Wireless Communication

Realizing the full potential of UWB with smart testing

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ROHDE&SCHWARZ

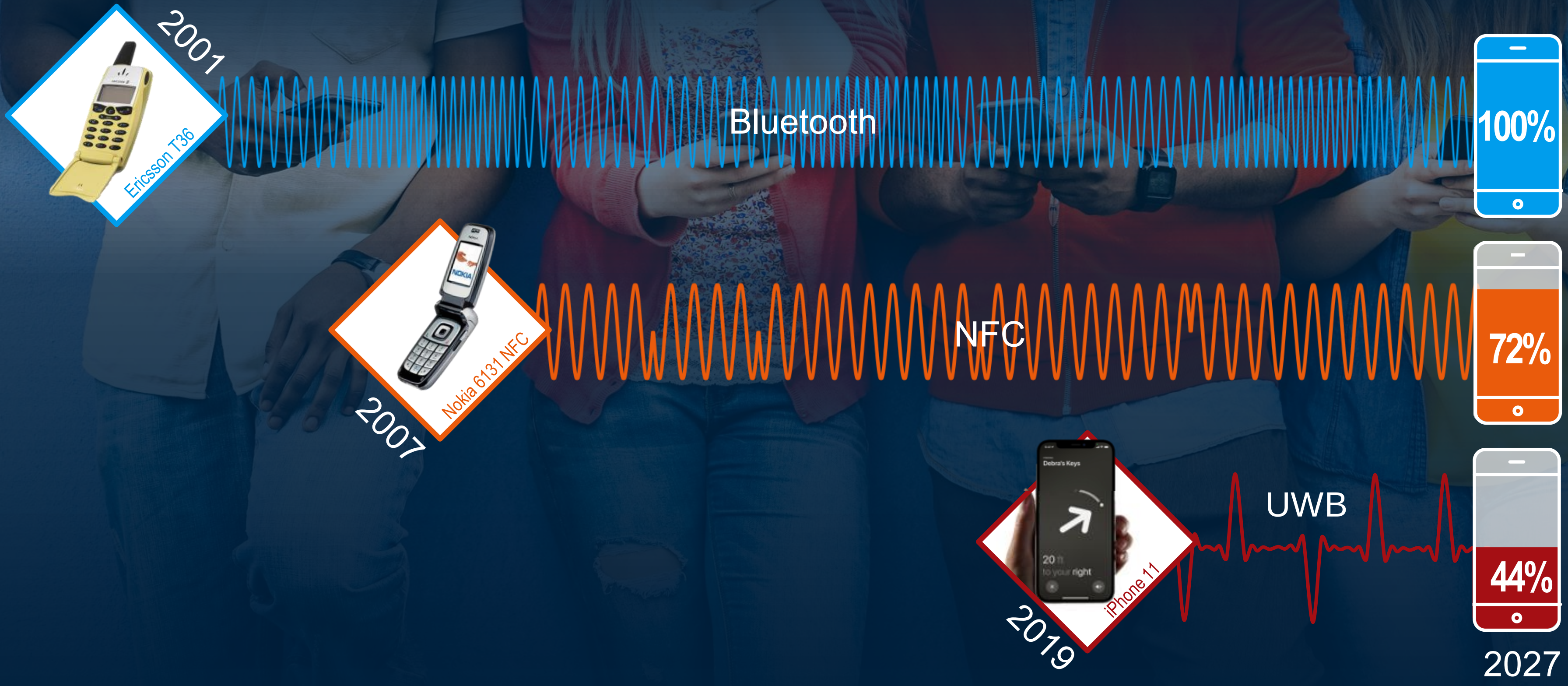
Make ideas real

An over 100-years-old wireless technology found it‘s way….

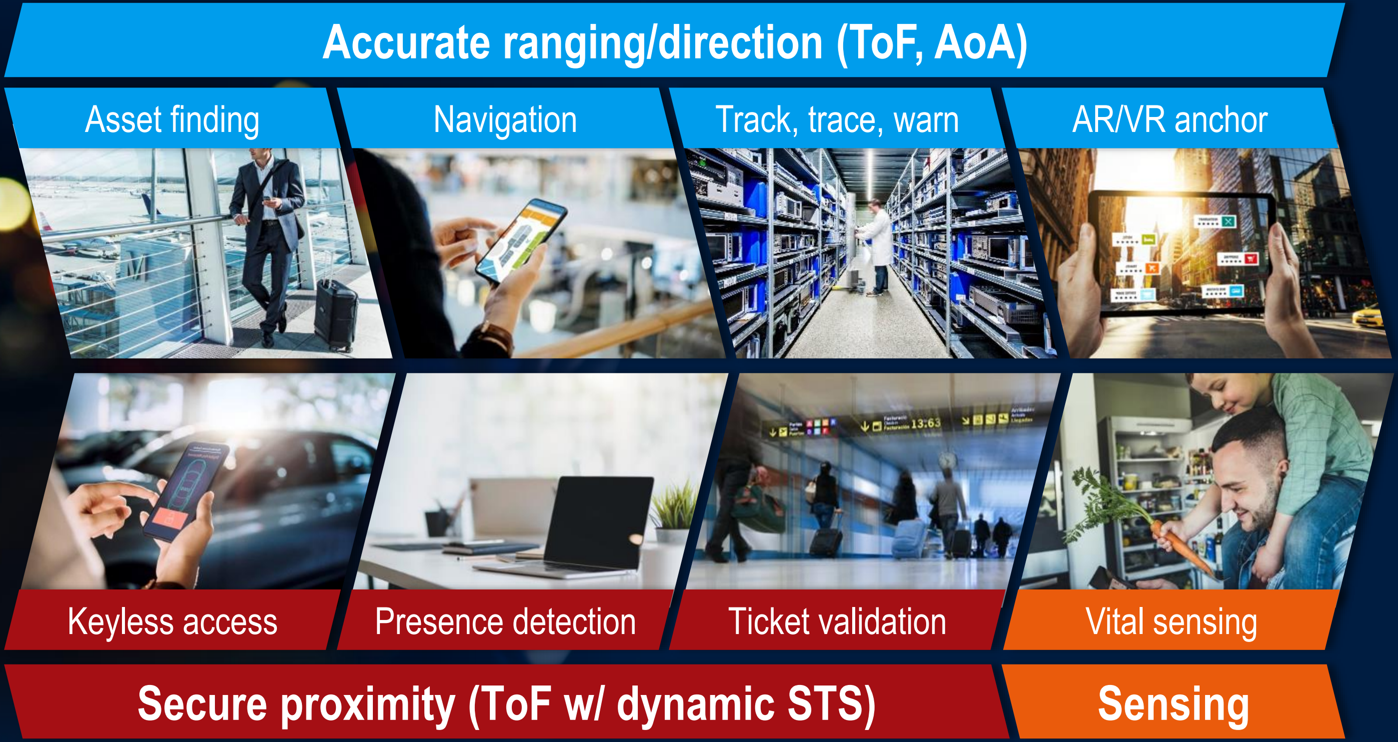
ACCURATE	RELIABLE	CO-EXSISTS	LOW POWER	SECURE	REAL TIME
Distance estimation down to <10 cm in line of sight or non-line of sight.	Use of short UWB pulses makes it stable to multipath effects	Operates away from the crowed bands used by Wi-Fi or Bluetooth	Short airtime and low power transmitter help to save battery lifetime	Cryptography and random number generation makes it more secure	High refresh rates of up to 1000 times per second enable real-time location service

See: www.firaconsortium.org/discover

Fast adoption of UWB on smart phones is enabling more and more applications



Enabling a now connectivity experience by integrated sensing and ranging as supported by UWB



Impulse radio ultra-wideband (IR-UWB) standardization by IEEE was/is driven by a strong ecosystem

2007
IEEE 802.15.4a
High Rate Pulse Repetition UWB

2020
IEEE 802.15.4z
HRP UWB enhanced ranging

2024
IEEE 802.15.4ab
Next generation UWB

2018
UWB ALLIANCE
uwballiance.org

2019
fira
firaconsortium.org

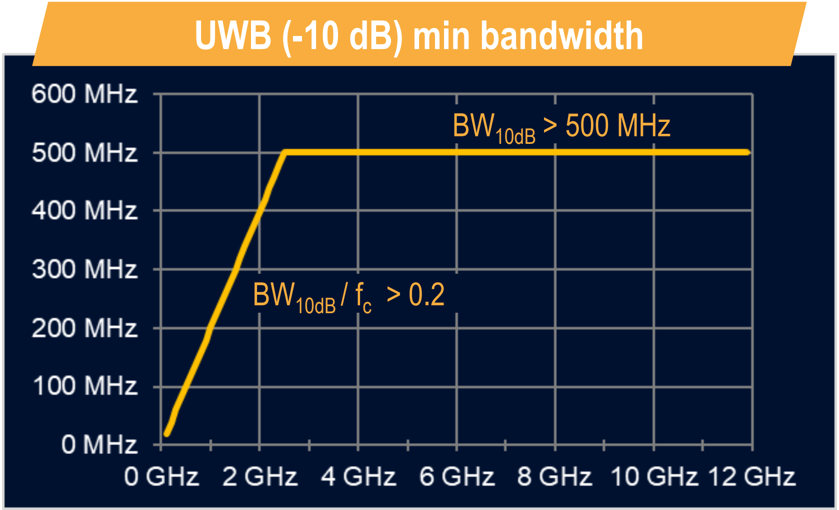
2020
omlox
omlox.com

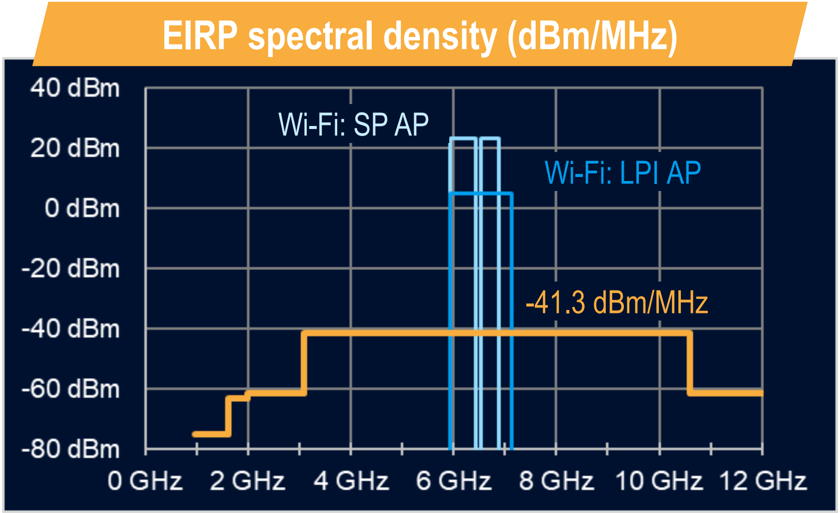
2020
CCC
carconnectivity.org

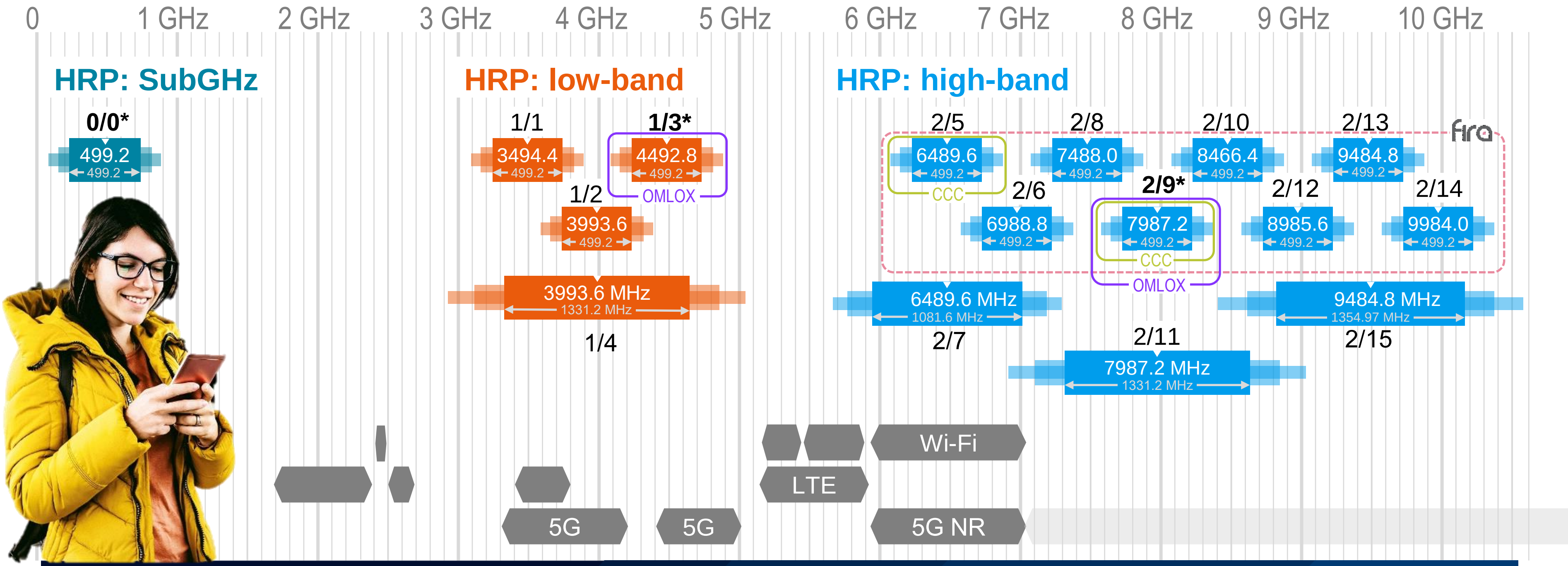
What is UWB about? – The FCC definition from 2002

Ultra-wideband (UWB) transmitter.
An intentional radiator that, at any point in time, has **a fractional bandwidth equal to or greater than 0.20** or has a **UWB bandwidth equal to or greater than 500 MHz**, regardless of the fractional bandwidth.

Equivalent isotropically radiated power (EIRP), in terms of dBm, refers to the highest signal strength measured in any direction and at any frequency from the UWB device. The **radiated emissions** between 3.1 and 10.6 GHz from a UWB device shall not exceed the average limit of -41.3 dBm/MHz

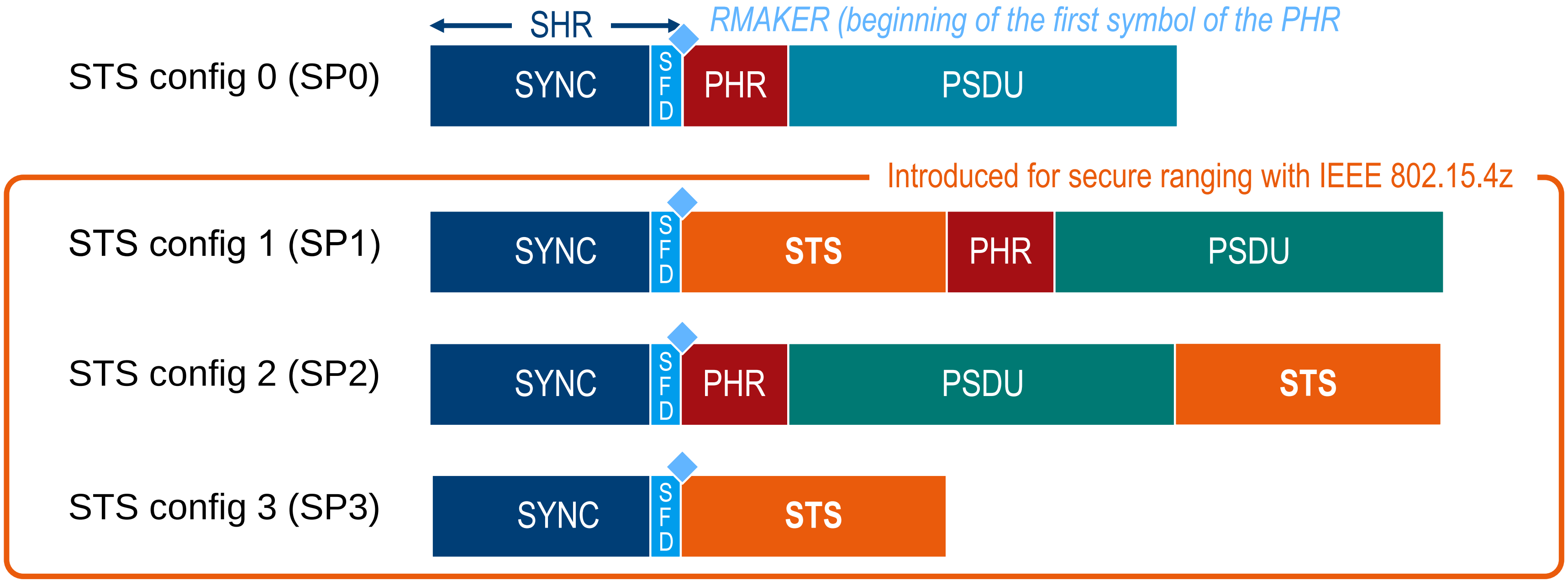






UWB channel allocation based on IEEE 802.15.4z-2020

Secure ranging using a scrambled timestamp sequence (STS) generated by AES-128 based deterministic random bit generator



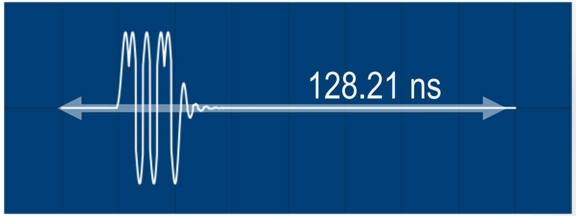
SFD: start-of-frame delimiter
SHR: synchronization header
RMARKER: ranging marker
PPDU: PHY protocol data unit
PSDU: PHY service data unit
PHR: PHY header
STS: scrambled timestamp sequence

Three modes for HRP Enhanced Ranging Devices (ERDEV)

BPRF
Base pulse repetition frequency

BPSK-BPM modulation

mean PRF: 62.4 MHz
peak PRF: 499.2 MHz

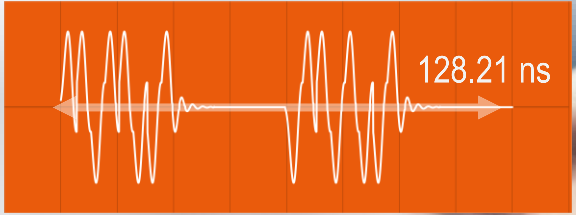


PHR burst length	PHR Bitrate	PSDU Bitrate
64 chips	0.9 Mbps	6.8 Mbps
8 chips	6.8 Mbps	6.8 Mbps

HPRF
Higher pulse repetition frequency

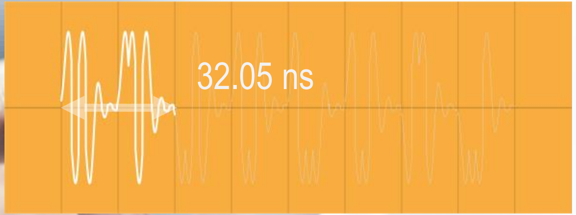
BPSK modulation at both burst positions

mean PRF: 124.8 MHz
peak PRF: 249.6 MHz



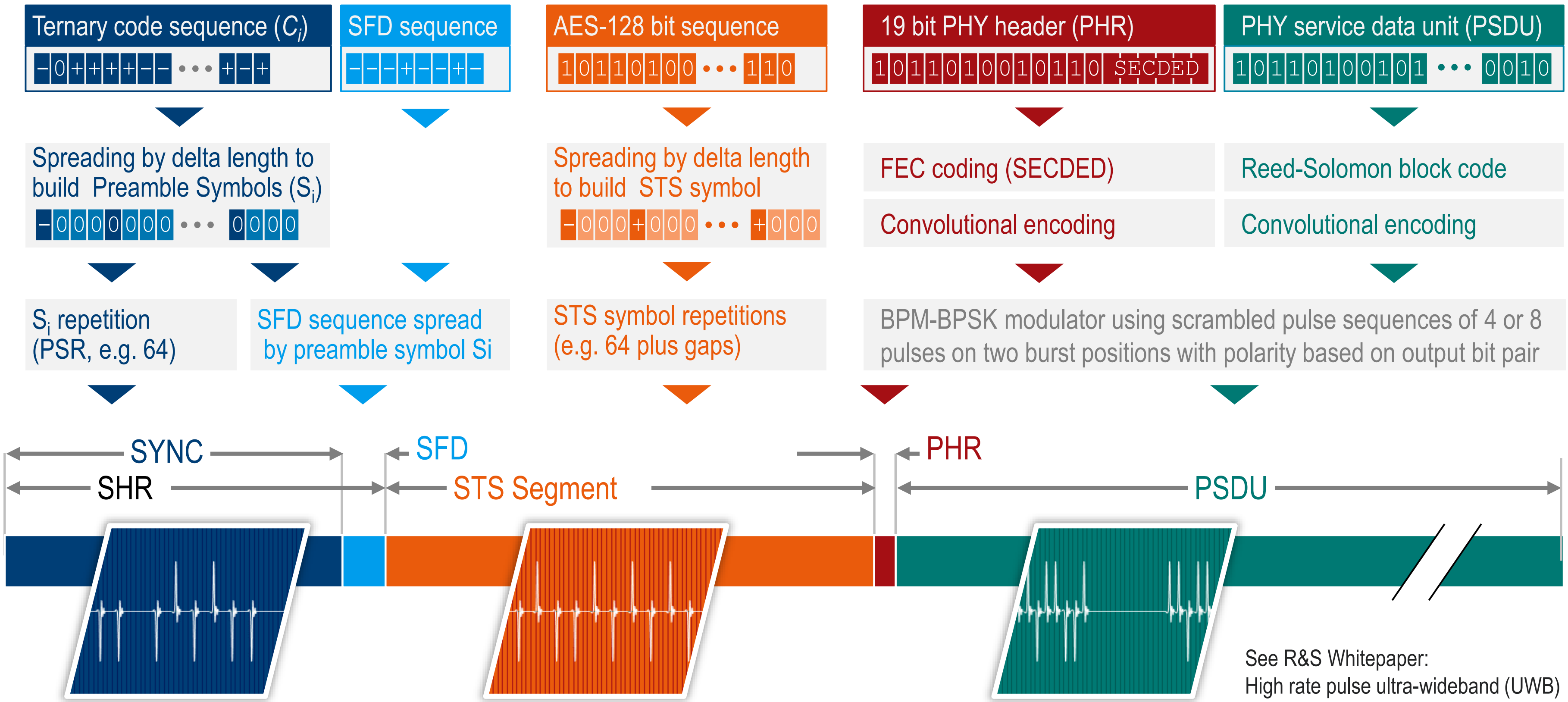
Constraint length (CL)	PHR Bitrate	PSDU Bitrate
CL3	3.9 Mbps	6.8 Mbps
CL7	7.8 Mbps	7.8 Mbps

mean PRF: 249.6 MHz
peak PRF: 499.2 MHz



Constraint length (CL)	PHR Bitrate	PSDU Bitrate
CL3	15.6 Mbps	27.2 Mbps
CL7	31.2 Mbps	31.2 Mbps

UWB packet structure in a nutshell (HRP-ERDEV: HPRF SP2)



See R&S Whitepaper:
High rate pulse ultra-wideband (UWB) physical layer test and certification

UWB physical layer test requirements

Standard conformance

- Operating frequency bands
- Channel assignments
- Baseband impulse response
- Transmit PSD mask
- Chip rate clock and chip carrier alignment

IEEE 802.15.4-2020
IEEE 802.15.4z-2020

Regulatory compliance

- Operating bandwidth
- Mean power spectral density
- Maximum value of peak power
- Other emissions
- Receiver spurious emissions
- Detect and avoid (DAA)
- Low duty cycle (LDC)

FCC part 15
§15.519, §15.517

ETSI EN 301 489-33 ,
EN 302 065, EN 303 883

Interoperability certification

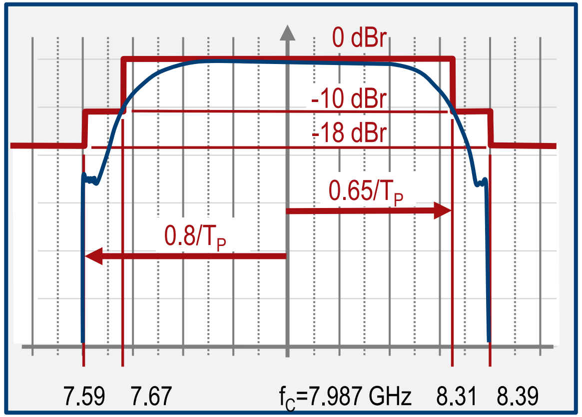
- Packet format
- Power spectral density mask
- Frequency tolerance, timing
- Baseband Impulse response
- NRMSE
- Packet reception sensitivity
- Dirty packet tests
- First path dynamic range

FiRa Consortium
UWB PHY Conformance

CCC Consortium
coming soon

Specific UWB measurements (IEEE, FiRa, etc.)

Transmit power spectrum density

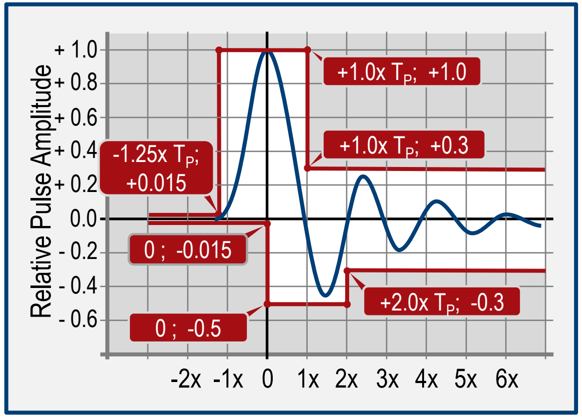


The transmitted spectrum shall be less than –10 dB relative to the maximum spectral density of the signal for

$0.65/T_P < |f – fc| < 0.8/T_P$

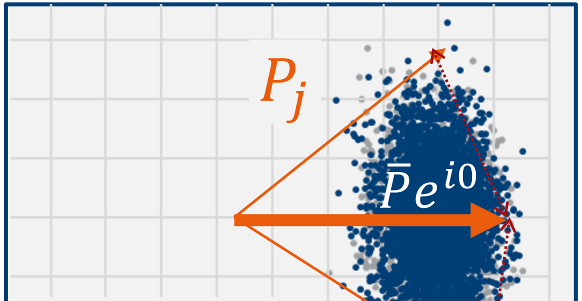
and –18 dB for $|f – fc| > 0.8/T_P$.

Impulse response



The pulse shape should be constrained by the time domain mask where the peak magnitude of the pulse is scaled to a value of one, and the time unit is pulse duration TP.

Transmitter quality (NRMSE)



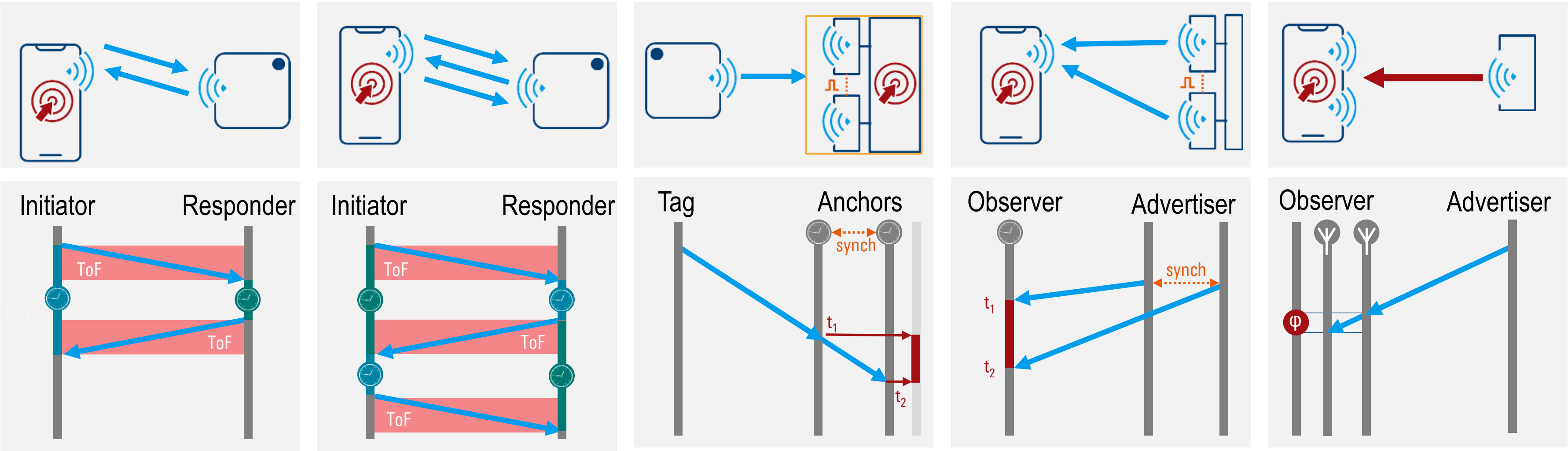
$$\bar{P} = \frac{1}{N}\sum_{j=0}^{N-1}|P_j|$$

The transmit signal quality should be measured using a normalized root mean square error (NRMSE) metric with the mean pulse amplitude $\bar{P}$

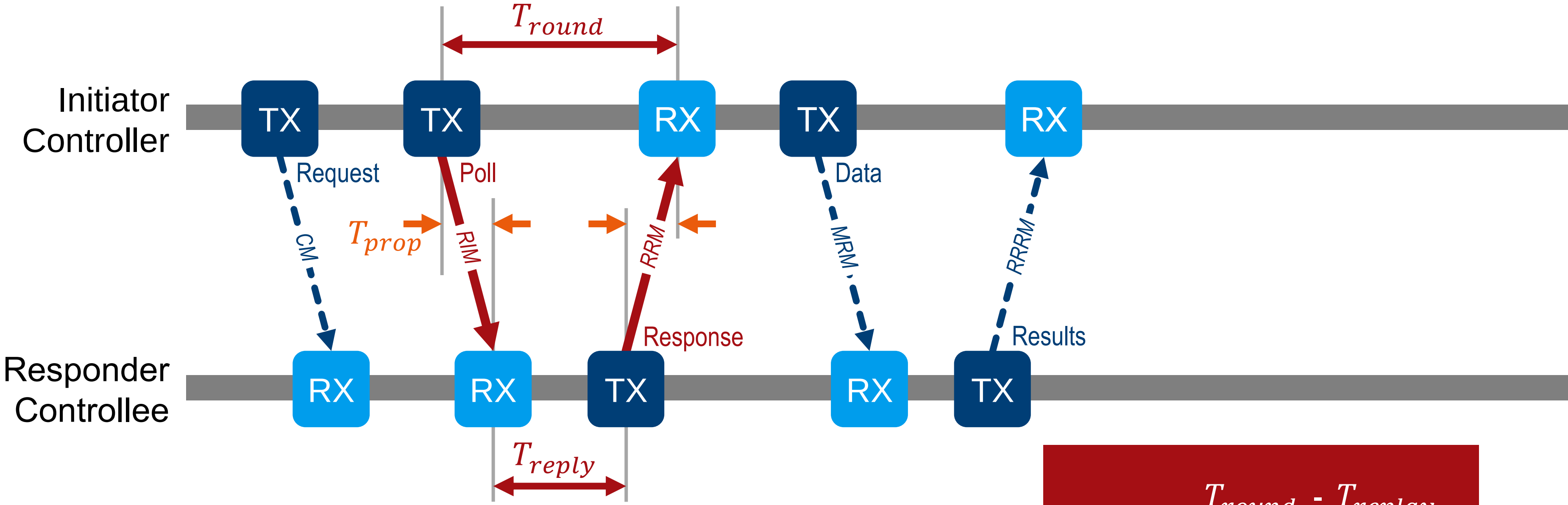
$$NRMSE = \sqrt{\frac{1}{N}\sum_{j=0}^{N-1}\frac{\left|P_j - \bar{P}e^{i0}\right|^2}{\bar{P}^2}}$$

UWB ranging and positioning is all about absolute/relative signal propagation time(s)

Two Way Ranging		One Way Ranging		
Single sided (SS-TWR)	Double sided (DS-TWR)	Uplink Time Difference of Arrival (UL-TDoA)	Downlink Time Diff. of Arrival (DL-TDoA)	Angle of Arrival (AoA) based on PDoA



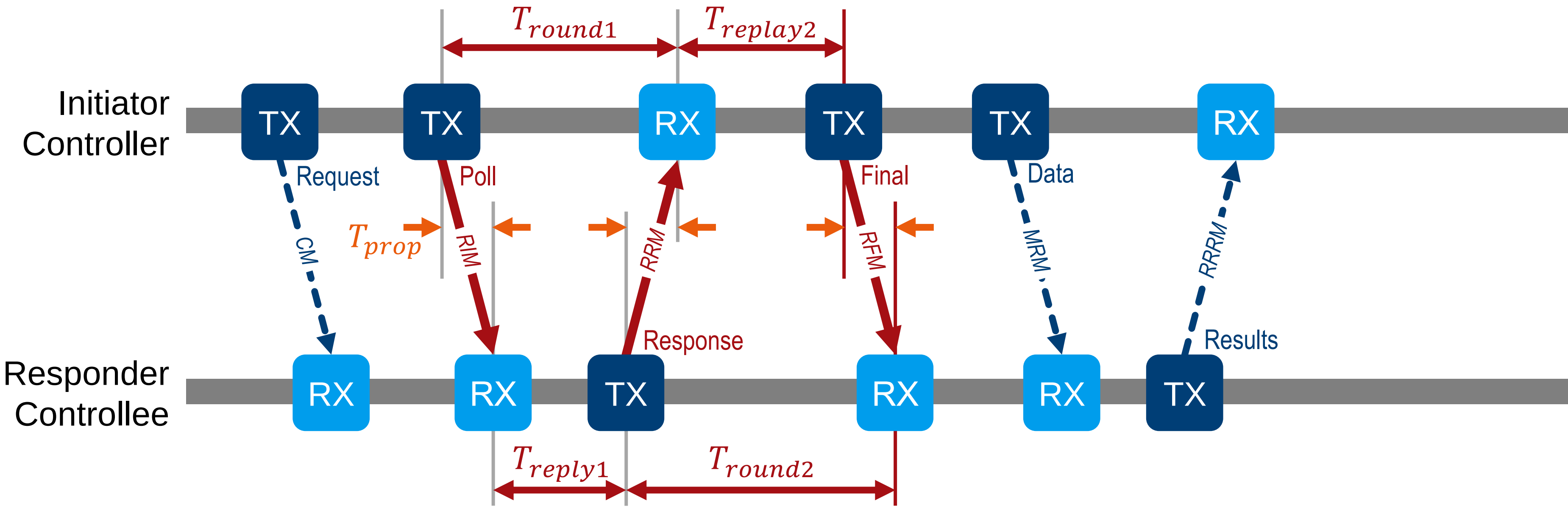
Single-sided two-way ranging



$$\hat{T}_{prop} = \frac{T_{round} - T_{replay}}{2}$$

Control Message (CM) is a message transmitted by the Controller in Slot zero of the ranging round.
Ranging Initiation Message (RIM) is a message transmitted by the Initiator to the Responder(s).
Ranging Response Message RRM) is a message transmitted by the Responder(s) to the Initiator.
Ranging Final Message (RFM) is a message transmitted by the Initiator to the Responder(s).
Measurement Report Message (MRM) is a message transmitted by the FiRa Device(s) to exchange measurement information.
Ranging Result Report Message (RRRM) is a message transmitted by the FiRa Device(s) in the MRP.

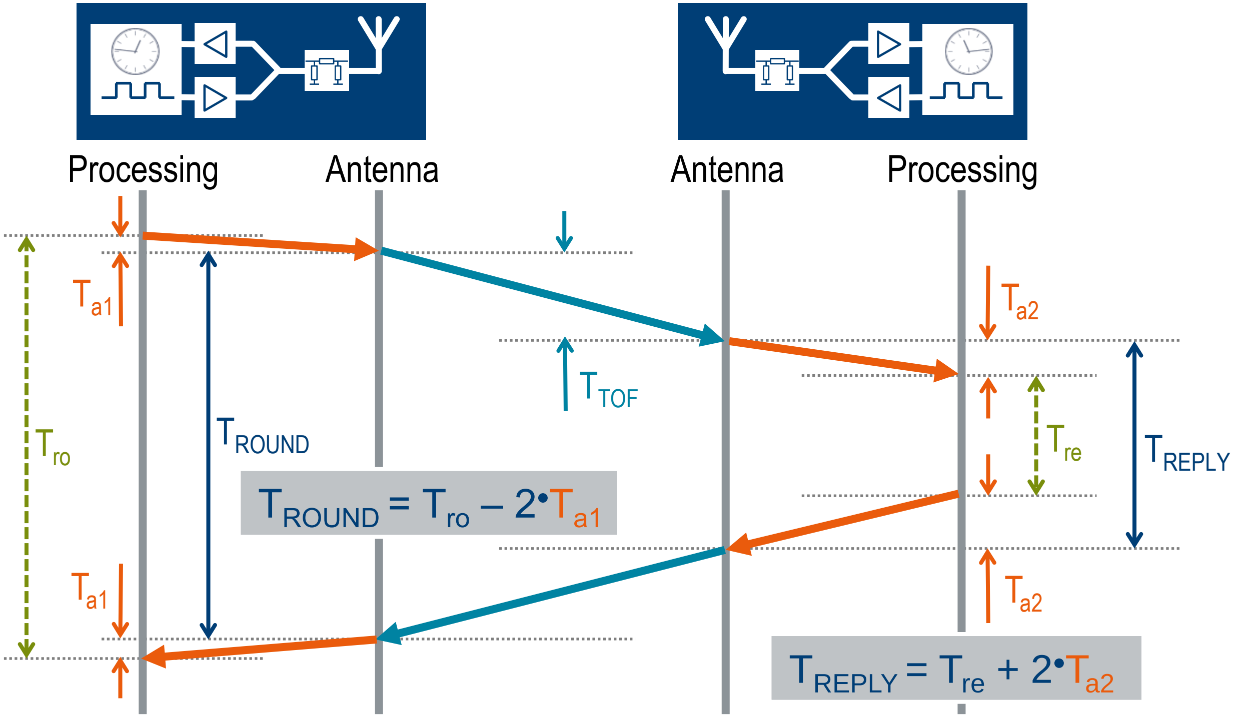
Double-sided two-way ranging



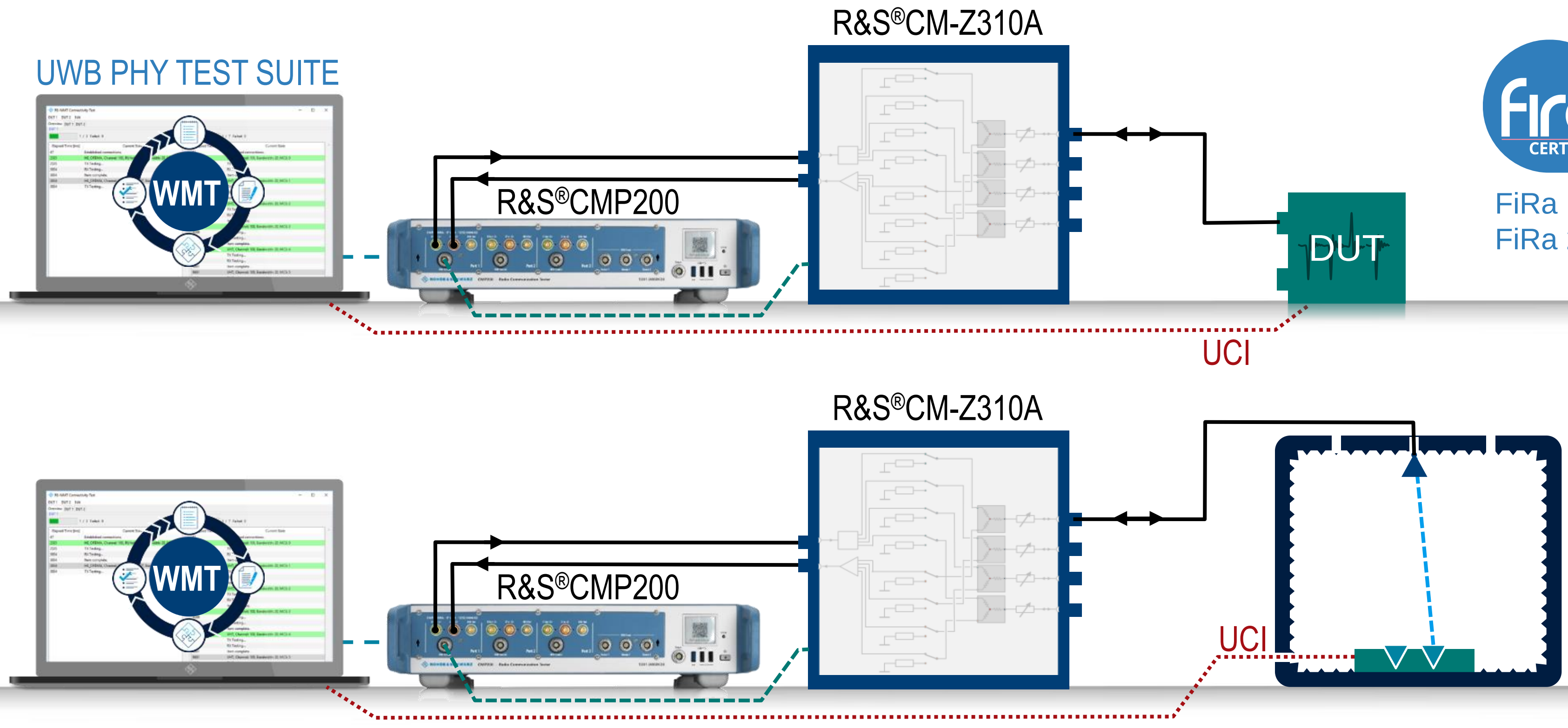
$$\hat{T}_{prop} = \frac{T_{round1} \times T_{round2} - T_{replay1} \times T_{replay2}}{T_{round1} + T_{round2} + T_{replay1} + T_{replay2}}$$

The on-board antenna delay determines the accuracy of the ToF (and AoA measurements) – need to calibrate and verify!

Dependent on the implementation the onboard antenna delay can easily vary by 1 ns which could result in a ranging error of more than 30 cm



Time of flight measurements – conducted or over-the-air



CERTIFIED

FiRa 1.0
FiRa 2.0

Angle of Arrival (AoA) based on phase difference of arrival (PDoA)

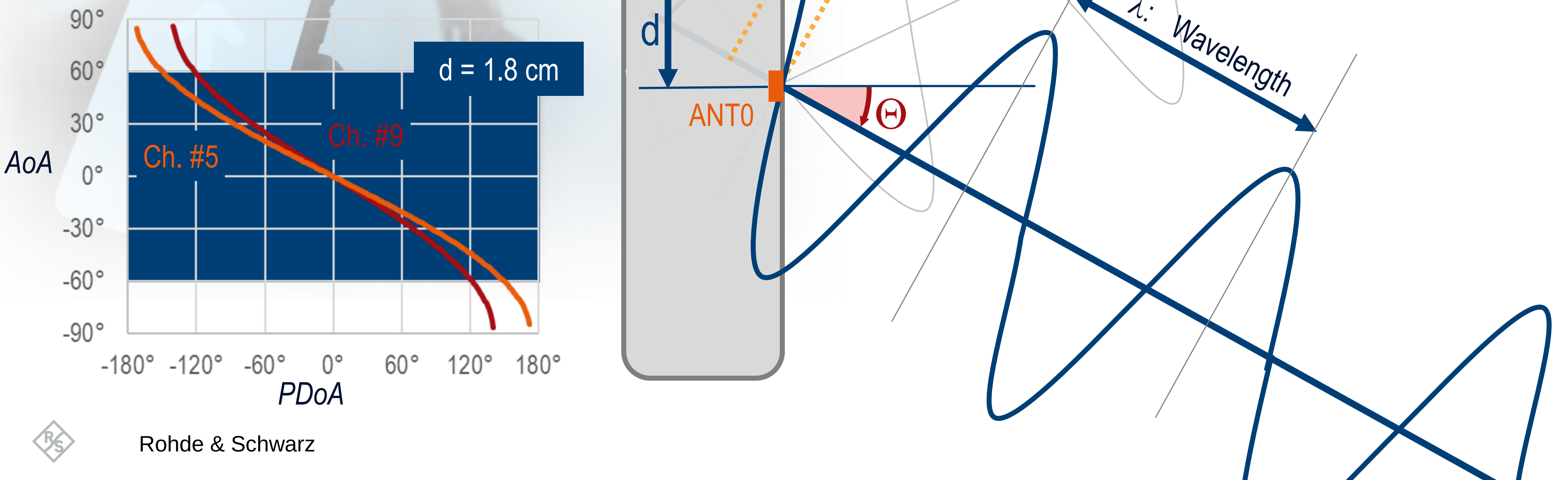
Phase difference — *Wavelength*

$$\Theta = \arccos\left(\frac{\psi\lambda}{2\pi d}\right) - \frac{\pi}{2}$$

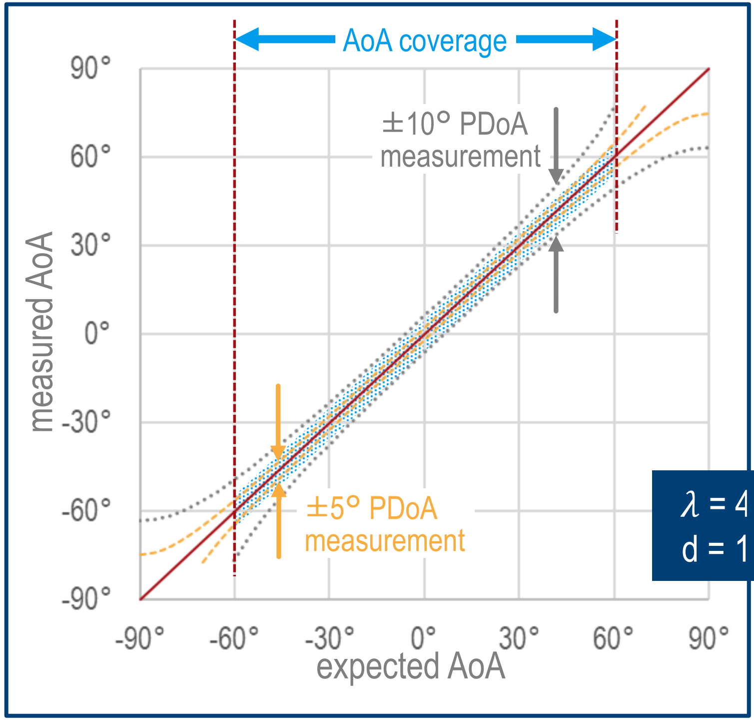
AoA

Antenna distance (d < $\lambda/2$)

Channel	Frequency	Wavelength	Periode
#9	6.49 GHz	4.62 cm	154 ps
#5	7.99 GHz	3.75 cm	125 ps



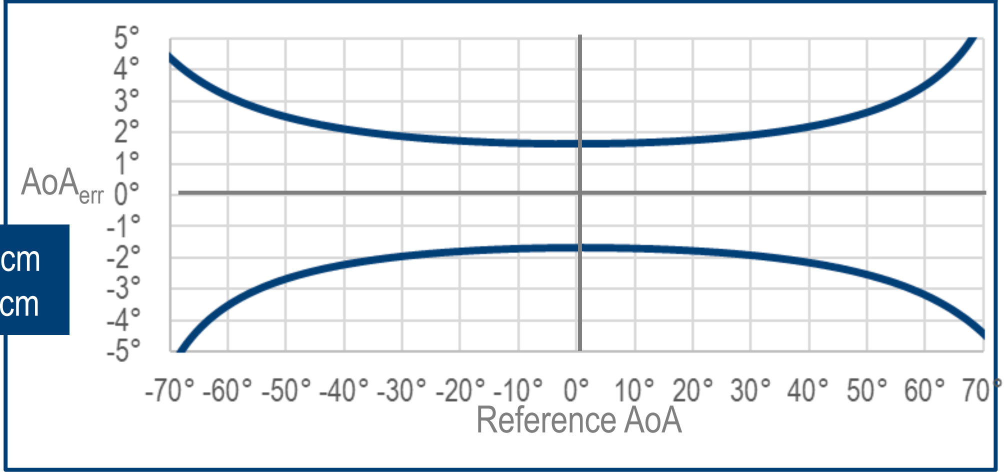
AOA accuracy is directly linked to PDOA measurement quality



λ = 4.6 cm
d = 1.8 cm

Typically expected AoA accurancy is ±5° at 0.1 to 2 meter distance and AoA coverage of ±60° in LOS environment (e.g. FiRa).

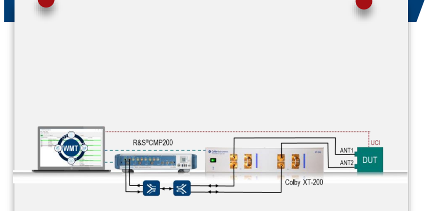
AoA error dependent on reference angle (PDoA error = ±5°



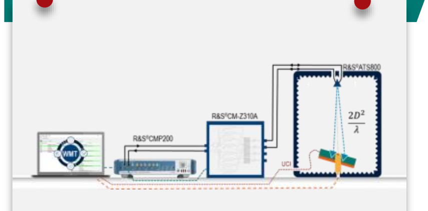
AoA verification and calibration in R&D and manufacturing

In praxis specific UWB device designs (reference point), specific antenna radiation pattern, imperfect RF paths/switches as well as variations in manufacturing require for several stages of verification and calibration to ensure the AoA accuracy as required

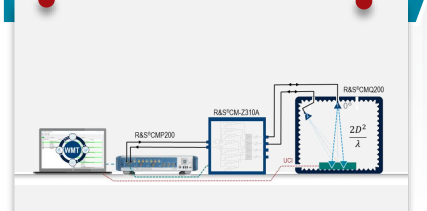
AoA/PDoA
Chipset Verification



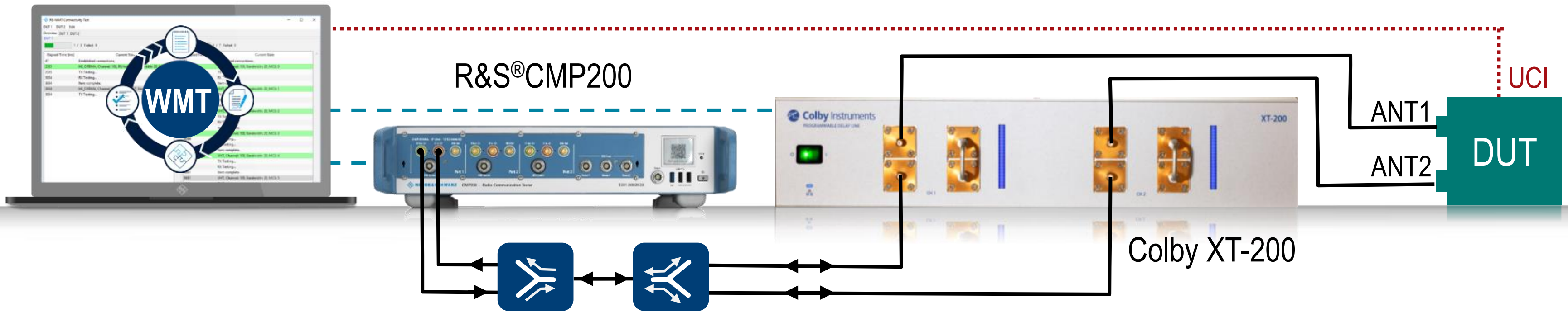
AoA/PDoA
Device Reference Calibration

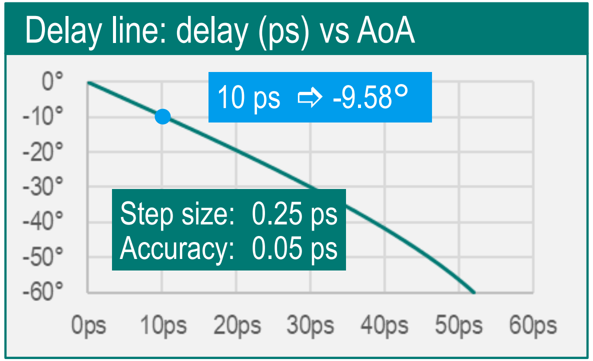


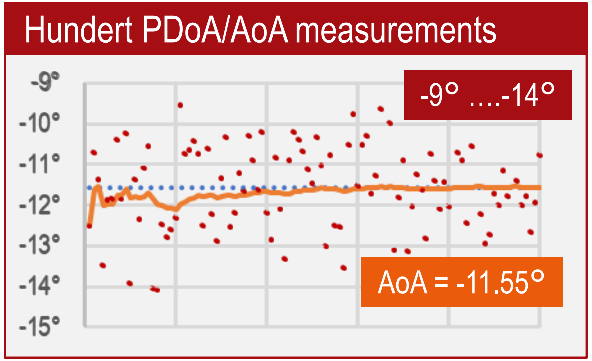
AoA/PDoA
Device Offset Calibration

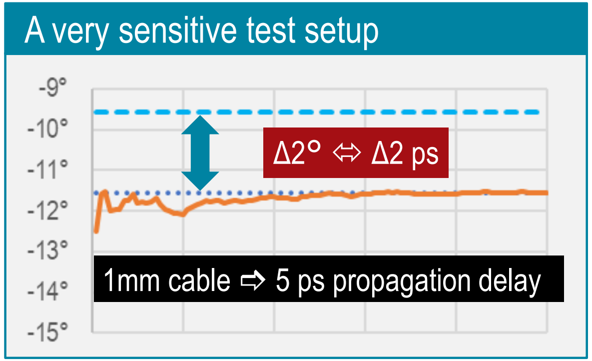


AoA verification in chipset R&D or benchmarking

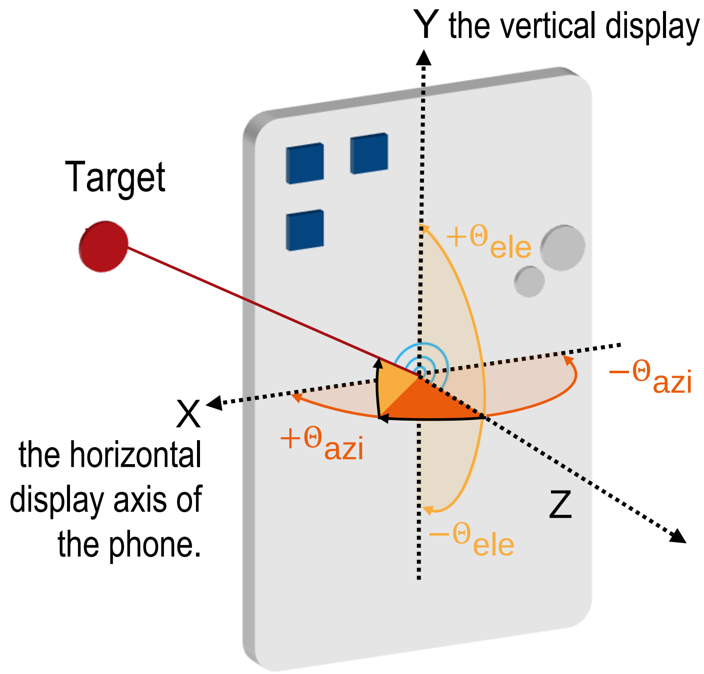








Definition of azhimuth and elevation angle based on FiRa



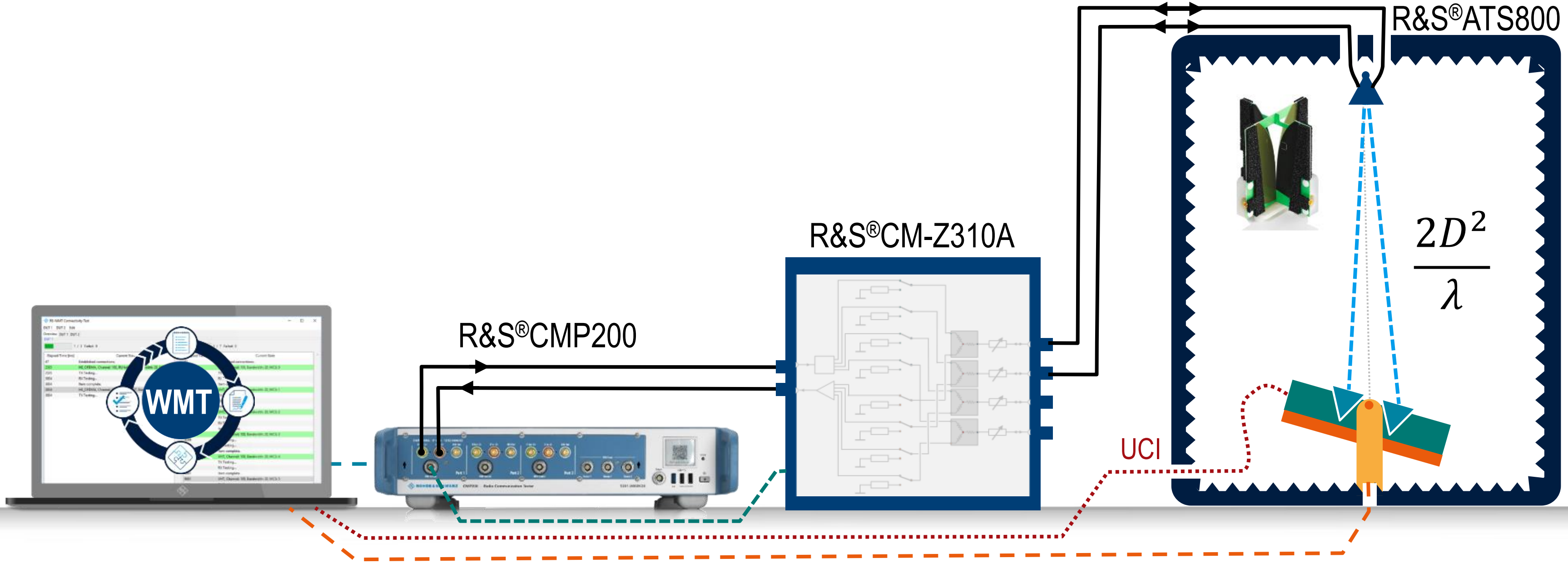
The azimuth and elevation angle measurements are always relative to the measurement device, they are not relative to antennas.
If the device rotates the reference axis are rotating too..

The **AoA azimuth angle** is the relative angle between the Z-axis and the incoming signal projected on the XZ-plane. It is 0 on the Z axis, it is positive towards the X axis clockwise direction, it is negative towards the X axis counterclockwise direction.

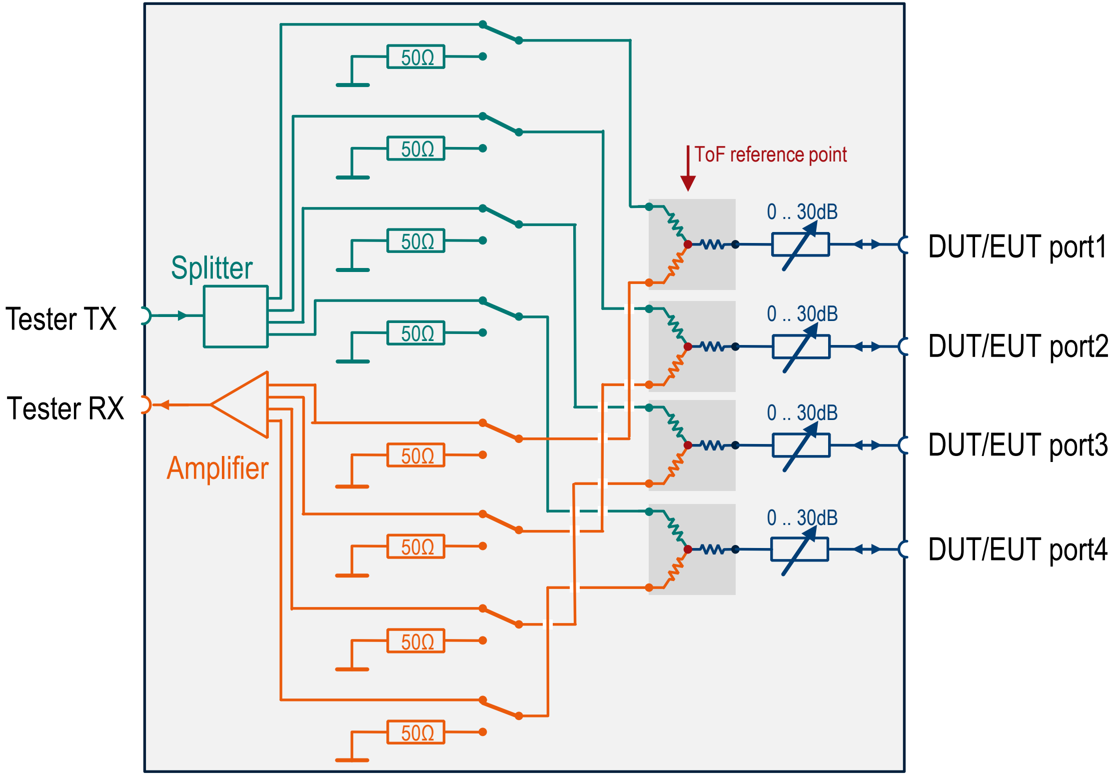
The **AoA elevation angle** is the relative angle between the XZ-Plane and the incoming signal.

The Z-axis Axis orthogonal to the Phones display (back camera view direction).

AOA center position factory calibration:
PDoA - device reference calibration



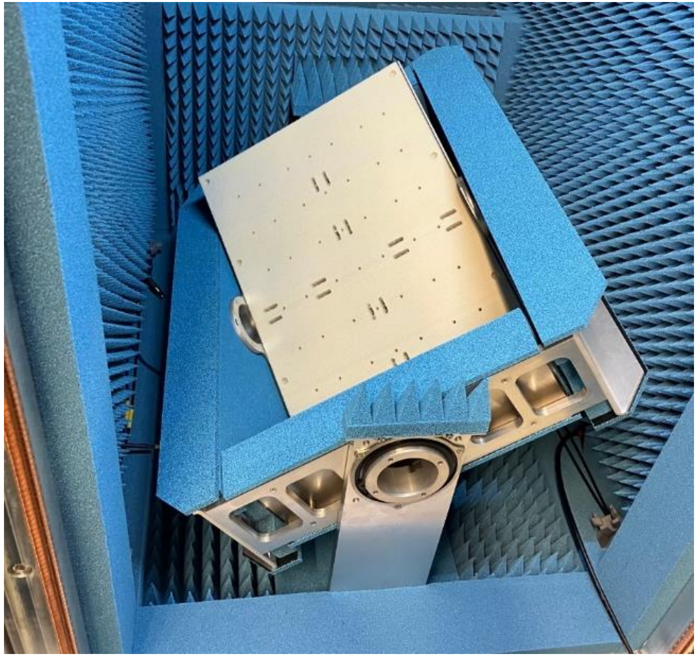
UWB head for conducted multi-port/-device testing



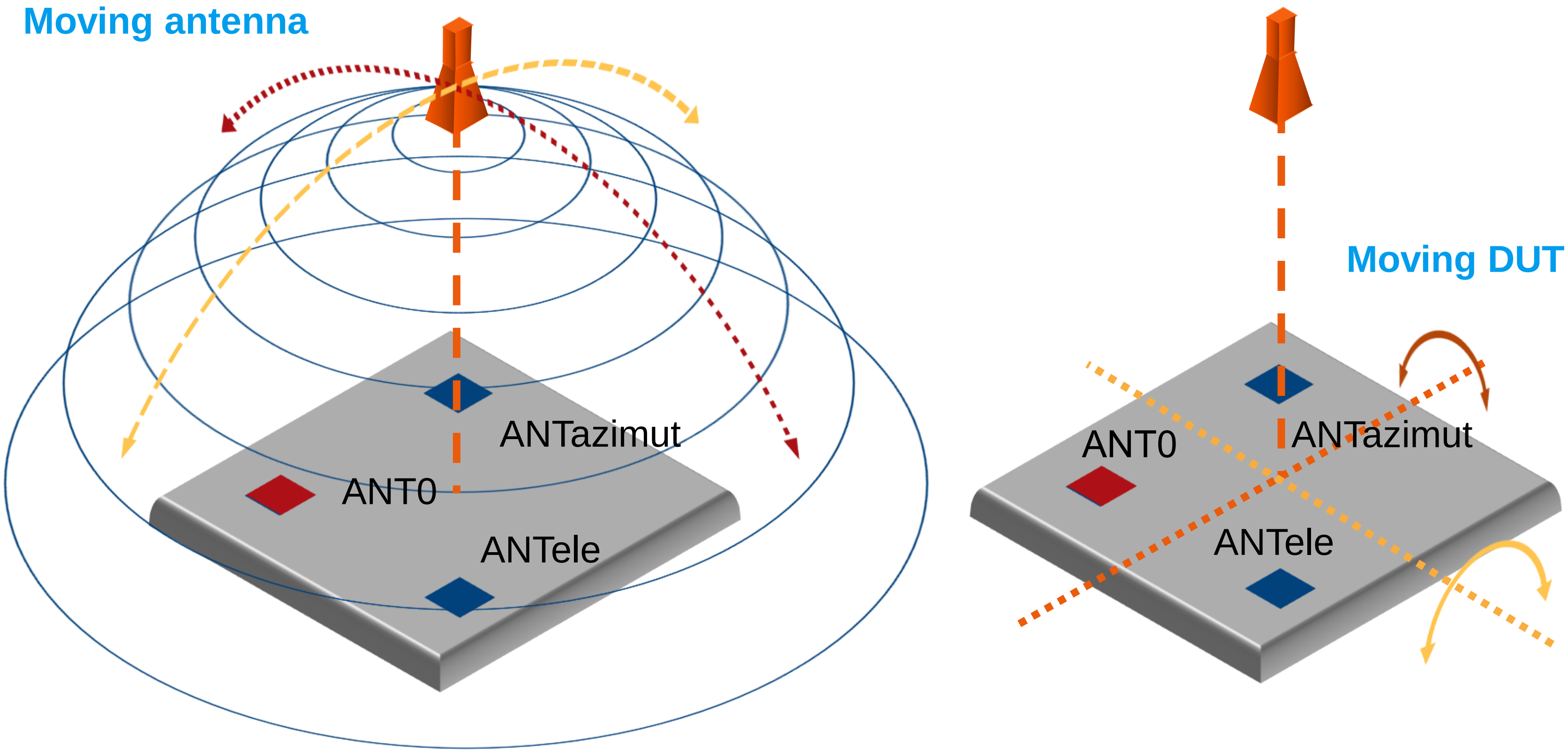
- Allows to connected 4 DUT ports (splitter/combiner)
- Includes amplifier and attenuator to adjust the RF setup
- Includes ToF Kit functionality for every port
- Three kits can be connected per CMP200
- Rx sensitivity test to -110 dBm possible

Tilt-tilt positioner for the ATS shielded chambers

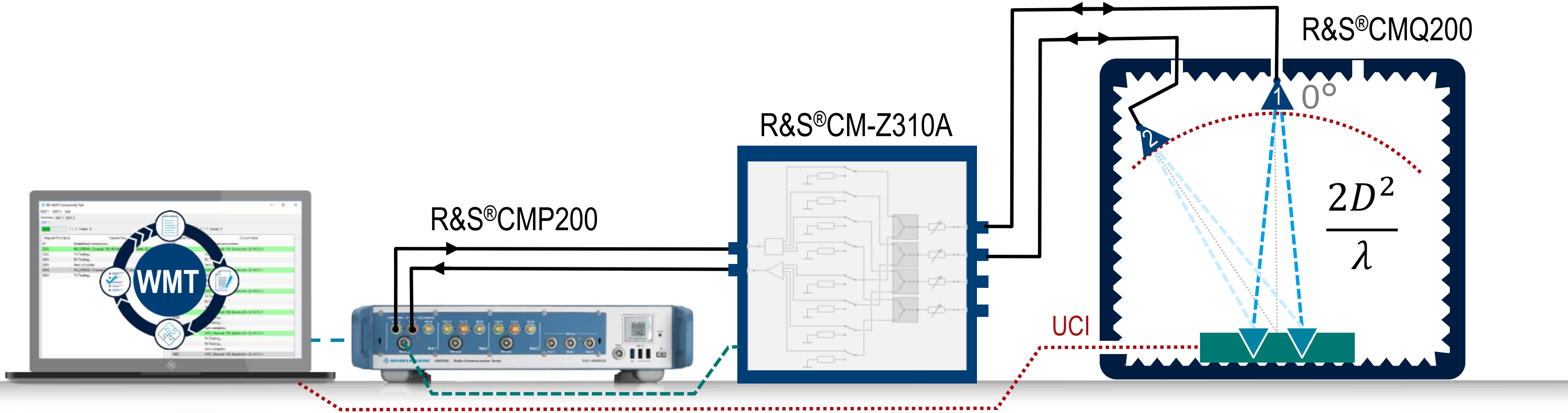
Category	Value
Positioner Type	Tilt and pan
DUT Weight	< 2.5kg, centered
Resolution	0.01 degrees
Elevation accuracy	0.25 degrees @1kg 0.50 degrees @ 2.5kg
Tilt Range	+/- 90 degrees
Pan Range	+/- 90 degrees
Rotation speed	< 45 degree/sec



AoA verification for over the air measurements in R&D



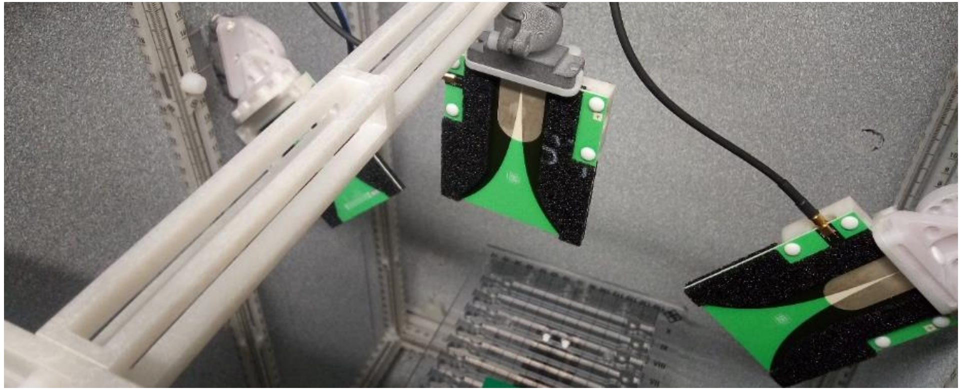
AOA center position factory calibration:
PDoA - device offset calibration



Correct antenna/DUT positioning and reasonable distance between antennas are essential for correct measurements

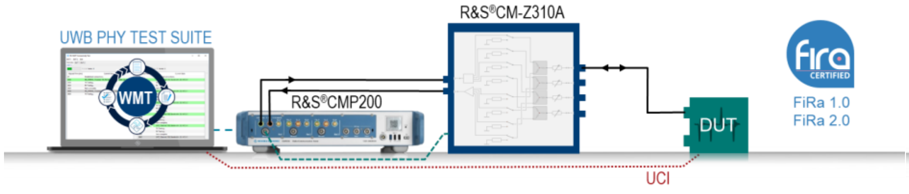
R&S®CMQ200-HS shielding cube designed for multi-antenna OTA testing for UWB in combination with the R&S®CMP200

- New member of the R&S® CMQ200/500 family for a frequency range of 0.3 to 14 GHz
- High shielding support of 80 dB
- Perfectly suited for multi-antenna setups required for UWB AoA measurements

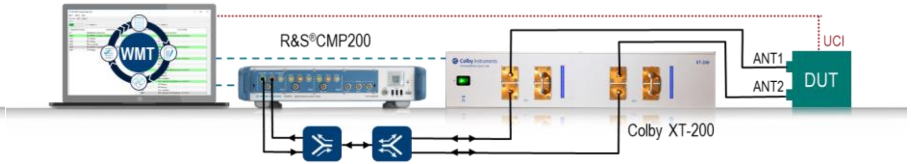


UWB test solution for different use cases based on the CMP200

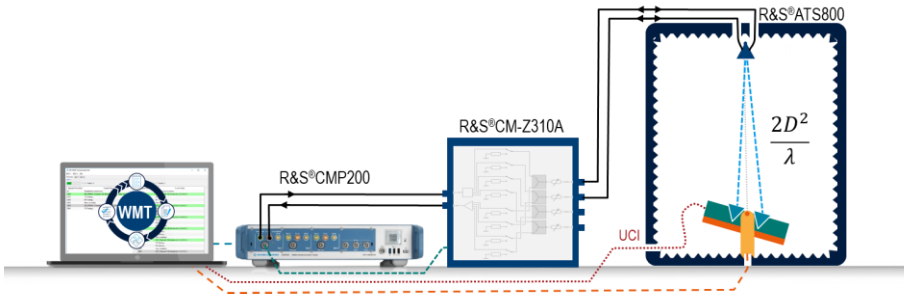
RF Performance and ToF incl FiRa



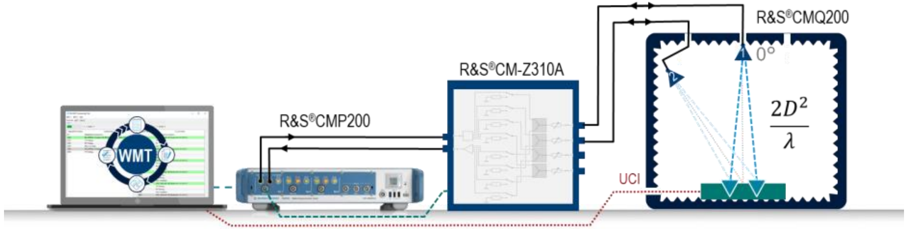
AoA verification and benchmarking



RF AoA verification and ref. calibration



PHY Perf. Check, AoA/ToF calibration



UWB test and measurement solutions for all phases of the product lifecycle from the UWB testing experts

R&S®ATS800R | R&S®CMQ200 HS | R&S®CMP200 | UWB PHY Test Suite | R&S®RTP+VSE | R&S®SMM100 | R&S®FSW26 | R&S®TS7124

Novel application requirements drive UWB standardization (802.15.4ab: NG-UWB) and related global regulation

Secure ranging

Vital sensing

Spatial Computing

The three cornerstones of next generation UWB

Advanced ranging (HRP-ARDEV)	Sensing capability (HRP-SEDEV)	Enhanced modulation (HRP-EMDV)
Multi-Millisecond (MMS) Ranging • Using ranging sequence fragment (RSF) based on repeated multi-millisecond ranging sequence (MMRS) • Using ranging integrity fragment (RSI) based on continuous STS sequences • MMS assisted by narrow-band (NBA-UWB), or pure UWB	**Sensing Sequence** • Sensing packet format with SENS fragments build from Ipatov (91) sequences • Sensing pulse shape • Channel impulse response report interface for sensing • Applying frequency stitching	**Enhanced HPRF (EHPRF)** • With dynamic PHR (PHR1 and PHR2) or 4z HPRF PHR with additional rates • LDPC/BCC encoding • w/ dynamic PHR supports of 1.95, 7.8, 31.2, 62.4 and 124.8 Mbps bit rates • With 4z HPRF PHR supports 1.95, 62.4, 124.8 Mbps bit rates

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