mmWave Wideband signal Analysis in Commercial communication

Senior Project Manger / Keysight Technologies

Philip Chang

Why Go To mmWave?

CUSTOMER PROBLEM

- That require more width bandwidths for new applications like 5G, WiGig, mmW backhaul, SatComm and Automotive Radar.
- VHF, UHF and Microwave bands becoming increasingly crowded
- Spectrum auctions provide revenue for governments

Example of mmW Wideband Standard

NEXT-GENERATION BROADBAND ACCESS SIGNAL EXAMPLES

	5G	SatComm	802.11ay	Automotive Radar
Complex Modulations	OFDM 256 QAM	OFDM 256 QAM	Single-Carrier 64 QAM	LFM Chirp / FMCW Various Modulations
Wider Bandwidth	100/400 MHz 1.2 GHz (CA)	0.5-2 GHz	4-8 GHz	4+ GHz
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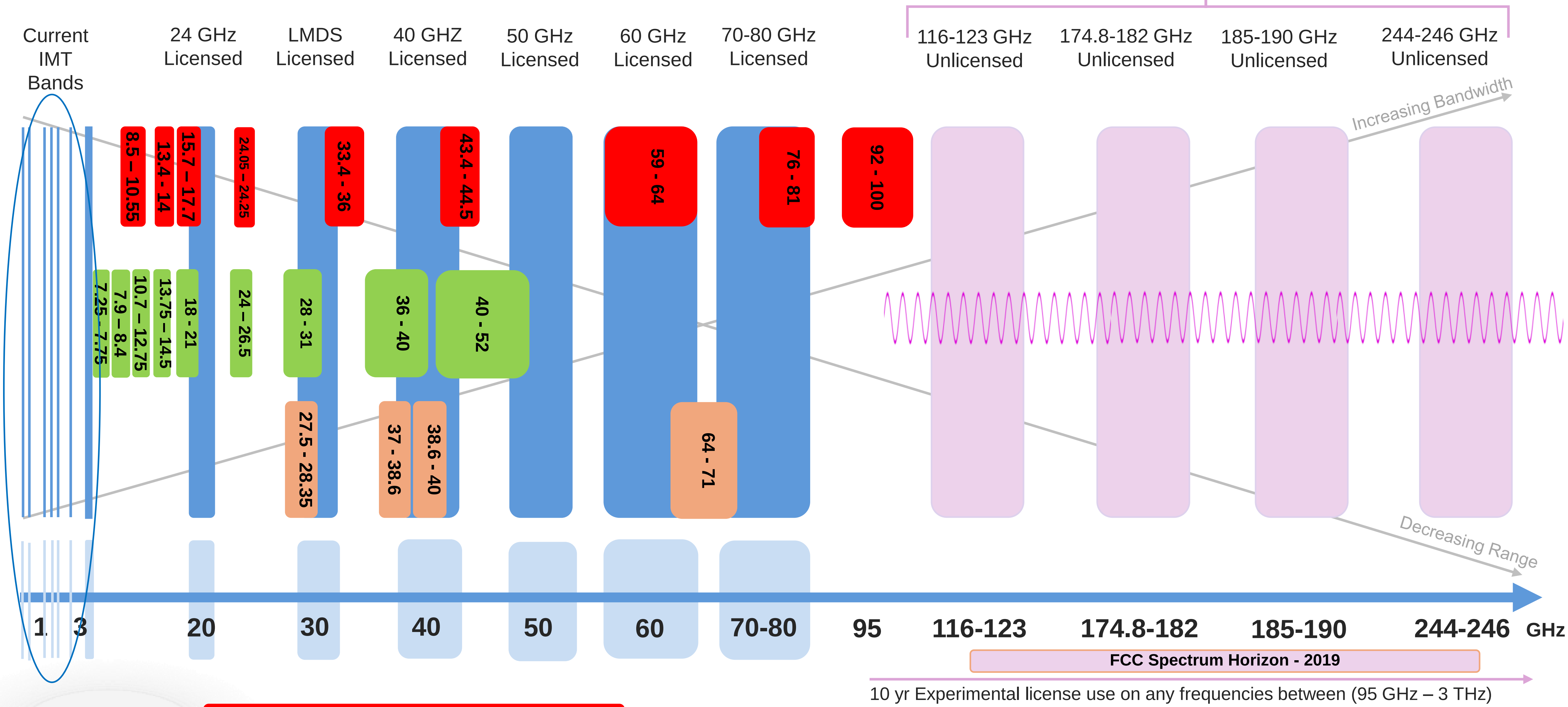
Spectrum

U.S. 10 YR EXPERIMENTAL LICENSED SPECTRUM

21.1 GHz of new unlicensed spectrum



Aerospace defense frequency allocations

Satellite communications frequency allocations

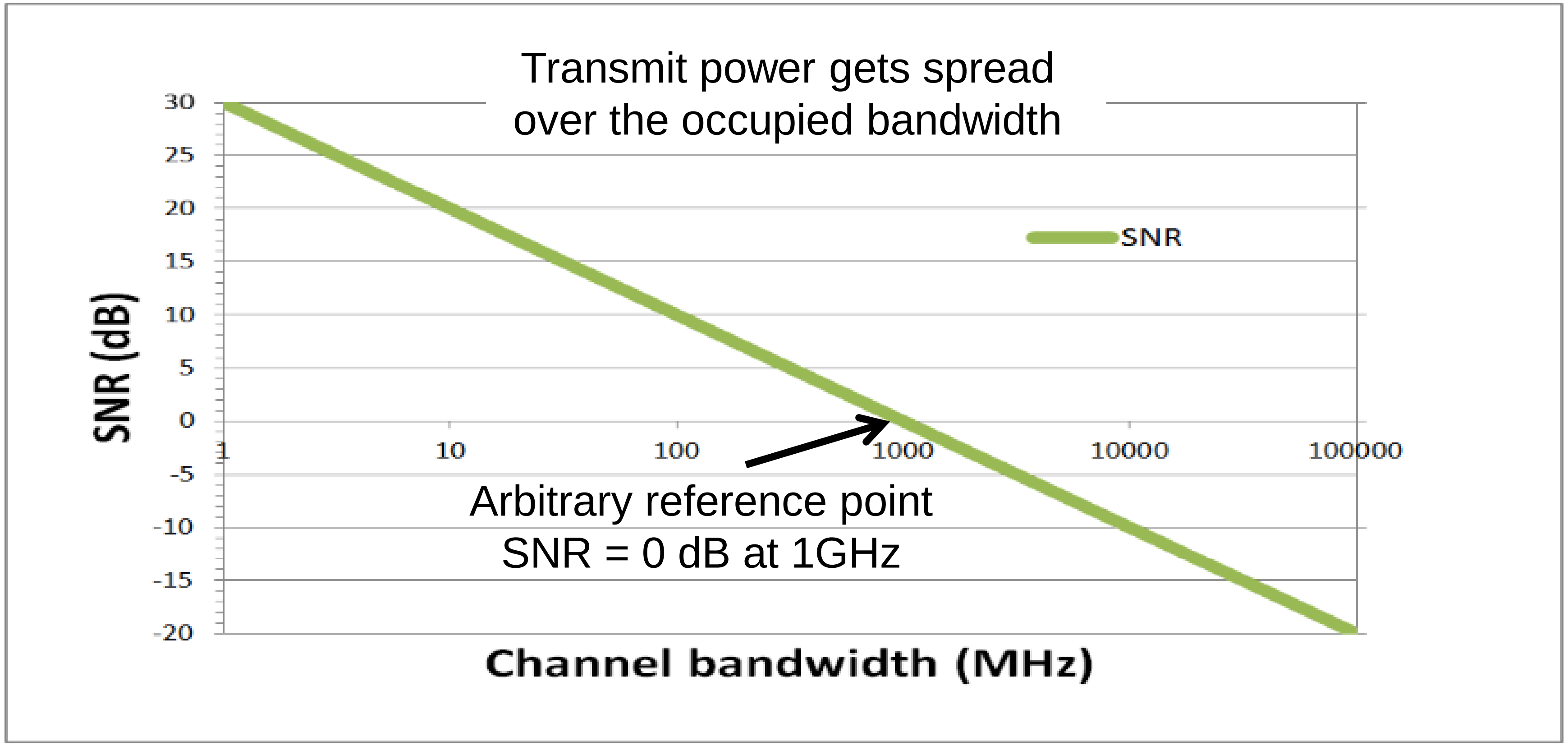
10.85 GHz of new spectrum released by FCC

KEYSIGHT TECHNOLOGIES

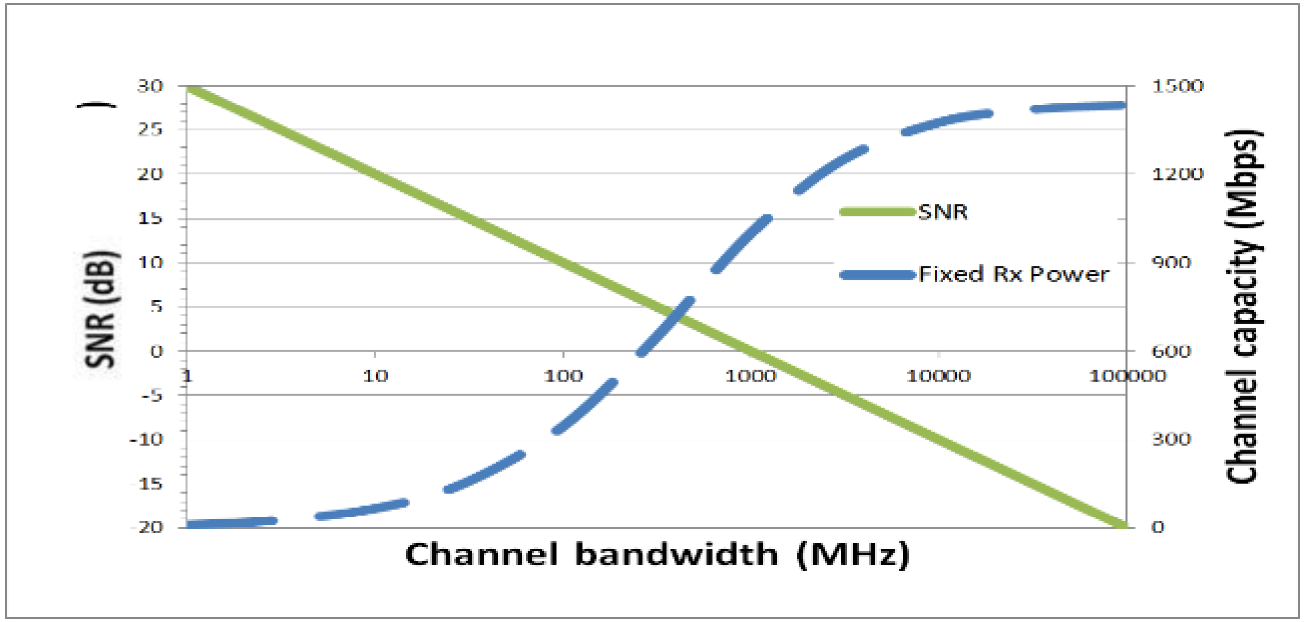
*Gigabit LTE and beyond: Mobilizing millimeter wave

Higher Frequencies = Wider Bandwidth?

bps/Hz is important; so is uJ/bit for a portable device



Higher Frequencies = Wider Bandwidth?

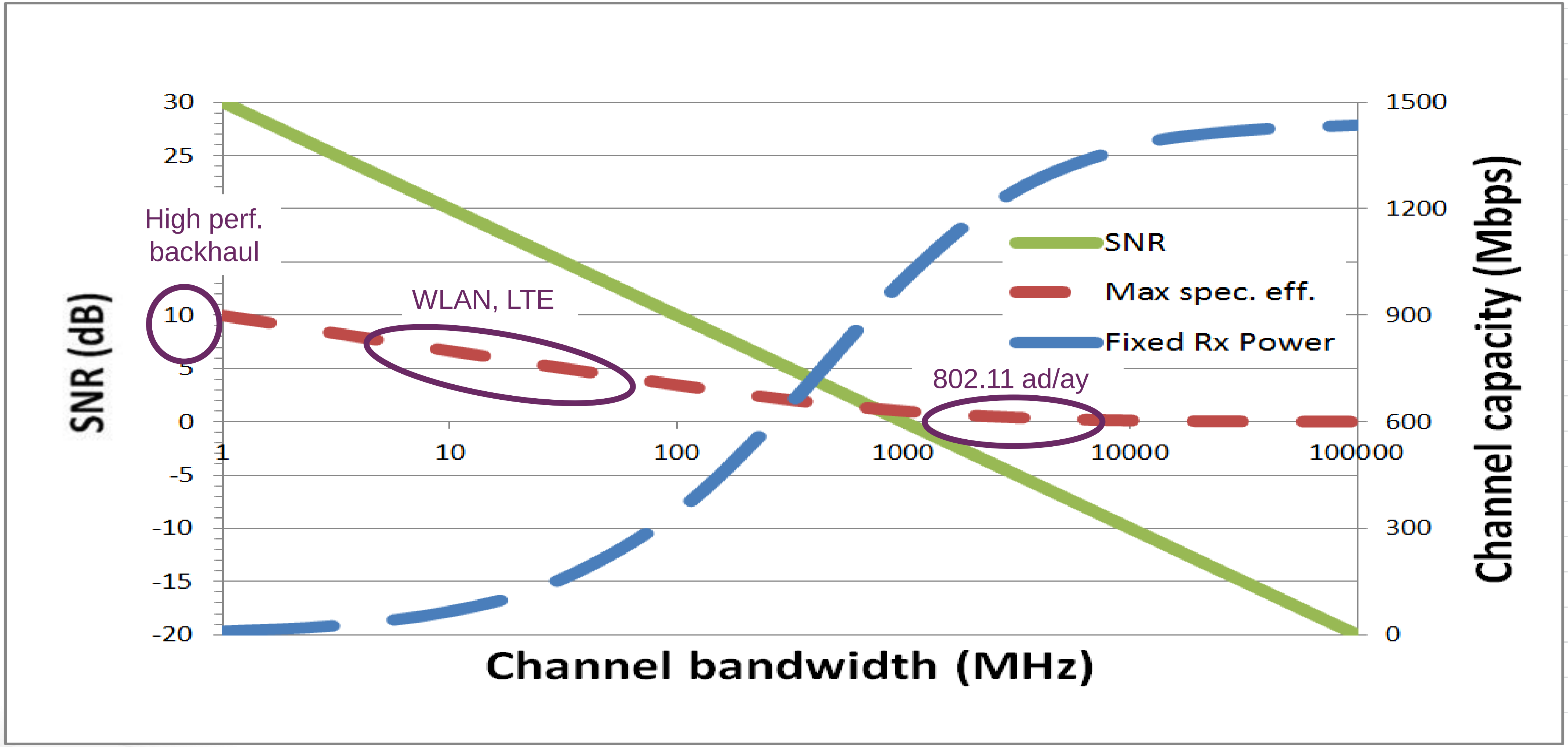


Some System Challenges with Higher Frequencies and Wider Bandwidths:

- Optimizing SNR
- Optimizing System Performance
  - Phase Noise
  - Linear Impairments (e.g. Amplitude and Phase vs. Frequency)
  - Nonlinear Impairments (e.g. Power Amplifier Gain Compression, Mixers, etc…)

Higher Frequencies = Wider Bandwidth?

SO HOW WIDE DO YOU GO?

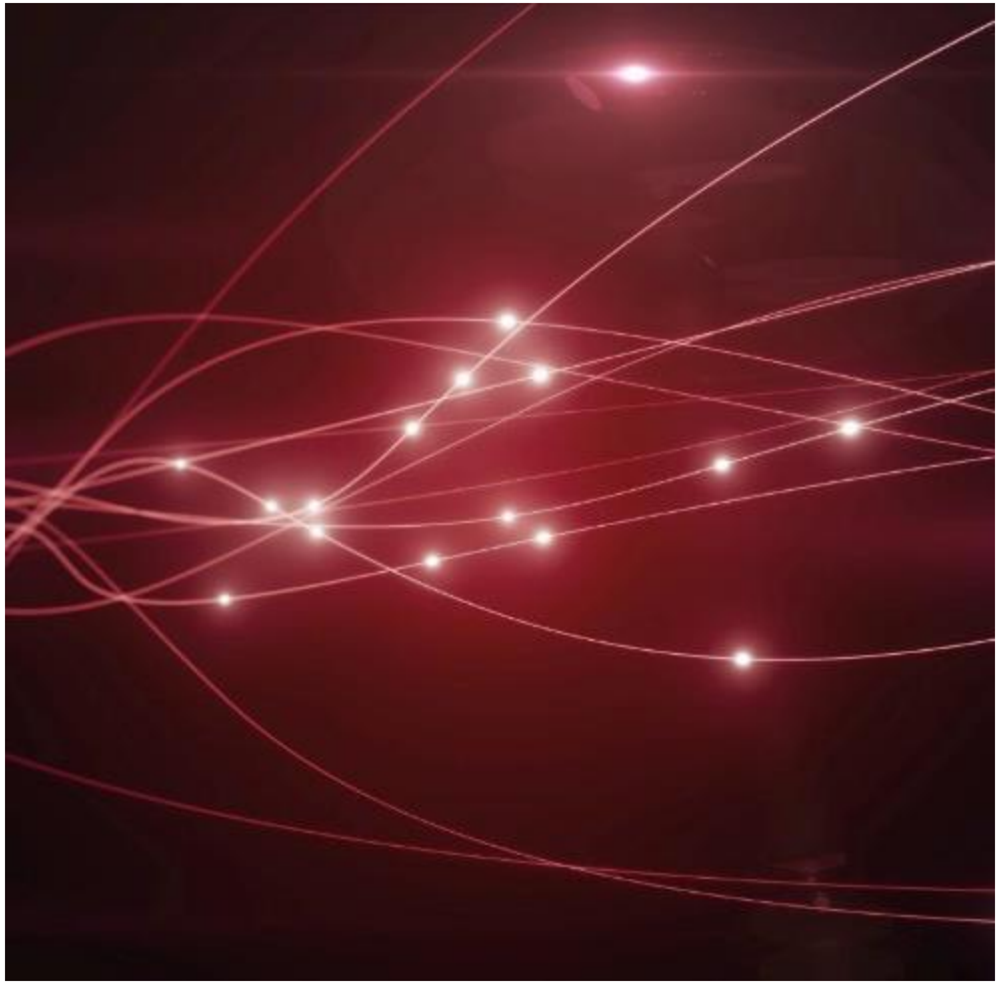


Challenges for High-Band mmWave

MOVING FORWARD FOR EMERGING STANDARDS

- Very wide bandwidths may be needed for high data throughput (e.g. 4.32-8.64 GHz bandwidth for 802.11ay)
- 6G may involve sub-THz and THz frequency bands, even wider BWs
- Multi-channel may also be needed for multiple antenna techniques (e.g. MIMO)

Flexibility for Frequency Bands, Bandwidths, and Multiple Channels is Needed



KEYSIGHT TECHNOLOGIES

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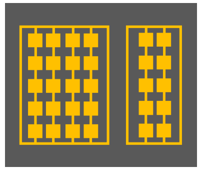
Automotive Radar Frequency

24GHz NB	24GHz UWB	26GHz UWB	77GHz	79GHz UWB
Worldwide	US/Canada Japan EU until 2013/ will be extended to 2022 but with reduced bandwidth	US/Canada Japan	"Worldwide"	Singapore EU
different bandwidth EU: 200MHz (75cm) [450MHz] (33cm) US: 200MHz (75cm) JP: 200MHz (75cm)	US: 7GHz (2.2cm) JP+EU: 5GHz (3cm)	US: 1 GHz (15cm) JP: July 2010 5 GHz (3cm)	1 GHz (15cm) JP: 500MHz (30cm)	4 GHz (4cm)
20dBm	-41dBm	-41dBm	23.5dBm	-9dBm

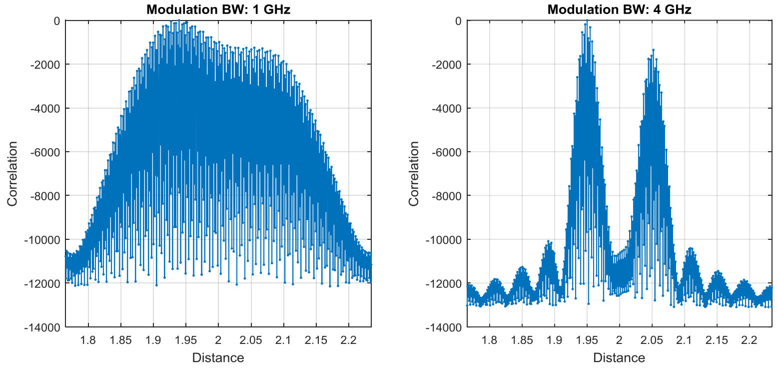


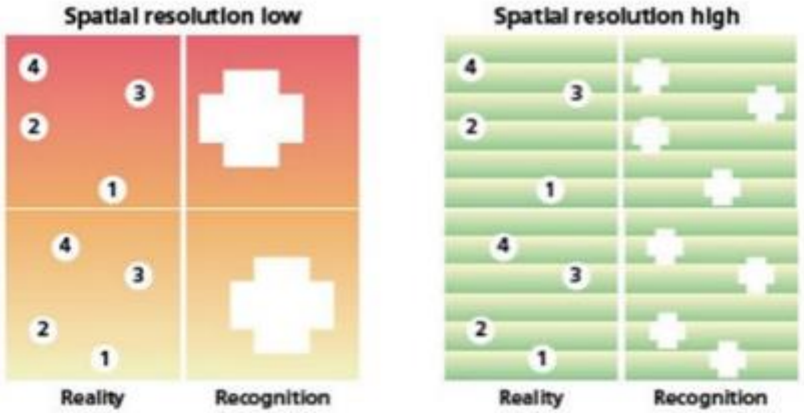



Automotive Radar

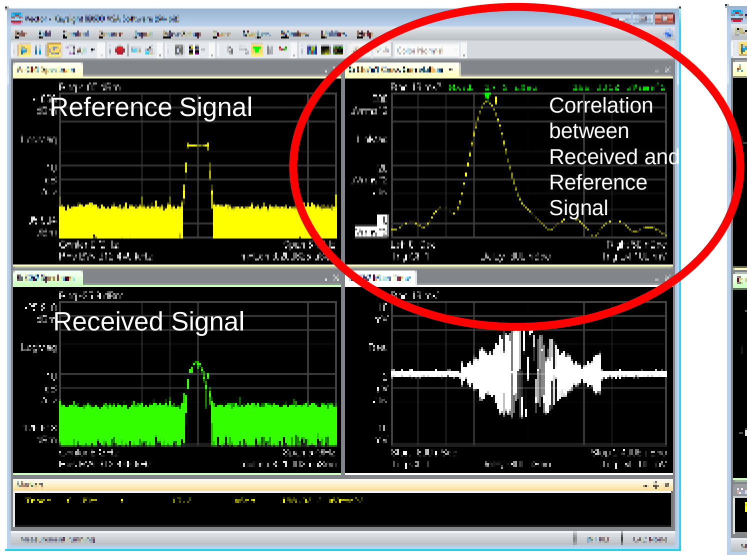
EXAMPLE OF 77 / 79GHZ RADAR SYSTEM & KEYSIGHT TEST SOLUTIONS- 4GHZ BW

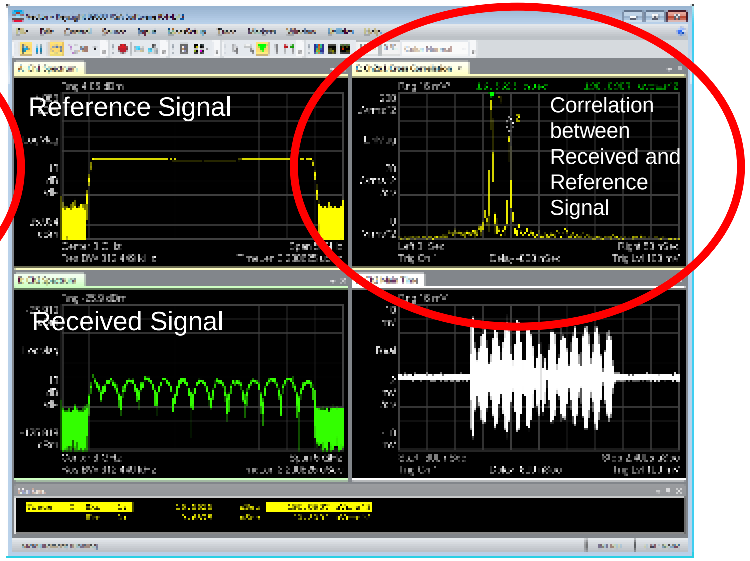
- Two objects, 10 cm apart, FMCW, 1 GHz and 4 GHz mod. BW.
- Simulation Result:





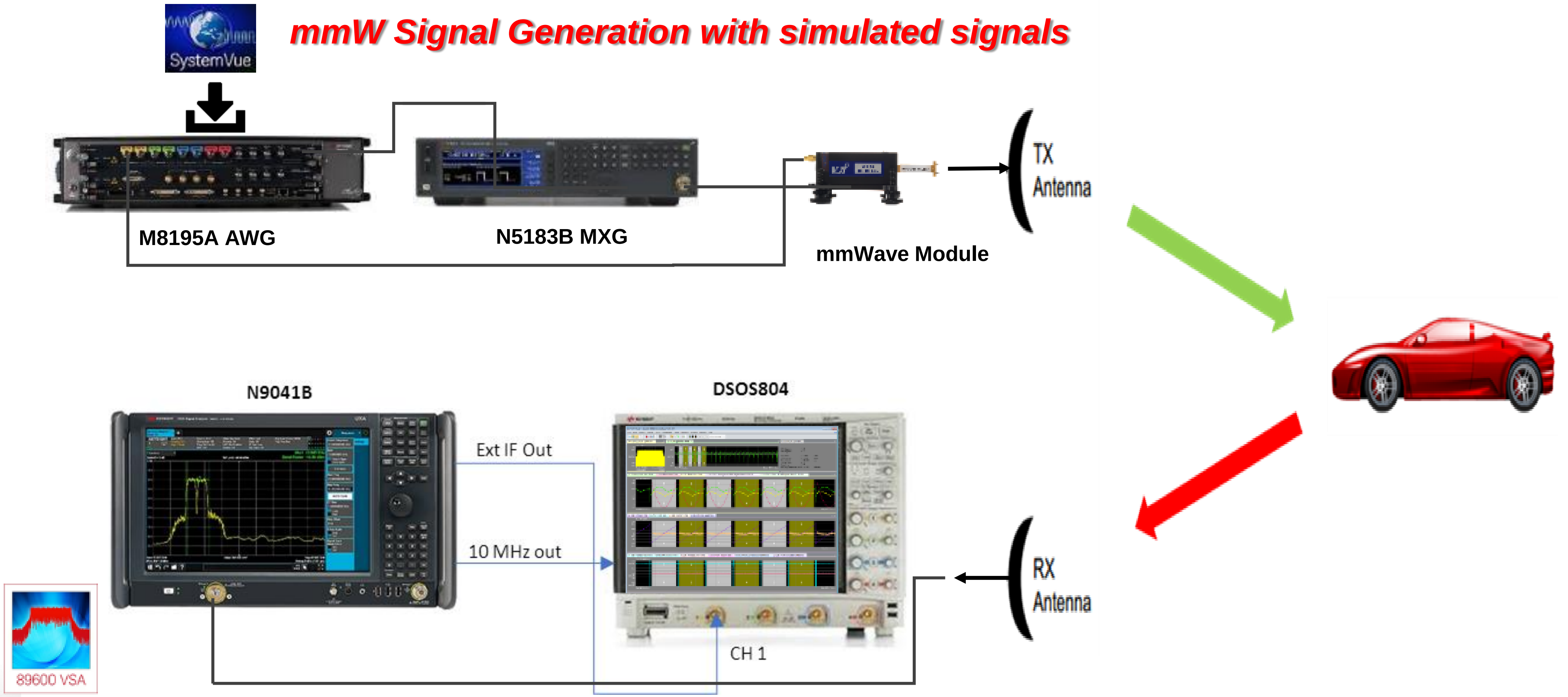
- Measurement Result:





Automotive Radar Development

MILLIMETER WAVE TEST SET UP EXAMPLE



mmW Signal Analysis

Example of mmW Wideband Standard

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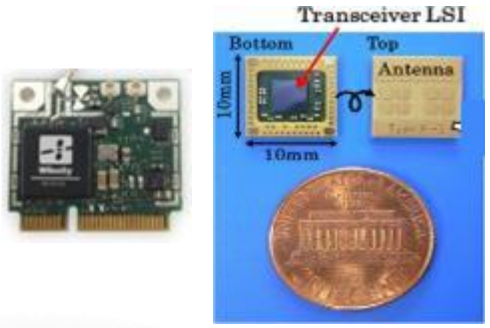
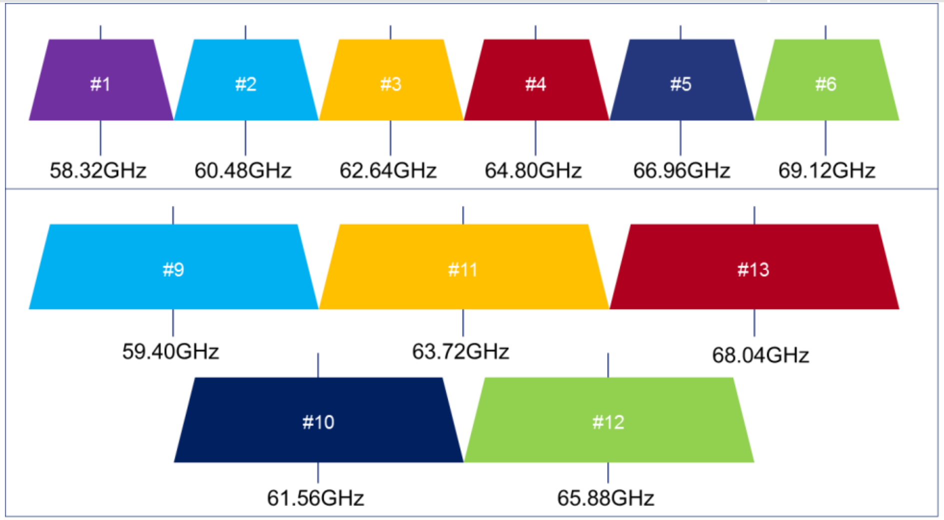
Example of an Emerging Standard: 802.11ay PHY

	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)

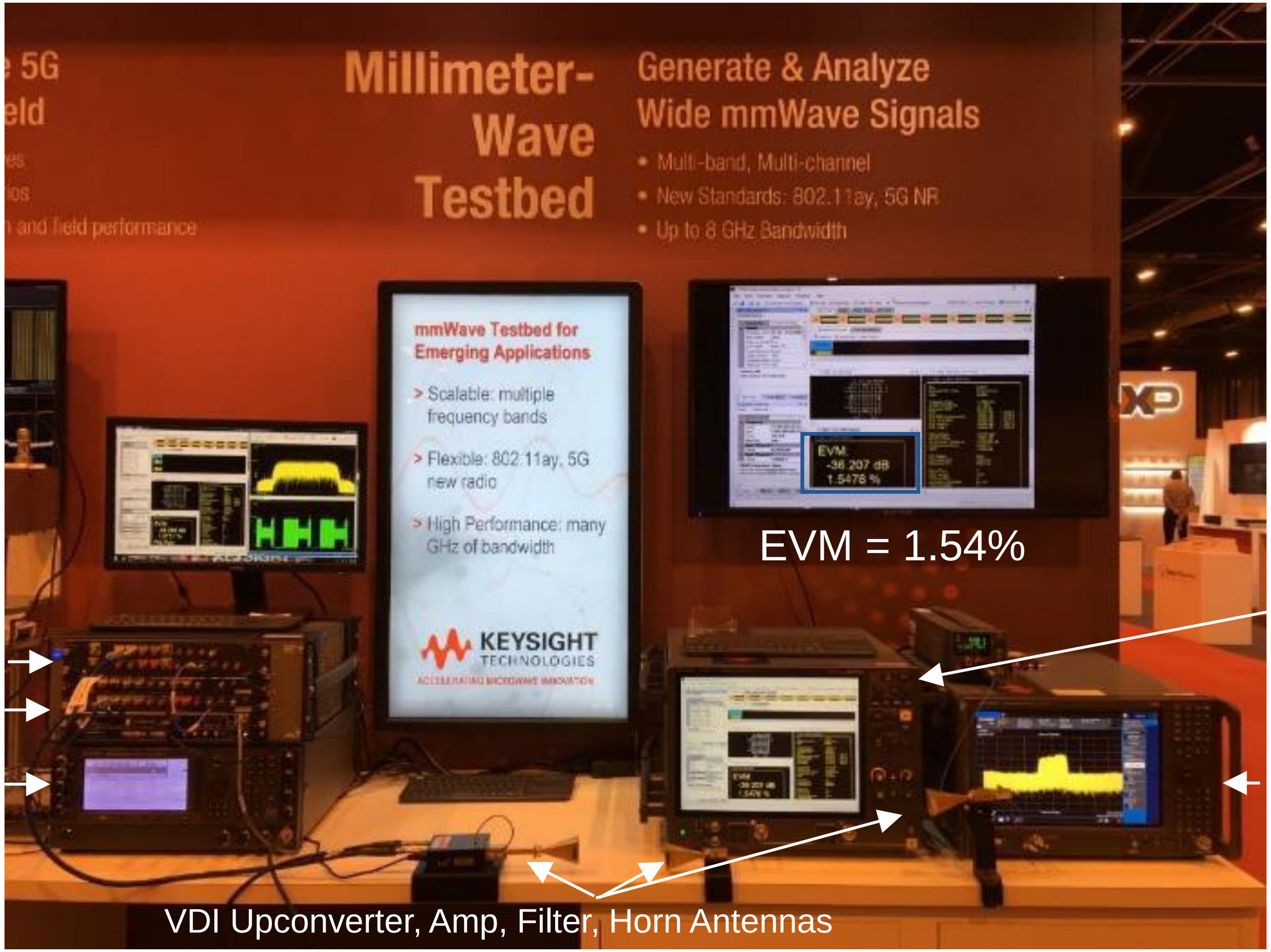




Two Channel Bonded 802.11ay Measurements

NEW WIDEBAND R&D TESTBED FOR EMERGING 5GNR, 802.11AY APPLICATIONS

4.32 GHz 802.11ay Example at European Microwave Tradeshow



M8131A Digitizer

M8195A AWG

PSG LO

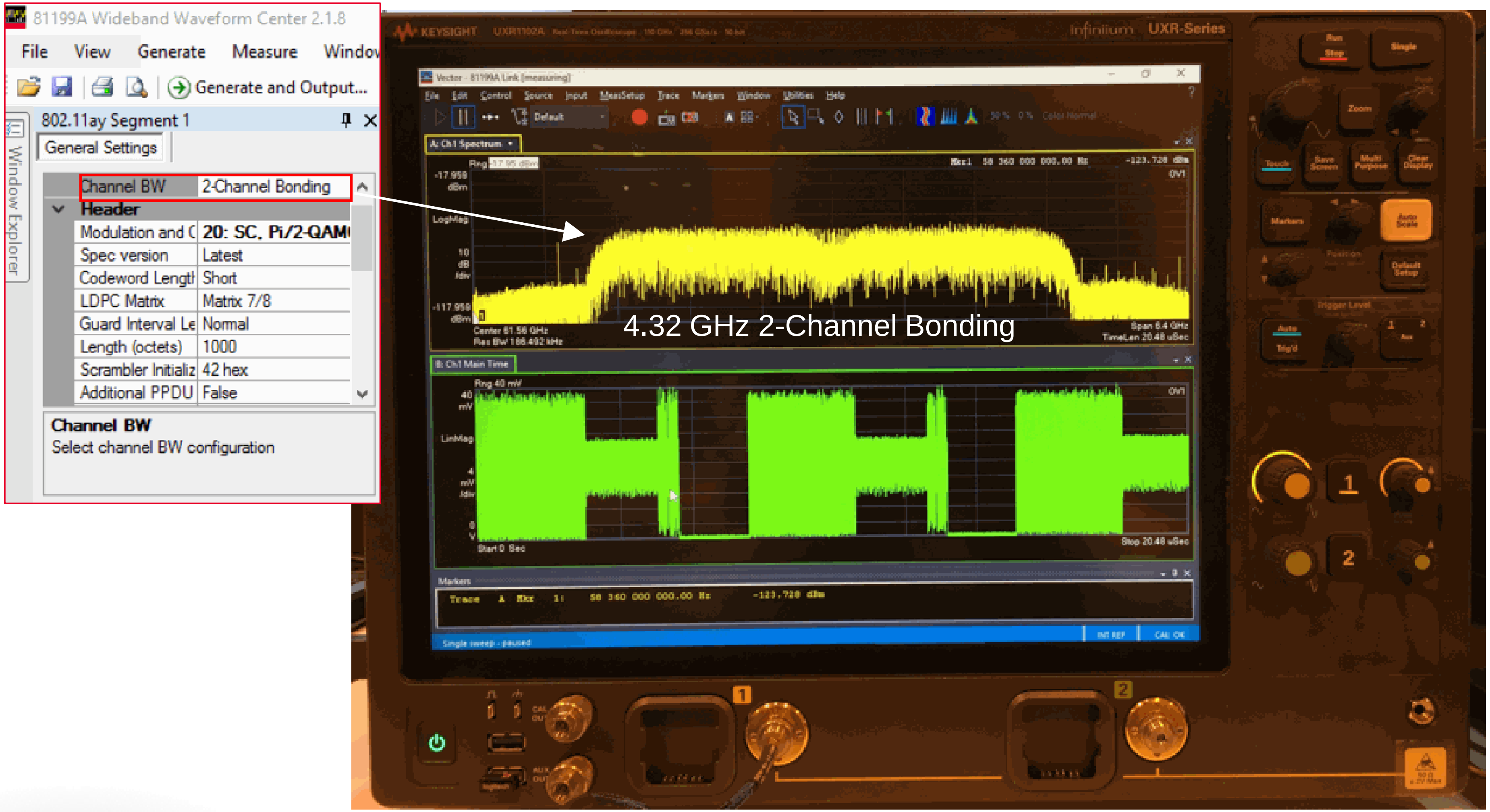
110 GHz UXR

110 GHz N9041B UXA

Measurement Performed after WWC Cal

Direct Digitization and Demod of Wideband mmWave Signal

4.32GHZ BANDWIDTH TWO-CHANNEL BONDED 802.11AY SPECTRUM AT 61.56 GHZ



Measurement Performed after WWC Cal

Direct Digitization and Demod of Wideband mmWave Signal

CLOSE-UP OF UXR DEMOD MEASUREMENT OF 61.56GHZ SIGNAL, 4.32GHZ BW

Signal Received into Horn Antenna. Input into Ch1 of UXR

Measurement Performed after WWC Cal

UXR Wideband mmWave Measurements

UXR 16QAM 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

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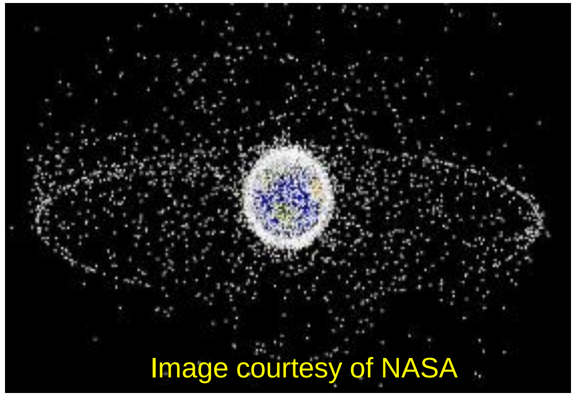
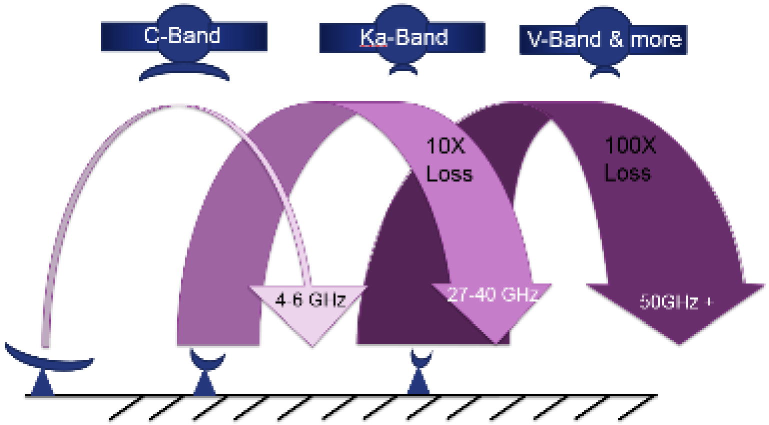
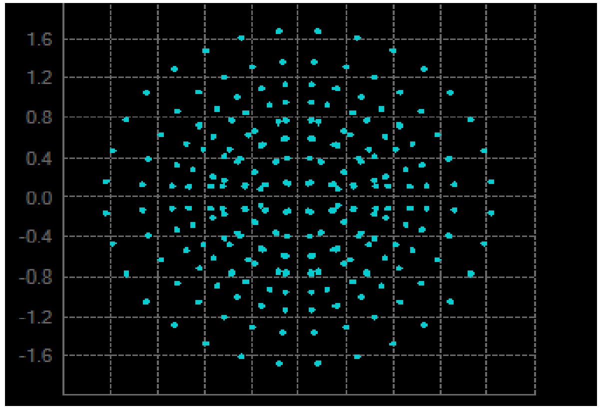
Tech Trend: High Throughput Satellite Constellations

INCREASING DATA DEMAND







Space

- Lowering costs
- 18,000 proposed LEOs
- Increasing electrical interference
- Hostile environment (TVAC) and radiation?
- COTs HW in space

Higher Frequency

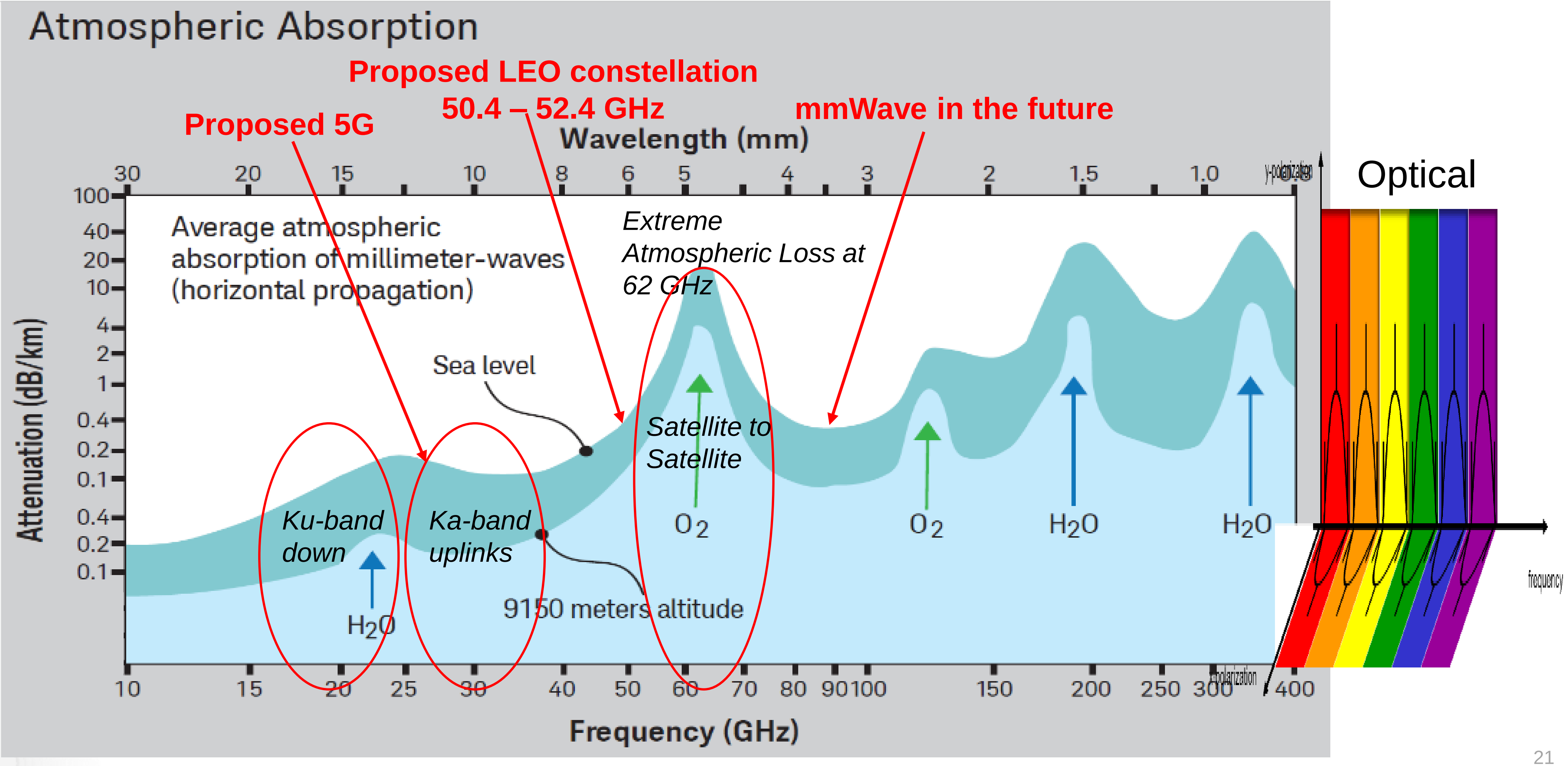
- Move to Ka-band and looking higher to V-band (more available bandwidth)
- Smaller antennas
- Spot beams and phased array antenna (satellite)
- Flat antenna, phased array (mobile, ground)

Higher Data Rates

- High throughput satellite (HTS)
- Frequency reuse
- Higher order modulation
- Wider bandwidth signals
- DVB-S2X, 2014 standard (up to 256 APSK)

Satellite Communications at Higher Frequencies

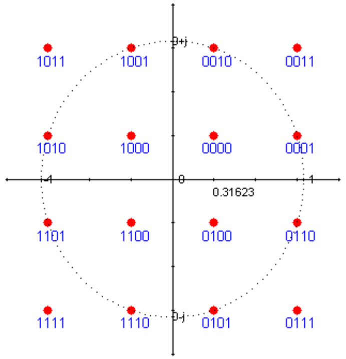
GAIN BECOMES A KEY ENABLER AS LOSS INCREASES

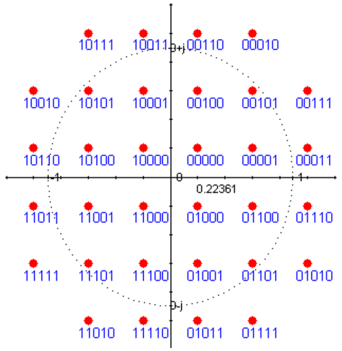


Higher Order Modulation for Satellite Applications

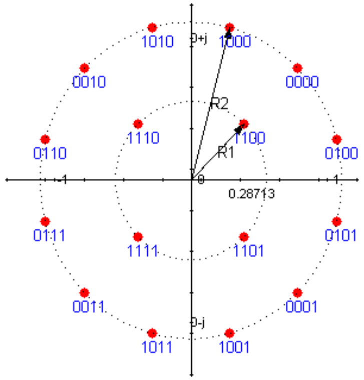
WHAT IS APSK?

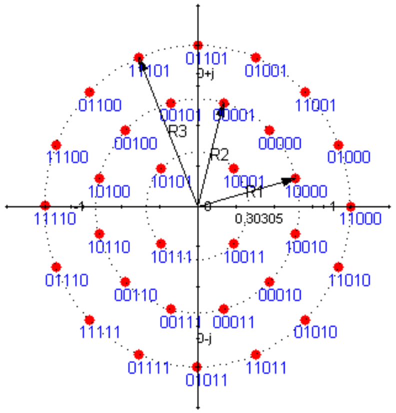
16, 32 QAM





16, 32 APSK





What is APSK?:

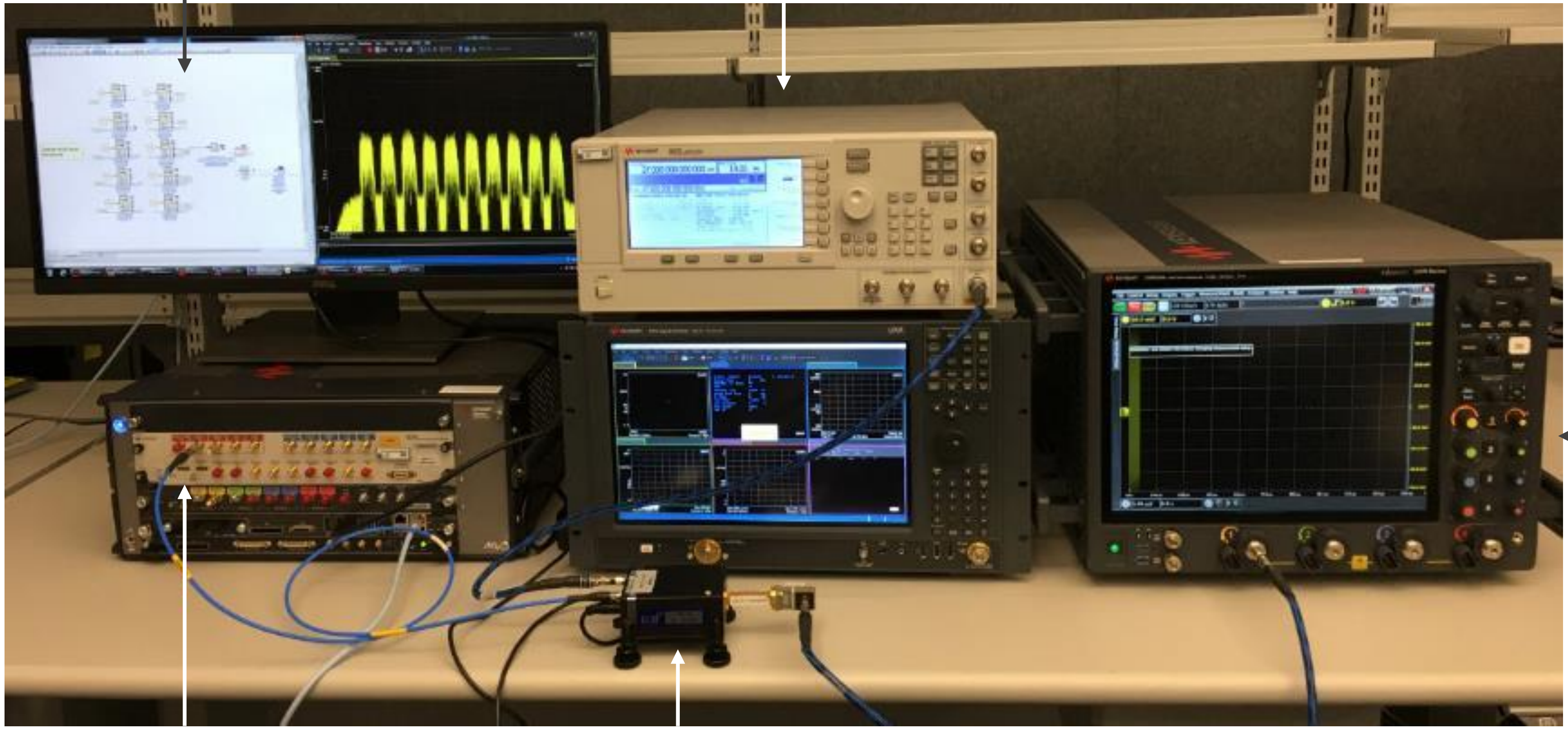
- Used in DVB-S2 (8 PSK, 16 APSK, 32 APSK)
- Compression has less effect on spacing, relative to QAM
- Lower PAPR than QAM
- May lend itself to pre-distortion by varying ring spacing

Analyzing Satellite Waveforms with New 33 GHz UXR

WIDEBAND APSK AND MULTI-CARRIER WAVEFORMS

SystemVue Design Software

PSG (LO)



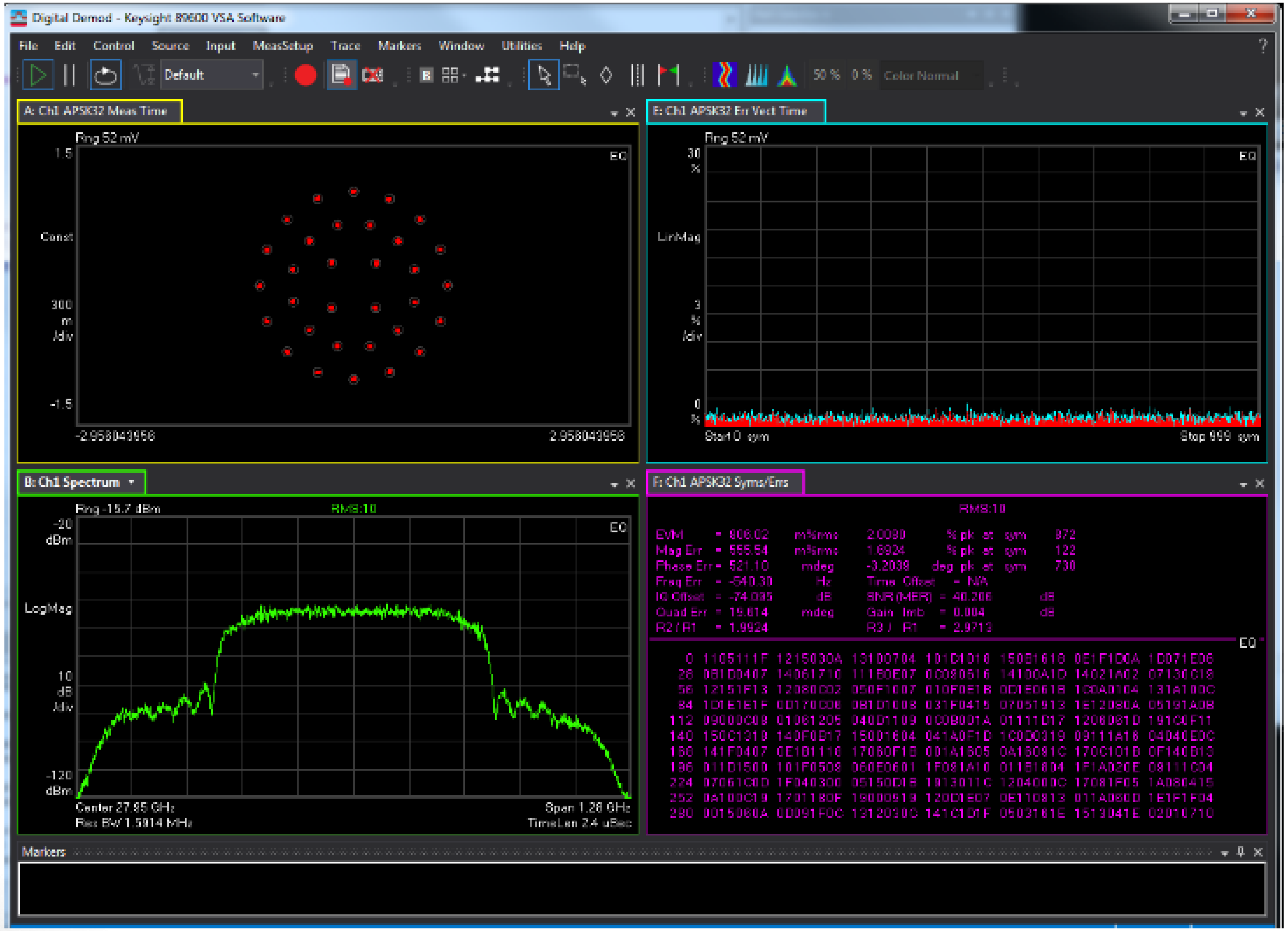
New **33GHz UXR**

M8190A AWG

VDI WR28
Compact Upconverter

Analyzing Satellite Waveforms with New 33 GHz UXR

32APSK WIDEBAND DEMODULATION RESULTS AT 27.95 GHZ, 500 MHZ SR



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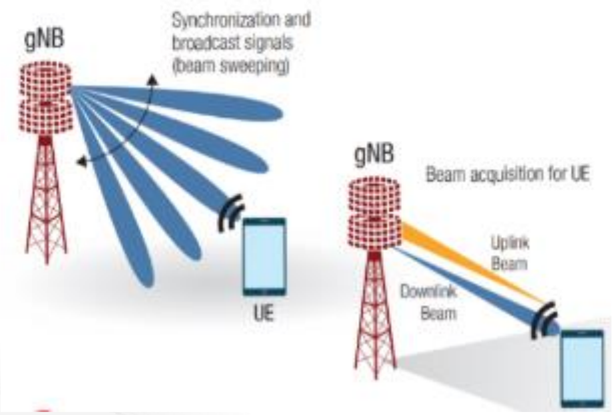
3GPP 5G NR Specification Spectrum

KEY ATTRIBUTES OF RELEASE 15

- 5G NR Release 15
- A revolution from LTE-A
- Key challenges
  - Bandwidth
  - mmWave and Massive MIMO
  - # subcarriers
  - Implementation of 256 QAM and MIMO



Frequency	**Frequency Range 1: 450 MHz – 7125 MHz Frequency Range 2: 24.25 to 52.6 GHz**
Transmission Bandwidths (CC)	FR1: 5 to 100 MHz FR2: 50 to 400 MHz
Sub Carrier Spacing	FR1: 15 kHz, 30 kHz, 60 kHz FR2: 60 kHz, 120 kHz, 240 kHz
Maximum number of Subcarriers	3276 (up to 4096 FFTs)
Carrier Aggregation	Up to 8 carriers, maximum BW of 400 MHz (FR1) and 1200 MHz / 1600 MHz (FR2)
Waveform & Modulation	• CP-OFDM (UL/DL): QPSK, 16QAM, 64QAM and 256QAM • DFT-s-OFDM (UL): π/2-BPSK, QPSK, 16QAM, 64QAM and 256QAM
MIMO	Up to 8 layers in downlink, up to 4 layers in the uplink

5G NR MIMO with New 110 GHz UXR

28 GHZ MIMO TEST SETUP WITH PHASED ARRAY

Device Under Test
Cross-polarized 28-GHz phased array

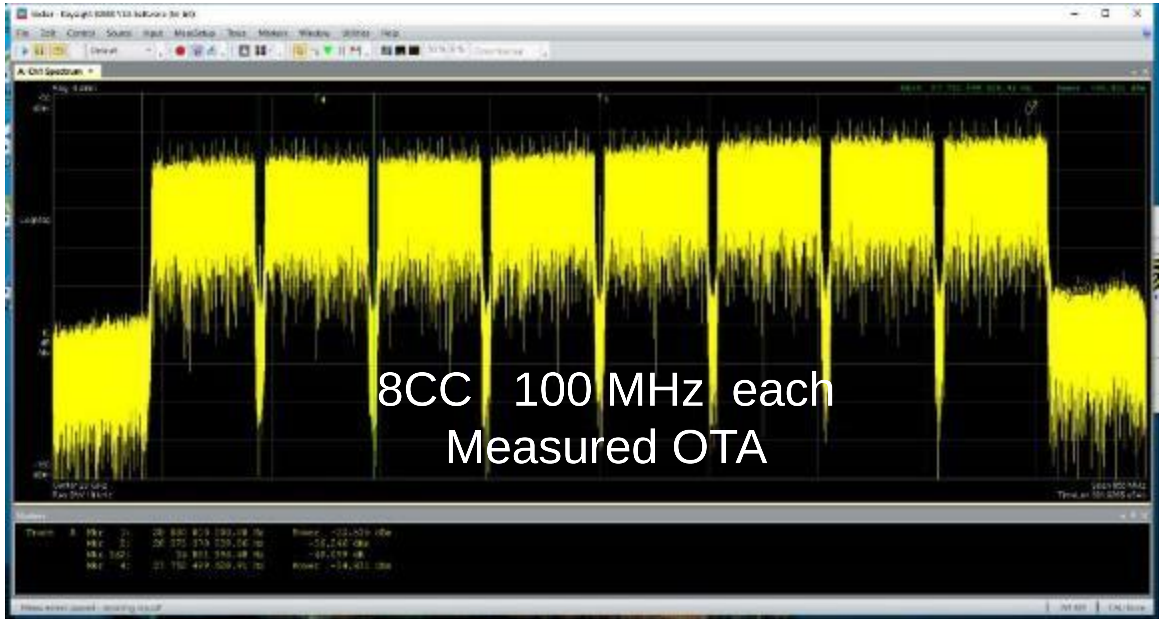
New **M9384B VXG Microwave Signal Generator**

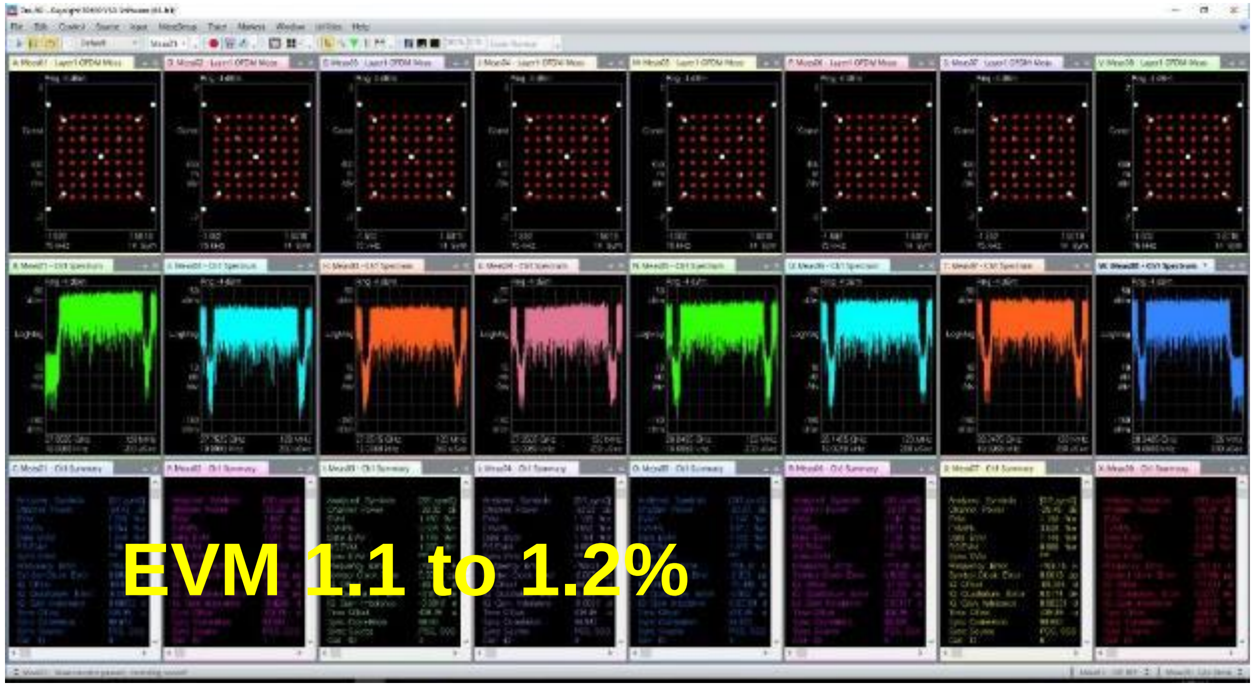
New **110 GHz UXR**

UXA Analyzer 110 GHz

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

Tomorrow: Enabling Next-Generation Broadband Access

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Rel-17 Content Summary

3GPP RAN1 STATUS UPDATE

- MIMO enhancements
- Sidelink enhancements
- DSS enhancements
- IIoT/URLLC enhancements
- Positioning enhancements
- Power saving enhancements
- Coverage enhancements
- NR up to 71 GHz
- NR over NTN
- NR-Light

NR over NTN (Non Terrestrial Networks)

- Satellite communications is becoming part the cellular networks
- Support the 5G deployments by covering difficult to reach areas
- Provide extra reliability for M2M / IoT and connectivity for moving platforms
  - Airplanes, trains, cars
- Scale the traffic, provide broadcast service, improve coverage

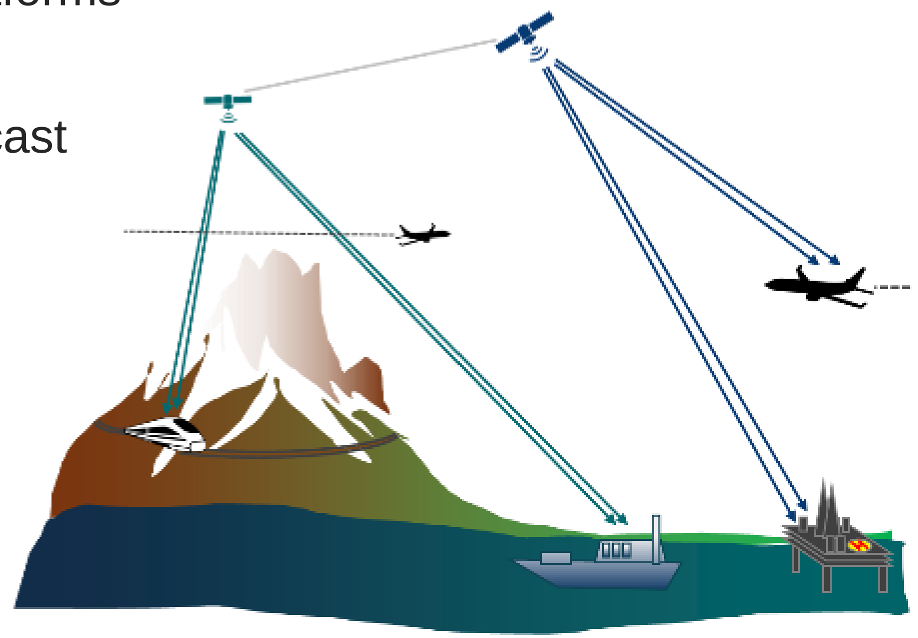


Figure: isolated and moving platforms, hard to reach places

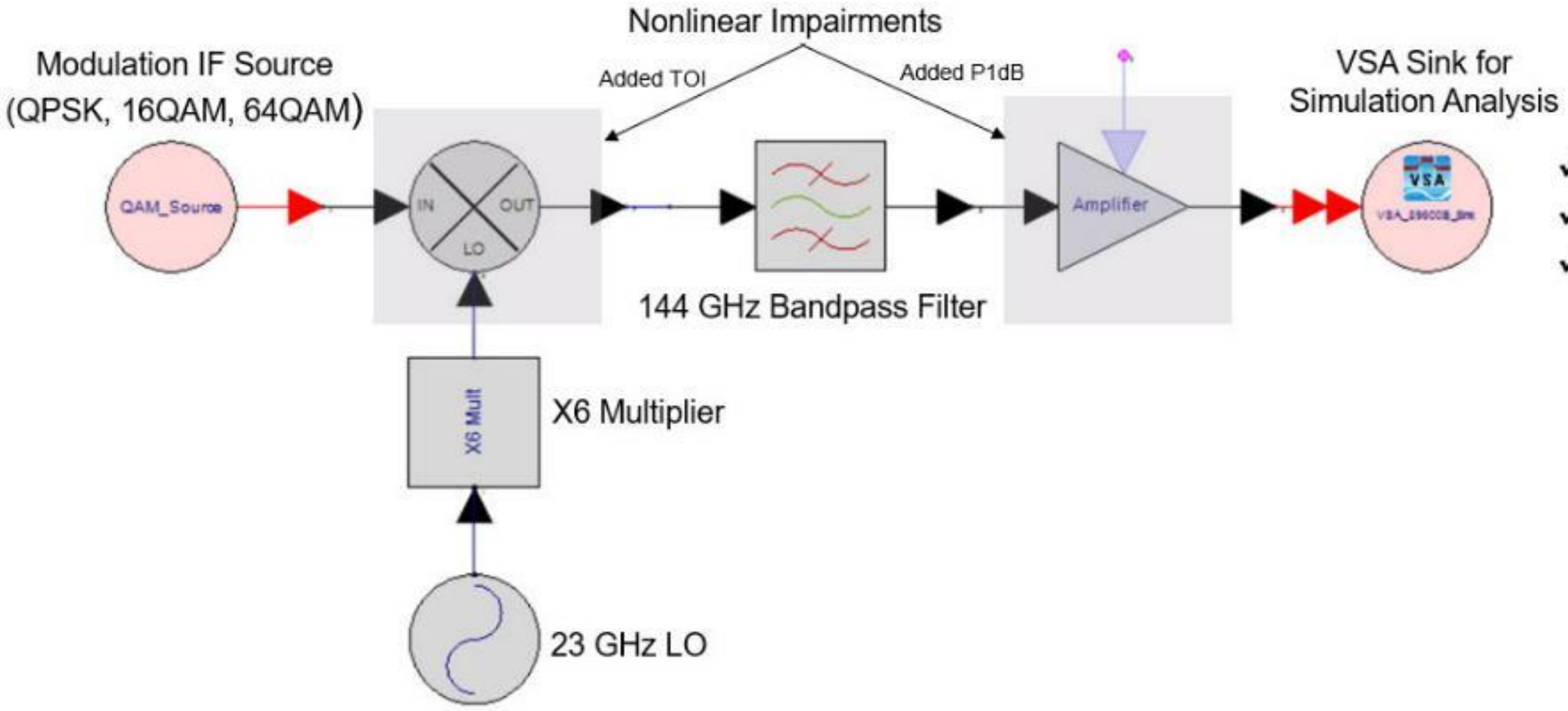
Sub Terahertz System Considerations

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

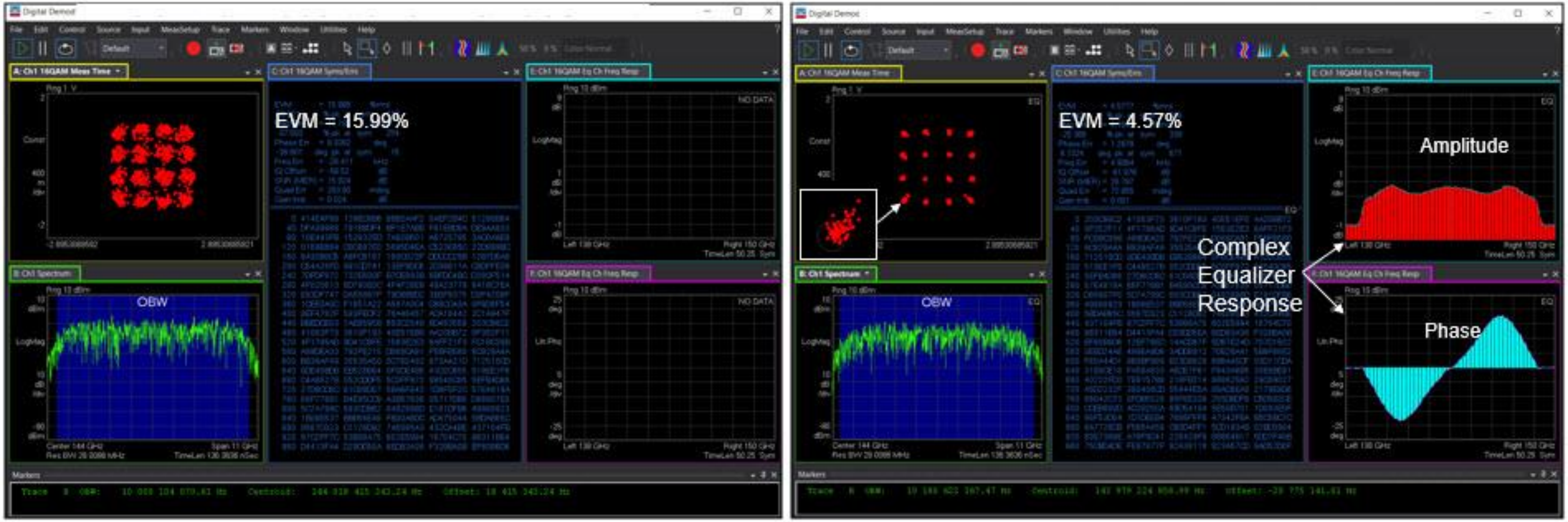


- ✓ Phase Noise
- ✓ Linear Impairments
- ✓ Nonlinear Impairments

Sub Terahertz System Considerations

SIMULATION CASE STUDY

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



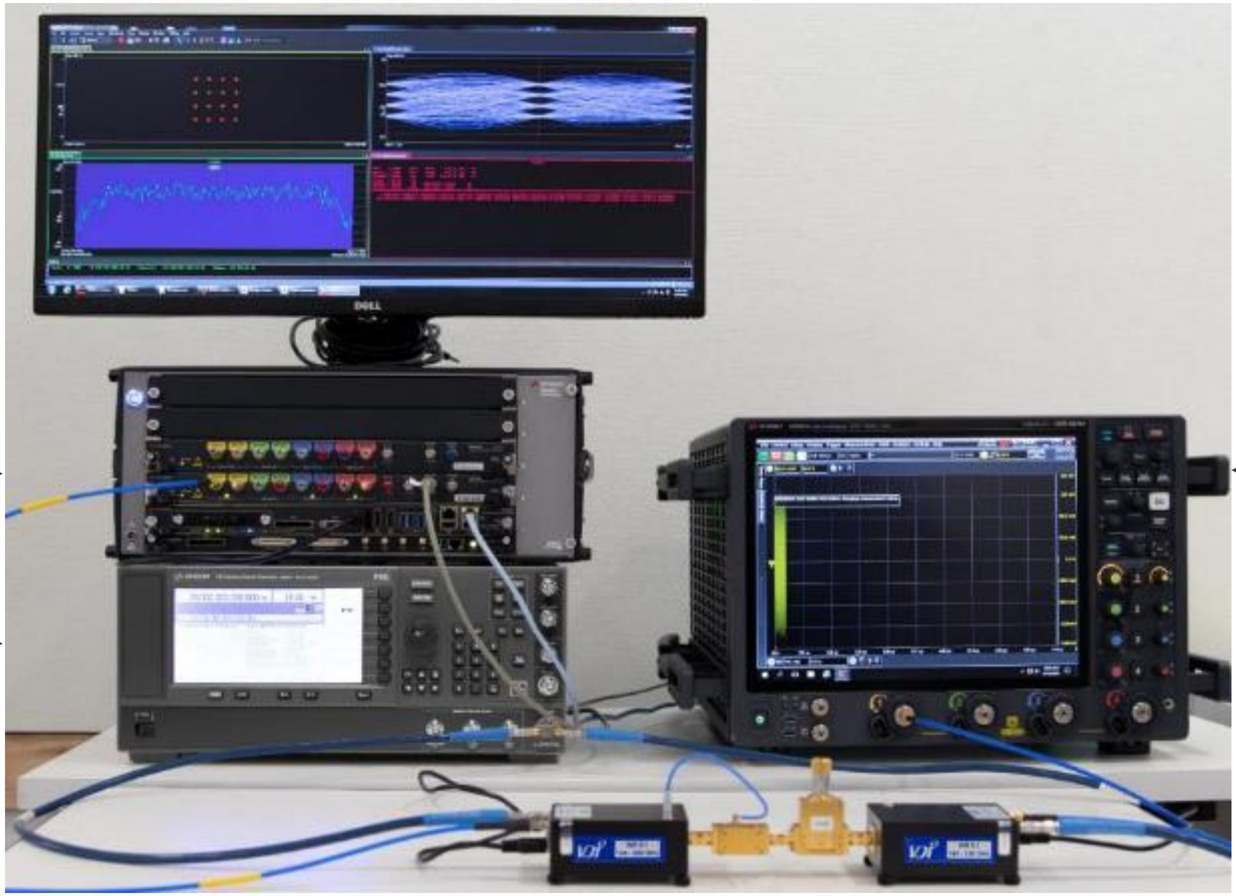
Sub Terahertz Testbed for 6G Research

G-BAND (140-220 GHZ)

VSA, WWC, iqtools

M8195A AWG (Wideband IF)

E8267D PSG (LO)



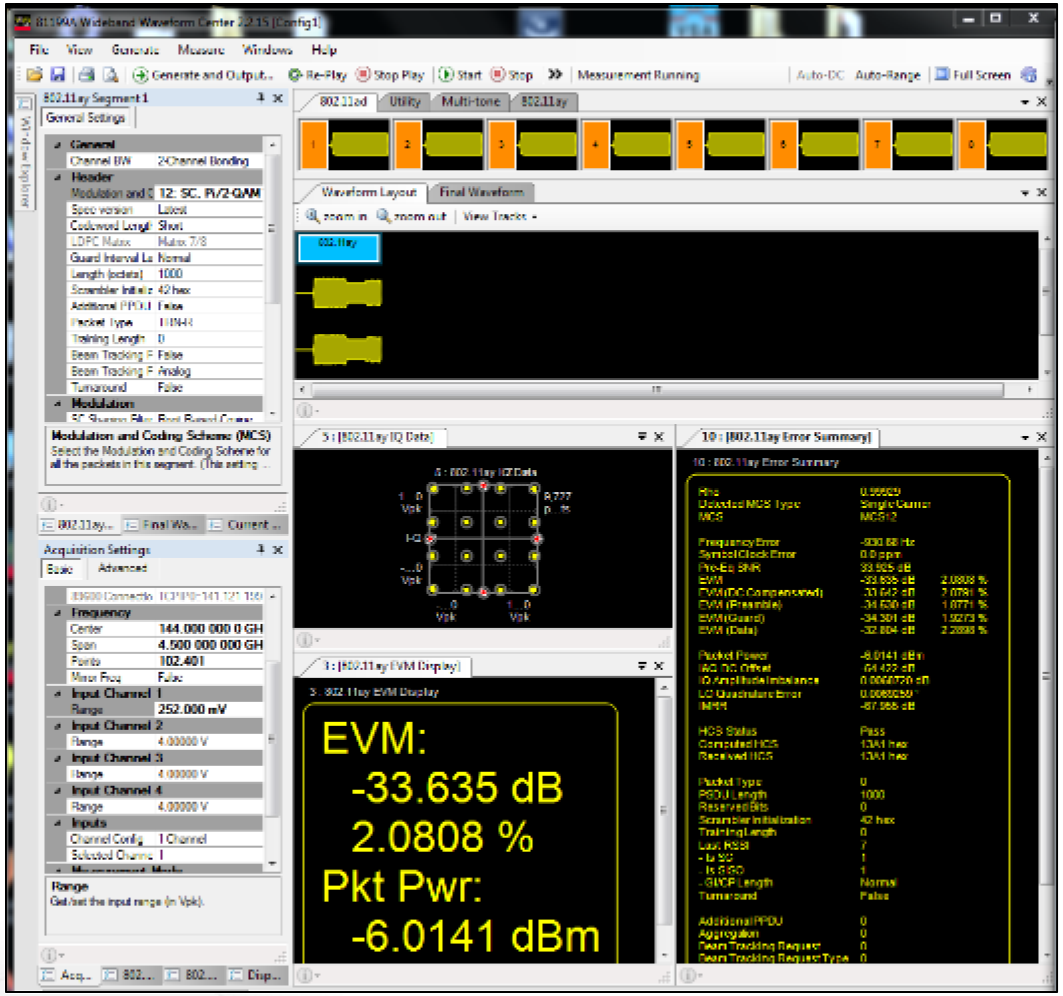
33 GHz UXR Oscilloscope

VDI Compact Upconverter (CCU), Amp, Bandpass Filter, Variable Attenuator, Compact Downconverter (CCD)

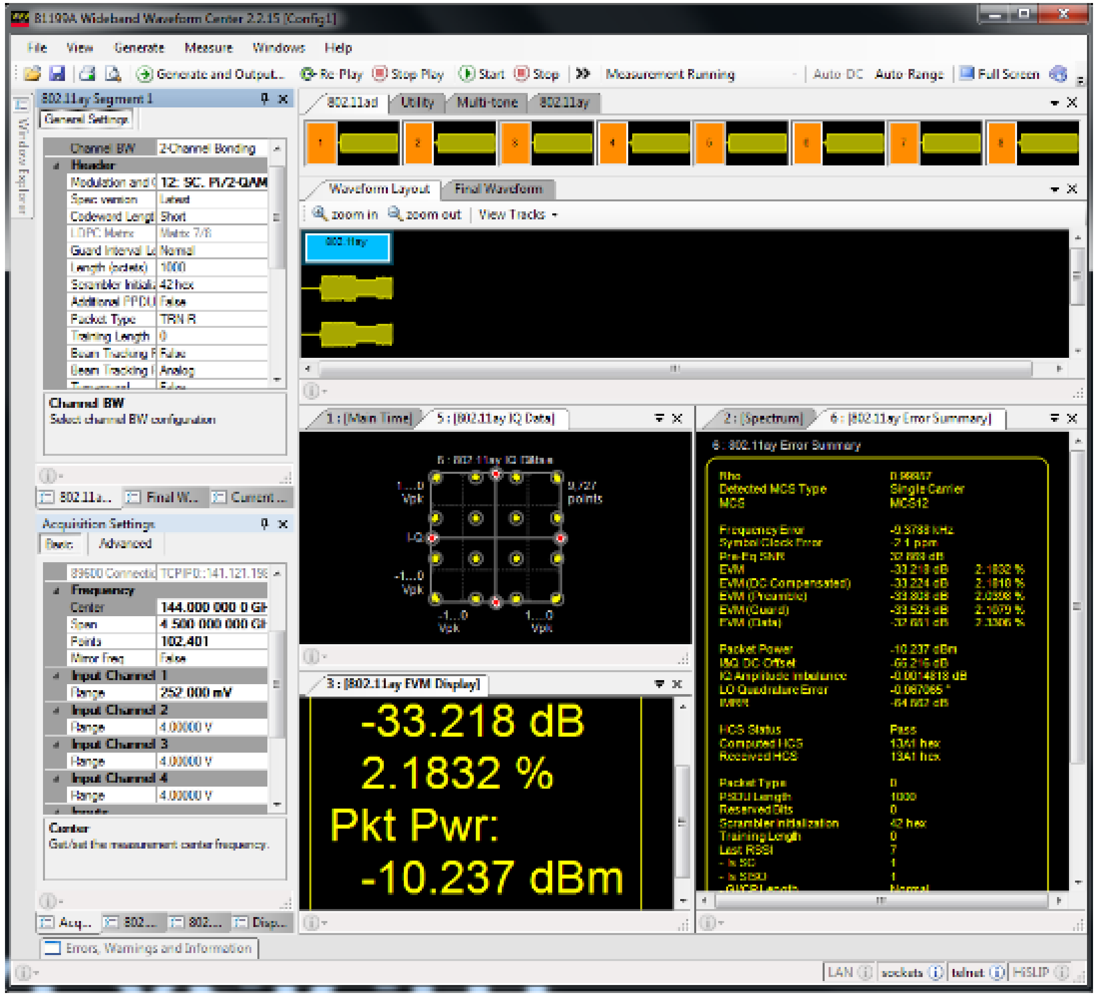
Sub Terahertz Testbed for 6G Research

144 GHZ CENTER FREQUENCY, 4.32 GHZ BW CB2 CASE, NO CAL

110-170 GHz CCU and CCD



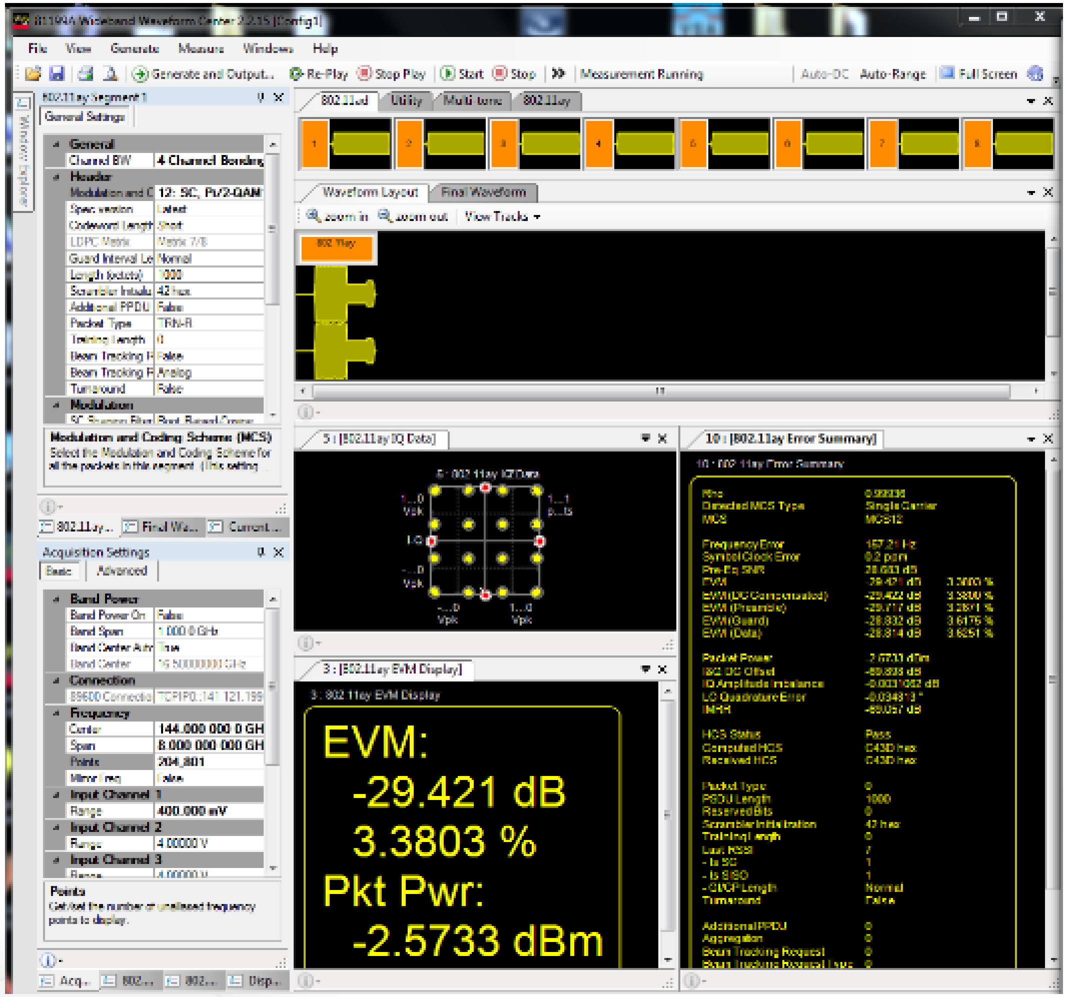
140-220 GHz CCU and CCD



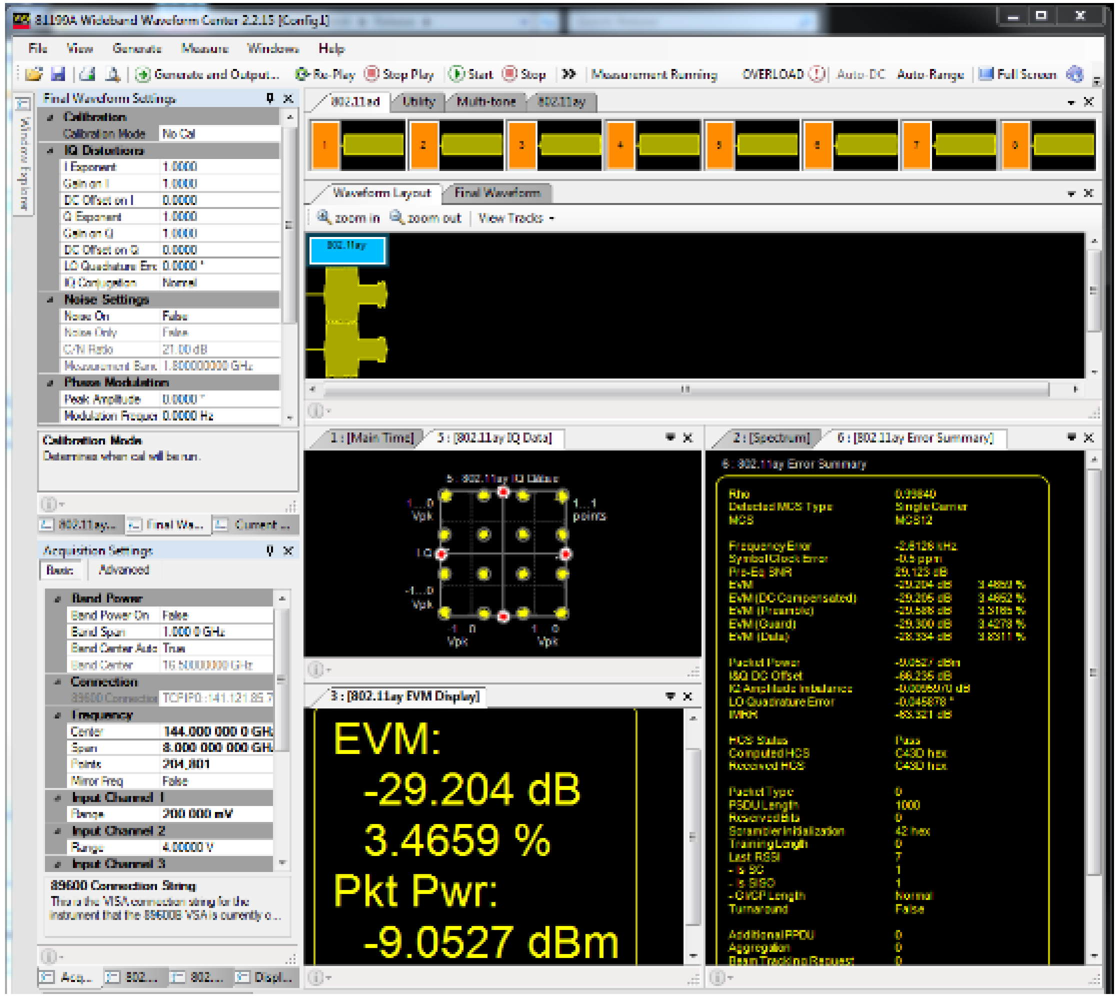
Sub Terahertz Testbed for 6G Research

144 GHZ CENTER FREQUENCY, 8.64 GHZ BW CB4 CASE, NO CAL

110-170 GHz CCU and CCD

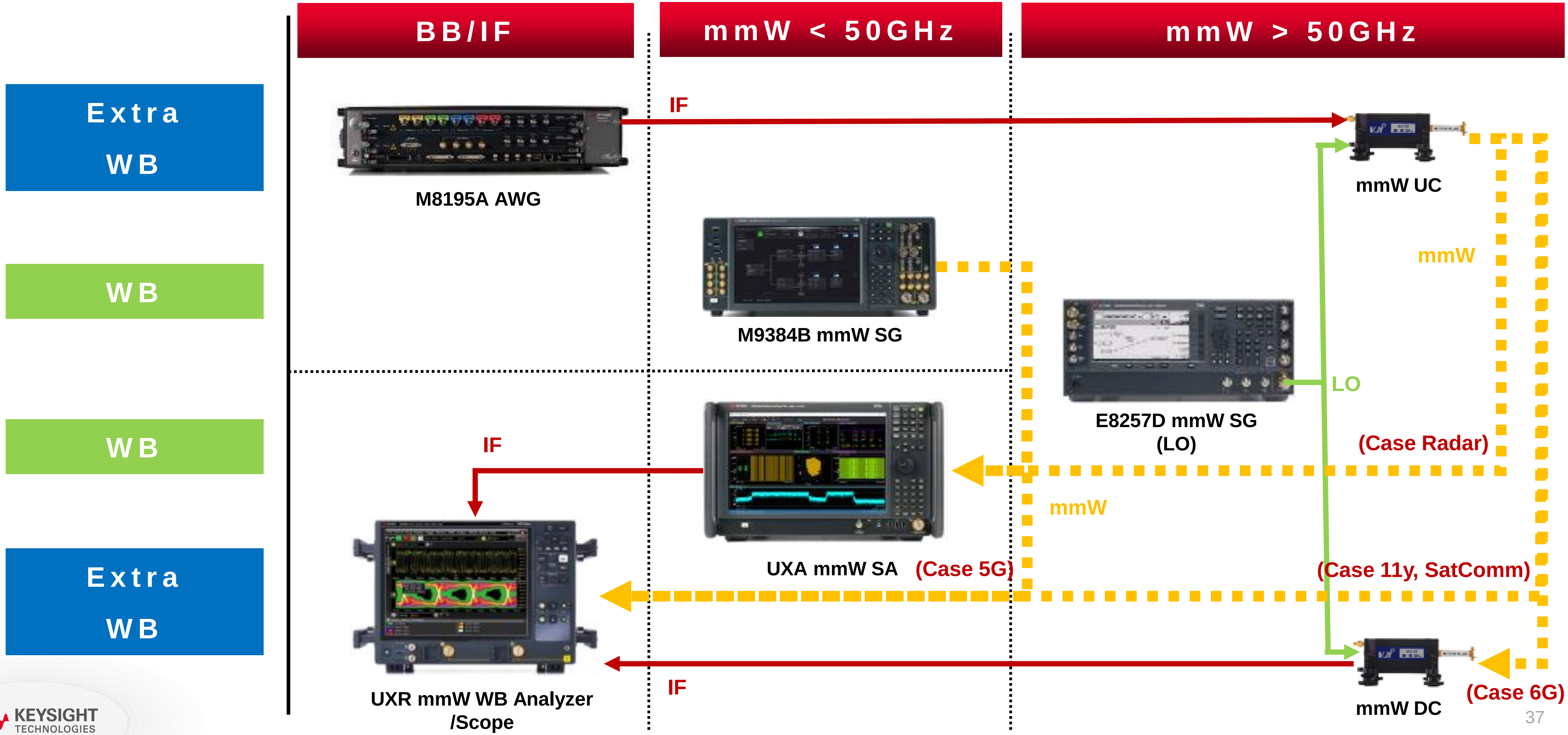


140-220 GHz CCU and CCD



Keysight Solution for mmWave Wideband Signal

MILLIMETER WAVE WIDEBAND



..and the solution is…

UXR: MMWAVE WIDEBAND ANALYZER

Ultra-Performance Real-Time analyzers up to 110 GHz on up to 4 channels.

- DC to 110 GHz of dynamically configurable frequency ranges
- High-definition 10-bit analog-to-digital converter (ADC)
- 256 GSa/s real-time or 3,200 MSa/s complex sample rates on up to 4 channels
- -158 dBm/Hz DANL from 50 GHz to 85 GHz
- Easy MIMO support with independently configurable coherent channels

UXR0051AP

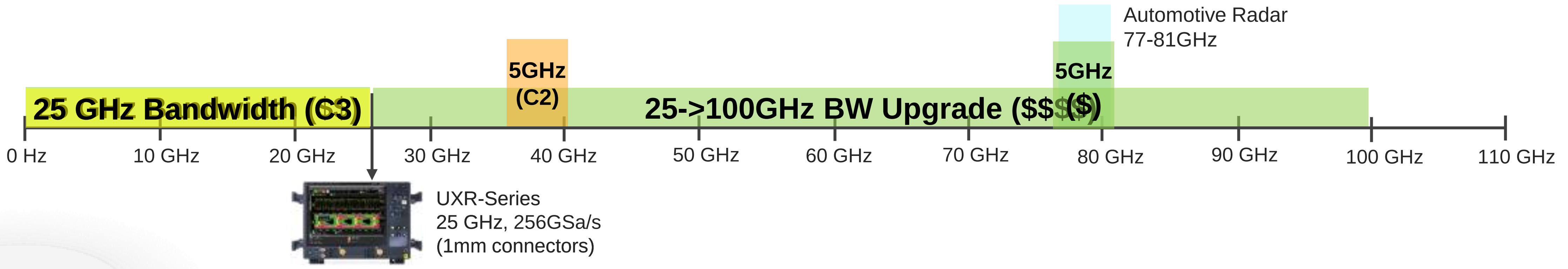
1 CHANNEL – 256 GSA/S – 5 GHZ BW – 110 GHZ FREQUENCY RANGE

- **NEW UXR0051AP**
  - Only channel 1 is available
    - Channel 2 is installed, but requires a license based upgrade to activate (N2166A)
  - 5 GHz native oscilloscope bandwidth
  - Full 110 GHz frequency range
    - REQUIRES mmWave extension to use
    - May use either 5 GHz or 10 GHz mmWave extension BW options
    - When the 10 GHz mmWave extension option is installed, the oscilloscope's native BW is increased to 10 GHz
  - Works with DDC options
    - 40 MHz standard DDC BW
    - Options for 160 MHz and 2.16 GHz BW
    - When combined with the mmWave extension options, DDC can be used over the full DC- 110 GHz frequency range

UXRs mmWave Configurable BW Windows (5 and 10GHz)

ALLOWS DSO TO BE PRICE COMPETITIVE WITH SA FOR MMWAVE

- Implement a ***dynamically*** movable 5 GHz or 10 GHz max wide “Bandpass” filter on the UXR
- Noise and ENOB are significantly improved due to the lower bandwidth window
- Sliding bandwidth windows allows you to selectively look at only the bands for signals you want
  - Can use 5GHz window anywhere from DC-110GHz
  - Can have different CF of window on different channels (or same for MIMO/Phased Array)
  - Can use some channels in 25GHz “scope” (DC coupled) mode and some channels in 5GHz window mode. You can use only “scope” or “window” mode on any one channel – not both.
  - Automatically recognized and utilized by VSA SW.
  - 40GHz is interesting point. 25GHz+5GHz window = 40GHz scope price.



New! 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 in 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.

KEYSIGHT TECHNOLOGIES

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http://www.keysight.com/find/6GTestBed

https://www.keysight.com/find/6GTestBed

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
- Demonstrated sub-terahertz testbed performance for D and G- bands

KEYSIGHT
WORLD 2020