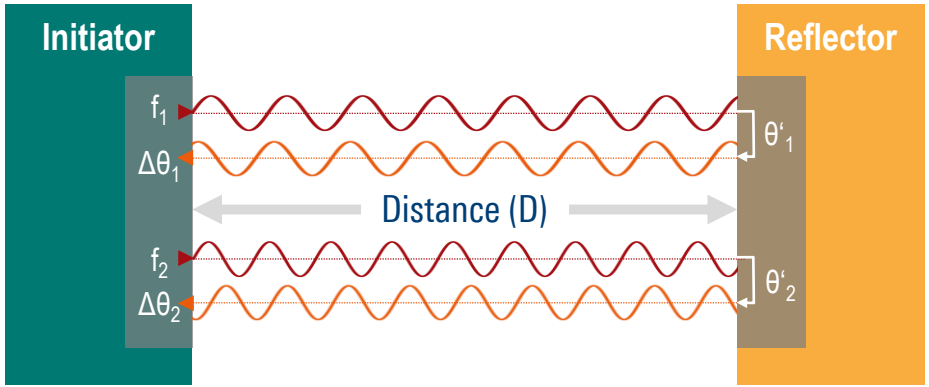

Rohde & Schwarz
Connectivity Day
MASTERING
NEXT GENERATION CONNECTIVITY
BY SMART TESTING

Bluetooth® LE Channel Sounding

Channel sounding applying phase based ranging (PBR) for high accurate distance measurements (HADM)



Total phase change over distance D

$$D = \frac{c\,\Delta\theta_i}{4\pi\,f_i}$$

Limited by wavelength

$$D_{max} = \frac{c}{2f_i}$$ e.g. 6 cm

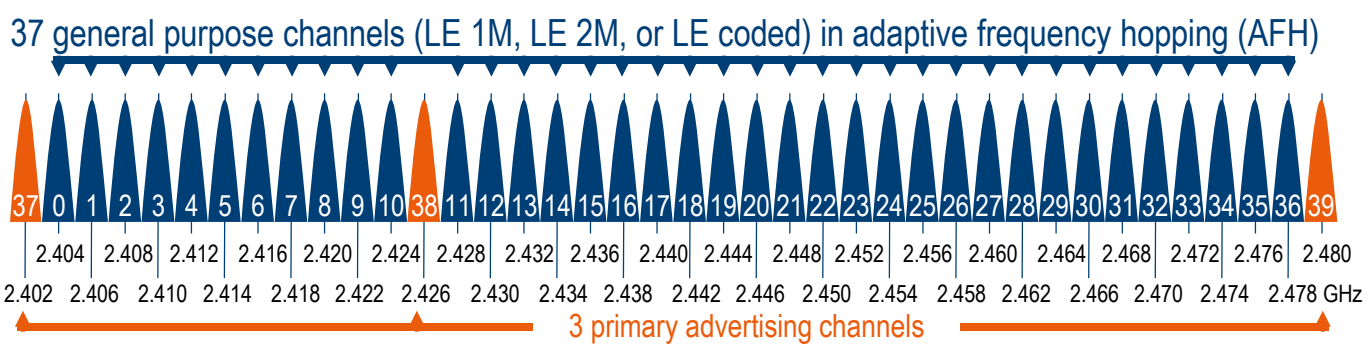
$$D = \frac{c(\Delta\theta_1 - \Delta\theta_2)}{4\pi\,(f_1 - f_2)}$$

Distance wrap

$$D_{max} = \frac{c}{2\Delta f}$$ e.g. 150 m

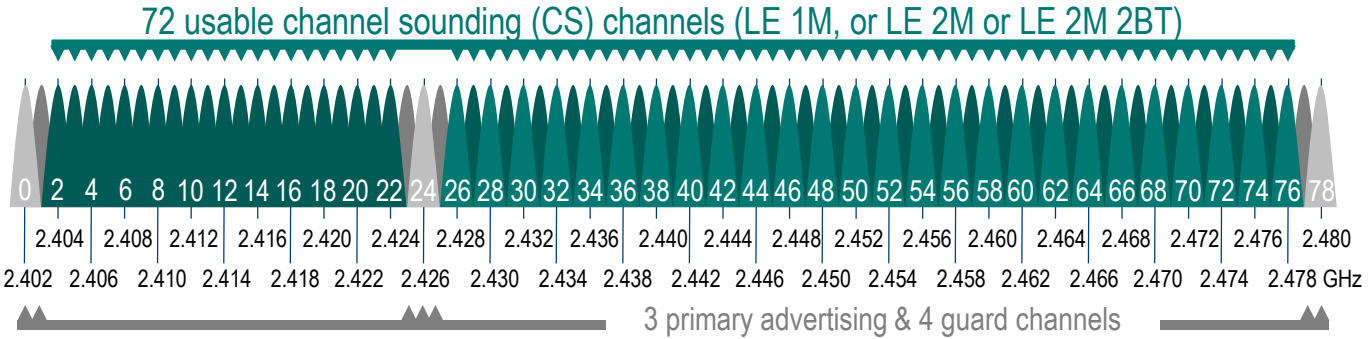
Δf = 1 MHz

Channel sounding applies a channel map with 1 MHz spacing



Bluetooth® LE physical channel map

- 2 MHz spacing
- 3 primary advertising channels
- 37 general purpose channels



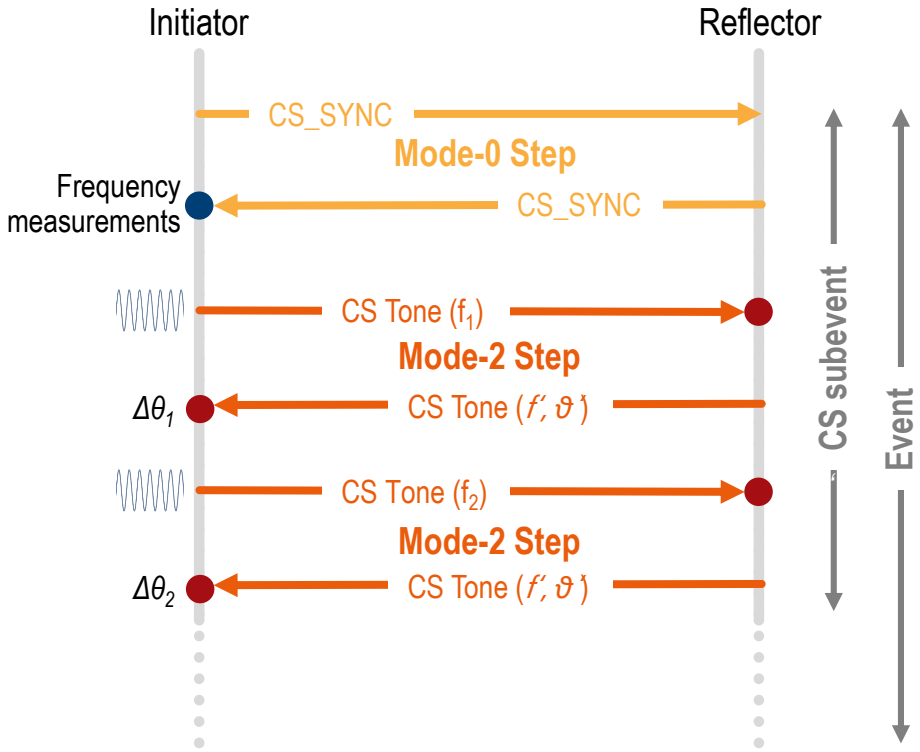
CS channel map

- 1 MHz spacing
- 72 CS channels
- No use of primary advertising and guard channels
- Optional CS companion signals in nearby channels

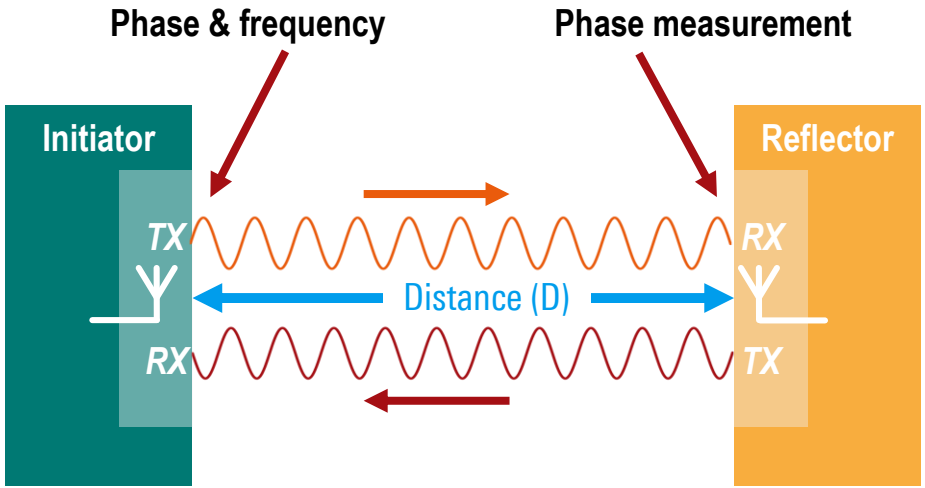
Principle of channel sounding (CS) for high accurate distance measurements (HADM)

There are four different CS step modes:

- Mode-0: measuring frequency offset (calibration)
- Mode-1: measuring RTT,
- Mode-2: measuring phase rotations
- Mode-3: measuring both RTT and phase rotations



RFPHY test specification coverage



Phase Stability (transmit)
Ensure that the phase of the transmitted CS signal is acceptable stable over the phase measurement period.

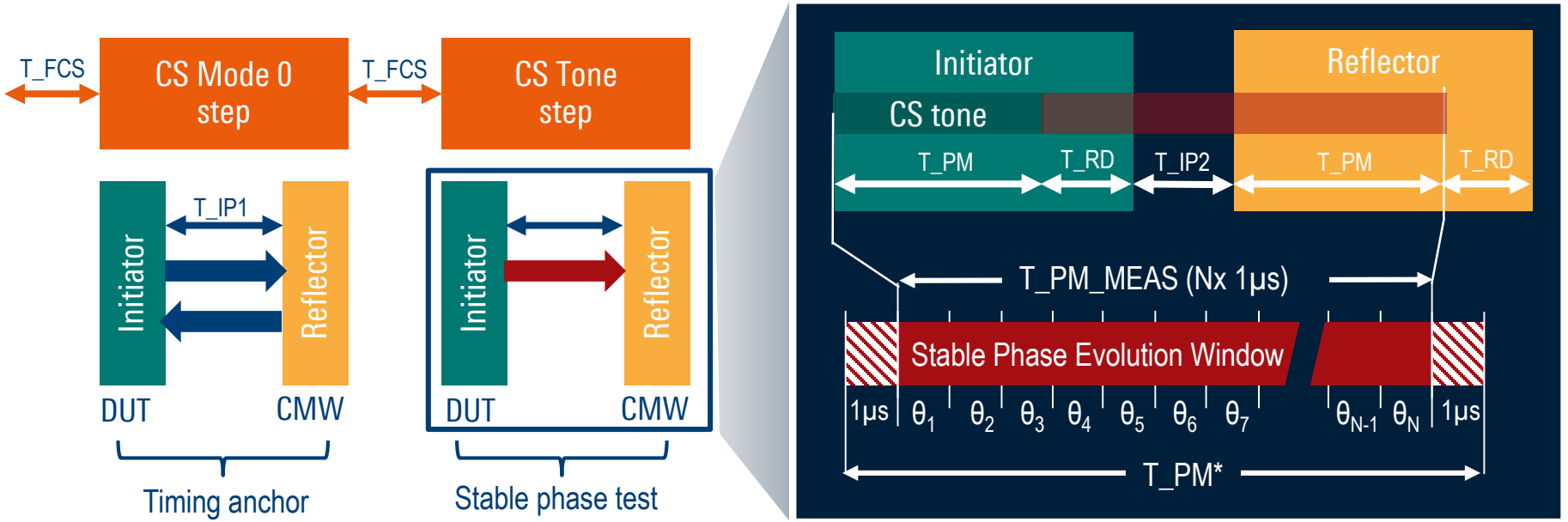
Phase Measurement Accuracy (receive)
Ensure that the phase measurement accuracy is within acceptable limits during the phase measurement period.

Step Mode, Frequency Verification
This test verifies the average frequency of each of the mode transmissions within the CS sub-event are aligned with the initial frequency offset measurement.

Modulation accuracy for CS signals and RX/TX antenna switching integrity are common aspects

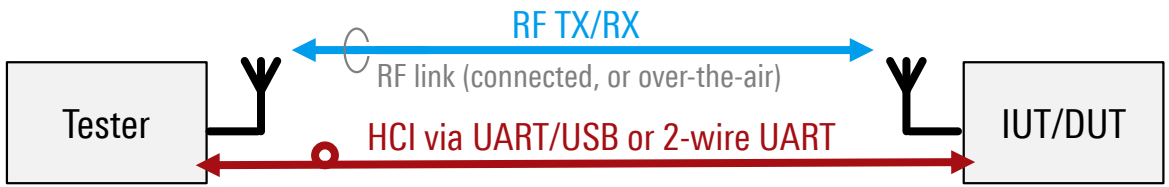
Stable phase test using a special test mode

Verifies that the devices carrier phase remains stable for a certain period by testing a number of absolute phase values



New Bluetooth® LE Test Protocol

Bluetooth® LE physical layer testing and qualification uses Direct Test Mode (DTM)



Direct Test Mode (DTM) provides a common interface for fast and repeatable test control,
but requires a wired connection to the Bluetooth® LE device.

Bluetooth® LE devices are becoming more compact and are often not equipped with wired control interfaces.

Testing requires hardware modifications of the DUT and typical RF/antenna performance measurements are cumbersome.

Growing demand for a Bluetooth® LE test control over the Bluetooth® LE RF interface, such as know from Bluetooth® BR/EDR test mode

The Unified Test Protocol (UTP) as enhanced alternative to the DTM

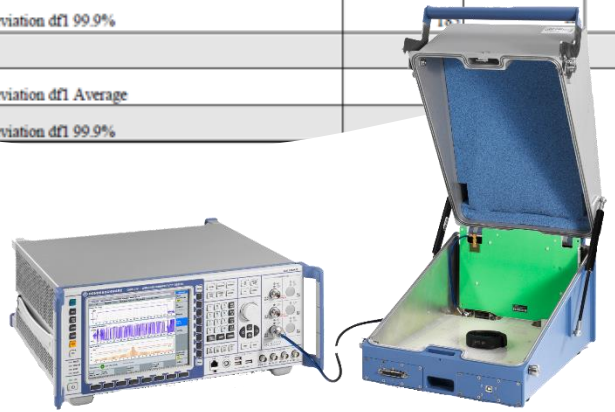
Today, LE RFPHY test cases are limited to being performed over either the 2-wire UART or Host Controller Interface (HCI) transports defined as Direct Test mode (DTM).

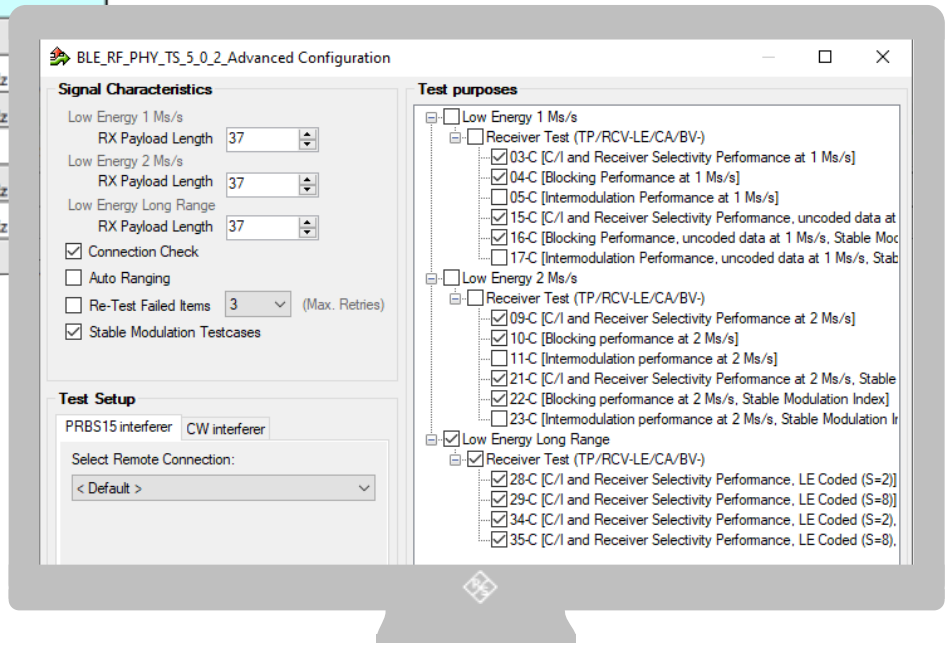
The new mode defines a unified and extensible control protocol for use across all existing transports and, in addition, the new OTA transport.

New OTA transport means that the control protocol (UTP) will be transported over the RF interface between tester and DUT (either conducted via a coaxial cable or radiated in nature).

DTM and UTP mode are supported by a comprehensive test automation software based on R&S®CMWrun

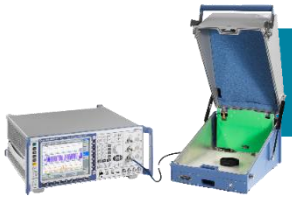
TP/TRM-LE/CA/BV-13-C [Modulation Characteristics, LE Coded (S=8)]	Lower Limit	Upper Limit	Measured	Unit	Status
Payload length: 31, Statistic Count: 10					
Channel 0					
Frequency Deviation df1 Average	225	275	258.48	kHz	
Frequency Deviation df1 99.9%	185	---	238.01	kHz	
Channel 19					
Frequency Deviation df1 Average	225	275	258.72	kHz	
Frequency Deviation df1 99.9%			237.41	kHz	
Channel 39					
Frequency Deviation df1 Average					
Frequency Deviation df1 99.9%					





ALWAYS USING THE BEST SOLUTION
to test Bluetooth® Low Energy chips, modules and devices

	Covered channels	Control transport
Standalone Test Mode Vendor specific test control	40	UART
Primary Advertiser Mode Quick & easy functional test	3	(LE Radio)
LE Direct Test Mode Standardized test mode	40	UART
LE Unified Test Protocol Mode Standardized test mode	40	LE Radio
Connected Mode Easy to use channel tests	37	(LE Radio)



R&S® CMW270

Design → Verification → (Pre-) conformance → Manu-facturing

R&S®CMW100

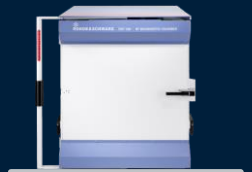
BLUETOOTH® TEST SOLUTIONS FOR THE PRODUCT LIFE CYCLE

Conformance

R&S®TS8997

RF performance/qualification

R&S®CMW500/270



R&S®DST200

R&S®CMW100

Production

R&S®CMP180

R&S®TS7124

R&S®ZNA

R&S®FSW

R&S®SMM100A

R&S®VSE

RF design and compliance

R&S®NGU

R&S®RTP

Embedded design & power

Wi-Fi7 Test Challenges

25 YEARS

What can we expect from Wi-Fi7?

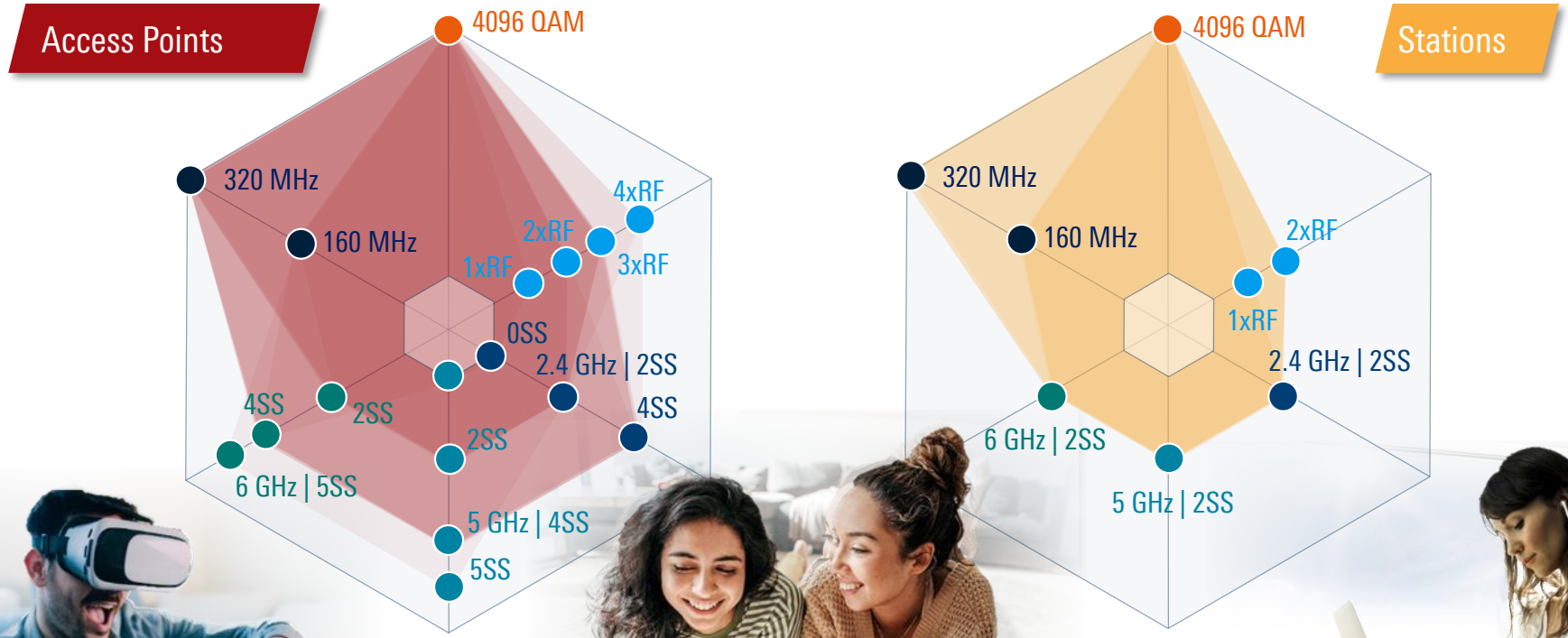
There is a limited number of **320 MHz** channels available
↳ preamble puncturing becomes more relevant

4096 QAM requires perfect RF conditions and ultimate RF designs, most probably applicable only for short distance communication

MIMO use is constrained by the device dimensions and the RF capabilities 2x2 and 4x4 will be common on mobile devices

Multi-Link operation has the potential to largely improve latency, reliability and throughput, but on costs of power and complexity

What can you get today – Wi-Fi7 chipset support



Conformance, compliance and acceptance
Diverse test requirements for Wi-Fi STAs and APs

Standard conformance

Based on requirements defined in IEEE 802.11 like:

- Spectrum mask
- Spectral flatness
- Transmitter modulation accuracy (EVM)
- Receiver minimum input sensitivity
- …..

Wi-Fi interoperability

Validate interoperability with other Wi-Fi CERTIFIED equipment operating in the same frequency band. Examples are
Wi-Fi certified 6 (incl. 6E) or Wi-Fi EasyMesh

Wi Fi CERTIFIED

Wi-Fi mobile converged devices

RF perform. evaluation of Wi-Fi mobile converged devices. The scope of testing includes handheld, self-contained Wi-Fi/ mobile modules, access point, notebook and tablet devices that support Wi-Fi as well as cellular technologies.

CTIA Certification

Wi-Fi AP operator acceptance

Test cases for RF performance, coverage, capacity & bandwidth, and stability / robustness.

broadband forum

BBF.398 Grade Wi-Fi Products

Regulatory compliance

Based on national laws covering:

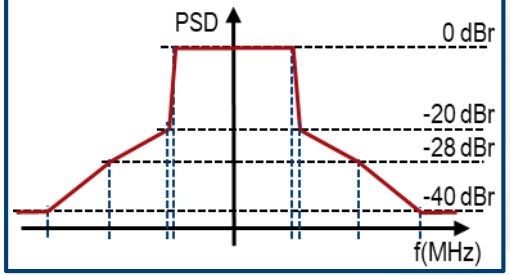
- Interference
- Efficient use of RF resource
- Coexistence

ETSI EN 300 328, EN 301 893, EN 303 687
FCC 15.407 & FCC 15.247

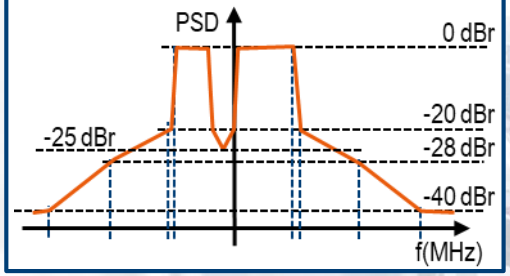
Receiver and transmitter requirement based on IEEE802.11be

- Spectral flatness
- Center frequ. leakage
- Min. input sensitivity
- Channel rejection
- Maximum input level

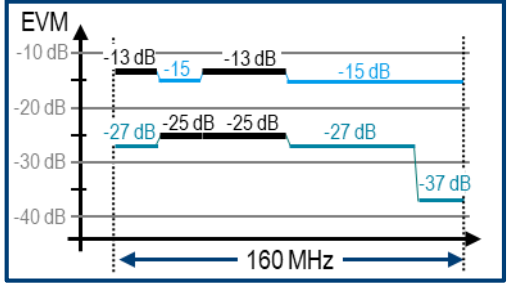
320 MHz spectrum mask



Punctured spectrum mask



MRU unused tone error

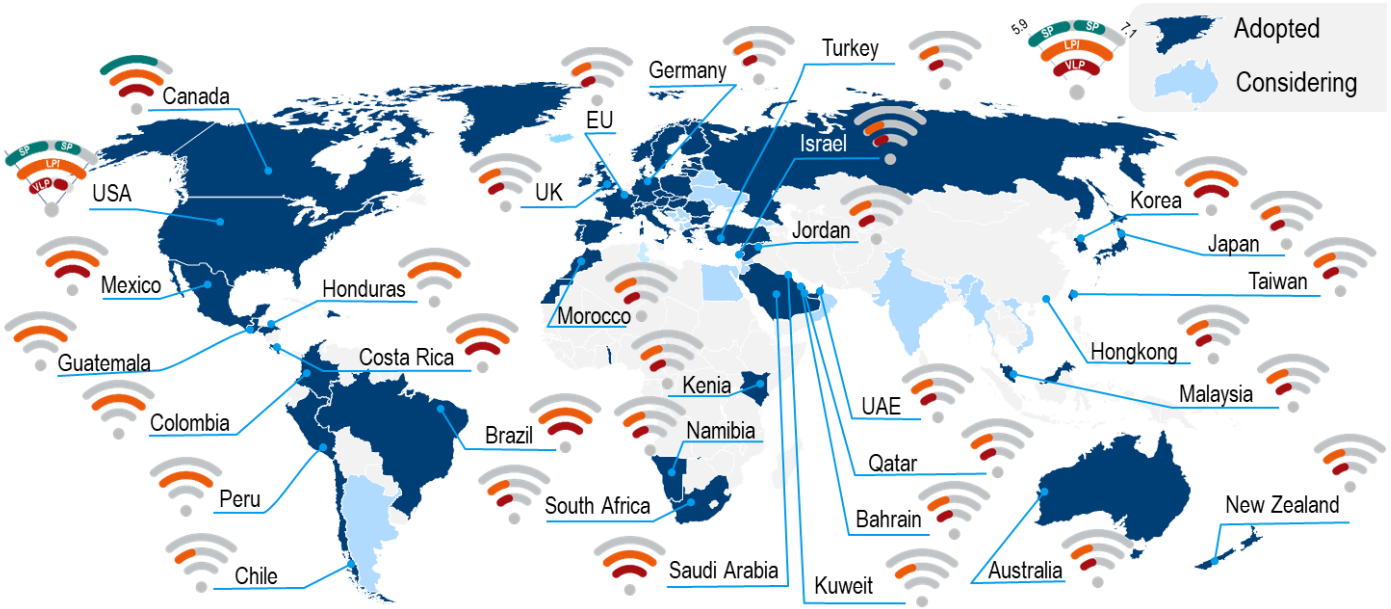


Transmitter constellation error

MCS	Mod.	Coding	Error Vector Magnitude of		
			EHT MU PDDU	EHT TB PDDU	
				P > MCS7	P ≤ MCS7
12	4096-QAM	3/4	-38 dB	-38 dB	- 38 dB
13		5/6	-38 dB	-38 dB	-38 dB

- Absolut power accuracy
- Relative power accuracy
- RSSI meas. accuracy
- Carrier frequency offset
- Timing drift

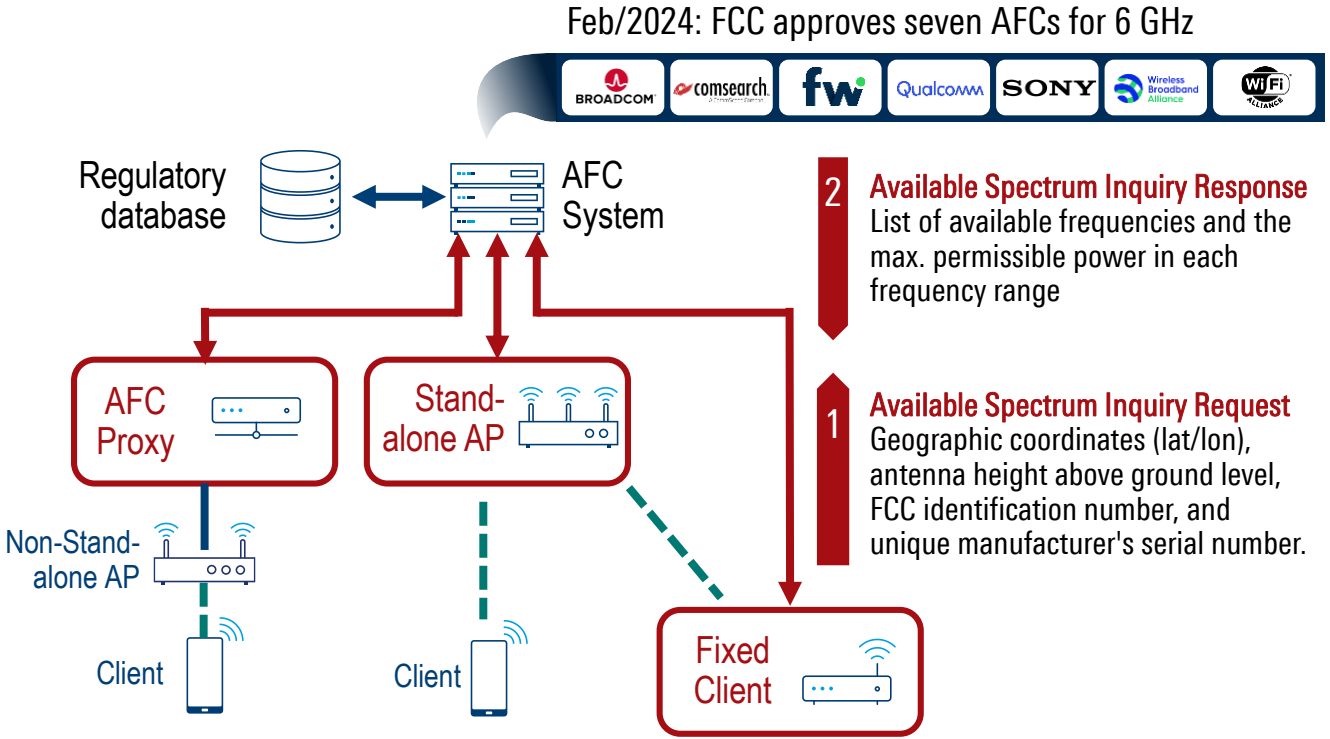
6 GHz band regulation around the globe



EIRP limits

FCC	CEPT ECC Electronic Communications Committee
Standard Power (SP)	
AP: 36 dBm UE: 30 dBm	**n.a.**
Low Power Indoor (LPI)	
AP: 30 dBm UE: 24 dBm	AP: 23 dBm UE: 23 dBm
Very Low Power (VLP)	
14 dBm	14 dBm

AFC system architecture and compliance testing



AFC Device (AFC DUT) Compliance Test Plan

Four test cases:

- Successful registration & spectrum access request
- Unsuccessful spectrum access request
- Successful spectrum access update
- Unsuccessful spectrum access update

A standard power AP and a fixed client must include either an internal geo-location capability or an integrated capability to securely connect to an external geolocation devices or service, to automatically determine geographic coordinates and location uncertainty (in meters), with a confidence level of 95%.

6 GHz band: Impact on AP discovery and client configuration

Discovery

Fast Initial Link Setup (FILS) as defined in 802.11ai adopted to speed up discovery time

Reduced Neighbor Report
Co-located "Neighbor" 6 GHz radio information in beacon and probe response of 2.4/5 GHz radios.

Unsolicited Broadcast Probe Response

Prefered Scanning Channels (PSC) for active scanning Every fourth 20MHz channel designated for active probing by Wi-Fi 6E Clients; restricts scanning to 15 channels, instead of 59.

Power limitations

Using **country information, regulatory info** and new **Transmit Power Envelope** in beacon and probe response to ensure regulatory power requirements of STAs (dual clients)

Country element: country info (e.g. US), operating class and max transmit power
HE/operation element: includes 6 GHz Operation Information with the **regulatory info** (standard power AP, Indoor AP)
Transmit power envelope defines max client EIRP and EIRP PSD

Client (STA) information about power limits

HE Operation Element

- …..
- 6 GHz Operation Info
  - Primary Channel
  - Control
    - Channel Width
    - Duplicate Beacon
    - Regulatory Info*
    - Reserved
  - Channel Center f0
  - Channel Center f1
  - Minimum Rate

*e.g. US: 0: Indoor AP, 1: Standard Power AP

Transmit Power Envelope Element

- Element ID
- Length
- Transmit Power Information
  - Maximum Transmit Power Count
  - Max Transmit Power Interpretation*
  - Max Transmit Power Category
- Maximum Transmit Power
  - Maximum Transmit Power 20 MHz
  - Maximum Transmit Power 40 MHz
  - Maximum Transmit Power 80 MHz
  - Maximum Transmit Power 80+80/160 MHz
- Extension Maximum Transmit Power
  - Maximum Transmit Power 320 MHz

* 0: Local EIRP, 1: Local EIRP PSD, 2: Regulatory client EIRP, ….

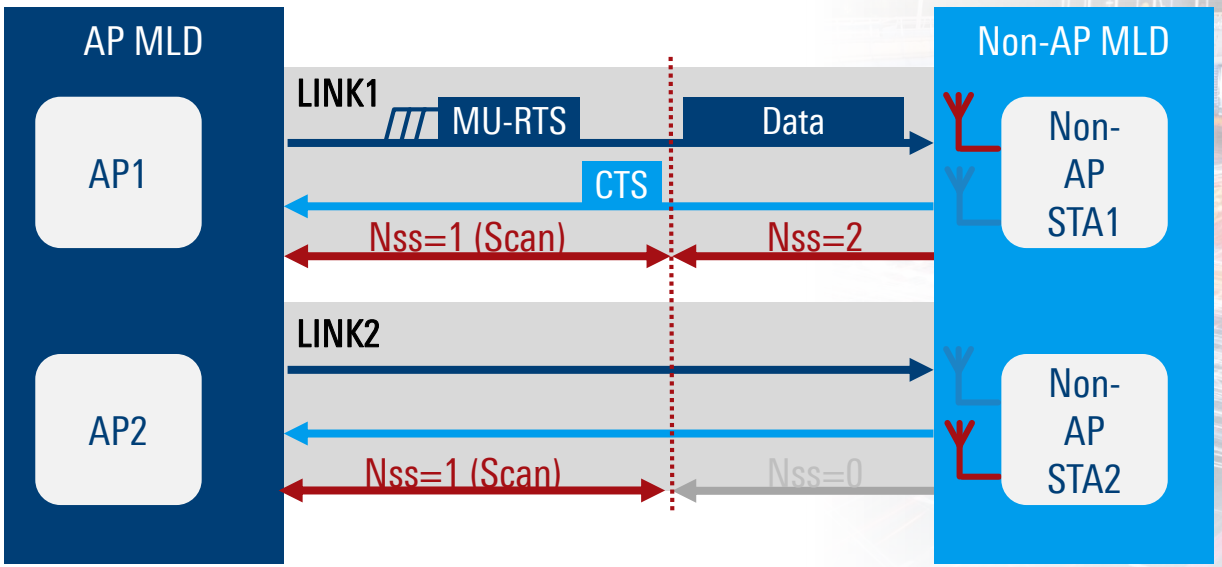
FCC KB 987594

(k) Demonstration of proper power adjustment based on associated AP (SP/LPI) of a dual client

(l) Proper Power Adjustment of client devices connected to a SP AP

Enhanced Multi-link single-radio (EMLSR) opration

Channel access MLD STR EMLSR operation

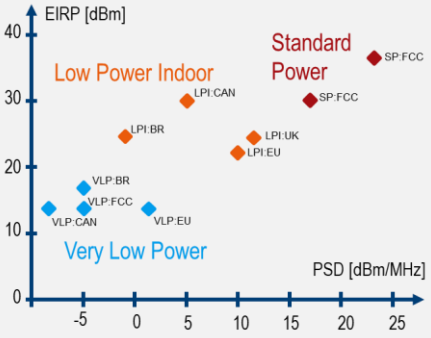


Extreme High Throughput Wi-Fi (802.11be) ask for extreme efficient, accurate and powerful test solutions

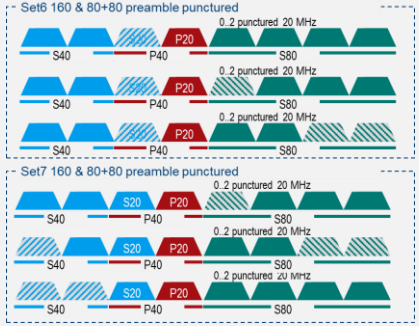
2.7x
of channels

20 MHz:	42 → 102
40 MHz:	16 → 45
80 MHz:	7 → 21
160 MHz:	2 → 10
320 MHz:	0 → 6
Total:	**67→ 184**

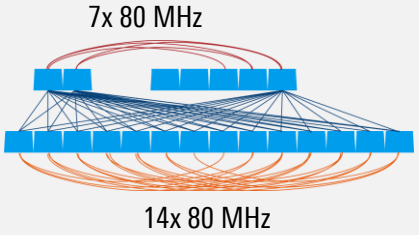
3+ more
regulatory variants



10‘s
of puncturing variants



100+‘s
of different MLO combinations



Wi-Fi test solutions for today and tomorrow

Conformance

R&S®TS8997

RF performance

R&S®CMW500/270

R&S®CMX500 OBT

Production

R&S®CMP180

R&S®CMW100

R&S®TS7124

R&S®ZNA

R&S®FSW

R&S®SMM100A

R&S®VSE

RF design and compliance

R&S®NGU

R&S®RTP

Embedded design & power

UWB Secure Ranging

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

ACCURATE	RELIABLE	CO-EXISTS	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

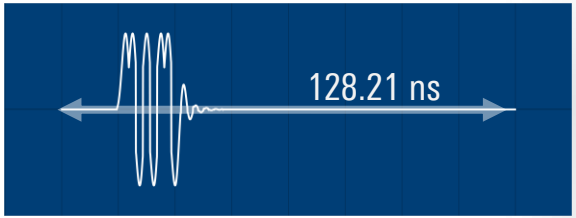
See: www.firaconsortium.org/discover

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

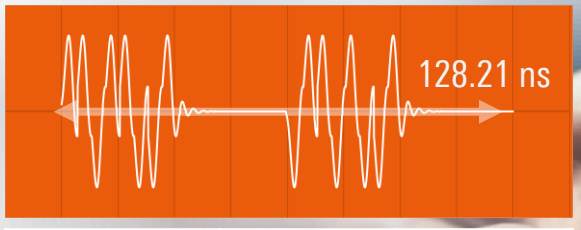


PHR burst length	PHR Bitrate	PSDU Bitrate
64 chips	0.9 Mbps	6.8 Mbps
8 chips	6.8 Mbps	6.8 Mbps

HPRF
Higher pulse repetition frequency

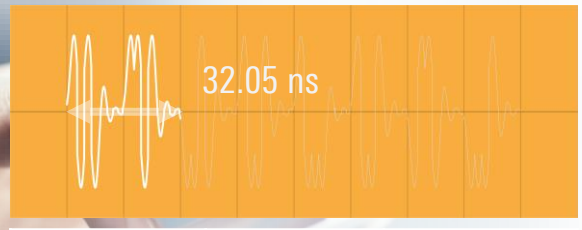
BPSK modulation at both burst positions

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



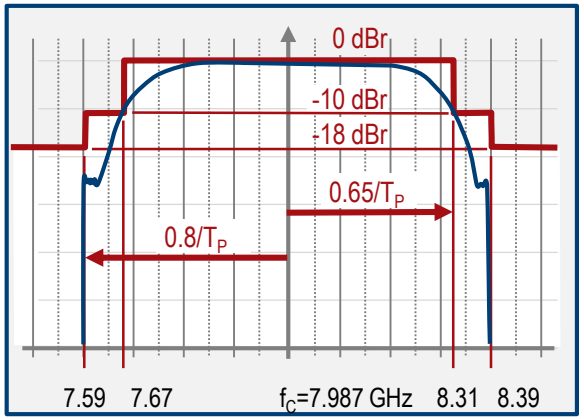
Constraint length (CL)	PHR Bitrate	PSDU Bitrate
CL3	15.6 Mbps	27.2 Mbps
CL7	31.2 Mbps	31.2 Mbps

UWB physical layer test requirements

Standard conformance	Regulatory compliance	Interoperability certification
- Operating frequency bands - Channel assignments - Baseband impulse response - Transmit PSD mask - Chip rate clock and chip carrier alignment	- Operating bandwidth - Mean power spectral density - Maximum value of peak power - Other emissions - Receiver spurious emissions - Detect and avoid (DAA) - Low duty cycle (LDC)	- Packet format - Power spectral density mask - Frequency tolerance, timing - Baseband Impulse response - NRMSE - Packet reception sensitivity - Dirty packet tests - First path dynamic range
IEEE 802.15.4-2020 IEEE 802.15.4z-2020	FCC part 15 §15.519, §15.517 ETSI EN 301 489-33 , EN 302 065, EN 303 883	FiRa Consortium UWB PHY Conformance CCC Consortium UWB PHY Test Suite

Specific UWB measurements (IEEE, FiRa)

Transmit Power Spectrum Density

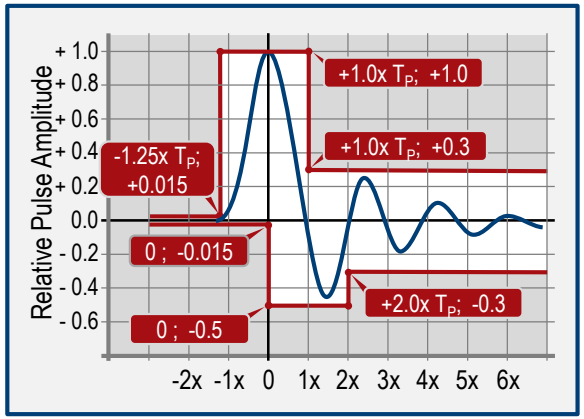


The transmitted spectrum shall be less than –10 dB relative to the maximum spectral density of the signal for

$0.65/T_P < |f - fc| < 0.8/T_P$

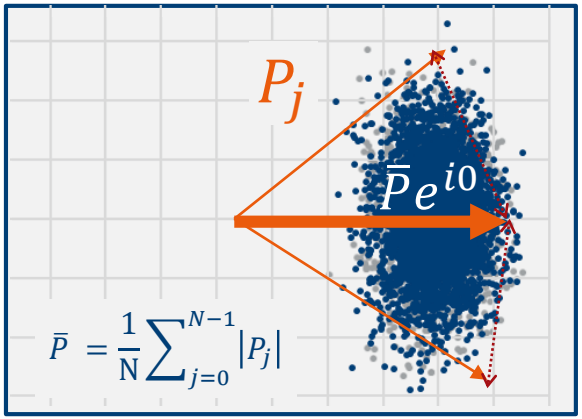
and –18 dB for $|f - fc| > 0.8/T_P$.

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)



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

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

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

Rohde & Schwarz PCTT based on CMP200/UWB Test suite is fully validated for FiRa 2.0

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)

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

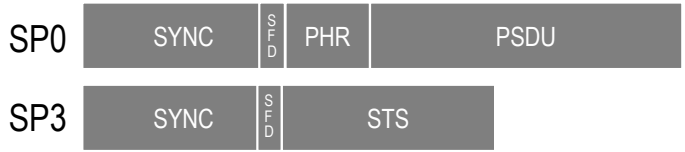
PCT_2_0_RX_BPRF_BV_01: Secure Ranging – First-Path Detection under Attack
PCT_2_0_RX_HPRF_BV_01: Secure Ranging – First-Path Detection under Attack

FiRa validated test tools: https://www.firaconsortium.org/certifications/fira-validated-test-tools

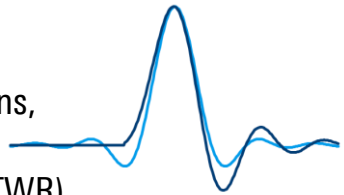
CCC Digital Key Certification Program (UWB PHY/MAC)

The CCC Digital Key Certification program will ensure interoperability and security of the digital key solution, to deliver the best and most secure user experience between the mobile device and the vehicle.

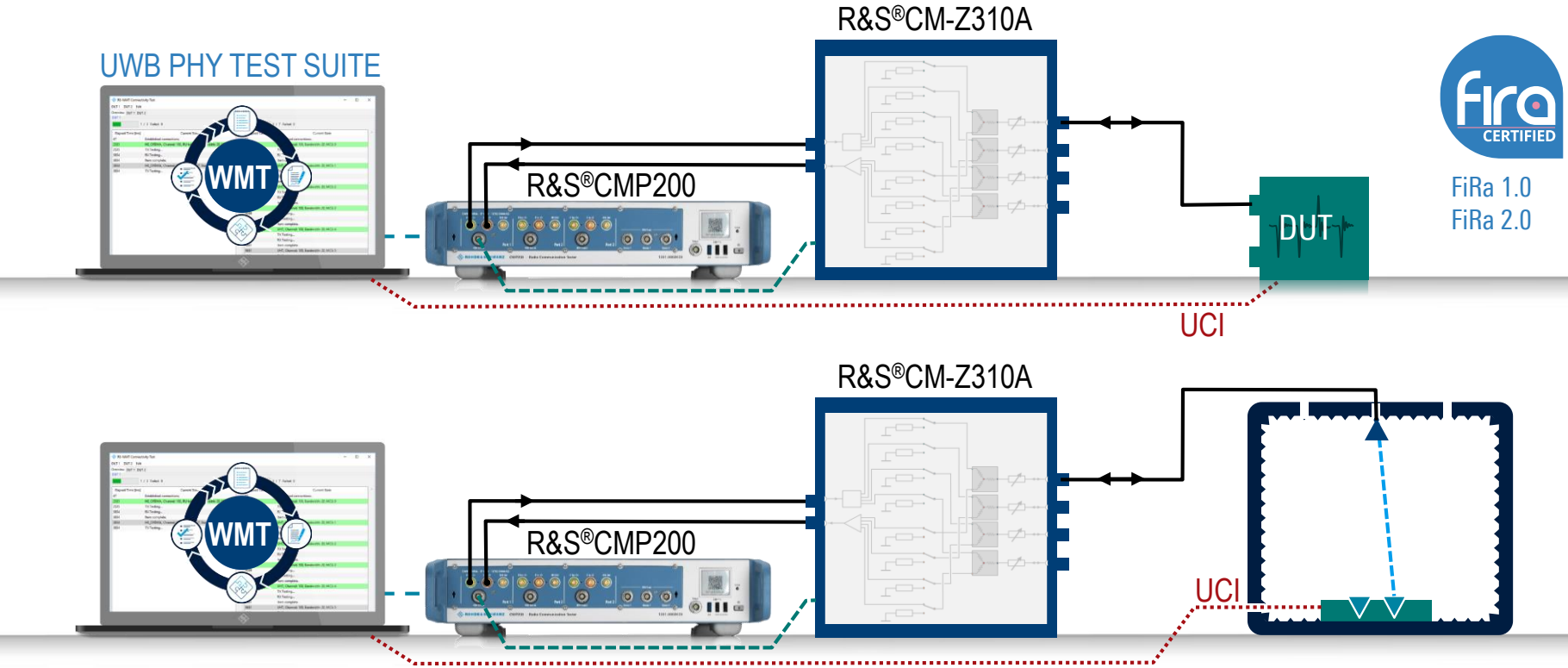
- CCC Digital Key certification testing covers several levels of interoperability including MAC/PHY-Layer certification
- Specification of PHY/MAC test cases as well as validation of test tools is still ongoing in close cooperation with FiRa consortium
- CCC is applying IEEE 802.15.4z HRP BPRF UWB SP0 and SP3 packets on channel 5 (6480 MHz) and 9 (7987 MHz) only



- Supporting different pulse shape combinations, symmetrical and precursor-free pulses
- Use only double sides two-way ranging (DS-TWR)



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

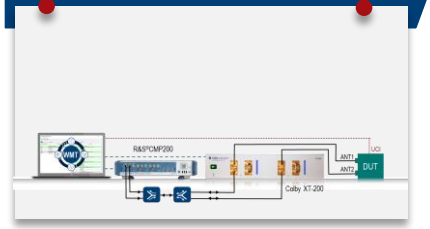


FiRa 1.0
FiRa 2.0

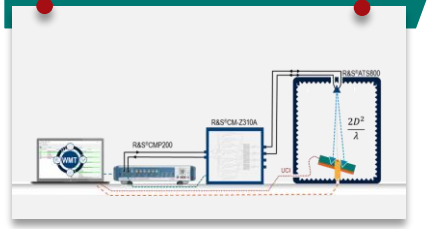
AoA verification and calibration in R&D and manufacturing

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

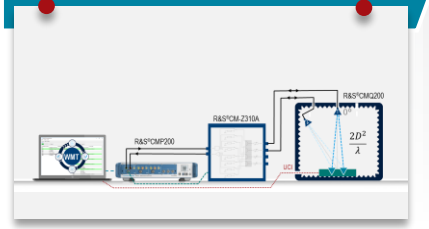
AoA/PDoA Chipset Verification



AoA/PDoA Device Reference Calibration



AoA/PDoA Device Offset Calibration



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