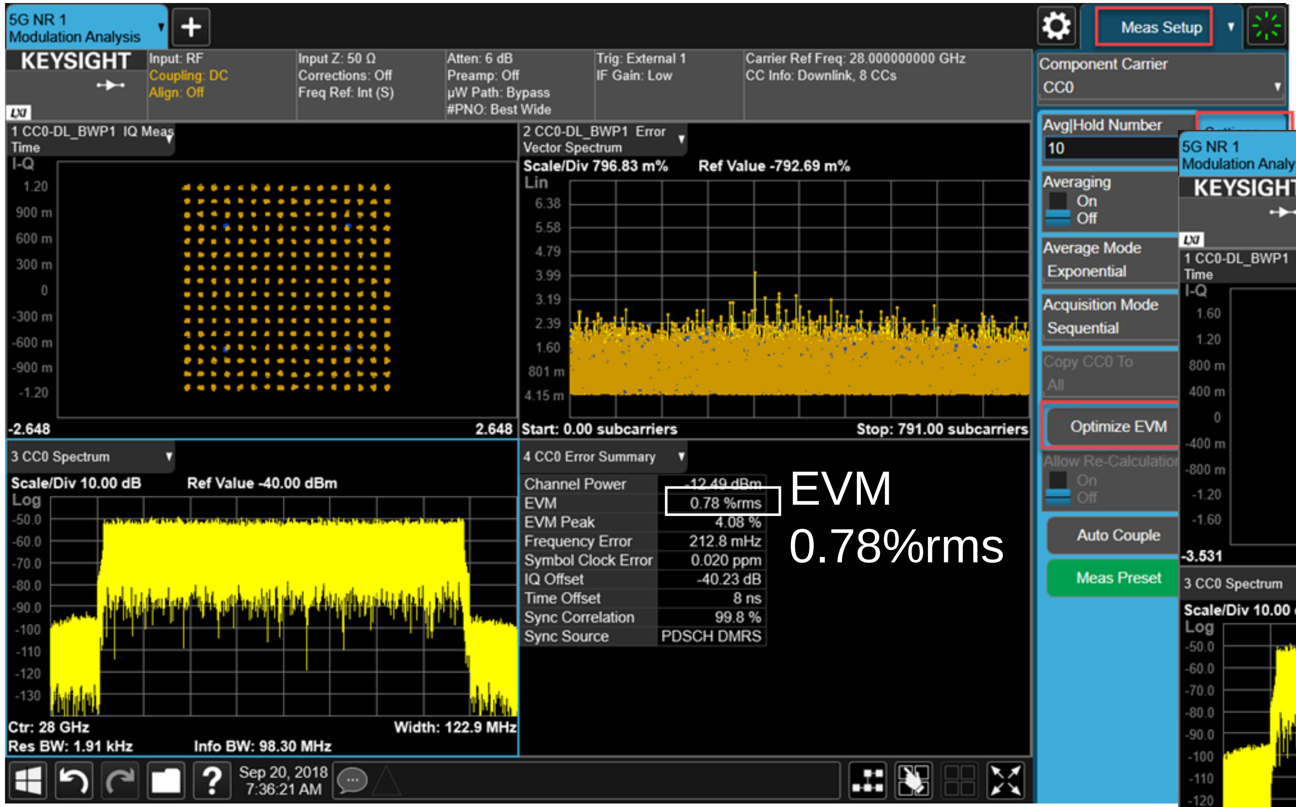


Note: "Optimize EVM" in X-Apps uses peak power to adjust hardware settings and 89600 VSA uses actual measurement results to optimize EVM

EVM Optimization @ mmWave

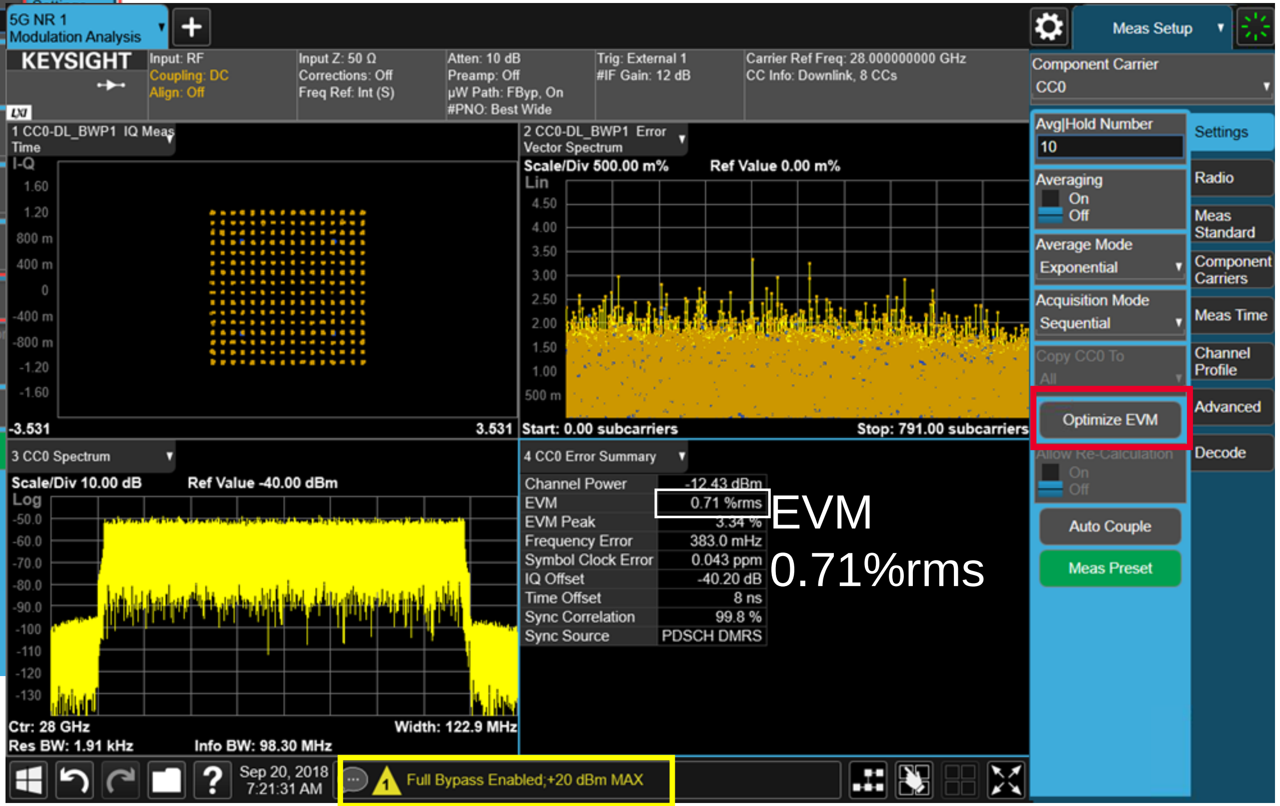
5G NR 28 GHZ 100 MHz 256QAM OPTIMIZED EVM RESULT

"Optimize EVM"



N9040B UXA with options 550 & H1G

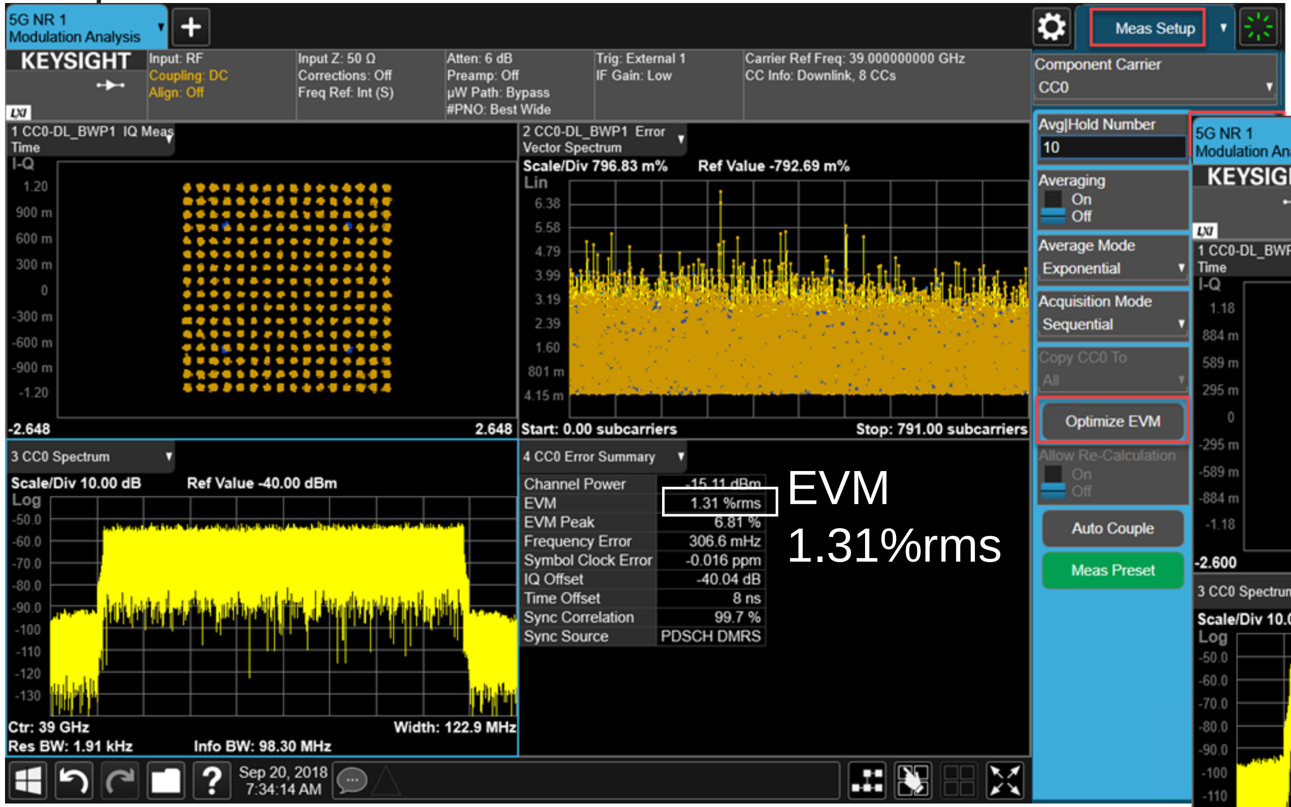
Full Bypass Path and "Optimize EVM"



EVM Optimization @ mmWave

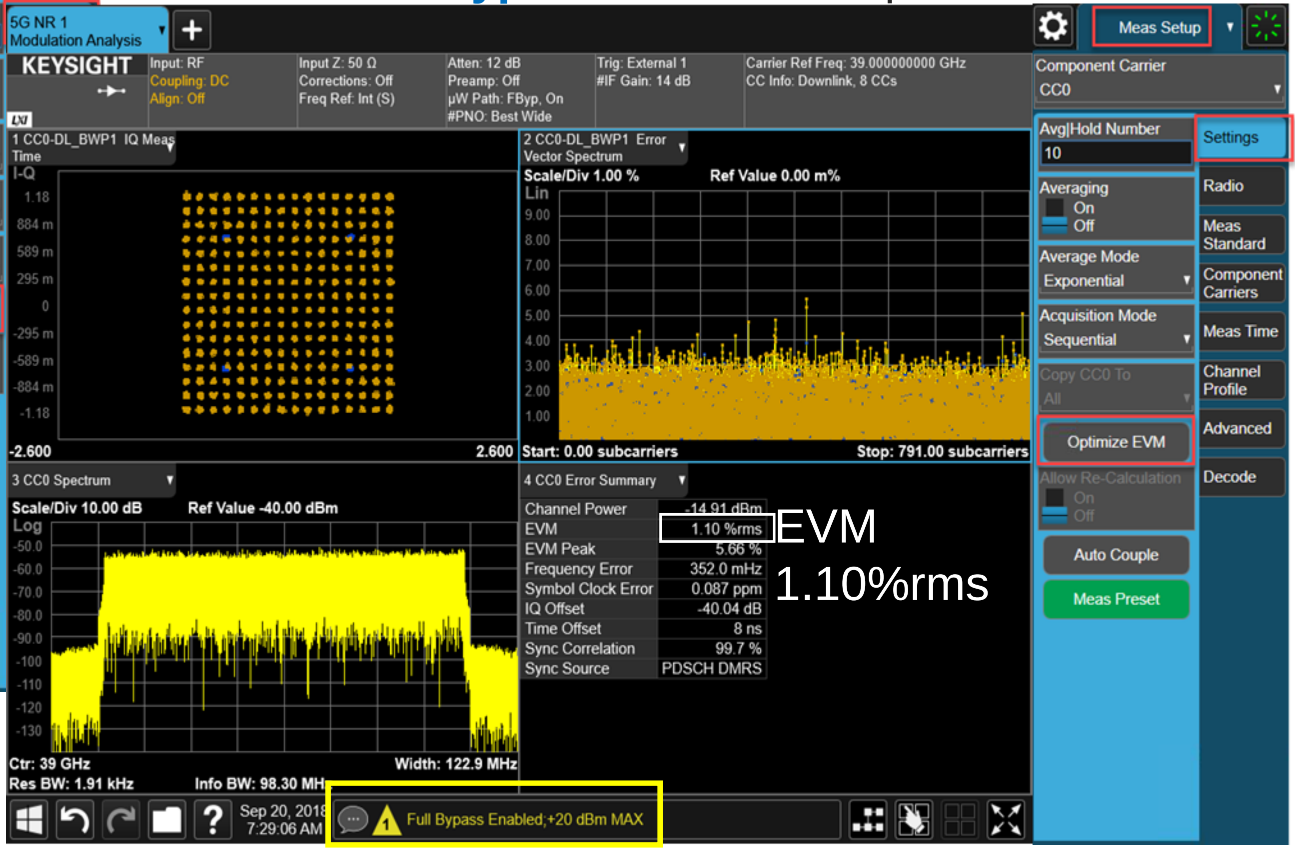
5G NR 39 GHZ 100 MHz 256QAM OPTIMIZED EVM RESULT

“Optimize EVM”



N9040B UXA with options 550 & H1G

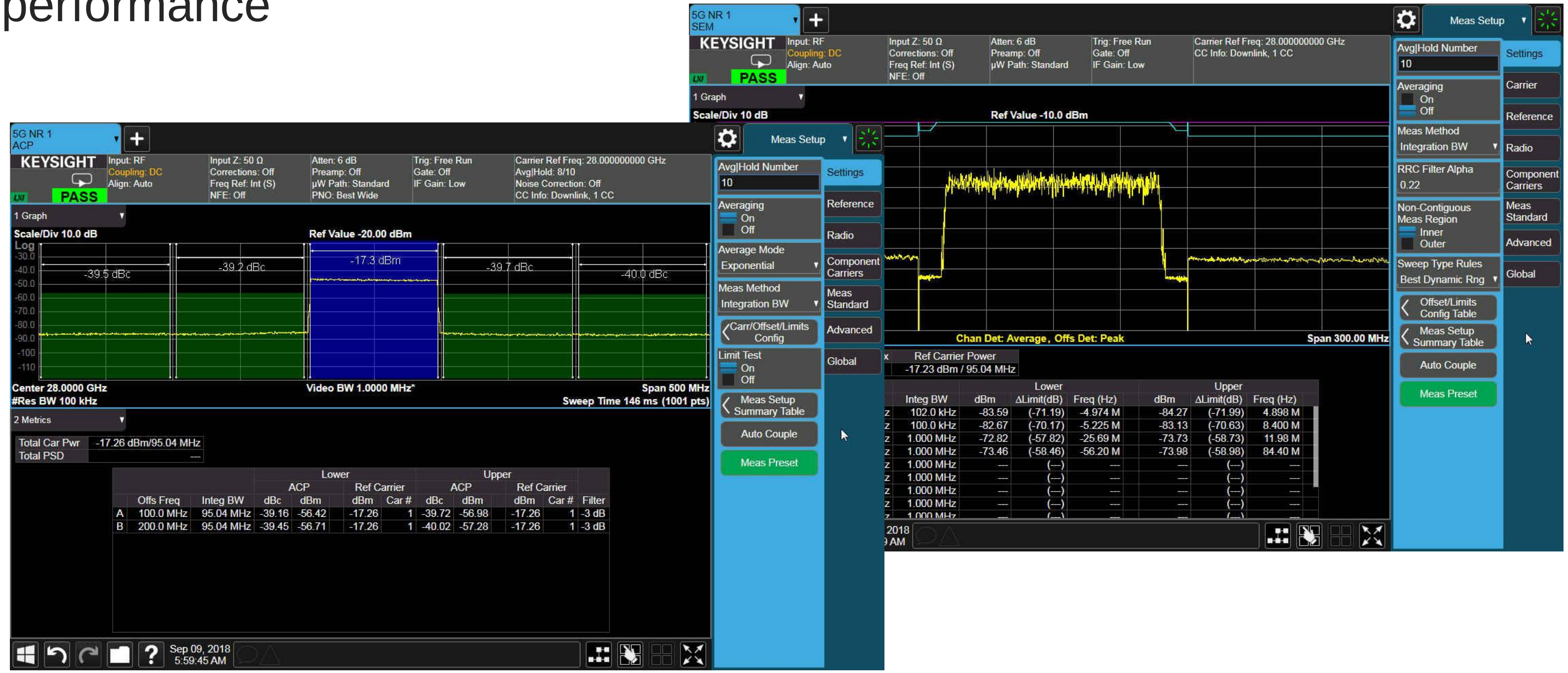
Full Bypass Path and “Optimize EVM”



ACLR Optimization

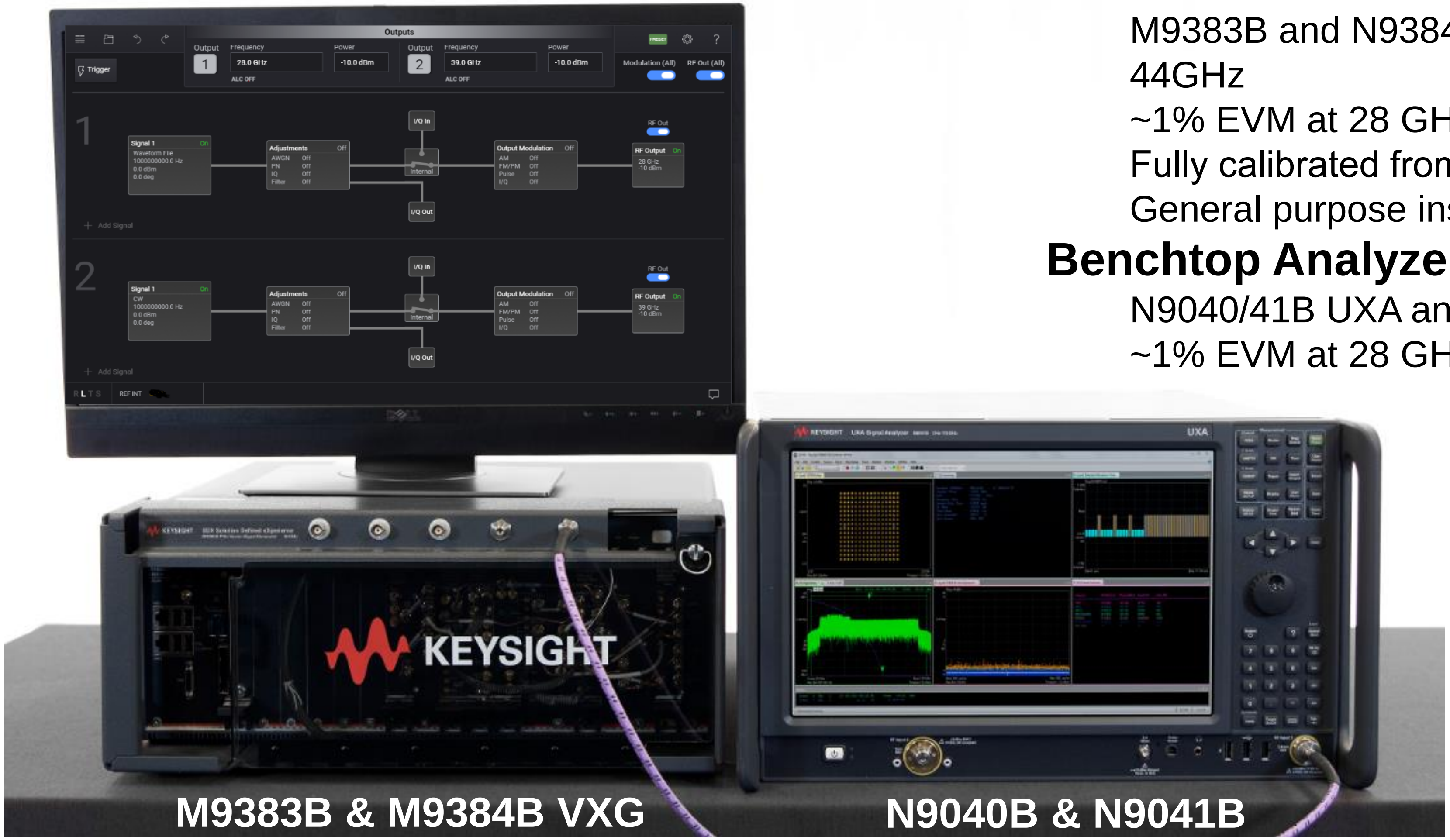
UXA KEY STEPS

- Do not use Full Bypass Path mode - the **microwave preselector filter is needed** for best ACLR performance.
- Above 3.6 GHz enable Low Noise Path (LNP). This bypasses lossy switches.
- Optimize attenuator for best performance
- Turn on Noise Corrections



5G Hardware Configurations: FR1 and FR2

NON-SIGNALING: WIDE BANDWIDTH SIGNAL GENERATION & ANALYSIS



PXI Source

M9383B and N9384B VXG PXI vector source, up to 44GHz
~1% EVM at 28 GHz w/2 GHz BW
Fully calibrated from factory across all BW’s
General purpose instruments (not banded)

Benchtop Analyzer

N9040/41B UXA analyzer, up to 50 / 90 / 110 GHz
~1% EVM at 28 GHz w/1 GHz BW (option H1G)

Example: Multi-Channel 5G Testbed for FR1 and FR2

Test Signal
2x2 MIMO at 28 GHz

Device Under Test
Cross-polarized 28 GHz phased array

Key Features

- 44 GHz Signal Creation / 110 GHz Analysis
- Multi-channel
- High Output Power
- 2 GHz signal creation BW
- 110 GHz BW Demodulation Analysis
- Swept-tuned measurements to 110 GHz
- Import S-Parameters to de-embed test fixture

DC Power Analyzer

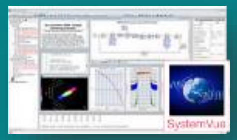
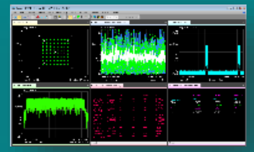
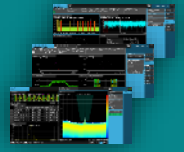
VXG
44 GHz Dual Ch. Source

UXR
110 GHz Oscilloscope

UXA
110 GHz Signal Analyzer

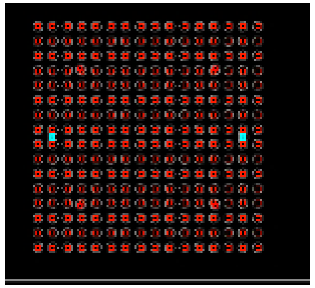
Precede the 5G Race with New Radio

KEYSIGHT 5G NR SOFTWARE SOLUTIONS

Software:	SystemVue 	Signal Studio 	89600 VSA 	X-Series Apps 
Category:	**ESL Design & Simulation software**	**Signal Creation software**	**Vector Signal Analysis software**	**Measurement Application software**
Custom OFDM: for 5G proto-typing	**W1461B**	**N7608APPC**	**89601B-BHF**	**N9054EM1E**
Pre-5G: for Verizon	**W1906E**	**N7630APPC**	**89601B-BHN**	
3GPP 5G NR:	**W1906E**	**N7631APPC (N7631C)**	**89601B-BHN**	**N9085EM0E**
Target Customers:	Simulation users who needs the world-best 5G NR PHY simulation	R&D who needs test vector waveforms on receiver or component tests	R&D who wants to get in-depth modulation analysis for transmitter tests	R&D plus early MFG for simple pass/fail tests

7 Key Measurement Challenges

Signal Quality
mmW, Waveform, Fidelity



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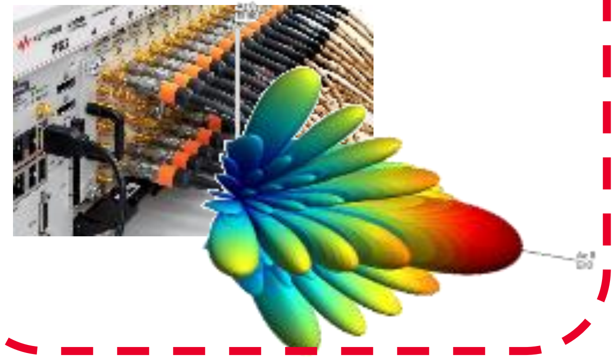
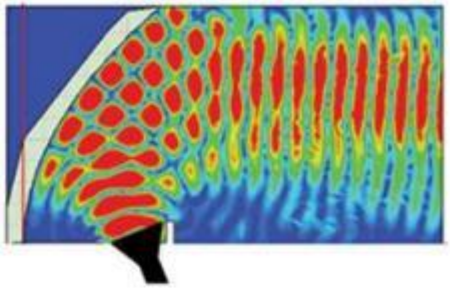
MIMO/Beamforming



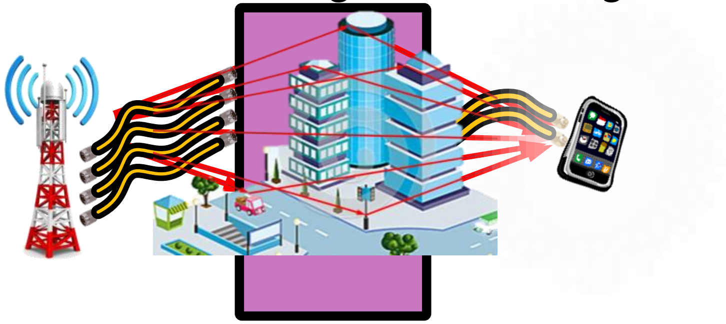
Connect Design & Test
Components, Systems

Design Simulate Validate Connect Test

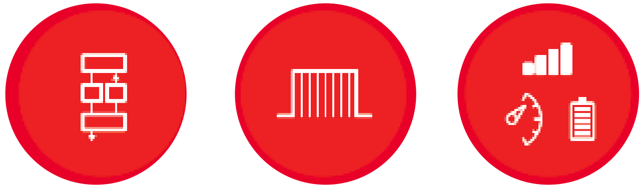
Life Beyond Connectors
Over-the-Air



Channel
Characterizing & Emulating



Performance on the Network
Network Emulation



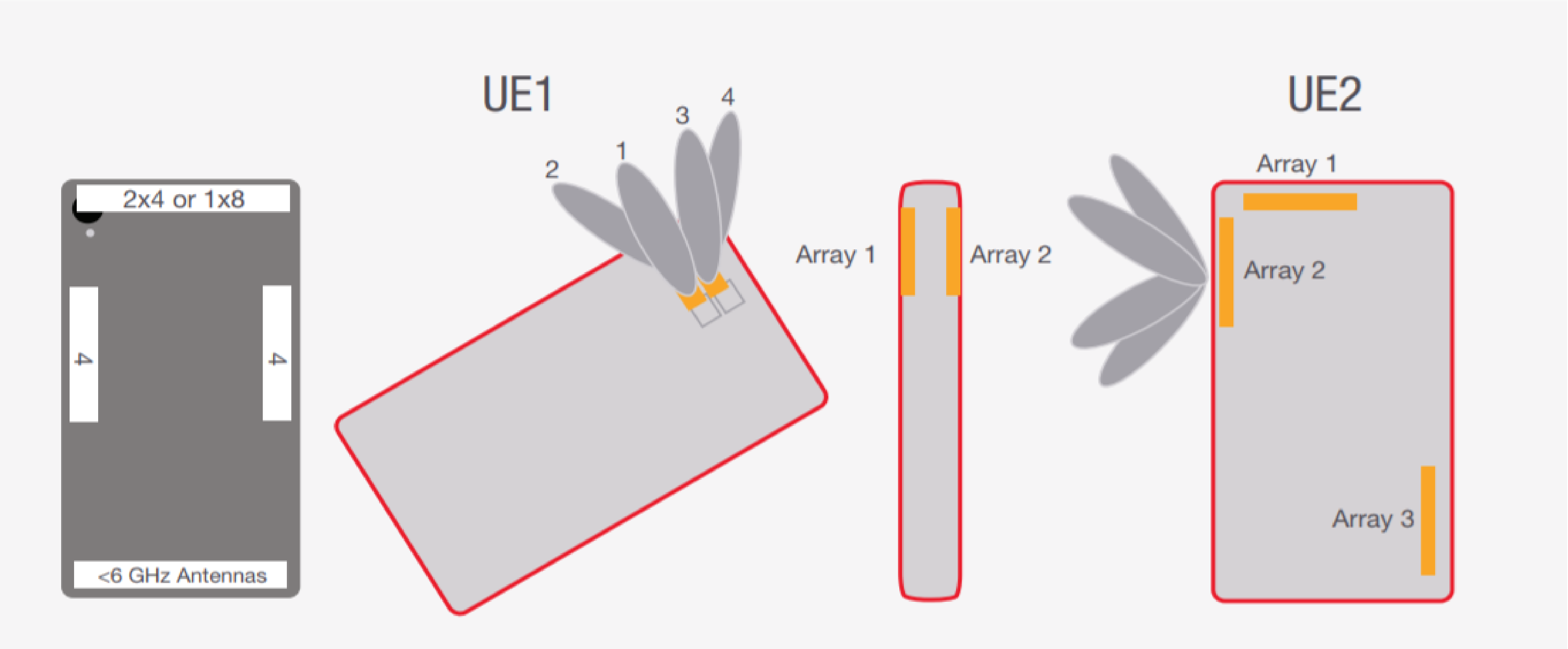
Protocol R&D *RF / RRM DVT* *Functional KPI*

Field Testing and Drive Test

Challenge: Multiple Antennas

Challenge: Understanding MIMO and Beamforming real-world performance including handover and throughput

- Characterized beam patterns have proper phase and magnitude relationship and beams and nulls are in the correct position
- Emulate real-world conditions in sub-6 GHz or mmWave



Example: Multi-Channel 5G Test Bed for NR FR1 and FR2

Test Signal
2x2 MIMO at 28 GHz

Key Features

- 44 GHz Signal Creation / 110 GHz Analysis
- Multi-channel
- High output power
- 2 GHz signal creation BW
- 110 GHz BW demodulation analysis
- Swept-tuned measurements to 110 GHz
- Import S-Parameters to de-embed test fixture

Device Under Test
Cross-polarized 28-GHz phased array

DC Power Analyzer

VXG
44 GHz Dual Ch. Source

UXR
110 GHz Oscilloscope

UXA
110 GHz Signal Analyzer

Case Study: Verify Antenna Performance

Challenge: Base station vendor wanted < 1 % EVM on a wideband signal

- Is the waveform created with 5G compliant waveform with numerology, UL, DL scheduling?
- Can the equipment produce clean mmWave signals?
- Performance mmWave measurements?

Solution: Flexible Test Bed

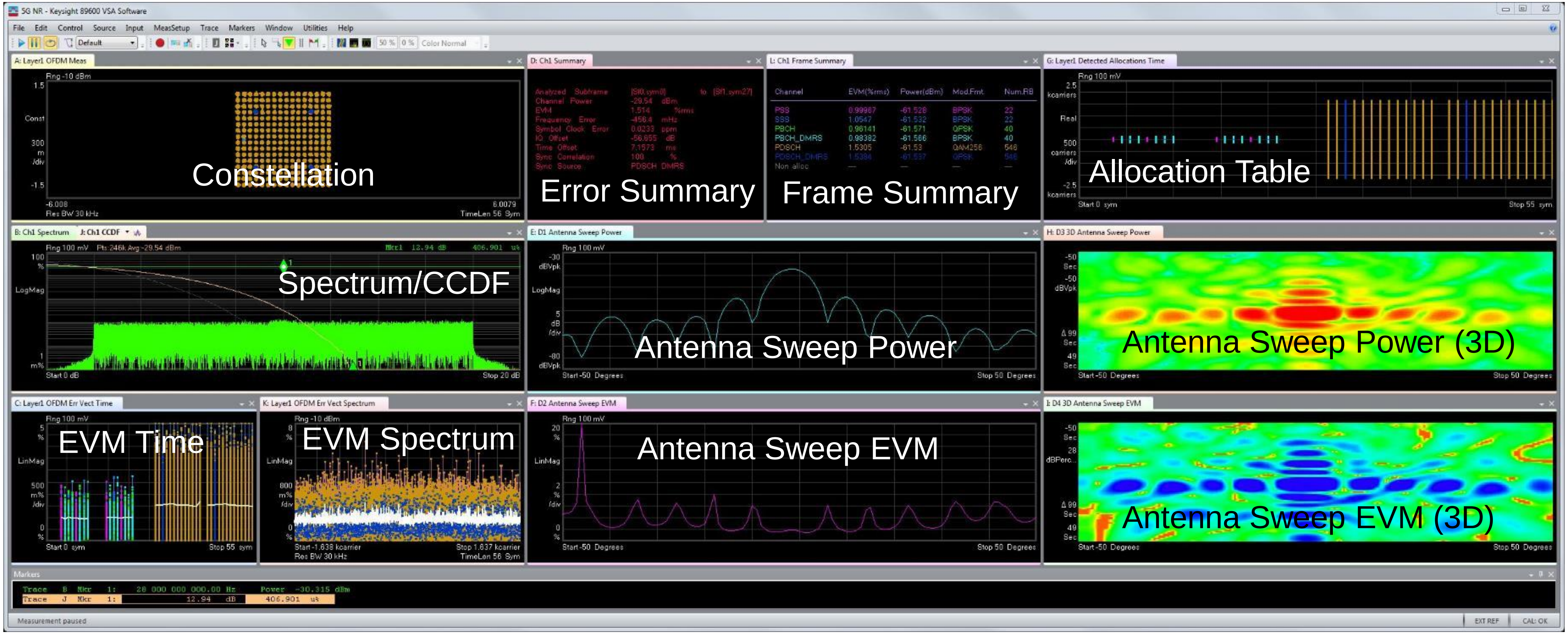
- 5G NR compliant waveform generation; N7631C & VXG Source
- Best-in-class EVM performance; VXG source & UXR 110 GHz oscilloscope with 89601C (VSA)
- Flexible configurations can scale as the standards evolve

5G Test Bed Demo Video MWC 2019

Verify Antenna Performance

3GPP 5G NR MEASUREMENT DETAIL WITH VSA

5G NR Downlink
100 MHz BW @ 28 GHz
256 QAM payload

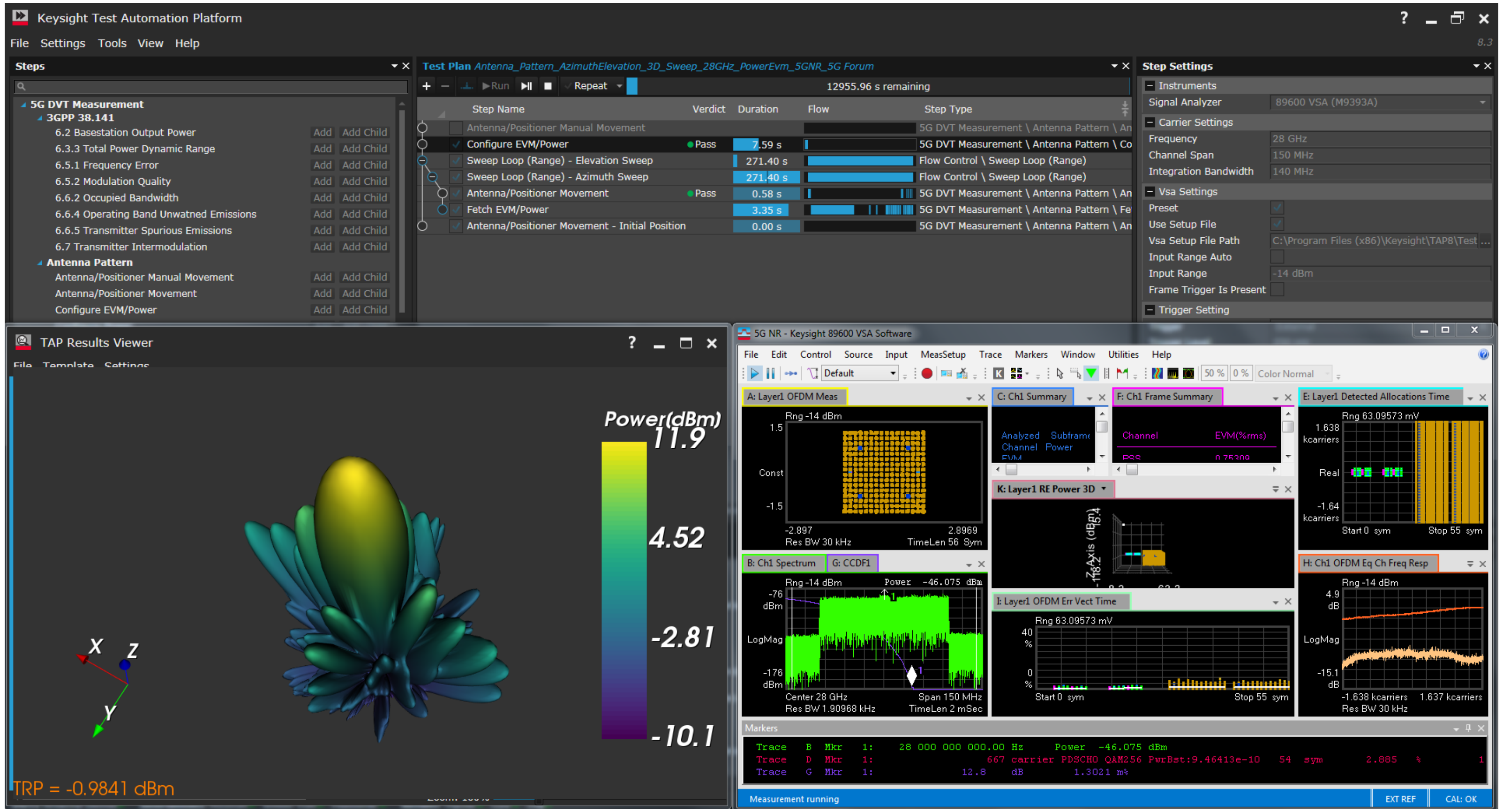


KEYSIGHT TECHNOLOGIES

5G Conformance Test SW

TEST AUTOMATION WITH PATHWAVE TEST

PathWave Test SW user interface showing results from phased array DUT



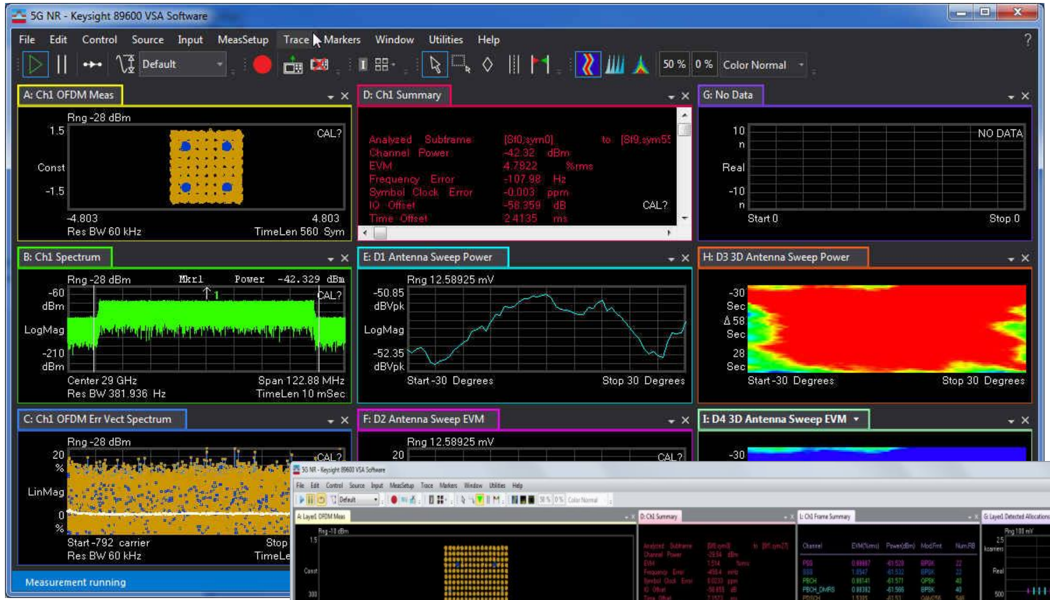
Conformance test measurements can be sequenced over frequency/amplitude to build specific test plans for a given base station class and configuration.

- Create & playback 5G test waveforms
- AUT control
  - Mode; Tx or Rx
  - Beam Steering or Boresight
- Positioning
  - Azimuth
  - Elevation
- Measurements;
  - Power / EVM
  - Antenna beam pattern (at boresight)
  - Antenna beam power surface over azimuth and elevation
  - And more

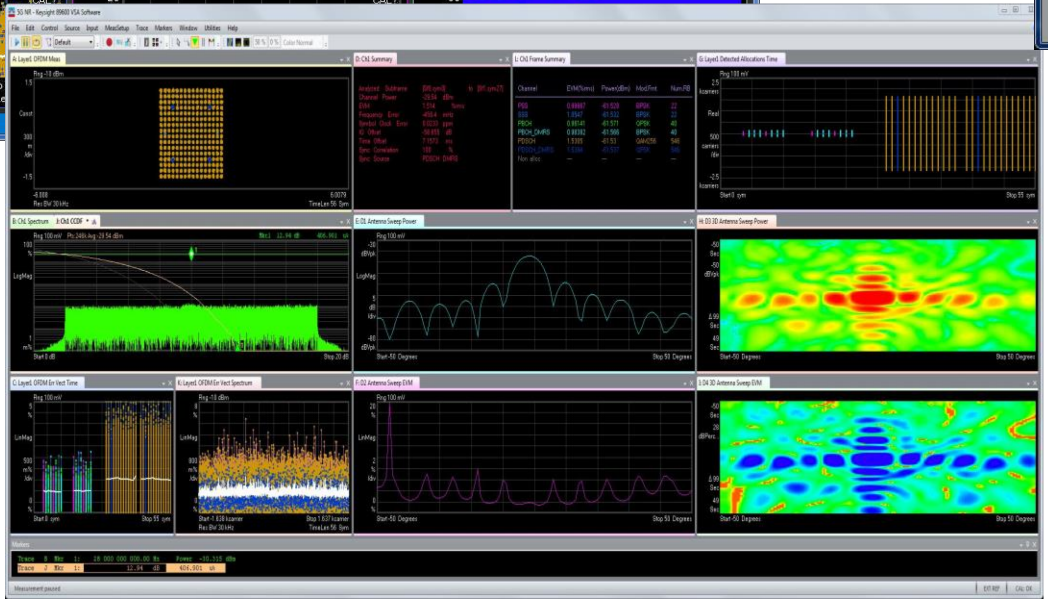
Verify Antenna Performance

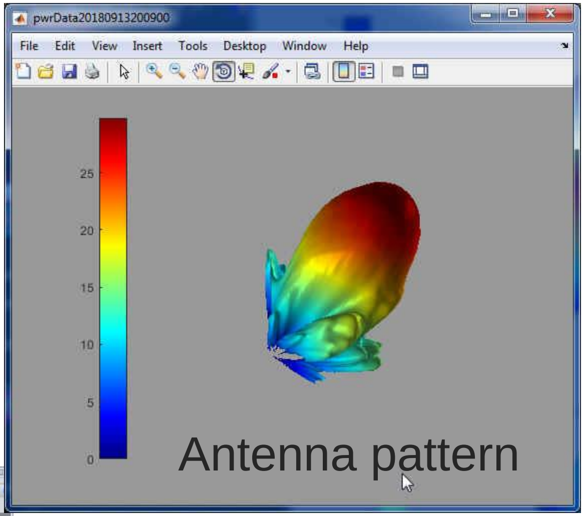
3GPP 5G NR MEASUREMENT DETAIL (EXAMPLES)

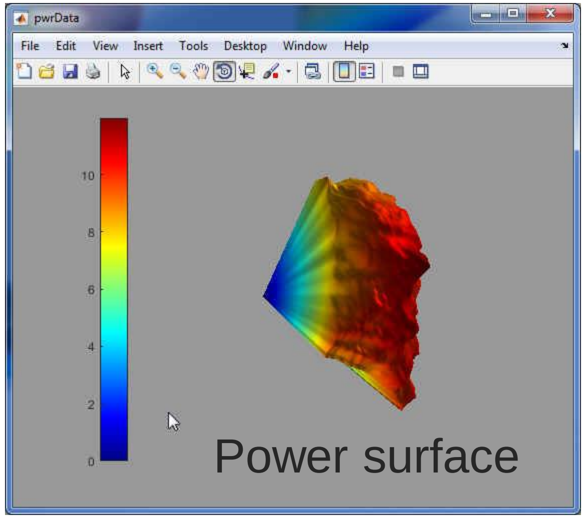
5G NR Downlink
100 MHz BW @ 28 GHz
64/256 QAM payload



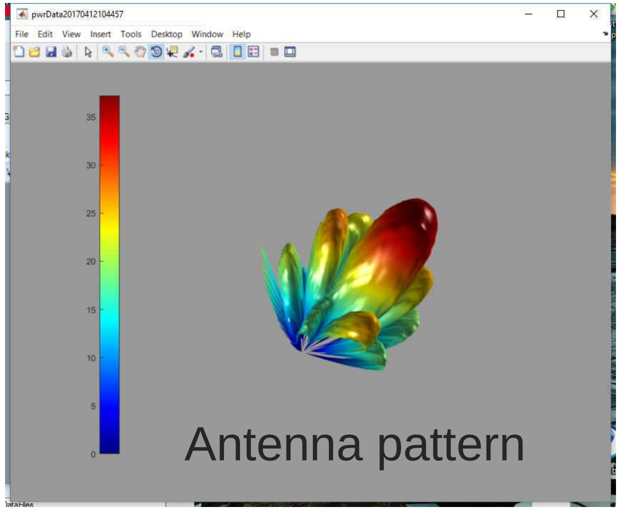
4x4 element array







16x16 element array



KEYSIGHT TECHNOLOGIES