Tackling Emerging Millimeter-Wave Applications Beyond 50 GHz
(802.11ay, 5G NR, Aerospace/Defense)

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KEYSIGHT TECHNOLOGIES

Agenda

- Opening Up Millimeter-Wave Spectrum
- Challenges of Very-Wideband Millimeter-Wave Applications
- Satellite Millimeter-Wave Applications
- Multi-Channel Applications: MIMO
- Emerging 60 GHz Millimeter-Wave Application Example: 802.11ay
- 71-76 and 81-86 GHz Millimeter-Wave Frequency Bands
- Summary and Additional Resources

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Enabling Next-Generation Broadband Access

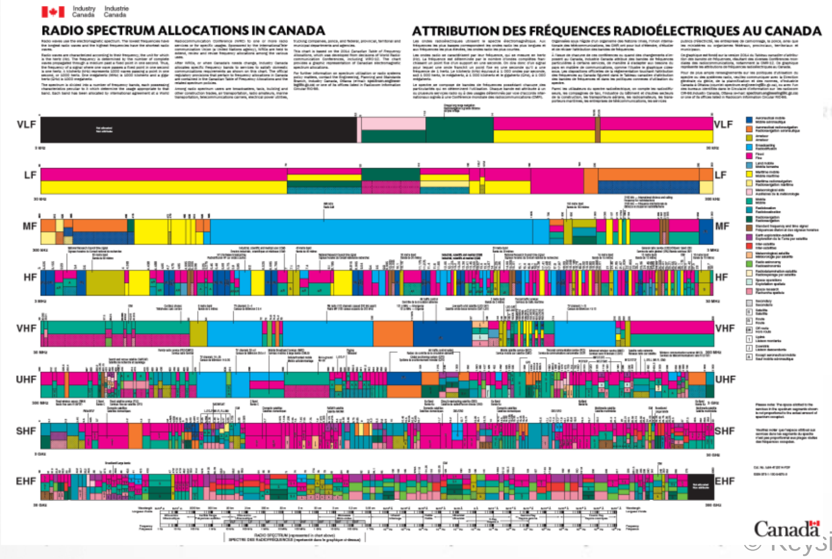
TODAY'S CHALLENGING APPLICATIONS

	5G	SatComm	802.11ay
Complex Modulations	OFDM 256 QAM	OFDM 256 QAM	Single-Carrier 64 QAM
Wider Bandwidth	100/400 MHz 1.2 GHz (CA)	0.5-2 GHz	4-8 GHz
Higher Frequencies	FR1: <6 GHz FR2: 24 - 52 GHz	Ka Band 27-40 GHz	57-71 GHz
Multiple Antennas Techniques	Phased array antenna MIMO FR1: 8x8 MIMO FR2: 2x2	Phased array antenna	Phased array antenna MIMO

Opening Up Spectrum

NEAR TERM

The FCC is facing pressure to speed up the process for auctioning off 5G-critical spectrum. Carriers plan to use the new spectrum to build out ultra-fast networks that will power the internet of things, autonomous vehicles, and other emerging technologies. Telecom companies and policymakers have urged the FCC to move more quickly to repurpose the spectrum.



Frequency Band	Auction Year
1300-1350 MHz	2024
3.7 GHz – 4.2 GHz	2019
24 GHz (24.75-25.25)	2018-2019
28 GHz (27.5-28.35)	2018
37 GHz (37-38.6)	2019
39 GHz (38.6-40)	2019
47 GHz (47.2-48.2)	2019

*FCC NPRM – "Use of Spectrum Bands Above 24 GHz For Mobile Radio Services"; October 2017

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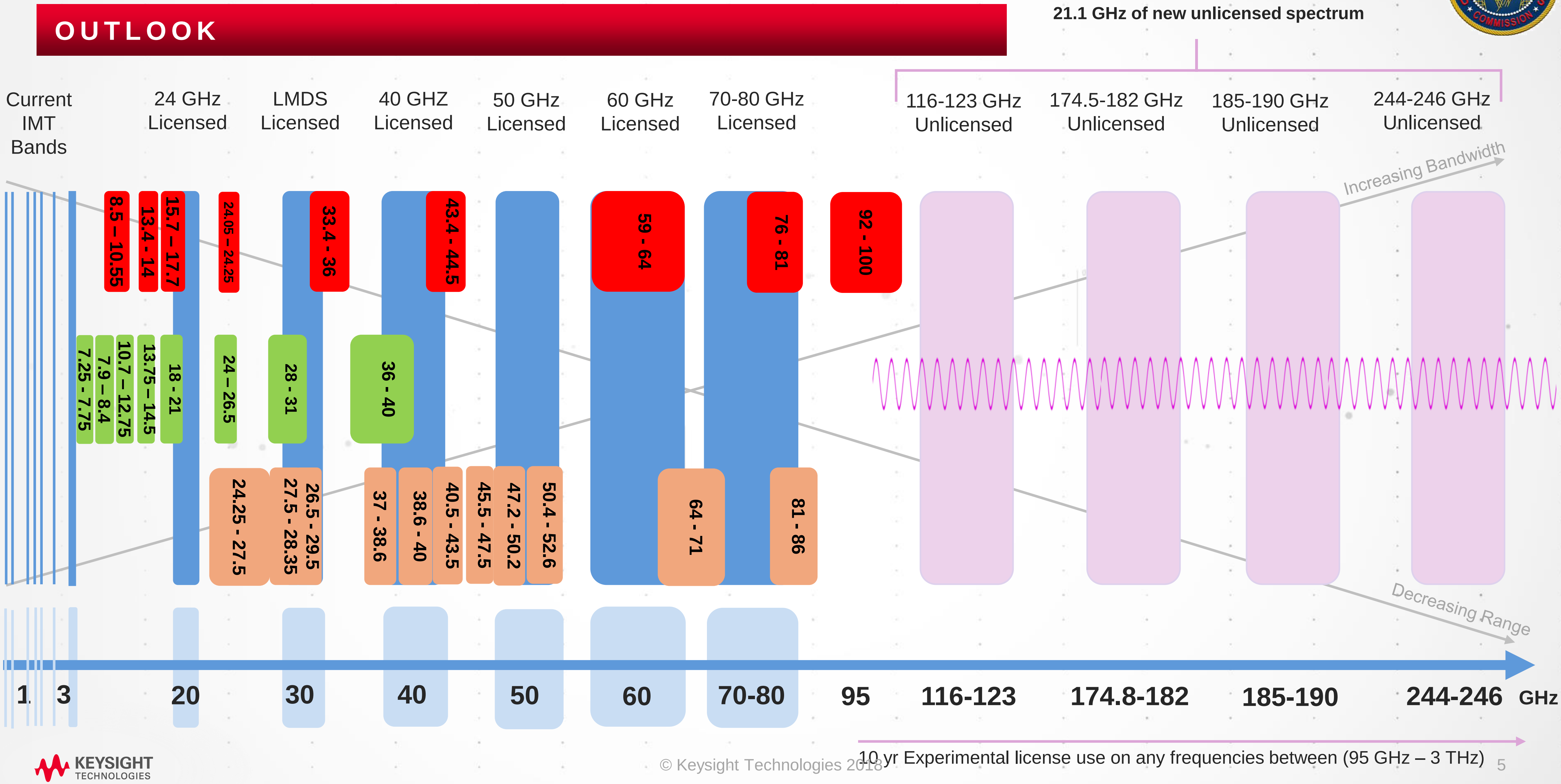
FCC mmWave Spectrum

OUTLOOK



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*Gigabit LTE and beyond: Mobilizing millimeter wave

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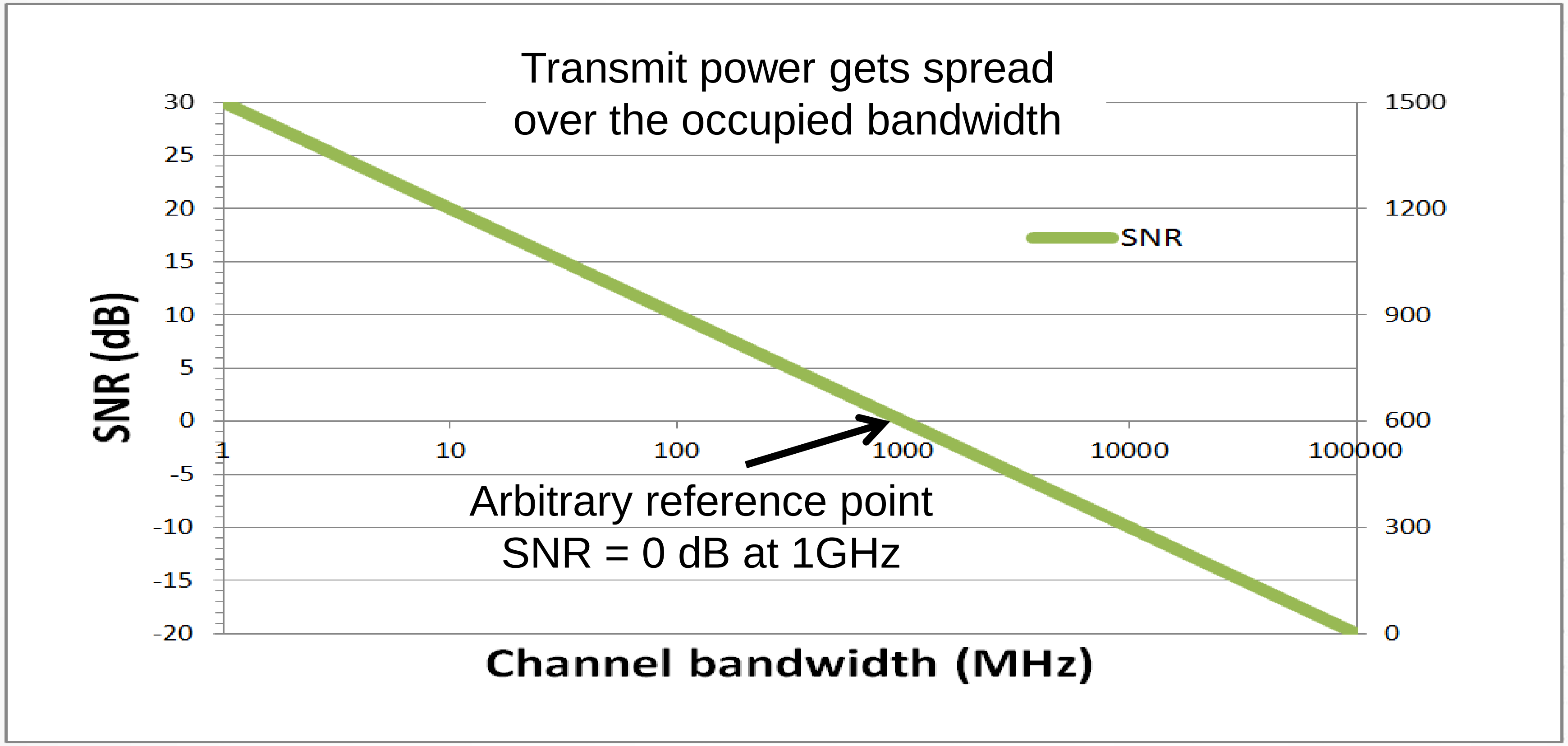
Higher Frequencies = Wider Bandwidth?

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



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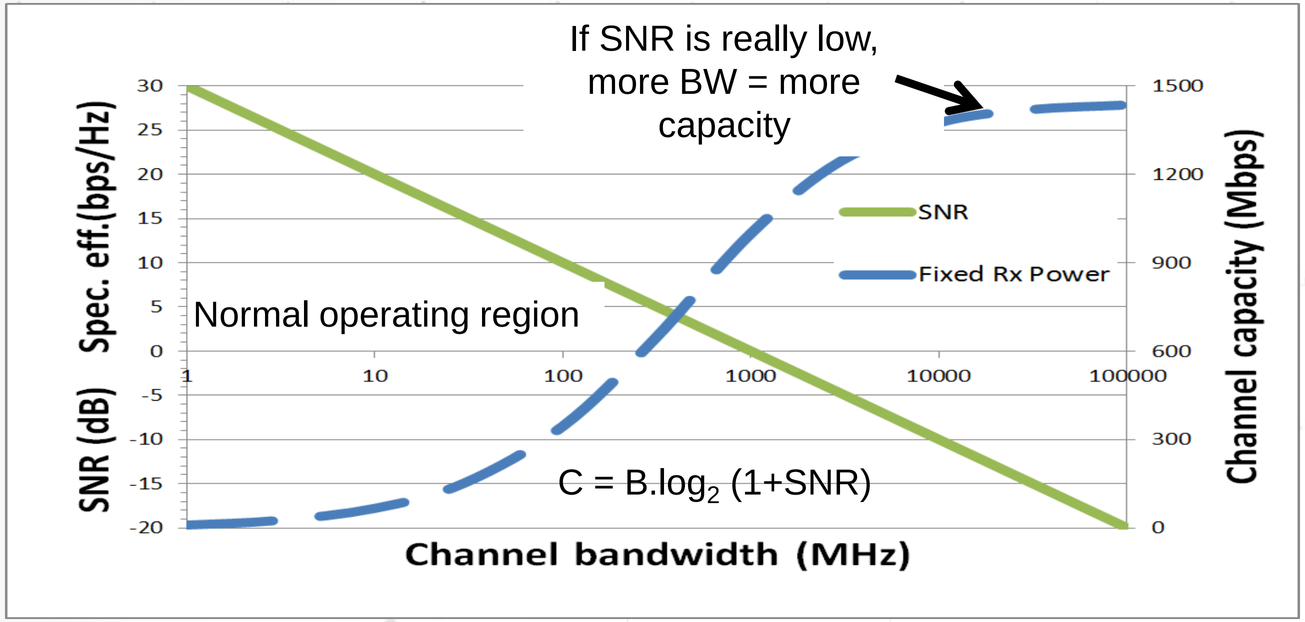
Higher Frequencies = Wider Bandwidth?



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…)

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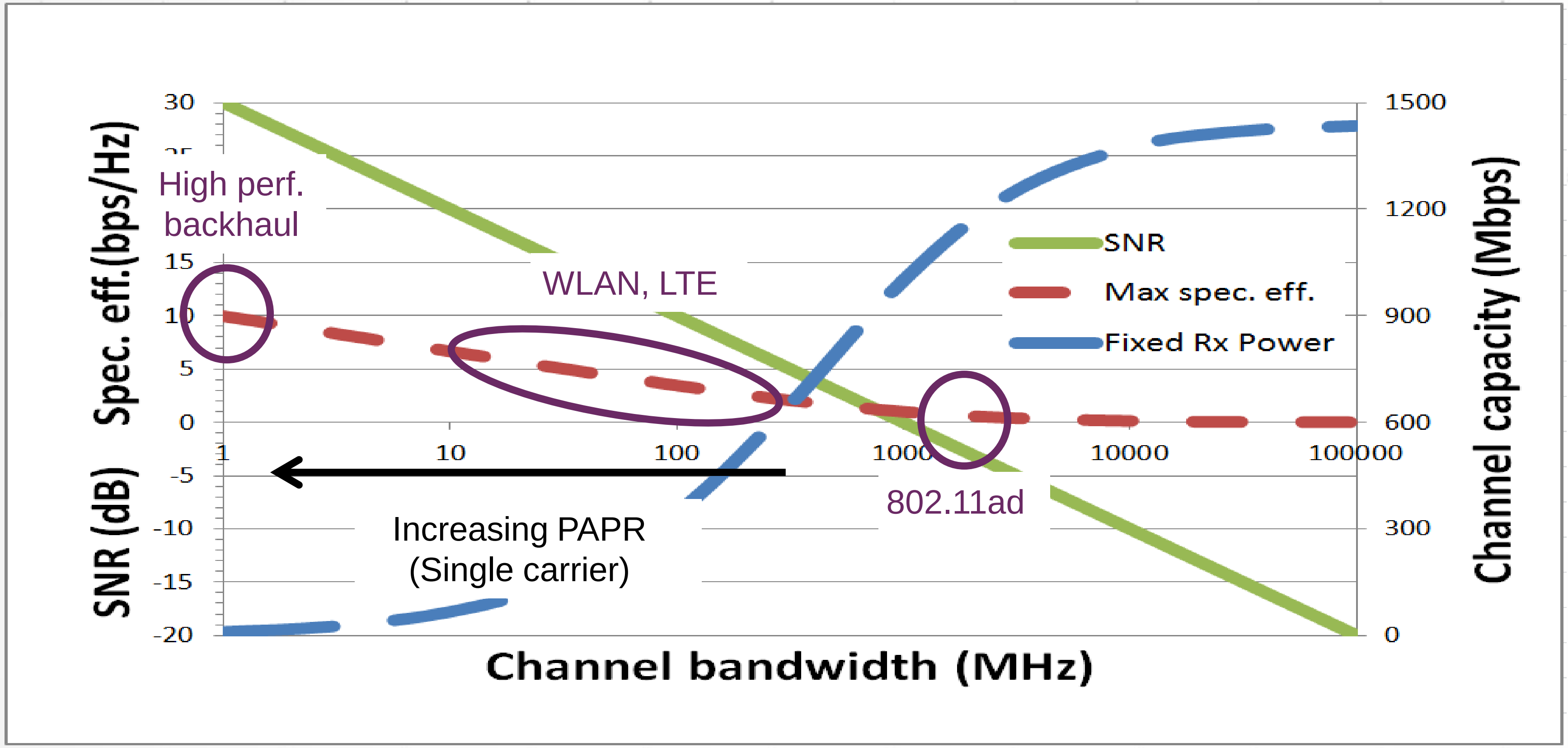
Higher Frequencies = Wider Bandwidth?

SO HOW WIDE DO YOU GO?



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Radar: Higher Frequencies and Wider Bandwidths

RADAR RANGE AND CROSS RANGE RESOLUTION

- This is ability of radar to differentiate multiple objects or targets present at the same range or cross range.
- There are two types of radar cross range:
  - Azimuth or horizontal cross range
  - Elevation or vertical cross range
- The cross range resolution is expressed in the equation below:

$$\Delta x = (R*\lambda)/L_{eff}$$

Where,

Δx = Radar Cross Range Resolution (in meters)
R = Target Range
L_{eff} = Effective length of antenna in direction where beam width is to be measured
λ = Wavelength

Higher frequency = More Cross Range Resolution

- The down range resolution is expressed in the equation below:

$$\Delta r = c/(2*BW)$$

Where,

Δr = Radar Down Range Resolution (in meters)
c = Speed of light (m/s)
BW = Signal baseband bandwidth

Wider bandwidth = More Down Range Resolution

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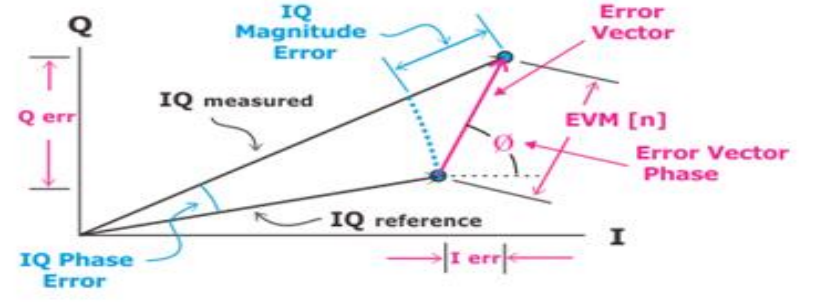
EVM Primer

A PROXY FOR A ‘NORMAL’ RECEIVER

- The normalized ratio of the difference between two vectors:
  - *IQ measured signal*
  - *IQ reference*
- *IQ reference* is normally a calculated value

EVM for a single constellation point



A useful measurement may also be made as the difference between two signals from different parts of the signal chain, e.g. the input & output of a power amplifier. Keysight refers to this as ***delta EVM***

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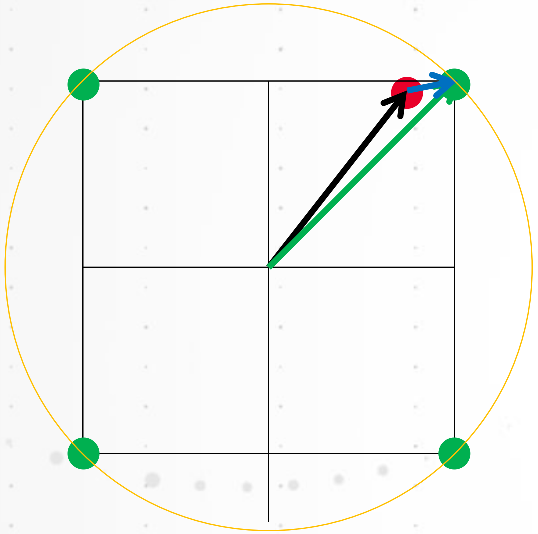
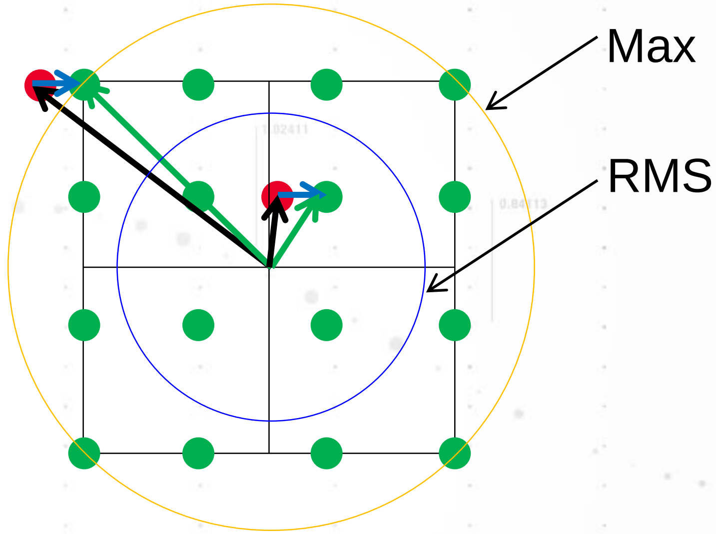
EVM Primer

POSSIBLE WAYS TO DEFINE ‘REFERENCE VECTOR’ FOR EVM CALCULATION

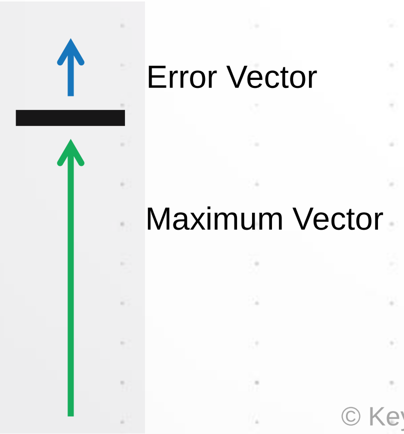
QPSK



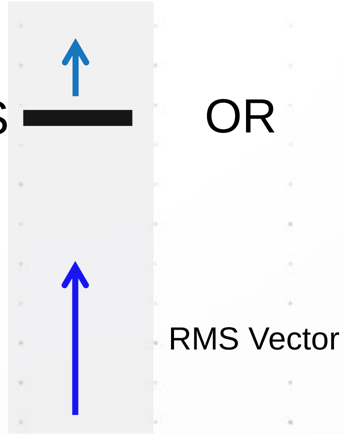
16QAM



EVM = RMS

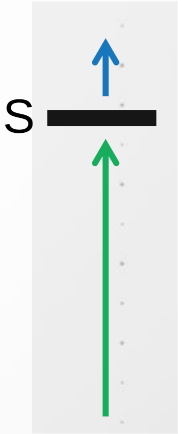


EVM = RMS



OR

EVM = RMS



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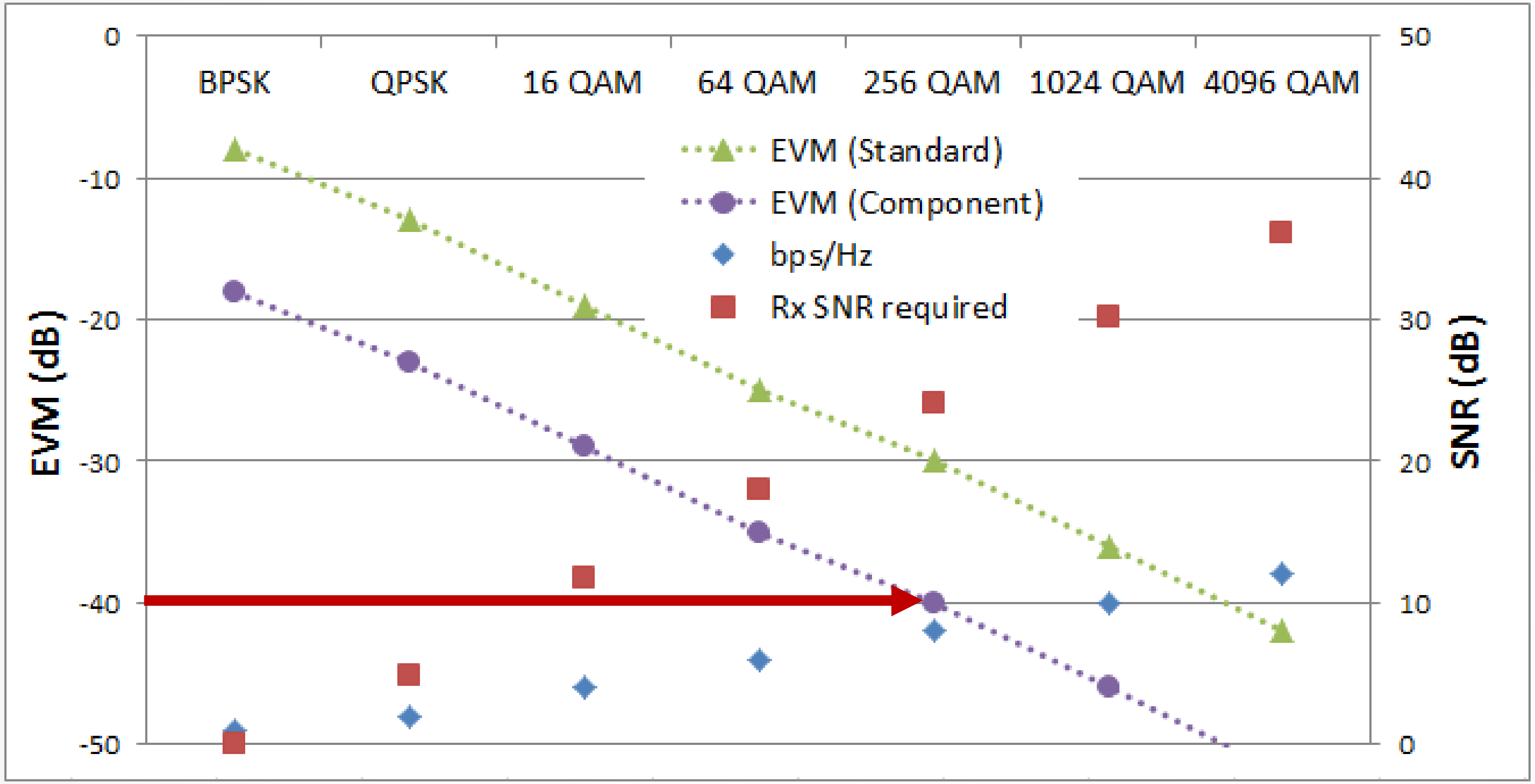
EVM Primer

HOW LOW DOES EVM NEED TO BE?



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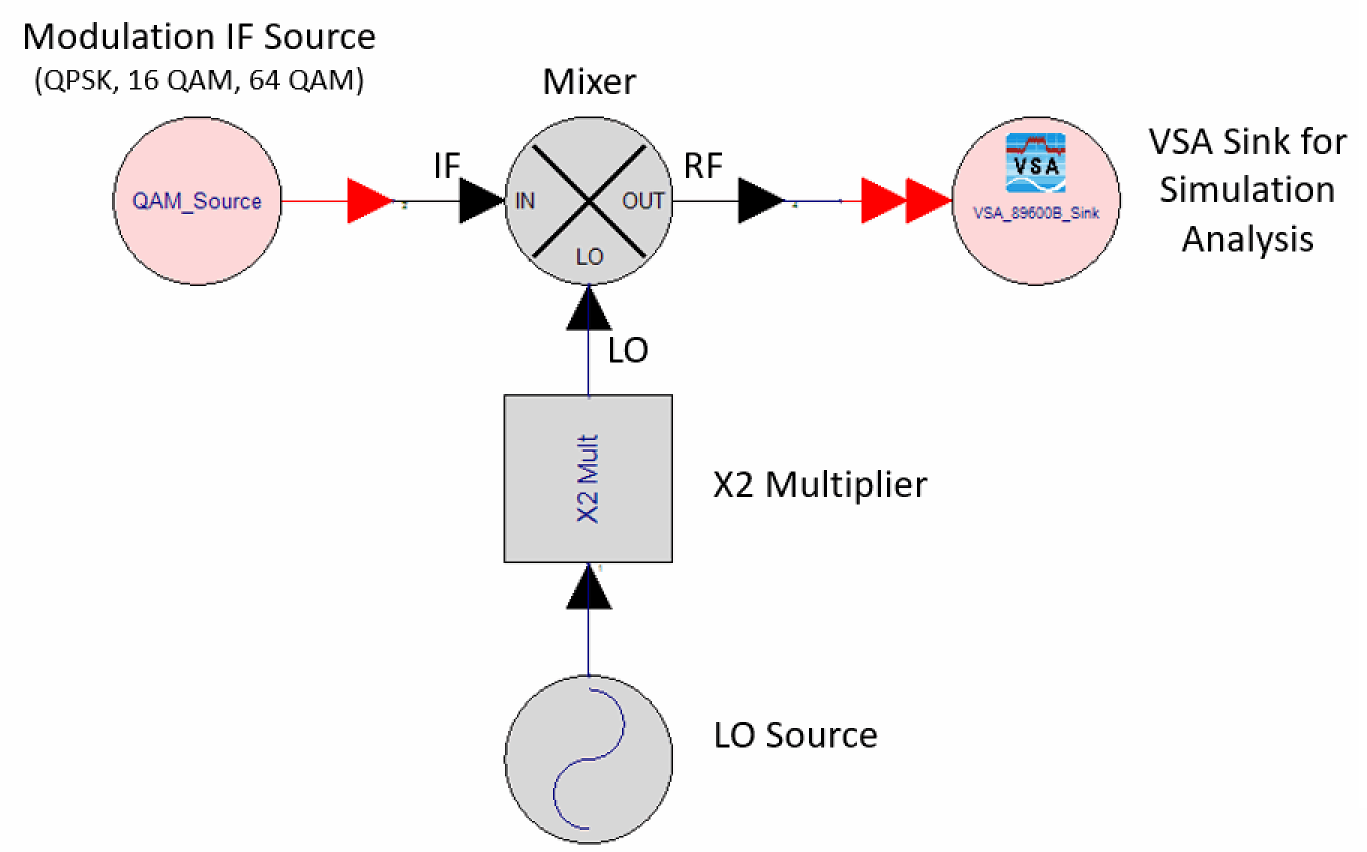
EVM Considerations: Impact of LO Phase Noise

SIMULATION CASE STUDY



✓ Phase Noise

Specify Phase Noise vs. Frequency Offset (dBc/Hz)

PhaseNoiseData	[100000, -120,1000000,-133,10000000,-148,100000000,-152,10000000000,-152]

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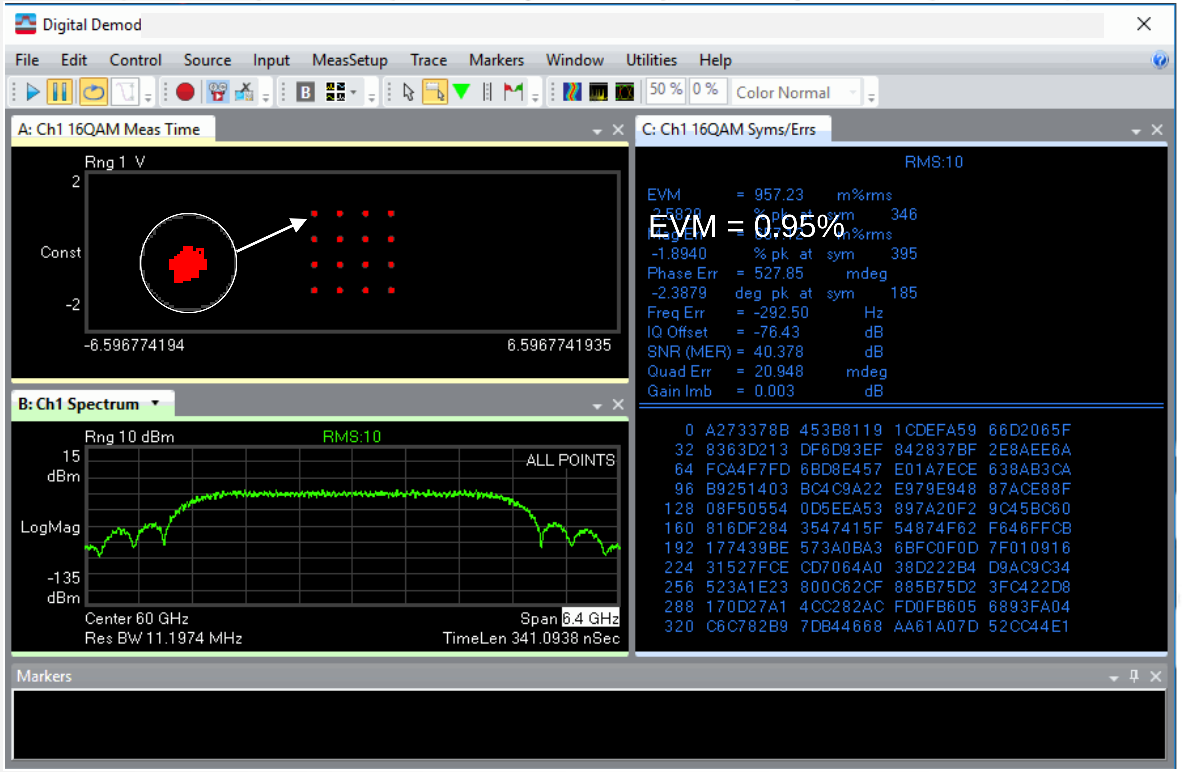
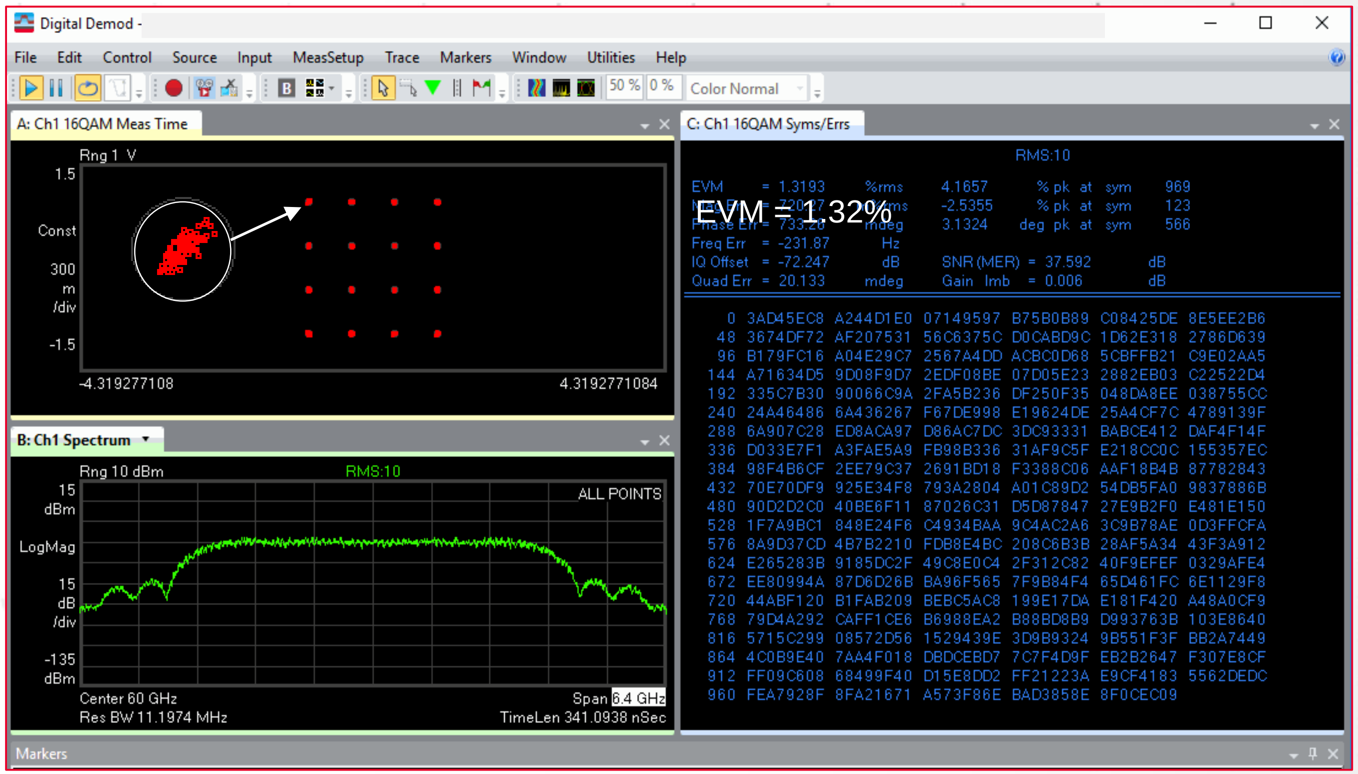
Simulation Results: LO Phase Noise

SIMULATION CASE STUDY

✓ Phase Noise



Simulated Using dBc/Hz
Measurement Plot in Previous Slide



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

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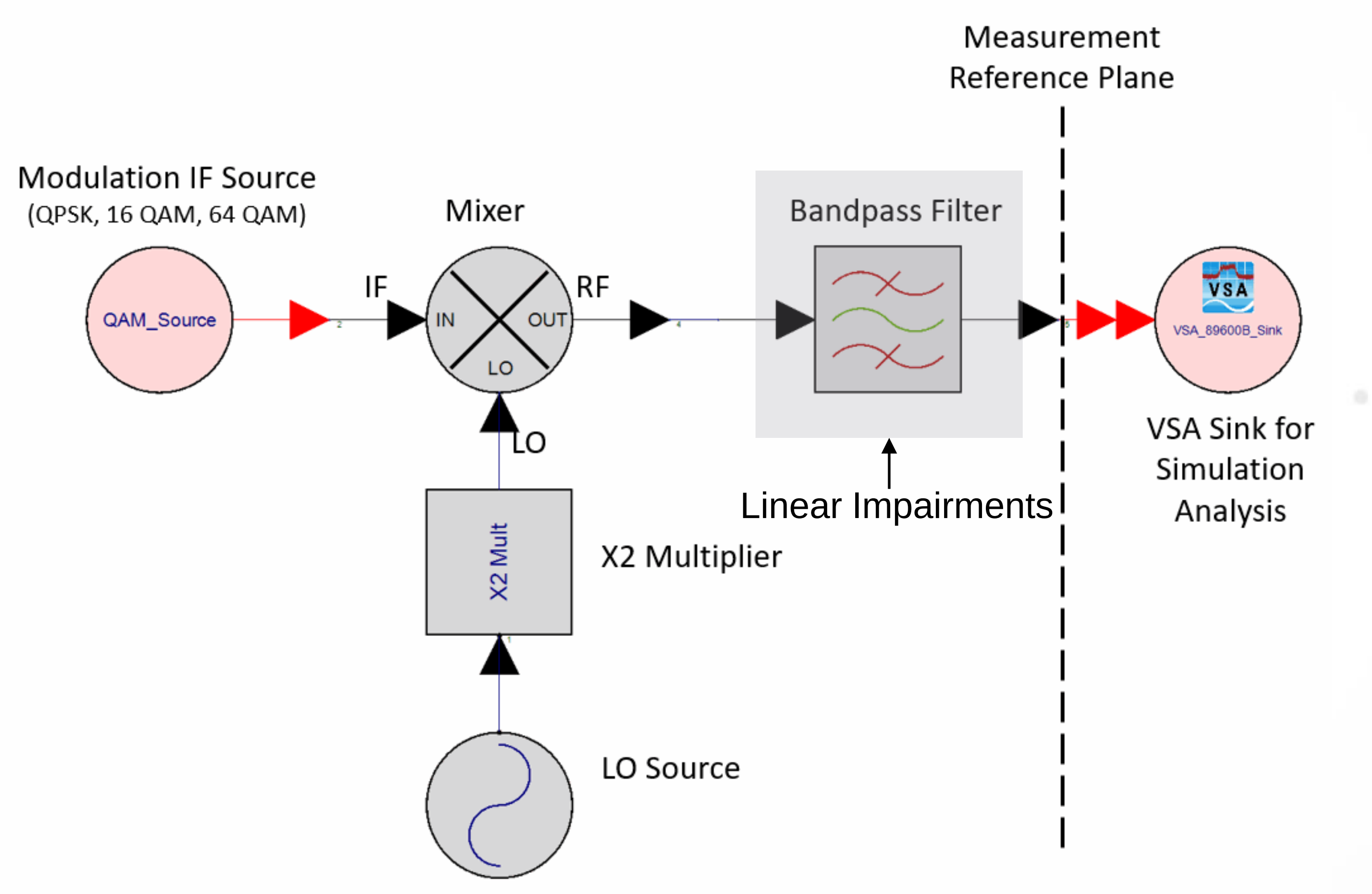
EVM Considerations: Linear Amplitude and Phase Impairments

SIMULATION CASE STUDY



- ✓ Phase Noise
- ✓ Linear Impairments

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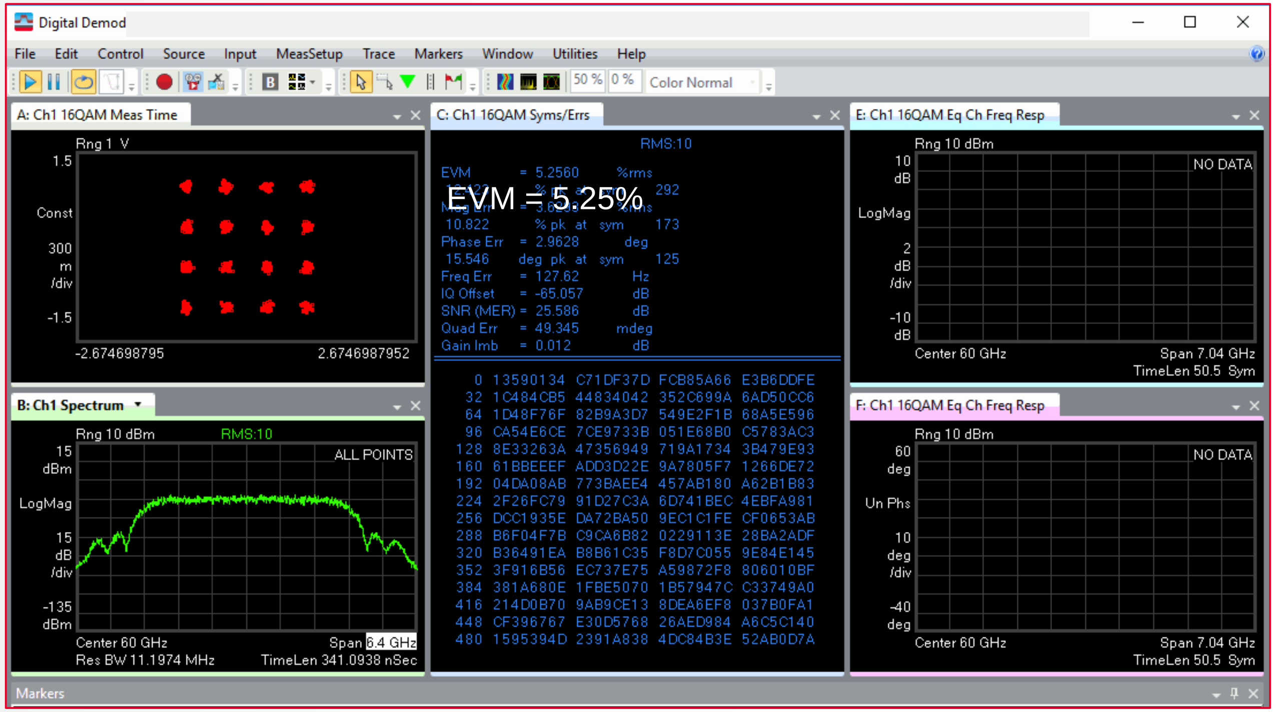
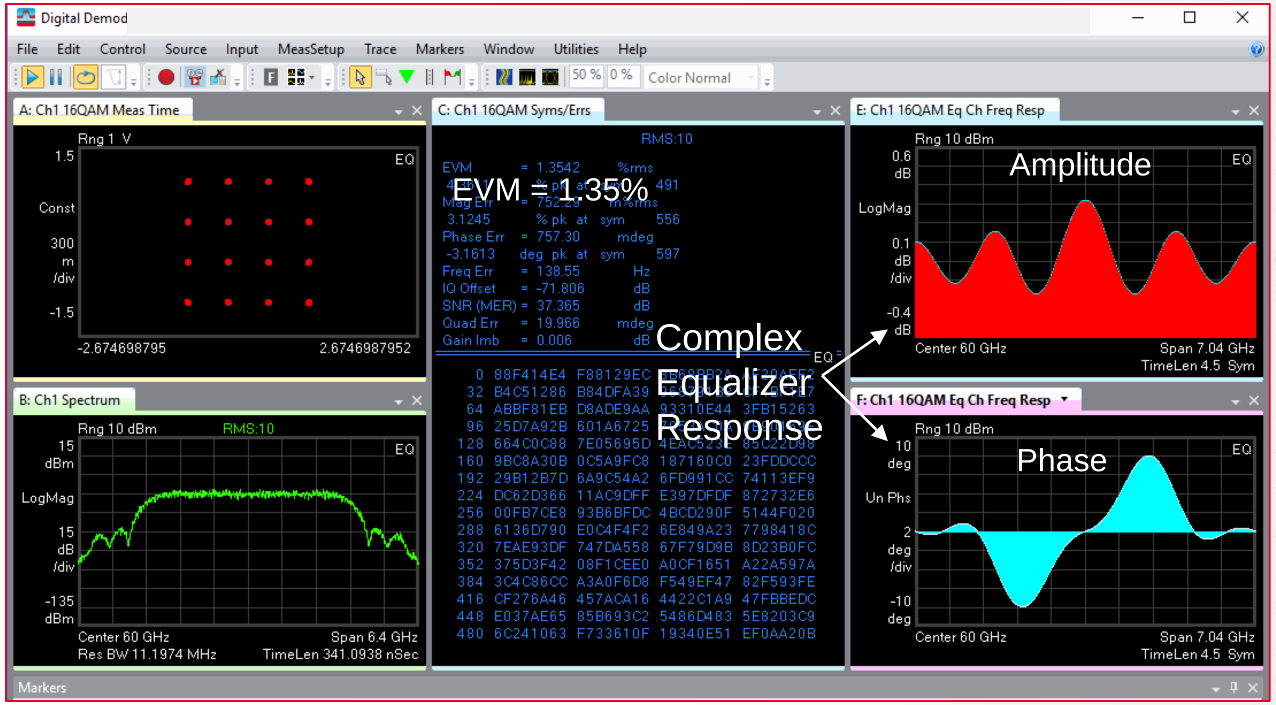
Simulation Results: Linear Amplitude and Phase Impairments

SIMULATION CASE STUDY

- ✓ Phase Noise
- ✓ Linear Impairments





Adaptive Equalizer Removes Linear Amplitude and Phase Impairments

Noise and Non-Linear Impairments Remain

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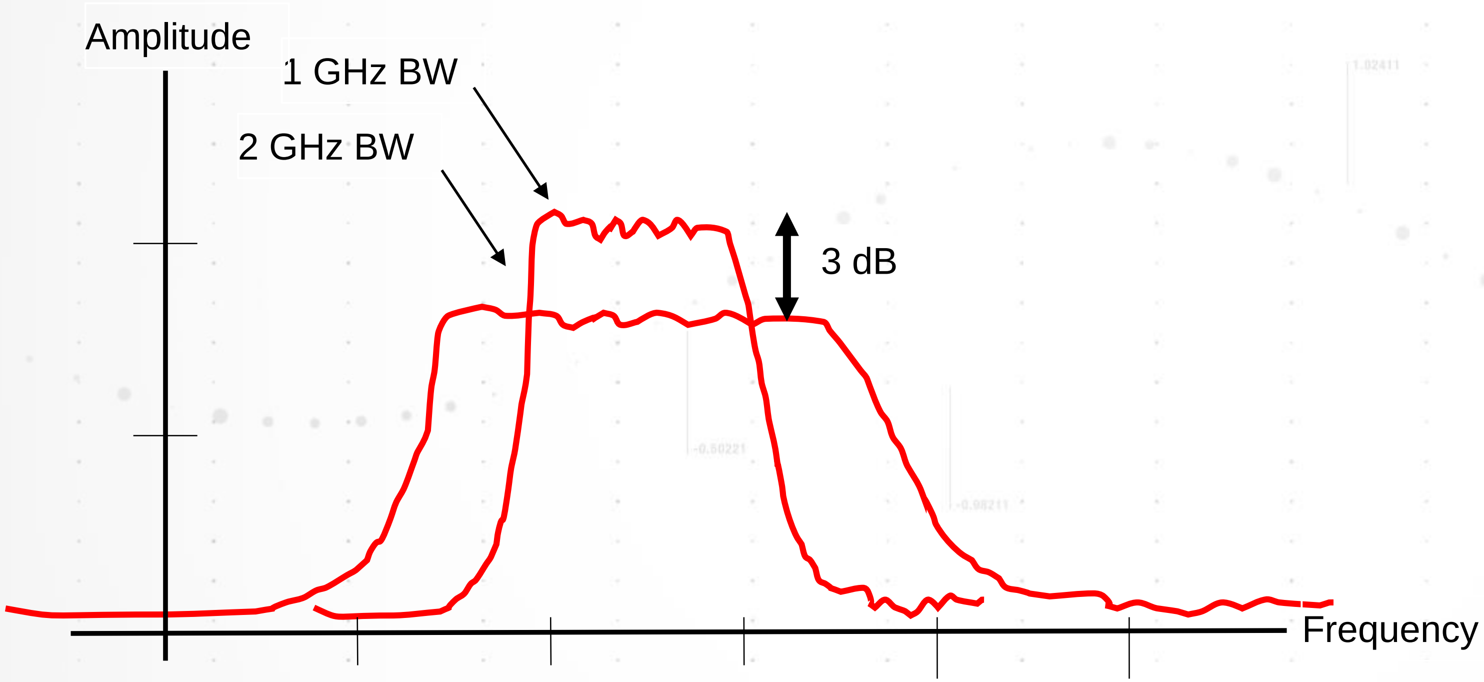
EVM Considerations: Signal-to-Noise Ratio (SNR)

SIMULATION CASE STUDY

Signal Power is Spread over Wider Bandwidths



Also, Wideband Noise Increases:
Example: LTE (20 MHz BW) compared to 2 GHz BW: SNR delta = 20 dB!

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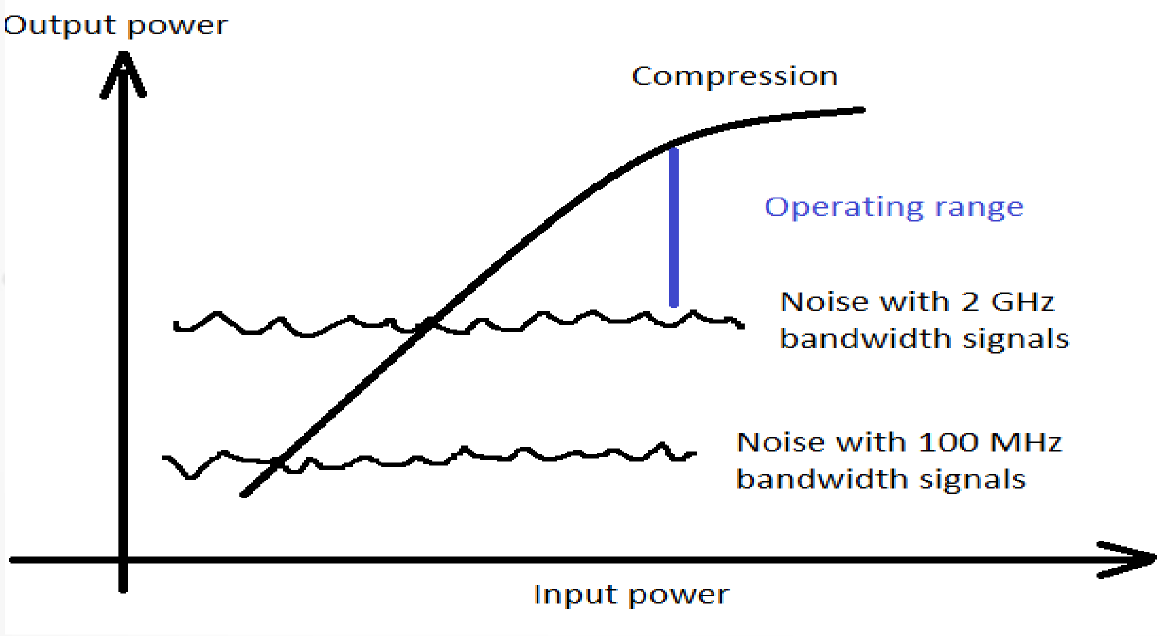
EVM Considerations: Signal-to-Noise Ratio (SNR)

SIMULATION CASE STUDY

Signal Compression and Wideband Noise Limit SNR



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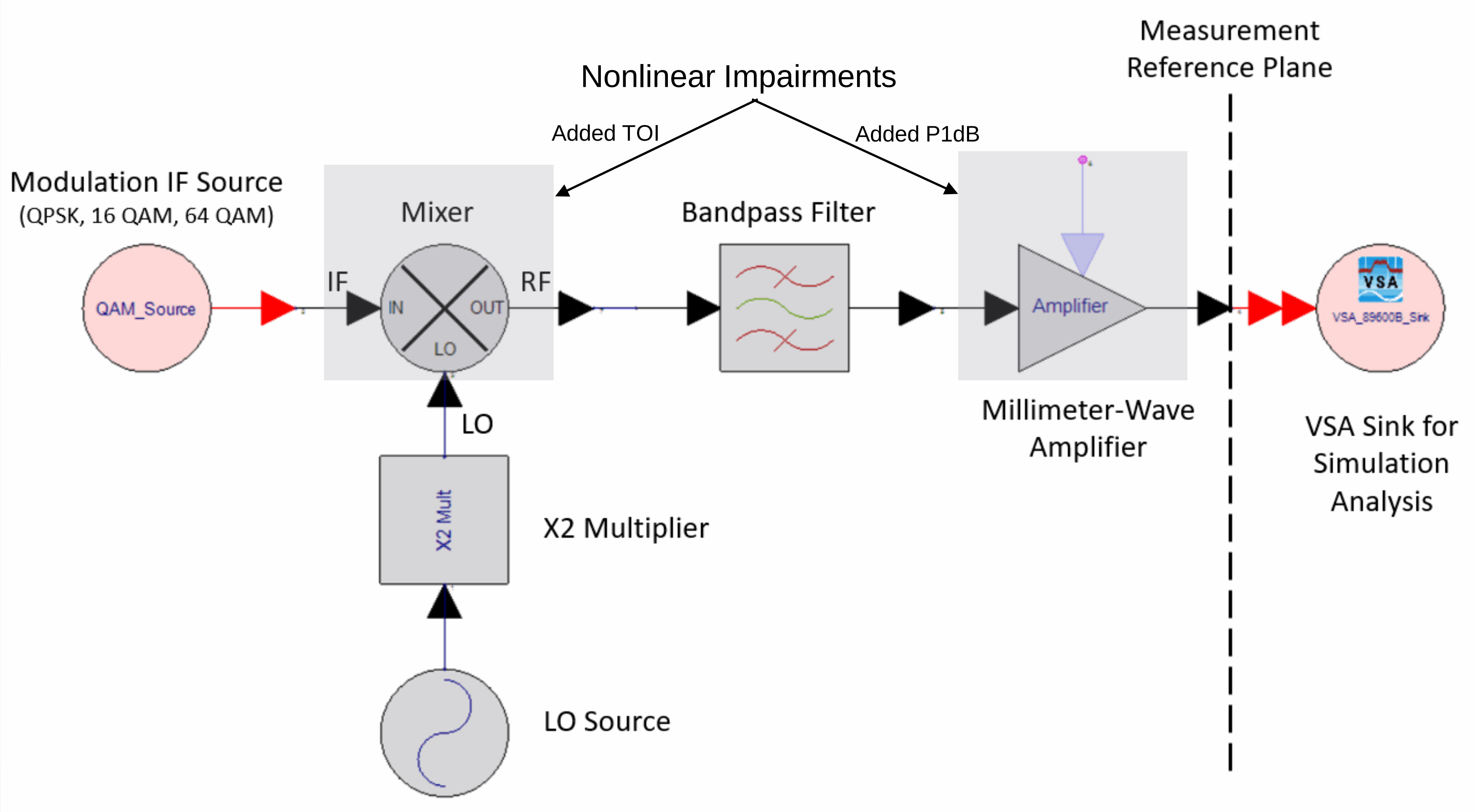
EVM Considerations: Non-Linear Impairments

SIMULATION CASE STUDY



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

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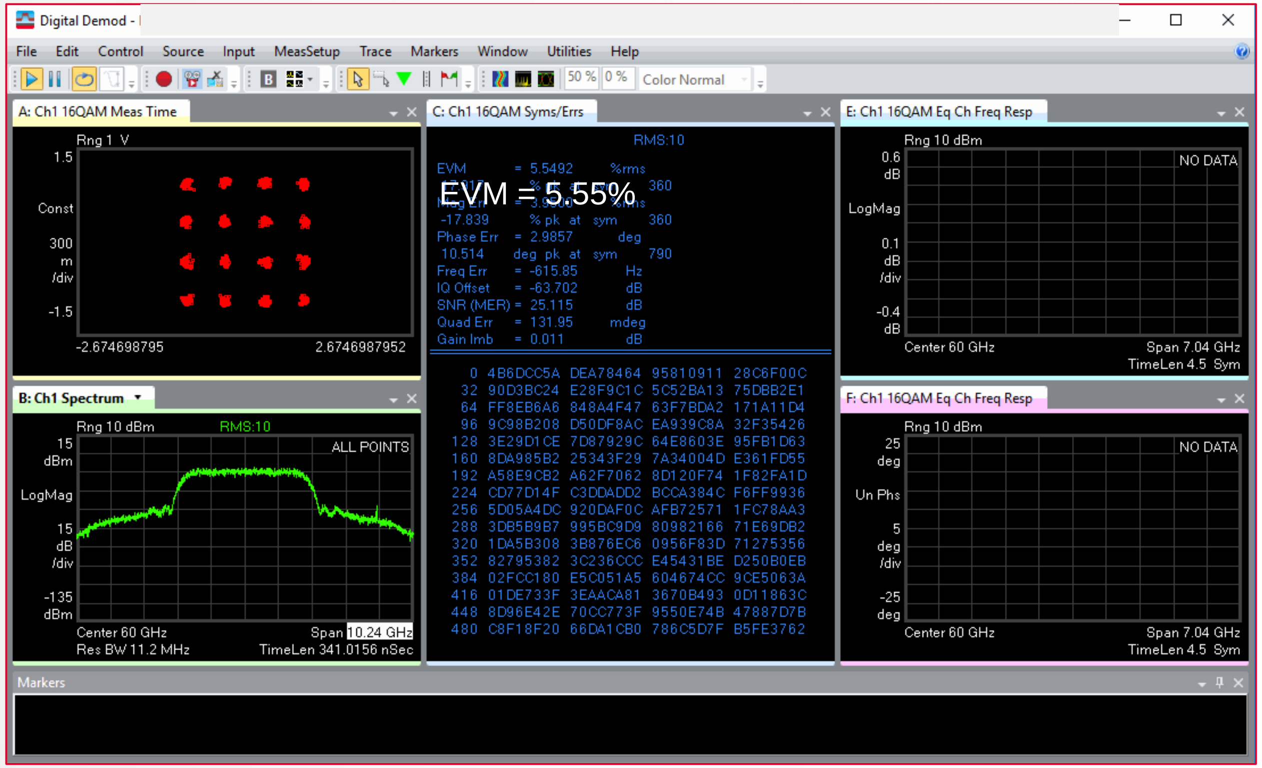
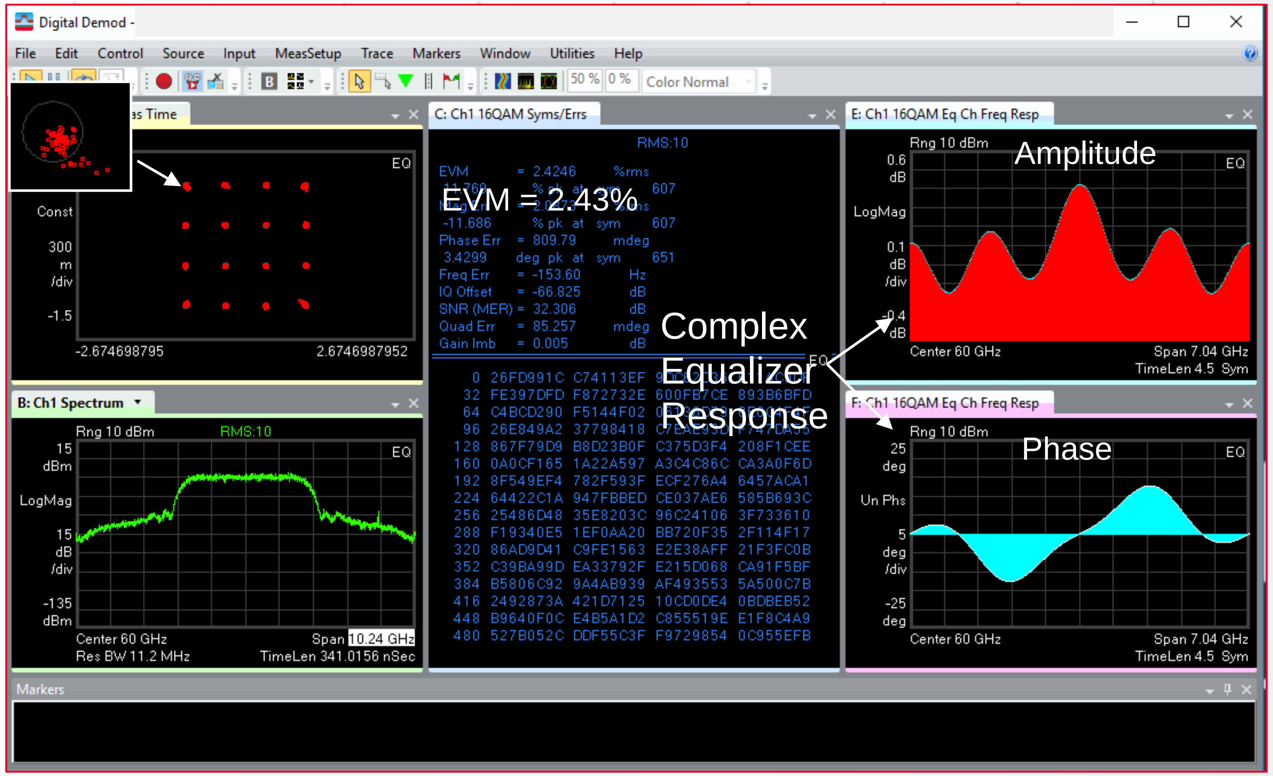
Simulation Results: Non-Linear Impairments

SIMULATION CASE STUDY

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





Adaptive Equalizer Removes Linear Amplitude and Phase Impairments

Noise and Non-Linear Impairments Remain

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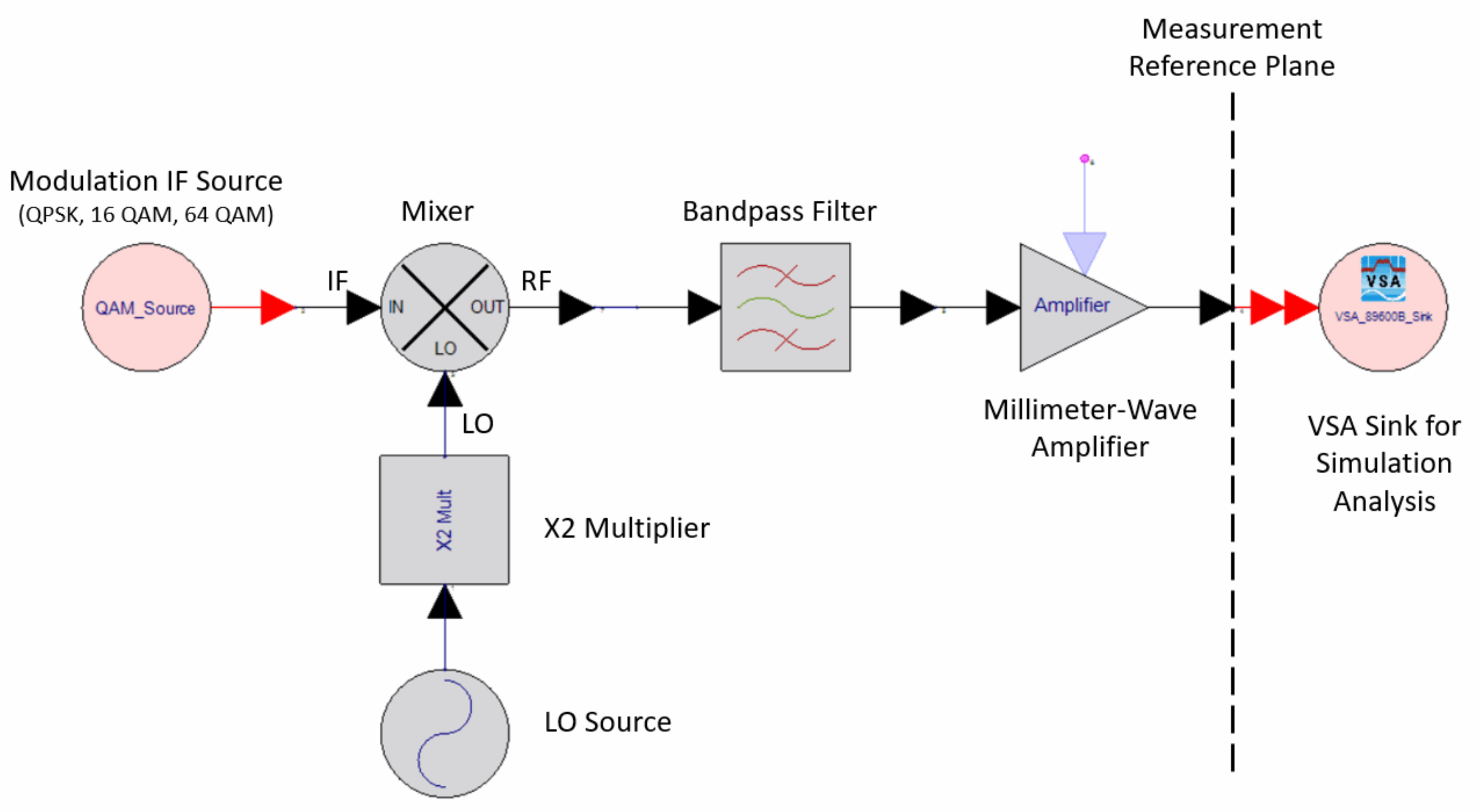
Simulation Case Study

SIMULATION DEMO



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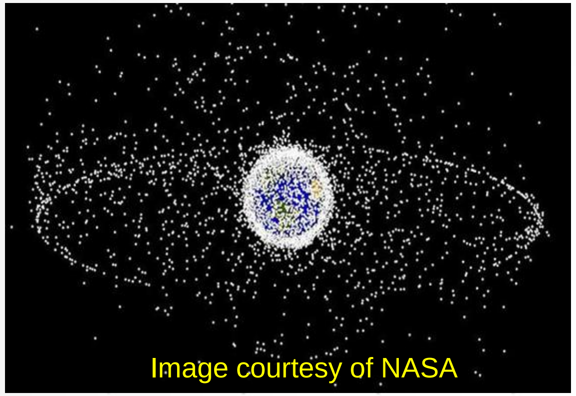
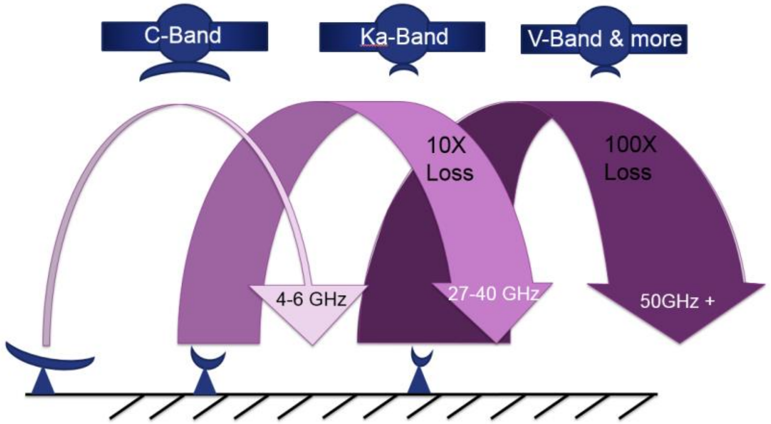
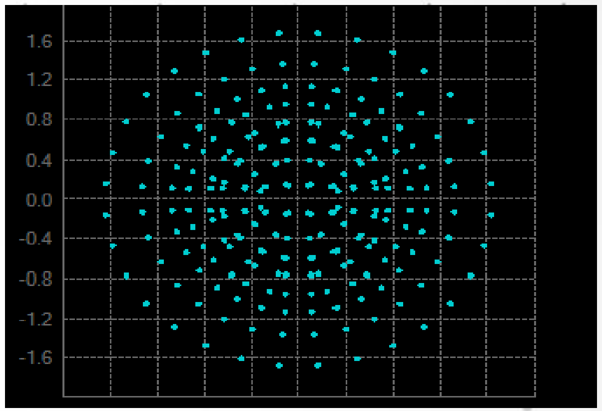
Tech Trend: High Throughput Satellite Constellations

INCREASING DATA DEMAND







Space

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

Higher Frequency

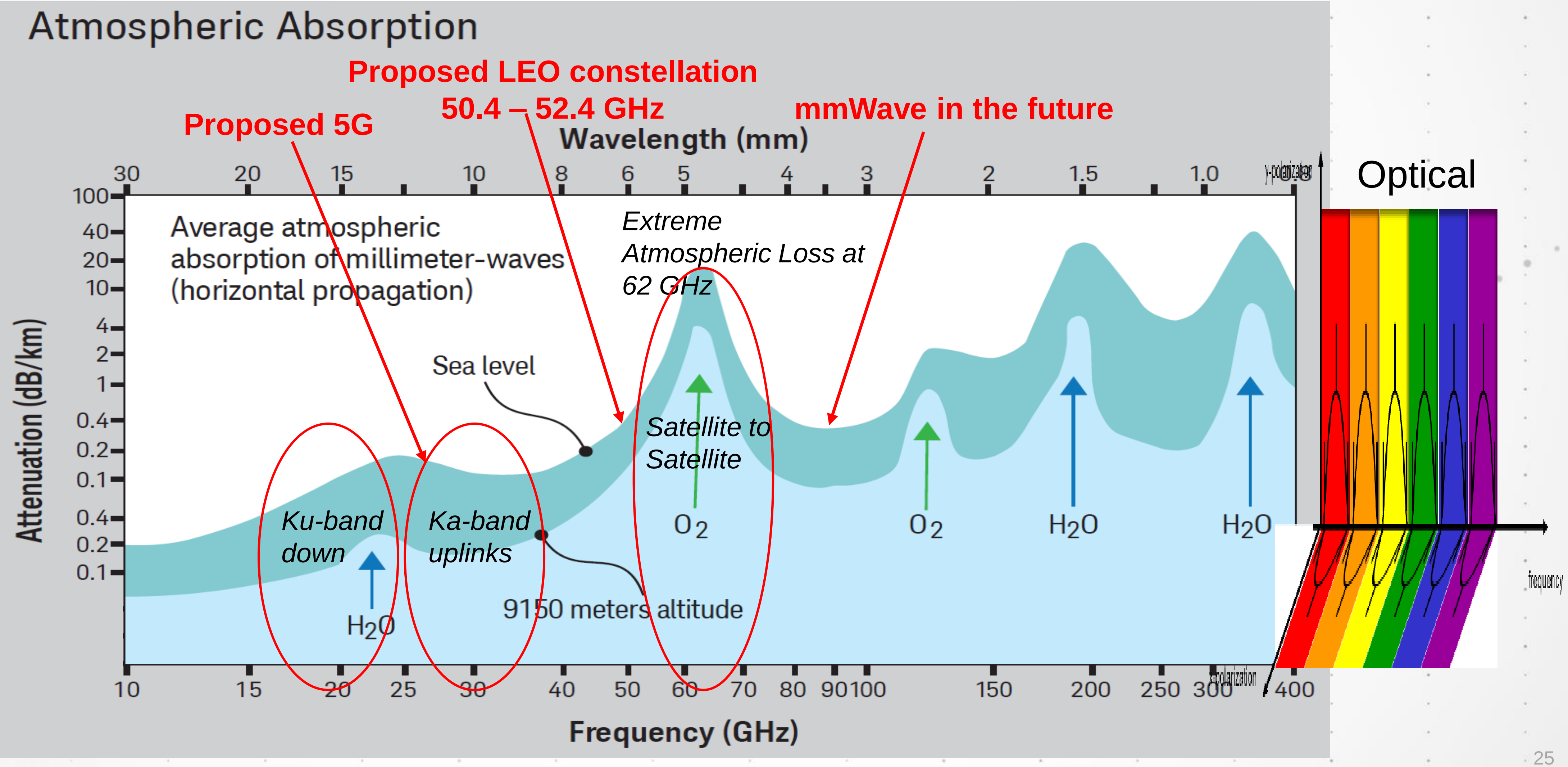
- Move to Ka-band and looking higher to V-band (more available bandwidth)
- Smaller antennas
- Spot beams and phased array antenna (satellite)
- Flat antenna, phased array (mobile, ground)

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

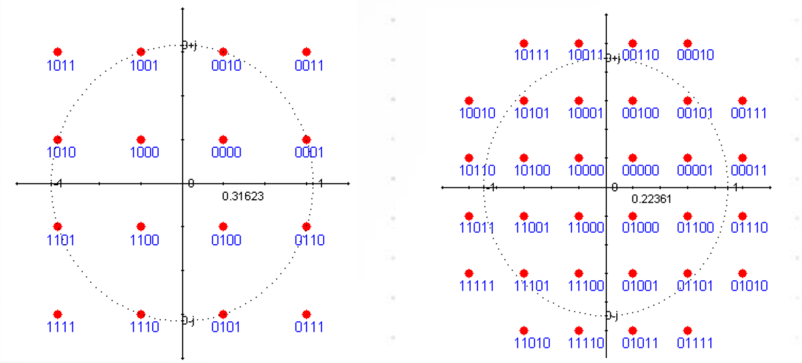
GAIN BECOMES A KEY ENABLER AS LOSS INCREASES



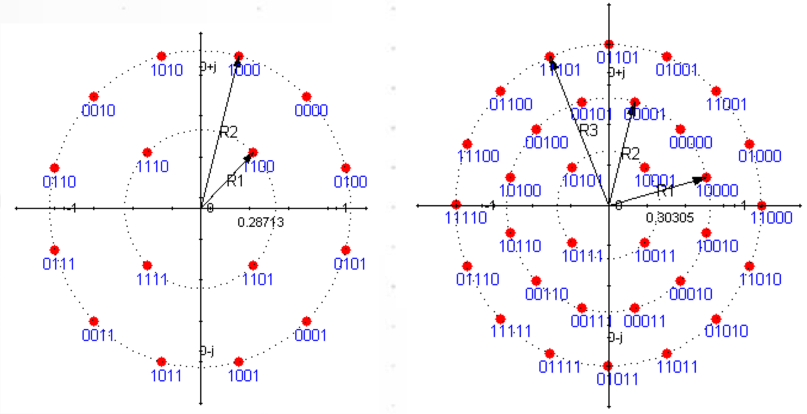
Higher Order Modulation for Satellite Applications

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

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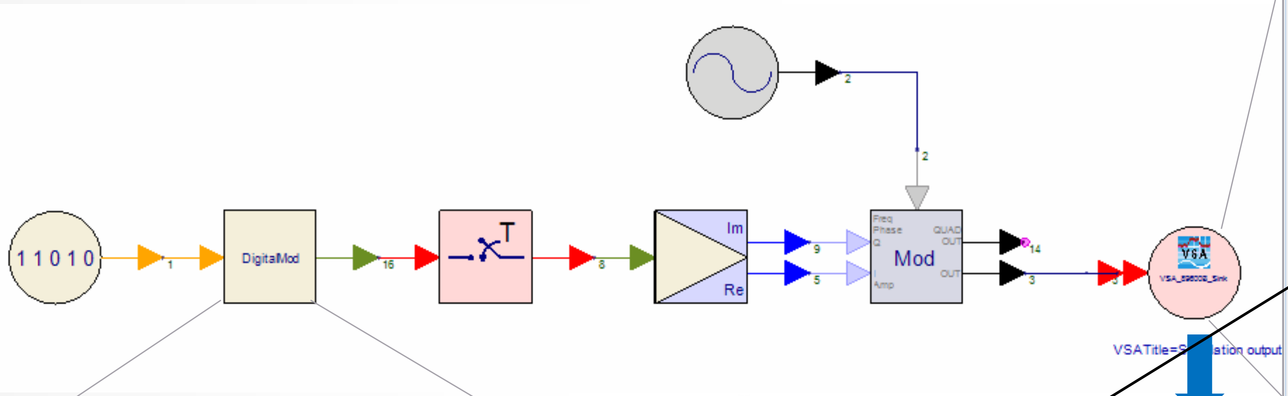
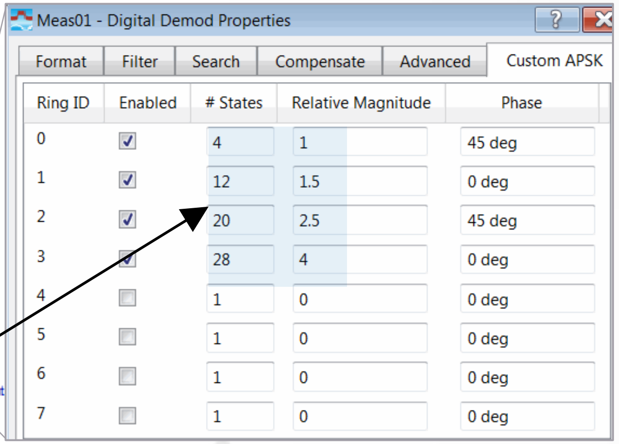
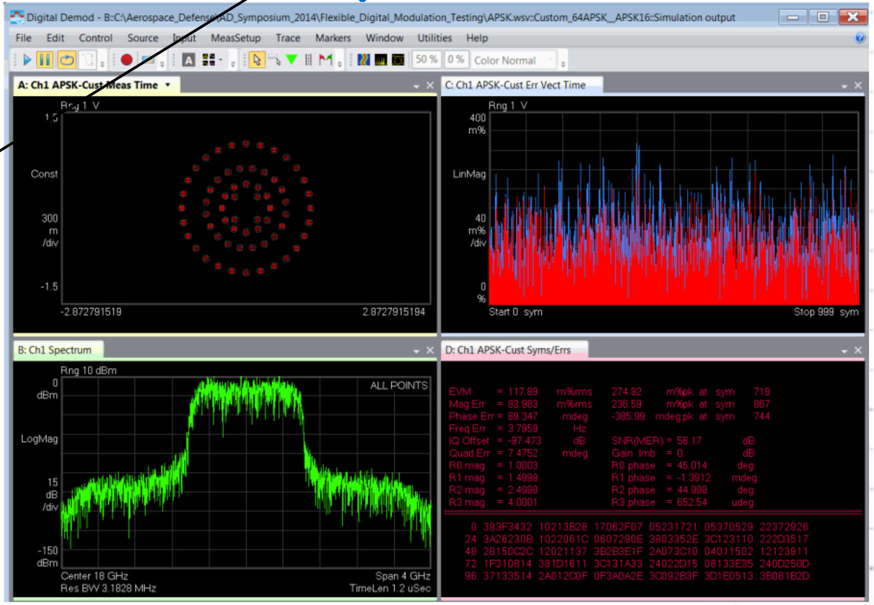
Customizing APSK

CUSTOM RING STATES, MAGNITUDES, AND PHASES





Name	Value
ModType	18:Custom APSK
RingStates	[4;12;20;28]
RingMagnitudes	[1;1.5;2.5;4]
RingInitialPhases	[45; 0;45;0]
DefaultState	DefaultState
OversampleRatio	OversamplingRatio
PulseShapingFiter	PulseShapingFilter
FilterLengthOption	FilterLengthOption
Length	LengthInTaps
Alpha	0.25
BitOrder	BitOrder
WorkMode	WorkMode



Custom Ring States, Magnitudes, and Phases

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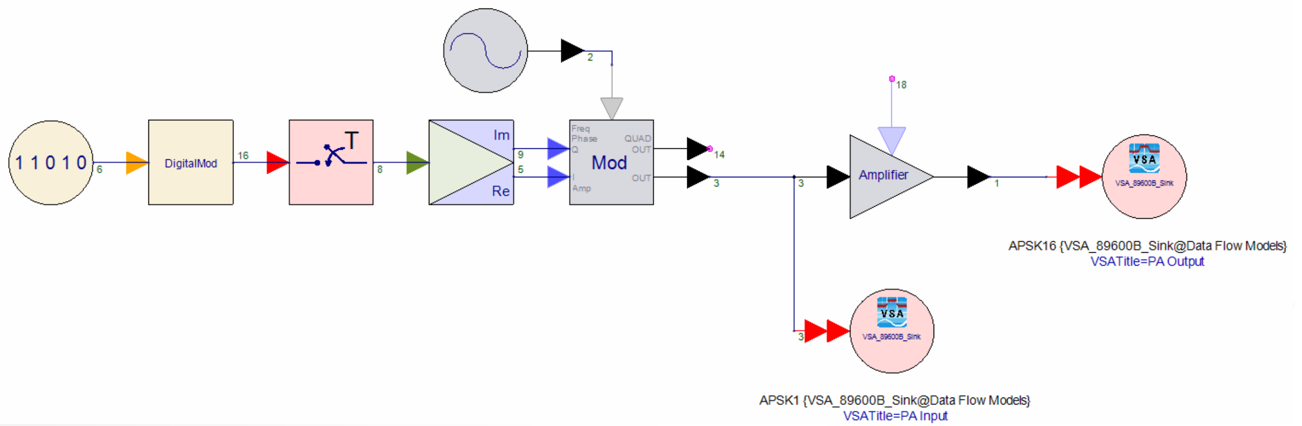
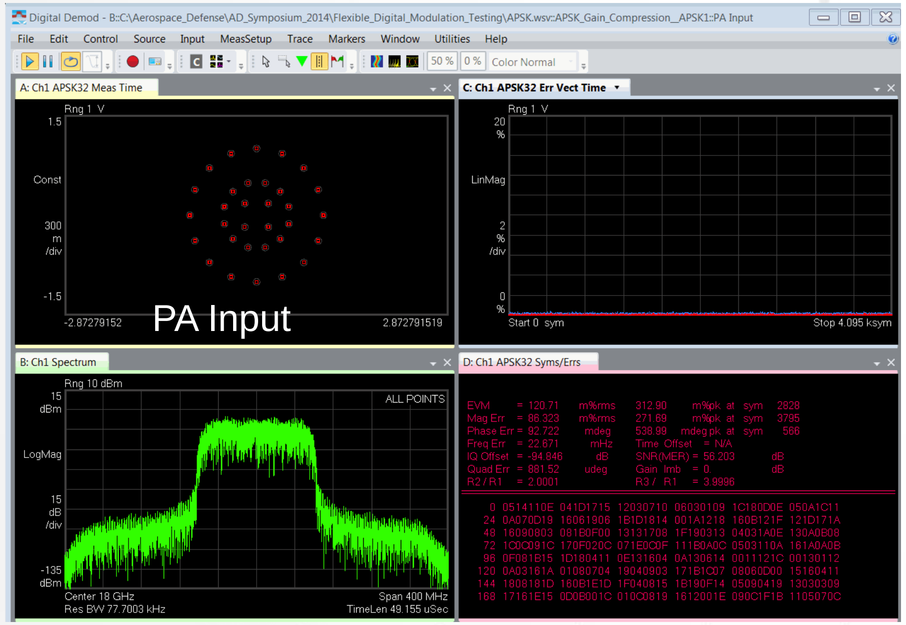
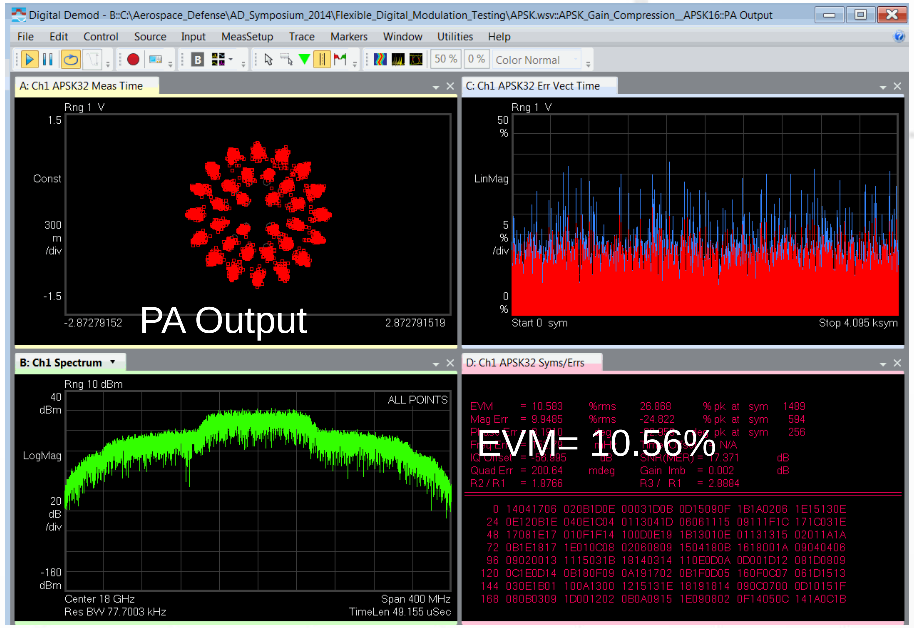
Customizing APSK

ADJUST RING RATIOS TO COMPENSATE FOR PA GAIN COMPRESSION







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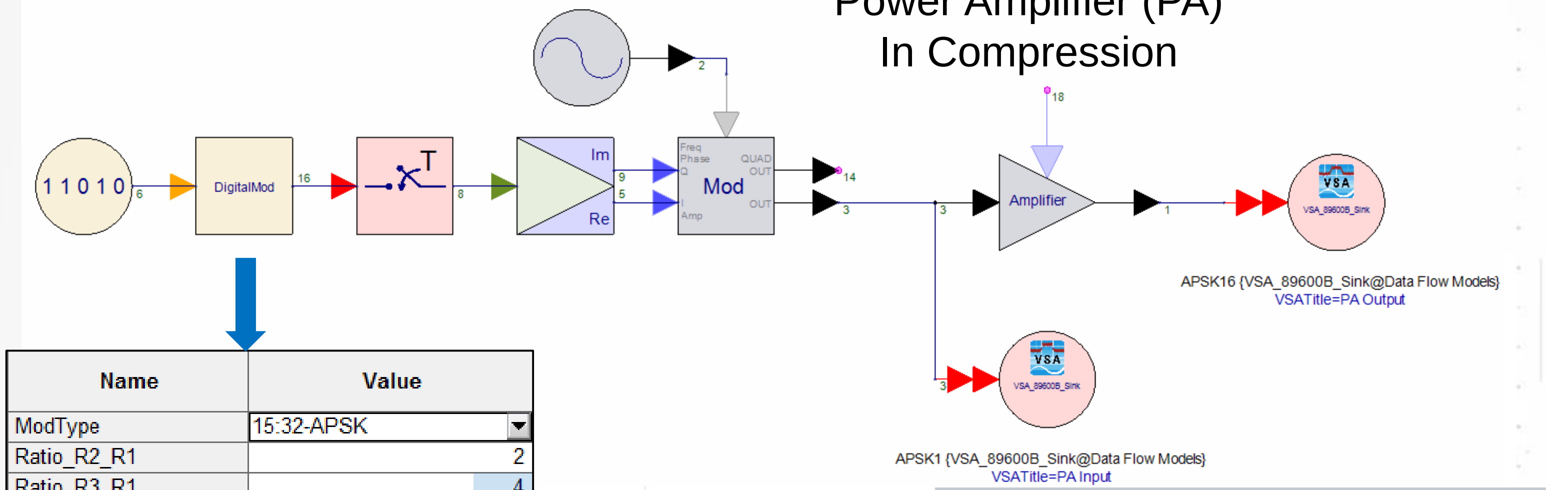
Customizing APSK

ADJUST RING RATIOS TO COMPENSATE FOR PA GAIN COMPRESSION

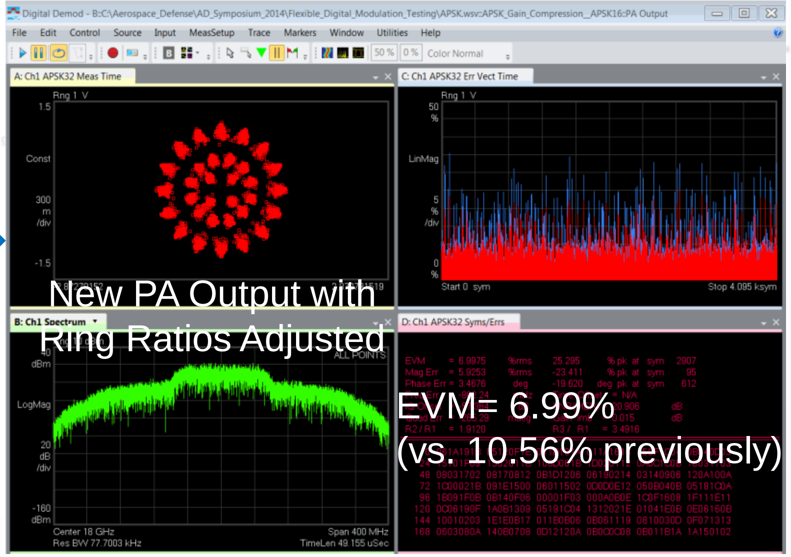
Power Amplifier (PA)
In Compression



Name	Value
ModType	15:32-APSK
Ratio_R2_R1	2
Ratio_R3_R1	4

Name	Value
ModType	15:32-APSK
Ratio_R2_R1	2
Ratio_R3_R1	5

Changed outer R3/R1 ring ratio from 4 to 5



New PA Output with Ring Ratios Adjusted

EVM= 6.99%
(vs. 10.56% previously)

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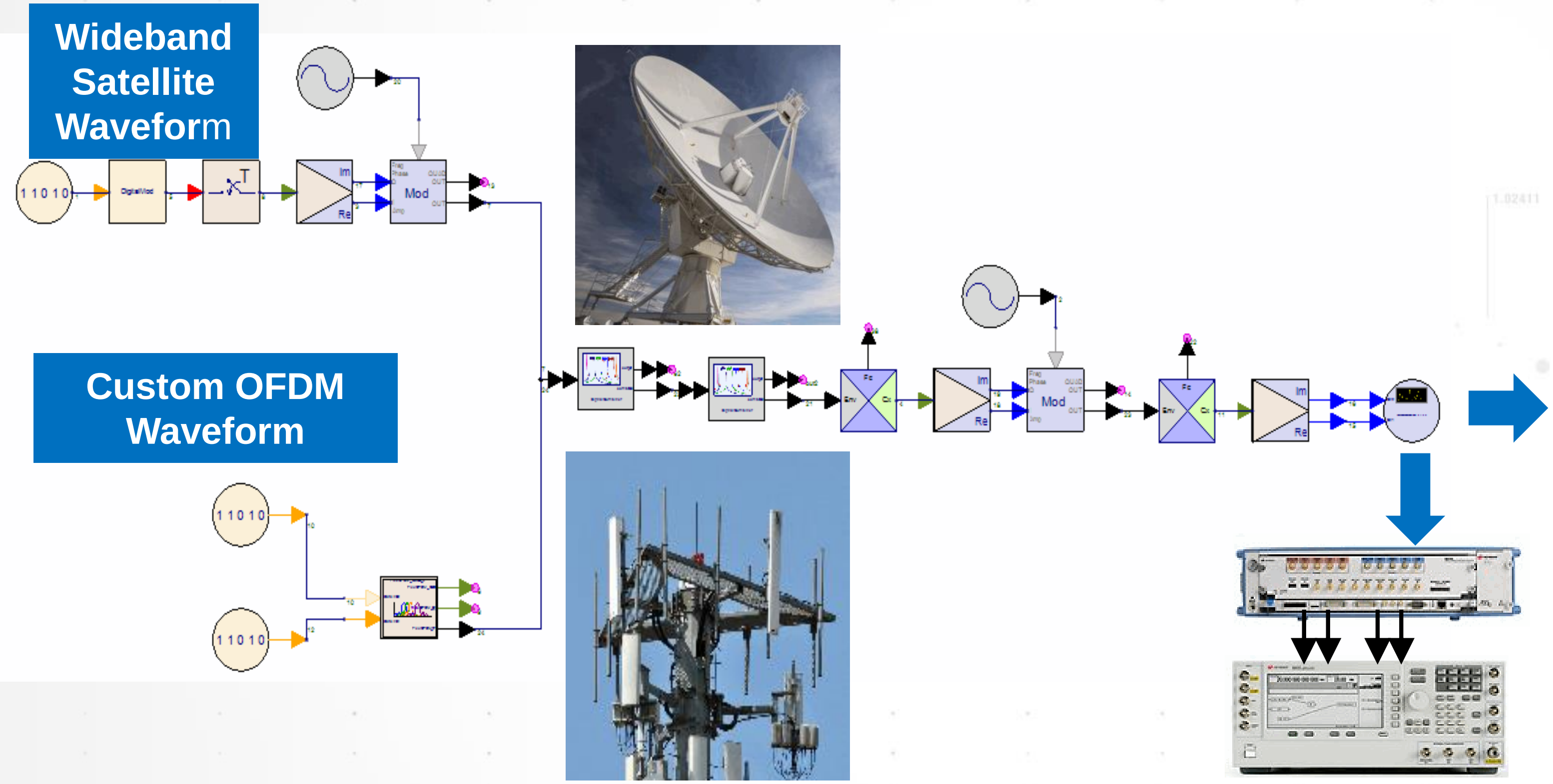
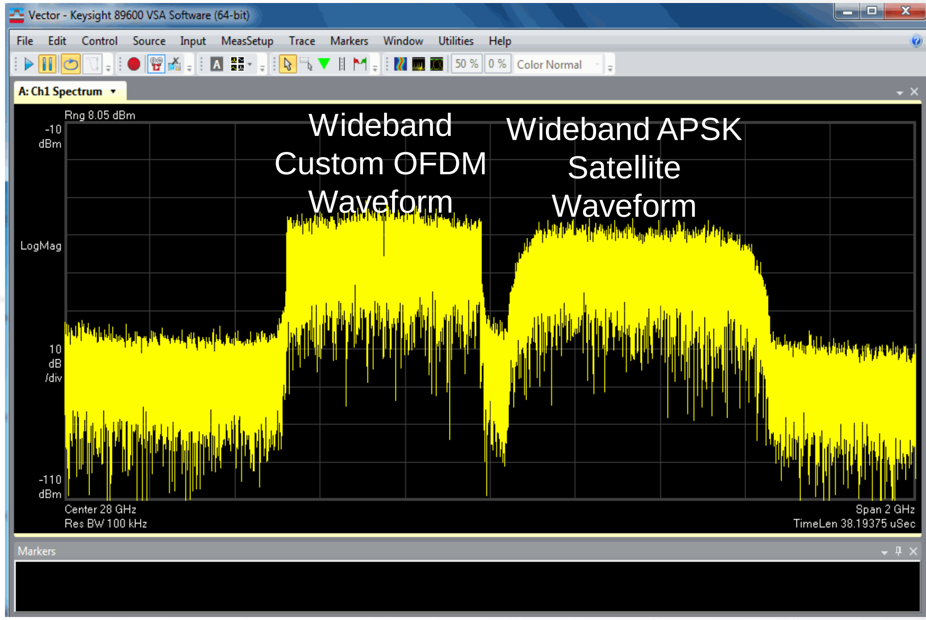
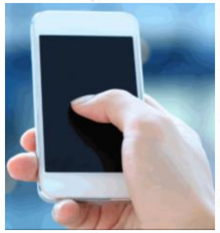
Custom OFDM & Satellite APSK Coexistence, 28 GHz

EVALUATE POTENTIAL INTERFERENCE SCENARIOS







Source: https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-138A1.pdf

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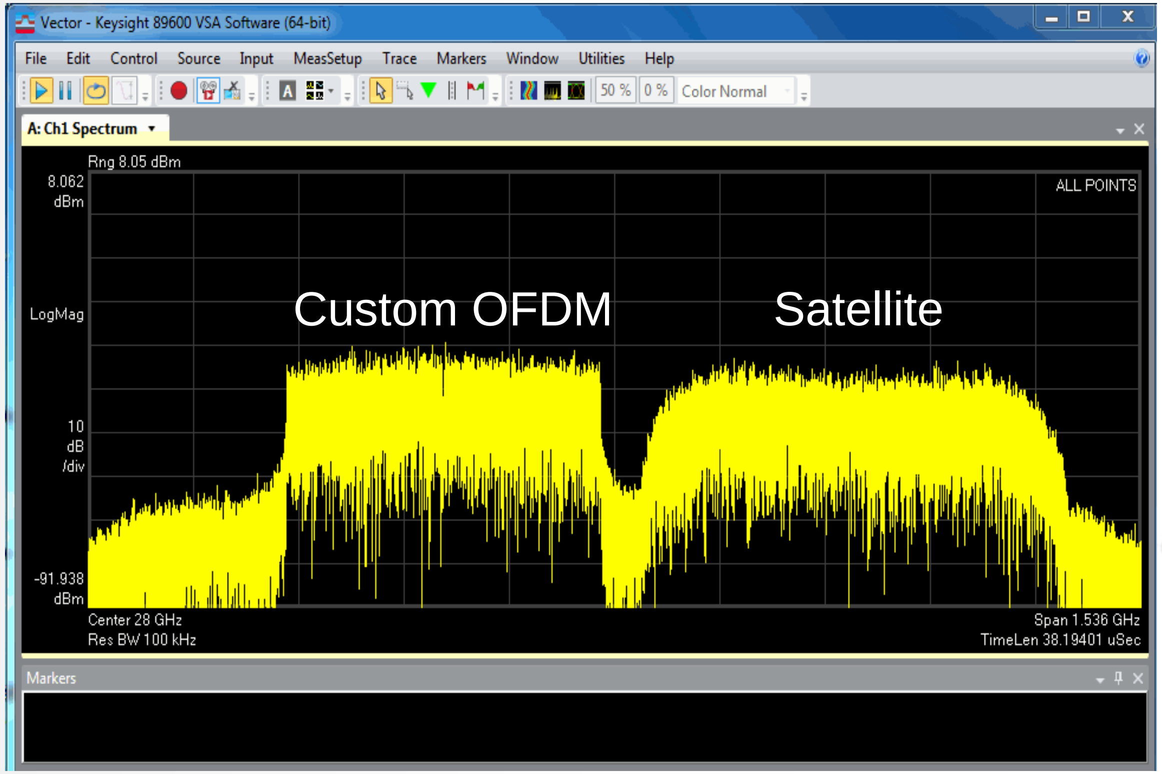
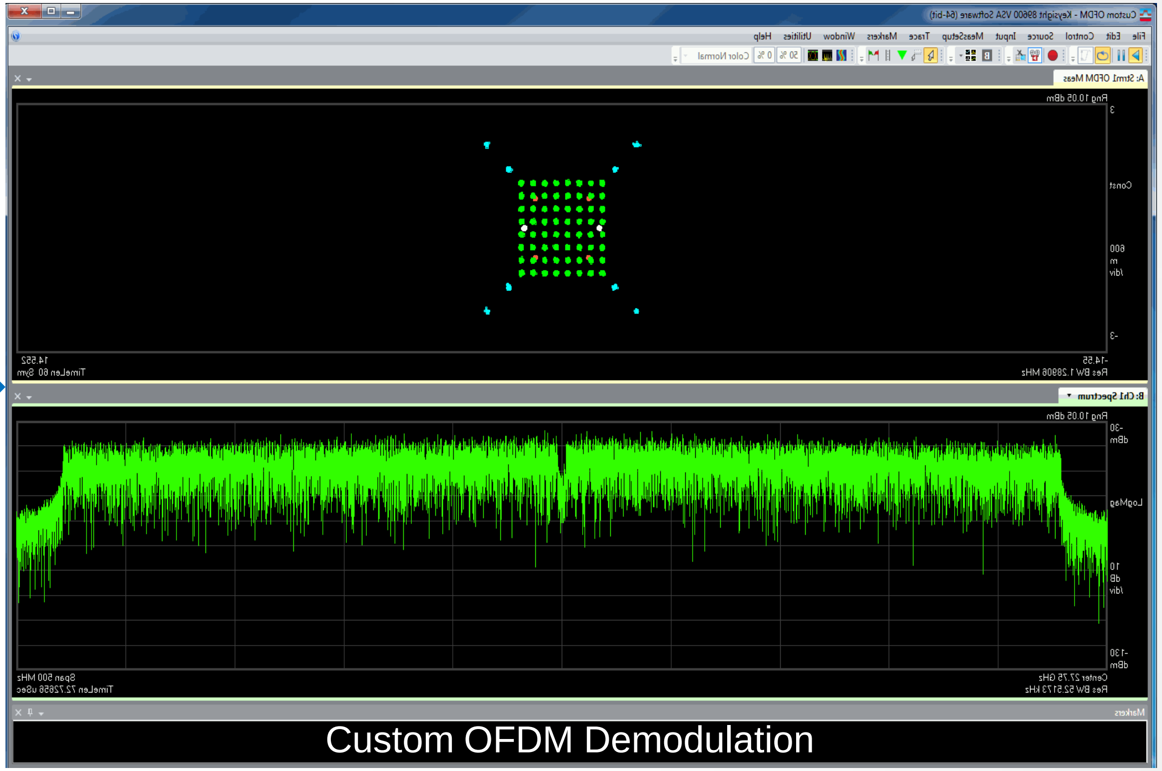
OFDM & Satellite APSK Coexistence, 28 GHz

SCENARIO 1- GOOD COEXISTENCE BETWEEN SATELLITE AND CUSTOM OFDM





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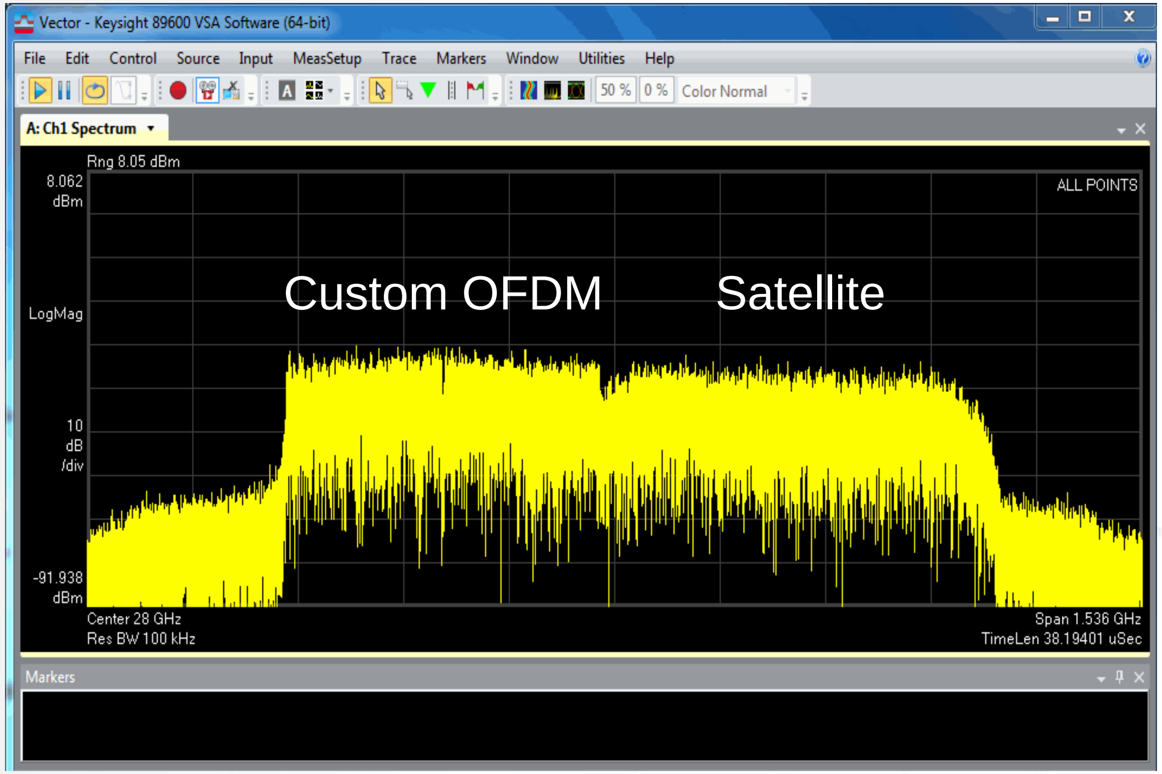
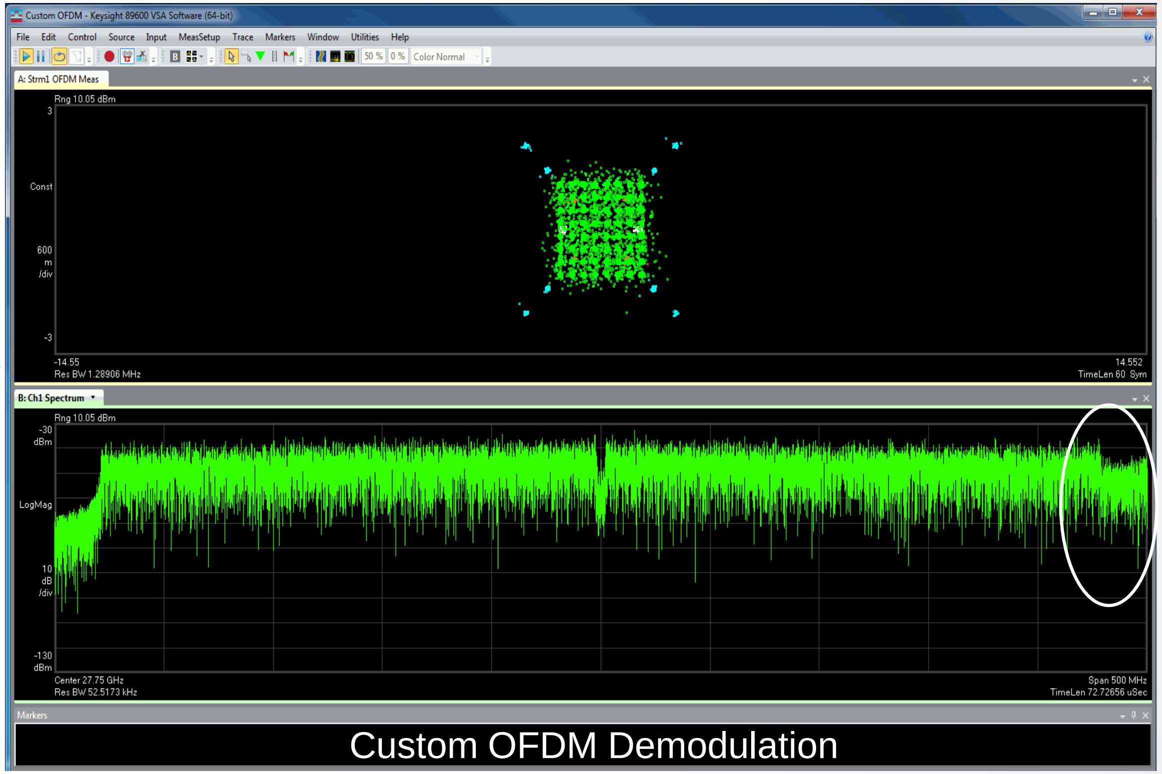
OFDM & Satellite Coexistence, 28 GHz

SCENARIO 1- POOR COEXISTENCE BETWEEN SATELLITE AND CUSTOM OFDM





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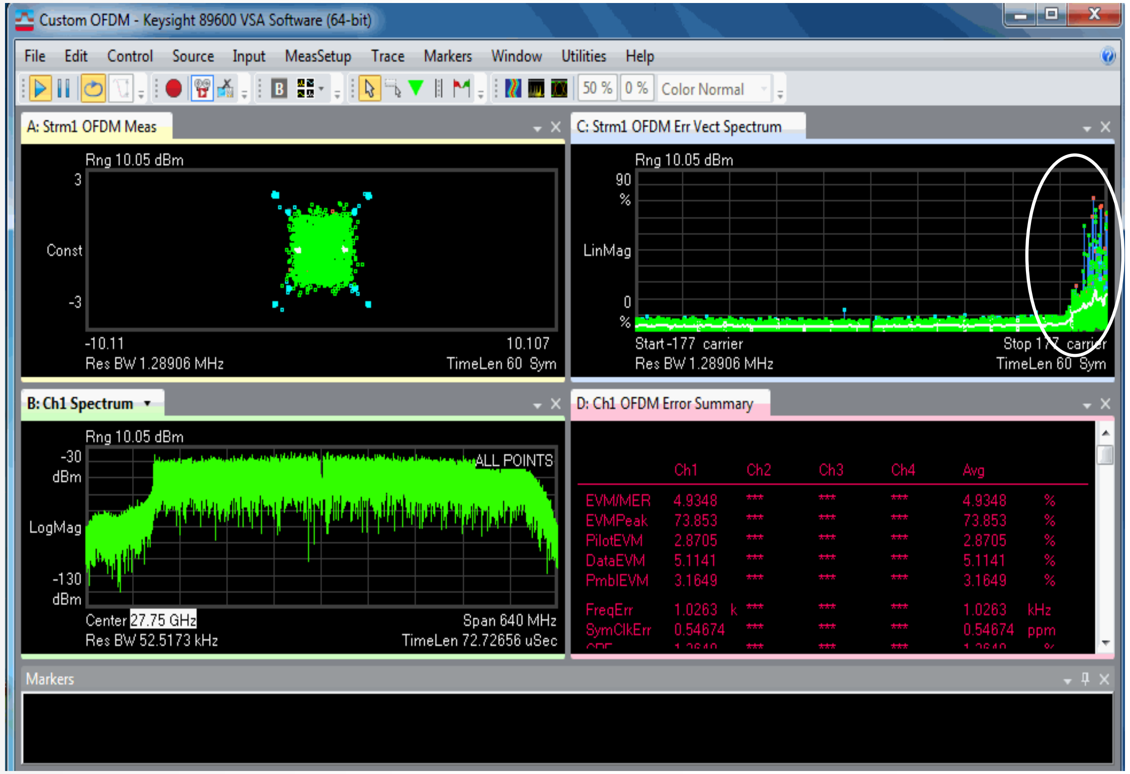
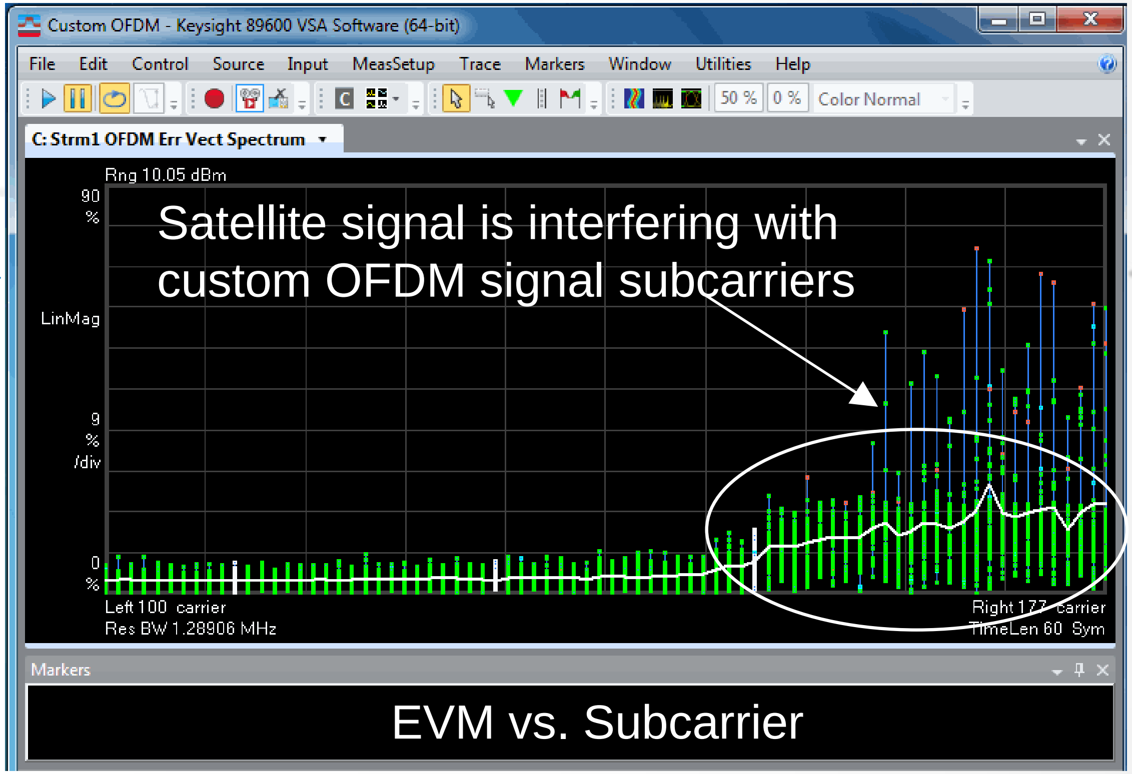
OFDM & Satellite APSK Coexistence, 28 GHz

SCENARIO 1- POOR COEXISTENCE BETWEEN SATELLITE AND CUSTOM OFDM





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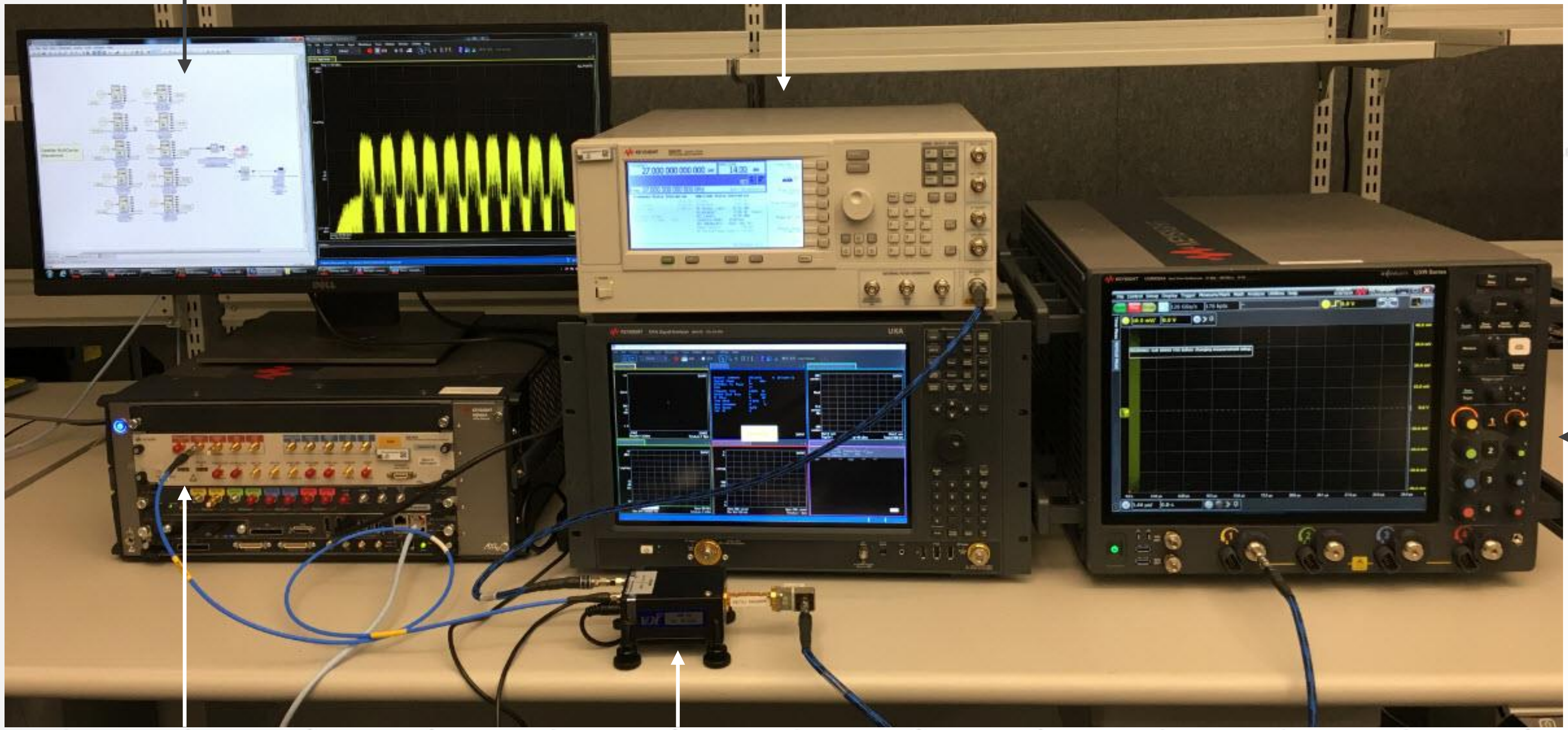
Analyzing Satellite Waveforms with New 33 GHz UXR

WIDEBAND APSK AND MULTI-CARRIER WAVEFORMS

SystemVue Design Software

PSG (LO)



New **33GHz UXR**

M8190A AWG

VDI WR28
Compact Upconverter

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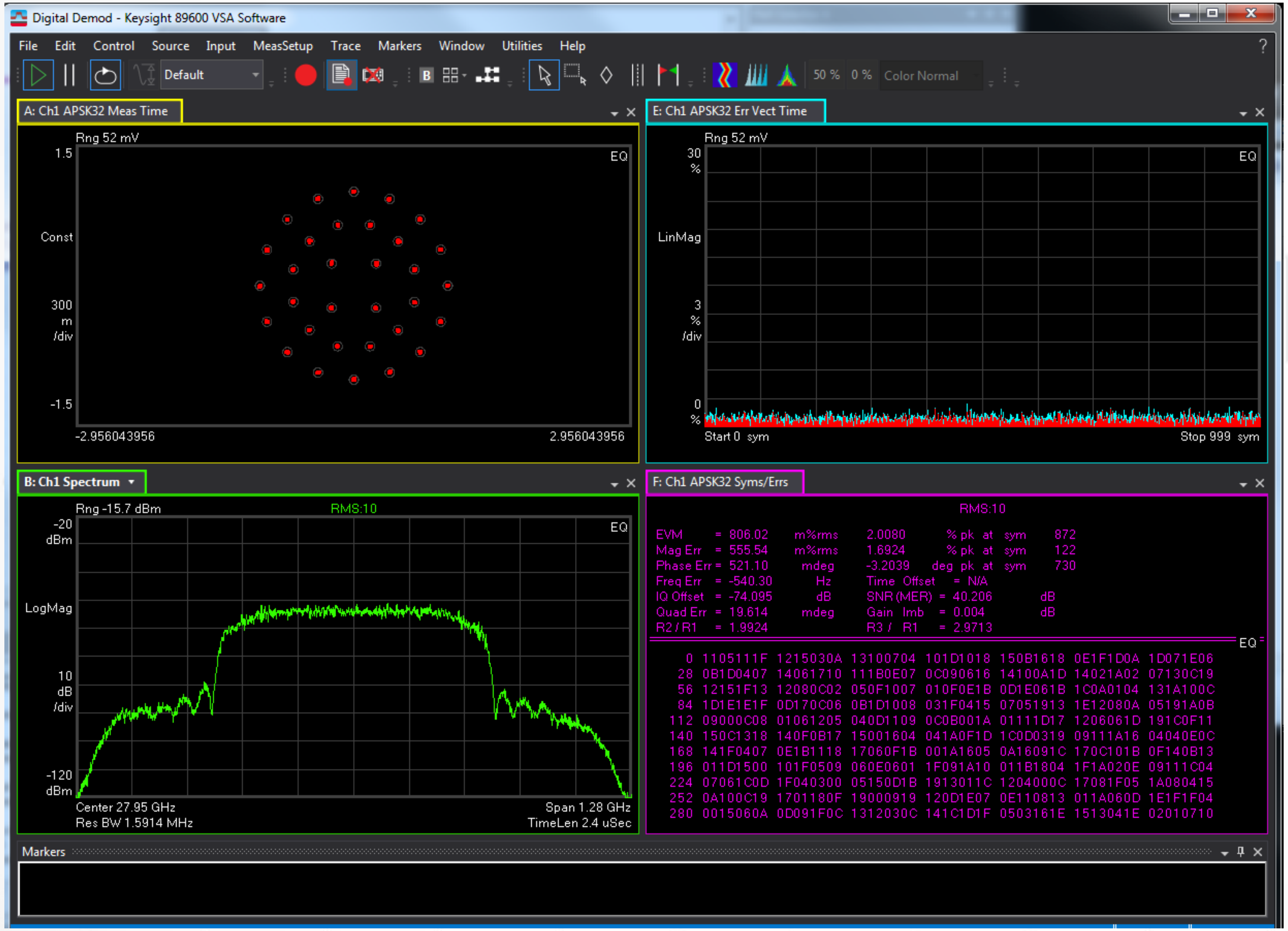
Analyzing Satellite Waveforms with New 33 GHz UXR

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



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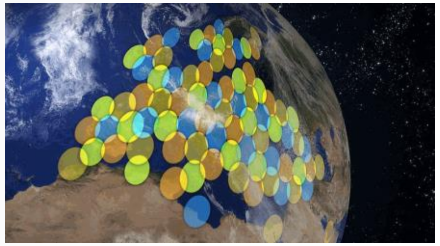
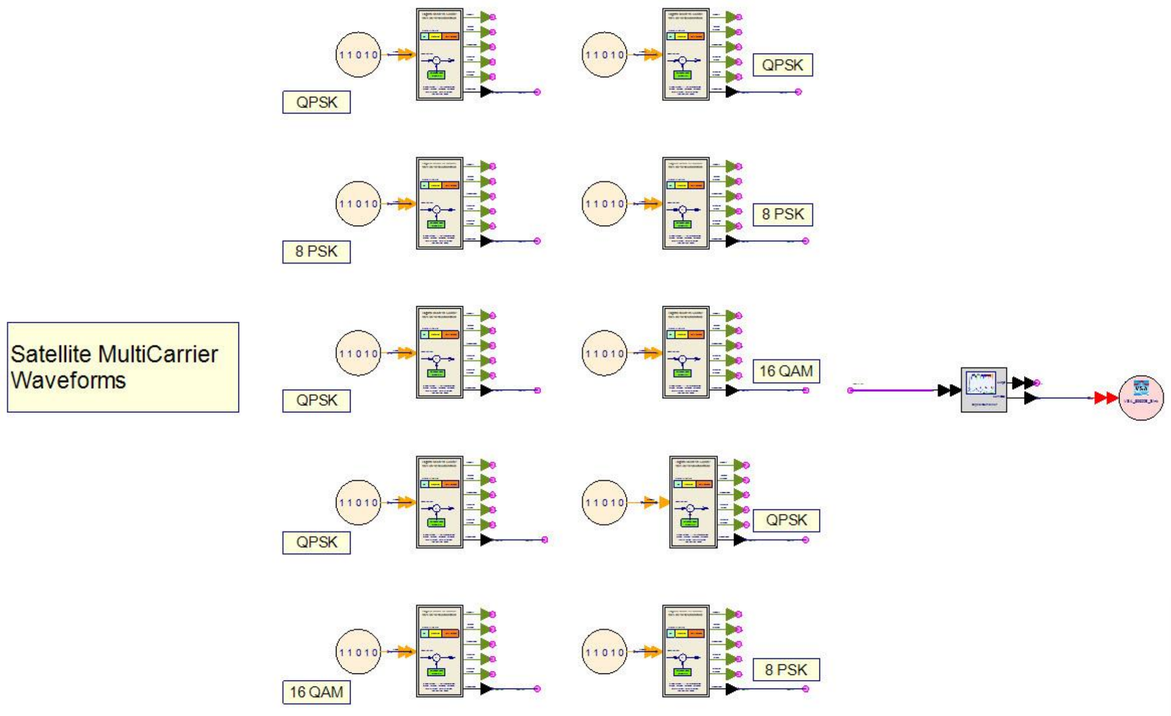
Satellite Multicarrier Waveforms, 28 GHz

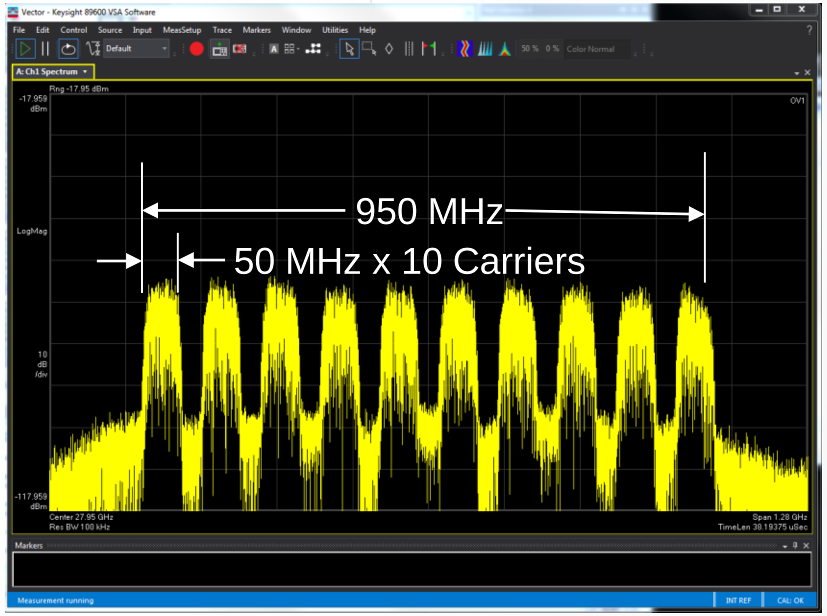
EVALUATE POTENTIAL INTERFERENCE SCENARIOS

Satellite Multicarrier Waveforms (1:N)



Source: http://en.wikipedia.org/wiki/High_throughput_satellite

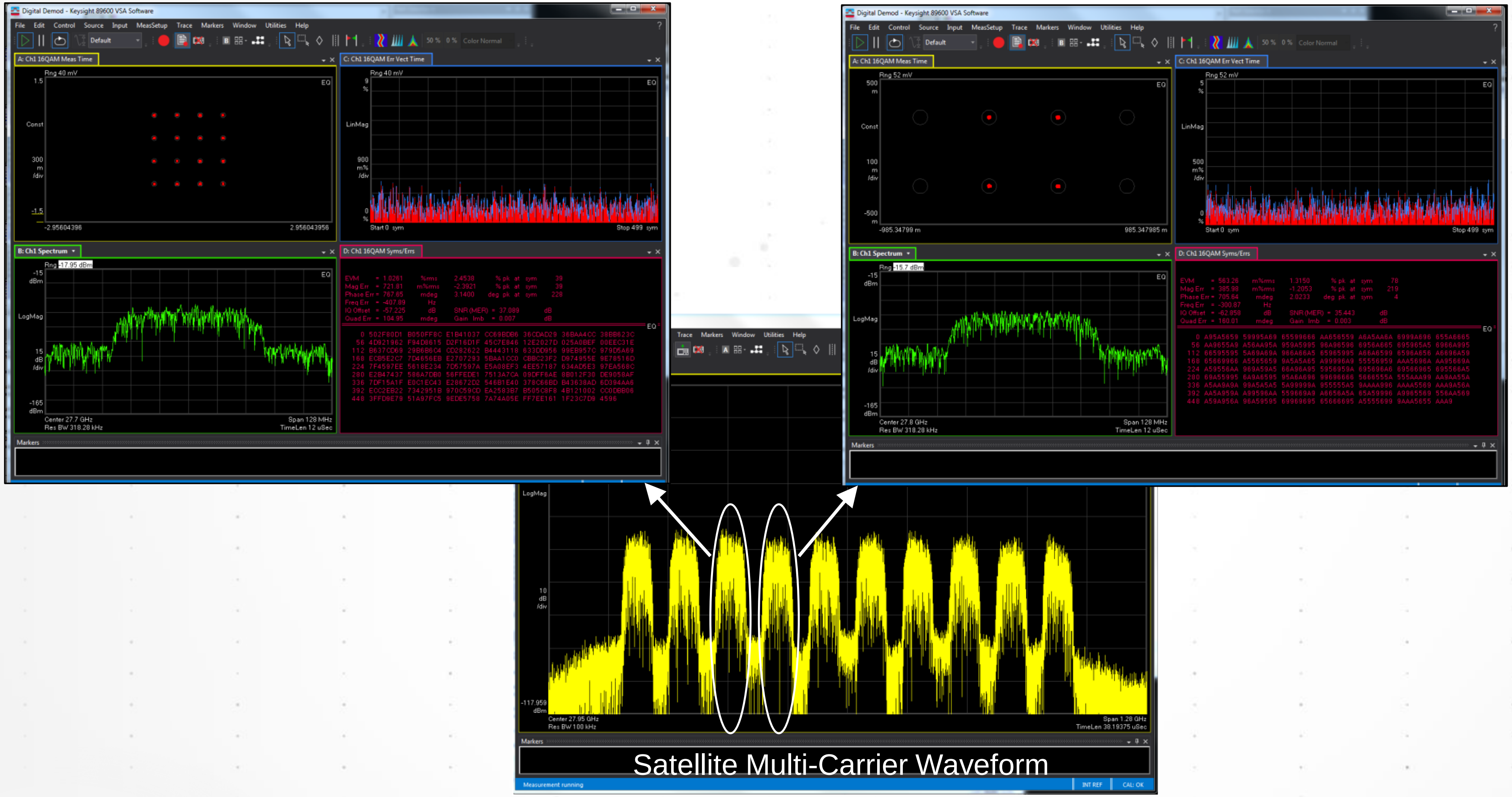




Ten 50 MHz Carriers Spaced 100 MHz Apart

Analyzing Satellite Waveforms with New 33 GHz UXR

MULTI-CARRIER DEMODULATION RESULTS



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Agenda

- Opening Up Millimeter-Wave Spectrum
- Challenges of Very-Wideband Millimeter-Wave Applications
- Satellite Millimeter-Wave Applications
- **Multi-Channel Applications: MIMO**
- Emerging 60 GHz Millimeter-Wave Application Example: 802.11ay
- 71-76 and 81-86 GHz Millimeter-Wave Frequency Bands
- Summary and Additional Resources

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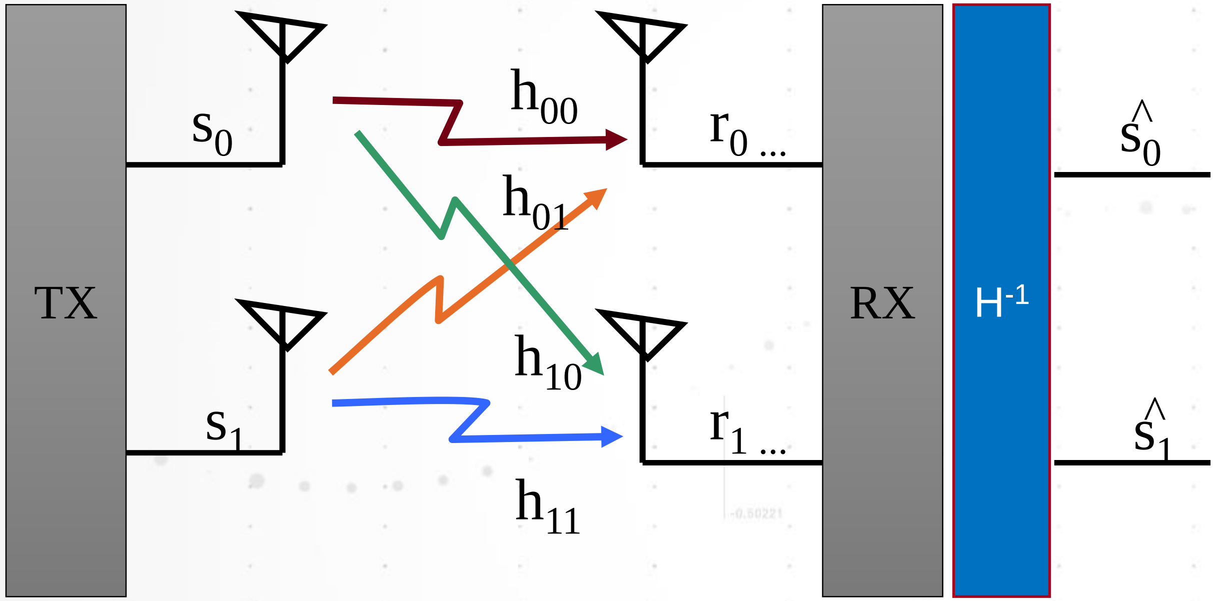
Single-User MIMO

MULTIPLE SPATIAL CHANNELS FOR HIGHER DATA RATES TO A SINGLE USER



Note: This is a conceptual implementation only. It doesn't take noise or non-square matrices into account

$$\begin{bmatrix} r_0 \\ r_1 \end{bmatrix} = \begin{bmatrix} h_{00} & h_{01} \\ h_{10} & h_{11} \end{bmatrix} \begin{bmatrix} s_0 \\ s_1 \end{bmatrix}$$

$$R = HS$$

or

$$\hat{S} = H^{-1}R$$

In this simple example, the receiver is responsible for de-multiplexing the two data streams. The receiver does this with knowledge of the channel [H]

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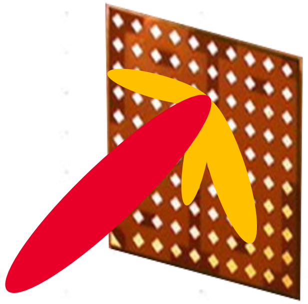
MIMO at Millimeter-Wave Frequencies?

BEAMFORMING RESOLVES MMWAVE ISSUES

Large available bandwidth at mmWave

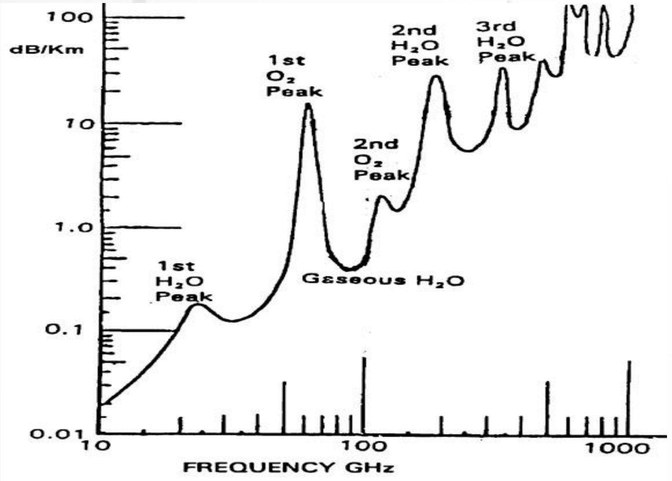
Frequency range	6-20 GHz	20-40 GHz	40-60 GHz	60-100 GHz
Specific bands identified	***10 GHz band*** *10.125-10.225 GHz* *10.475–10.575 GHz*	**32 GHz band** *31.8-33.4 GHz*	**40 GHz band** *40.5-43.5 GHz* **'45 GHz' band** *45.5-48.9 GHz*	**66 GHz band** *66-71 GHz*
Potential bandwidth	*2 x 100 MHz*	*1.6 GHz*	*5.8 GHz total*	*5 GHz*

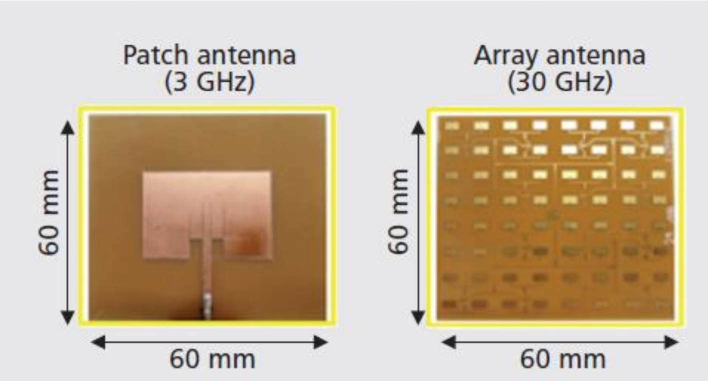
Source: Ofcom, Apr 2015



Path loss can be mitigated by high gain directional antennas

High path loss due to antenna aperture size and atmospheric absorption





mmWave geometry allows for very small, high gain antennas

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5G NR MIMO with New 110 GHz UXR

28 GHZ MIMO TEST SETUP WITH PHASED ARRAY

New M9384B VXG Microwave Signal Generator *New* 110 GHz UXR

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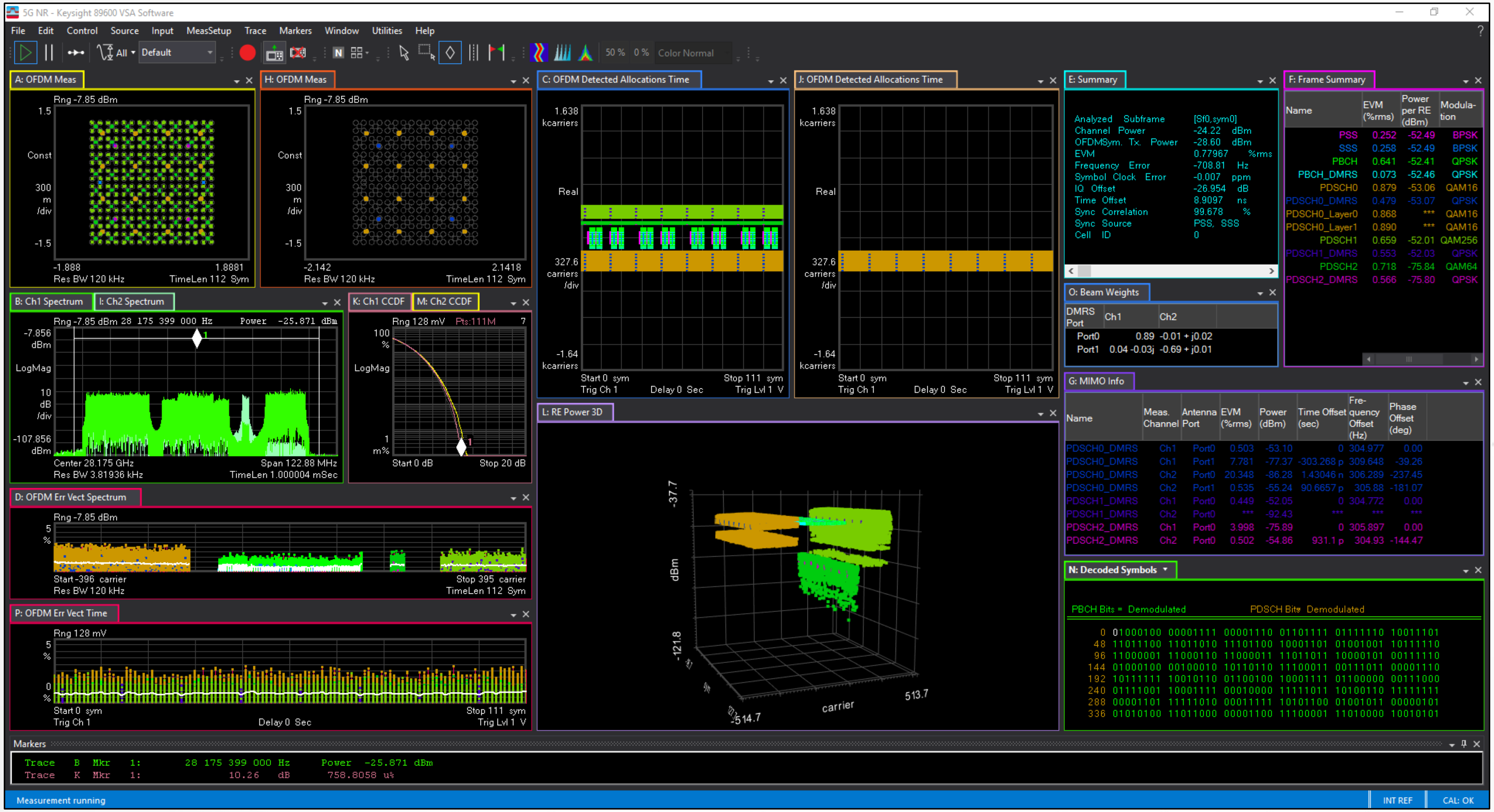
5G NR MIMO with New 110 GHz UXR

28 GHZ MIMO DEMODULATION RESULTS



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Agenda

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- Challenges of Very-Wideband Millimeter-Wave Applications
- Satellite Millimeter-Wave Applications
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- 71-76 and 81-86 GHz Millimeter-Wave Frequency Bands
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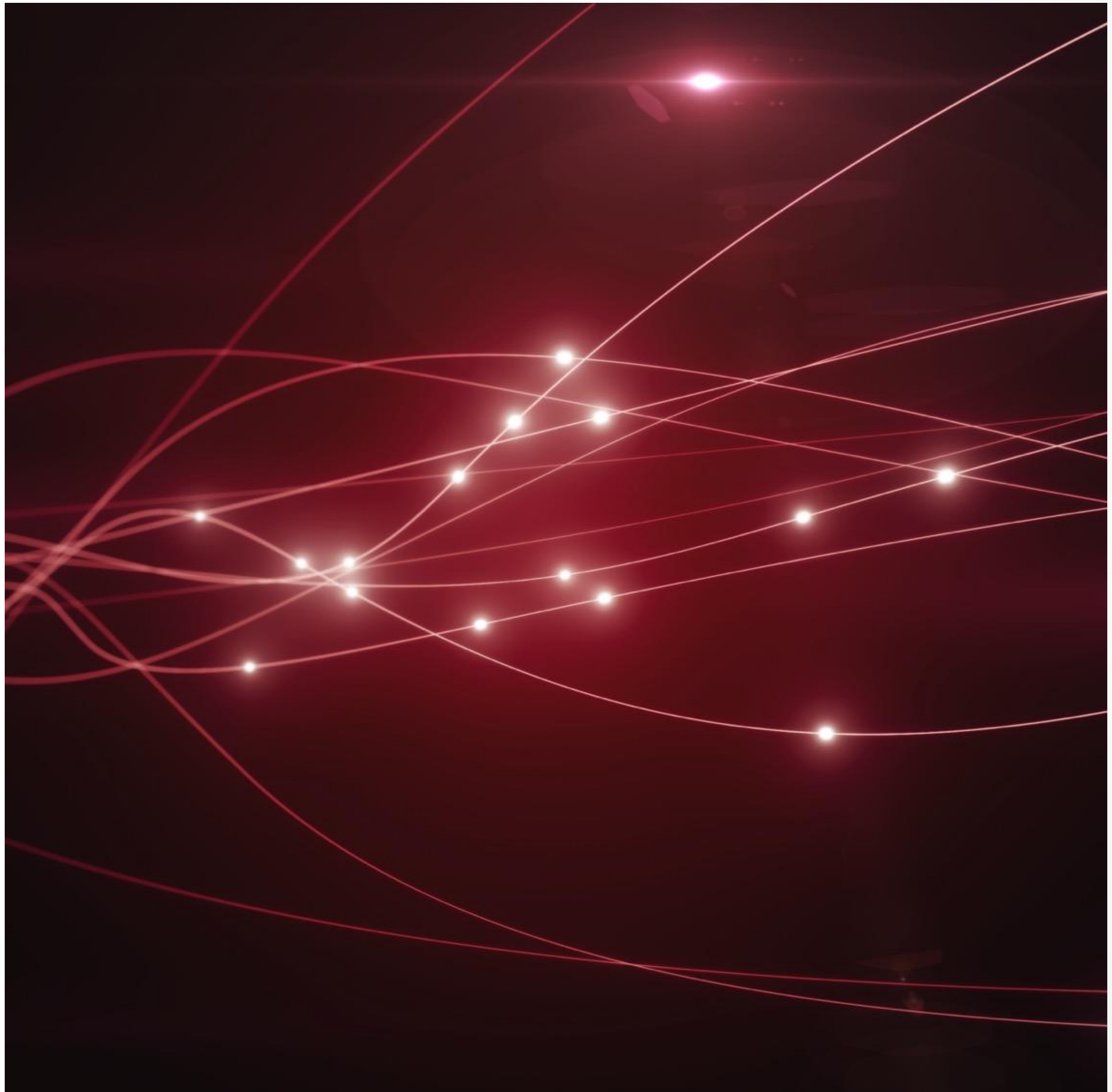
Challenges for High-Band mmWave

MOVING FORWARD FOR 5G NR AND 802.11AY

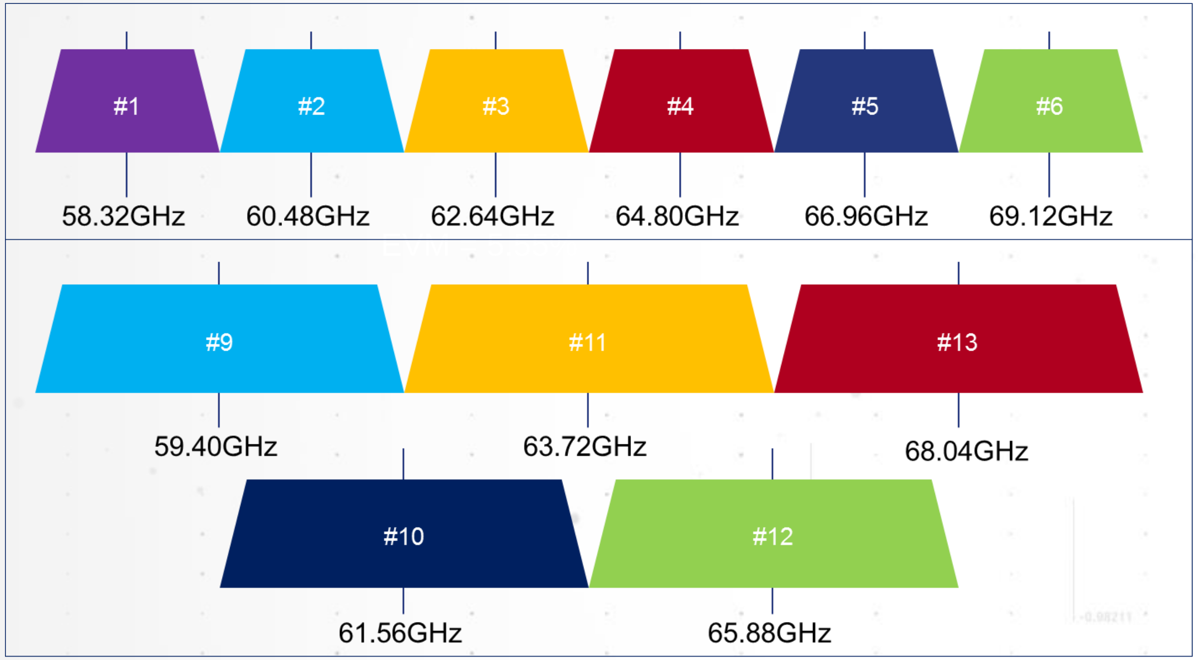
- Currently unclear which upper mmWave frequency bands may be of interest for 5G NR (57-64, 64-71, 71-76, 81-86 GHz?....others?)
- Very wide bandwidths may be needed for high data throughput (e.g. 4.32-8.64 GHz bandwidth for 802.11ay)
- Multi-channel may also be needed for multiple antenna techniques (e.g. MIMO)

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



WiGig

60GHZ: 802.11AD/AY



802.11ad and 802.11ay channels

Support of 2.16 GHz channels and channel bonding of two 2.16 GHz channels, or 4.32 GHz, is mandatory for EDMG STA

Channel aggregation and bonding of three or four 2.16 GHz channels is optional.

Ref: IEEE P802.11ay/D1.4, Jul 2018

Using unlicensed spectrum at mmWave band

- 802.11ad, published in 2012, was the first of the new specific-use Wi-Fi standards, created to facilitate very-high-speed data transfer using the 60-GHz band.
  - DMG (Directional Multi-Gigabit) PHY
    - Bandwidth: 2.16GHz
    - Single Carrier: QAM (OFDM Obsoleted)
    - Beam Steering
- IEEE 802.11ay is the next-generation wireless standard at 60 GHz, an extension of the existing 11ad, aimed to extend the throughput, range and use-cases, and is expected to be completed in 2019. Draft 2.1 in Oct, 2018.
  - *Enables at least one mode of operation capable of supporting a maximum throughput of at least 20Gbps, while maintaining/improving the power efficiency.*
  - EDMG (Enhanced DMG) PHY, backward compatibility with 11ad, add support for space-time streams, DL MU transmissions and multiple channel widths.

(http://www.ieee802.org/11/Reports/tgay_update.htm)

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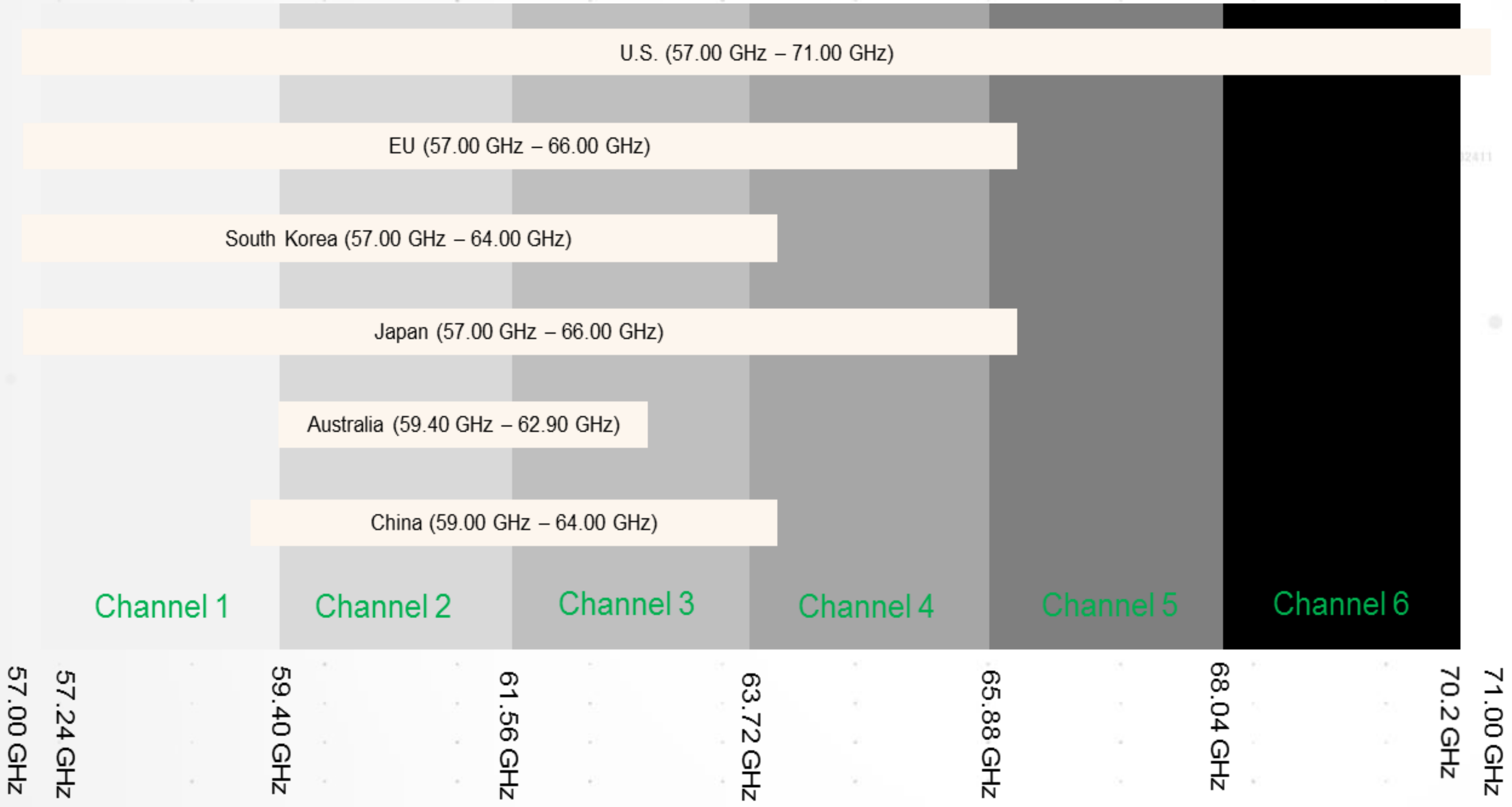
WiGig

WORLDWIDE SPECTRUM



- ***Advantages*** of 60GHz band
  - Large spectrum
  - Small antenna size
  - Beamforming
  - Directional antennas for spatial reuse
  - Low interference
  - Increased security
- ***Disadvantages*** of 60GHz band
  - Large attenuation and oxygen absorption
  - Directional deafness
  - Easily blocked

Ref: WFA, Wi-Fi CERTIFIED WiGig Messaging Architecture v1.0

Directional transmission with large arrays provides necessary gain

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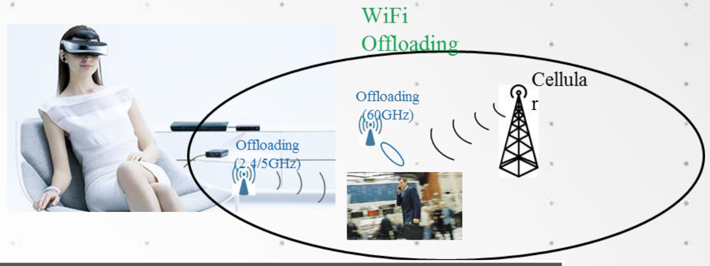
Usage Scenarios Proposal for 802.11ay



UNDER CONSIDERATION FOR STANDARD DEFINITION

Usage model	Target data rate	Other requirements
Ultra Short Range (USR) Communications	10 Gbps	Transaction time: <1sec
8K UHD Wireless Transfer at Smart Home	>28 Gbps	latency < 5ms, jitter<5ms
AR/VR Headsets and Other High-End Wearables	20 Gbps	latency < 5 ms, jitter <5 ms, PER<10E-2
Data Center 11ay Inter-Rack Connectivity	>20 Gbps	PER<10E-2; Link setup time < 100ms
Video/Mass-Data Distribution/Video on Demand System	20 Gbps	Distance < 100m
Mobile Offloading and Multi-Band Operation (MBO)	20 Gbps	Handoff disconnection <100ms, PER<10E-2.
Mobile Fronthauling	20 Gbps	99.99% reliability and availability
Wireless Backhauling	2~20 Gbps	99.99% reliability and availability Latency <35ms
Office docking	10-20 Gbps	Multiple simultaneous high performance links
mmWave Distribution Network	>4 Gbps	Latency: < 2~15ms
USR Wireless Docking	1 -10 Gbps	Latency; 10~50ms

Ref: IEEE 802.11-2-15/0625r7; Requirements for applications described

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Summary of 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)

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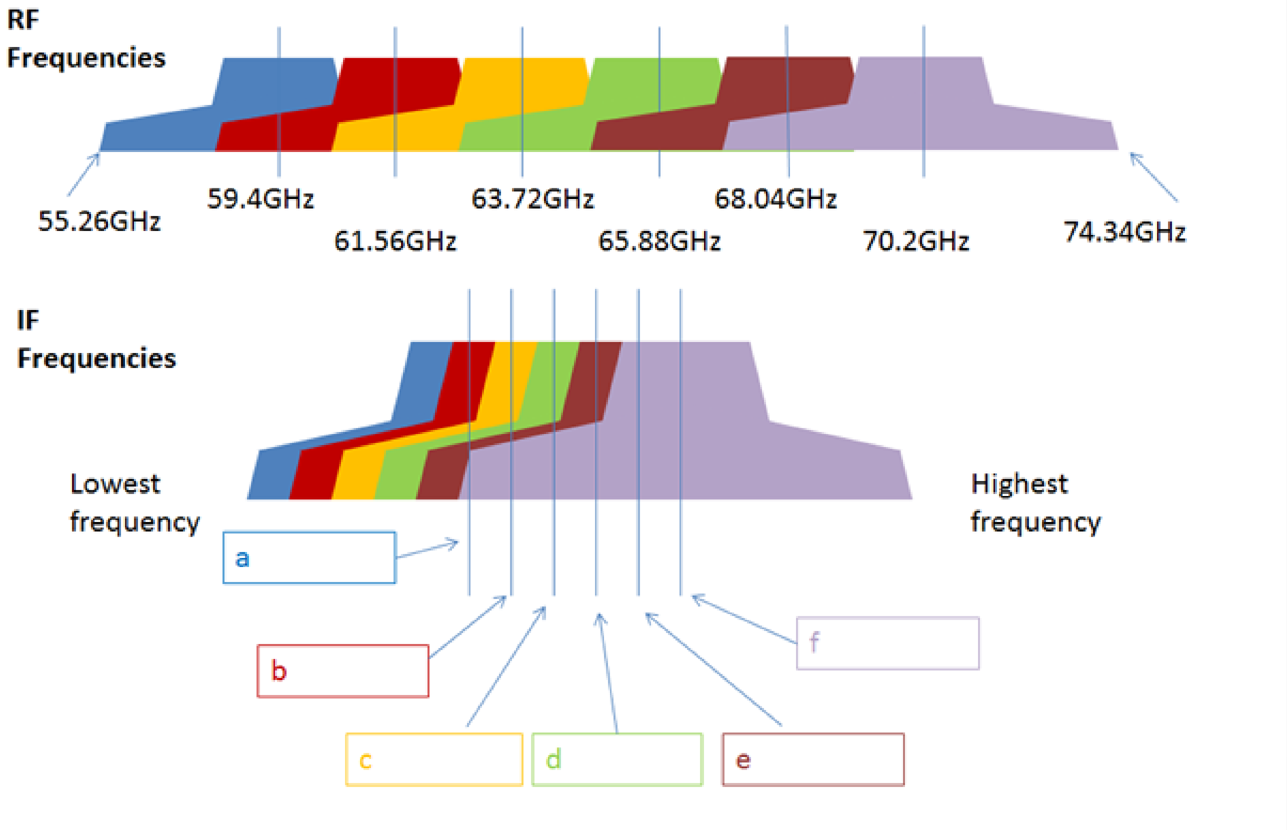
802.11ay Test Challenges

Wide bandwidth signals in millimeter-wave bands (57 GHz to 72GHz)

- Good EVM
- Spectrum flatness
- Over the air – Transmit in High Power
- Dynamic range (Good SNR)
- Wide frequency ranges



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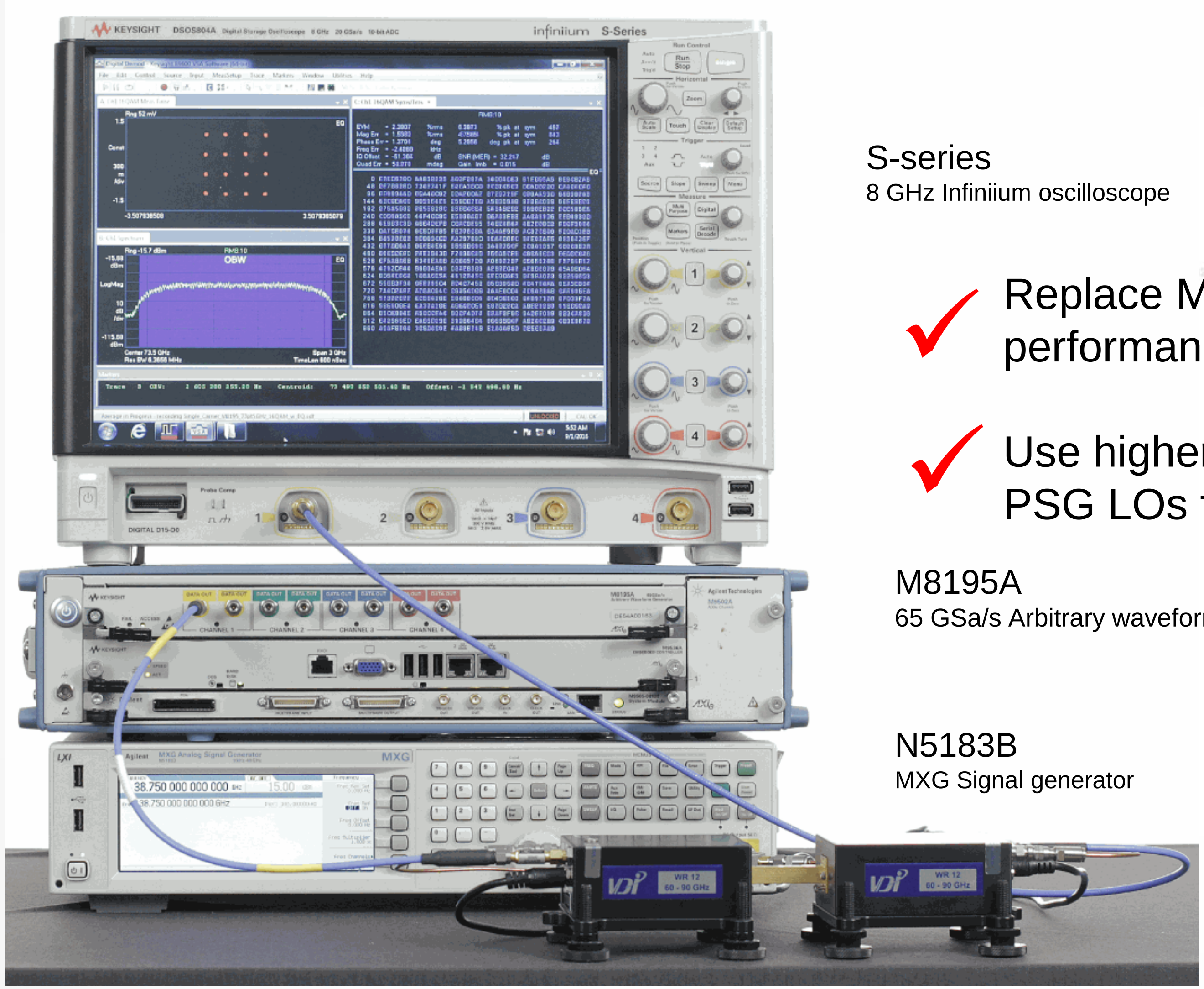
Wideband Millimeter-Wave R&D Testbed



S-series
8 GHz Infiniium oscilloscope

- ✓ Replace MXG LOs with PSG LOs for better performance
- ✓ Use higher-performance oscilloscope and PSG LOs for best performance

M8195A
65 GSa/s Arbitrary waveform generator

N5183B
MXG Signal generator

V-band converters
(E-band are shown here)

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Wideband Millimeter-Wave R&D Testbed

M8195A AWG AS A WIDEBAND IF SOURCE

M8195A 65 GSa/s AWG
Wide Bandwidth and Multichannel

- **Sample rate 54 GSa/s to 65 GSa/s per channel**
- **25 GHz bandwidth**
- **Up to 16 Gsa of waveform memory per module**
- **1, 2 or 4 differential channels per 1-slot AXIe module**

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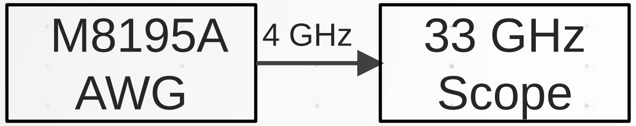
Wideband Millimeter-Wave R&D Testbed

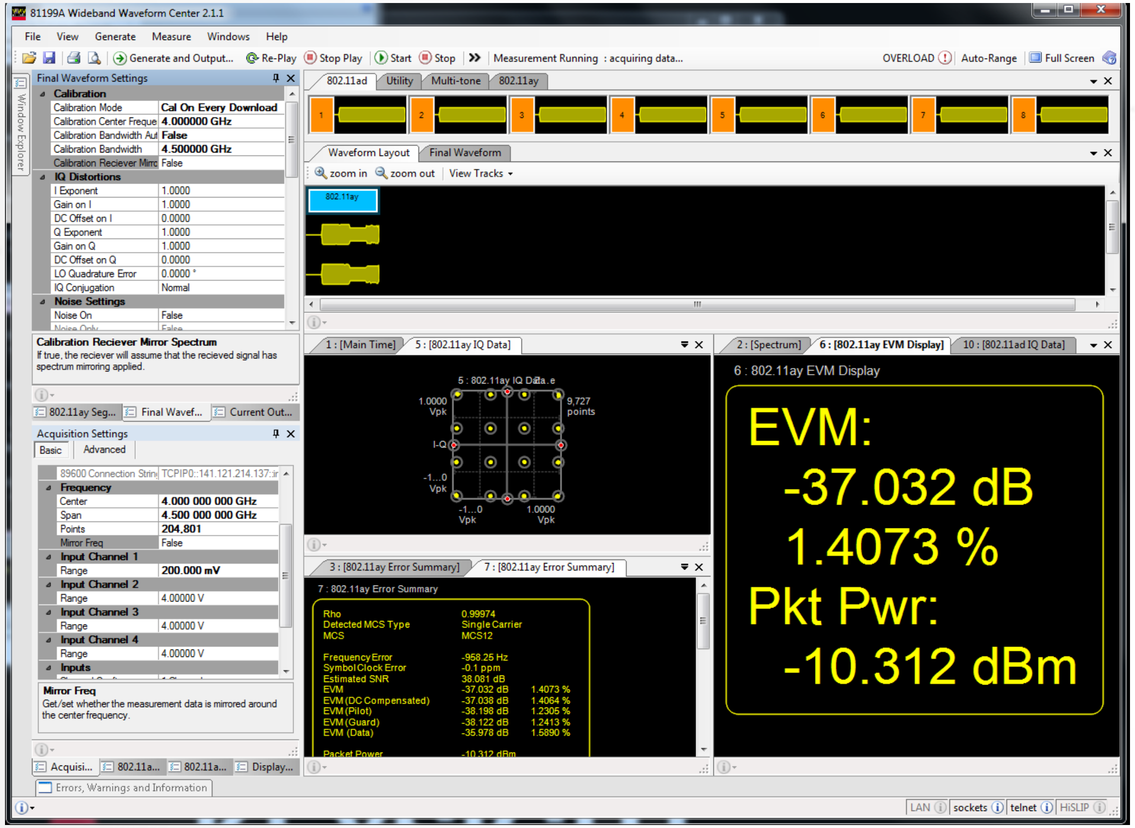
M8195A AWG AS A WIDEBAND 802.11AY IF SOURCE



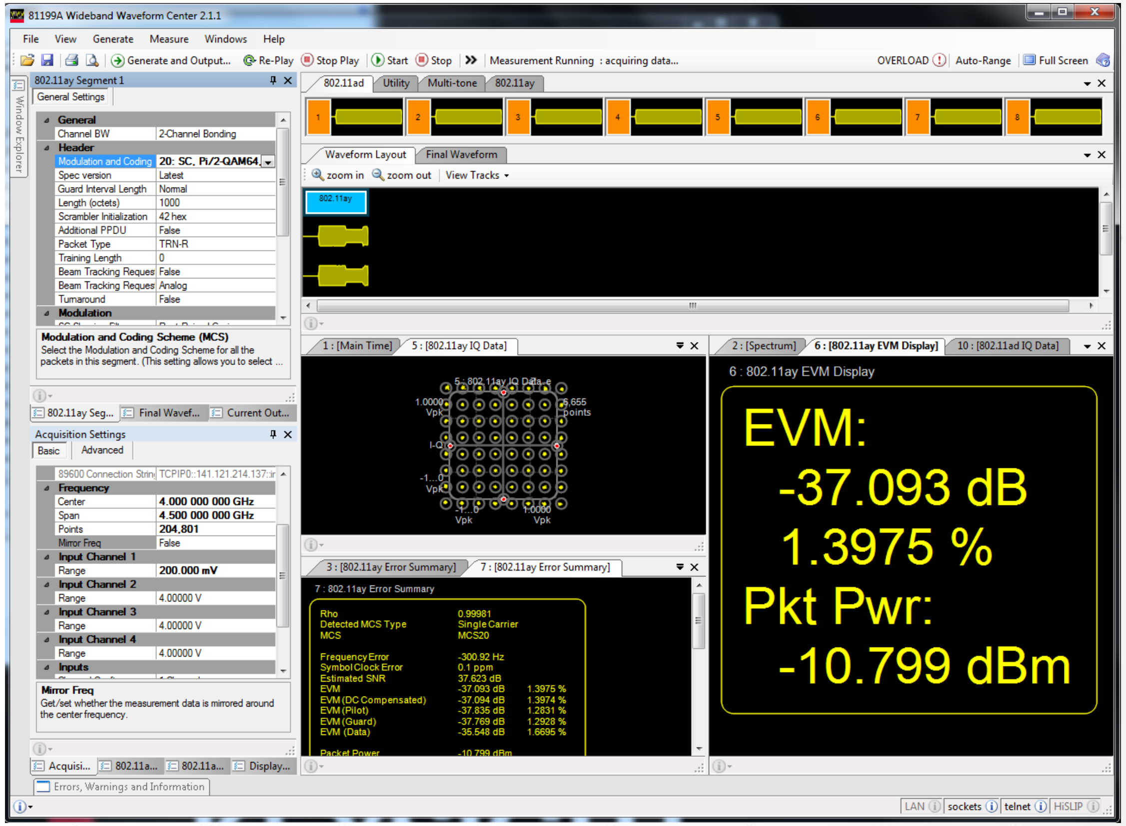
802.11ay MCS 12
-37.03 dB (1.41%) with WWC cal

802.11ay MCS 20
-37.09 dB (1.39%) with WWC cal

MCS 12, 4GHz IF M8195→ 33 GHz Scope, WWC Cal



MCS 20, 4GHz IF M8195→ 33 GHz Scope, WWC Cal



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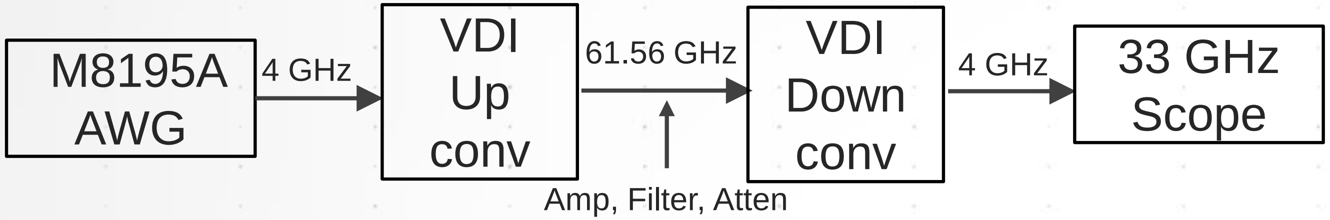
Wideband Millimeter-Wave R&D Testbed

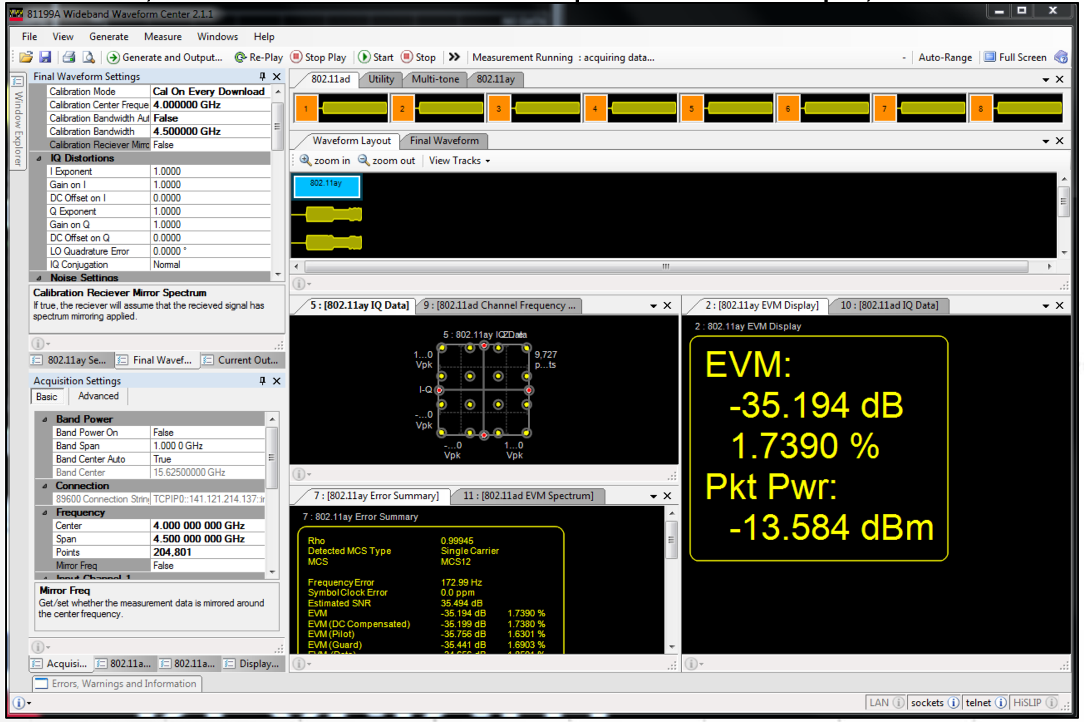
802.11AY mmWAVE PERFORMANCE, 4GHZ→61.56GHZ→4GHZ, WITH WWC CAL



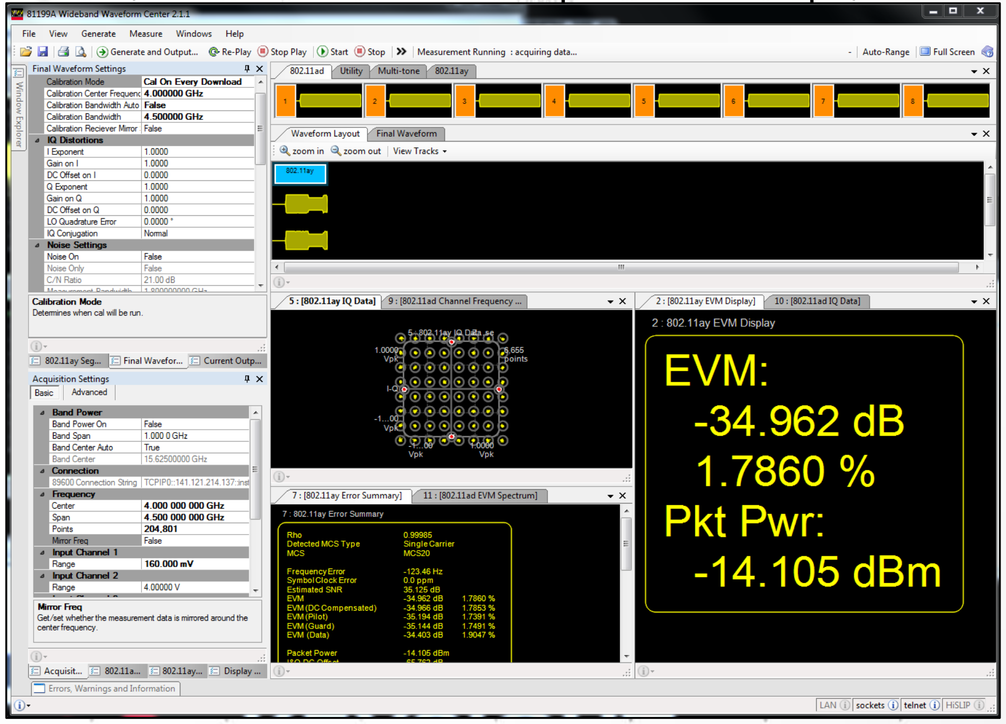
MCS 12
-35.19 dB (1.74%) with WWC cal

MCS 20
-34.96 dB (1.78%) with WWC cal

MCS 12, 4GHz IF M8195→ VDI Up/Down → Scope, WWC Cal



MCS 20, 4GHz IF M8195→ VDI Up/Down → Scope, WWC Cal



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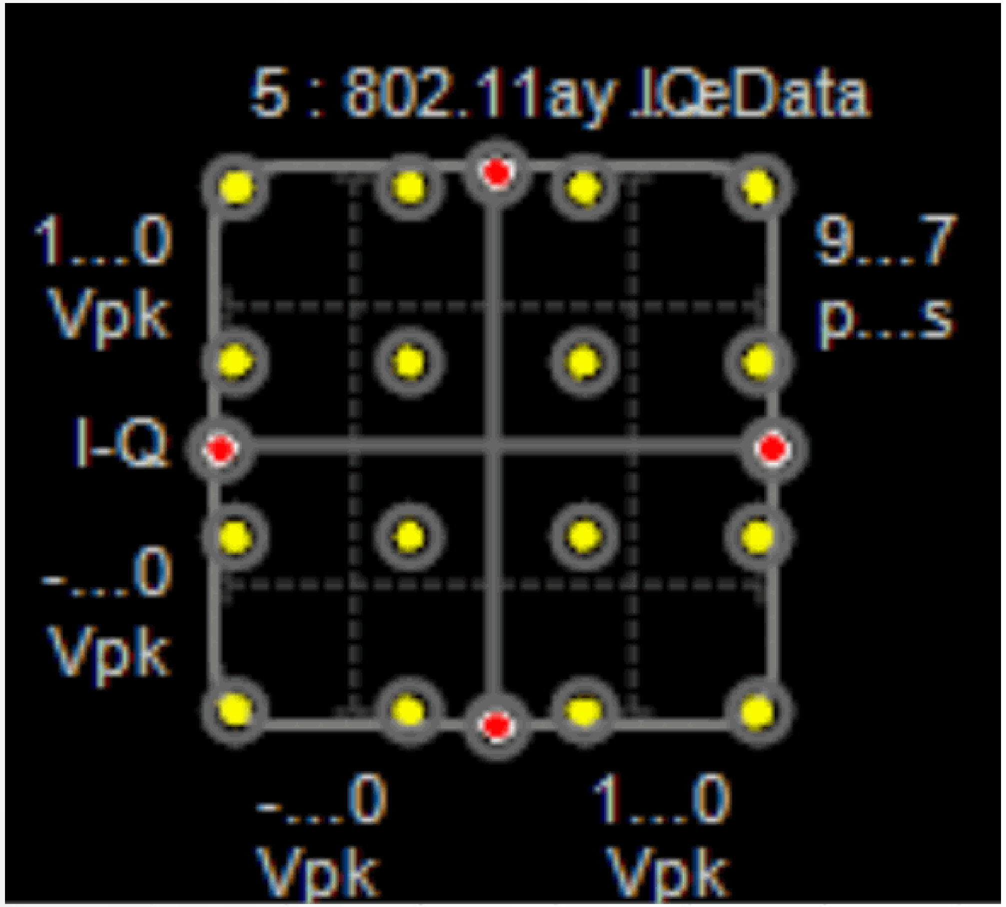
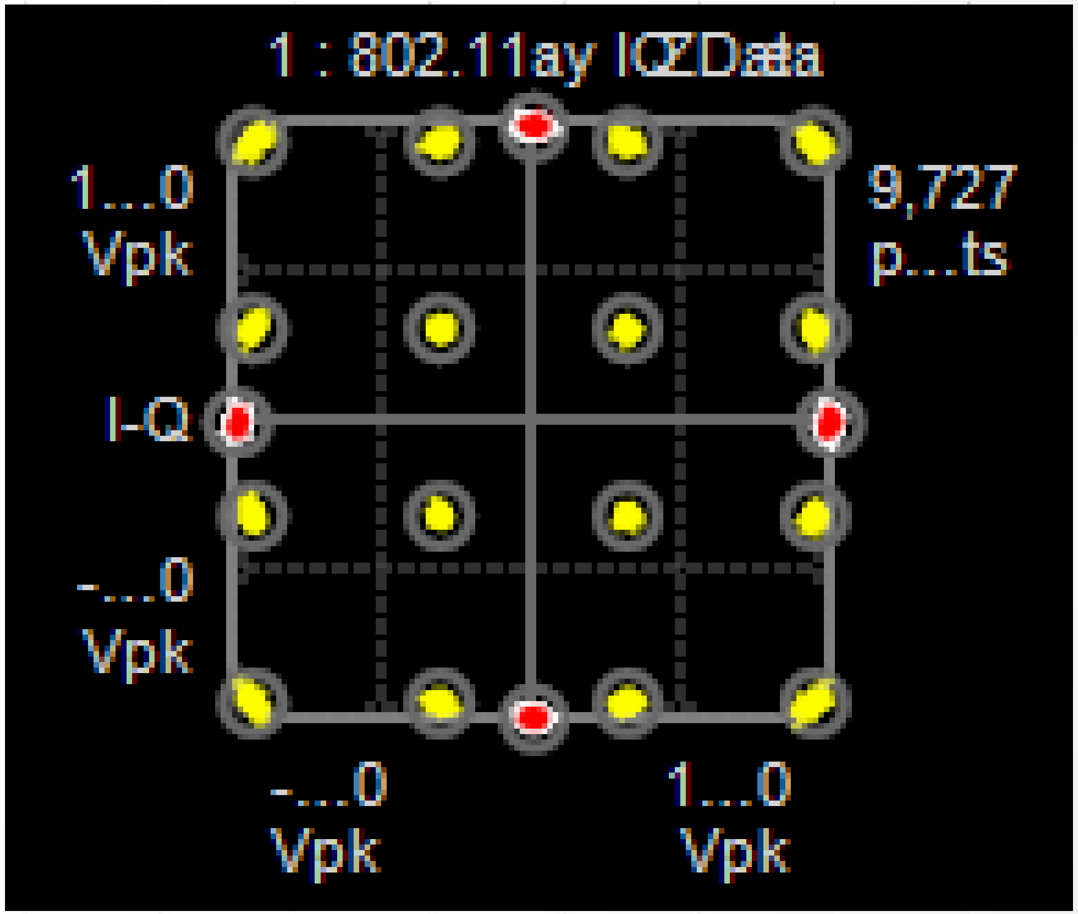
Wideband Millimeter-Wave R&D Testbed

LO PHASE NOISE IS IMPORTANT 4GHZ→61.56GHZ→4GHZ, WITH WWC CAL

PSGs for Upconverter and Downconverter LOs



MXGs for Upconverter and Downconverter LOs



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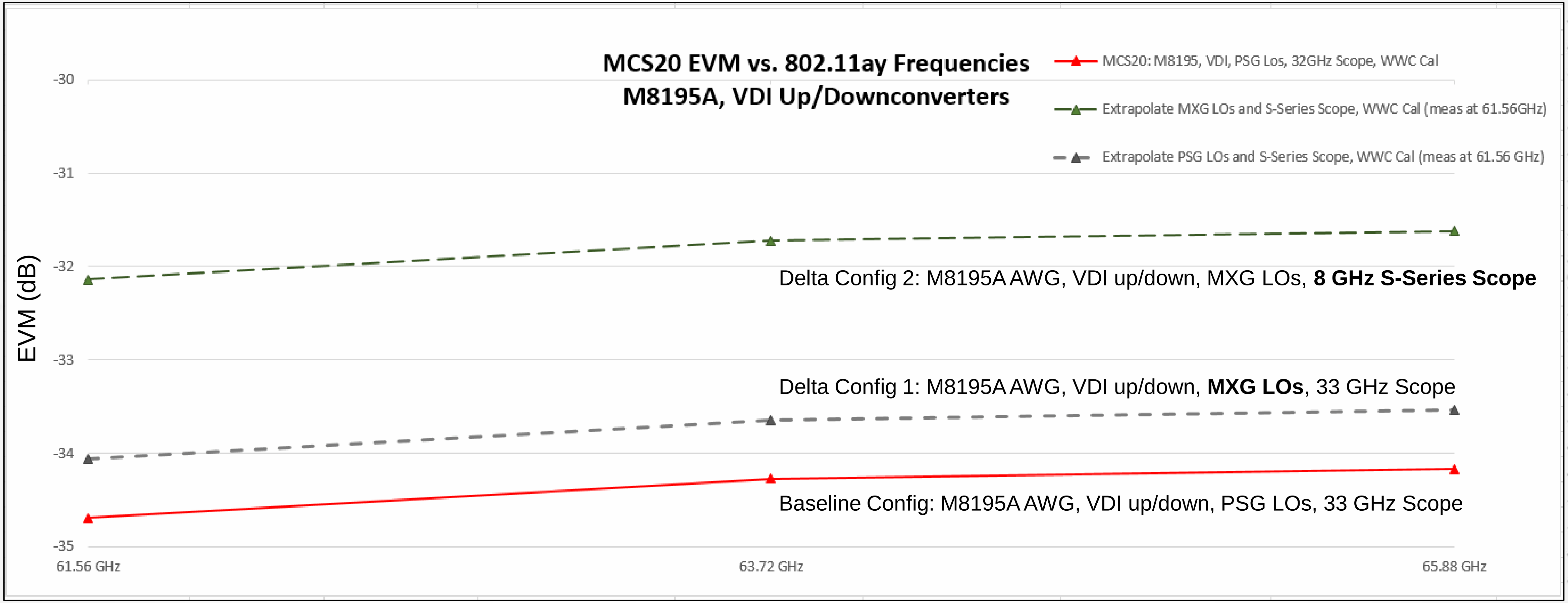
Wideband Millimeter-Wave R&D Testbed

802.11AY mmWAVE PERFORMANCE VS FREQUENCY, 4GHZ→mmWAVE→4GHZ, WWC CAL



Dashed lines are extrapolated from measurements made at 61.56 GHz

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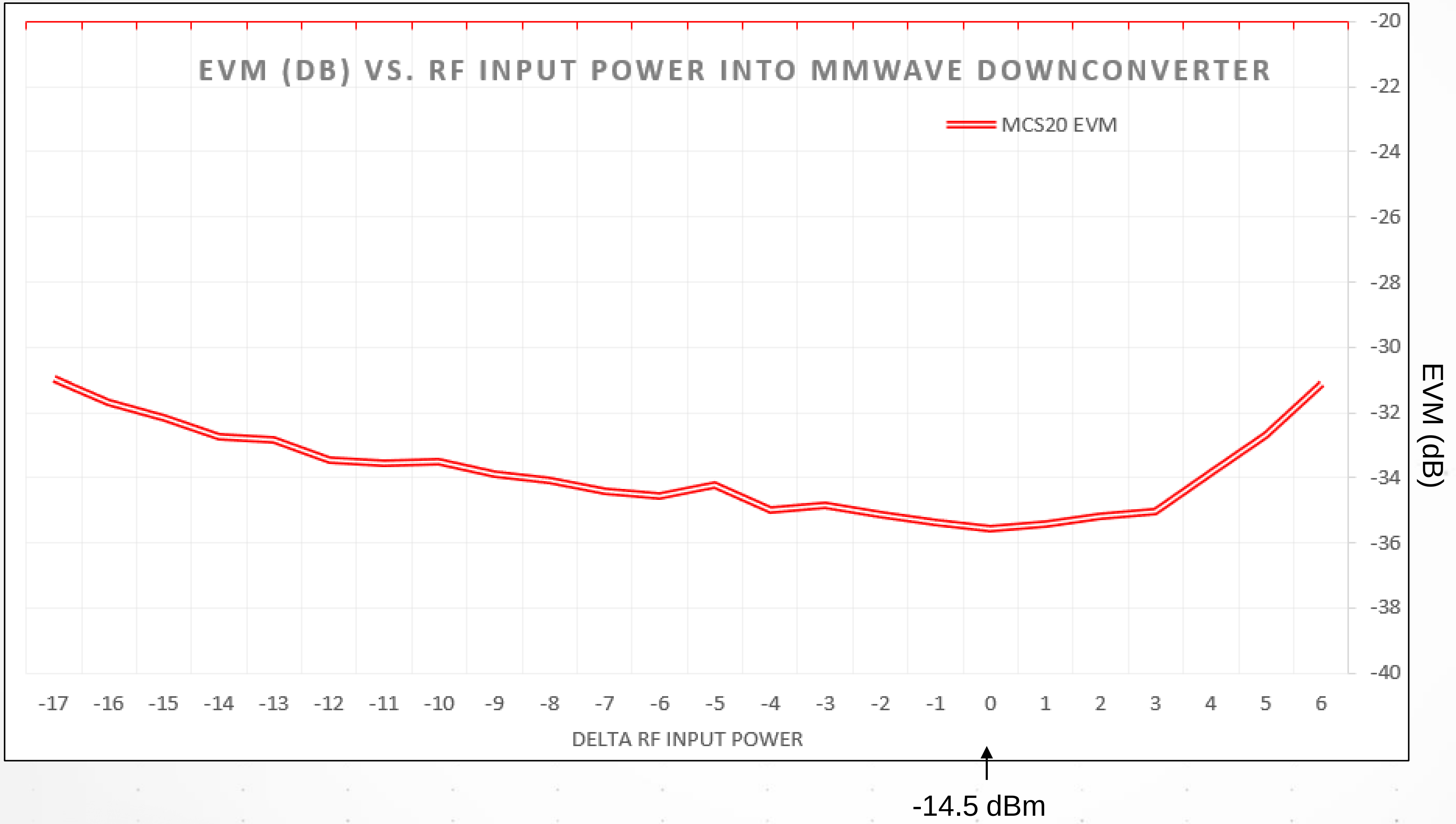
Wideband Millimeter-Wave R&D Testbed

802.11AY mmWAVE PERFORMANCE VS mmWAVE INPUT POWER, 61.56GHZ, WWC CAL



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New UXR for Wideband mmWave Measurements

ULTRA PERFORMANCE REAL-TIME 110 GHZ OSCILLOSCOPE

- Models from **<u>13 GHz to 110 GHz</u>** of real-time bandwidth
- 2 or 4 channels per scope - **<u>ALL</u>** with **<u>FULL</u>** rated bandwidth
- Best in class sample rates:
  - 13 – 33 GHz models: 128 GSa/s per channel
  - 40 – 110 GHz models: 256 GSa/s per channel
- 200 Mpts/ch standard – Upgradable to 2 Gpts per channel
- **High-Definition 10-bit Analog-to-Digital Converter (ADC)**
- Best signal integrity and vertical resolution
- **Hardware based acceleration ASICs**
- Optional self calibration module – enables you to perform a full factory quality calibration at your location

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The NEW mmWave HW Extension on the UXR

HOW IT WORKS

Buy one of the 1 mm input UXR scope models

25, 40, 59, **70,** 80 or 100 GHz **(new mmWave 'AP' Models)**

Then, buy either the 5 GHz or 10 GHz mmWave extension option

- This gives flexible banded support all the way from DC to 110 GHz

Add the VSA software for powerful RF and Vector analysis

Instead of paying over $1M for a 110 GHz scope, pay for only the bandwidth needed and look at only the frequency bands needed

Plus, a fully capable scope to use to at the licensed BW

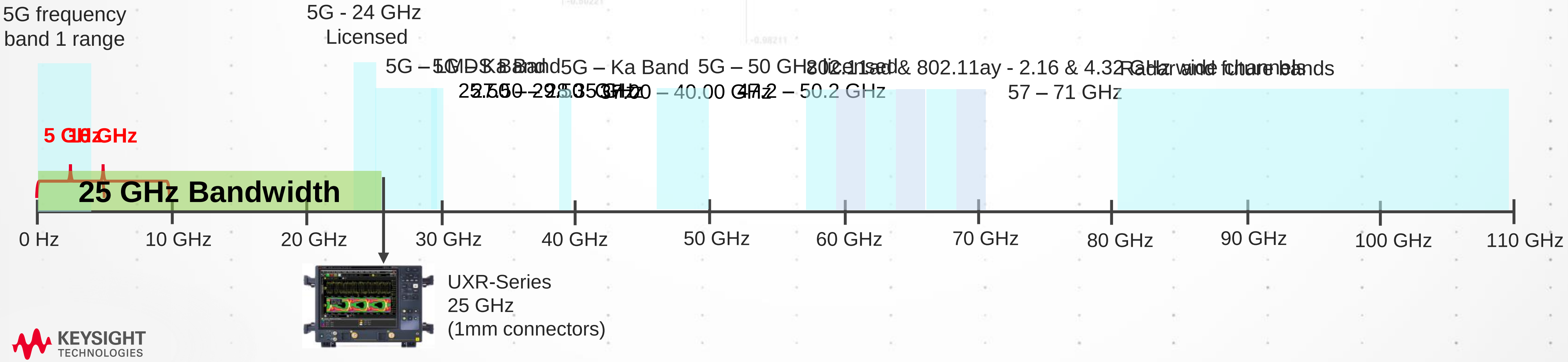
i.e. $\leq$ 25 GHz for $300K

Typical configured price: 25 GHz scope, 5GHz mmWave extension (any 5 GHz band to 110 GHz), 2GSa memory option (~8ms capture time before DDC), VSA SW … ~$450K

UXR-Series mmWave extension option

ECONOMICAL RF MEASUREMENTS AND ANALYSIS

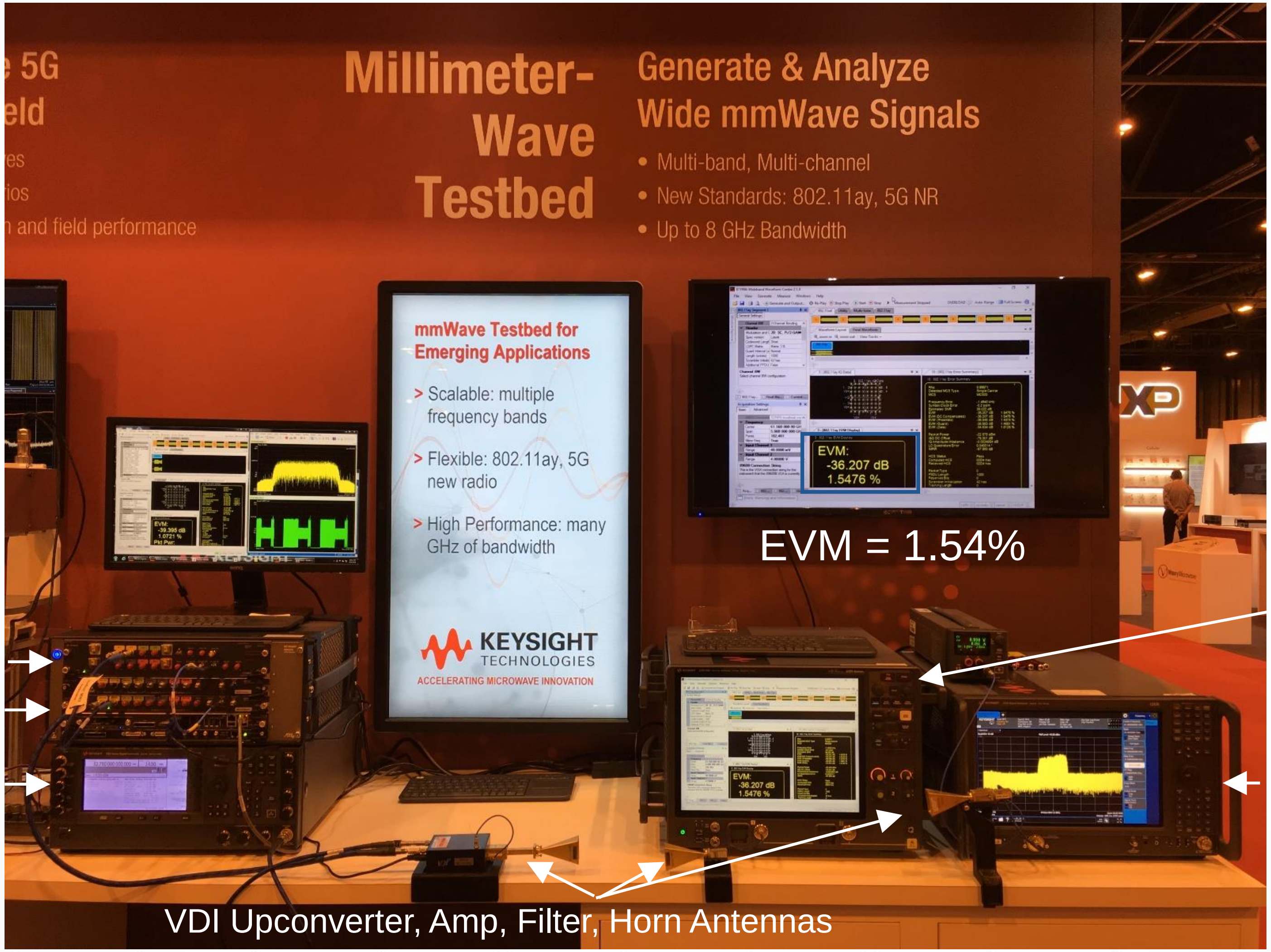
- Typical: Purchase a 25 GHz ‘AP’ model UXR-Series oscilloscope (or any 1 mm UXR model)
  - Receive full real-time scope functionality and bandwidth to the purchased bandwidth
- Add the flexible mmWave extension option and VSA software
  - Analyze 5 GHz or 10 GHz wide Bands / Channels from DC all the way up to 110 GHz
  - 802.11 ad/ay (57 GHz to 71 GHz)
  - 5G (Existing bands <6 GHz & Future bands >24 GHz)
- Sliding bandwidth windows allows you to selectively look at only the bands for signals you want



New 110 GHz UXR for Ultra-Wideband Measurements

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

4.32 GHz 802.11ay Example at European Microwave 2018



***New* M8131A Digitizer**

M8195A AWG

PSG LO

***New* 110 GHz UXR**

110 GHz N9041B UXA

Measurement Performed after WWC Cal

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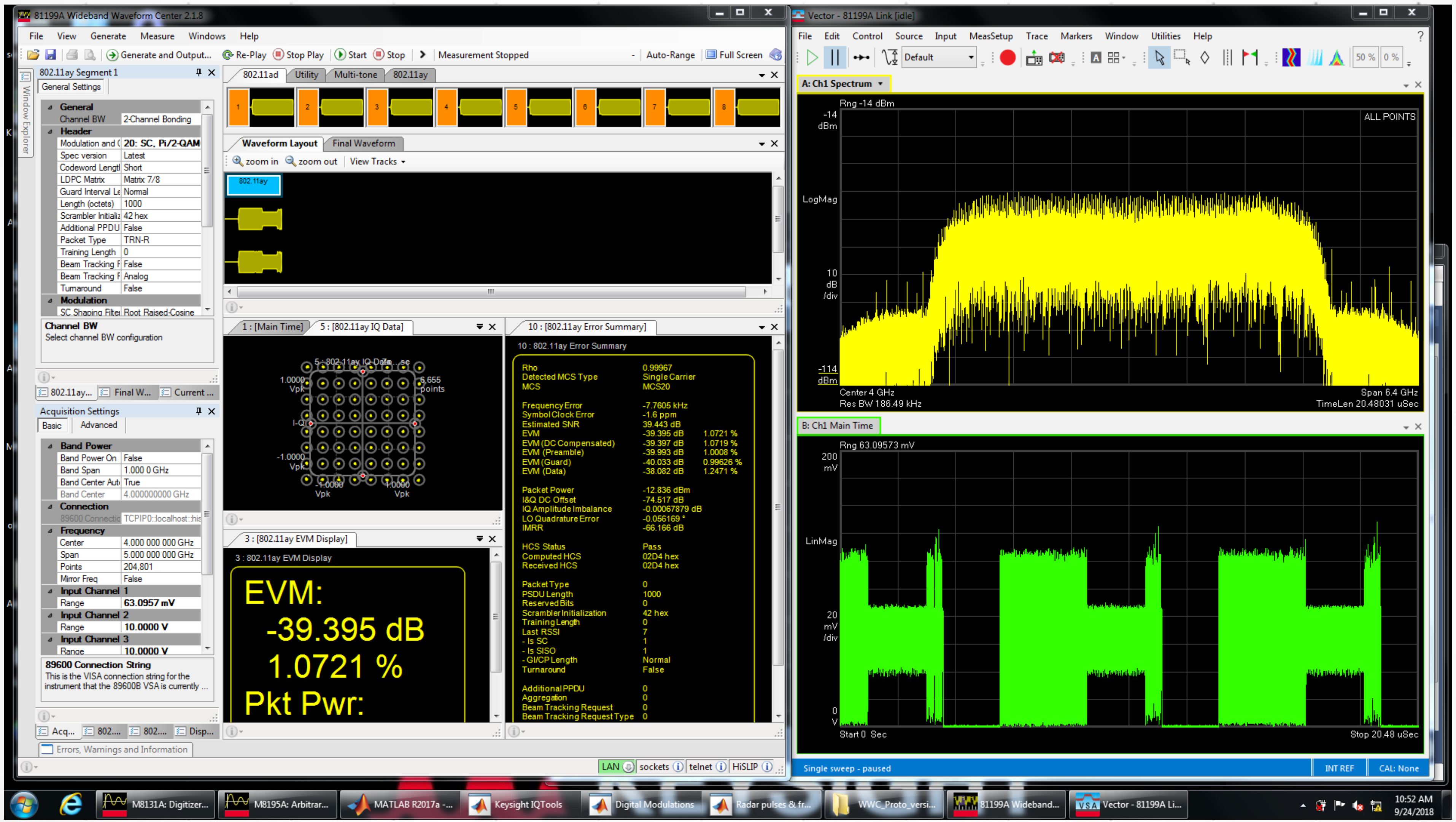
Digitization of IF Before Upconversion to mmWave

M8195A AWG OUTPUT MEASURED WITH M8131A DIGITIZER, 4GHZ IF, 4.32GHZ BW



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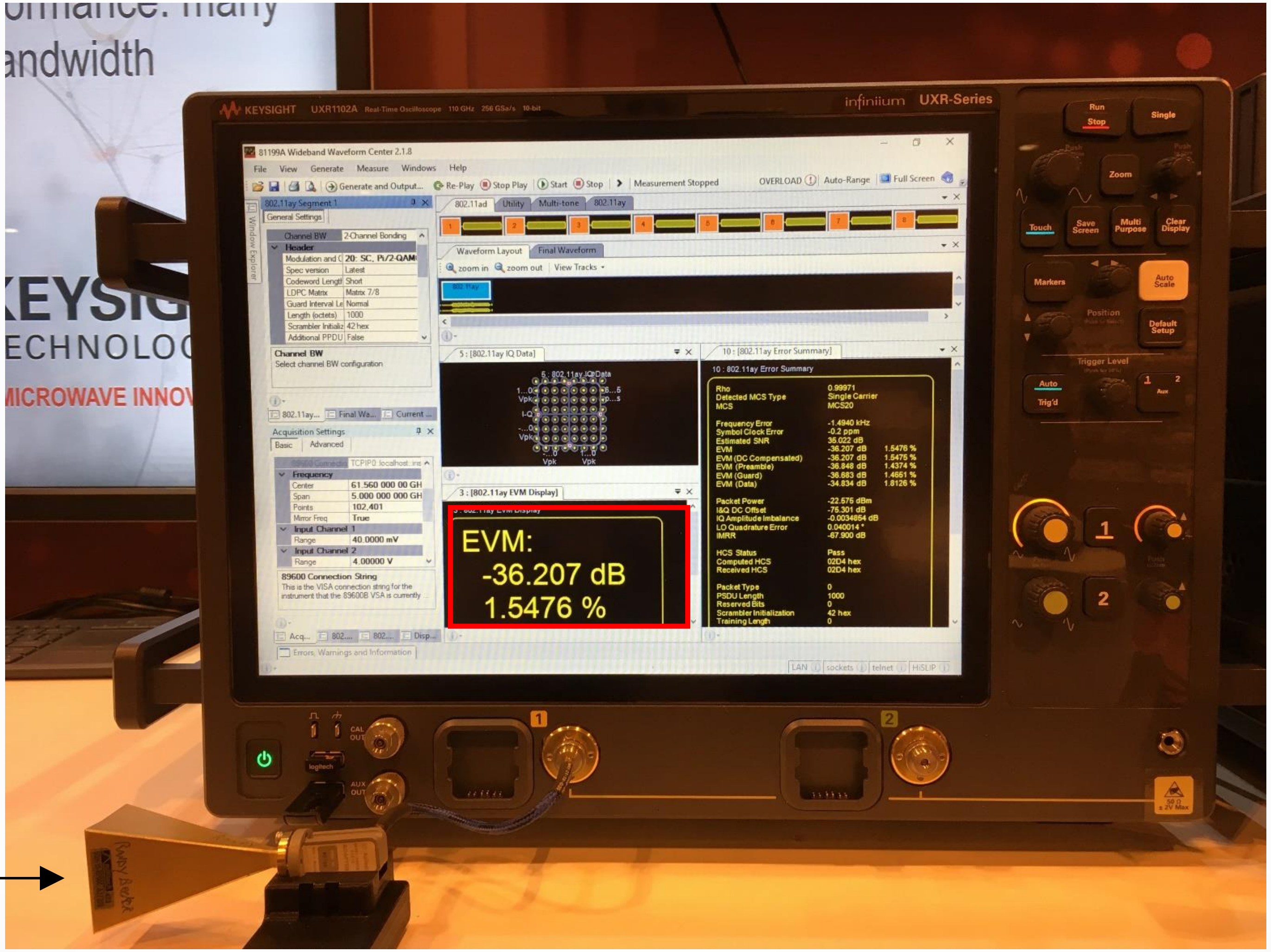
Measurement Performed after WWC Cal

Direct Digitization and Demod of Wideband mmWave Signal

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

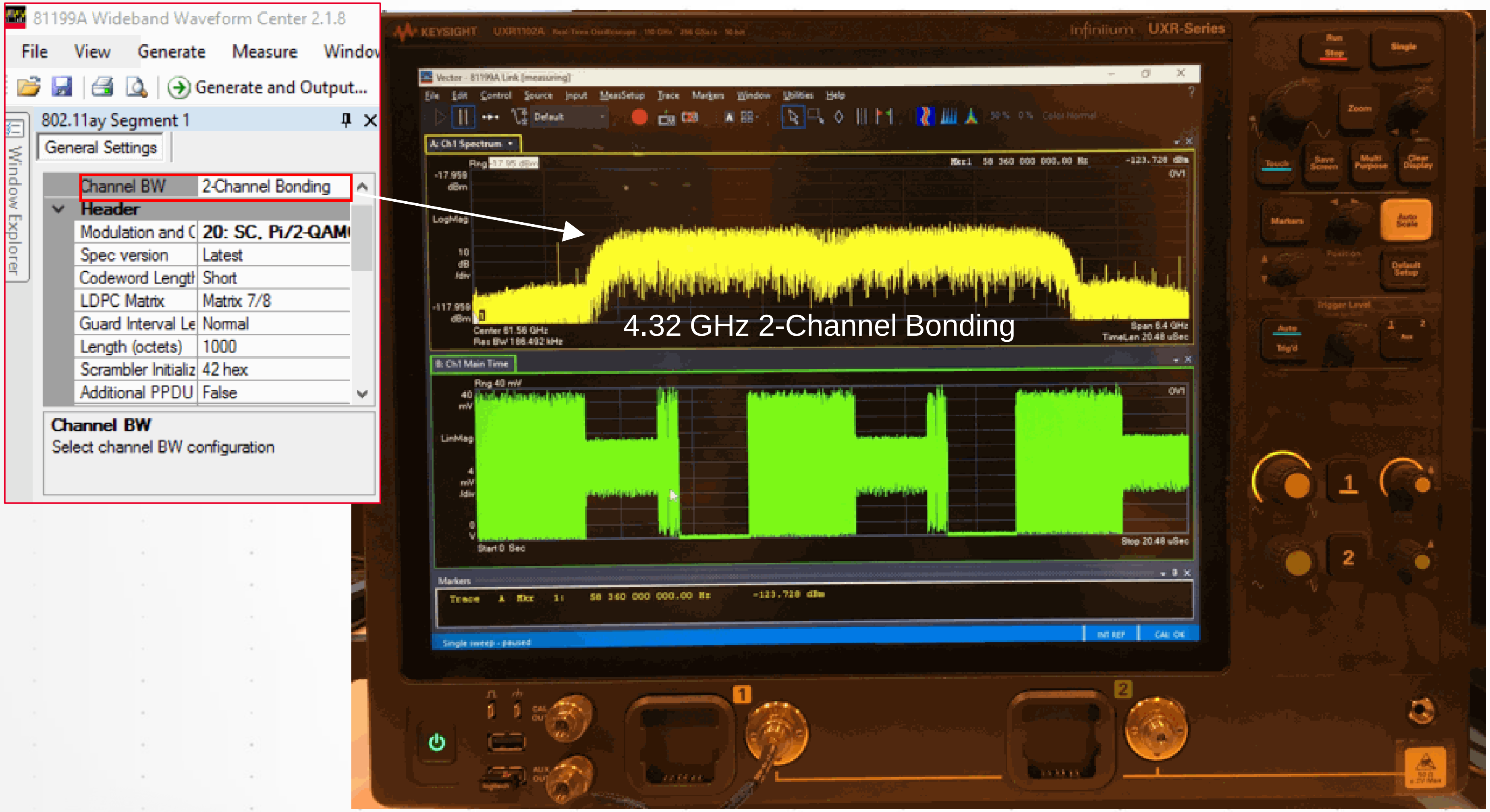


Signal Received into Horn Antenna. Input into Ch1 of UXR

© Keysight Technologies 2018 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



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© Keysight Technologies 2018 Measurement Performed after WWC Cal

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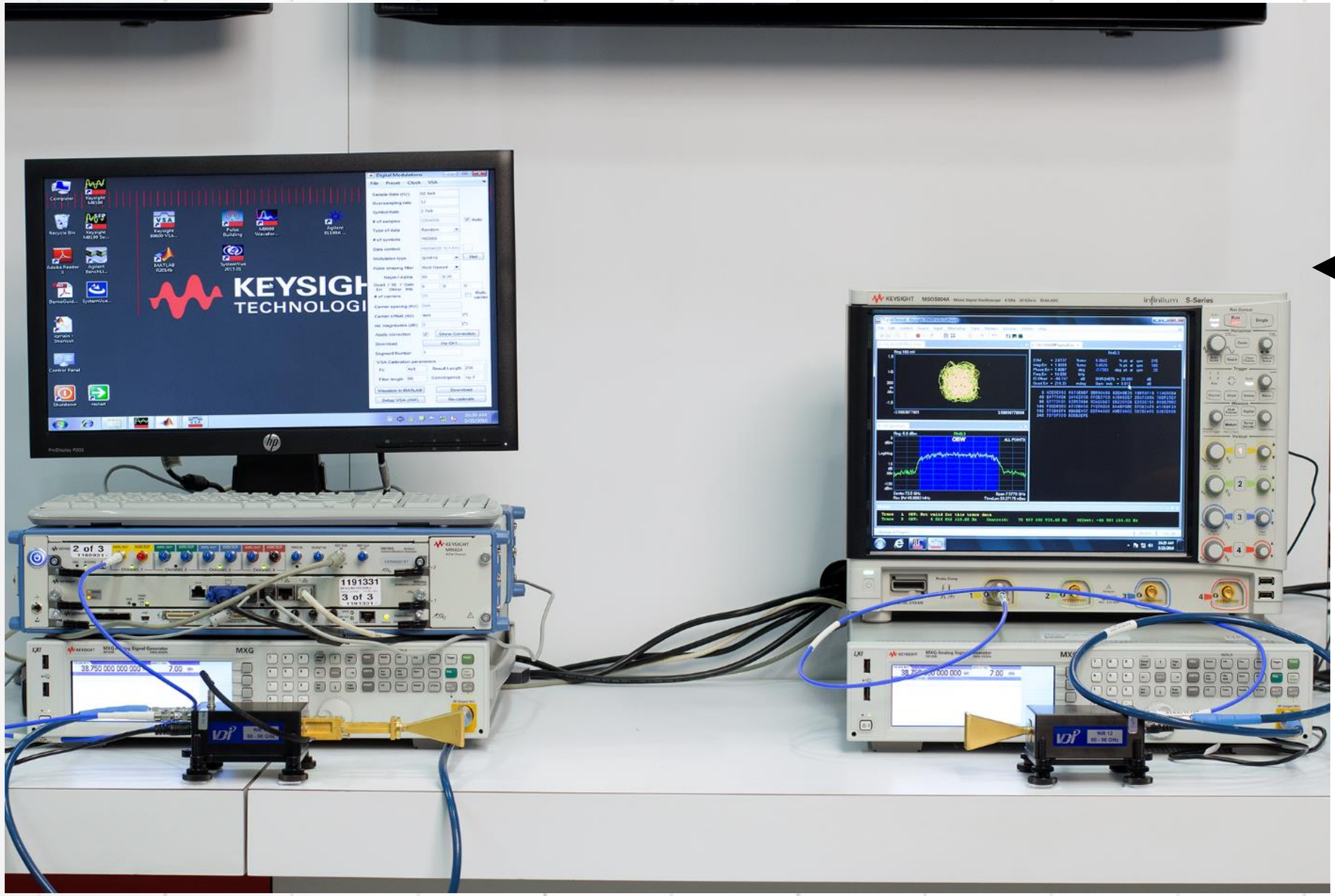
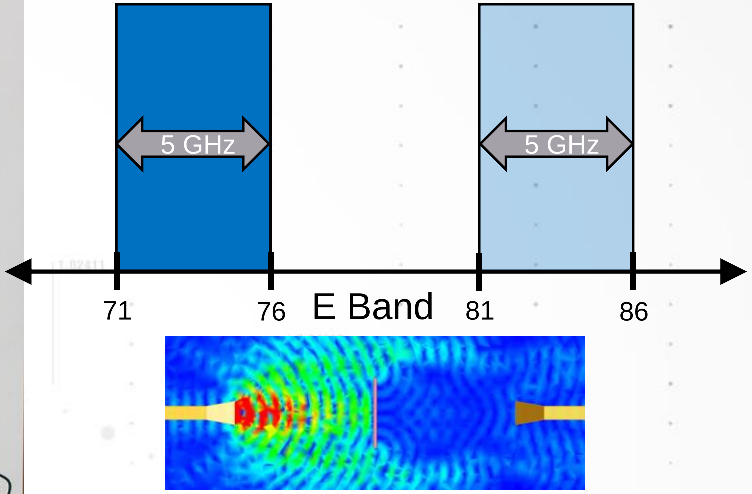
E-Band Demo Setup, 71-76 GHz with 5 GHz Bandwidth

PREVIOUS IMS DEMO SETUP





Used VDI Compact E-Band Upconverter and Downconverter, E-Band Amp,
71-76 GHz Bandpass Filter, and Horn Antennas. OTA Demo Previously shown at IMS

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New UXR for 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, 81-76 GHz Bandpass Filter for 83.5 GHz Measurements

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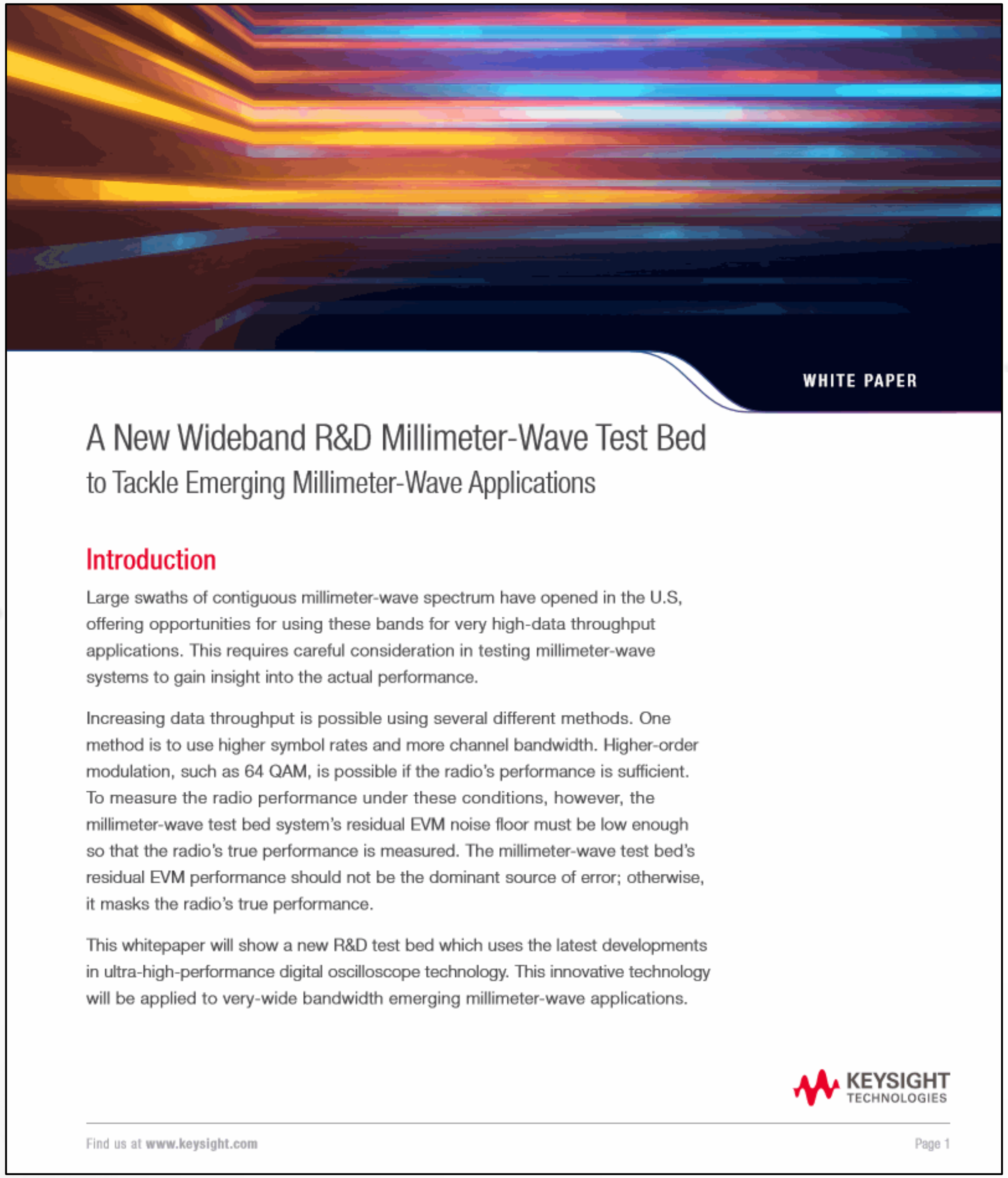
Additional Resources: Whitepaper

http://literature.cdn.keysight.com/litweb/pdf/5992-3721EN.pdf


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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Summary

- New wideband millimeter-wave R&D testbeds offers flexibility and scalability
- Satellite and 5G NR MIMO applications were shown for 28 GHz
- 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
- New UXR brings new breakthrough capability for wideband signal analysis

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Thank You!

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