Demystifying the Path from 5G to sub-TeraHz 6G

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Wireless Knowledge Summit 2022

KEYSIGHT TECHNOLOGIES

Agenda

- **Opening Up Millimeter Wave Spectrum and Challenges**
- Emerging 60 GHz, 71-76 GHz and 81-86 GHz Millimeter Wave Frequency Bands
- Moving beyond 110 GHz into 6G
- Simulation Case Study
- Summary and Additional Resources

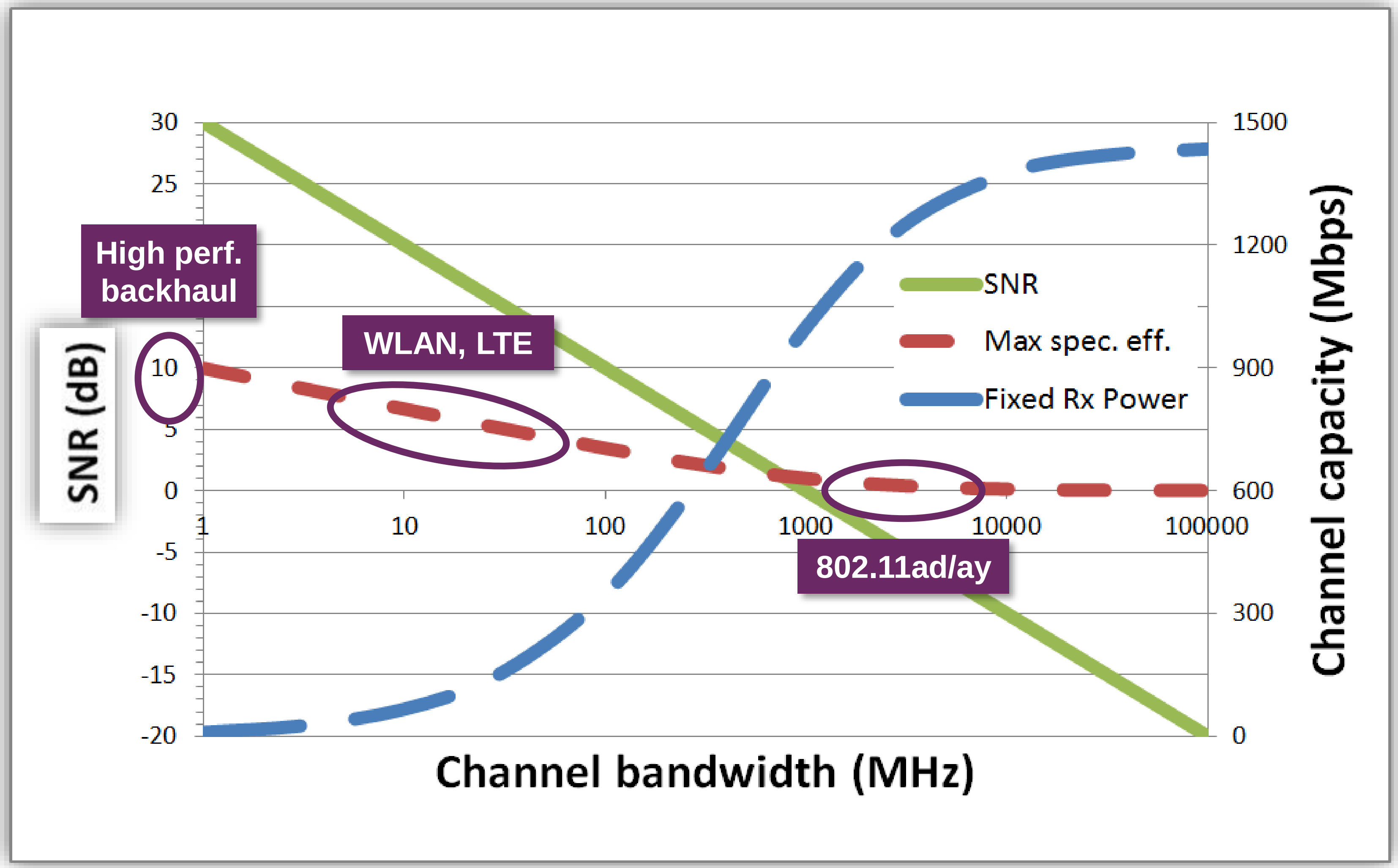
Today: Enabling Next-Generation Broadband Access

TODAY'S CHALLENGING APPLICATIONS

	5G	SatComm	802.11ay
Complex Modulations	OFDM 256 QAM	OFDM 256 APSK	Single-Carrier 64 QAM
Wider Bandwidth	100/400 MHz 1.2 GHz (CA)	0.5-3 GHz	4-8 GHz
Higher Frequencies	FR1: < 7.125 GHz FR2: 24 - 52 GHz	Ka Band V Band	57-71 GHz
Multiple Antennas Techniques	Phased array antenna MIMO FR1: 8x8 MIMO FR2: 2x2	Phased array antenna	Phased array antenna MIMO

Higher Frequencies = Wider Bandwidth?

SO HOW WIDE DO YOU GO?



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Example of an Emerging Standard: 802.11ay PHY

	802.11ad	802.11ay
PHY Modes	• SC QAM, 2.16GHz, up to 8 Gbps	• SC QAM, 4.32 GHz • OFDM (optional)
Channelization	• 2.16GHz/channel • No channel bonding/aggregation	• 2.16, 4.32, 6.48 (optional), 8.64GHz (optional) • Channel aggregation (optional): 2.16+2.16GHz, 4.32+4.32GHz

Beamforming/steering	• Supports multiple antennas, one at a time
	• Single stream
		• MIMO (optional)
		  • Multiple streams
		  • Multiple transmit chains
		  • Multiple antennas
		• Downlink Multi-user (optional)

802.11ay Measurement Setup: 4.32 GHz BW @ 61.56 GHz

UXR Wideband mmWave Measurements

UXR 16 QAM MEASUREMENTS IN THE 60, 70, AND 80 GHZ FREQUENCY BANDS

	1 GHz SR (OBW= 1.22 GHz)	2 GHz SR (OBW= 2.44 GHz)	3 GHz SR (OBW=3.66 GHz)	4 GHz SR (OBW=4.88 GHz)
UXR 61.56 GHz	1.18%	1.28%	1.48%	1.71%
UXR 73.5 GHz	1.36%	1.57 %	1.79 %	2.08%
UXR 83.5 GHz	1.45%	1.86 %	2.15%	2.45%

Used VDI Compact V-Band Upconverter, V-Band Amp, 57.2-65.9 GHz Bandpass Filter for 61.56 GHz Measurements

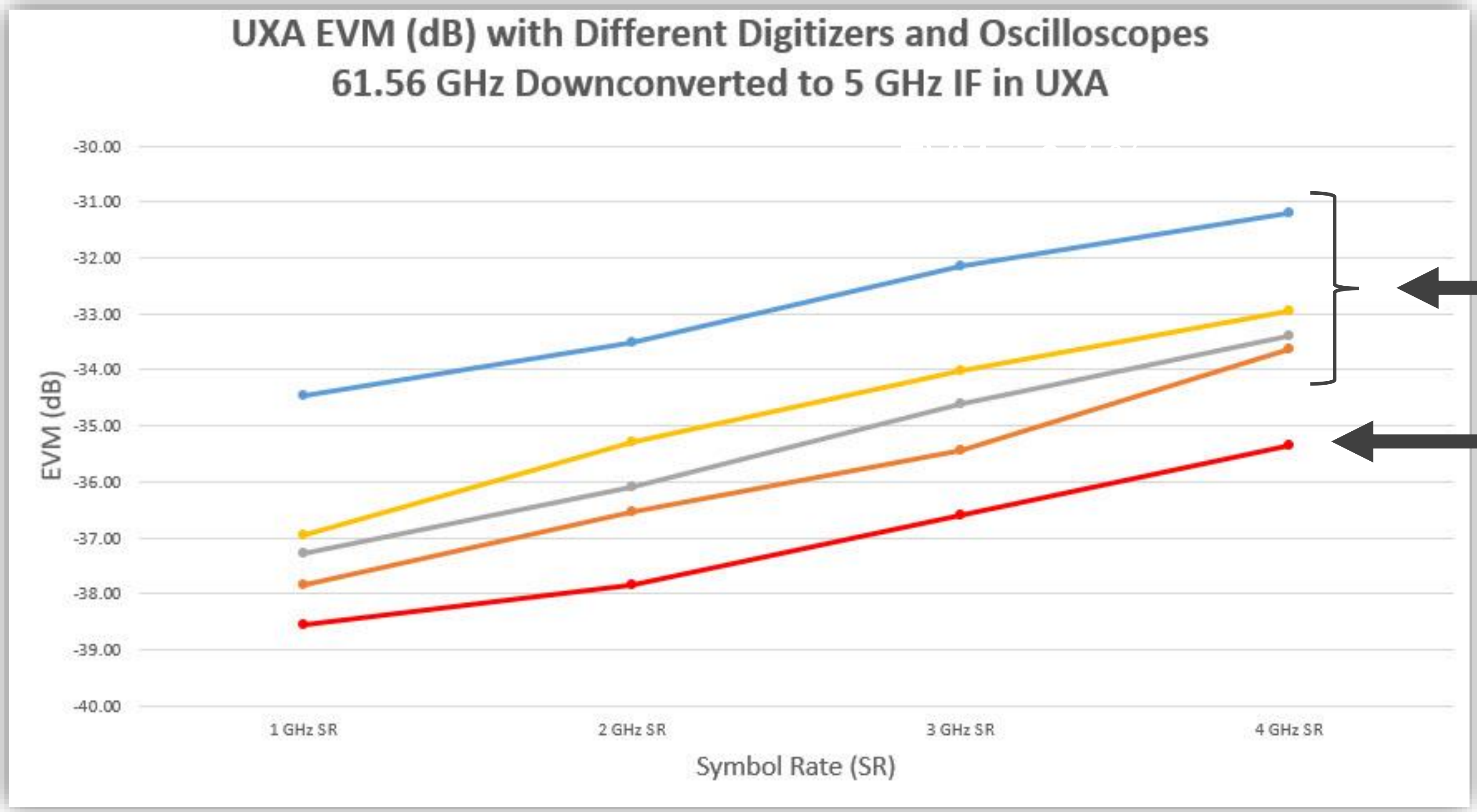
Used VDI Compact E-Band Upconverter, E-Band Amp, 71-76 GHz Bandpass Filter for 73.5 GHz Measurements

Used VDI Compact E-Band Upconverter, E-Band Amp, 81-86 GHz Bandpass Filter for 83.5 GHz Measurements

All measurement results used reference RMS as the EVM normalization reference with adaptive equalization enabled

UXA and Digitizers – Comparison of mmWave Capabilities

EVM PERFORMANCE WITH DIFFERENT EXTERNAL DIGITIZERS



61.56 GHz down-converted to 5 GHz IF; IF digitized with various Keysight digitizers and oscilloscopes

Direct UXR measurement at 61.56 GHz (no down-conversion)

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6G Wireless

WHAT IT MEANS FOR SIMULATION, DESIGN, TEST & MEASUREMENT

>1 Tbps/user

- Simulate/Design/Measure Sub THz RF
- Baseband: extreme-speed, real-time
- Extreme-speed interconnect (board-to-board)
- Optical WiFi Communications
- Optical Networks: beyond 800G

Physical Measurements!

Complex Radio Systems Design & Testing

- Heterogeneous: WiFi, Cellular, FR1+FR2+FRN
- Test in simultaneous modes
- Design/simulate complex systems
- Extreme power efficiency

Complex System Interaction

E2E Network Design, Validation, Optimization

- QoS (quantitative) – Validate SLA
- QoE (qualitative) – Validate SLA
- Security – All facets

System ←→ Society Interaction

Tomorrow: Enabling Next-Generation Broadband Access

TOMORROW'S CHALLENGING APPLICATIONS

	5G	SatComm	802.11ay	6G ??
Complex Modulations	OFDM 256 QAM	OFDM 256 APSK	Single-Carrier 64 QAM	Single-Carrier? OFDM? Others?
Wider Bandwidth	100/400 MHz 1.2 GHz (CA)	0.5-3 GHz	4-8 GHz	>10 GHz?
Higher Frequencies	FR1: <7.125 GHz FR2: 24 - 52 GHz	Ka Band V Band	57-71 GHz	Sub-THz, THz?
Multiple Antennas Techniques	Phased array antenna MIMO FR1: 8x8 MIMO FR2: 2x2	Phased array antenna	Phased array antenna MIMO	Phased array antenna? MIMO ? Others?

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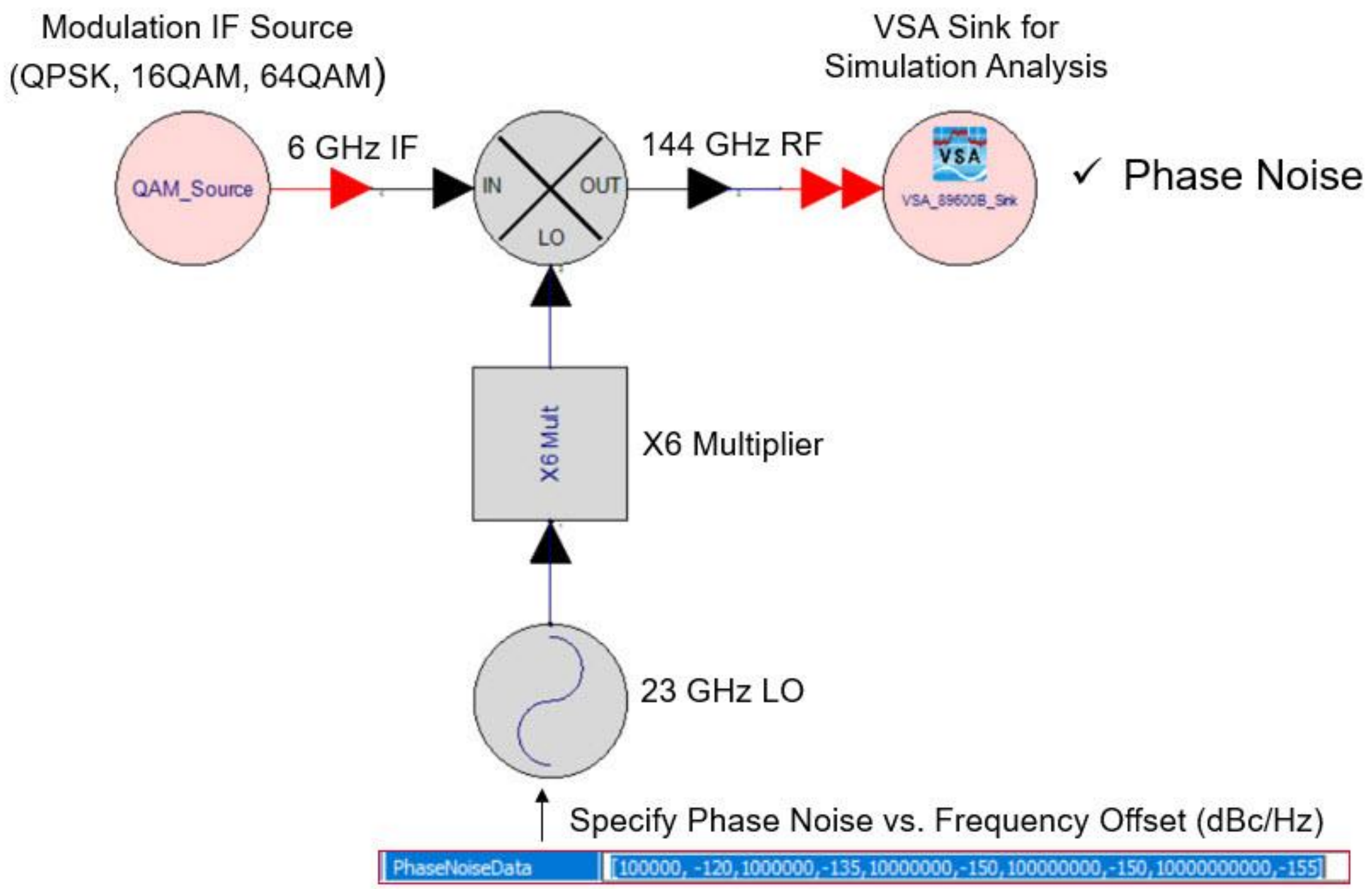
Sub Terahertz System Considerations

KEY CONSIDERATIONS

- Optimizing Signal-to-Noise Ratio (SNR)
- Minimizing Phase Noise
- Addressing Linear and Nonlinear Impairments
- Making a Waveform Selection

Sub Terahertz System Considerations

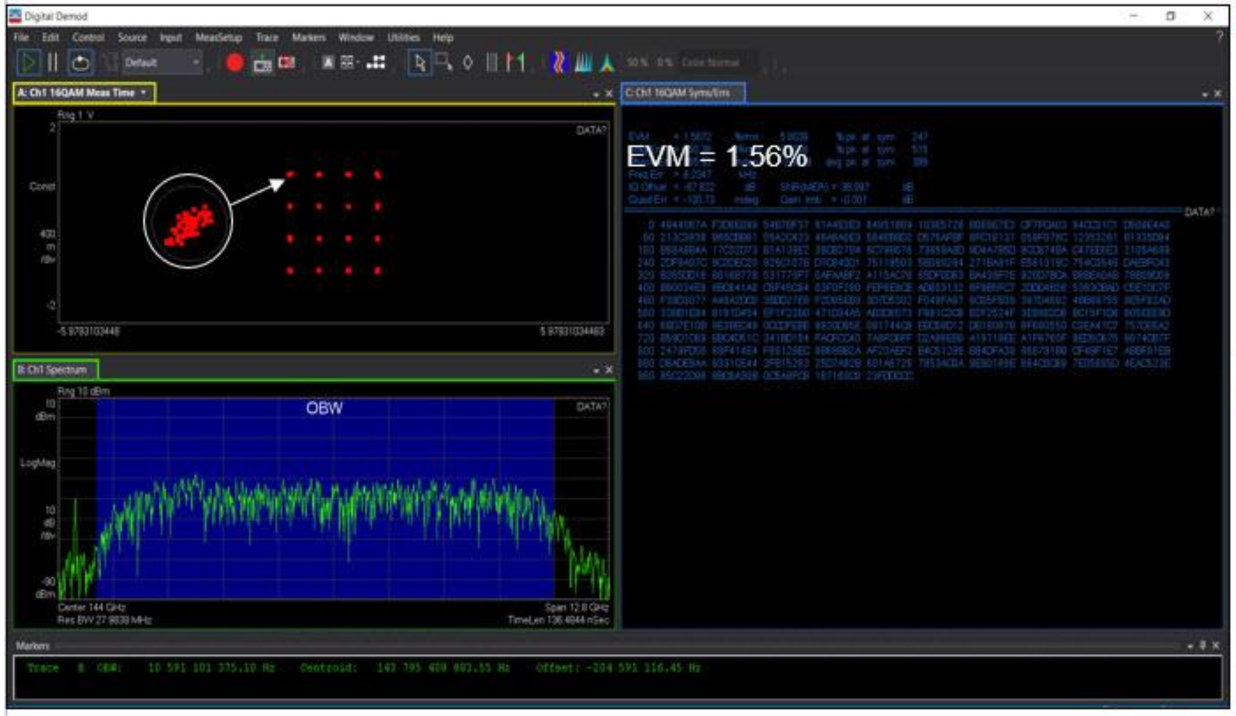
SIMULATION CASE STUDY



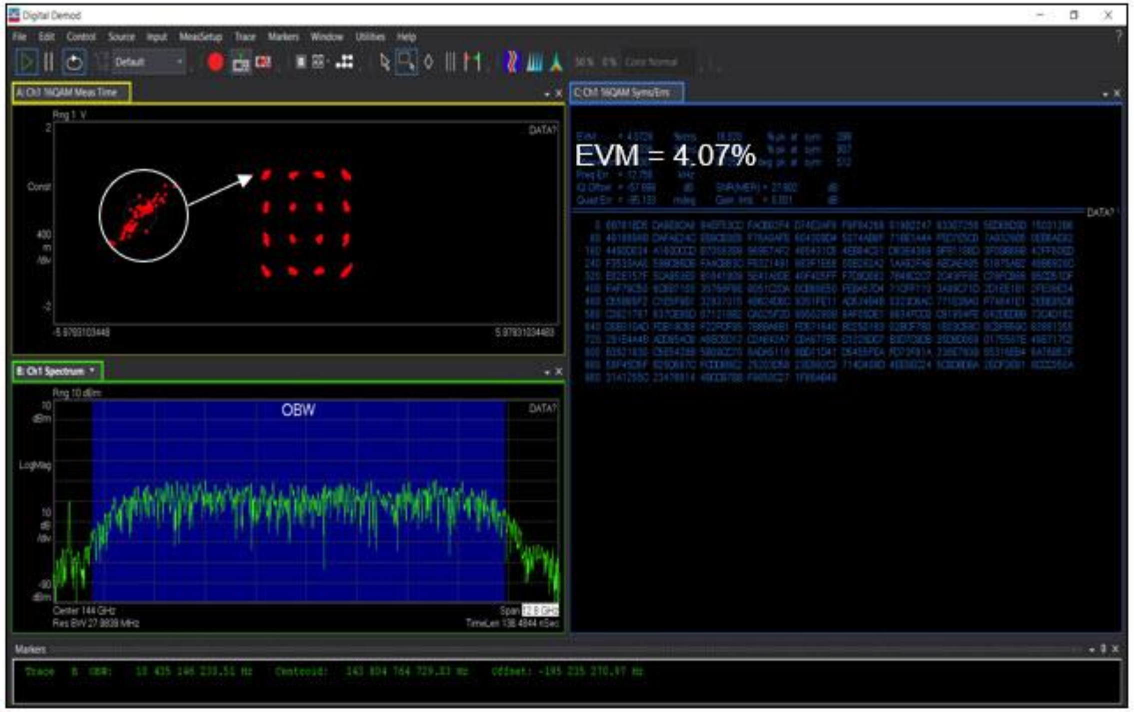
Sub Terahertz System Considerations

SIMULATION CASE STUDY

✓ Phase Noise



Simulated Using dBc/Hz from Phase Noise Profile in Previous Slide



Increased Phase Noise by 10 dBc/Hz for Higher Frequency Offsets

Sub Terahertz System Considerations

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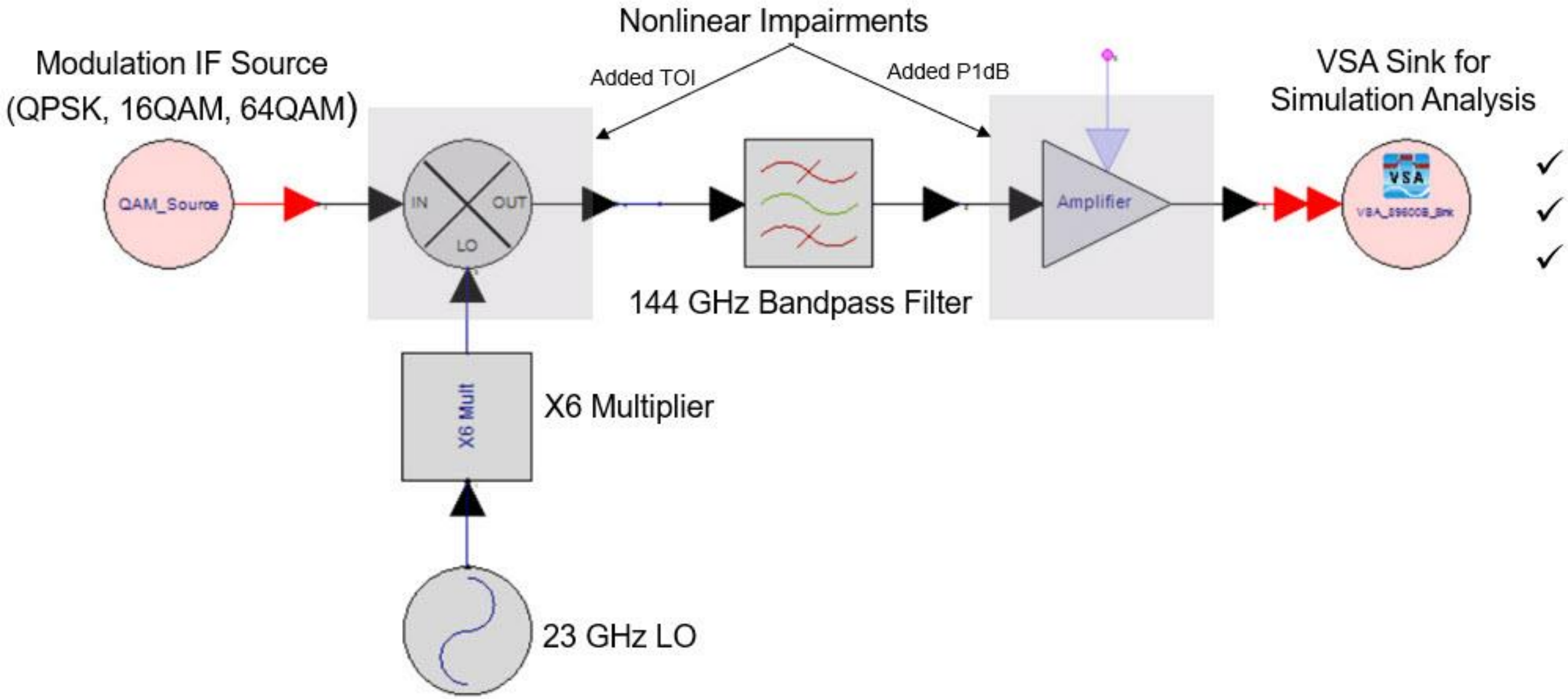
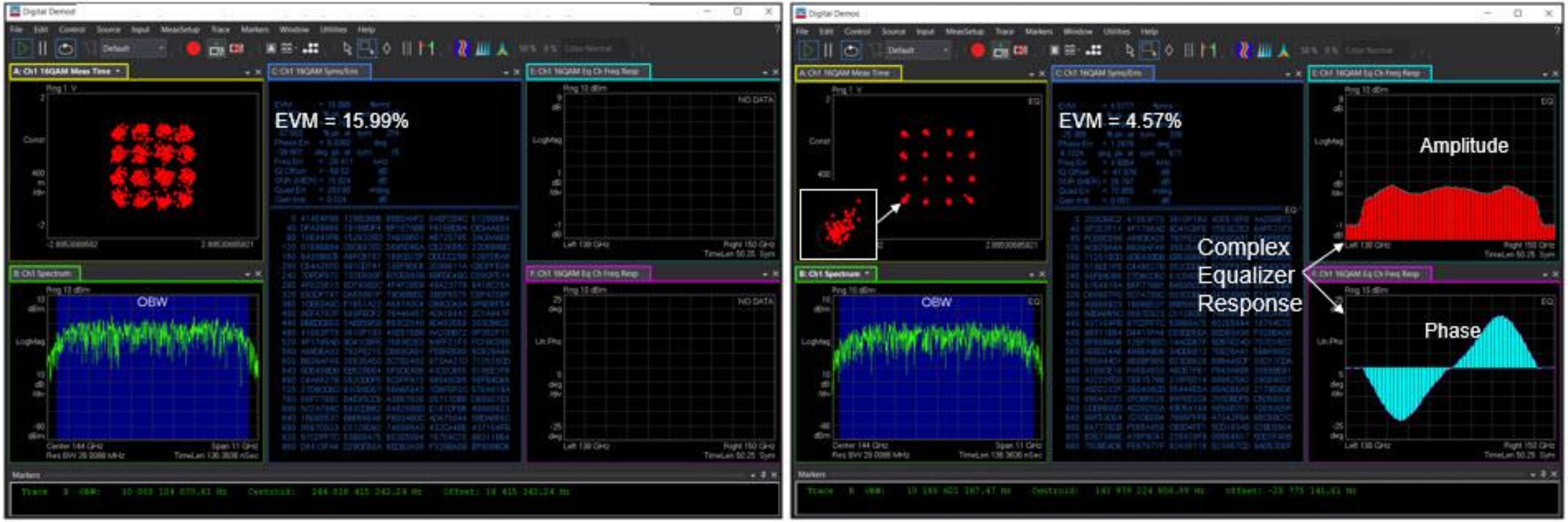


- ✓ Phase Noise
- ✓ Linear Impairments
- ✓ Nonlinear Impairments

Sub Terahertz System Considerations

SIMULATION CASE STUDY

- ✓ Phase Noise
- ✓ Linear Impairments
- ✓ Nonlinear Impairments



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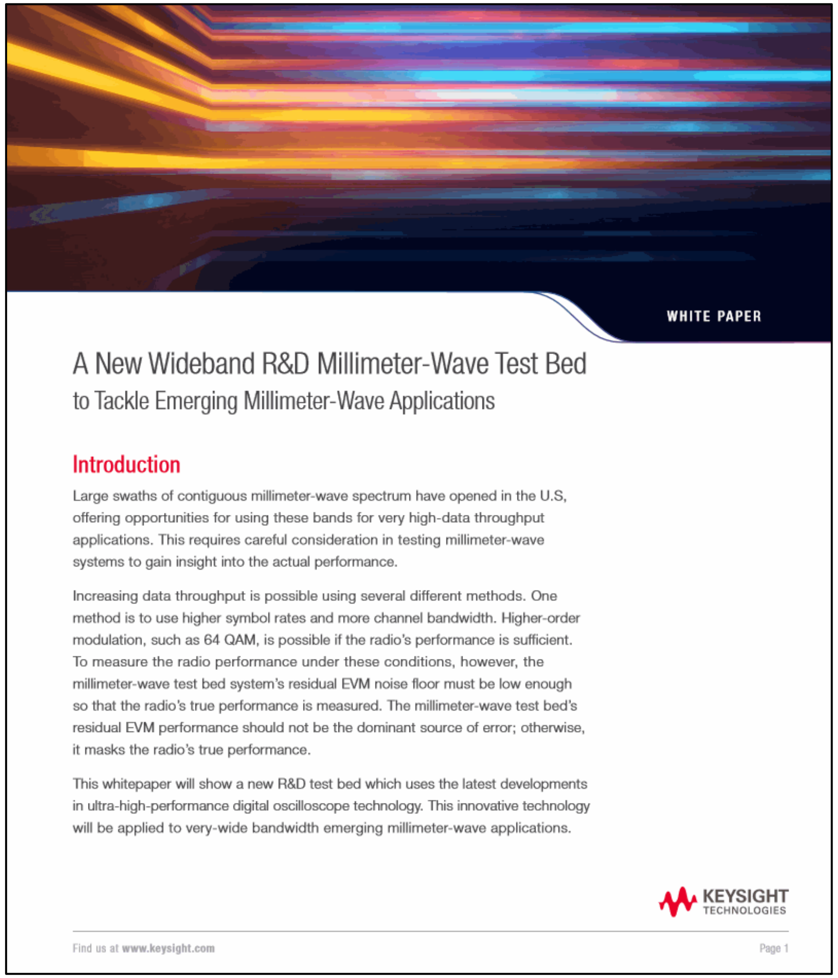
Summary

- R&D testbed offer flexibility and scalability for emerging millimeter wave applications
- Testbed was applied to 802.11ay as an example of an emerging millimeter wave application
- Demonstrated performance achievable in the 60, 70, and 80 GHz frequency bands
- Early 6G research is already underway
- Discussed key considerations for sub-terahertz systems

Additional Resources

R&D Testbed Whitepaper



WHITE PAPER

A New Wideband R&D Millimeter-Wave Test Bed to Tackle Emerging Millimeter-Wave Applications

Introduction

Large swaths of contiguous millimeter-wave spectrum have opened in the U.S, offering opportunities for using these bands for very high-data throughput applications. This requires careful consideration in testing millimeter-wave systems to gain insight into the actual performance.

Increasing data throughput is possible using several different methods. One method is to use higher symbol rates and more channel bandwidth. Higher-order modulation, such as 64 QAM, is possible if the radio's performance is sufficient. To measure the radio performance under these conditions, however, the millimeter-wave test bed system's residual EVM noise floor must be low enough so that the radio's true performance is measured. The millimeter-wave test bed's residual EVM performance should not be the dominant source of error; otherwise, it masks the radio's true performance.

This whitepaper will show a new R&D test bed which uses the latest developments in ultra-high-performance digital oscilloscope technology. This innovative technology will be applied to very-wide bandwidth emerging millimeter-wave applications.

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6G Sub-THz Testbed Whitepaper

WHITE PAPER

A New Sub-Terahertz Testbed for 6G Research

The first 5G networks are commercial and expanding. We are on the cusp of realizing the next generation of high-speed, high-reliability, and flexible mobile connectivity. This connectivity is driving advanced new consumer applications as the second generation of commercial 5G user equipment arrives on the market. It also opens up new possibilities in developing smart factories and smart cities and in meeting challenges in sectors as diverse as agriculture, public health, and global resource management.

The pace of innovation continues to accelerate. Even with 5G is its early stages of expansion, research has begun for 6G. Keysight has joined the multiparty 6G Flagship Program. As a founding member, Keysight will participate in groundbreaking 6G research that pushes the boundaries of high-speed, high-bandwidth communications. The vision for 6G includes concepts such as holographic communications and time-engineered systems that take the next step beyond the benefits of 5G — thus expanding into even more sectors that depend upon always-on connectivity.

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