Ultra-wideband (UWB) communication

Application Engineer
Chuck Lo

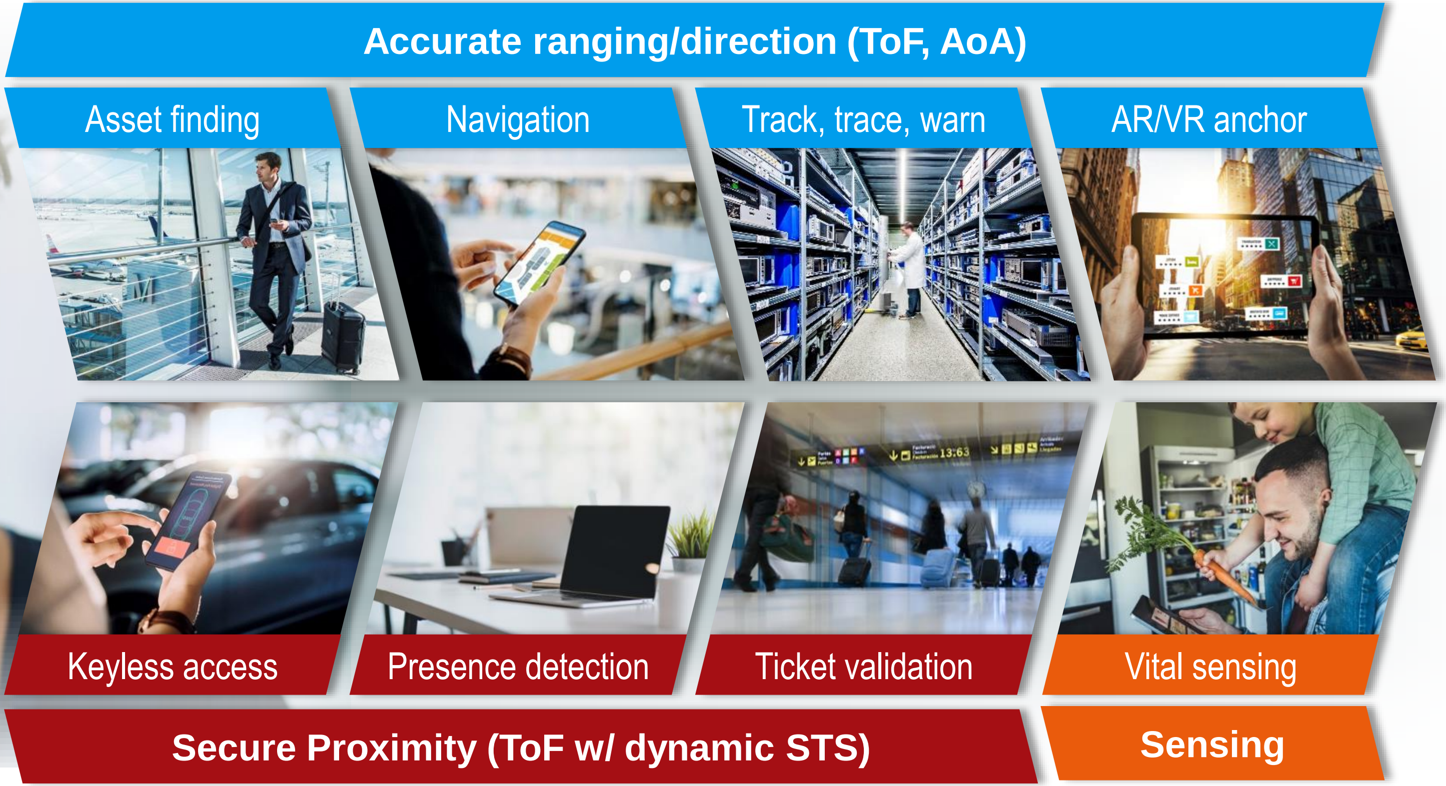
ROHDE&SCHWARZ

Make ideas real

Impulse radio ultra-wideband (802.15.4)

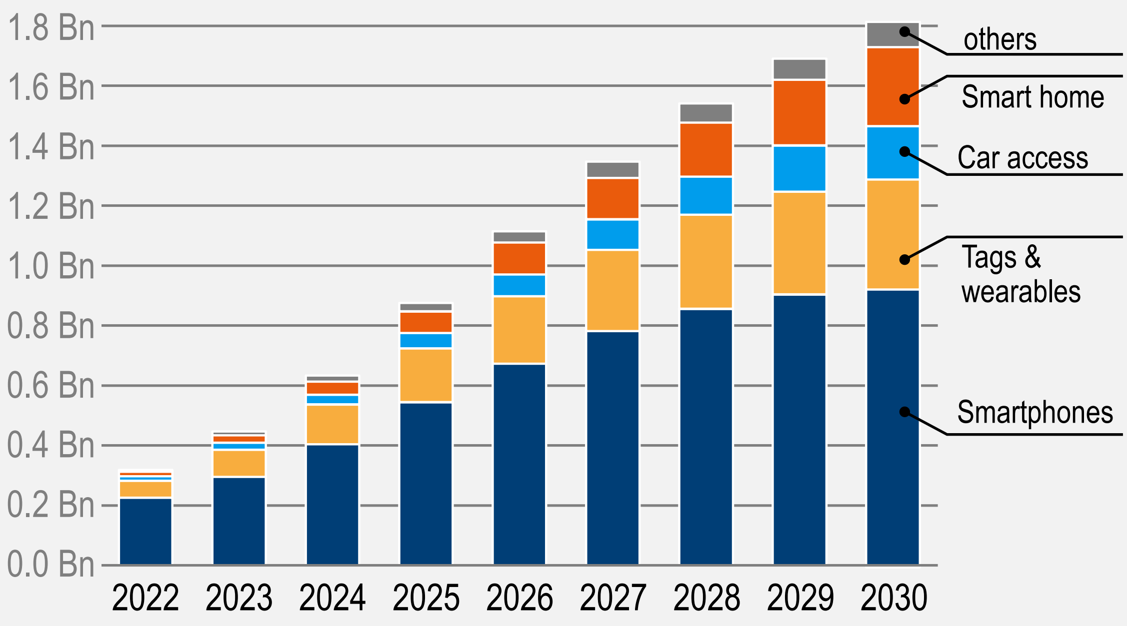
- History, applications and markets
- Test Requirements
- Solutions

More and more applications relying on UWB capabilities



Global forecast: More than 300 M UWB units shipped in 2022 and more than 1.8 Bn units shipped by 2030.

UWB shipment forecast from Techno Systems Research Co. Ltd.



Consumer devices available

Samsung:
Galaxy Note 20 Ultra,
Galaxy Z Fold 2,
S21 Series (S21 +, S21 Ultra),
Galaxy Z Fold 3,
Galaxy S22 Series (S22+, S22 Ultra) and
Samsung Galaxy smart tag+
Apple:
iPhone 11/12/13 Series,
Apple watch 6/7 Series and Airtag.
Xiaomi: Mix 4
Google: Pixel 6 Pro
Oppo and **Vivo** are expected to release their first UWB smartphone during 2022.

https://www.eetasia.com/global-uwb-market-shipment-to-reach-317-million-units-in-2022/

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

UWB Alliance

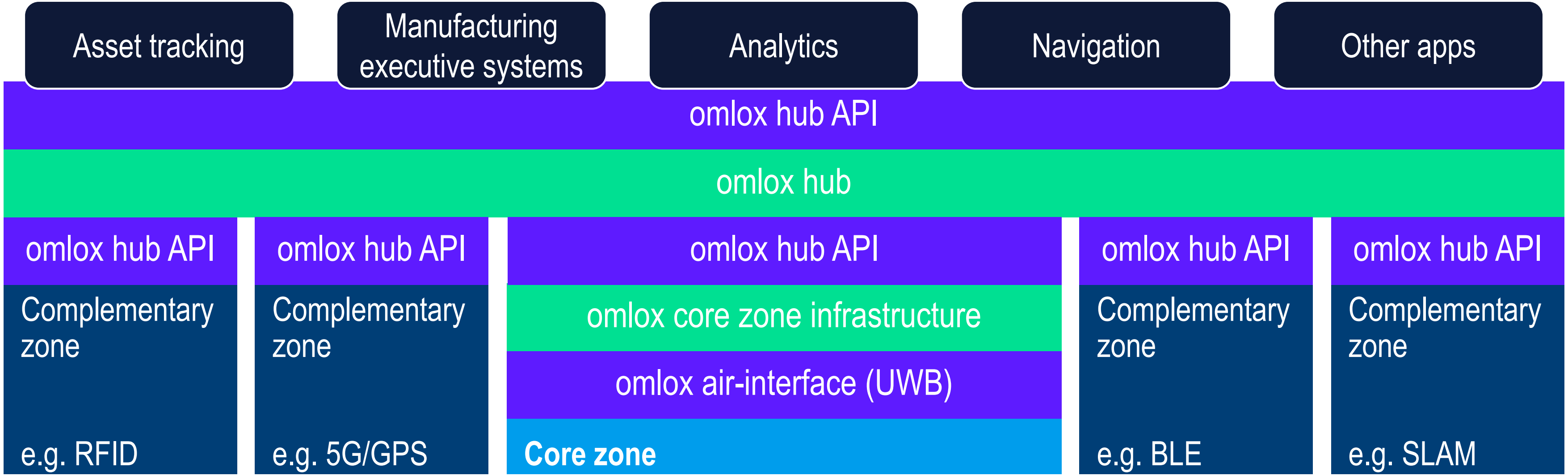
Since 2019, UWB has been expanding into a mainstream consumer technology for smartphones, wearables, automotive and industry, forecasted to drive sales volumes in excess of one billion devices annually by 2025.
The mission of the UWB Alliance is to be the voice of the designers and manufacturers committed to establishing ultra wideband (UWB) technology as a significant open standards industry.

- Establish Ultra-Wideband (UWB) technology as a significant open standards industry
- Promote 802.15.4z and other standards based UWB technologies
- Define and propose interoperability profiles through multiple industry use cases
- Define testing methodology for interoperability
- Develop relationships to provide recommended test facilities

https://uwballiance.org/

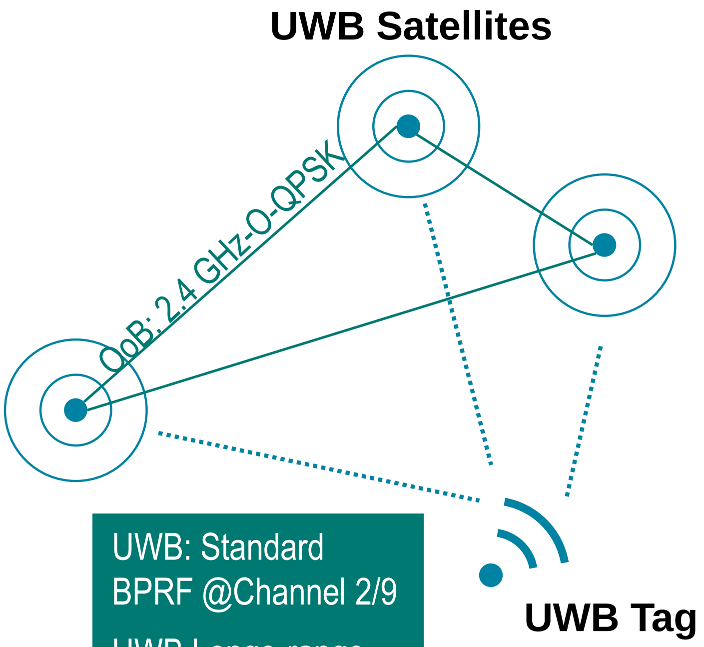
OMLOX: open standard for precise real-time industrial indoor localization system

The focus of omlox is to define open interfaces for an interoperable localization system. omlox enables various industries to use a single infrastructure with different applications from different providers.



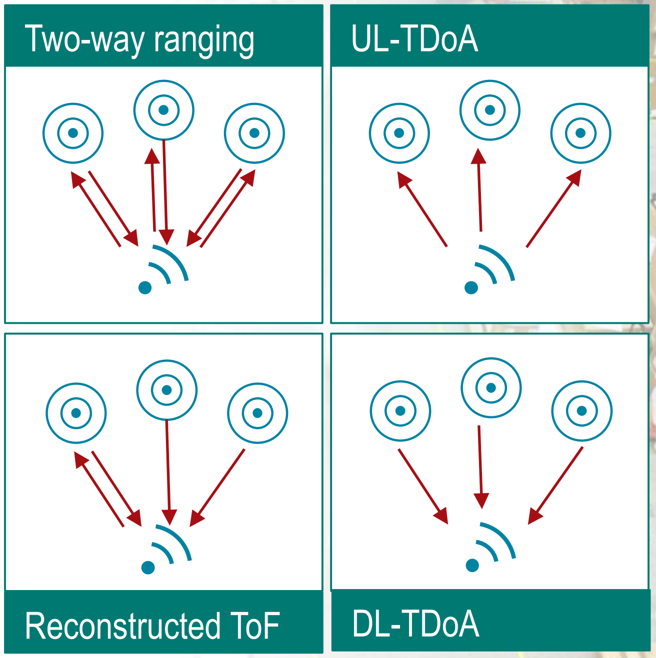
https://omlox.com/home

The OMLOX Core zone for UWB based real time location services RTLS



UWB: Standard
BPRF @Channel 2/9

UWB Longe-range
HPRF @ channel 1/3



Cross-industry organizations for smartphone-to-car connectivity solutions

CARCONNECTIVITY consortium®

When it comes to cars and smartphones, the Car Connectivity Consortium (CCC) makes it possible to simply connect and ride.

- The CCC makes this possible via **MirrorLink™**, a standard for controlling handsets from the dashboard or steering wheel.
- **Digital Key** will enable consumers to conveniently lock/unlock their vehicle and start their engine using their smart devices. Advanced key provisioning and sharing will also be supported.
- And **Car Data** will connect consumers to service providers who will offer tailored vehicular services enhanced by vehicle data.

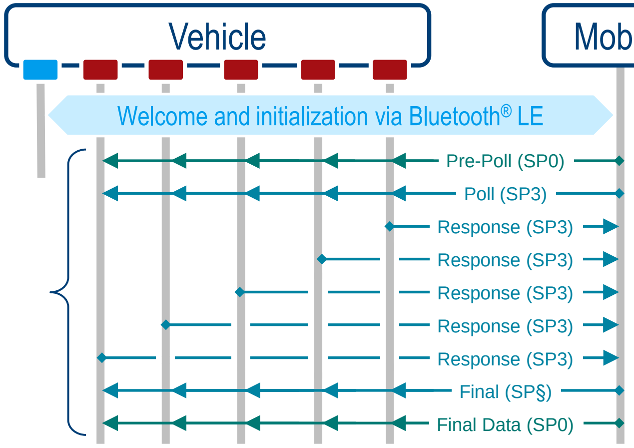
Digital Key 3.0 addresses security and usability by authenticating the Digital Key between a vehicle and the mobile device over Bluetooth Low Energy. UWB offers secure and accurate distance measurement allowing cars to locate authenticated mobile devices so that it not only prevents attacks but also adds a new level of convenience when entering, interacting and starting the car.

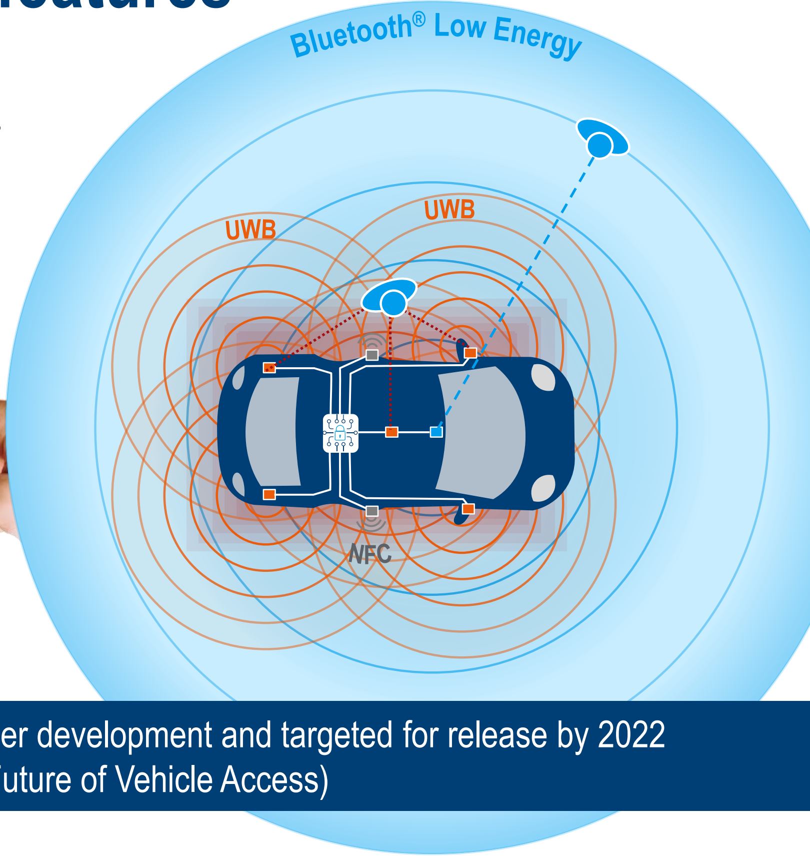
Through its well-developed certification programs, CCC rigorously evaluates and certifies devices, cars and apps for their compliance and interoperability.

https://carconnectivity.org/

CCC Digital Key Release 3.0 adds hands-free, location-aware keyless access and location-aware features

The CCC has adopted the UWB secure ranging technology based on High Rate Pulse repetition frequency (HRP) standardized in IEEE 802.15.4z in combination with standard Bluetooth® Low Energy connectivity.





Rohde & Schwarz member of CARCONNECTIVITY consortium®

The CCC Digital Key certification program is under development and targeted for release by 2022 (see CCC Whitepaper “ CCC Digital Key – The Future of Vehicle Access)

Fine Ranging (FiRa): UWB accuracy and security in measuring distance to a target or determining position

Goal to develop compelling UWB use cases, ensure seamless UWB interoperability and promote UWB ranging

Service-specific protocols for multiple verticals
- Hands-free access control, location-based services, and device-to-device (peer-to-peer) applications;

Mechanisms which are not within IEEE scope
- Discover UWB devices and services
- Configure devices in an interoperable manner
- Specify interoperable security requirements

Interoperability Standard
- Profiled features among 802.15.4/4z PHY/MAC
- Performance requirements
- Test methods and procedures
- Certification program

Rohde & Schwarz ins member of FiRa, actively working in several the FiRa working groups

https://www.firaconsortium.org/

FiRa Consortium: the scope of use cases

Source: FiRa Consortium Webpage

FiRa™ Consortium drives interoperability at all levels

Rohde & Schwarz member of FiRa – The Power to Be Precise

Security

Services

Application Layer

MAC Layer

PHY Layer

FiRa CERTIFIED

IEEE 802.15.4/4z

Enhanced UWB PHY & MAC

- Coding and preambles
- Improved integrity & accuracy
- Information elements
- Multiple ranging methods

FiRa Consortium

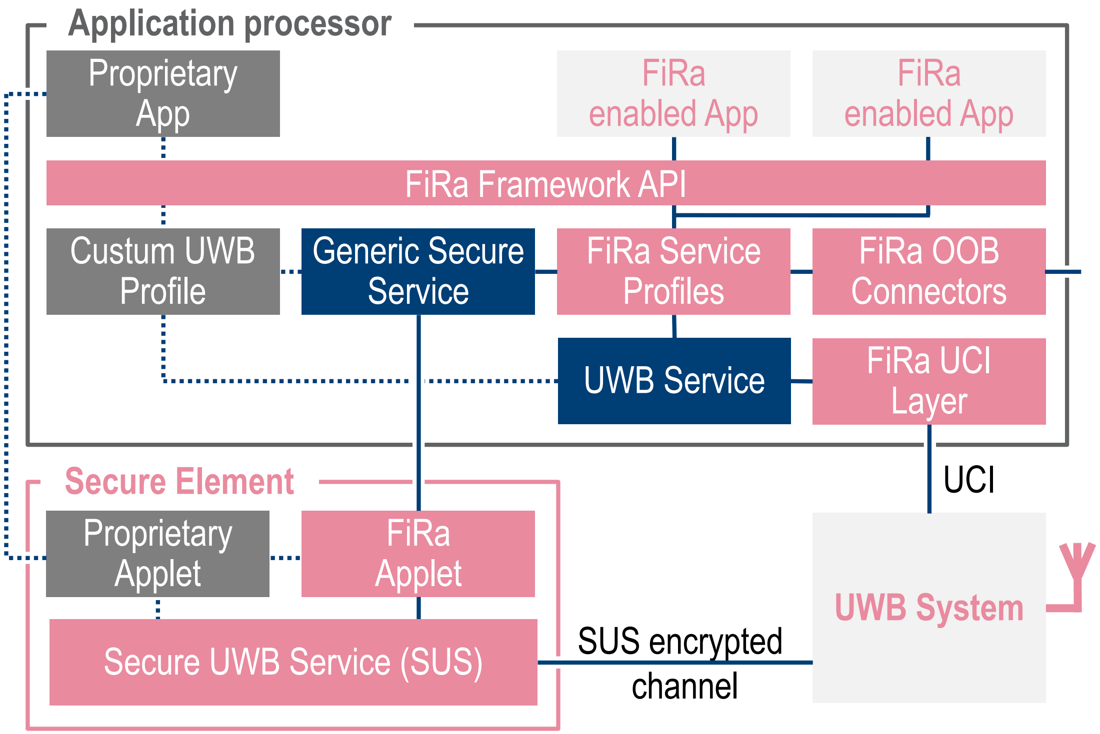
Service-specific protocols for multiple verticals

- Hands-free access control, location-based services, and device-to-device (peer-to-peer) applications

Interoperability Standard

- Profiled features among 802.15.4/4z PHY/MAC (e.g. UWB HRP-EREDV HPRF & BPRF)
- Performance requirements (e.g. ranging accuracy, AoA accuracy)
- Test methods and procedures
- Certification program

Transforming the way we interact with our environment by enabling precise location awareness for people and devices.



fira | The Power to Be Precise

- Support the development of compelling use cases across broad business domains
- Define specifications and certify products to ensure interoperability
- Foster a robust UWB ecosystem to enable rapid technology deployment

www.firaconsortium.org

Impulse radio ultra-wideband (802.15.4)

- History, applications and markets
- **Test Requirements**
- Solutions

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

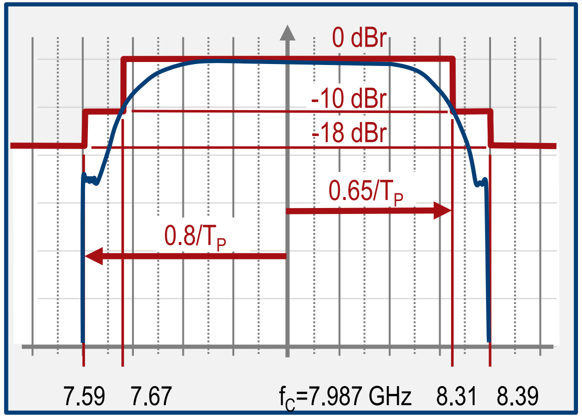
Interoperability certification

- 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
UWB PHY Test Suite

Specific UWB measurements (IEEE, FiRa)

Transmit Power Spectrum Density

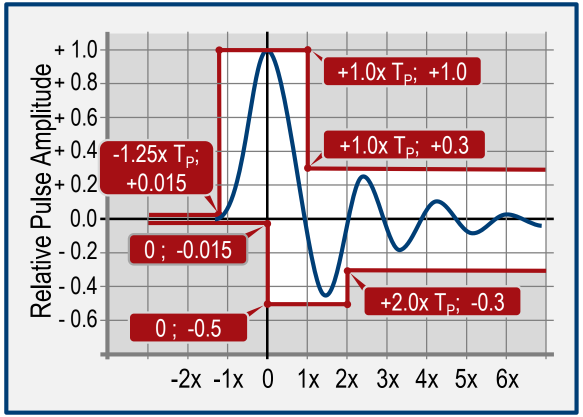


The transmitted spectrum shall be less than –10 dB relative to the maximum spectral density of the signal for

$0.65/T_P < |f – fc| < 0.8/T_P$

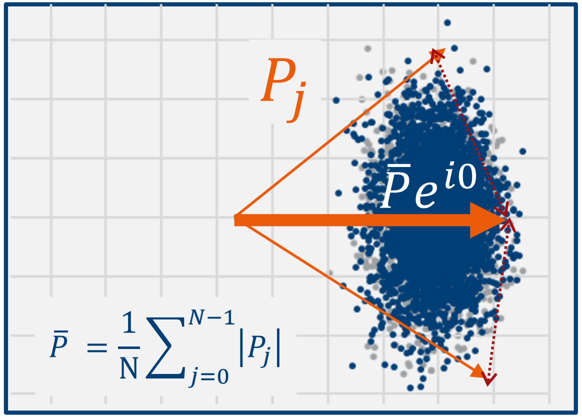
and –18 dB for $|f – fc| > 0.8/T_P$.

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)



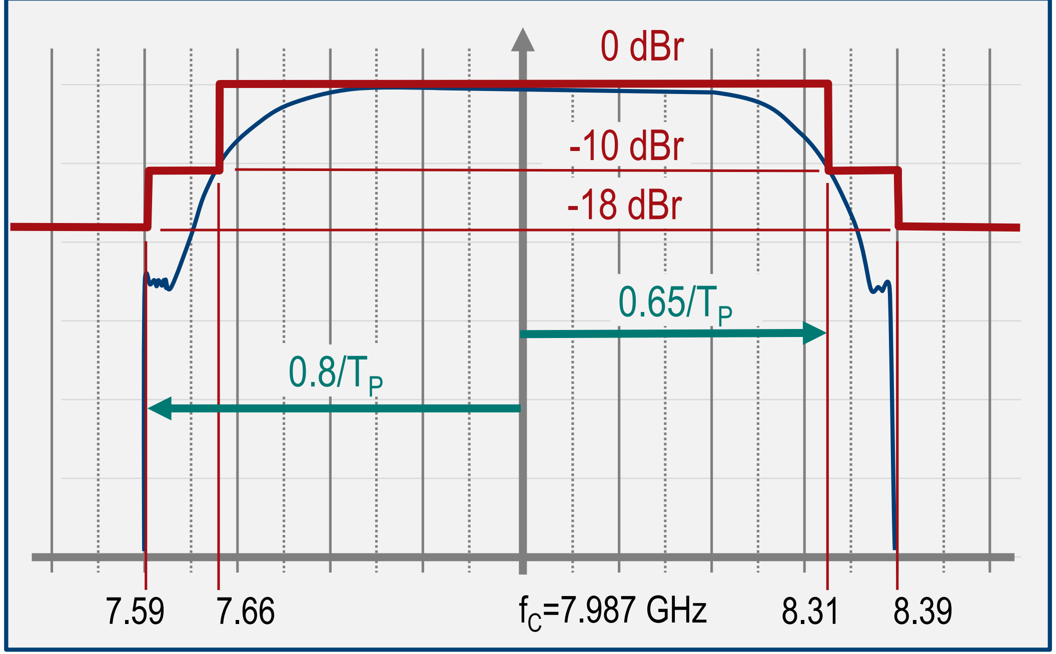
$$\bar{P} = \frac{1}{N}\sum_{j=0}^{N-1}|P_j|$$

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

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

Transmit power spectrum density (PSD) in 802.15.4

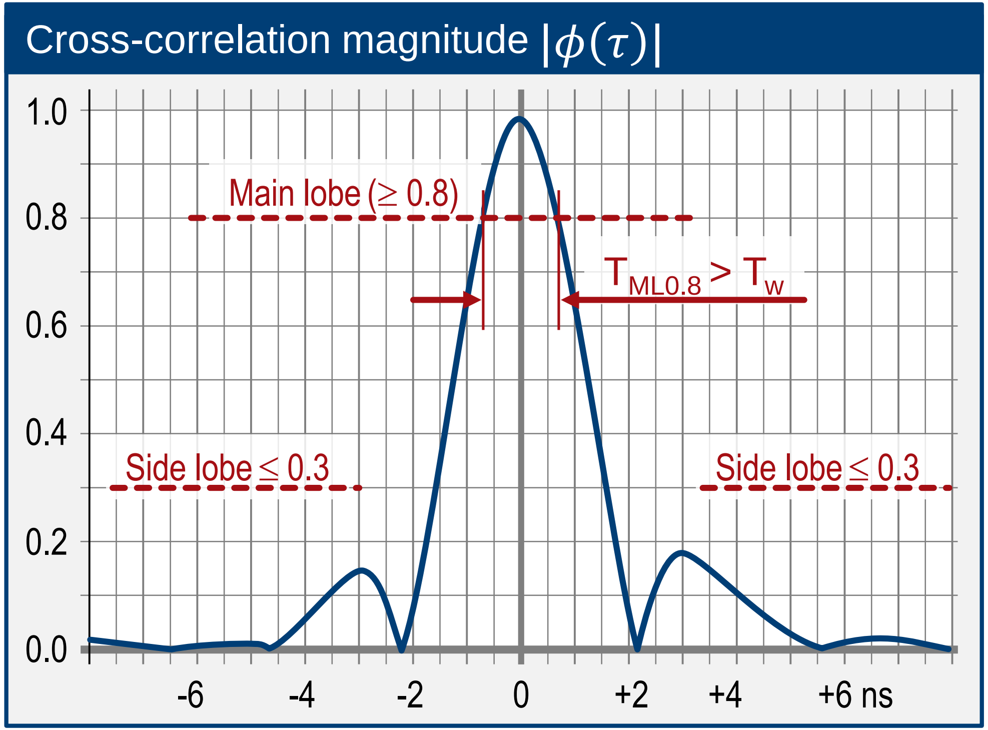
Transmit Power Spectrum Density (PSD) mask



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 $|f – fc| > 0.8/Tp$.
The measurements shall be made using a 1 MHz resolution bandwidth and a 1 kHz video bandwidth.

T_P	$\lvert f_c – f\rvert$ -10 dBr	$\lvert f_c – f\rvert$ -18 dBr
2.00 ns	325 MHz	400 MHz
0.92 ns	705 MHz	870 MHz
0.75 ns	867 MHz	1067 MHz
0.74 ns	878 MHz	1081 MHz

Normalized RRC cross-correlation magnitude (802.15.4)



The transmitted pulse shape p(t) shall be constrained by the shape of its cross-correlation function with a standard reference pulse, r(t), which is a root raised cosine pulse with a roll-off factor of $\beta = 0.5$.

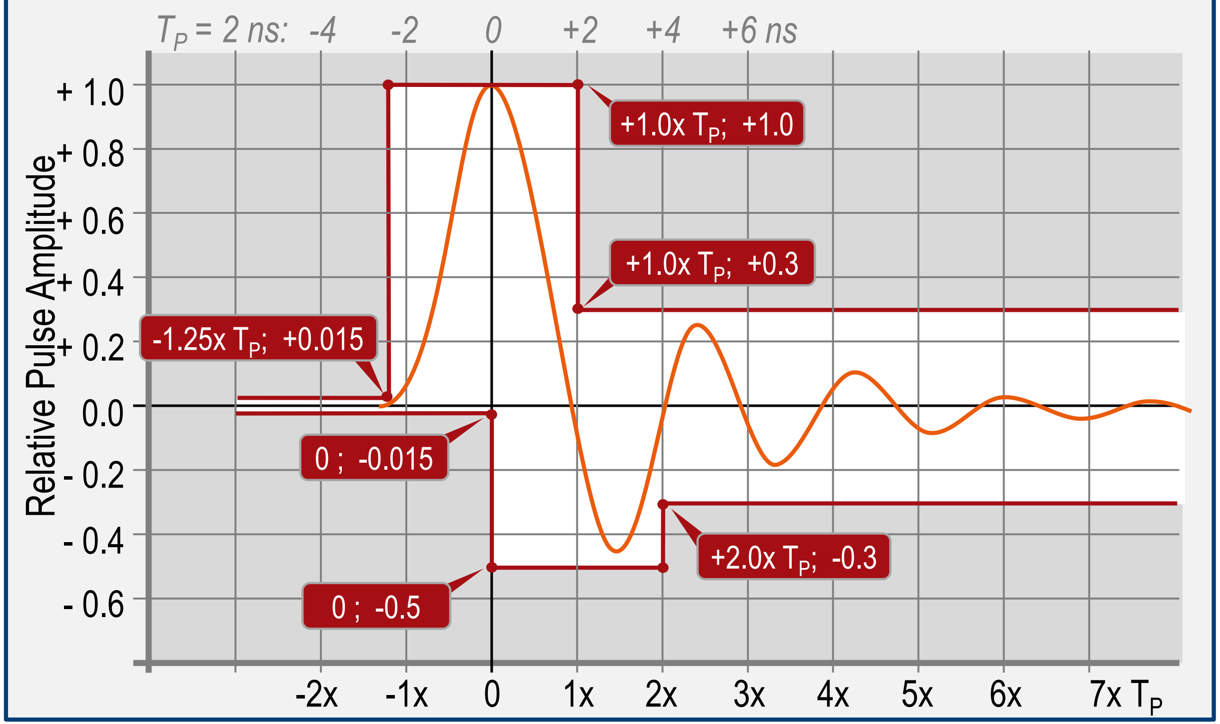
$$\phi(\tau) = \frac{1}{\sqrt{E_r E_p}} \int_{-\infty}^{\infty} r(t)\, p^*(t+\tau)\, dt$$

The main lobe should be $|\phi(\tau)| \geq 0.8$ for a duration of at least T_W. Any side lobe shall be no greater than 0.3.

Channel #	T_P	T_W
0:3. 5:6, 8:10; 12:14	2.00 ns	0.5 ns
7	0.92 ns	0.2 ns
4, 11	0.75 ns	0.2 ns
15	0.74 ns	0.2 ns

Recommended time domain mask for HRP-UWB (802.15.4)

Relative pulse amplitude – time domain mask



If the transmitted pulse follows the minimum precursor pulse recommendation, 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 T_P.

Channel #	T_P
0:3. 5:6, 8:10; 12:14	2.00 ns
7	0.92 ns
4, 11	0.75 ns
15	0.74 ns

FiRa™ Certification test process and documents

Rohde & Schwarz member of fira The Power to Be Precise

UWB PHY Technical Requirements	UWB MAC Technical Requirements	Interoperability Requirements
PHY Compliance Test specification	MAC Compliance Test specification	Interoperability Test specification

UCI Test specification
Test mode and test Interface

Join FiRa

Prepare
(e.g. use validated test tools)

Certification testing
(by authorized test labs)

Apply

Promote

- FiRa validates **test tools to** ensure that they conform to the requirements defined in the FiRa test specifications
- FiRa authorizes **test labs** to ensure that they have the competence to conduct certification testing

FiRa physical layer conformance test cases (V1.3)

Transmitter Tests

PCT1.1.1: BPRF - Packet Format
PCT1.1.2: HPRF - Packet Format

PCT1.2.1: BPRF - Power Spectral Density Mask
PCT1.2.2: HPRF - Power Spectral Density Mask

PCT1.3.1: BPRF - Carrier Frequency Tolerance and Pulse Timing
PCT1.3.2: HPRF - Carrier Frequency Tolerance and Pulse Timing

PCT1.4.1: BPRF - Baseband Impulse Response
PCT1.4.2: HPRF - Baseband Impulse Response

PCT1.5.1: BPRF - Transmit Signal Quality (NRMSE)
PCT1.5.2: HPRF - Transmit Signal Quality (NRMSE)

Receiver Tests

PCT2.1.1: BPRF - SP0 & SP1 Packet Reception Sensitivity
PCT2.1.2: HPRF - SP0 & SP1 Packet Reception Sensitivity

PCT2.2.1: BPRF - SP3 Packet Reception Sensitivity
PCT2.2.2: HPRF - SP3 Packet Reception Sensitivity

PCT2.3.1: BPRF - SP0 & SP1 Dirty Packet Test
PCT2.3.2: HPRF - SP0 & SP1 Dirty Packet Test

PCT2.4.1: BPRF - SP3 Dirty Packet Test
PCT2.4.2: HPRF - SP3 Dirty Packet Test

PCT2.5.1: BPRF - SP3 Packet First-Path Dynamic Range
PCT2.5.2: HPRF - SP3 Packet First-Path Dynamic Range

PCT2.6.1: BPRF - Packet Format
PCT2.6.2: HPRF - Packet Format

R&S validated test cases based on FiRa TRSL v1.4.0 – June 2022

FiRa physical layer conformance test cases (V2.0) using the new UCI version 2.0

FiRa CERTIFIED

Transmitter Tests

PCT_1_0_TX_BPRF_BV_01: Packet Format
PCT_1_0_TX_HPRF_BV_01: Packet Format

PCT_1_0_TX_BPRF_BV_02: Power Spectral Density Mask
PCT_1_0_TX_HPRF_BV_02: Power Spectral Density Mask

PCT_1_0_TX_BPRF_BV_03: CF Tolerance and Pulse Timing
PCT_1_0_TX_HPRF_BV_03: CF Tolerance and Pulse Timing

PCT_1_0_TX_BPRF_BV_04: Baseband Impulse Response
PCT_1_0_TX_HPRF_BV_04: Baseband Impulse Response

PCT_1_0_TX_BPRF_BV_05: Transmit Signal Quality (NRMSE)
PCT_1_0_TX_HPRF_BV_05: - Transmit Signal Quality (NRMSE)

New NRMSE test cases not yet defined/validated

Receiver Tests

PCT_1_0_RX_BPRF_BV_01: SP0 & SP1 Packet Reception Sensitivity
PCT_1_0_RX_HPRF_BV_01: SP0 & SP1 Packet Reception Sensitivity

PCT_1_0_RX_BPRF_BV_02: SP3 Packet Reception Sensitivity
PCT_1_0_RX_HPRF_BV_02: SP3 Packet Reception Sensitivity

PCT_1_0_RX_BPRF_BI_01: SP0 & SP1 Dirty Packet Test
PCT_1_0_RX_HPRF_BI_01: SP0 & SP1 Dirty Packet Test

PCT_1_0_RX_BPRF_BI_02: SP3 Dirty Packet Test
PCT_1_0_RX_HPRF_BI_02: SP3 Dirty Packet Test

PCT_1_0_RX_BPRF_BV_03: SP3 Packet First-Path Dynamic Range
PCT_1_0_RX_HPRF_BV_03: SP3 Packet First-Path Dynamic Range

PCT_1_0_RX_BPRF_BV_04: Packet Format
PCT_1_0_RX_HPRF_BV_04: Packet Format

PCT_2_0_RX_BPRF_BI_01: Secure Ranging – Hamming Distance Test
PCT_2_0_RX_HPRF_BI_01: Secure Ranging – Hamming Distance Test

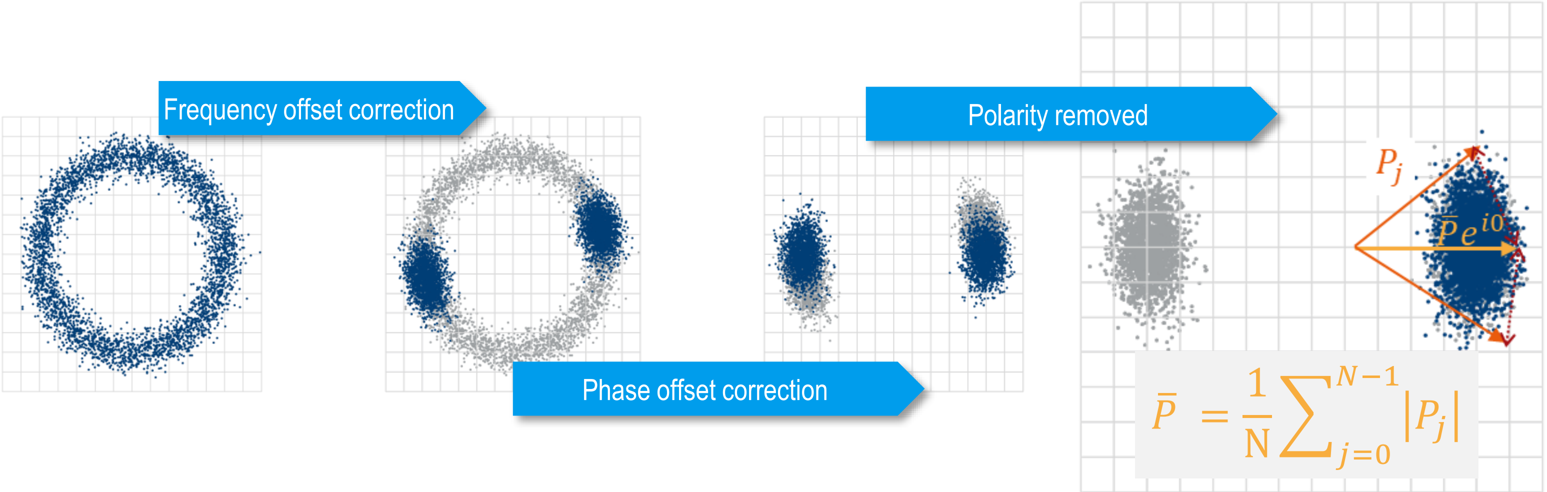
PCT_2_0_RX_BPRF_BV_01: Secure Ranging – First-Path Detection under Attack
PCT_2_0_RX_HPRF_BV_01: Secure Ranging – First-Path Detection under Attack

New security test cases not part of phase 1 duet to lack of devices supporting secure ranging

PCTT validation ongoing

UWB transmitter quality: NRMSE based on FiRa Consortium

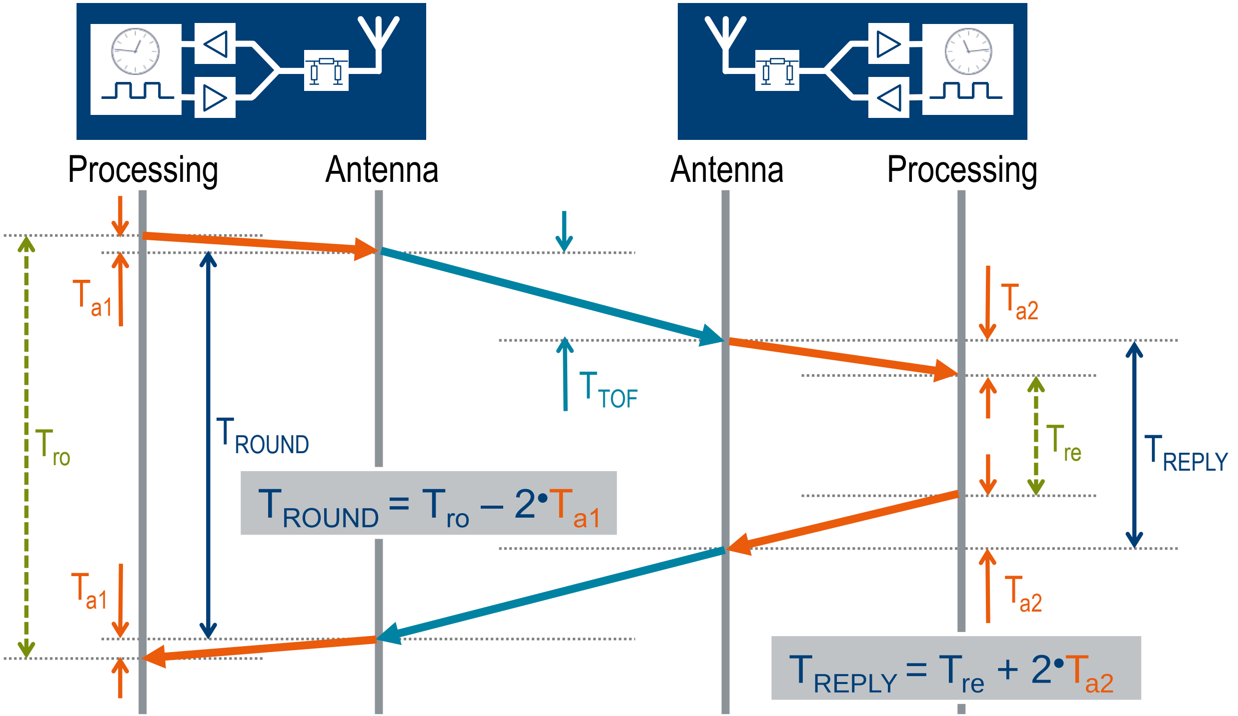
P_j is the complex pulse amplitude after frequency/phase offset and polarity are removed.



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

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

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

Impulse radio ultra-wideband (802.15.4)

UWB History, applications and markets

UWB Test Requirements

UWB **Solutions**

R&S®CMP200

CMP200 features

- One general purpose analyzer
  Frequency range: 4 to 20 GHz
- One ARB generator
  Replay of predefined waveforms
  Frequency range: 6 to 20 GHz
- Planned for 802.15.4ab

Compact UWB non-signaling tester for HRP in high band

- HRP UWB PHY TX measurements (802.15.4)
  Band group 2: 6.5 to 9.5 GHz
- HRP UWB RX measurements by use of customer waveforms or R&S®WinIQSIM2
- Time of flight and angle of arrival measurements
- New UWB Head for Multi DUT Testing

R&S® CMP200 TEST Environments

The instrument can be divided

- ► Every UWB Head could represent one sub instrument
- ► Every RF connector could represent one sub instrument

Inst.1	Inst.2	Inst.3	Inst.4	Inst.5	Inst.6

Instrument 1 | Instrument 2 | Instrument 3

Instrument 1

Wireless Communication - Solutions

R&S® Chambers

CMQ Family

- Shielding of 80dB
- Height Extension possible
- CMQ 200 HS
  - 0.3 – 14 GHz
- CMQ 200
  - 20 – 77 GHz
- CMQ 500
  - 0.7 – 77 GHz
- Production focused chambers

R&S® ATS800R

- Key Features & Benefits
  - Footprint of 0.7 m^2
  - Easily transportable on wheels
  - High shielding effectiveness
  - 12HU space for instruments in optional rack
  - Flexible in use and setup
    - With rack
    - Benchtop
    - On wheels but without rack
    - As shield box (no reflector/feed but absorber cover)

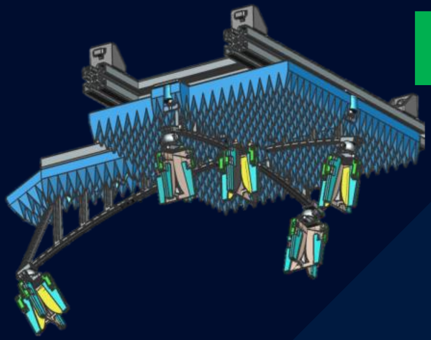
R&S® ATS800R – Tilt & PAN Positioner

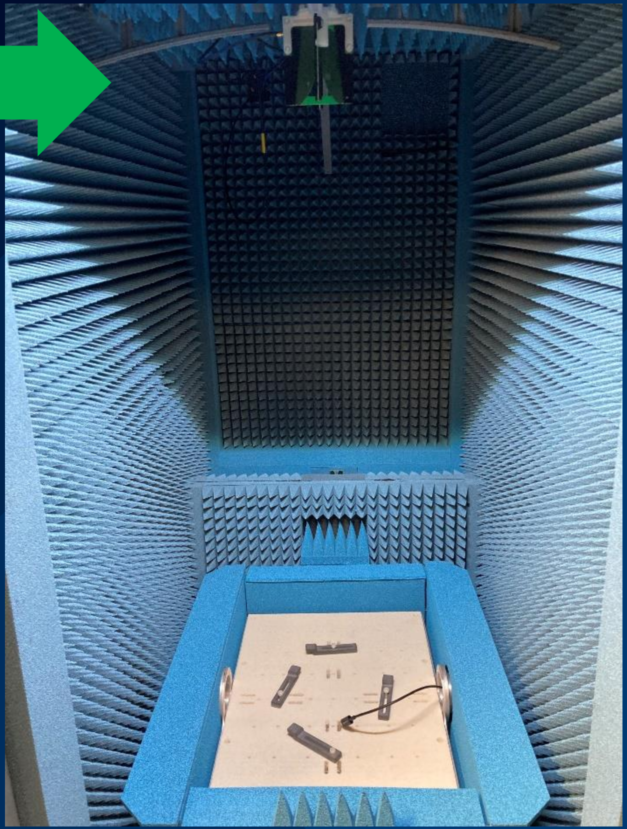
Category	Value
Positioner Type	Tilt and pan
DUT Weight Max Size	< 2.5kg, centred 27cm x 41cm
Resolution	0.01 degrees
Accuracy	0.25 degrees @1kg 0.50 degrees @ 2.5kg
Tilt Range	+/- 90 degrees
Pan Range	+/- 90 degrees
Rotation speed	< 45 degree/sec

Launch in Q1/2024

R&S® ATS800R – Antenna Arc

Antenna Arc
UWB testing/ SatCom/ NTN testing
Antenna Arc mounted instead of CATR reflector and feed
Fixed antenna in centre
Four Arc arms in all directions
Up to 5 antennas





Launch in Q1/2024

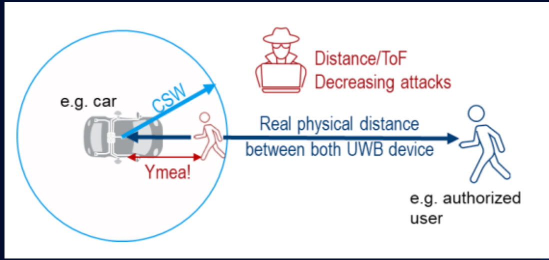
Wireless Communication - Solutions

UWB Setups

Status FiRa – PHY layer

June 2022

- June 2022: CMP200 validated based on FiRa PHY Spec. 1.3
- October 2023: CMP200 re-validated based on UCI 2.0



Planning for re-validation for FiRa 2.1:

New test cases for secure ranging:

- *PCT_2_0_RX_BPRF_BI_01: BPRF Secure Ranging – Hamming Distance Test*
- *PCT_2_0_RX_HPRF_BI_01: HPRF Secure Ranging – Hamming Distance Test*
- *PCT_2_0_RX_BPRF_BV_01 : BPRF Secure Ranging – First-Path Detection under Attack*
- *PCT_2_0_RX_HPRF_BV_01 : HPRF Secure Ranging – First-Path Detection under Attack*

UWB FiRa Conformance Setup

The Power to Be Precise

R&S®CMP200

FiRa CERTIFIED

FiRa 1.0
FiRa 2.0

- Transmitter Tests
- TX_BPRF_BV_01: BPRF –Packet Format
- TX_HPRF_BV_01: HPRF –Packet Format
- TX_BPRF_BV_02: BPRF –Power Spectral Density Mask
- TX_HPRF_BV_02: HPRF –Power Spectral Density Mask
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- TX_BPRF_BV_05: BPRF –Transmit Signal Quality
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- Receiver Tests
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- RX_BPRF_BV_02: BPRF –SP3 Packet Reception Sensitivity
- RX_HPRF_BV_02: HPRF –SP3 Packet Reception Sensitivity
- RX_BPRF_BI_01: BPRF –SP0 & SP1 Dirty Packet Test
- RX_HPRF_BI_01: HPRF –SP0 & SP1 Dirty Packet Test
- RX_BPRF_BI_02: BPRF –SP3 Dirty Packet Test
- RX_HPRF_BI_02: HPRF –SP3 Dirty Packet Test
- RX_BPRF_BV_03: BPRF –SP3 Packet First-Path Dynamic Range
- RX_HPRF_BV_03: HPRF –SP3 Packet First-Path Dynamic Range
- RX_BPRF_BV_04: BPRF –Packet Format
- RX_HPRF_BV_04: HPRF –Packet Format
- RX_BPRF_BI_01: BPRF Secure Ranging –Hamming Distance Test
- RX_HPRF_BI_01: HPRF Secure Ranging –Hamming Distance Test
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- RX_HPRF_BV_01: HPRF Secure Ranging –First-Path Detection under Attack

CARCONNECTIVITY consortium®

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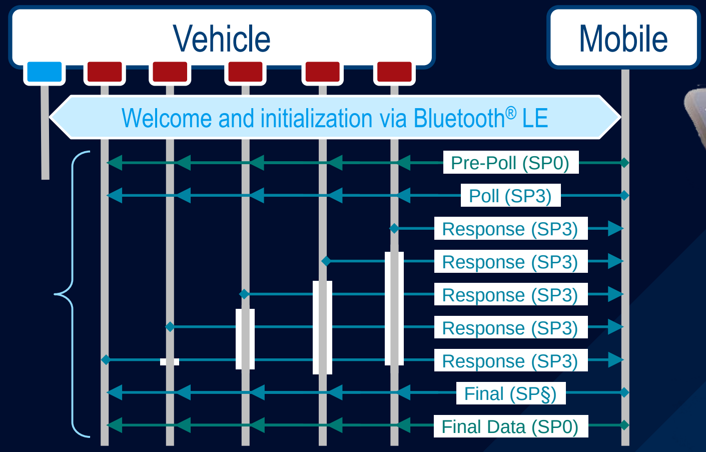
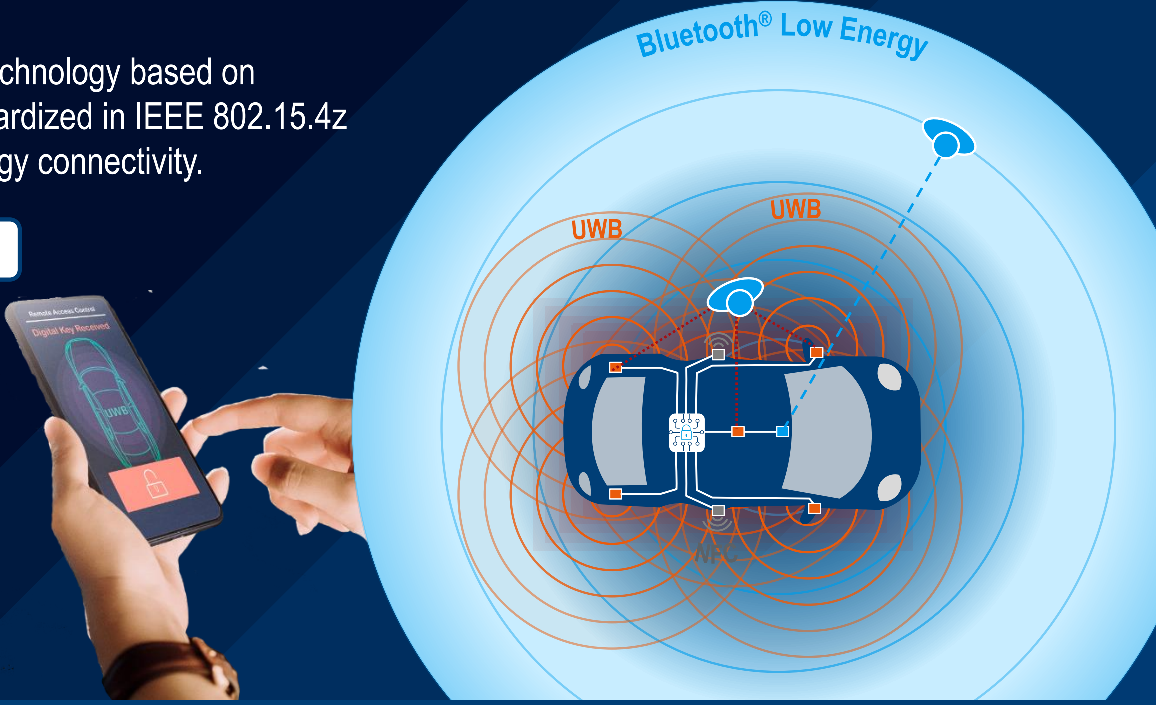
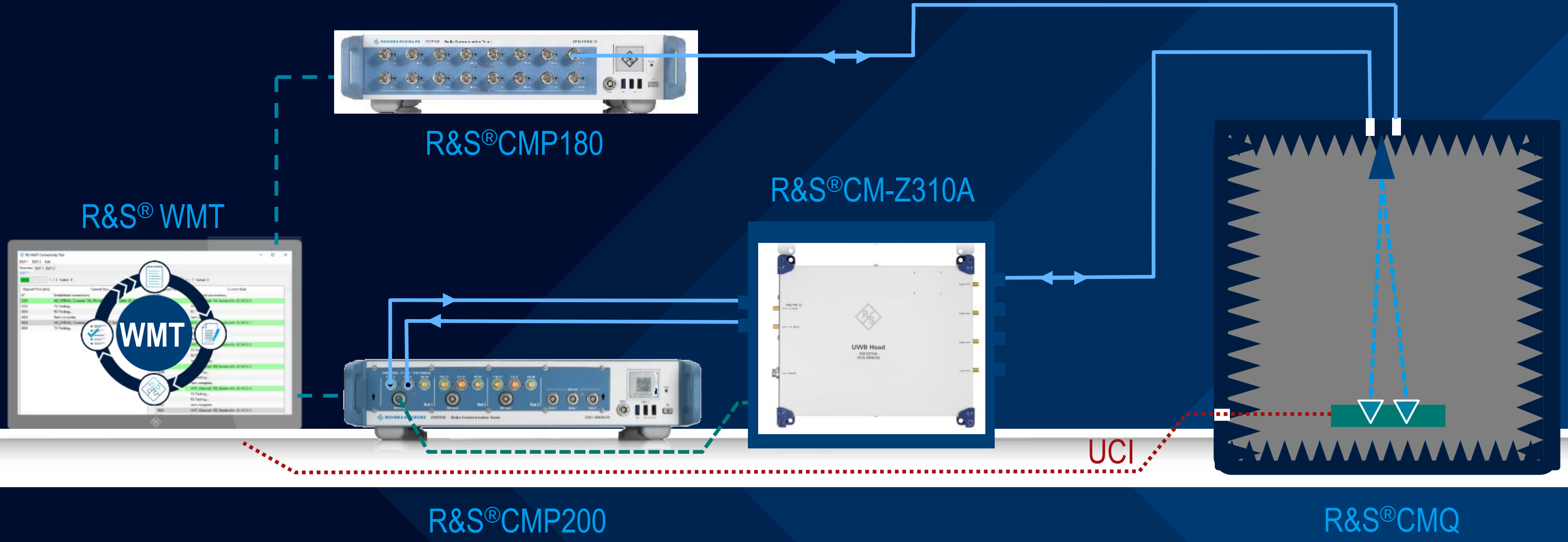




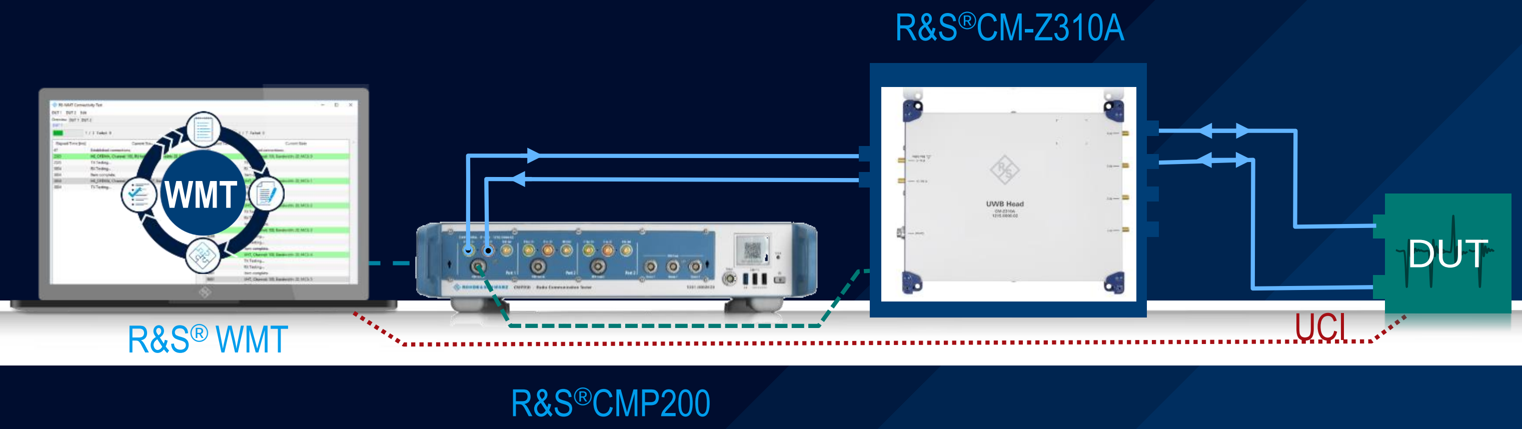
Rohde & Schwarz member of CARCONNECTIVITY consortium®

The CCC Digital Key certification program is under development (see CCC Whitepaper " CCC Digital Key – The Future of Vehicle Access)

UWB+BLE Radiated Setup – CMQ For Automotive CCC testing



UWB Conducted Setup - Calibration

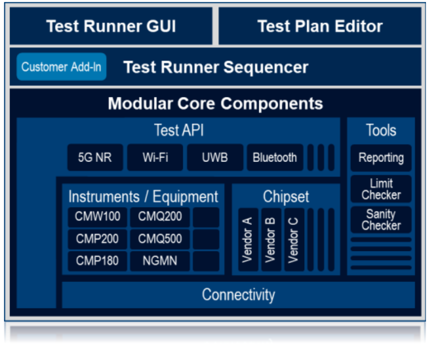


List of Tests	Description
XTal Calibration (CFO)	Calibrate the centre frequency offset
Tx Calibration	Calibrate Tx Power according to specification (e.g. FCC)
Tx Verification	The Tx power can be verified across as many use cases as desired
Rx Verification	Check that the device meets one sensitivity level limit
ToF Calibration	Calibrate the antenna delay
ToF Verification	Verify the ranging performance

Wireless Communication - Solutions

R&S ® WMT

Our offering to provide a customized automated test solution based on WMT

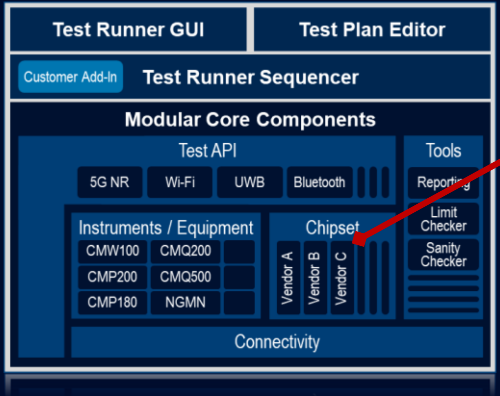


Phyton based Framework

Customization & Integration

Automated Test Solution

R&S WMT UWB chipset support List



NXP Chipsets

Available drivers:

- SR40, SR100, SR150
- SR160, SR200 (planned)
- NCJ29D5 – Ranger 4 (Automotive)
- NCJ29D6 – Ranger 5 (ongoing)

Supported Tests

Vendor	Chipset	Xtal cal	Tx cal	Tx ver	ToF cal	ToF ver	AoA cal	AoA ver	Radar Tx ver	Radar Rx ver
NXP	SR100	✓	✓	✓	✓	✓	✓	✓	✓	✓
	SR040	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	N/A	N/A
	SR150	✓	✓	✓	✓	✓	✓	✓	N/A	N/A
	SR160	✓	✓	✓	✓	✓	✓	✓	✓	✓
	SR200	planned	planned	planned	planned	planned	planned	planned	planned	planned
	NCJ29D5	✓	✓	✓	✓	✓	N/A	N/A	N/A	N/A
	NCJ29D6	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing

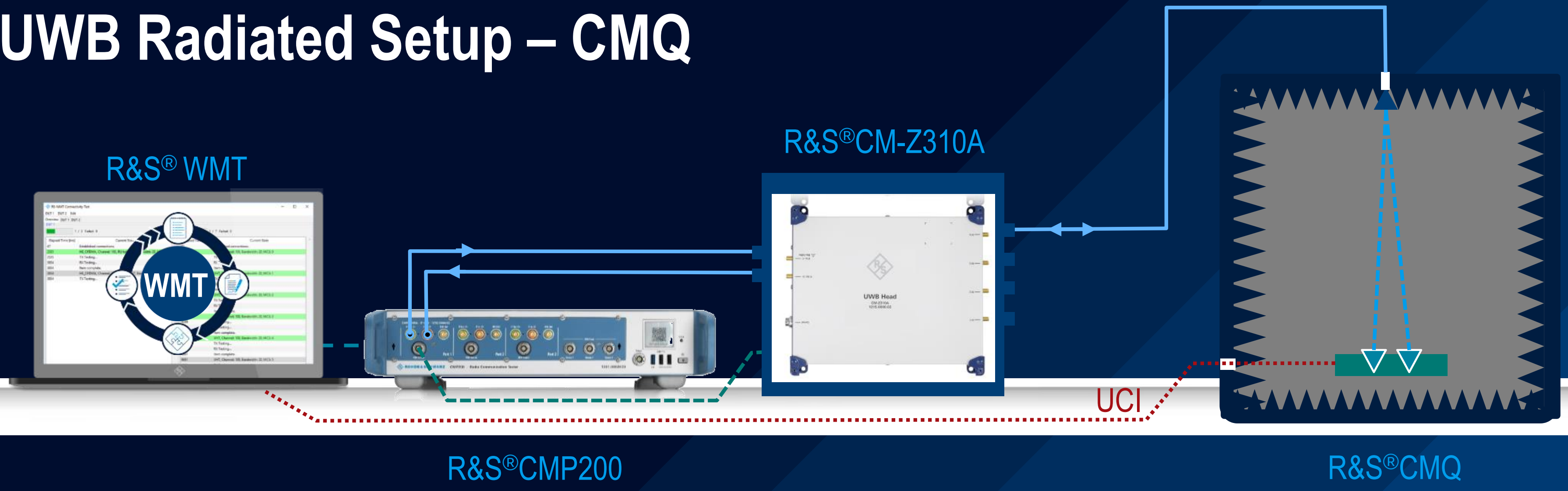
UWB Conducted Setup + Z310A + Delay Line

List of Tests	Description
XTal Calibration (CFO)	Calibrate the centre frequency offset
Tx Calibration	Calibrate Tx Power according to specification (e.g. FCC)
Tx Verification	The Tx power can be verified across as many use cases as desired
Rx Verification	Check that the device meets one sensitivity level limit
ToF Calibration	Calibrate the antenna delay
ToF Verification	Verify the ranging performance
AoA Verification	Verify AoA/PdoA measurement

UWB Radiated Setup – ATS800R

List of Tests	Description
XTal Calibration (CFO)	Calibrate the centre frequency offset
Tx Calibration	Calibrate Tx Power according to specification (e.g. FCC)
Tx Verification	The Tx power can be verified across as many use cases as desired
Rx Verification	Check that the device meets one sensitivity level limit
ToF Calibration	Calibrate the antenna delay
ToF Verification	Verify the ranging performance
AoA Calibration	Create reference table for AoA/PdoA
AoA Verification	Verify AoA/PdoA measurement

UWB Radiated Setup – CMQ

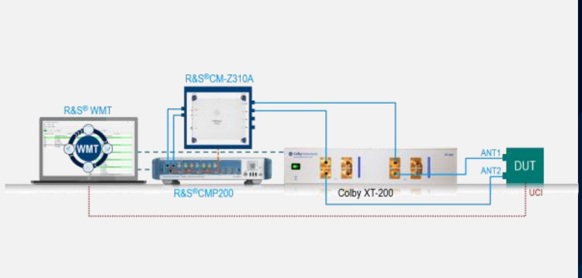


List of Tests	Description
XTal Calibration (CFO)	Calibrate the centre frequency offset
Tx Calibration	Calibrate Tx Power according to specification (e.g. FCC)
Tx Verification	The Tx power can be verified across as many use cases as desired
Rx Verification	Check that the device meets one sensitivity level limit
ToF Calibration	Calibrate the antenna delay
ToF Verification	Verify the ranging performance
AoA Calibration	Calibrate PdoA offset
AoA Verification	Verify AoA/PdoA measurement

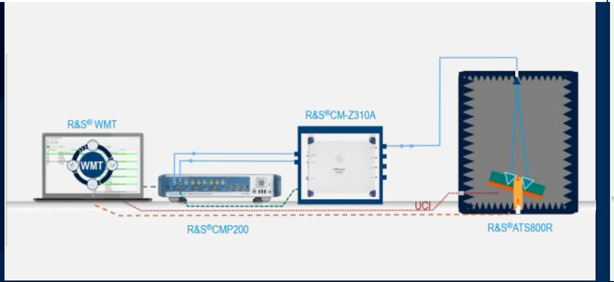
AoA verification and calibration in R&D and Manufacturing

In practice, 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

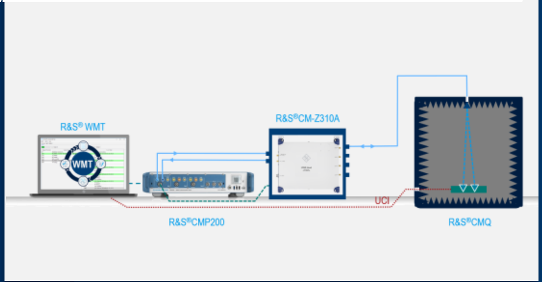
AoA/PDoA **Chipset Verification**



AoA/PDoA **Device Reference Calibration**



AoA/PDoA **Device Offset Calibration**



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