7 Key Measurement Challenges

- Signal Quality
  - mmWave, Waveform, Fidelity

- Lots of Channels
  - MIMO & Beamforming

- Channel
  - Characterizing & Emulating

- Life Beyond Connectors
  - Over-the-Air

Performance on the Network
- Network Emulation

Connect Design & Test
- Components & Systems

Field & Drive Test

Protocol R&D
RF/RRM DVT
Functional KPI

Design
Simulate
Validate
Connect
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.

\[
\frac{10 \times \log[30 \text{ kHz}/(273 \text{ PRB} \times 12 \text{ SC/PRB} \times 30 \text{ kHz})]}{\text{dB}} = -35 \text{ dB}
\]

**Noise Temperature (Nt)**

\[
N_t = k T B \quad \text{(Watts)} = -124 \text{ dBW}
\]

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

<table>
<thead>
<tr>
<th>Mod</th>
<th>Required EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pi/2 BPSK</td>
<td>30% (-5.2 dB)</td>
</tr>
<tr>
<td>QPSK</td>
<td>17.5% (-15.1 dB)</td>
</tr>
<tr>
<td>16QAM</td>
<td>12.5% (-18.1 dB)</td>
</tr>
<tr>
<td>64QAM</td>
<td>8% (-21.9 dB)</td>
</tr>
<tr>
<td>256QAM</td>
<td>3.5% (-29.1 dB)</td>
</tr>
</tbody>
</table>
Signal Quality at mmWave Frequencies

CHALLENGES AND TIPS

- 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
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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
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

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**

8CC, 100 MHz each
Measured OTA

Signal creation

EVM 1.1 to 1.2%

Modulation analysis of each 100 MHz carrier

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

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**Diagram:**

- **N7631C Signal Studio**
- **Wideband Source:** M9383/84B
- **Wideband Analyzer:** N9040B
- **89601BHNC VSA 5G NR**
- **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.
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
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
**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
- **UXA with #550 & #H1G only**
- **FBP allows bypassing both LNP and MPB at same time.**
  - Cal data is applied for this new path.
  - **UXA with #550 & #H1G only**

**Diagram:**

- **3.5-50 GHz high band**
- **Low noise path**
- **μW preamp**
- **μW converters**
- **YIG filter with bypass relay**
- **LO**
- **Digitizer**

**Notes:**

- **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.
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.

![Simplified UXA Diagram](image)

- RF Attenuation 70dB in 2dB steps
- Pre-Selector Bypass
- IF Gain -31dB to +15dB in 1dB steps
- ADC
- LO
- Set Mixer Level Typically -10 to -20 dBm
- Switches for e-atten and Pre-amp paths

Optimize attenuator & IF gain together

EVM (%) vs. RF Attenuation / IF Gain optimization

**Sweet Spot**

12
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 0.78%rms

EVM 0.71%rms
EVM Optimization @ mmWave

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

“Optimize EVM”

Full Bypass Path and “Optimize EVM”

N9040B UXA with options 550 & H1G

EVM 1.31%rms

EVM 1.10%rms
ACLX Optimization

UXA KEY STEPS

- Do not use Full Bypass Path mode - the microwave preselector filter is needed for best ACLX 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

**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

**Test Signal**
2x2 MIMO at 28 GHz

**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
## Precede the 5G Race with New Radio

### KEYSIGHT 5G NR SOFTWARE SOLUTIONS

<table>
<thead>
<tr>
<th>Software:</th>
<th>SystemVue</th>
<th>Signal Studio</th>
<th>89600 VSA</th>
<th>X-Series Apps</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category:</strong></td>
<td>ESL Design &amp; Simulation software</td>
<td>Signal Creation software</td>
<td>Vector Signal Analysis software</td>
<td>Measurement Application software</td>
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<td>Custom OFDM:</td>
<td>W1461B</td>
<td>N7608APPC</td>
<td>89601B-BHF</td>
<td>N9054EM1E</td>
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<td>for 5G proto-typing</td>
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<td>Pre-5G:</td>
<td>W1906E</td>
<td>N7630APPC</td>
<td>89601B-BHN</td>
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<td>for Verizon</td>
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<tr>
<td>3GPP 5G NR:</td>
<td>W1906E</td>
<td>N7631APPC (N7631C)</td>
<td>89601B-BHN</td>
<td>N9085EM0E</td>
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</tbody>
</table>

### 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**