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A Teradyne Company

The Latest Trends in UWB: the Market, Manufacturing, and More

UWB Refresher – What & Why?

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Why is UWB for Ranging Needed?

Security

- UWB can be used for user authentication based on location
- Compared to RSSI ranging, UWB uses Time-of-Flight (ToF). RSSI is easy to hack, time is difficult to fake

Likely UWB applications are in three main use cases

HANDS-FREE ACCESS CONTROL

Simply approach the door and it opens, leave the door on the unsecure (outside) and it locks

LOCATION-BASED SERVICES

Bring positioning functionality with a high degree of accuracy to indoor environments

DEVICE-TO-DEVICE SERVICES

Let two UWB devices share relative ranging and positioning data to localize each other

Source: FiRa Consortium

UWB Applications: Automotive Access Control

BMW's Digital Key Plus will let iPhones unlock the iX from a pocket or bag

Using the ultra wideband chip that debuted in the iPhone 11

By Jon Porter | @JonPorty | Jan 14, 2021, 7:26am EST

Source: TheVerge / BMW

Accessibility

- UWB enables precision localization of car keys, instantly and precisely

Convenience

- Your car will be able to recognize when you are getting closer and automatically unlock, turn on lights, or launch personalized settings

Security

- UWB puts an end to relay attacks

UWB Applications: Location Based Services

UWB technology brings GPS-style positioning functionality to indoor environments.

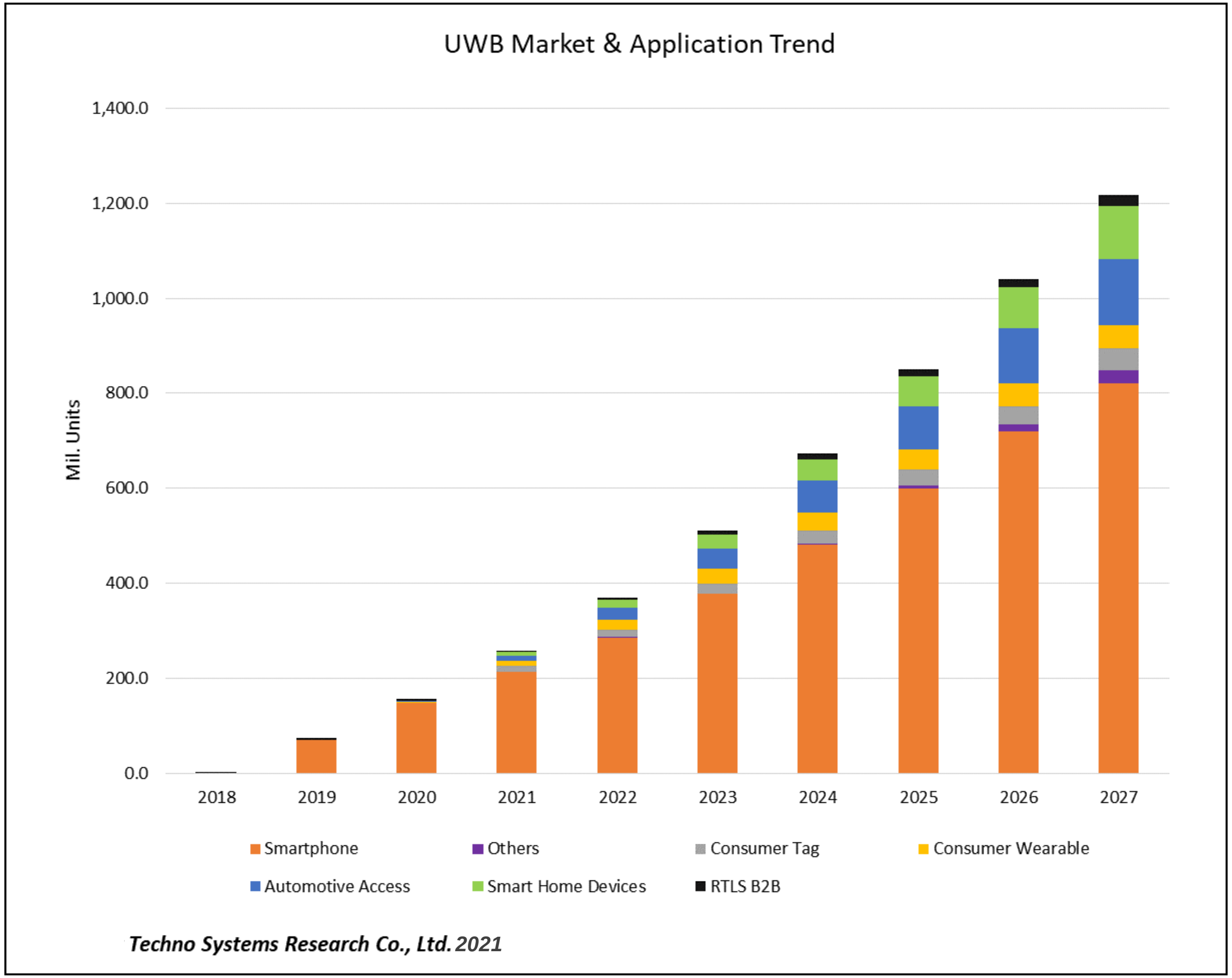
<u>Highly precise</u> positioning (<10 cm)

Operates in crowded, multipath signal environments, and can pass through walls, machinery, and other obstacles.

Easier to navigate large spaces, such as airports and shopping malls

UWB Unit Shipments to Grow at 35% CAGR through 2025

- Main Adoption Areas:
  - – Mobile
  - – Automotive
  - – Smart Home
  - – Wearables / Tags



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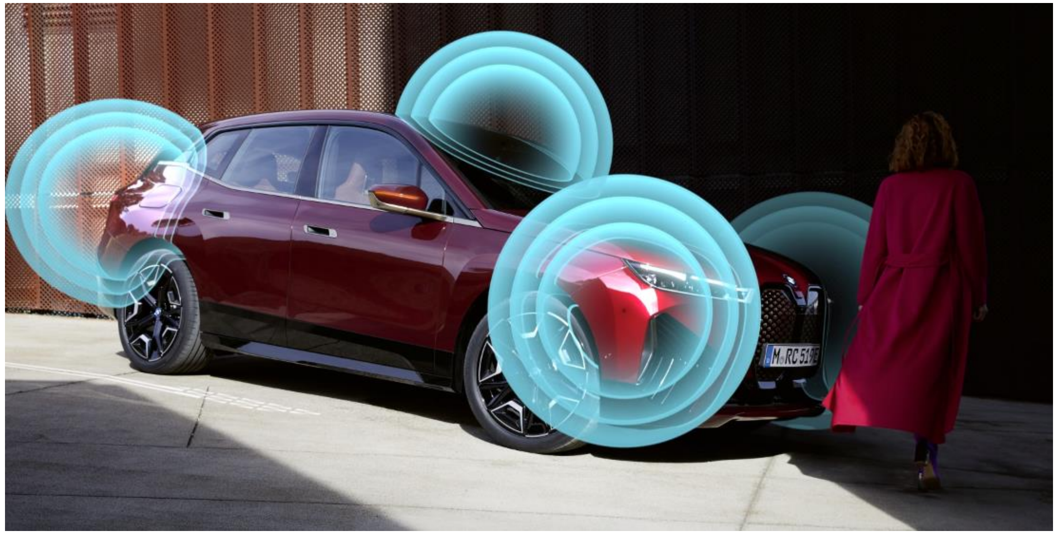
UWB-Enabled Products



How Does UWB Ranging Work?

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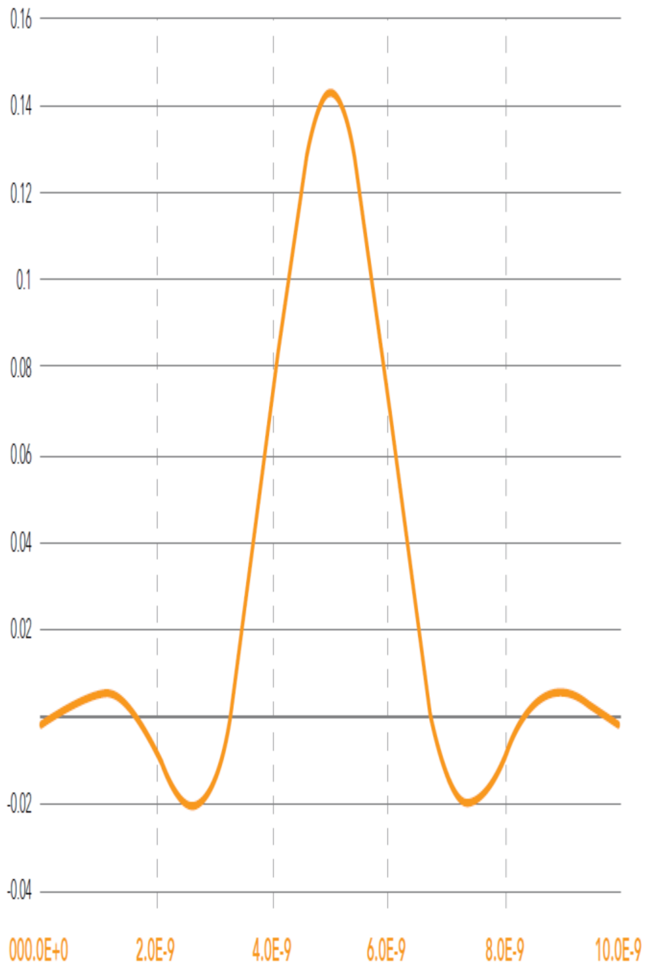
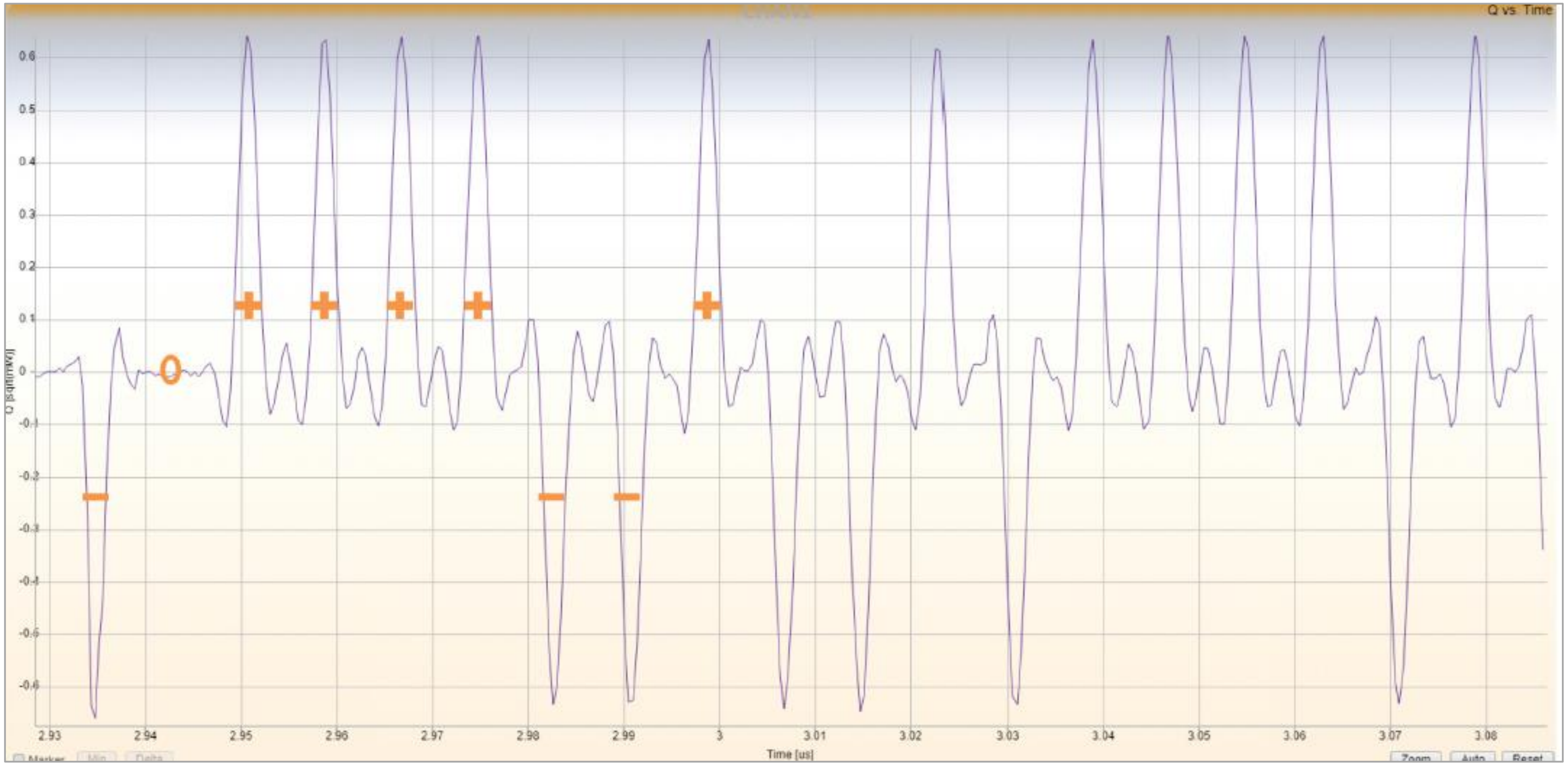
UWB Encodes the Data in the Pulses

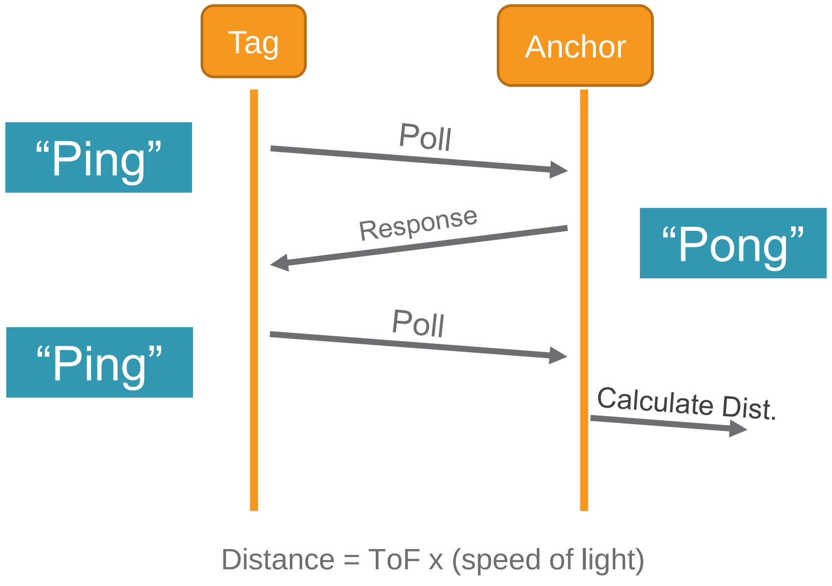
Reference Pulse



Code Sequence of Pulses



How UWB Ranging Works - Time of Flight (ToF)



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

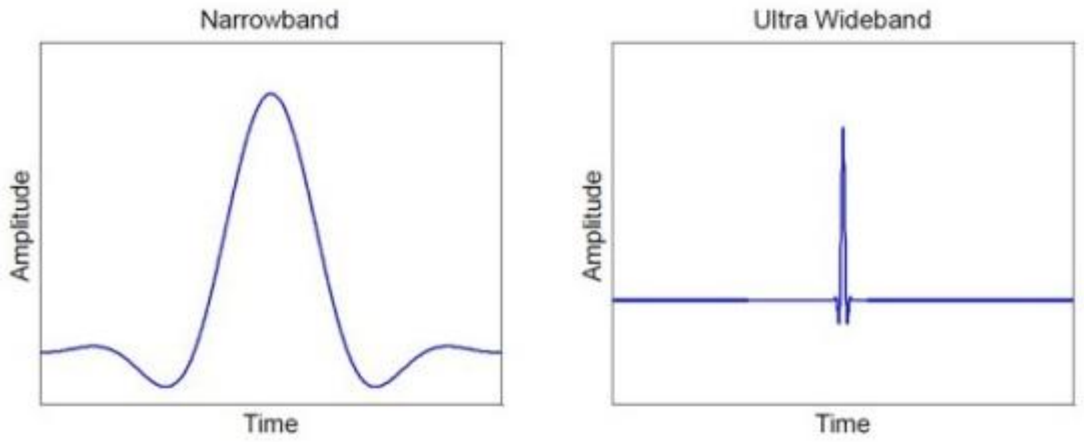
This measurement technique is called:

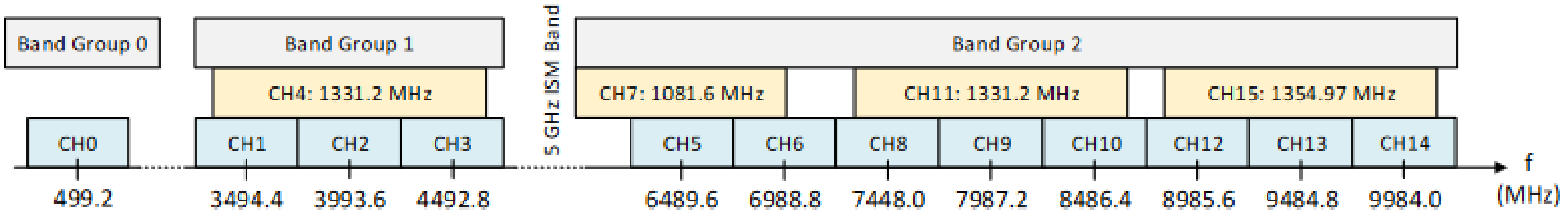
- Single-Sided Two-Way Ranging (aka "Ping – Pong")
- Double-Sided Two-Way Ranging (aka "Ping – Pong – Ping")

High Level UWB Specs (802.15.4z)

Parameter	Value
Center Frequency Range (HRP- Band Group 2)	6489.6 – 9984.0 MHz
Channel Bandwidth	500 MHz (typical) up to >1 GHz
Transmit Output Power	< -41.3 dBm / MHz
Data Rates	110 kpbs, 425 kbps, 850 kbps, 1.7 Mbps, 6.81 Mbps, 27.24 Mbps
Ranging Support	Yes
Range	10 m – 100 m
Positional Accuracy	<10 cm*

*after system calibration





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What Are the Critical UWB Tests and Why?

UWB Test Categories

Regulatory

Ensures that the device meets all local emissions rules

Interoperability

Ensures that the devices functions in the end-application per the standard

Performance

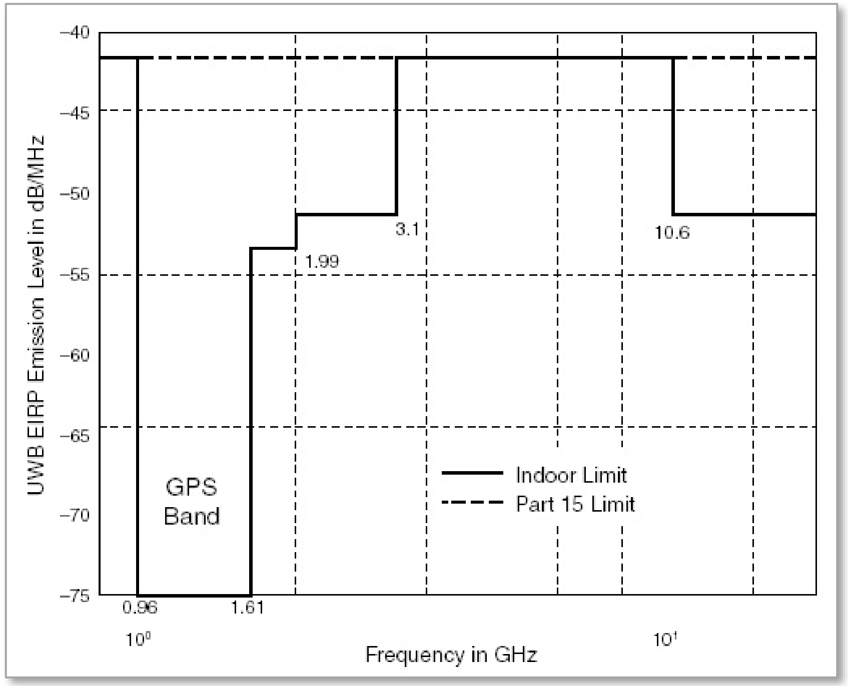
Ensures that the device provides a positive user experience and avoids customer returns

UWB Tests and How they Check Quality

UWB Test	Regulatory	Standards and Interoperability	Performance / User Experience
Crystal Trim Calibration		✓	✓
Antenna Delay Calibration			✓
TX Power Calibration	✓		✓
Data / Preamble Power	✓		
Data / Preamble Peak Power	✓		
Spectrum Mask Margins	✓		
Carrier Frequency Offset		✓	✓
Chip Clock and Frequency Error		✓	✓
Pulse Main Lobe Width, Side Lobe Power		✓	✓
Symbol Modulation Accuracy		✓	✓
Pulse NMSE		✓	✓
RX Sensitivity Verification		✓	✓
ToF Calibration / Verification			✓
AoA Calibration / Verification			✓

FCC Regulatory Compliance

- UWB has been authorized to operate under “Part 15” of the FCC rules
- This enables UWB devices to **operate without a license**
- Devices <u>must</u> adhere to emissions limits
  - For UWB Band Groups 0, 1, & 2 this corresponds to -41.3 dBm / MHz

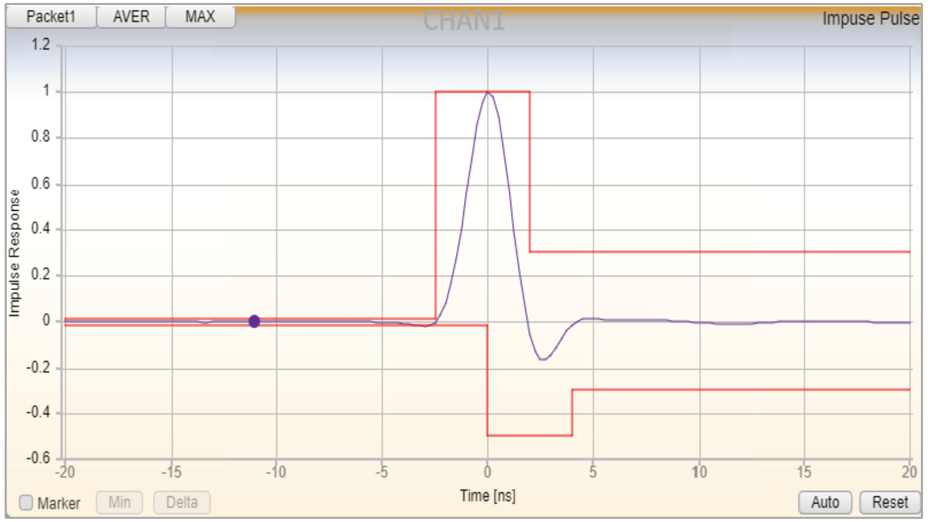


Critical Regulatory Compliance Tests

✓ TX Power Calibration

TX Power calibration to ensure compliance to regulatory limits

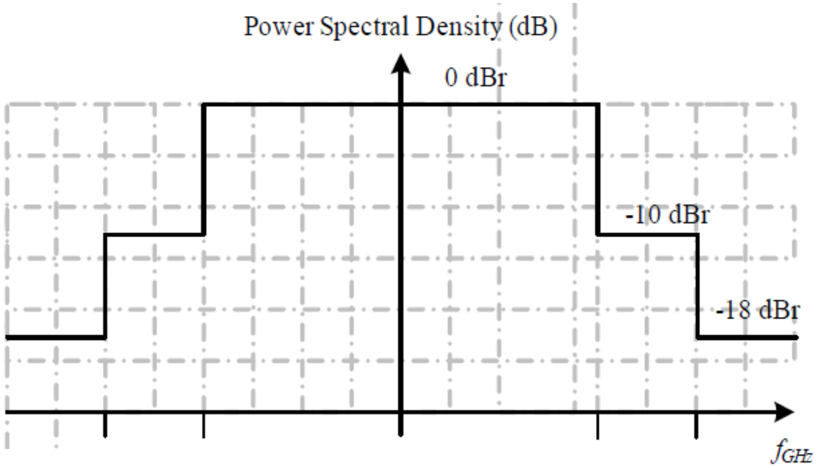
- Transmission duty cycle affects the packet power
- DUT gain can be calibrated to maximize TX power while remaining compliant with FCC limits
- Pulse shape has high impact on mask emissions



✓ Spectrum Mask Margins

TX Power Mask:

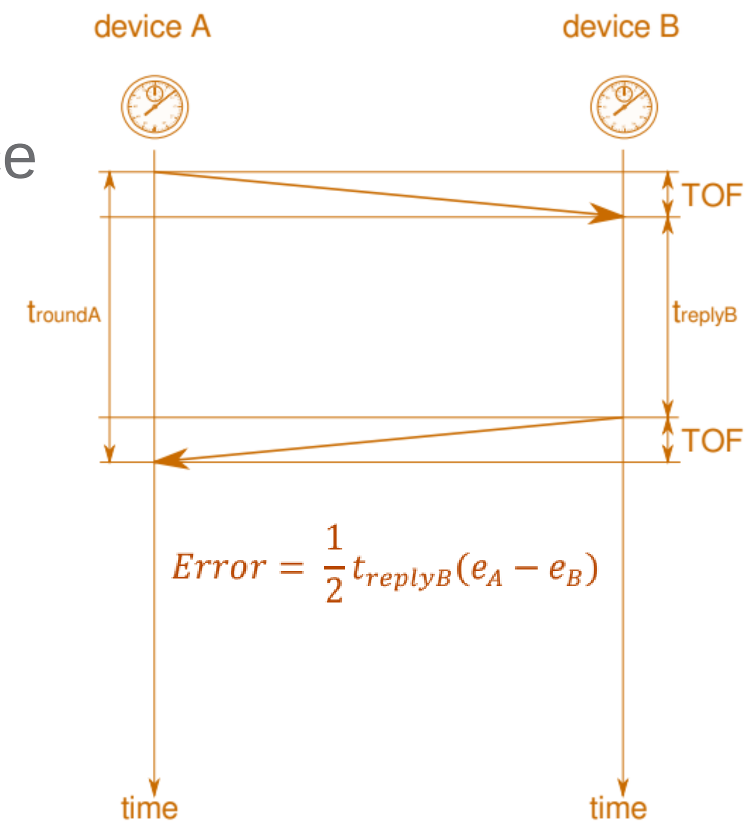
- UWB emissions are highly sensitive to pulse shape
- Ensure that output power < -41.3dBm/MHz (FCC)
- Device can implement power “back off” to ensure meeting mask limit, however at the expense of range



Transmit spectrum mask

Critical Performance Optimization: Crystal Calibration / Trim

- ✓ Crystal calibration trims crystal tuning capacitors to reduce frequency offset error
- ✓ Improves receiver sensitivity by minimizing CFO error
- ✓ Improves interoperability and ToF accuracy
- ✓ Calibration requires high performance Clock Reference
- ✓ Enables cost-effective XTAL selection for BOM



$$Error = \frac{1}{2} t_{replyB}(e_A - e_B)$$

Source: decaWave Application Note APS011

- Example of Frequency Error / Drift on Accuracy
  - ToF Ping-Pong round-trip time of 4ms:
    - ➢ 1 PPM offset/drift results in timing inaccuracy of 4ns
    - ➢ Resulting positional error would be 0.6m

Critical Interoperability UWB Test Areas

Parametric tests to ensure device functionality to the standard:

IEEE Standards

Reference Pulse Correlation
- IEEE 802.15.4 Section 16.4.5, "Baseband Impulse Response"

Main Lobe Width
- IEEE 802.15.4 Section 16.4.5, "Baseband Impulse Response"

Side Lobe Width
- IEEE 802.15.4 Section 16.4.5, "Baseband Impulse Response"

Data Integrity

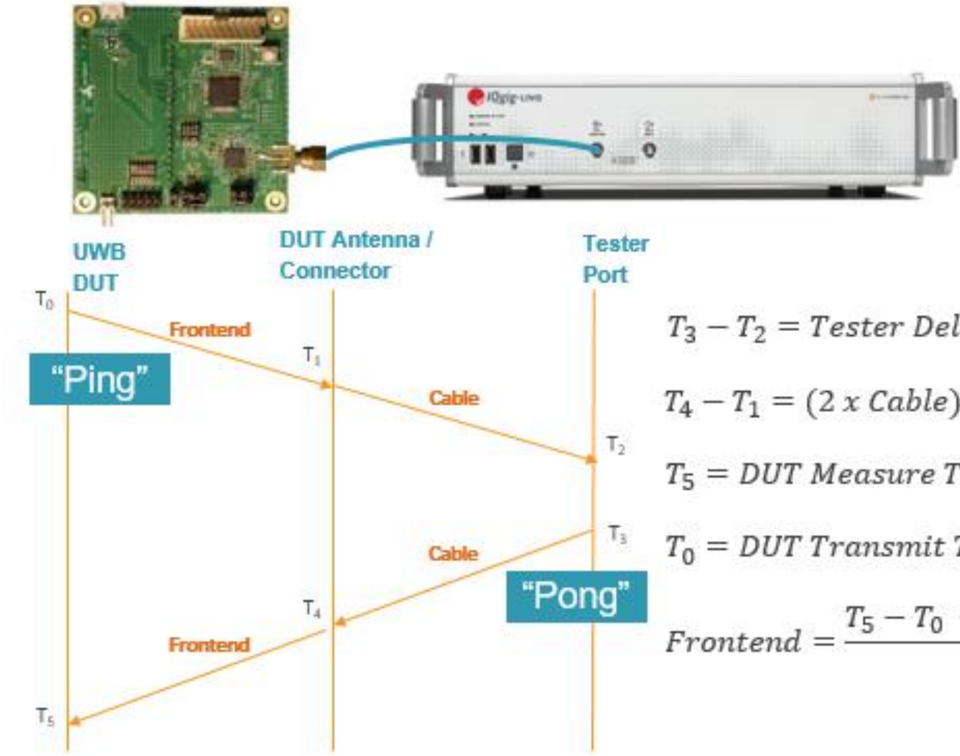
Symbol Modulation Accuracy
- "EVM" for UWB
- Measure of symbol correlation to "ideal" reference pulse
- Summary of system performance and demodulation accuracy

Normalized Mean Square Error
- Comparison of the DUT captured pulse to the reference pulse
- Summary Measurement of many system effects (matching performance, filter effects, group delay)

Measurement	Value	Unit
Carrier Frequency Offset	0.58	Hz
Chip Clock Error	-0.01	ppm
Chip Frequency Error	0.55	Hz
Symbol Modulation Accuracy	98.95	%
Pulse Main Lobe Width	0.939	ns
Pulse Side Lobe Power	20.96	%
Data Rate	6.81	Mbps
PSDU Length	20	Bytes
Analysed Symbols	240	
Preamble Power	-39.39	dBm
Preamble Peak Power	-28.59	dBm
Data Power	-39.5	dBm
Data Peak Power	-26.92	dBm
PHR CRC	Pass	
Pulse Jitter	31.34	ps
Pulse NMSE	34.98	ppm
PSDU CRC	Pass	

Critical Performance Optimization: Antenna Delay Calibration

- ✓ Component tolerances differ from Device to Device
- ✓ Calibration compensates for delays introduced by PCB, external components, antenna, and chipset variation
- ✓ Antenna Delay Calibration ensures accuracy of ToF measurement



$$T_3 - T_2 = Tester\ Delay$$

$$T_4 - T_1 = (2\ x\ Cable) + Tester\ Delay$$

$$T_5 = DUT\ Measure\ Time$$

$$T_0 = DUT\ Transmit\ Time$$

$$Frontend = \frac{T_5 - T_0 - (T_4 - T_1)}{2}$$

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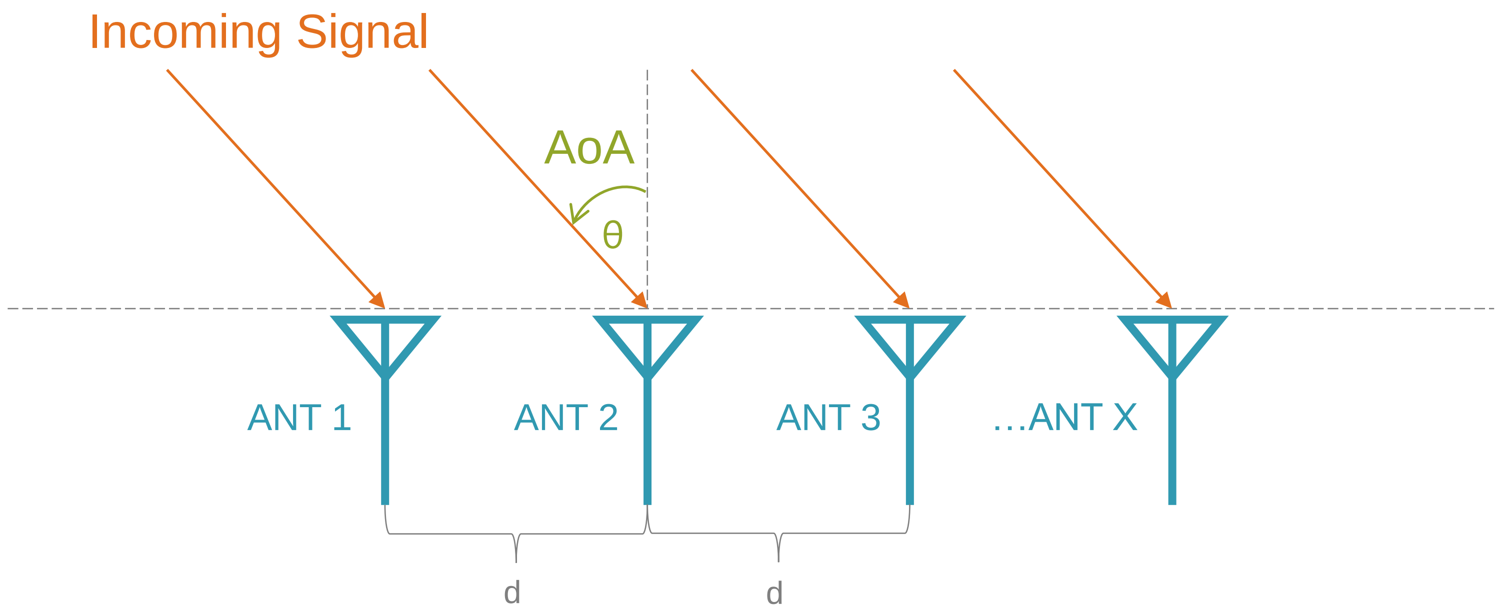
Critical Performance Optimization: AoA Calibration / Verification

- Used in applications for localization, tracking, etc.
- Enables peer-to-peer communication of UWB devices
- Requires 2 or more antennas on the device
- AoA (Angle-of-Arrival) is based on the Time Difference of Arrival (TDoA) between individual elements of the antenna array



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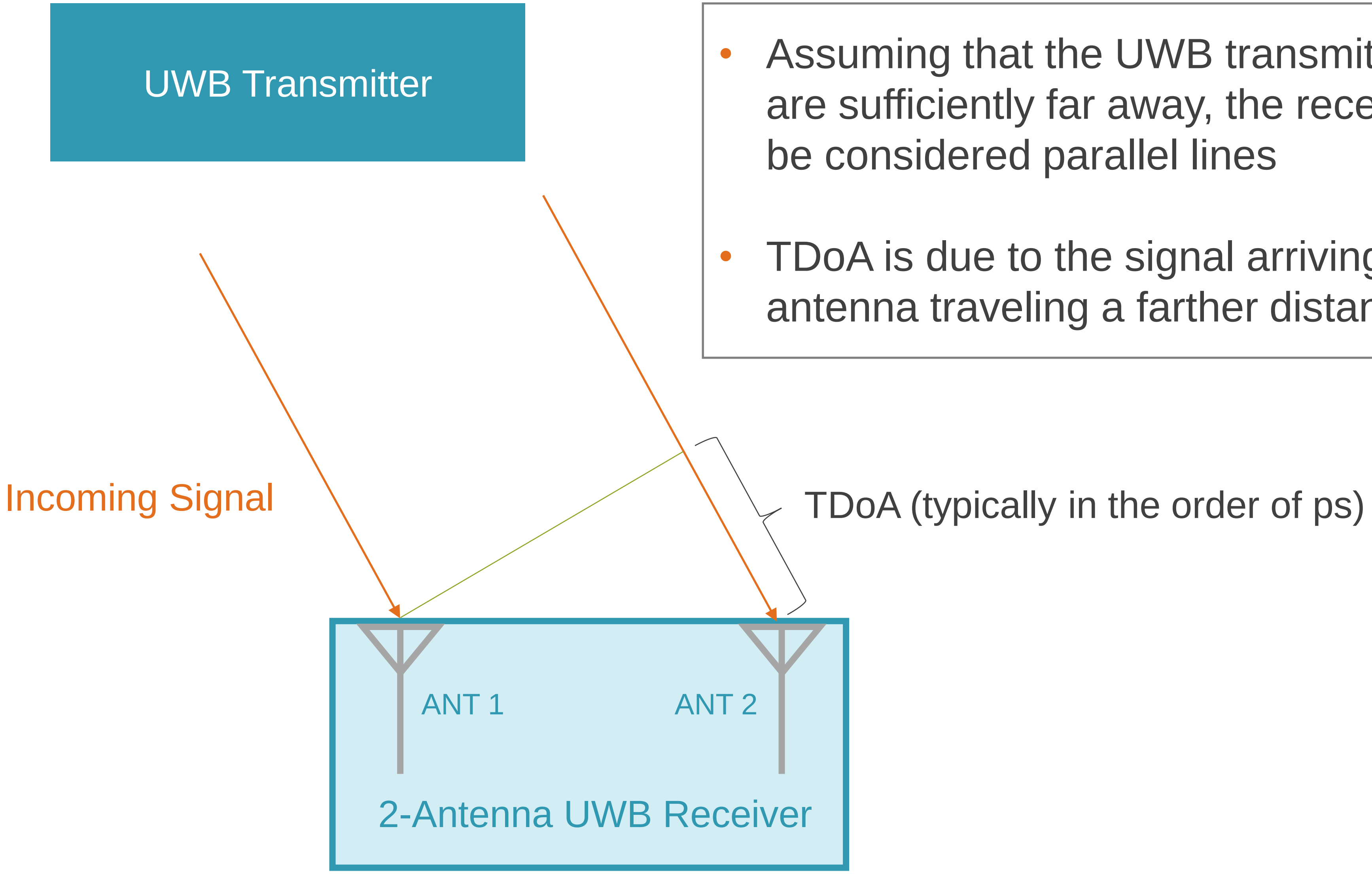
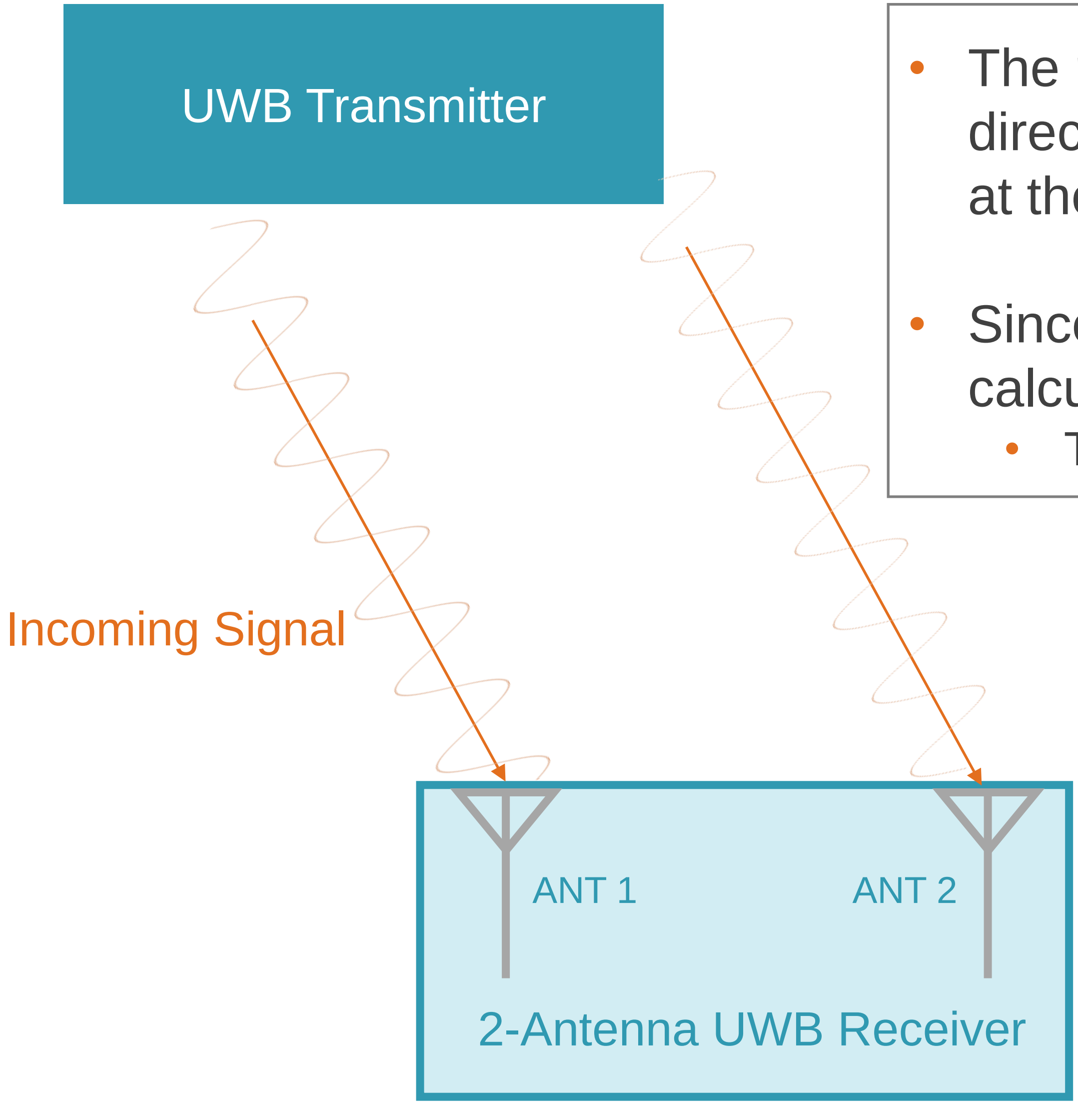
Angle-of-Arrival Example: Time Difference of Arrival (TDoA)

- Assuming that the UWB transmitter and receiver are sufficiently far away, the received signals can be considered parallel lines
- TDoA is due to the signal arriving at the right antenna traveling a farther distance



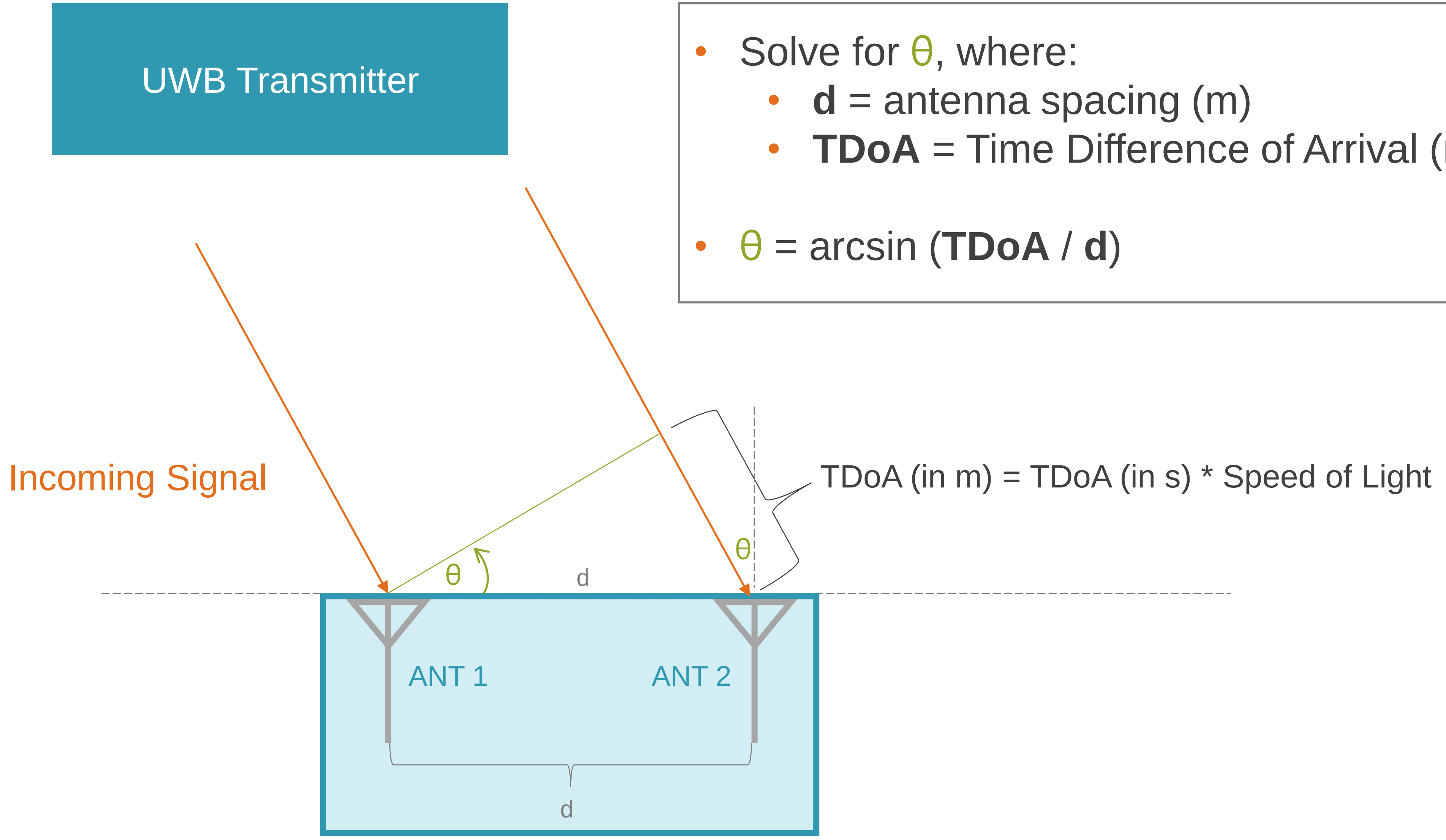
Angle-of-Arrival Example: Phase Difference of Arrival (PDoA)



- The receiver does not typically measure TDoA directly, it measures the difference in phases seen at the antennas (PDoA)
- Since the carrier frequency is known, TDoA can be calculated from PDoA:
  - TDoA = PDoA (in degrees) / (Carrier Freq * 360)

Angle-of-Arrival Example: Dust off that Trigonometry

- Solve for θ, where:
  - **d** = antenna spacing (m)
  - **TDoA** = Time Difference of Arrival (m)
- θ = arcsin (**TDoA** / **d**)



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Comprehensive UWB Test Solutions

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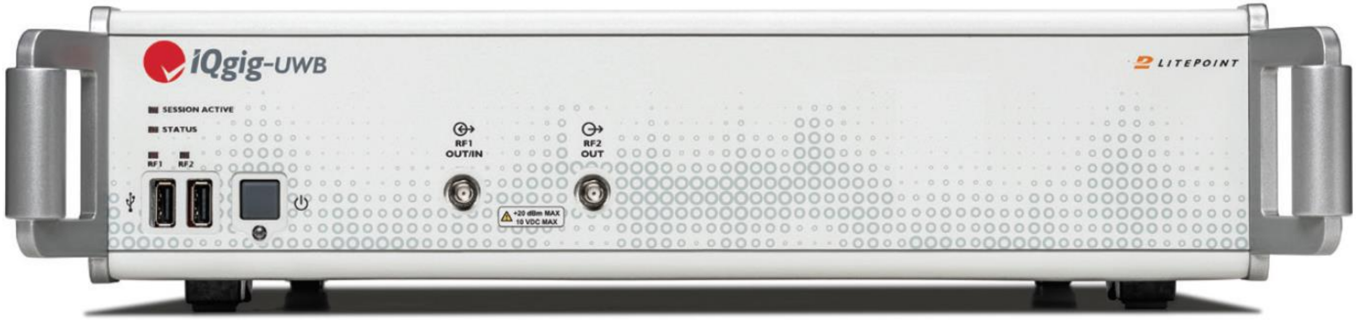
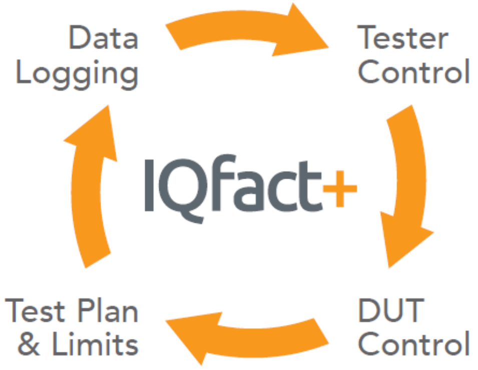
Designed for UWB



- **Fully-integrated test system for UWB**
  - Hundreds of systems in volume production
- **Complete UWB calibration and test coverage**
  - Time of Flight, Angle of Arrival, Power/XTAL Cal, RX Sensitivity
- **Close collaboration with leading UWB chipset vendors**
  - Turnkey IQfact+ software solutions provide out-of-the-box results
- **FiRa Consortium certification**
  - Turnkey Solution for FiRa Consortium PHY Conformance Testing



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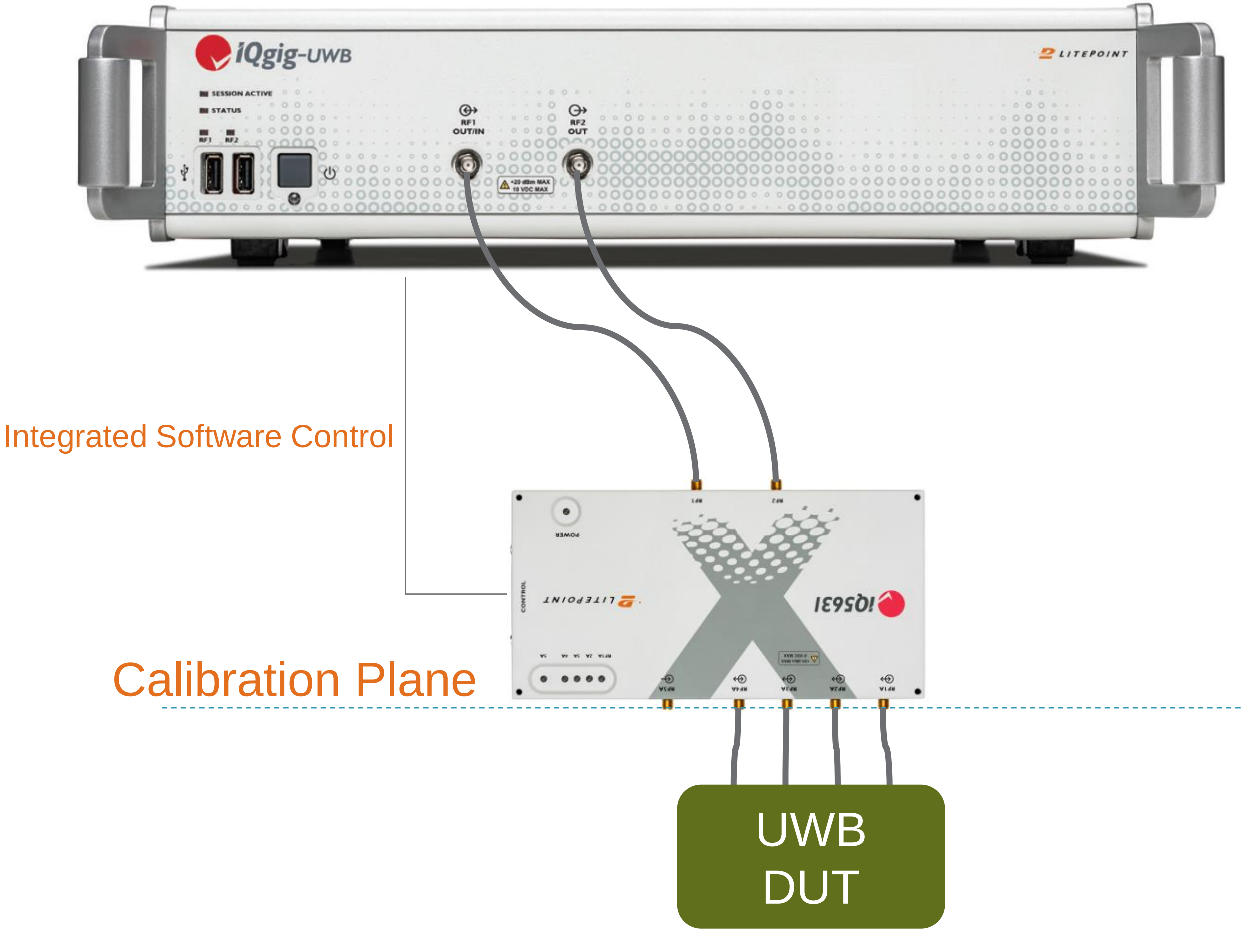
UWB Solution Overview: IQgig-UWB

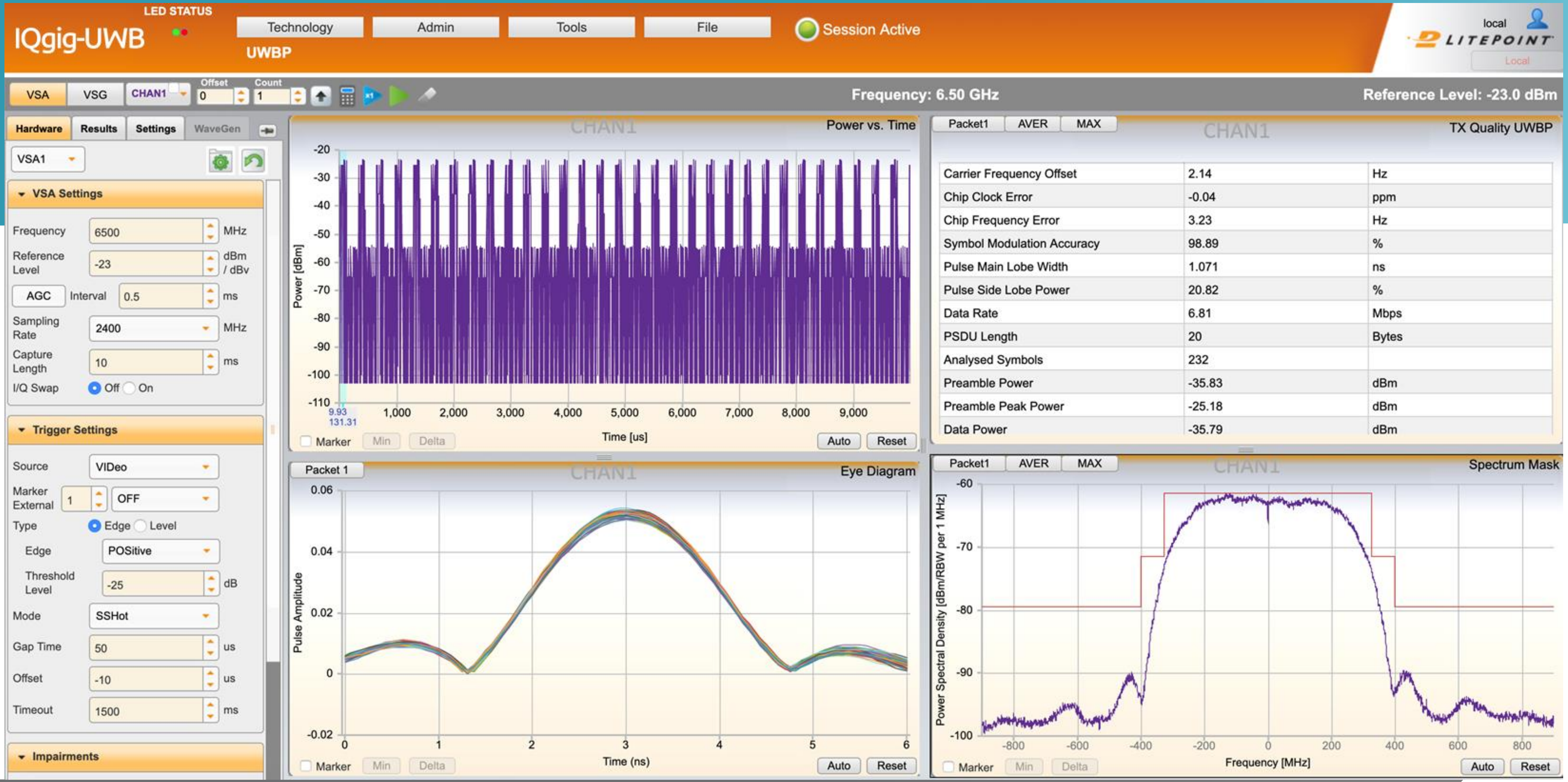


Integrated VSA / VSG and
UWB Signal Processing

Power and Delay Control Module:
- RX Sensitivity to -110 dBm
- Integrated Delay for AoA Calibration
- Fully-integrated in Software
- Supports up to 4 Antenna DUT

Calibrated to the DUT Interface
100% Native Software Integration
Supports <u>All</u> Critical UWB Measurements
Multi-Antenna, Multi-DUT Scalability

Integrated UWB PHY Layer Measurements



The FiRa Consortium

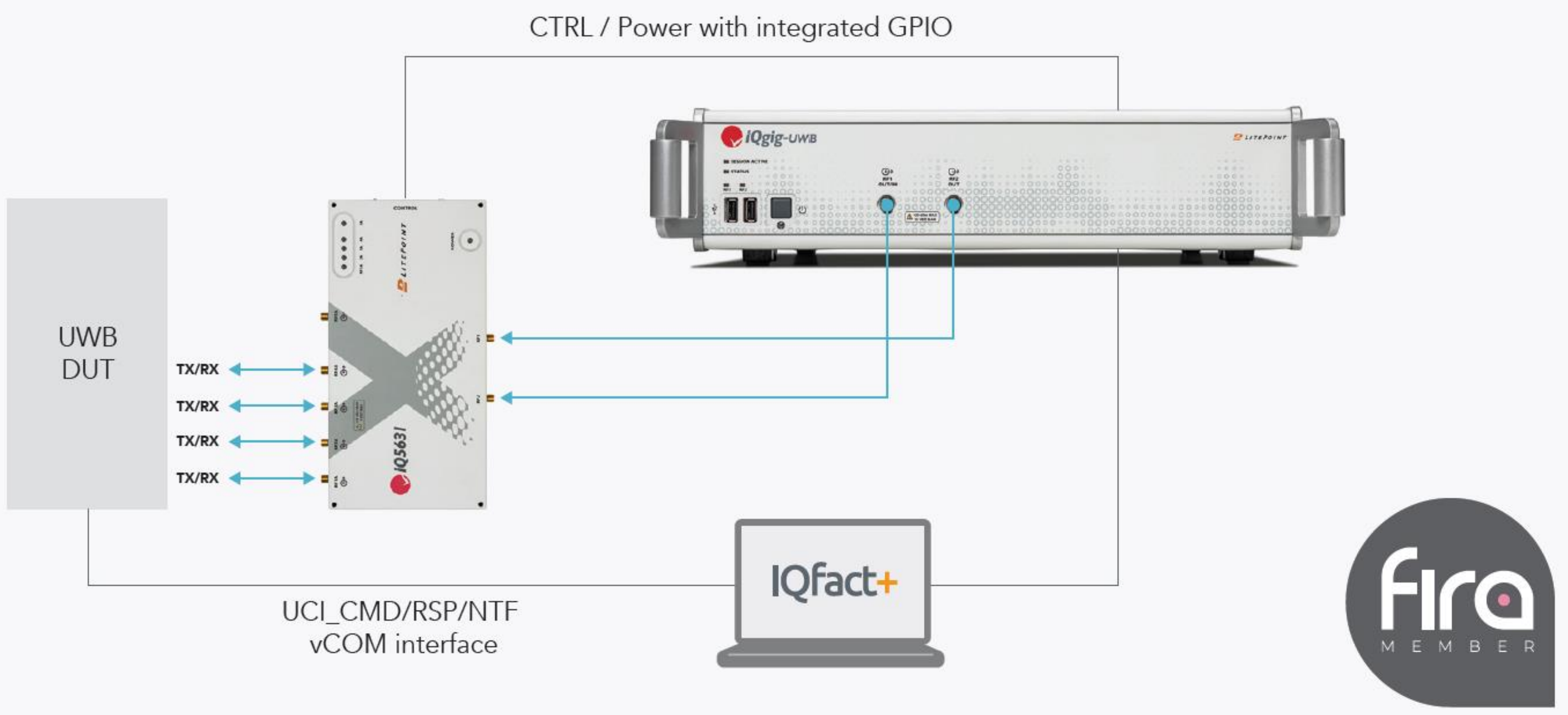
UWB – Accuracy redefined

Vision is to provide seamless user experiences using the secured fine ranging and positioning capabilities of interoperable UWB technologies.

To achieve this vision, FiRa Consortium will:

- Bring together elite industry leaders who share a common vision and goal to develop a UWB open ecosystem with standards-based interoperability
- Develop use cases based on IEEE 802.15.4 enhanced ranging technologies
- Develop specifications and a certification program to ensure interoperability among chipsets, devices and solutions
- Influence industry trends around the use of UWB technology for a variety of applications
- Certify products as interoperable, providing customers with confidence in their choice of products and/or solutions

FiRa Consortium RF PHY Conformance Solution



UWB Test Coverage

- BPRF, HPRF
- TX packet format verification: SYNC, SFD, STS, PHR, DATA, CRC
- TX PSD mask verification
- Baseband impulse response
- Carrier frequency tolerance
- Pulse timing verification
- TX signal quality
- NRMSE
- RX sensitivity
- RX first path dynamic range
- RX packet format verification: SYNC, SFD, STS, PHR, DATA, CRC
- RX Dirty packet test

The FiRa Consortium PHY Technical Requirements Specification is based on the High-Rate Pulse (HRP) portion of the IEEE 802.15.4 specifications and 802.15.4z amendment for fine-ranging UWB technology

THANKS

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