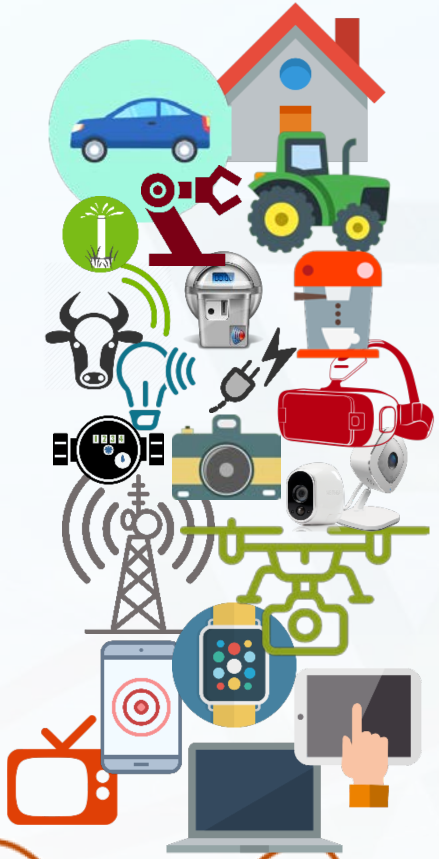
Test Challenges and Solutions for Testing Wi-Fi 6E, UWB and 5G NR IF Devices in the 3-12 GHz Range

Dr. Jeorge S. Hurtarte
Teradyne

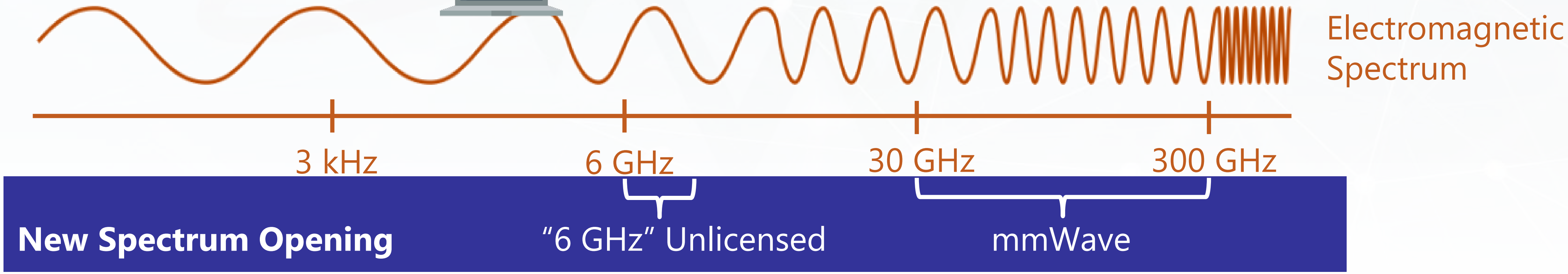
TERADYNE

PROBE TODAY, FOR TOMORROW



Spectrum is Getting Crowded!

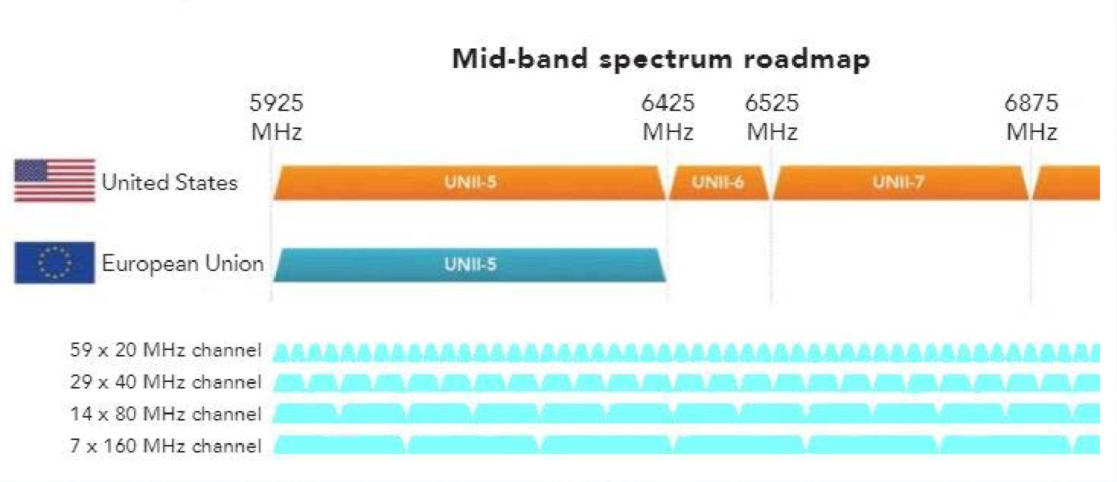
But new Spectrum is being allocated!



Unlicensed Spectrum Expansion Beyond 6GHz

- ***The total amount of internet traffic from 2017-2022 will be higher than in the previous 32 years of the internet. Wi-Fi will be the transport mechanism for more than half of that traffic.*** – Cisco Meraki Whitepaper

- **WLAN and cellular both take advantage of "unlicensed" spectrum for either their core usage or as additional bandwidth.**



- **Device performance will need to be equivalent (if not better) when operating above 6GHz.**
  - Pushing EVM & ACLR performance
  - Roadmap to 4k QAM for WLAN
- **Expect drop-in functionality to existing products and test solutions.**

Global snapshot of allocated/targeted 5G spectrum

Source: https://www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf (September 2020)

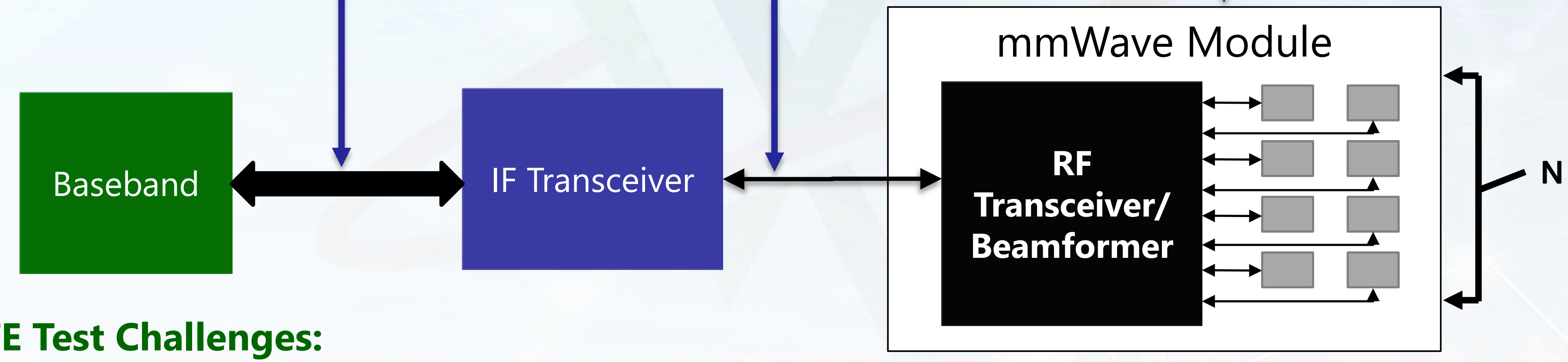
5G mmWave is Changing Traditional Cell Phone Architecture and Test Needs

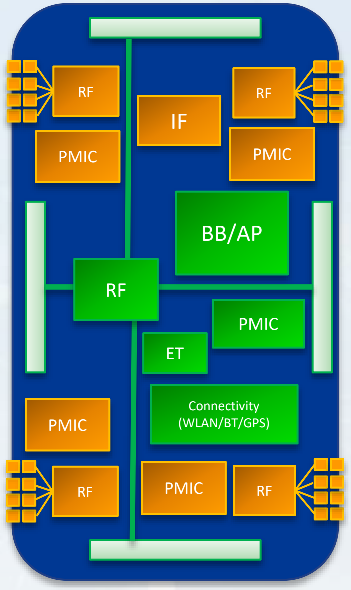
Interface Characteristics:

DigRF/Analog IQ
Up to 16Gbps

5G IF
6-15 GHz (non-standard)
BW: 100MHz/400MHz/800MHz

5G RF mmWave
(24.25-27.5), (31.8-33.4), (37-40.5), (40.5-42.5),
(42.5-43.5) (47.2-48.2) GHz
BW: 100MHz/400MHz/800MHz





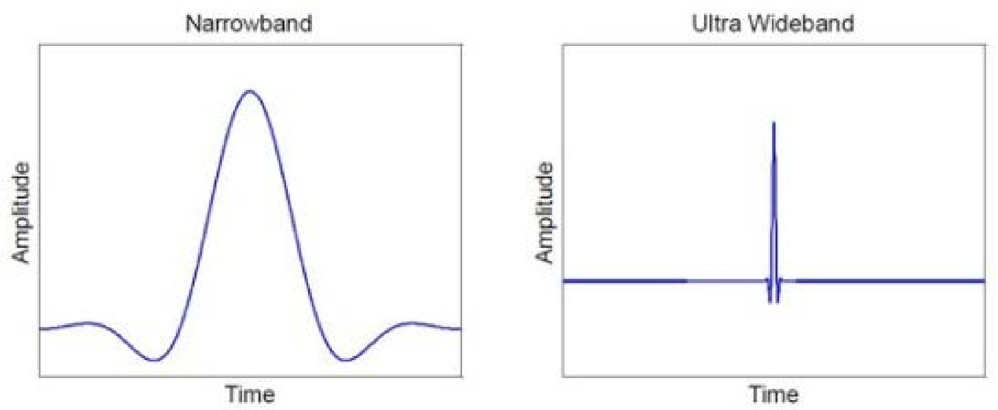
New mmWave Semiconductor Content

ATE Test Challenges:

- New IF and RF frequencies > 6GHz, into mmWave
- Use of antenna arrays require **higher port count** at mmWave frequencies
- Signal beamforming require **new and innovative test techniques**
- Exponential volume growth drives **site count and throughput improvements** at record pace

High Level UWB Specs (802.15.4z)

Parameter	Value
Center Frequency Range	6489.6 – 9945.6 MHz
Channel Bandwidth	500 MHz (typical) up to >1 GHz
Transmit Output Power	< -41.3 dBm / MHz
Data Rates	110 kpbs, 425 kbps, 850 kpbs, 1.7 Mbps, 6.81 Mbps, 27.24 Mbps
Ranging Support	Yes
Range	10 m – 100 m
Positional Accuracy	~10 cm



Channel number	Center frequency (MHz)
0	6489.6
1	6988.8
2	7987.2
3	8486.4
4	6681.6
5	7334.4
6	7987.2
7	8640.0
8	9292.8
9	9945.6

Wi-Fi 6E

Testing

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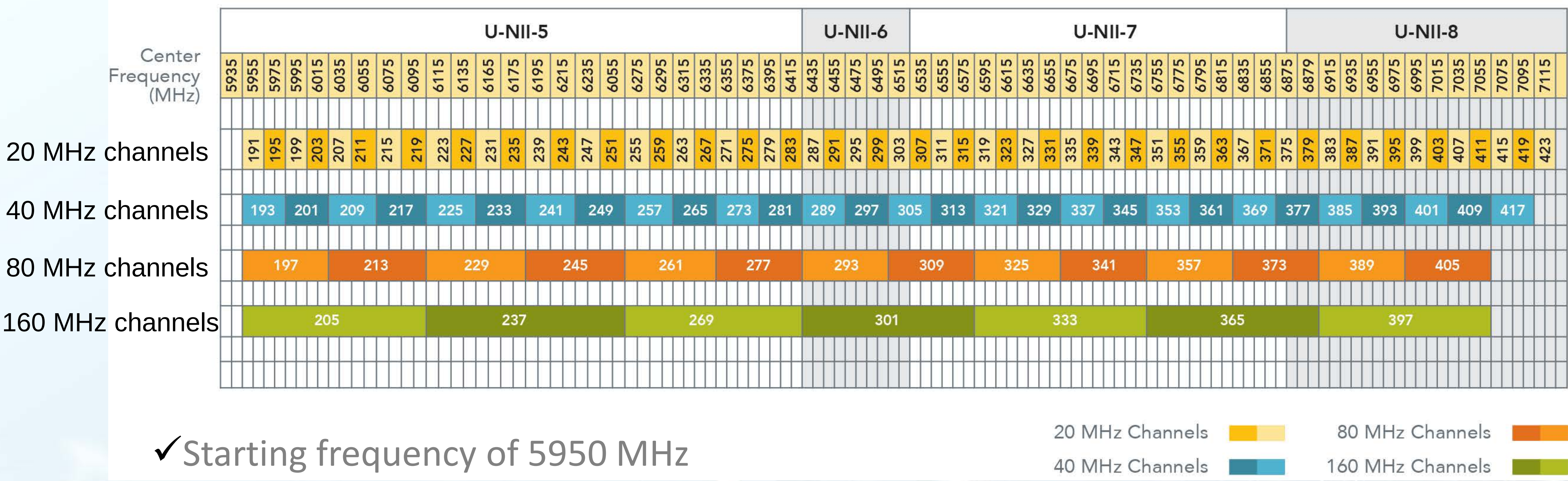
Wi-Fi (WLAN) Standard Evolution

IEEE: 802.11b → 80211g → 802.11n → 802.11ac → 802.11ax → 802.11be

Wi-Fi Alliance: Wi-Fi → Wi-Fi 4 → Wi-Fi 5 → Wi-Fi 6/6E → Wi-Fi 7 (?)

Rel. Year	1999	2007	2009	2013	2020	2023(?)
Freq. Band	2.4 GHz	2.4 GHz	2.4 + 5 GHz	5 GHz	2.4 + 5 + 6 GHz (6E)	2.4 + 5 + 6 GHz
Bandwidth	20 MHz	20 MHz	40 MHz	80 MHz, 160 MHz	80 MHz, 160 MHz	240 MHz, 320 MHz

Channelization



- ✓Starting frequency of 5950 MHz
- ✓20 MHz of Guard band for U-NII 5
- ✓Channels can cross U-NII boundaries

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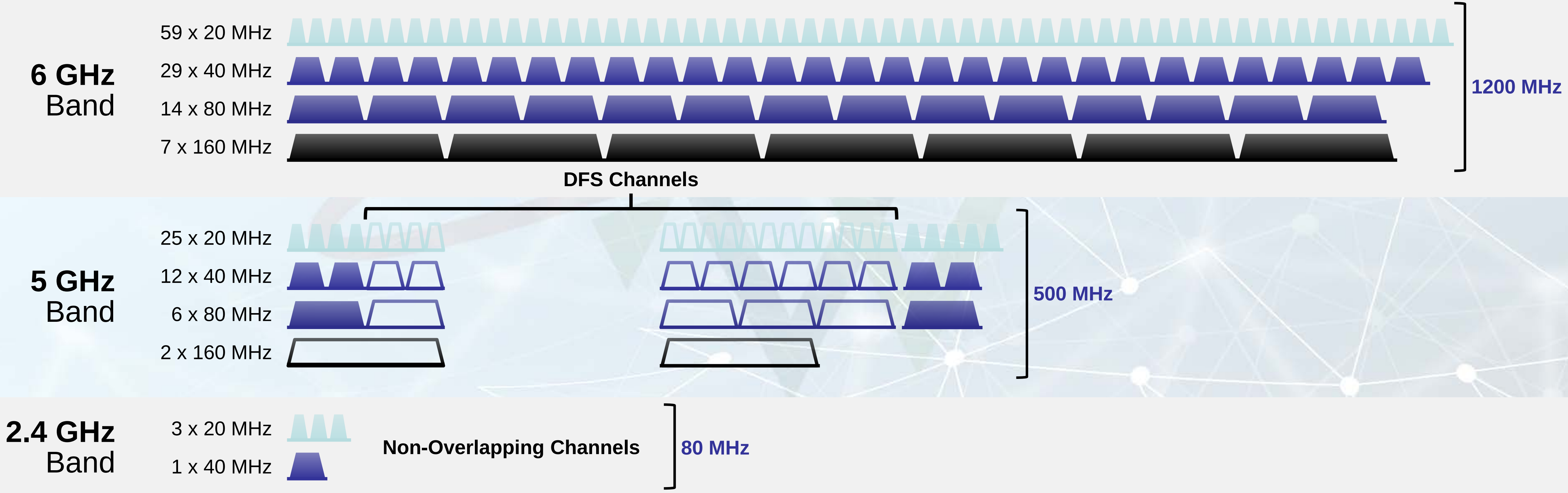
Range

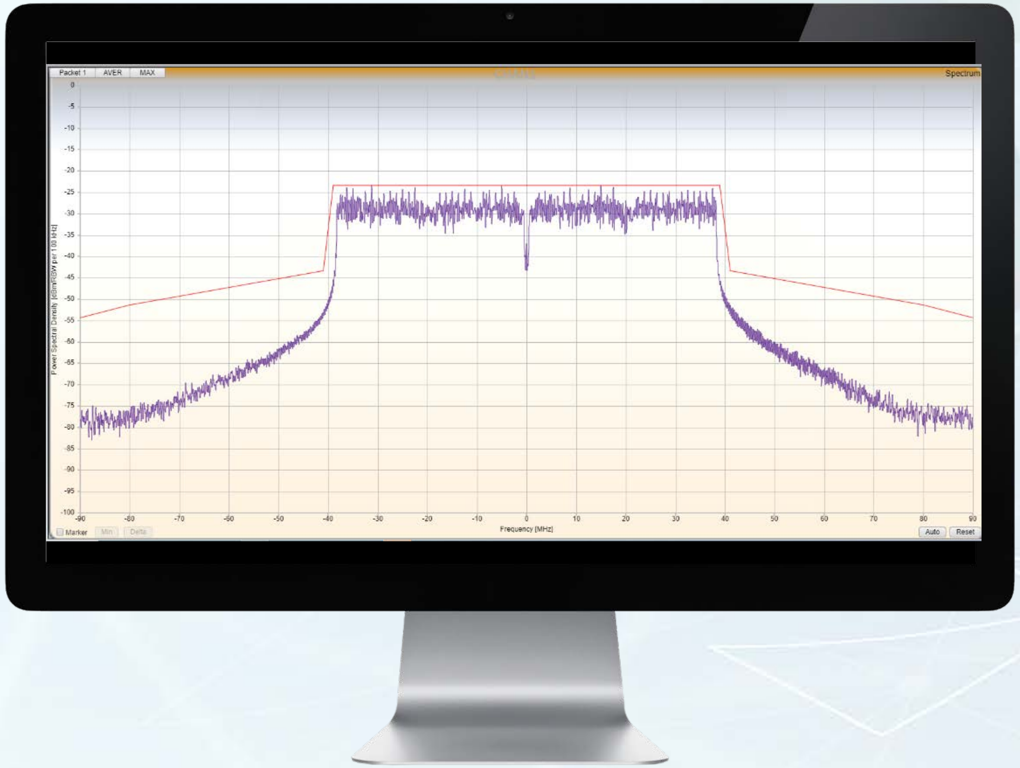
- ✓ **Goal**: Devices need to deliver **consistent performance** across the **full frequency** range (1200 MHz) as well as dual-band / tri-band devices

Tri-Band 6G + 5G + 2.4G



Performance

✓ **Goal**: Optimize performance for wider channels: **80 MHz**, **160 MHz** and future **320 MHz** channels



HE-SU **80 MHz**

HE-SU **160 MHz**

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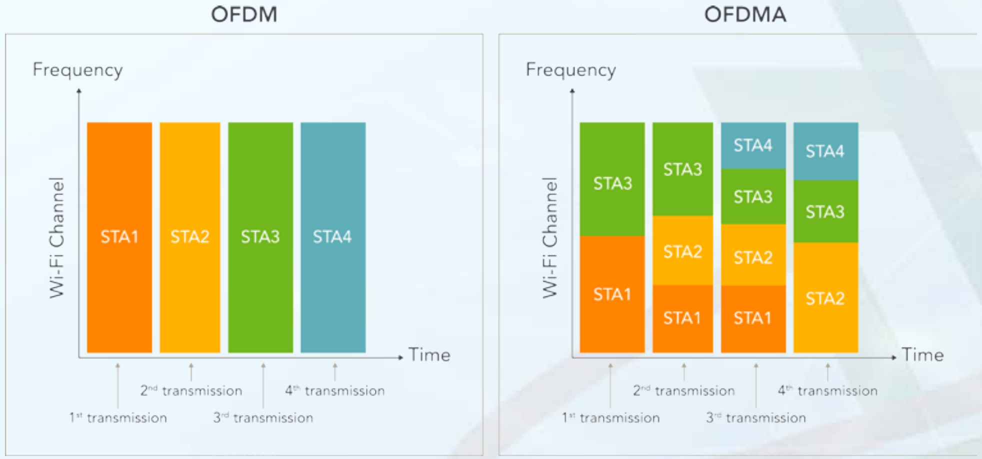
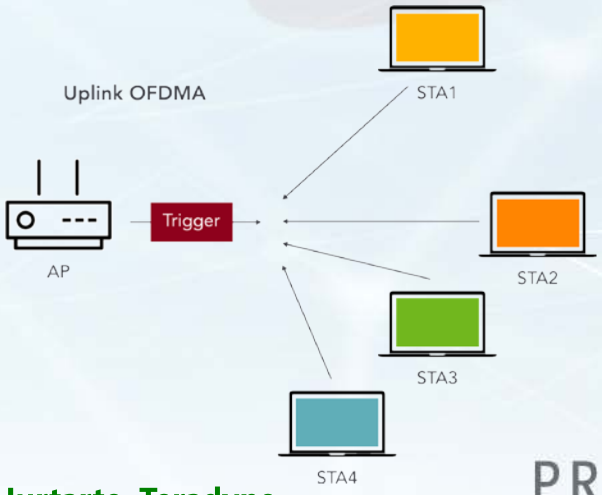
Efficiency

✓ **Goal**: Maximize usage of OFDMA for **network efficiency** and **latency improvements**





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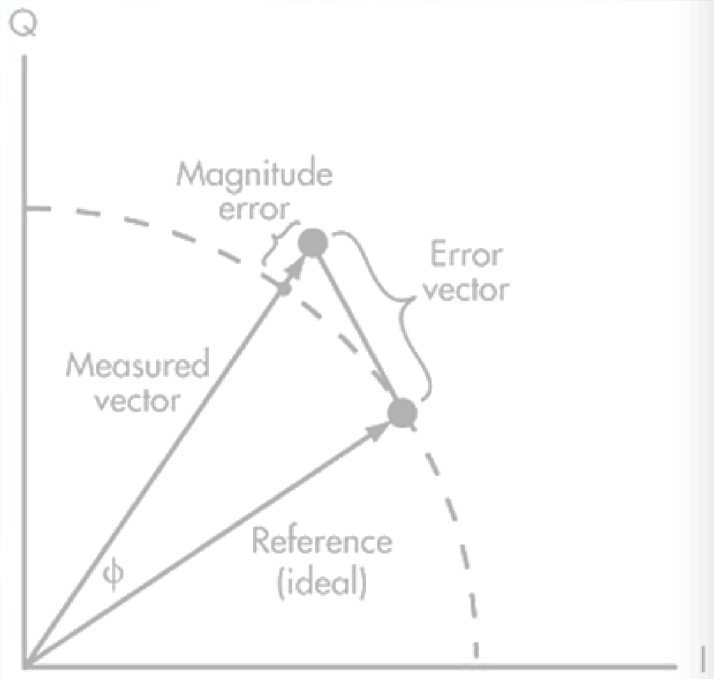
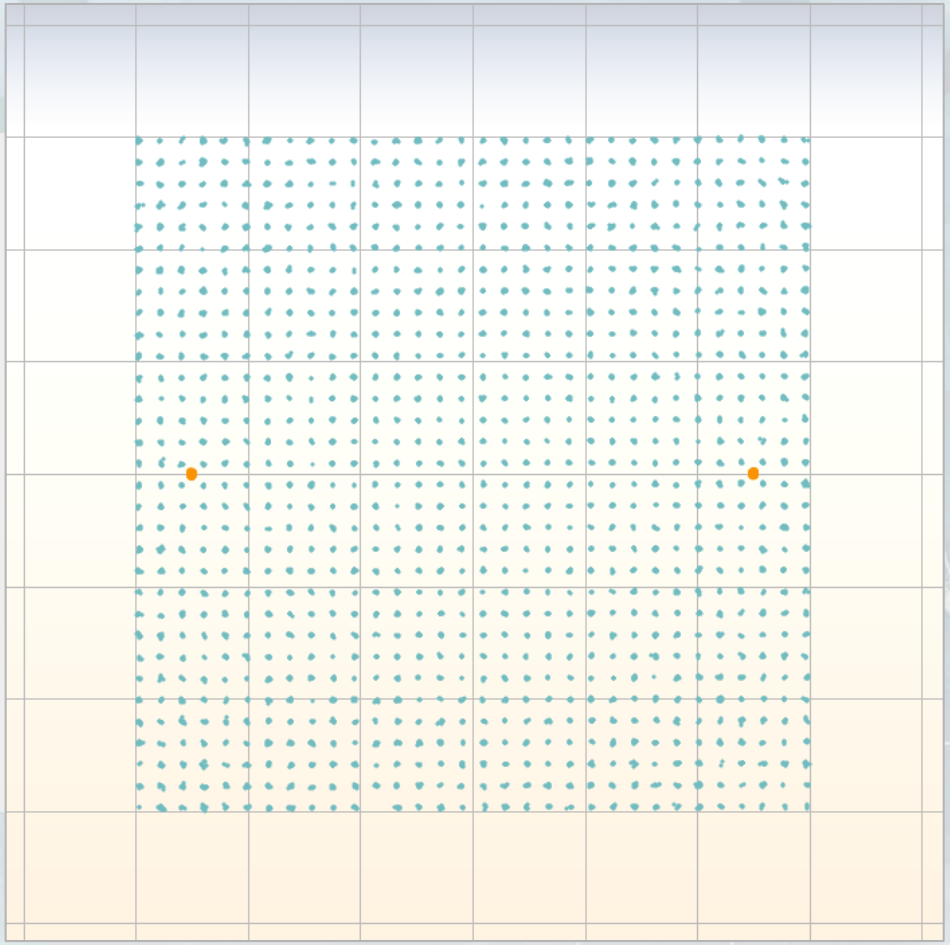
Speed

✓**Goal**: Ensure the highest level of **modulation accuracy** for **peak data rates**



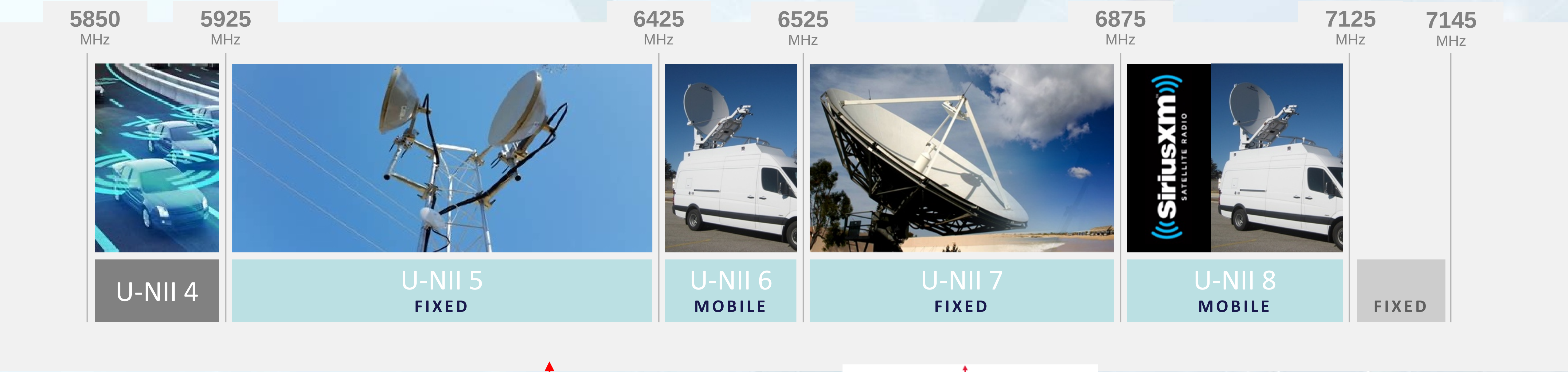


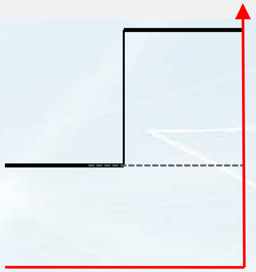
1024QAM
802.11ax

EVM requirement
-35dB

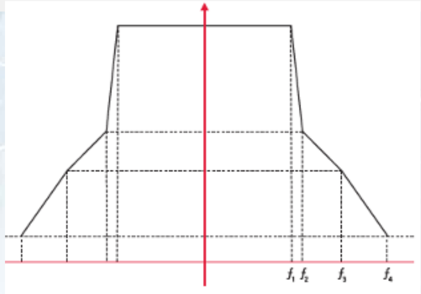
Emissions

✓ **Goal**: Protection of incumbents **in band** and **out of band** while maximizing channel usage and power levels





Out of Band



In Band

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IQxel-MW7G

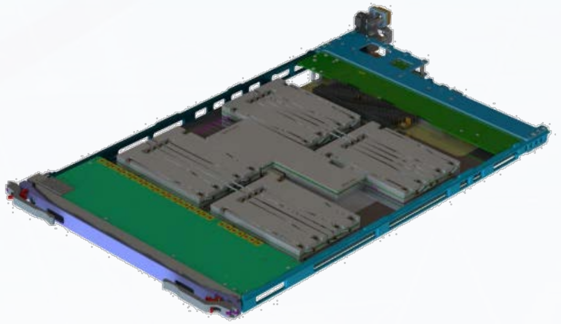
The *IQxel-MW 7G* is LitePoint's test solution for advanced Wi-Fi 6 and 6E testing on 2.4GHz, 5 GHz and 6 GHz frequency bands

- Continuous frequency range from 400 MHz to 7300 MHz
- 80+80, 160MHz and dual-band concurrent on a single port
- Exceeds stringent 802.11ax EVM requirements over entire frequency range
- Packet detection and timing capabilities for advanced Wi-Fi 6 testing
- True MIMO testing support
- Support for all Wi-Fi standards: WiFi 6/6E (11ax), WiFi 5 (11ac) and 802.11 a/b/g/n/ah/af
- Support for major connectivity technologies: BT, Zigbee, Z-Wave, Sigfox DECT and LTE

ATE UltraWaveMX8 Instrument

Key Features	Benefit
Integrated single slot instrument upgrade to UltaWave24	✓ Lowest cost of ownership
Bi-directional 1:2 muxed connections	✓ Simplified DIB designs
Continuous frequency coverage	✓ Single tester resource across pins
Native IG-XL programming & debug	✓ Simple instrument use-model
Integrated **power detectors** and **NIST-traceable calibration**	✓ Industry-leading specifications guaranteed
Zero tester re-configuration required	✓ 100% compatible with legacy applications
Integrated **cross-correlation** circuitry	✓ Enhanced capability for characterization level performance

UltraWaveMX8



- Upgrade to any UltraWave24 system
- 50MHz - 7.5GHz testing
- 8 channels
- 16 ports

Target Market

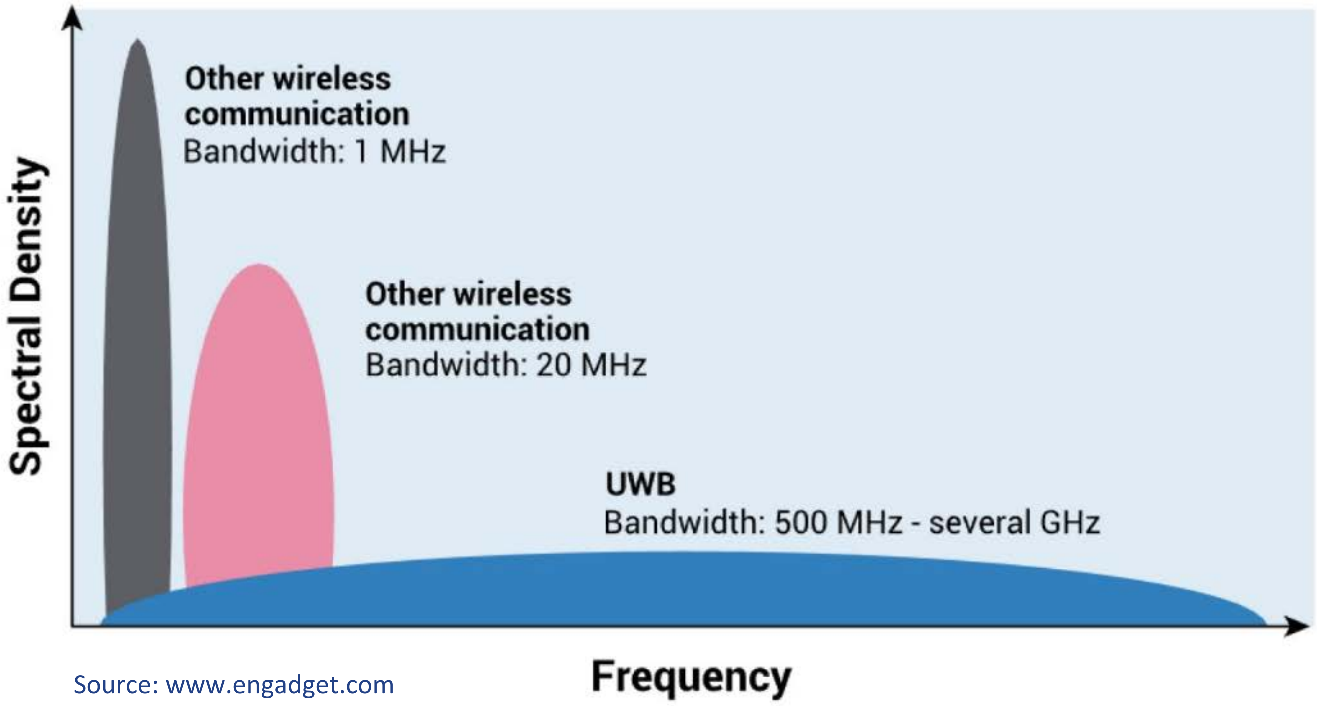
✓ **WiFi6**

✓ **Sub-6GHz 5G**

UWB Testing

Why is Ultra Wideband Different?

- Unlicensed spectrum from 3.1 to 10.6 GHz first authorized by FCC in February 2002.
- Uses very low power consumption for short-range, high-bandwidth communications over a large radio spectrum
- Utilizes time specific transmission intervals, which enables very accurate “time of flight” measurements
- Most recent applications target sensor data collection, precision locating and tracking applications.



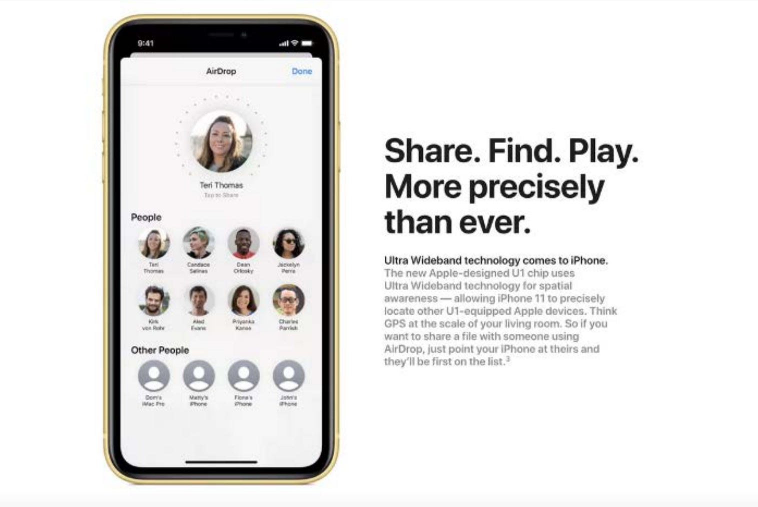
Source: www.engadget.com

New Applications for Ultra Wideband

Enhanced localization with a new level of security

	Smart Home and Enterprises	Smart Cities and Mobility	Consumer	Smart Retail	Industrial and Healthcare
Hands-Free Access Control	• Residential access control • Restricted enterprise access	• Smart parking garage • Keyless car access (standardized by CCC)	• Logical access control	• Unmanned store access	• Barrier-free and restricted access control
Location-Based Services	• Employee mustering in emergencies	• Ride sharing • Bike sharing	• AR gaming	• Indoor navigation • Foot traffic and shopping behavior analytics	• Asset tracking • Patient tracking
Device-to-Device (Peer-to-Peer) Services	• Smart conference systems	• Drone-controlled delivery • V2X*, autonomous driving	• VR gaming and group play • Find someone nearby	• Targeted marketing	• Proximity-based patient data sharing • Find equipment

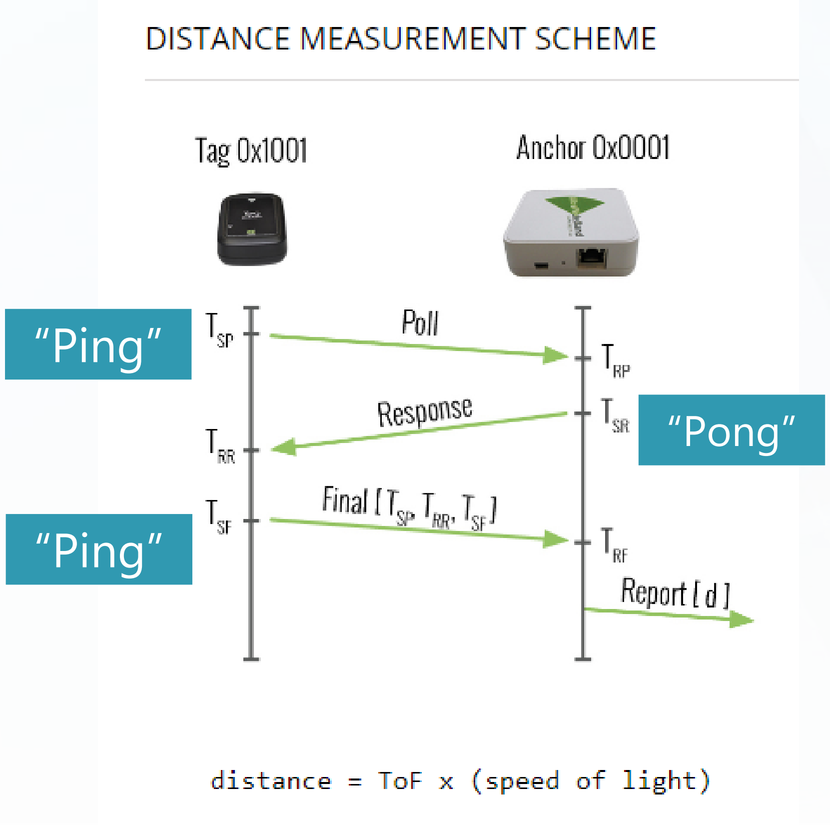
*Connected Vehicle-to-Everything Communication



Source: FIRA CONSORTIUM, Apple, NXP

How UWB Ranging Works - Time of Flight (ToF)

1st – you need to measure distance



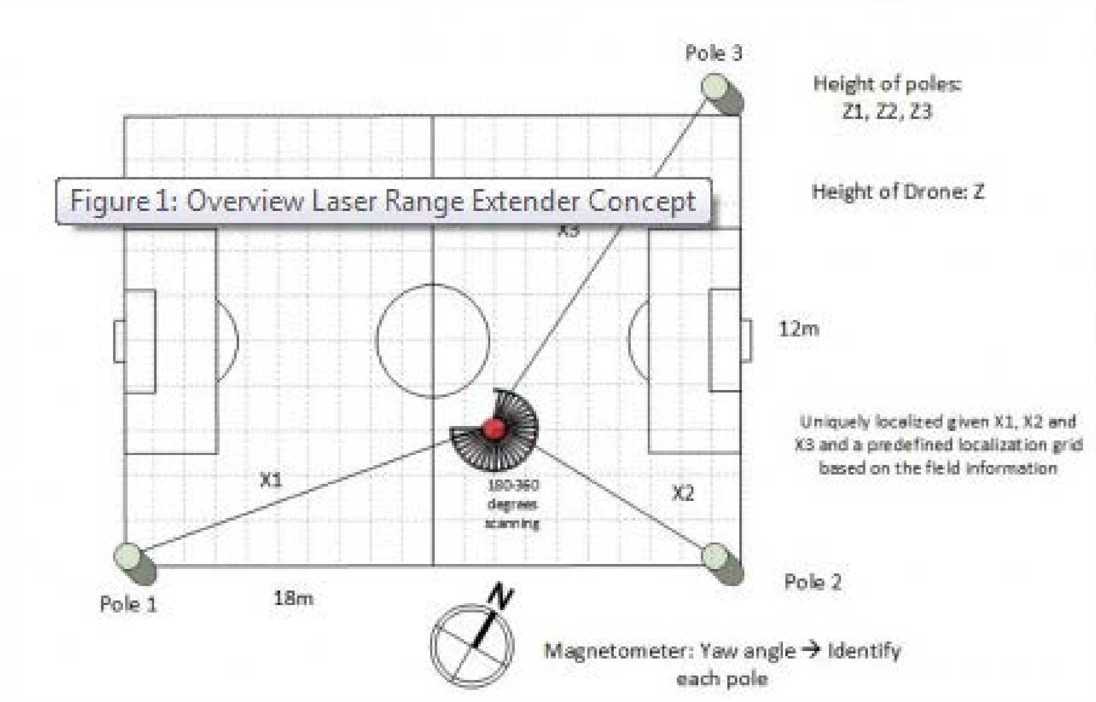
UWB uses "Time of Flight" to measure distance between an Anchor and a Tag

1. Tag sends out a poll ("Ping") and measures the time required to receive a response ("Pong").
2. The delay in the Anchor is known
3. The Tag calculates the actual ToF and uses this to calculate distance
4. The Tag can send an additional "Ping" back to the Anchor to compare the times

This measurement technique is called "Ping – Pong" or "Ping – Pong – Ping"

How UWB works

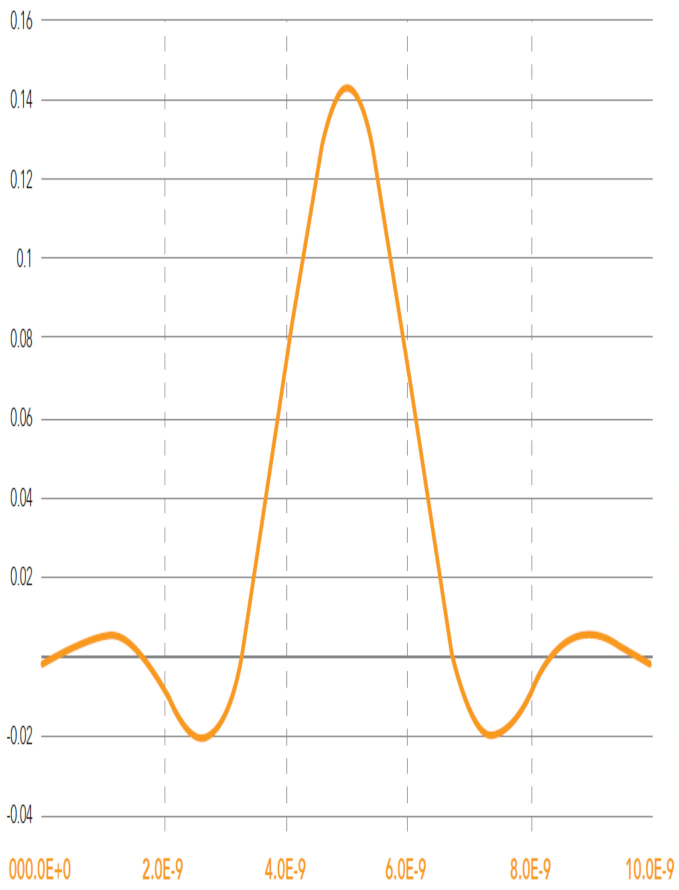
Determining location requires multiple receivers. The technique is called “trilateration” (not triangulation)



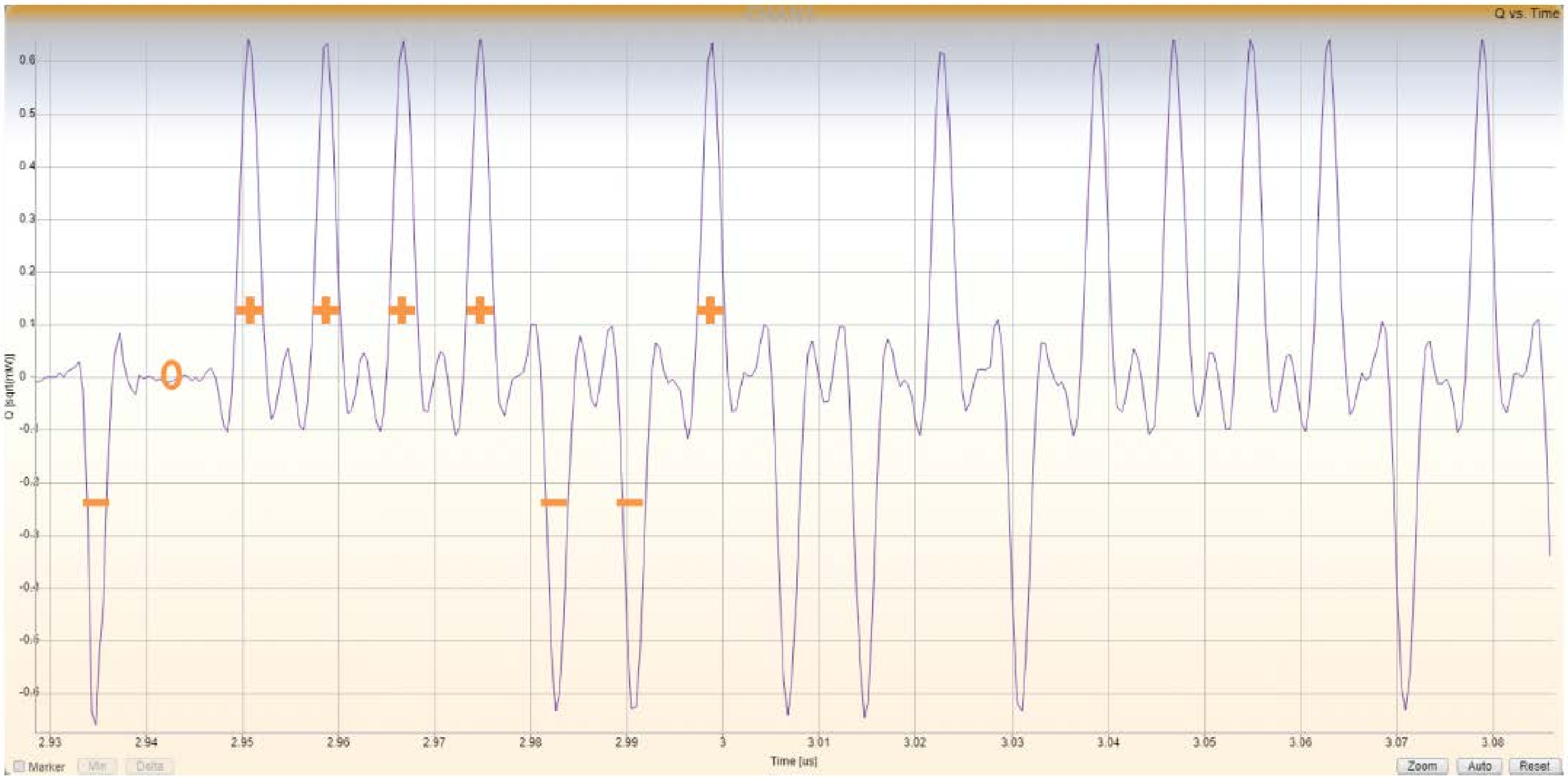
- **In a <u>2-dimensional world</u>, with 3 distance measurements you can accurately determine location.**
- **In this example, if the target is on the playing field, we can tell its location with 3 transceivers placed in the corners.**
- **If the target is above or below the playing field, we need a <u>4th receiver</u> that is above or below the playing field.**

UWB Encodes the Data in the Pulses

Reference Pulse



Code Sequence of Pulses



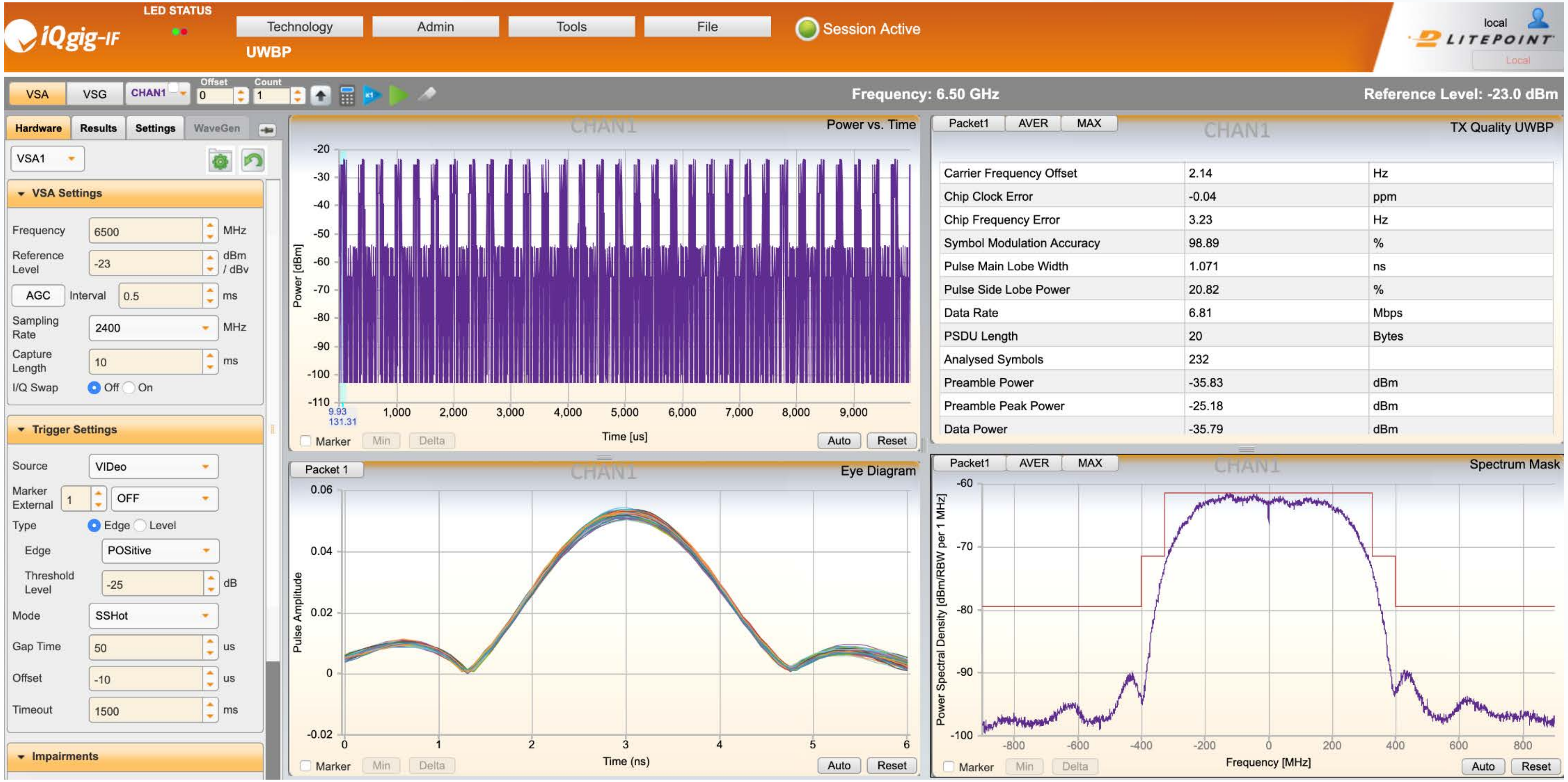
Standard UWB PHY Layer Measurements

UWB (802.15.4) Measurement Specification

Measurement	Description
Spectrum Mask	Transmit spectrum mask
Symbol Modulation Accuracy	Correlation to reference pulse (%)
Carrier Frequency Offset	Carrier frequency error (kHz)
Chip Clock Error	Error in ppm
Chip Frequency Error	Error in Hz
Pulse Main Lobe Width	Width of main lobe in time (ns)
Pulse Side Lobe Power	Power relative to main lobe (%)
Power (Preamble & Data)	Average power of complete data capture (dBm)
Peak Power (Preamble & Data)	Peak power over all symbols (dBm)
Pulse Jitter	Jitter in ps
Pulse NMSE	Normalized Mean Square Error (ppm)
RX PER	Receiver Packet Error Rate (requires DUT support)

Additionally, Time of Flight (ToF) & Angle of Arrival (AoA)

Integrated UWB PHY Layer Measurements



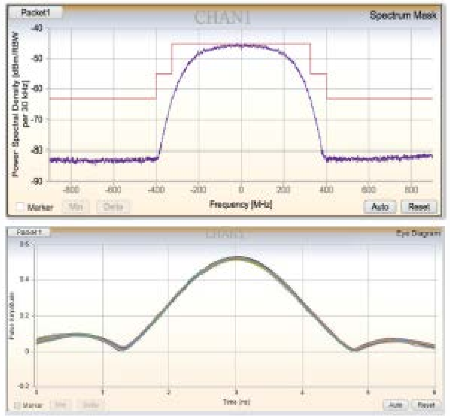
Integrated UWB Ranging Test Solution: IQgig-UWB

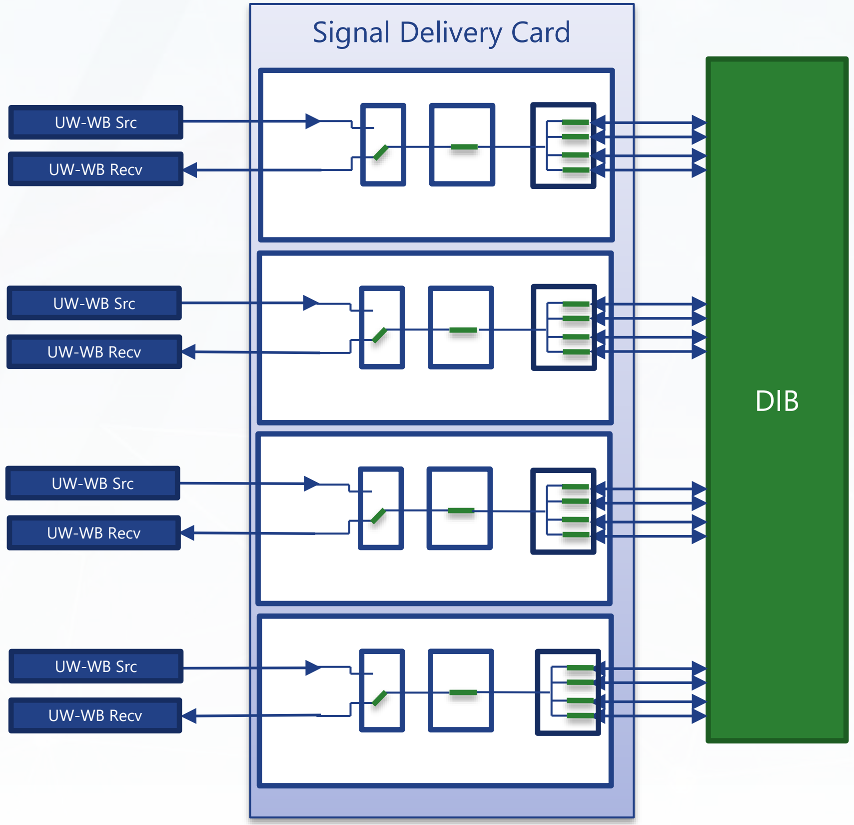
- **First Integrated Test Solution for Complete UWB Testing**
  - Integrated VSG and VSA for high-performance TX / RX testing of UWB devices
  - 5 to 19 GHz frequency range covers core UWB channels
  - 2 GHz single-shot VSA & VSG modulation bandwidth
  - Supports **802.15.4z standard**

- **Time of Flight Calibration**
- **Precision trigger / response mechanism to deliver ≤ 20 us response time with ps level jitter**
- **Wide Dynamic Range for Sensitivity Testing**
- **Combined with the IQ5631 Power and Delay Control Module (PDCM), IQgig-UWB enables receiver sensitivity testing for below -100 dBm**

ATE UltraWaveLX+ Instrument

- **16 Ports / 4 Channels per Instrument**
  - Configurable up to 2 instruments per system
- **5.8GHz to 18.5GHz**
- **1.9GHz Modulation Bandwidth**
- **Stand-alone Instrument – No UltraWave24 Required**
- **Standard RF Logical Instrument Language**
- **Background DSP**
- **Fully supported testing for Ultra Wideband**
  - Spectral Mask
  - Pulse Mask
  - Modulation Quality





5G NR IF Testing

5G NR Key Parameters

Item	Frequency Range 1 (FR1)	Frequency Range 2 (FR2)
Known As	Sub 6 GHz	mmWave
Frequency Range	450 MHz - 6000 MHz	24250 MHz - 52600 MHz
Duplex Mode	FDD, TDD	TDD
Subcarrier Spacing	15, 30, 60 KHz	60, 120 KHz
Bandwidth	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz	50, 100, 200, 400 MHz
MIMO	DL: 8x8 UL: 4x4	DL: 2x2 UL: 2x2
MIMO Method	Spatial Multiplexing for higher Throughput	Beamforming for better SNR
Radio Frame Duration	10ms	
Subframe Duration	1ms	
Modulation	pi/2-BPSK, QPSK, 16QAM, 64QAM, 256QAM	pi/2-BPSK, QPSK, 16QAM, 64QAM
Access	DL: CP-OFDM UL: CP-OFDM, DFT-s-OFDM	
Carrier Aggregation	16 carriers maximum	
Channel Coding	Polar Codes, LDPC Codes	

Higher Frequencies

Higher Bandwidth

Maximum CC (Component Carrier) bandwidth is 100 MHz for FR1 and 400 MHz for FR2: *a 5x to 20x improvement over 4G LTE!*

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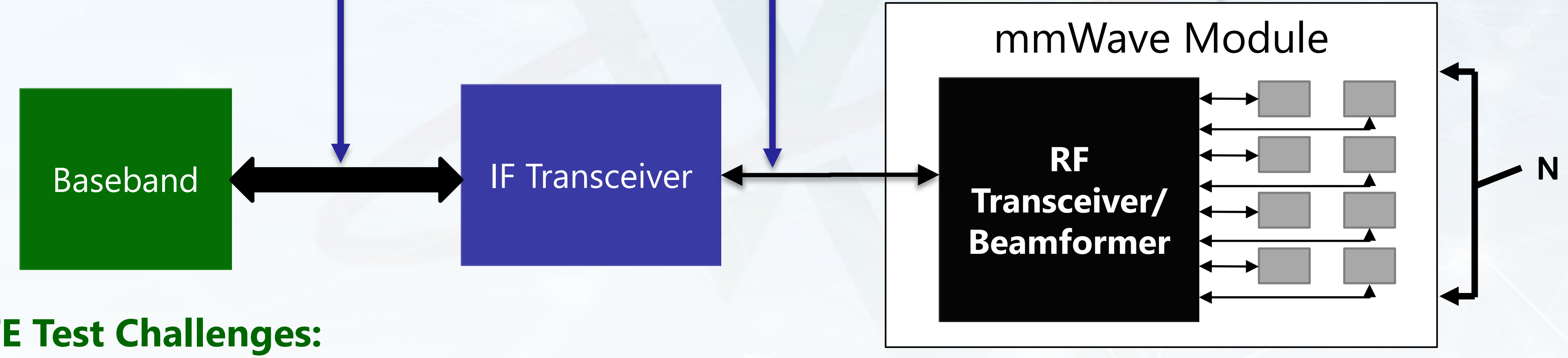

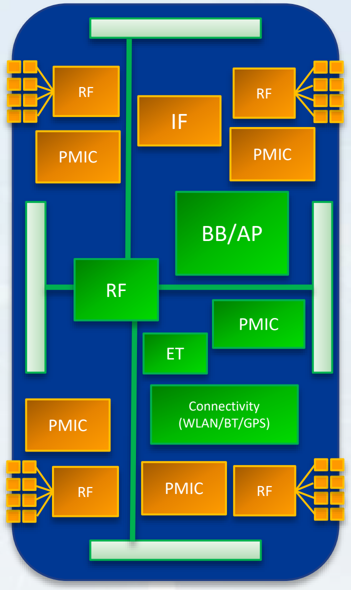

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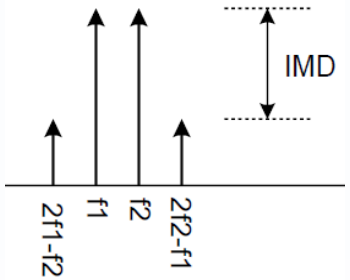
What to Test?

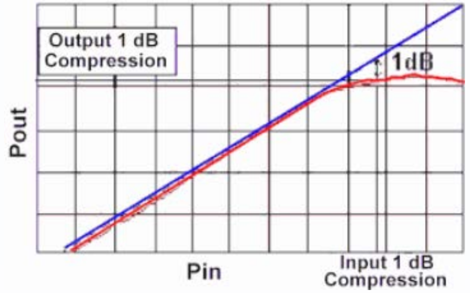
mmWave RFIC

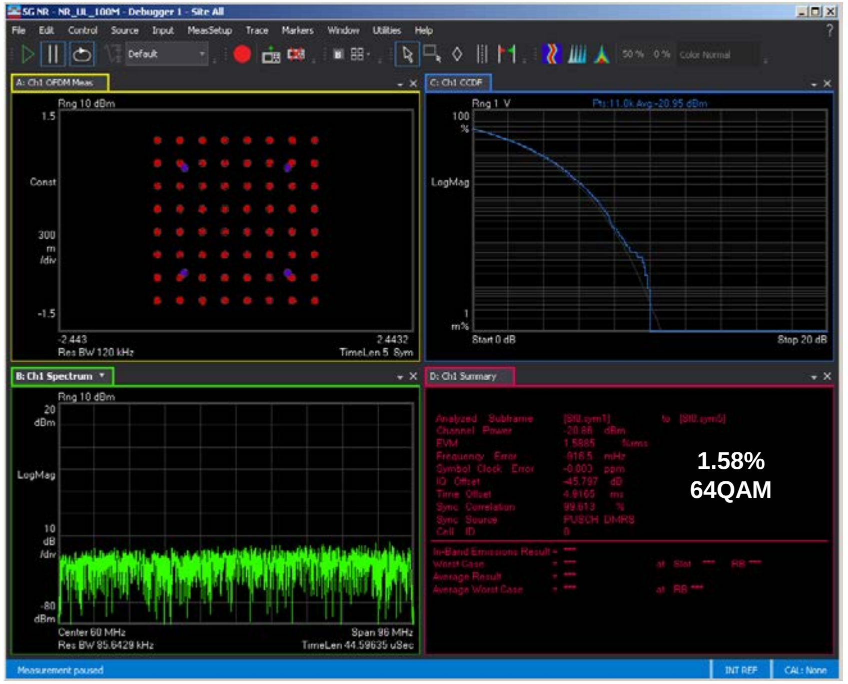
- Gain
- P1dB and IP3
- Band pass filter(channel select) gain/flatness/out-band attenuation
- PLL lock
- ACLR
- EVM
- Phase trimming
- Beamforming?
- Others (DC, leakage, pattern-scan and BIST)

mmWave RFBB (IFIC)

- Gain
- IP3
- Low pass filter(channel select) gain/flatness/out-band attenuation
- PLL lock
- ACLR
- EVM
- IQ mismatch / IQ cal(phase and gain cal for Image rejection and carrier suppression)
- Others (DC, leakage, pattern-scan and BIST)







5G mmWave Test Strategies in Mass Production

UltraFLEX mmWave ATE

IQgig-5G

LITEPOINT
A Teradyne Company

Silicon Wafer Test

Verify performance in order to maximize upstream test yields

- **ATE Probe**
- CW mmWave functional test
- DC/Digital
- BIST
- Tri-Temp for 5G RAN

Module Assembly (AiP or AoB)

Need 0 DPPM for mmWave Antenna Assembly

- **X-Ray Inspection** for mmWave antennas
- AiP vs AoB assembly yields?
- Multiple SKUs for different frequency bands

Module "OTA Continuity" Test

Need 0 DPPM for mmWave Antenna Radiation

- **ATE Handler**
- OTA Socket
- "Continuity" test for dipole and patch antennas
- Limited functional tests
- Multiple SKUs

Module Functional OTA Test

Need 0 DPPM for mmWave module performance

- **Functional Test**
- OTA Socket or shield box
- OTA NF or FF
- Full functional test
- Beamforming corner tests (FF)
- Multiple SKUs
- Tri-Temp for 5G RAN

Sub-Assembly PCBA OTA Test

Need mmWave performance test of sub-assembly antenna interaction

- **System Level Test**
- OTA Far Field
- Full Functional Test
- Beamforming corner tests
- Multiple SKUs
- Can add value if calibration factors can be added

Final Product OTA Test

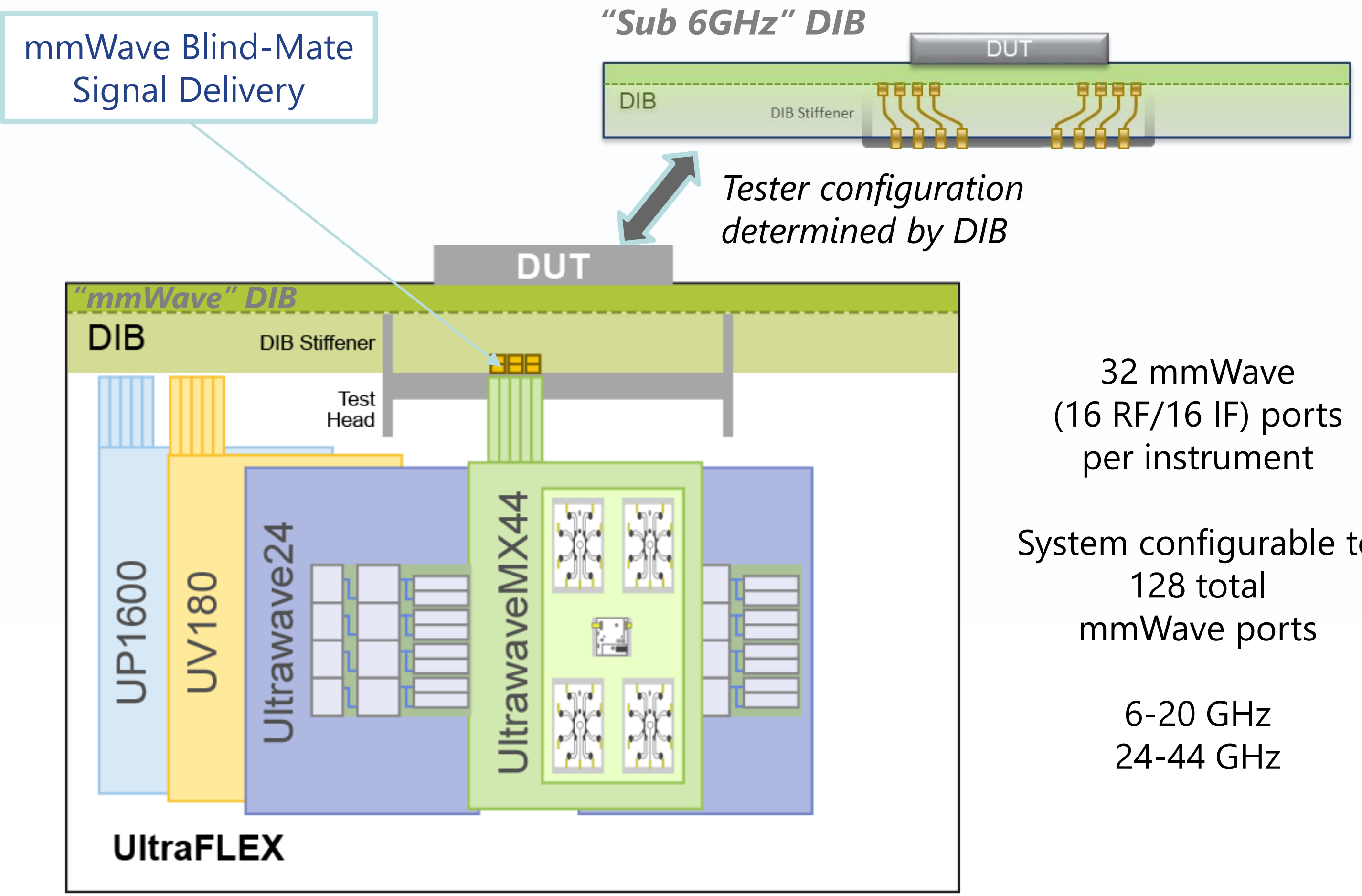
Need 0 RMA. Need mmWave performance test and calibration of final assembly antenna interaction.

- **System Level Test**
- OTA Far Field
- Full Functional Test
- Full CC BW EVM Test
- Full CA Test Possible
- Beamforming calibration
- Multiple SKUs
- Tri-Temp for 5G RAN

= Must = Likely = Optional

Need ATE with a Simple Upgrade from Sub 6GHz to mmWave: *UltraWaveMX44*

- Zero change to existing DIB load board standard
- No system reconfiguration required to switch between sub-6GHz and mmWave applications
- Performance specified at blind-mate with fully integrated calibrations
- No change to docking or Z-height



32 mmWave (16 RF/16 IF) ports per instrument

System configurable to 128 total mmWave ports

6-20 GHz
24-44 GHz

https://www.teradyne.com/products/test-solutions/semiconductor-test/ultraflex-mmwave-instruments

High Performance 5G IF and mmWave Test Solutions

Fully-integrated 5G mmWave test system

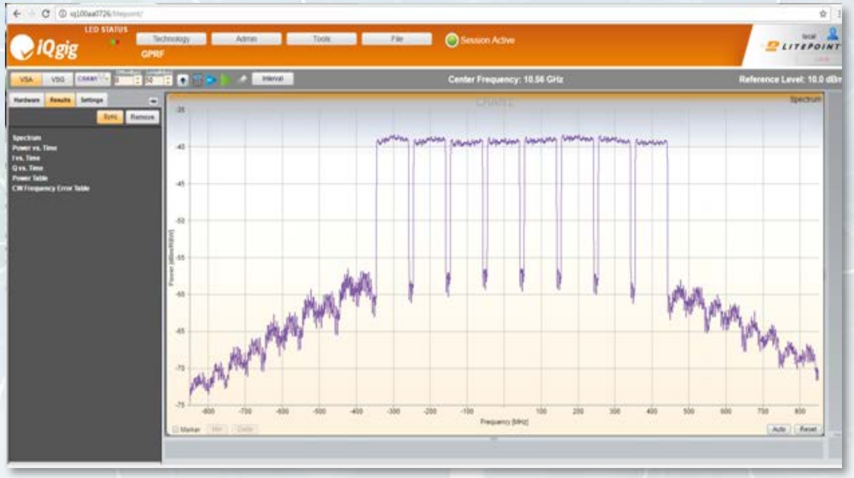
- Simplest 5G IF and mmWave testing covering:
  - IQgig-IF: 4.9 to 19.4 GHz
  - IQgig-5G: 23 – 45 GHz
- All signal generation, analysis, and RF front-end routing H/W are self-contained
- Single intuitive S/W interface

Simple Migration from the Lab to Manufacturing

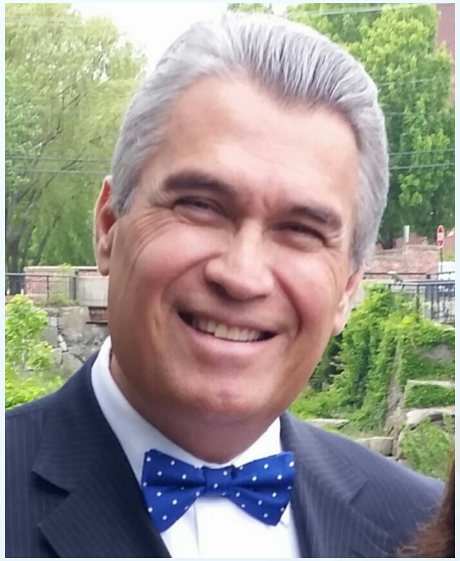
- Simple connections – just power up and go
- Source and Measure capabilities fully calibrated to the instrument front panel

No Compromise 5G performance

- Supports the 3GPP NR standards evolution
- 1.7 GHz of single-shot bandwidth.



Q & A



Dr. Jeorge S. Hurtarte, Wireless Product Marketing Strategist, Teradyne. Dr. Jeorge S. Hurtarte is currently Wireless Product Marketing Strategist at Teradyne, Boston, USA. Dr. Hurtarte has held various technical and management positions at Teradyne, LitePoint, TranSwitch, and Rockwell Semiconductors. He holds Ph.D. and B.S. degrees in electrical engineering, an M.S. in telecommunications, and an M.B.A. Dr. Hurtarte has served on the Advisory Board of Directors of the Global Semiconductor Alliance, TUV Rheinland of North America, and the NSF's Wireless Internet Center for Advanced RF Technology. He is the secretary of the IEEE 802.11ay task group. Dr Hurtarte is also professor at the University of California, Santa Cruz and at the University of Phoenix, Bay Area, California. He is also the lead co-author of the book *Understanding Fabless IC Technology*.