connect

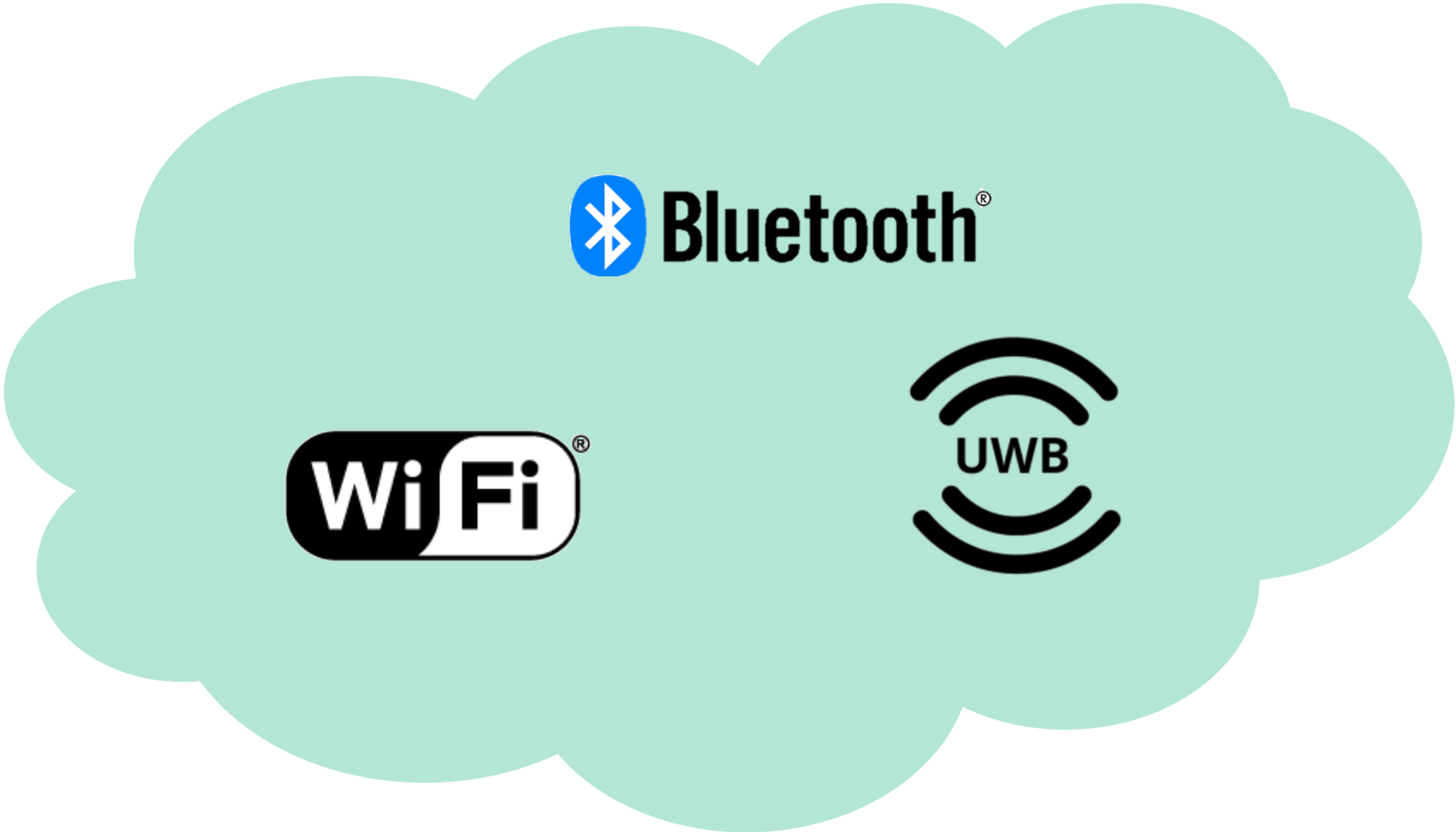
EMERSON | NI

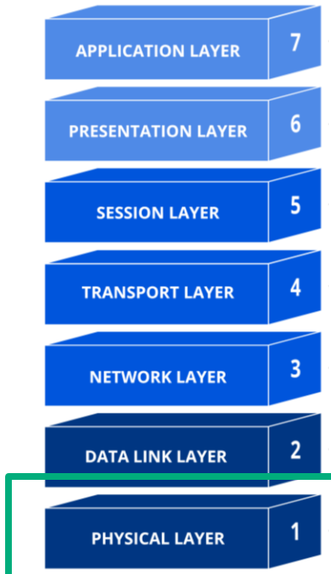
Trends in Wireless Connectivity Standards

What's next for Wi-Fi, Bluetooth, and UWB

Jake Harnack | *Chris Luton*

Wireless Connectivity Standards





IEEE 802.11 Bluetooth SIG IEEE 802.15.4/4z FiRa

	Wi Fi	Bluetooth	UWB
Strengths	High data rates High power and range	Low power consumption Positioning Mesh, broadcast, and point-to-point	Low power consumption Highly accurate positioning Security
Common Applications	Home/office connectivity Video streaming Transferring large files	Audio streaming Peripheral connectivity Location services	Location services Key fobs
What's next	IEEE 802.11bn (Wi-Fi 8) **Ultra High Reliability**	Bluetooth LE **high-accuracy distance measurements** and **high data throughput**	IEEE 802.15.4ab **Advanced ranging**, **sensing**, and **low-latency**

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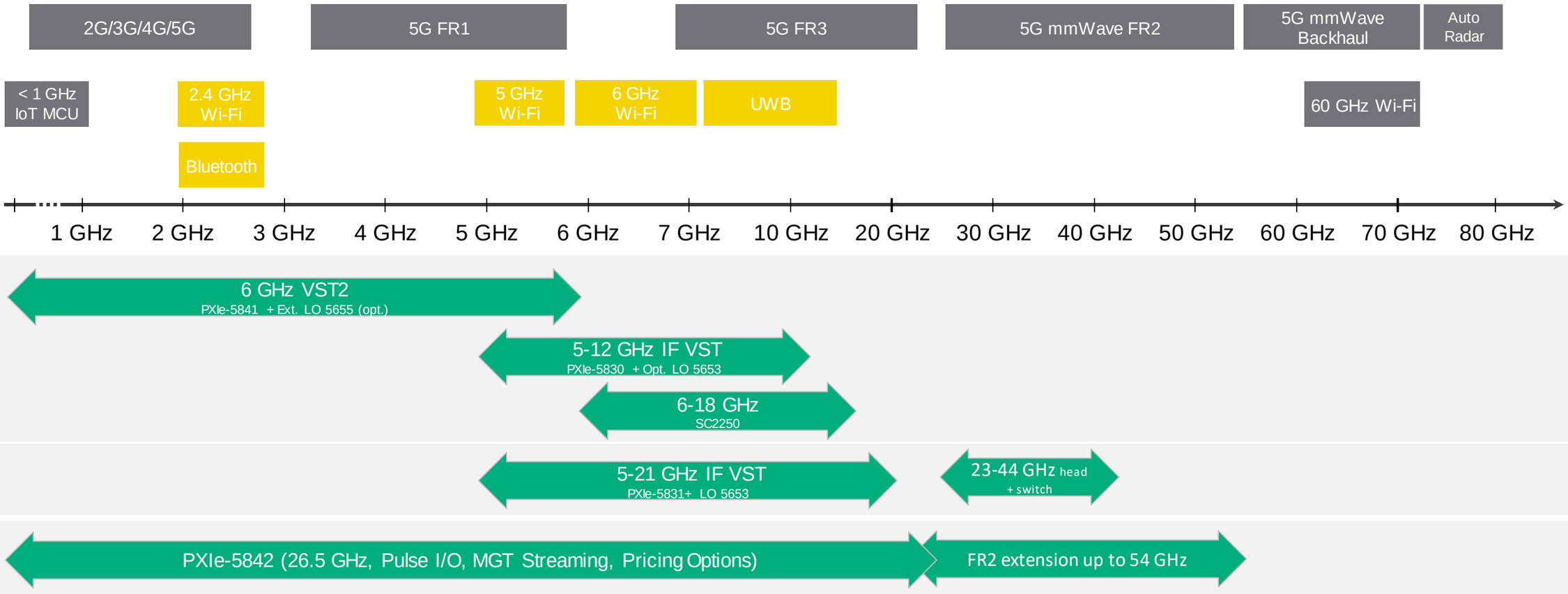


26.5GHz VSG and VSA
with up to **2 GHz** Instantaneous BW and
industry-leading **EVM performance**

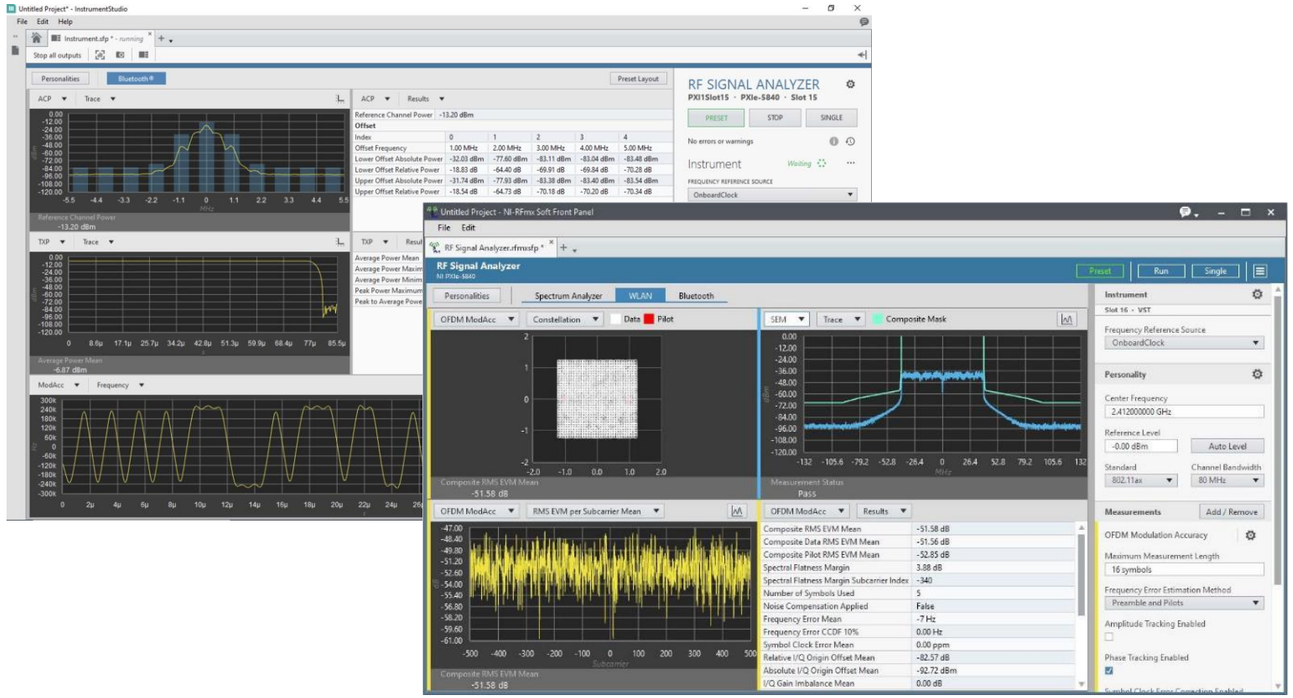
Testing Connectivity Standards with NI VST and RFmx

PXIe-5842 Vector Signal Transceiver

26.5 GHz frequency

Up to 2 GHz bandwidth

PXIe-5842 Cross-Correlation EVM loopback, measured*	
Wi-Fi 7, 80 MHz BW, 6 GHz	-57 dB
Wi-Fi 7, 320 MHz BW, 6 GHz	-53 dB



RFmx Test Software

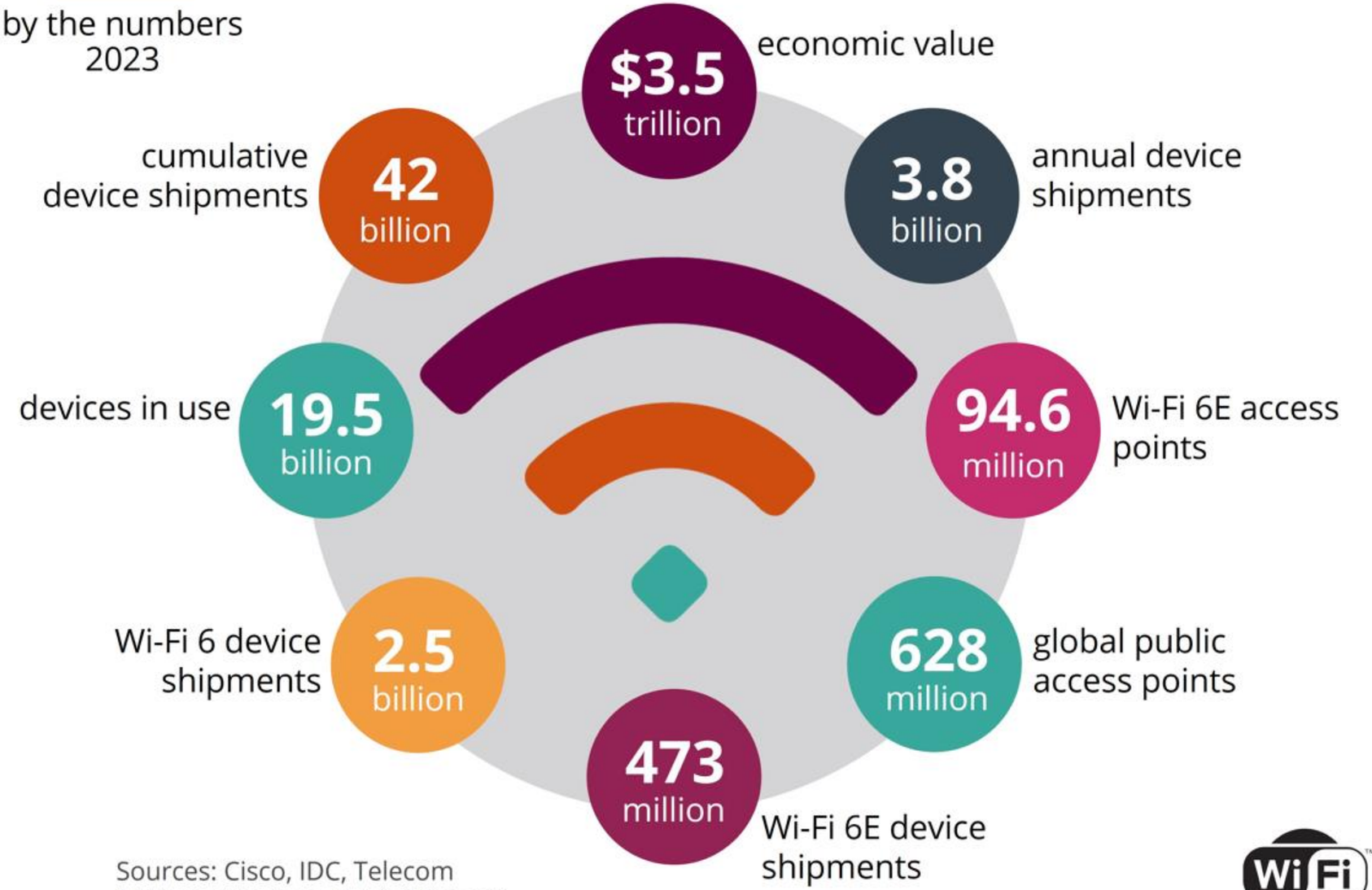
Personalities for WLAN, Bluetooth, Spectral Analysis, etc.

Interactive soft front panels

Wi-Fi

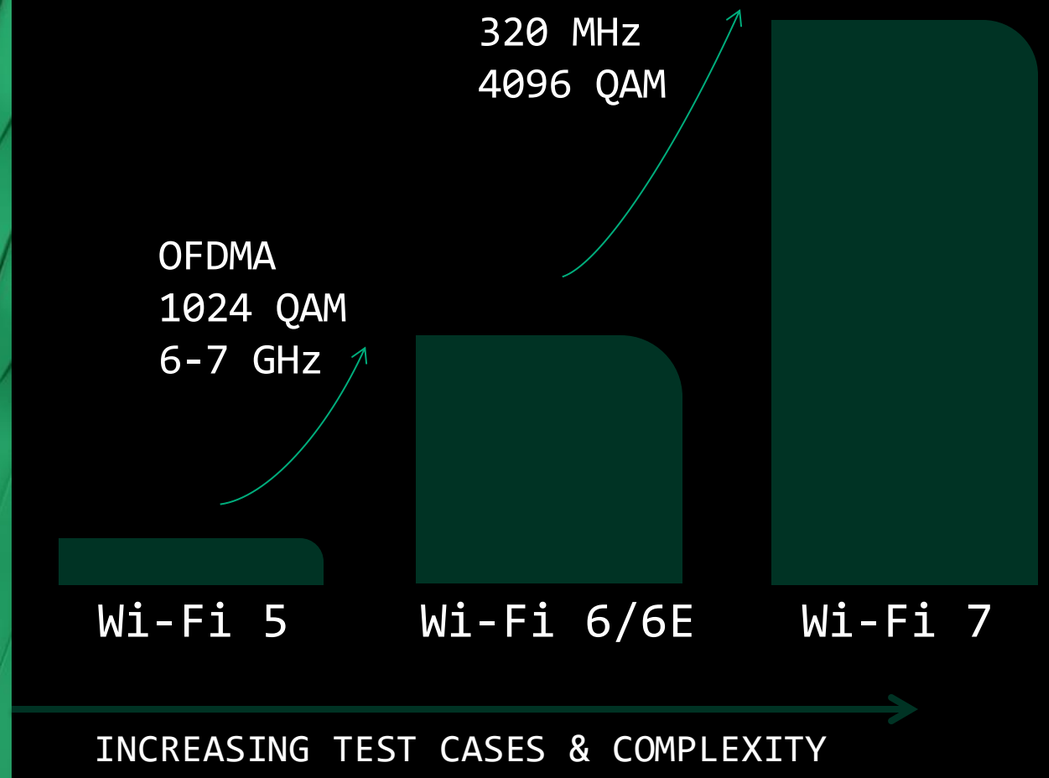
Wi-Fi®

by the numbers
2023



Sources: Cisco, IDC, Telecom Advisory Services, Wi-Fi Alliance®

Wi-Fi 7 Introduces Exponential Growth in Test Cases and Complexity



320 MHz
CHANNEL BANDWIDTH

4096-QAM
MODULATION SCHEME

8X MIMO
SPATIAL STREAMS

5X DATA RATE
> 40 Gbps

MULTI-LINK
2X CONCURRENT CHANNELS

Wi-Fi 8 UHR (Ultra High Reliability)

IEEE 802.11bn

- Target applications
  - Metaverse, augmented and virtual reality
  - Robotics, industrial automation for industrial IoT, logistics and smart agriculture
- Goals
  - Increase throughput by 25% compared to 802.11be
  - Decrease latency by 25% compared to 802.11be
  - Reduce MPDU loss by 25% compared to 802.11be

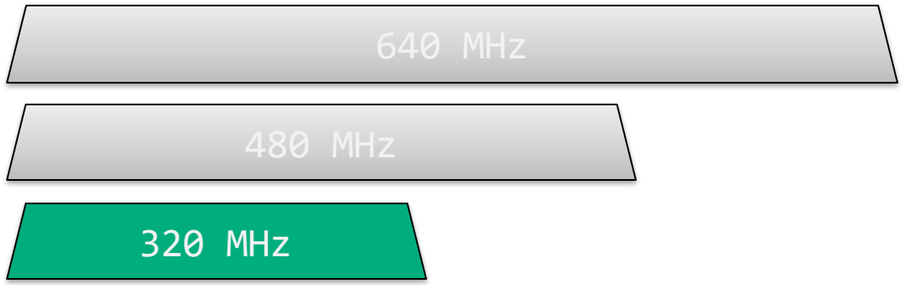
Task Group Timeline

MILESTONE	PROJECTED	CURRENT
PAR approved	July 2023	July 2023
First TG meeting	November 2023	November 2023
D0.1	January 2025	
D1.0 Initial WG Letter Ballot	May 2025	
D2.0 WG Letter Ballot	May 2026	
D3.0 WG Letter Ballot	January 2027	
D4.0 Initial SA Ballot	May 2027	
Final 802.11 WG approval	March 2028	
802 EC approval	March 2028	
RevCom and SASB approval	May 2028	

Potential PHY Changes in 802.11bn

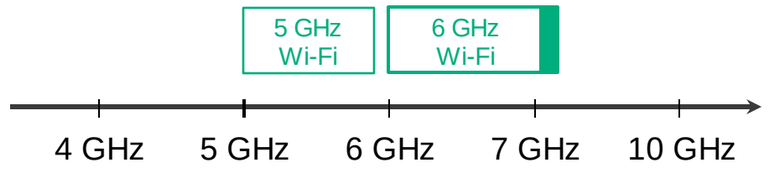
Tracking the impact of Wi-Fi 8 on RFmx

- Deferred or rumored features
  - mmWave >> IMMW Study Group (42-71 GHz)
  - > 320 MHz channel bandwidths
  - 8k QAM

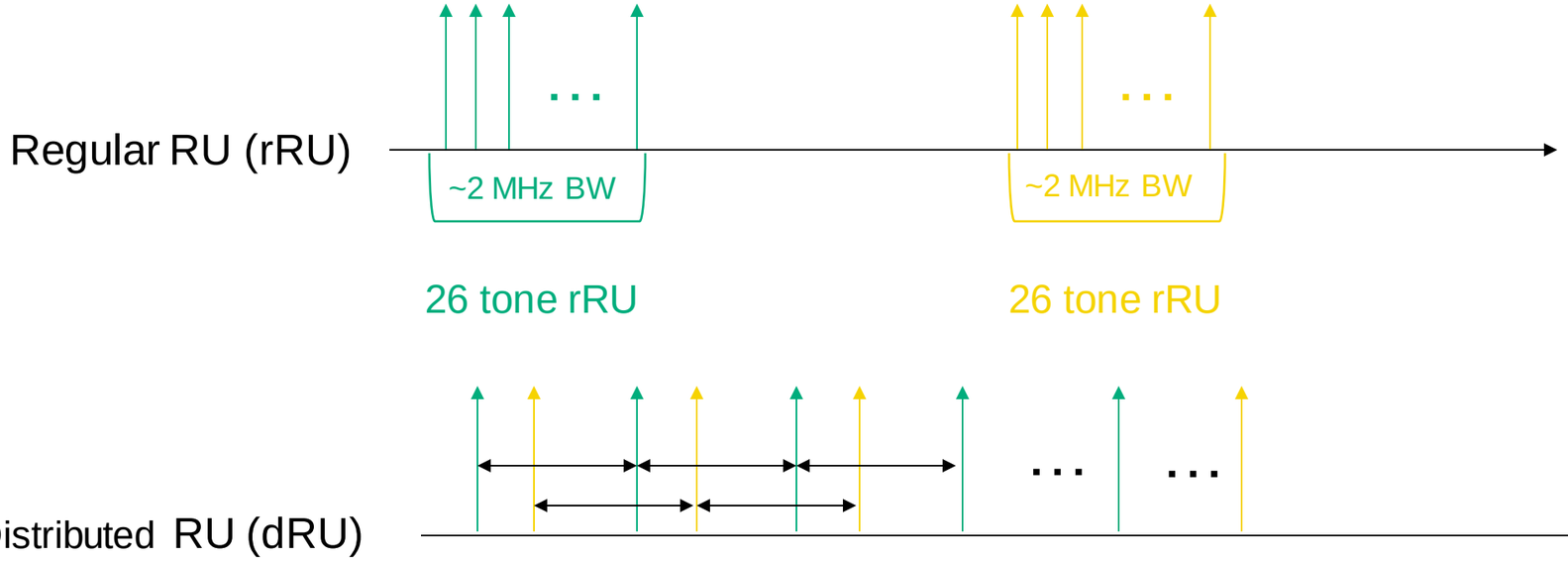


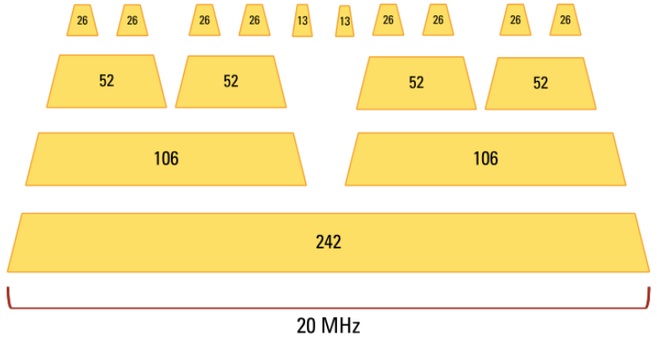
- Probable features
  - Distributed resource unit (dRU)
  - Hybrid dRU and regular RU (rRU) mode
  - Extended frequency range up to 7.25 GHz
  - Multidimensional PPDU design
  - Multi AP coordination
  - Multilink operation

introduced in 802.11be



Distributed RU (dRU)





Max PSD for 6GHz Low Power Indoor Wi-Fi: **1dBm/MHz**

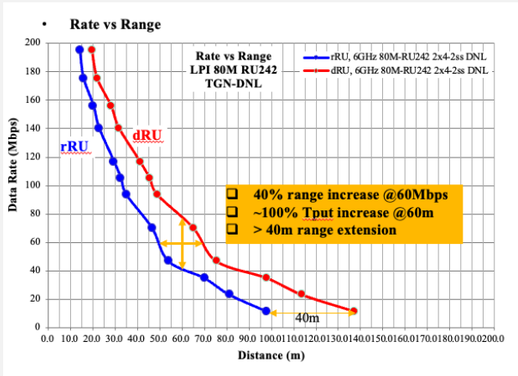
Boost transmission power

RU Size	**rRU** Tx Power (dBm)	**dRU** Tx Power (dBm)		
		dRU→BW20	**dRU**→BW40	**dRU**→BW80
RU26	2.08	**10.21**	**13.22**	**13.22**
RU52	5.09	**11.46**	**13.22**	**16.23**
RU106	8.18	**11.74**	**14.55**	**16.31**
RU242	11.77		**14.46**	**16.89**
RU484	14.78			**17.47**

power boost

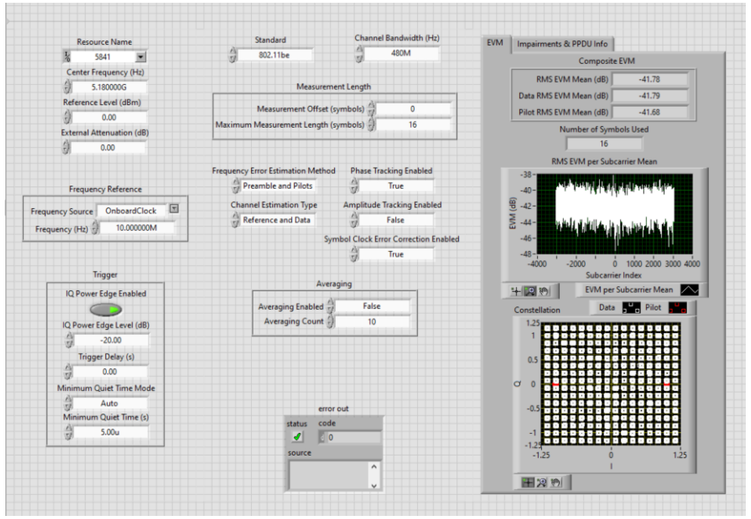
Source: MediaTek

Improve coverage range

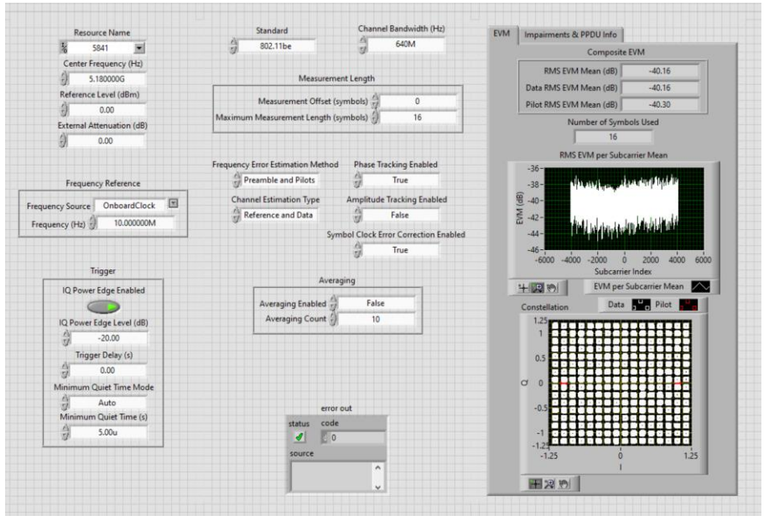


Source: MediaTek

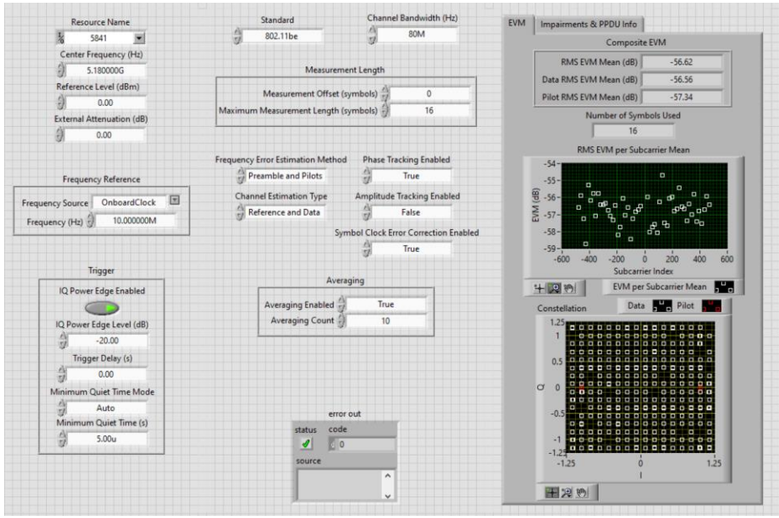
Wi-Fi 8 EVM Measurements in RFmx WLAN



480 MHz EVM



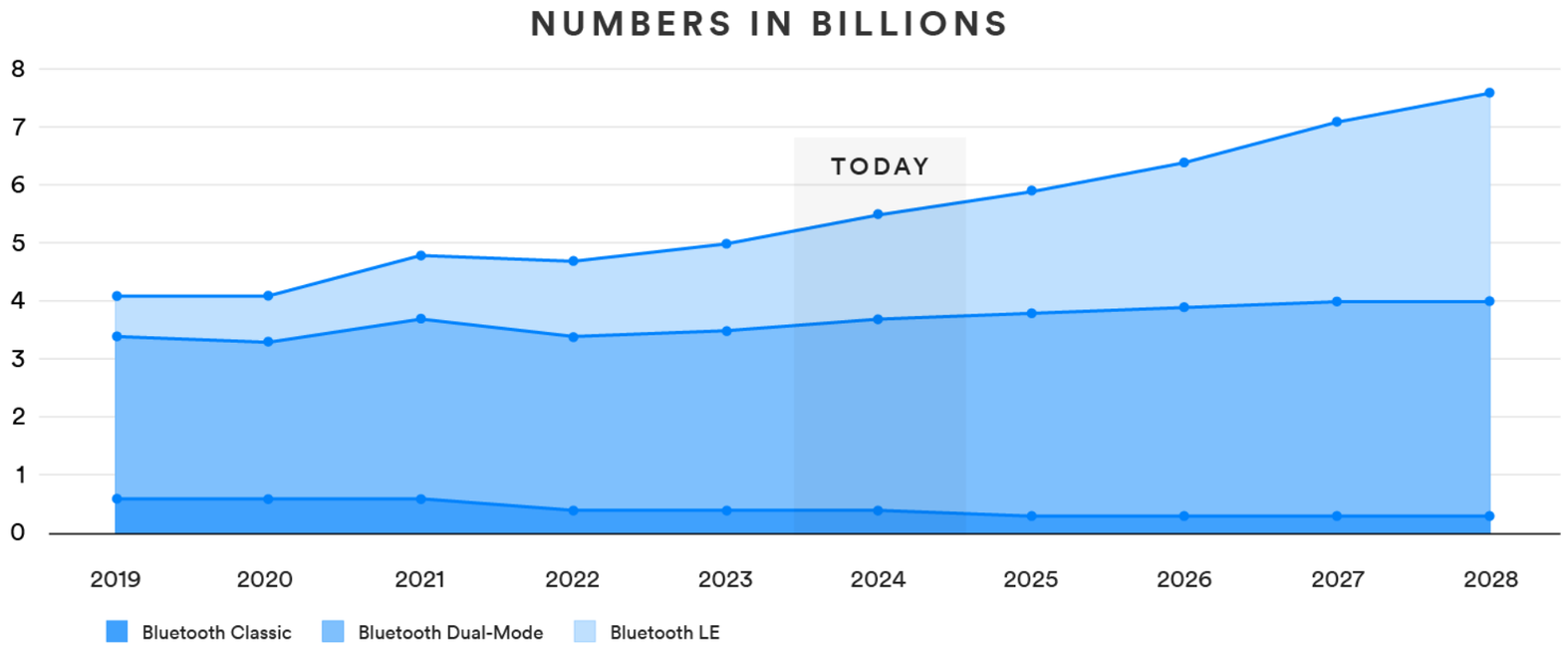
640 MHz EVM



dRU (size 52)

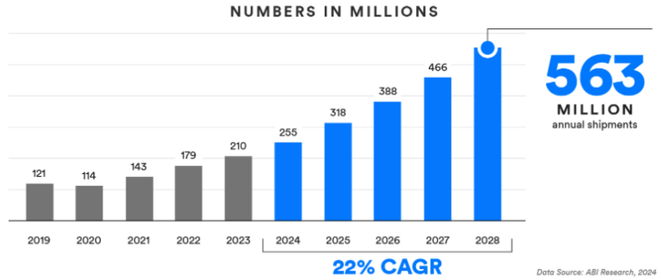
Bluetooth

Bluetooth® Enabled Device Shipments by Radio Version

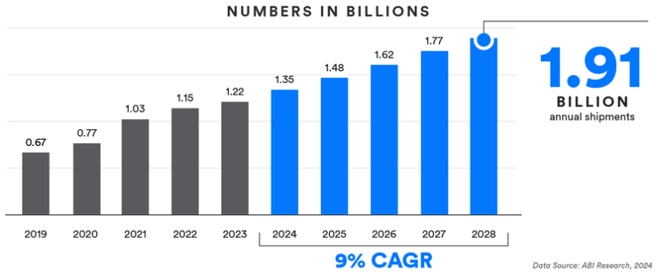


Data Source: ABI Research, 2024

Annual Bluetooth® Location Services Device Shipments



Annual Bluetooth® Data Transfer Device Shipments



100% of key new smartphones, tablets, and laptops support dual mode (Bluetooth® Classic + Bluetooth LE)

All key platform devices support Bluetooth® Classic and Bluetooth LE

3.5 BILLION Bluetooth® peripheral devices are expected to ship in 2024, growing to 5.5 billion in 2028

Peripherals will continue to drive the growth of Bluetooth® device shipments

Bluetooth®

The global standard for simple, secure device communication and positioning

Bluetooth® Classic

Solution Areas

AUDIO STREAMING

DATA TRANSFER

Device Communication

POINT-TO-POINT

Basic Rate/Enhanced Data Rate Radio

SPECTRUM: 2.4 GHz ISM band
CHANNELS: 79 one MHz channel with Adaptive Frequency Hopping
BIT RATES: 1 Mb/s, 2 Mb/s, 3 Mb/s

Bluetooth® Low Energy

Solution Areas

AUDIO STREAMING

DATA TRANSFER

LOCATION SERVICES

DEVICE NETWORKS

Device Communication

POINT-TO-POINT BROADCAST MESH

Device Positioning

PRESENCE DISTANCE DIRECTION

Low Energy Radio

SPECTRUM: 2.4 GHz ISM band
CHANNELS: 40 two MHz channel with Adaptive Frequency Hopping
BIT RATES: 125 Kb/s, 500 Kb/s, 1 Mb/s, 2 Mb/s

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Bluetooth®

The global standard for simple, secure device communication and positioning

Bluetooth® Classic

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Bluetooth® Low Energy

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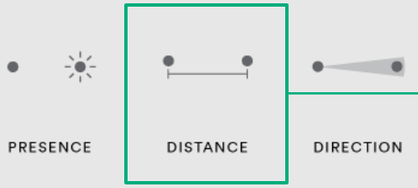

PRESENCE DISTANCE DIRECTION

Low Energy Radio

SPECTRUM: 2.4 GHz ISM band
CHANNELS: 40 two MHz channel with Adaptive Frequency Hopping
BIT RATES: 125 Kb/s, 500 Kb/s, 1 Mb/s, 2 Mb/s

Increase accuracy for distance

Open additional spectrum

Increase bit rate

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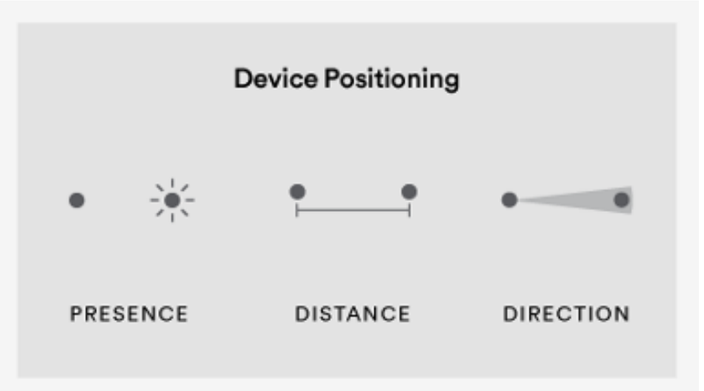
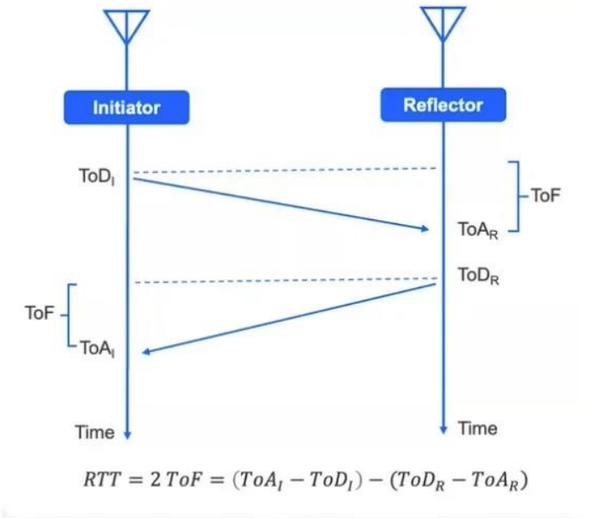
Channel Sounding (HADM)

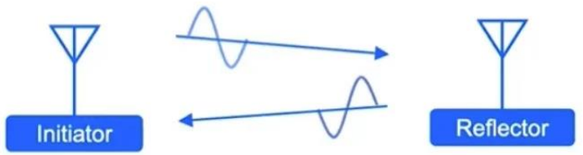
- **Goals**
  - Improve accuracy of distance measurements from 3-5m (RSSI) to 10-30 cm
  - Improve security and minimize interference
- **Applications**
  - Real-time location services
  - Secure building access
  - Digital keys (automotive)
  - Proximity detection
- **Implementation**
  - Uses phase-based ranging across multiple frequency tones
  - Uses round-trip timing

Mode	Description
Mode 0	Used to exchange synchronization information to align on timing and calibrate frequency of one side w.r.t. the other
Mode 1	Used to exchange a Round Trip Timing (RTT) packets
Mode 2	Used to exchange phase-based ranging (PBR) CS tones, to measure phase and amplitude of the communication channel
Mode 3	Used to exchange both RTT and PBR CS tones

Source: TI





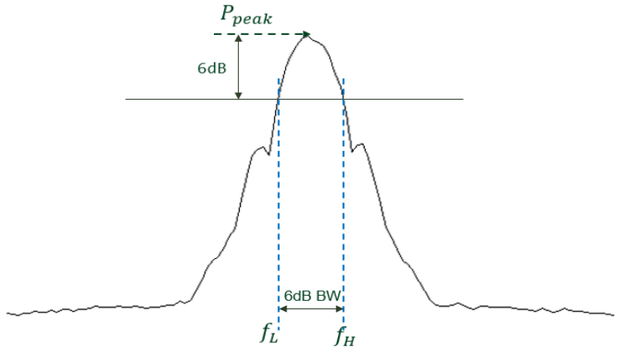


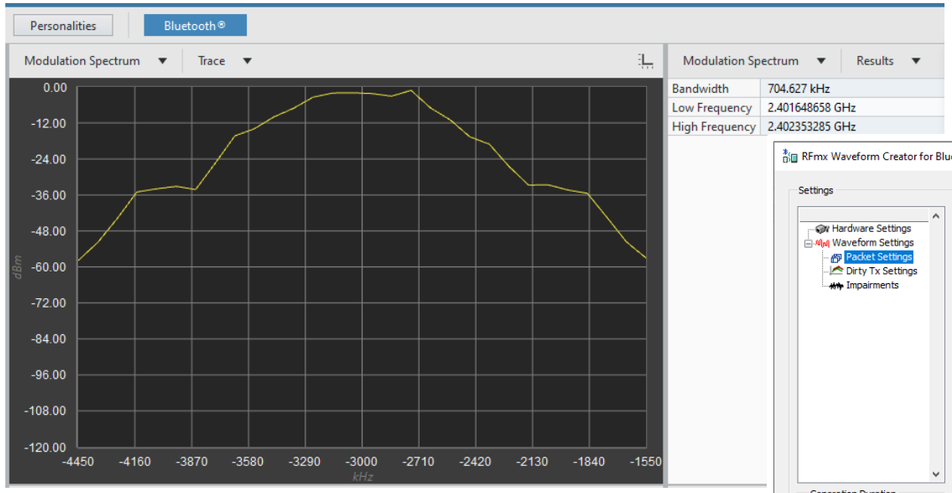
Source: SiLabs

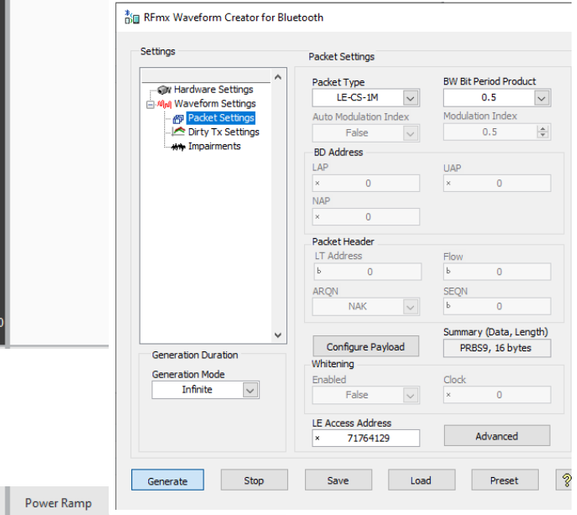
Bluetooth Channel Sounding Tests

Modulation spectrum

Δf > 500 kHz

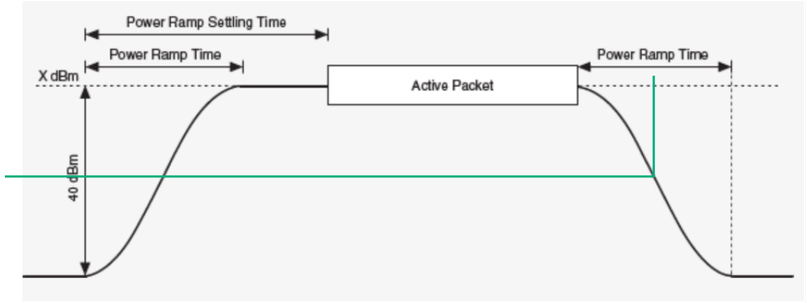


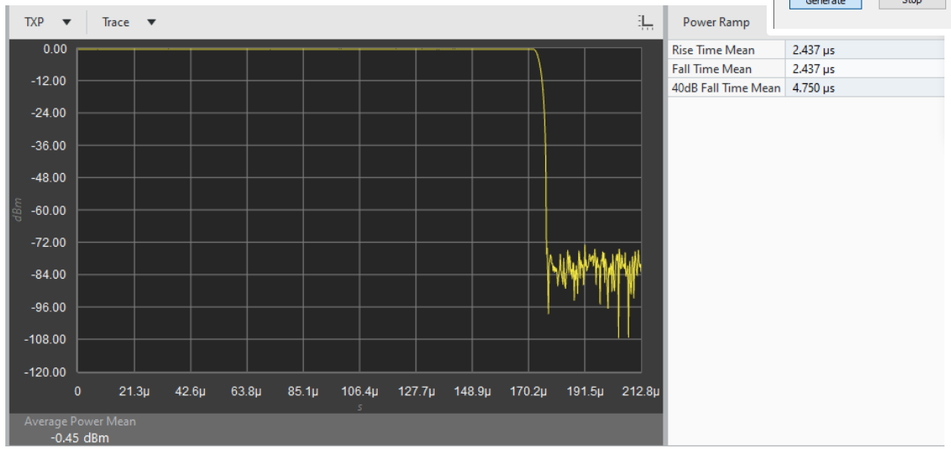




Power ramp

40 dB ramp down time < 5 µs

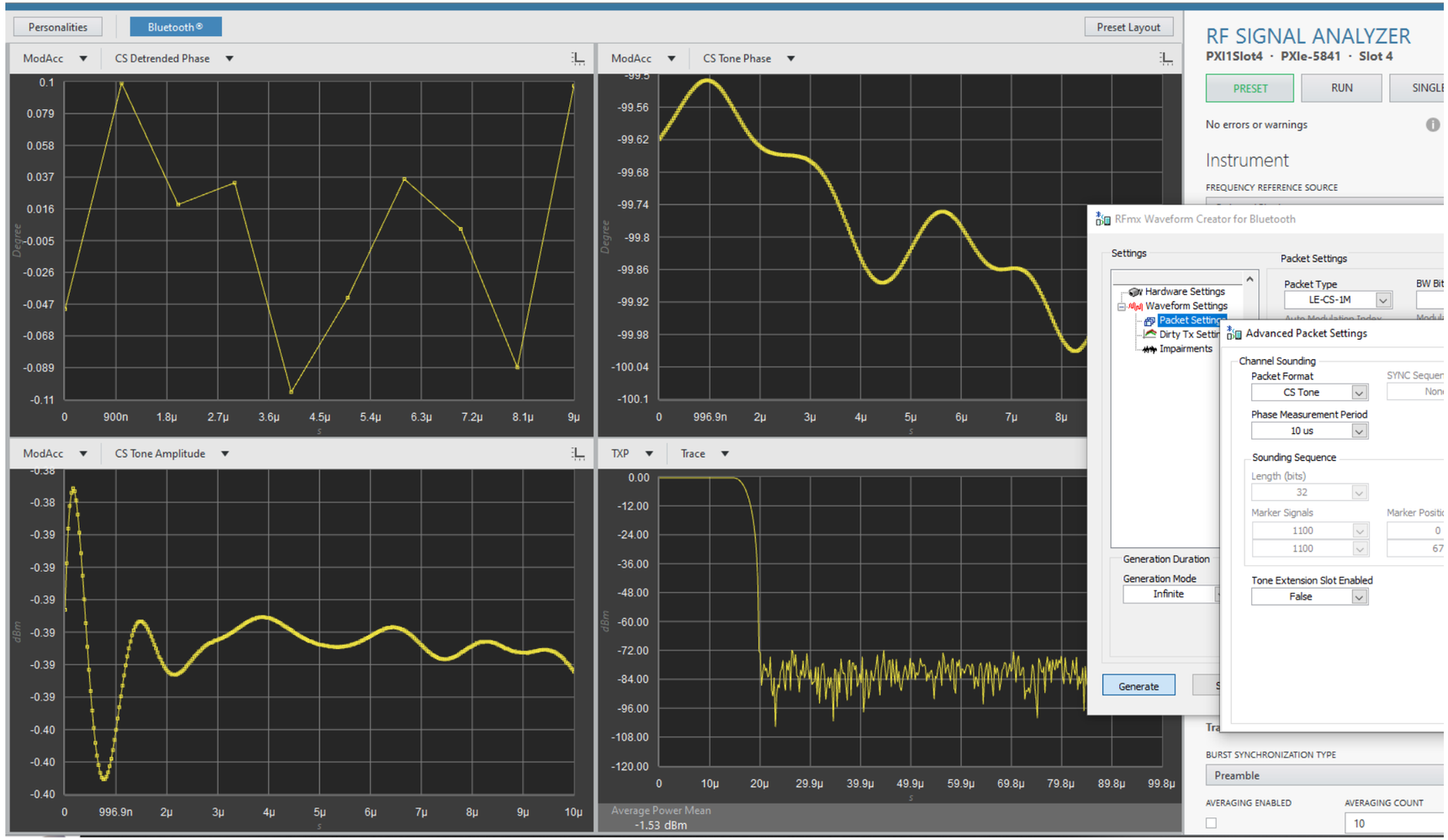




Bluetooth Channel Sounding Phase Measurements

CS Detrended Phase: returns the zero-mean detrended phase versus time trace

Stable Phase Test: 95% of $\phi_{zmd}[n]$ are 20 degrees or less

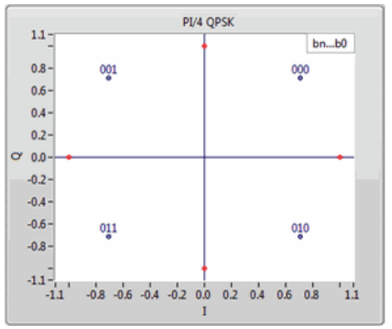


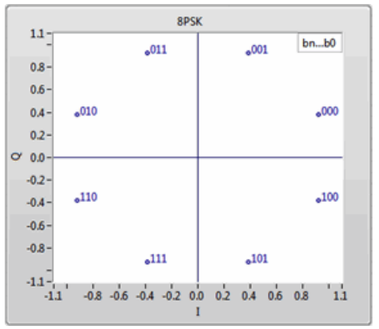
Apply Filter as per spec → Burst Sync → FM Demod → Phase measurement

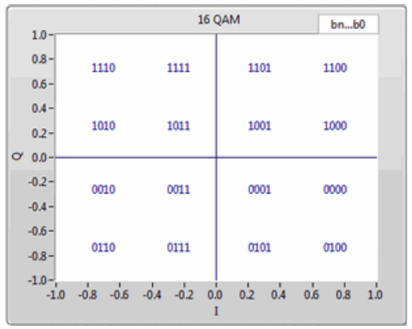
High Data Throughput (HDT)

Bit rate	2 Mb/s	3 Mb/s	4 Mb/s	6 Mb/s	7.5 Mb/s
LE HDT Designation	HDT2	HDT3	HDT4	HDT6	HDT7.5
Proposed TX EVM limit	-10 dB	-13 dB	-16 dB	-19 dB	-22 dB
Proposed maximum drift rate of the non-ideal source used in sensitivity measurements	4 Hz/us	4 Hz/us	2 Hz/us	2 Hz/us	1 Hz/us

- **Goals**
  - Improve data rates of Bluetooth LE 2M PHY
  - Support rates up to 7.5 Mbps
  - Shorten time to transfer data between devices
  - Enable new applications that require > 2 Mbps
- **Applications**
  - Enhanced data transfer rates between devices
  - Streaming high-definition audio
- **Implementation**
  - Longer packets, extended payload length (hyperlength)
  - Higher order modulation (single-carrier), up to 16 QAM
- **Test challenges**
  - Stricter EVM requirements
  - Extended payload length (hyperlength)
  - ACP limits (new measurement at +/- 3 MHz)

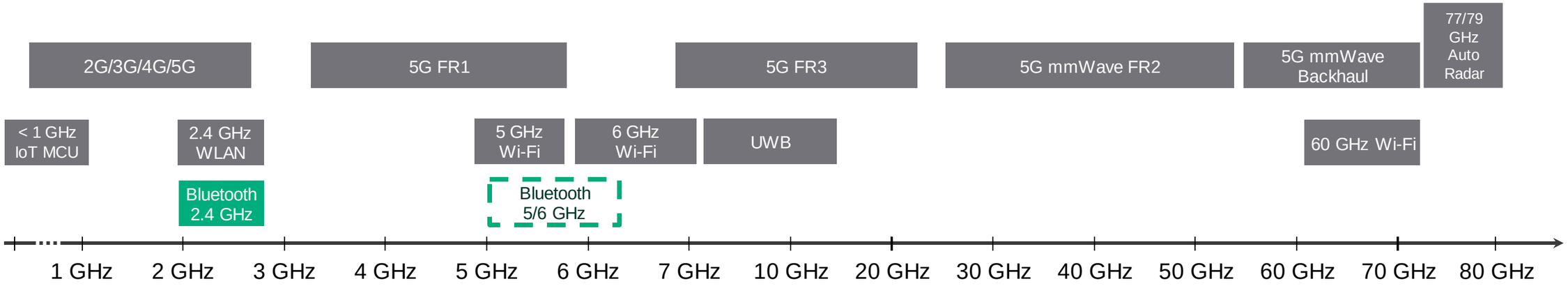






Data Rate	Modulation	Coding Rate	Termination Sequence- two symbols (Bits)	Payload Bits Per Symbols
2Mb/s	Pi/4-QPSK	1/2	4	2
3Mb/s	Pi/4-QPSK	3/4	4	2
4Mb/s	8PSK	2/3	6	3
6Mb/s	16QAM	3/4	8	4
7.5Mb/s	16QAM	15/16	8	4

Higher Frequency Range for Bluetooth LE



Goals

- Higher data throughput
- Lower latency
- Accuracy performance

Applications

- High-resolution audio in congested environment
- Video streaming
- Multi-channel surround

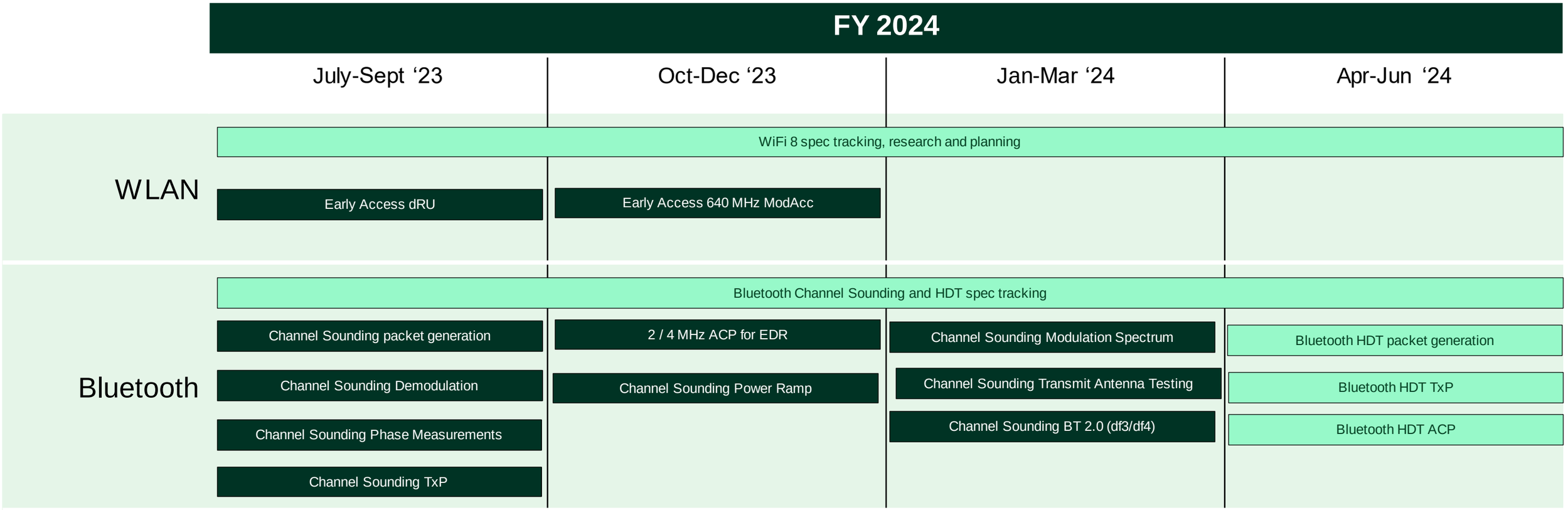
Test Challenges

- Additional spectrum coverage
- Coexistence testing and coordination w/ Wi-Fi and other standards

RFmx Connectivity Features

Released

In Development



UWB

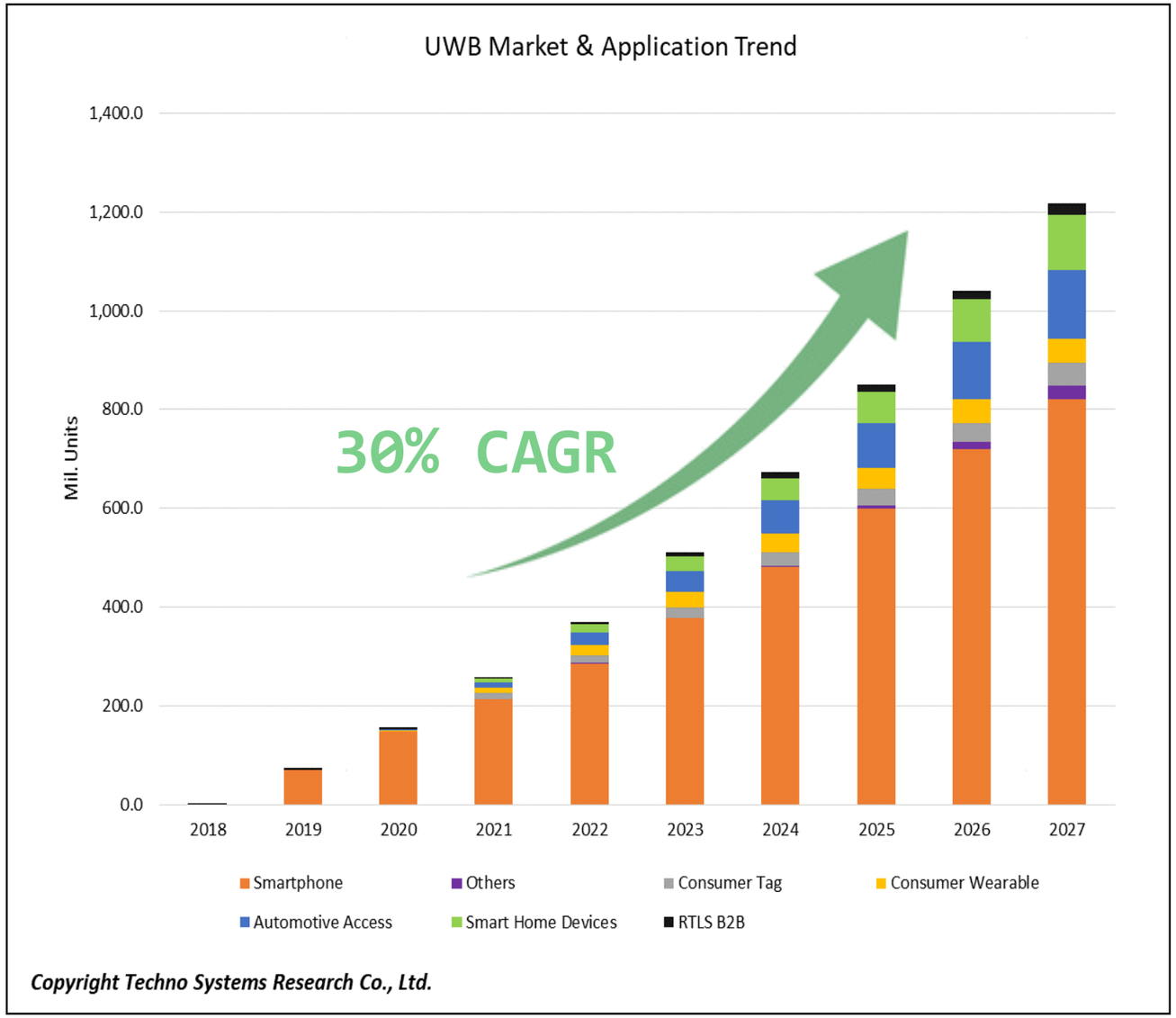
UWB Use Cases...

SMART CITIES & MOBILITY		SMART BUILDING & INDUSTRIAL		SMART RETAIL		SMART HOME & CONSUMER	
Indoor Navigation	V2X* and Autonomous Driving	Social Distancing	Asset Tracking	Tap-Free Mobile Payment	Targeted Marketing	Point and Trigger Controller App	Gesture-Based Control
Vehicle Digital Key (Standardized by CCC)	Ticket Validation (Public Transport Services)	Controlled Access	Find Equipment	Unmanned Store Access	Drone-Controlled Delivery	Residential Access Control	VR Gaming and Group Play
Rider Identification (Private Transport Services)	Reserved Seat Validation	Physical Access Control	Patient Tracking	Foot Traffic and Shopping Behavior Analytics	In-Vehicle Payment	Easy (Logical) Access to Personal Devices	Find Someone/ Something Nearby
Transportation Sharing (Find a Bike or Scooter Nearby)	Transportation Fare Payment	Indoor Navigation	Teleconference System	Exhibition Attendee Management		AR Gaming	Presence-Based Device Activation
Ride Sharing (Precise Positioning)	eID Validation in Crowded Environments	Employee Gathering in Emergencies	Proximity-Based Patient Data Sharing				
Driverless Valet Parking and Pick-Up	Parking Garage Access Control						

Image from FiRa Consortium

...and many more

UWB Market Trend



Copyright Techno Systems Research Co., Ltd.

Mobile

Source: Samsung

Tags

Smart home controls

RTLS (real-time location system)

Asset Tracking

People Tracking

UWB Basics – Band Allocations

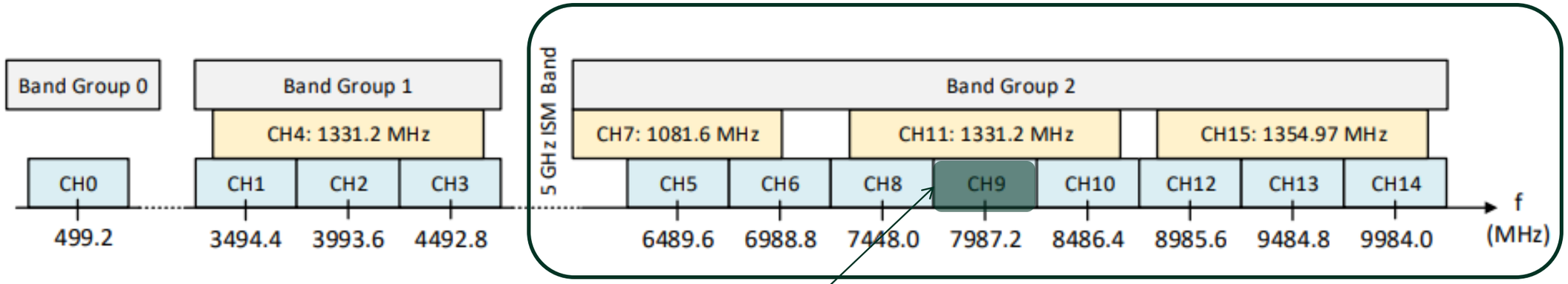
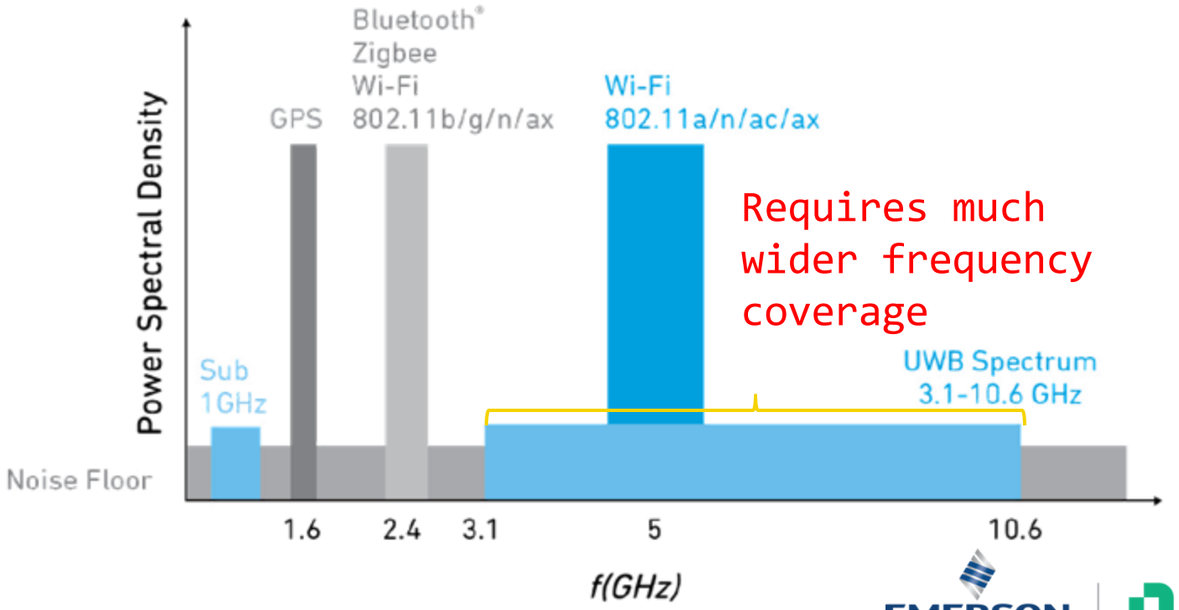


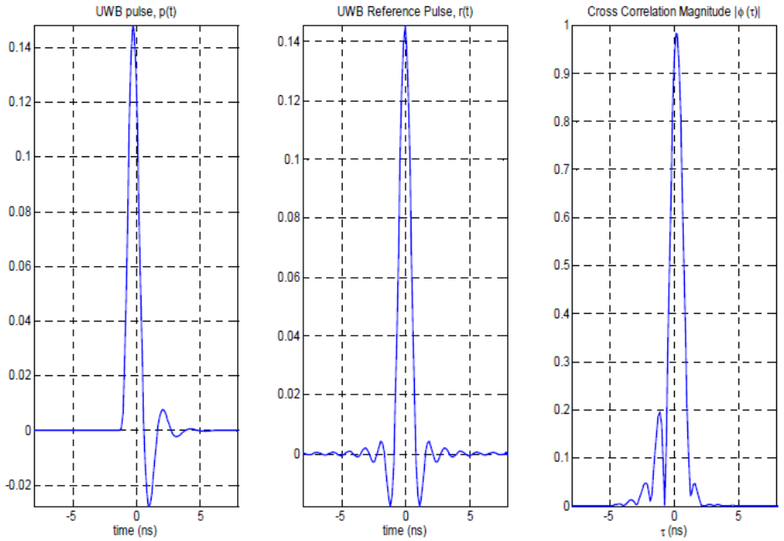
Figure 1: IEEE 802.15.4-2015 - HRP PHY band allocation (blue channels have 499.2 MHz bandwidth, others as noted)

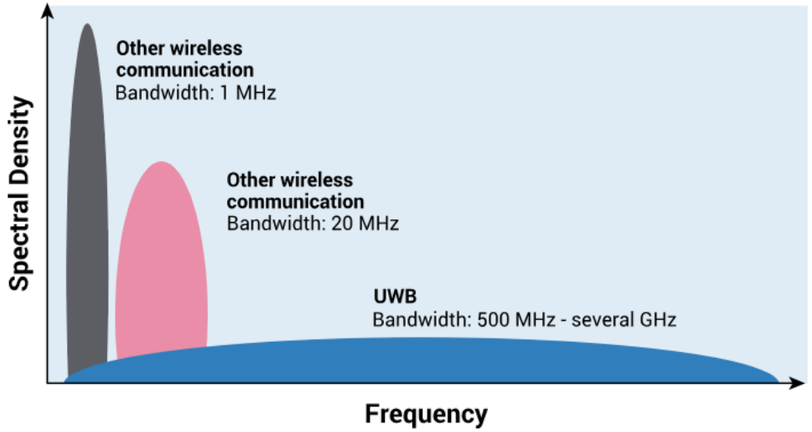
FiRa uses Band Group 2 only with CH9 being mandatory



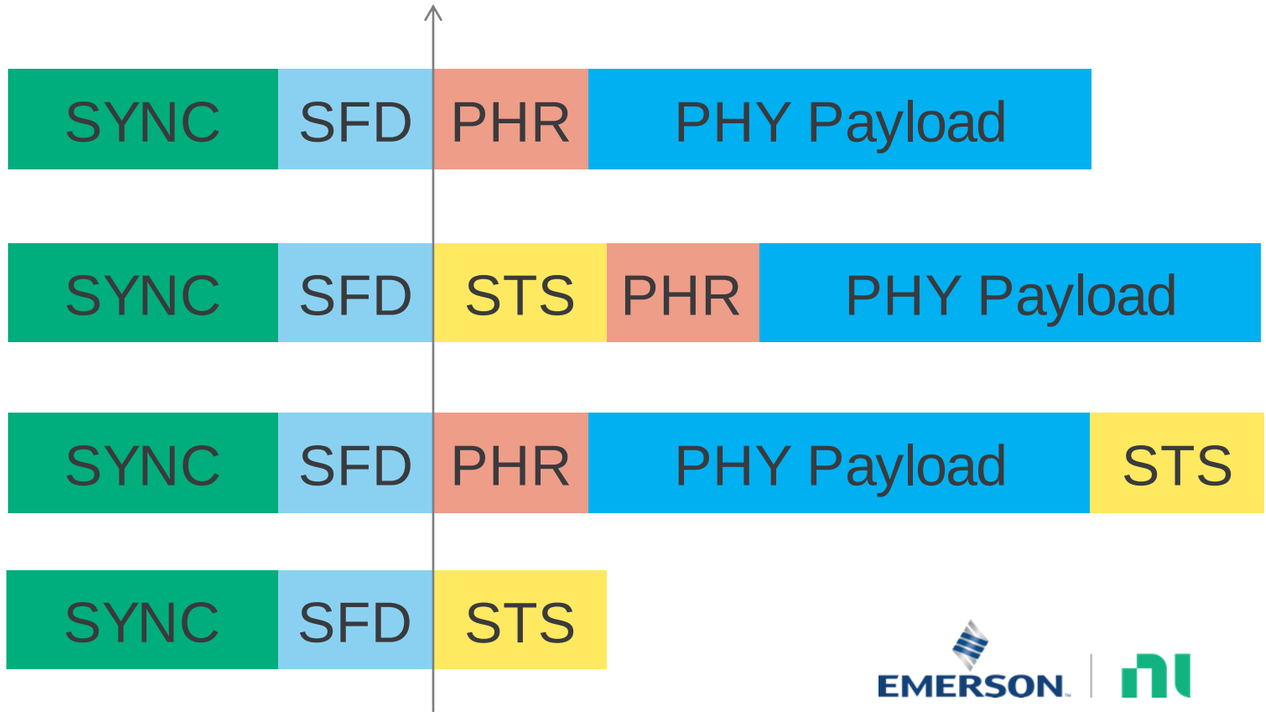
Signal & Packet Format

- Ultra-short pulses in time domain, Ultra-wide in frequency domain.

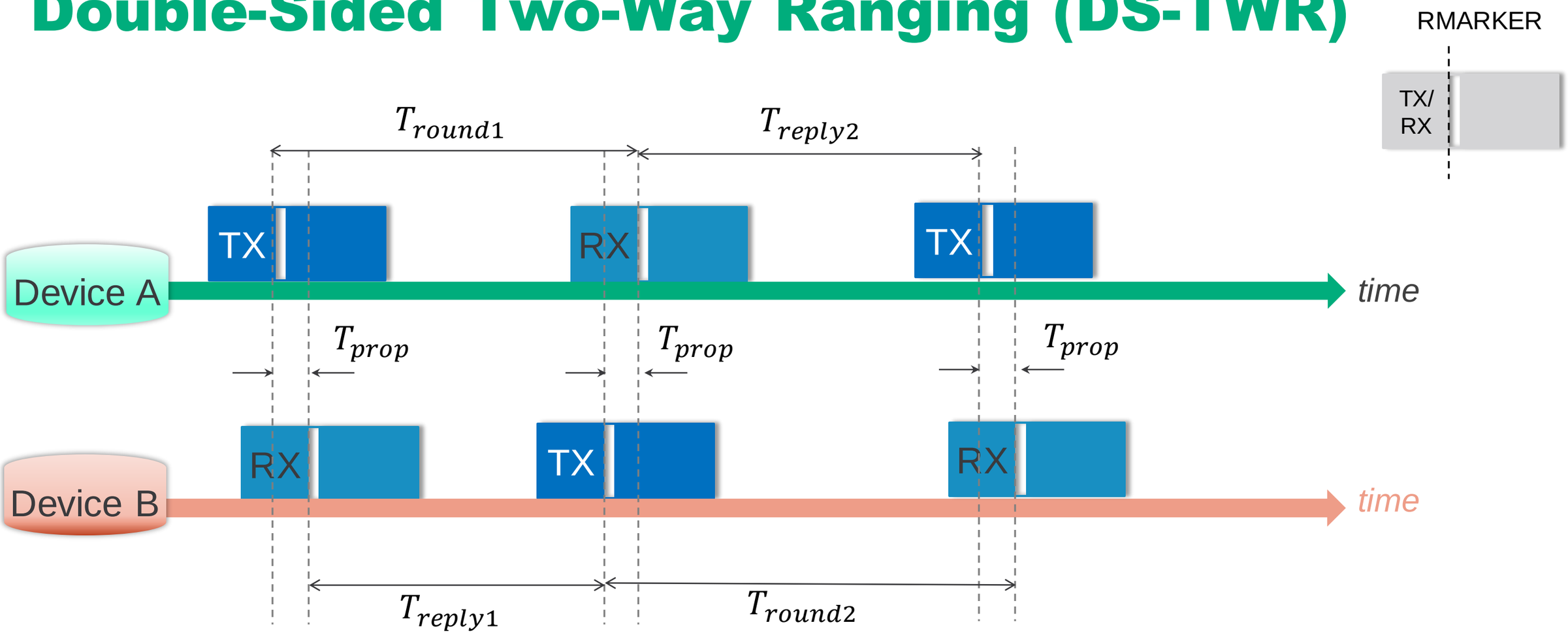




- Sync = Synchronization Section
- SFD = Start-of-frame Delimiter
- PHR = Physical Layer Header
- STS = Scrambled Timestamp Sequence
- PHY Payload Field = Physical Layer Payload



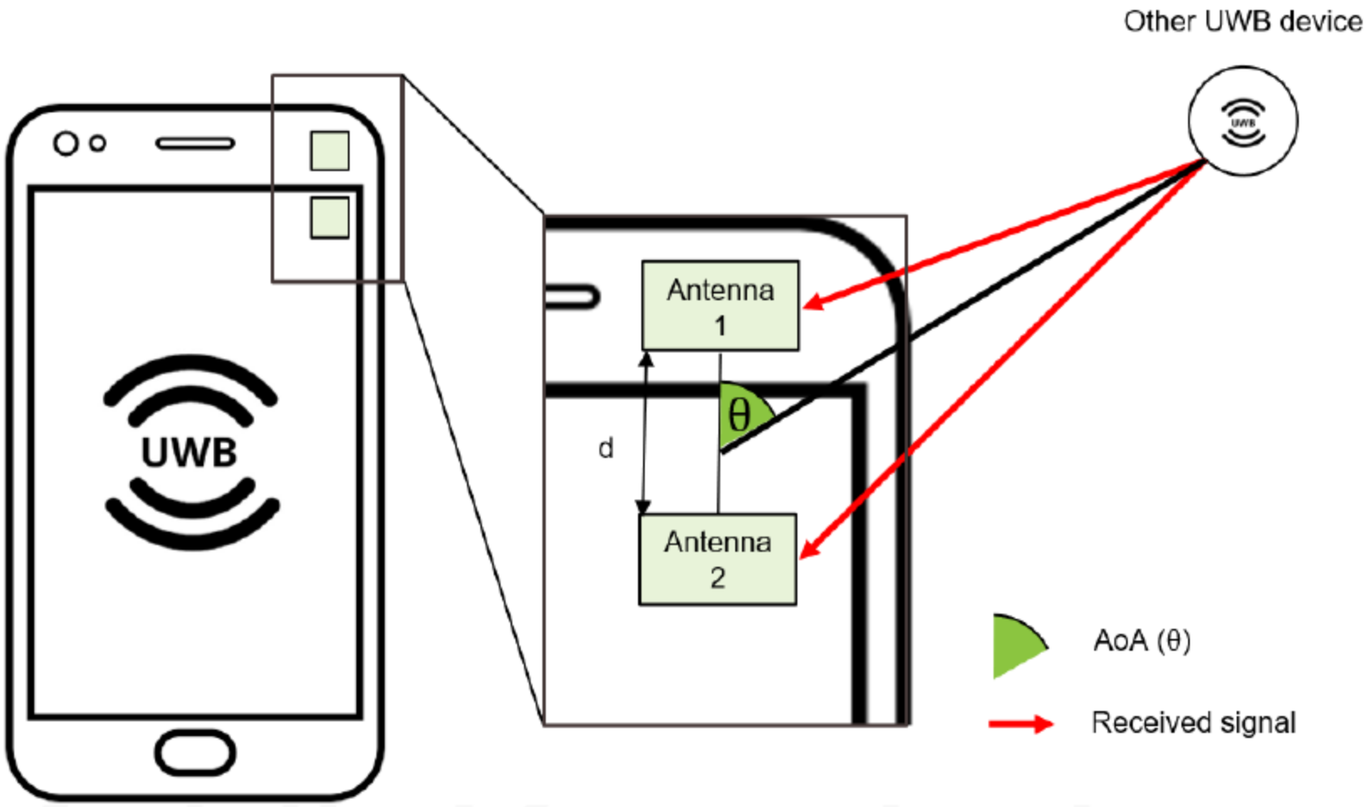
Double-Sided Two-Way Ranging (DS-TWR)

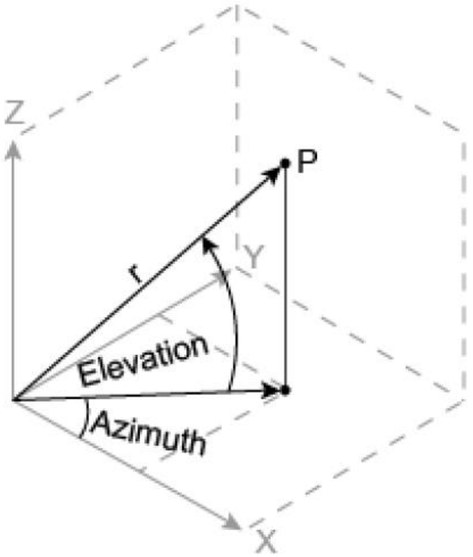


When the clock synchronization between devices are absent, DS-TWR improves accuracy with both devices measuring the time between packets. Estimated time of flight (ToF) could then be derived as

$$T_{prop} = \frac{(T_{round1} \cdot T_{round2} - T_{reply1} \cdot T_{reply2})}{(T_{round1} + T_{round2} + T_{reply1} + T_{reply2})}$$

Angle-of-Arrival (AoA)





The AoA (θ) is a function of the Phase Difference of Arrival (PDoA)

$$\theta = \text{acos}\left(\frac{\Delta\varphi * c}{2\pi d f}\right)$$ The ideal antenna spacing is $$d_{ideal} = \frac{\lambda}{2}$$

Images from Mobile Knowledge

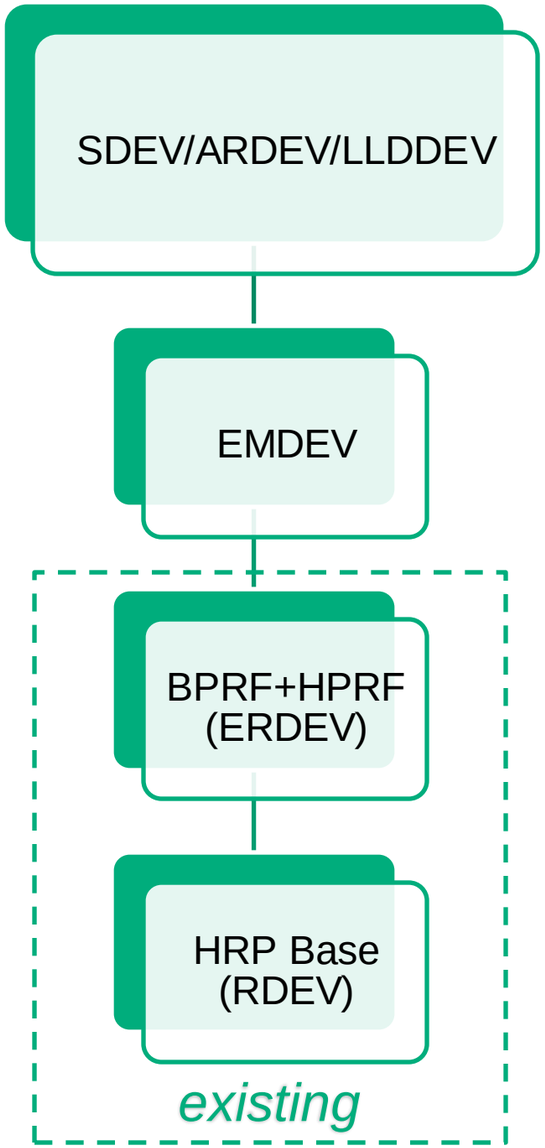
UWB Enhancements - IEEE 802.15.4ab

Additional coding, preamble and modulation schemes

- Existing variants:
  - Base/RDEV or Ranging DEVice (802.15.4)
  - ERDEV or Enhanced Ranging DEVice (802.15.4z)

- These new variants are introduced in 802.15.4ab:
  - EMDEV (enhanced modulations)
    - HPRF (Higher Pulse Repetition Frequency) modes with additional data modulation choices to better support ranging
  - SDEV (sensing)
    - Modes supporting sensing
  - ARDEV (advanced ranging)
    - Modes improving the first path sensitivity by accumulating the channel sounding sequence from a sequence of fragments each sent in a separate millisecond to utilize the allowed per millisecond regulatory transmit power budget
  - LLDDEV (low latency data)
    - Allows dynamic selection between modulation rates and coding schemes with a special PHR (packet header) arrangement

- All the above variants are built on ERDEV and shall support HRP-ERDEV mandatory features



UWB Enhancements - IEEE 802.15.4ab

Narrow Band Assisted multi-millisecond UWB

- Distributes UWB over short bursts spanning N milliseconds providing an emissions up to N*37nJ
- Uses a Narrow Band Companion link to provide time and frequency sync
- Allows low-complexity UWB procession to integrate energies

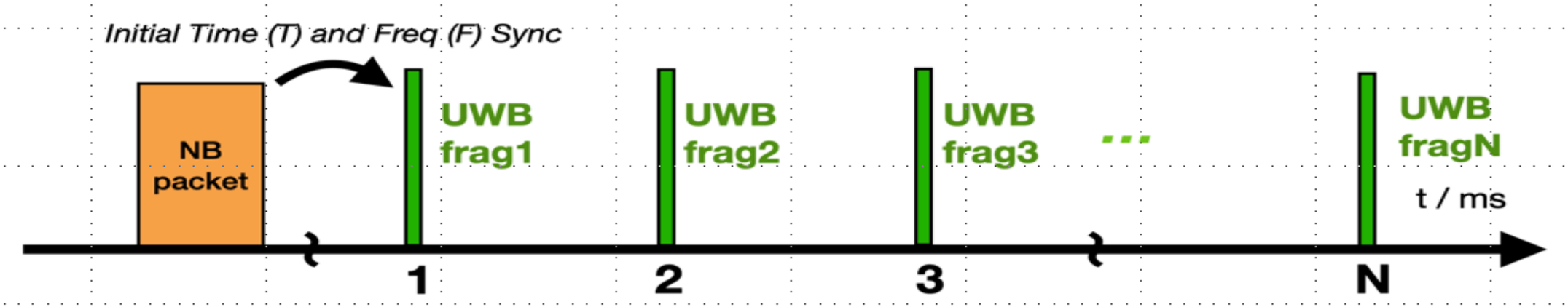


Image from IEEE

UWB Enhancements - IEEE 802.15.4ab

NBA Multi-Millisecond UWB (ranging example)

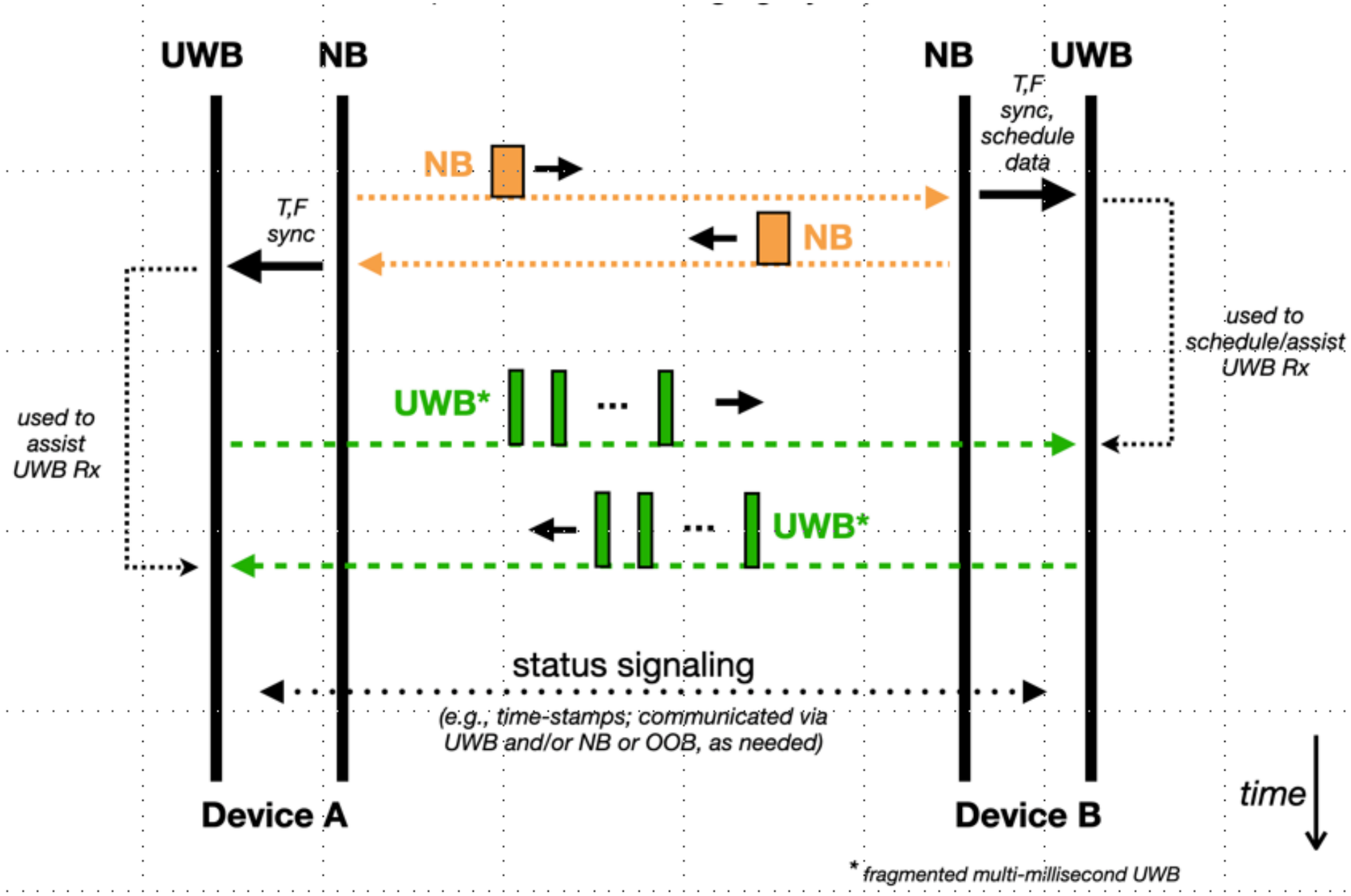
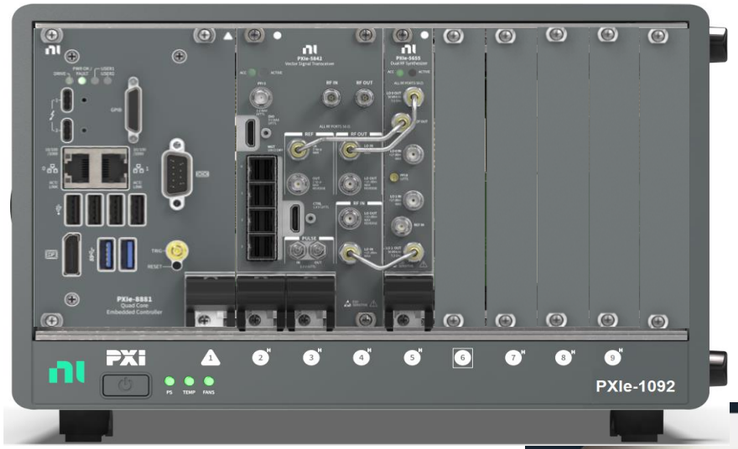


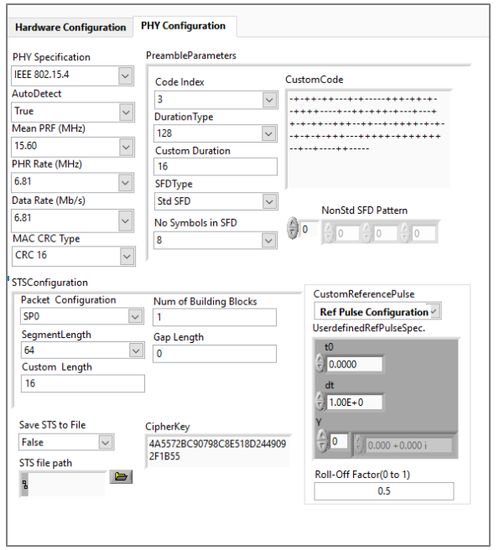
Image from IEEE

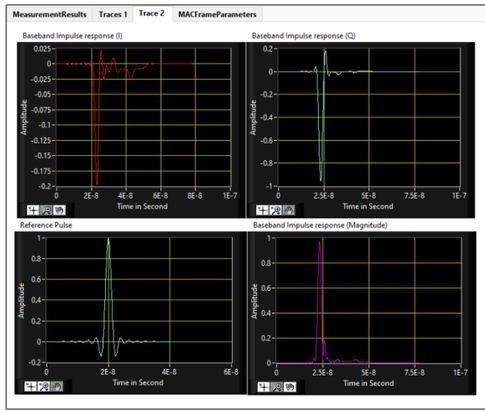
NI UWB PHY Test Solution

Complete FiRa PHY Conformance Test

- **Hardware**
  - PXI Vector Signal Transceiver
  - Colby XT-200 Programmable Delay Line instrument
- **Software**
  - Ultra-Wideband Test Toolkit*
    - Intuitive and flexible software ready-to-run code modules in LabVIEW and C#
    - Precise ToF ranging and AoA measurement support
    - On-the-fly 802.15.4z/FiRa waveform generation with deterministic timing engine
    - Tightly synchronized DC, digital, analog, and RF measurements with unified test platform





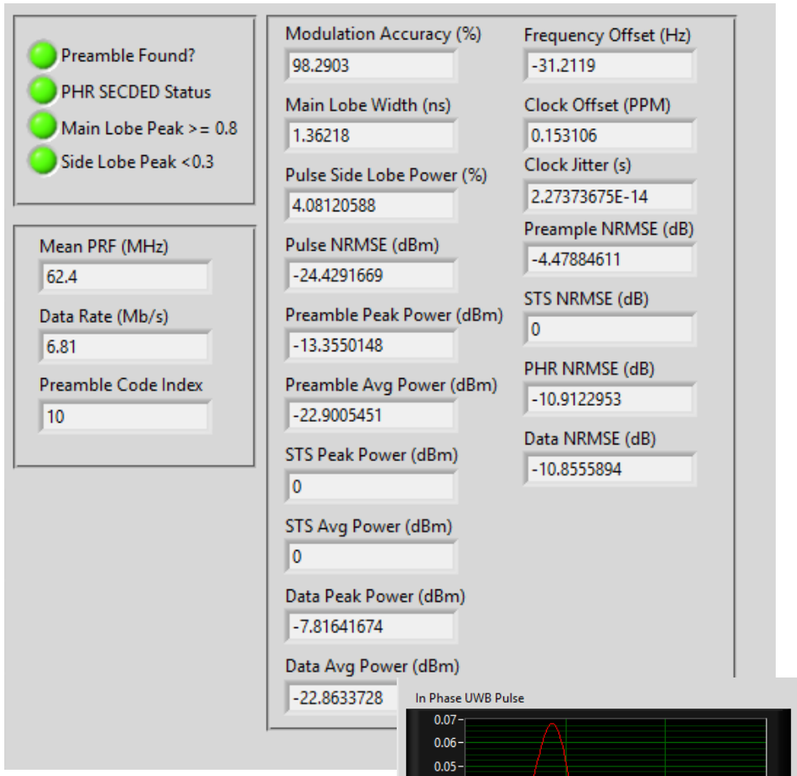


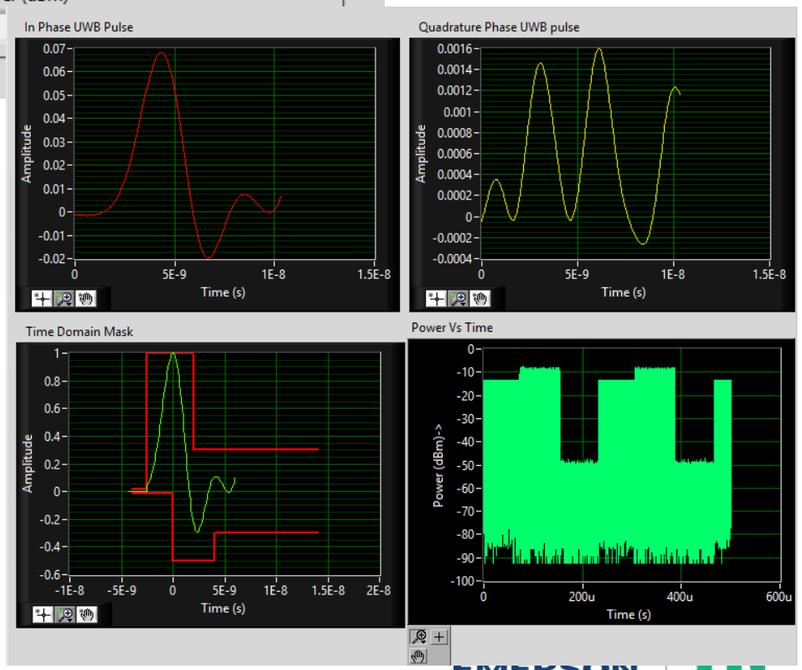
*based on MaxEye UWB Toolkit

UWB Measurements

- **Supports IEEE 802.15.4 and 15.4z HRP standard**
- **FIRA PHY and MAC Specifications 1.1 (2.0)**

- **Supported Tests**
  - Power Measurements
  - Modulation Accuracy
  - Frequency and Clock Offset Measurements
  - Spectral Emission Mask
  - Pulse Main Lobe Width
  - MAC CRC, Packet Error Rate and Payload Bits
  - Baseband Impulse Response
  - UWB Pulse Time Domain Mask
  - Time of Flight (Ranging Test)





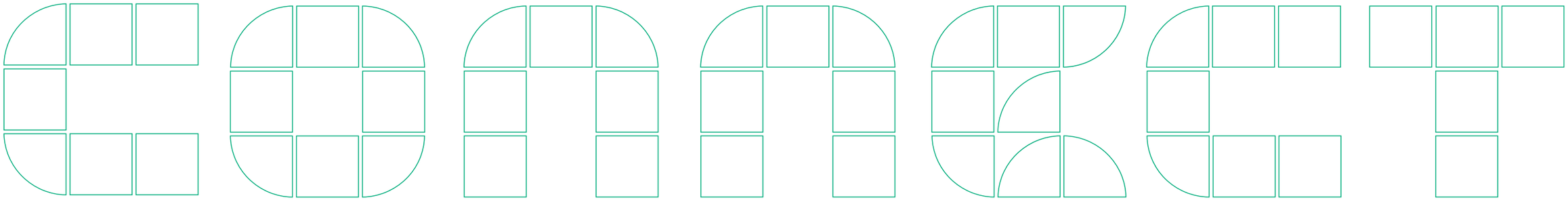
RF Software Connectivity Features

Released

In Development

FY 2024

	July-Sept ‘23	Oct-Dec ‘23	Jan-Mar ‘24	Apr-Jun ‘24
RFmx WLAN	Early Access dRU	Early Access 640 MHz ModAcc		
RFmx Bluetooth	Bluetooth Channel Sounding and HDT spec tracking			
	Channel Sounding packet generation	2 / 4 MHz ACP for EDR	Channel Sounding Modulation Spectrum	Bluetooth HDT packet generation
	Channel Sounding Demodulation	Channel Sounding Power Ramp	Channel Sounding Transmit Antenna Testing	Bluetooth HDT TxP
	Channel Sounding Phase Measurements		Channel Sounding df1/df2 measurements	Bluetooth HDT ACP
	Channel Sounding TxP			
UWB (MaxEye-based)	FiRa PHY Conformance spec tracking			
			FiRa 2.0 Certification	802.15.4ab support
			OTA Evaluation and App Note	ToF/AoA for VST3
				FiRa 2.1 Secure Ranging



Q&A

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