Empowering the mobile device experience with Wi-Fi6E/7 and UWB

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Rohde & Schwarz

ROHDE&SCHWARZ

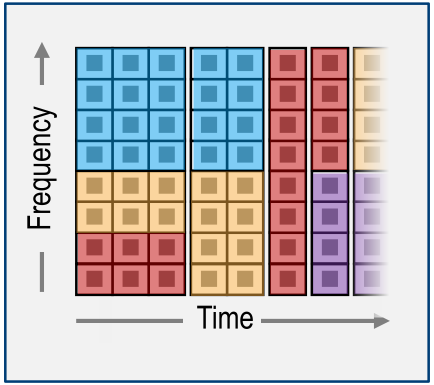
Make ideas real

Enabling immersive customer experience

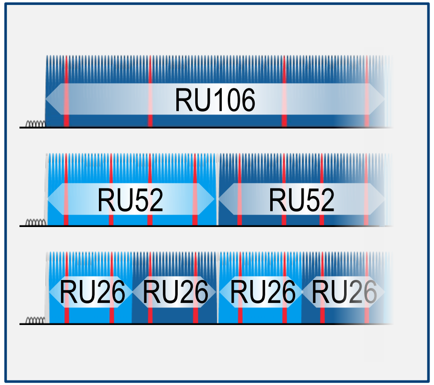
The 6th generation of Wi-Fi® for high efficiency in dense areas (indoor and outdoor environments)

Cornerstones of the Wi-Fi 6 revolution

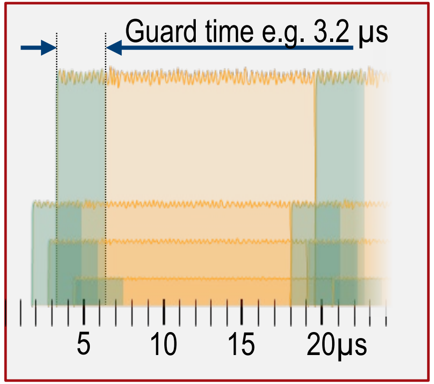
OFDMA



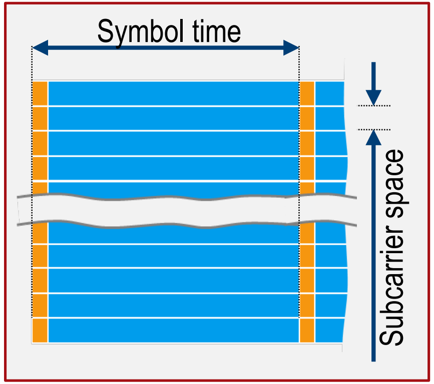
Resource units



Long guard interval



Long symbol time



- Efficient use of available spectrum
- Multi-user operation and latency reduction

- Avoiding inter-symbol interferences
- More efficient use of available resources

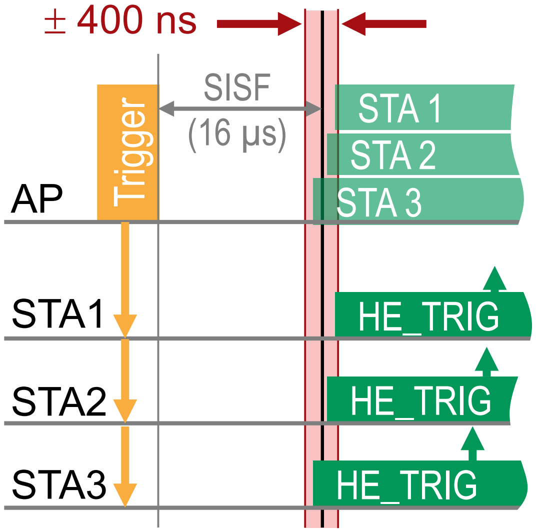
What are the main differences?

	Wi-Fi 4 (802.11n) *High Throughput (HT)*	Wi-Fi 5 (802.11ac) *Very High Throughput (VHT)*	Wi-Fi 6 (802.11ax) *High Efficiency (HE)*
Supported bands	2 GHz, 5 GHz	5 GHz	2 GHz, 5 GHz
Channel bandwidth (MHz)	20, 40	20, 40, 80, 80+80, 160	20, 40, 80, 80+80, 160
Transmission scheme	OFDM	OFDM	OFDM, **OFDMA**
Subcarrier spacing	312.5 kHz	312.5 kHz	**78.125 kHz**
Guard interval	0.4 µs, 0.8 µs	0.4 µs, 0.8 µs	0.8 µs, **1.6 µs, 3.2 µs**
Spatial streams	4x4 (SU-MIMO only)	8x8 (incl. DL-MU-MIMO)	8x8 (incl. MU-MIMO)
Modulation (highest)	64QAM	256QAM	**1024QAM**
Max. data rate*	*0.5 Gbps*	*6.9 Gbps*	*9.6 Gbps*

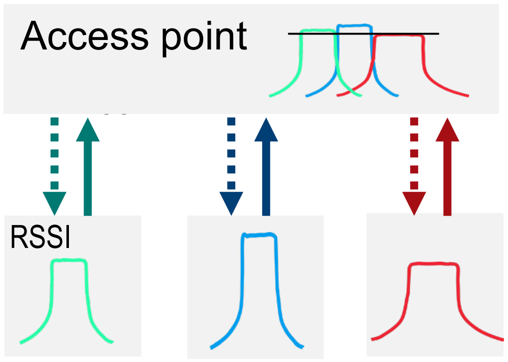
** dependent on configuration (GI) and incl. signaling overhead*

Wi-Fi 6 test challenges related to OFDMA in Wi-Fi6 (11ax)

Accurate start time



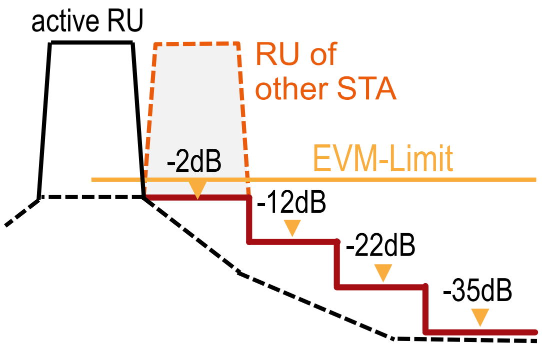
Accurate power control



STA RSSI measurement accuracy:
class A: ± 3 dB class B: ± 5 dB

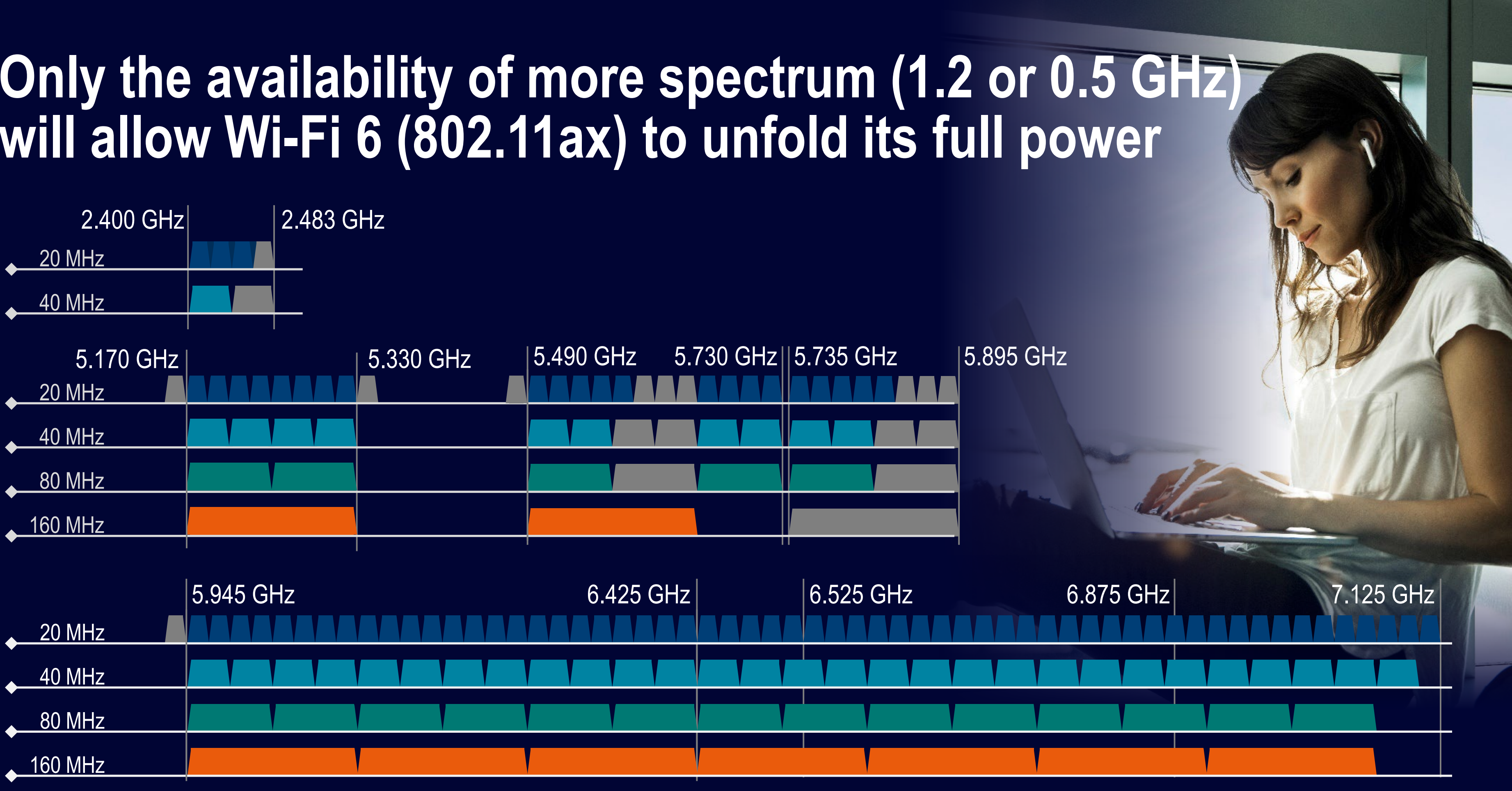
STA transmit power accuracy:
class A: ± 3 dB class B: ± 9 dB

Clean RU spectrum



Ensure RU transmit modulation accuracy for the unoccupied subcarriers to avoid interference:
Unused Tone Error

Only the availability of more spectrum (1.2 or 0.5 GHz) will allow Wi-Fi 6 (802.11ax) to unfold its full power

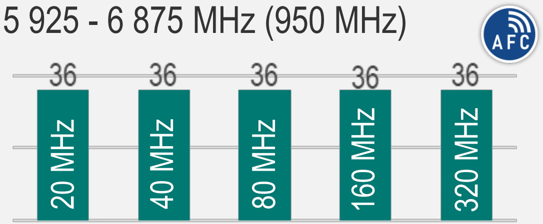


Examples of regulation in 6 GHz band

Canada

Standard Power (AFC only)

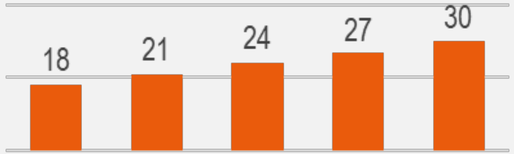
5 925 - 6 875 MHz (950 MHz)



EIRP: 36 dBm & PSD: 23 dBm/MHz

Low Power Indoor (LPI)

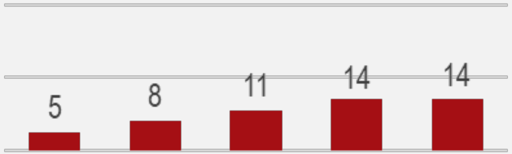
5 925 - 7 125 MHz (1 200 MHz)



EIRP: 30 dBm & PSD: 5 dBm/MHz

Very Low Power (VLP)

5 925 - 7 125 MHz (1 200 MHz)



EIRP: 14 dBm & PSD: -8 dBm/MHz

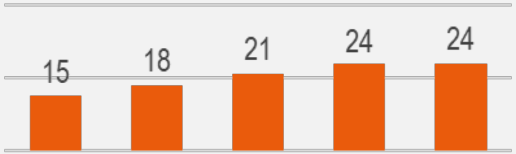
South Korea

Standard Power (AFC only)

N.A.

Low Power Indoor (LPI)

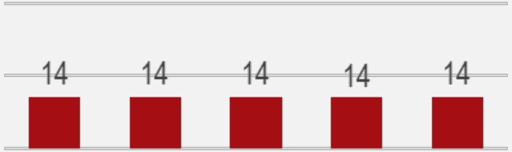
5 925 - 7 125 MHz (1 200 MHz)



EIRP: 24 dBm & PSD: 2 dBm/MHz

Very Low Power (VLP)

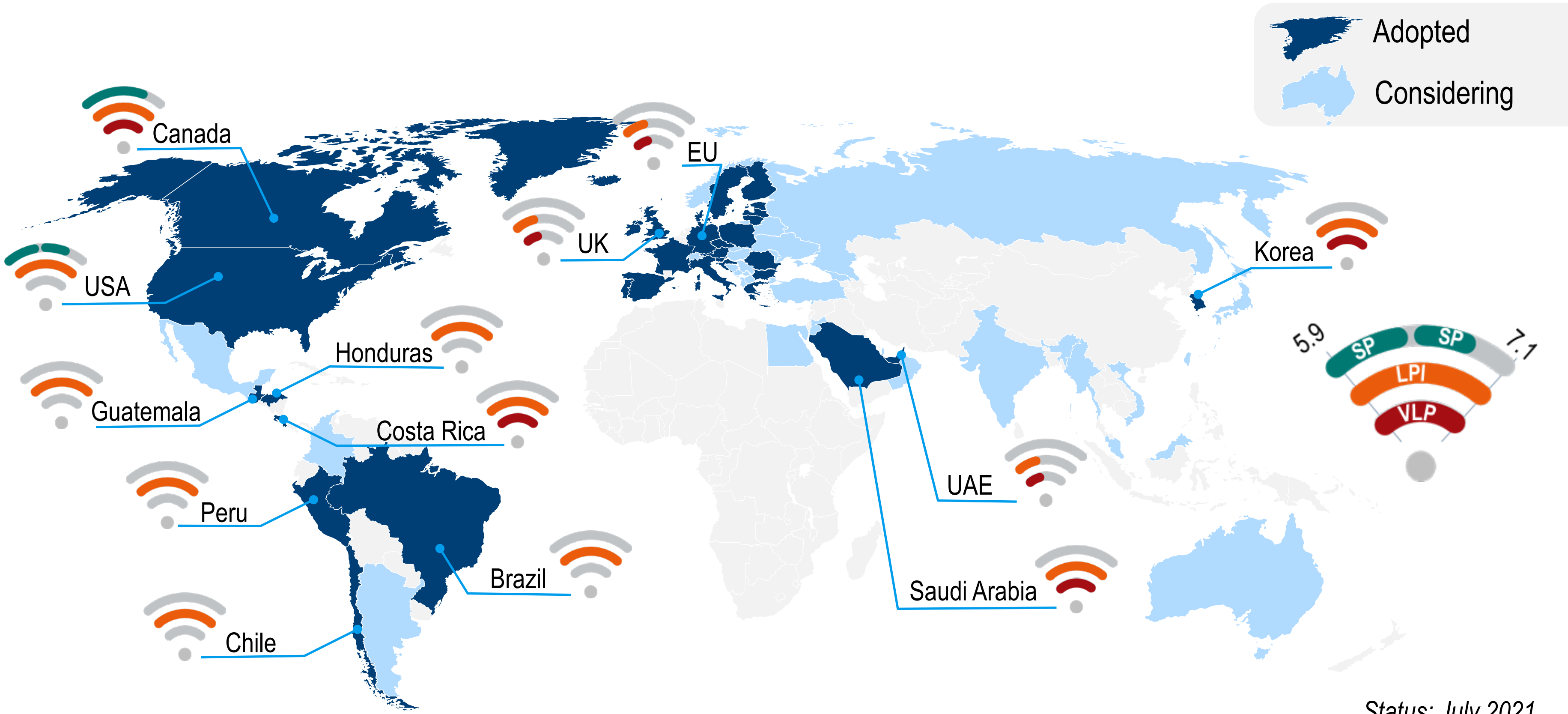
5 925 - 7 125 MHz (1 200 MHz)



EIRP: 14 dBm & PSD: 1 dBm/MHz

AFC: Automated Frequency Coordination

Global 6 GHz band regulation for licensed exempt use

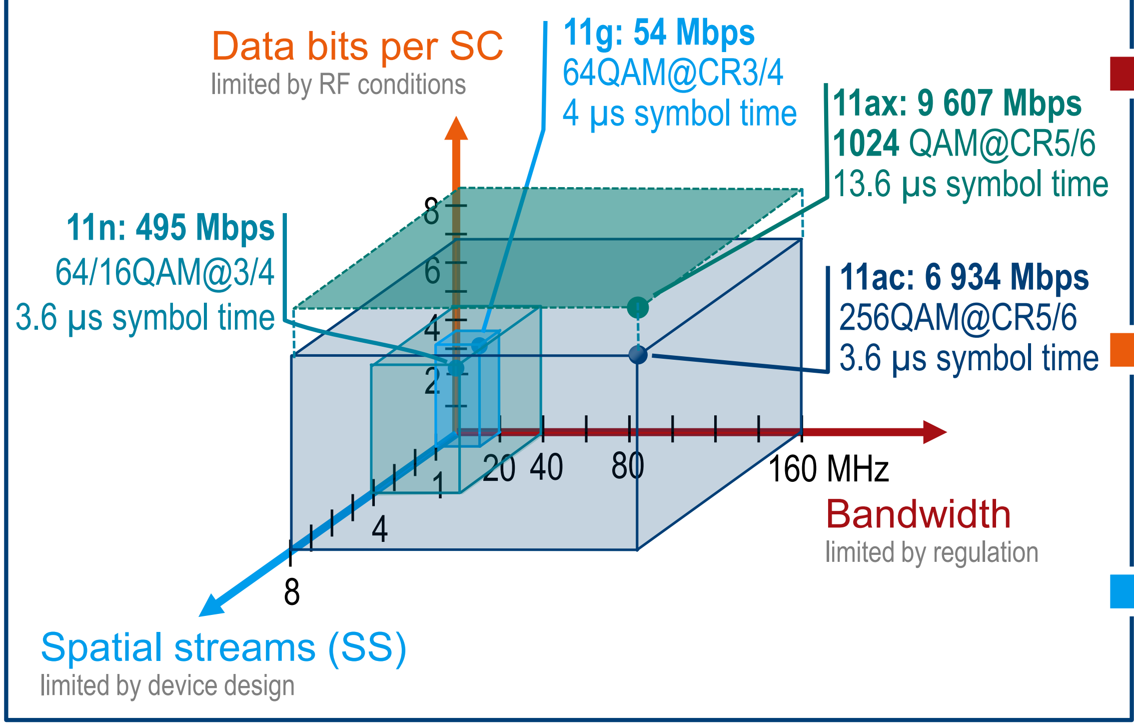


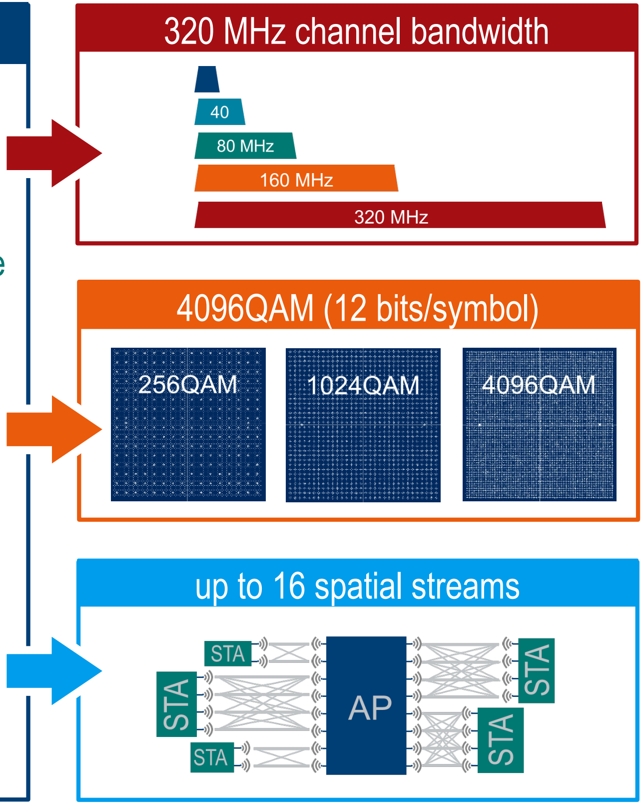
Status: July 2021

The 7th generation of Wi-Fi® for Extreme High Throughput (EHT) AT HOME, OFFICES AND FACTORIES

The everlasting demand for higher data rates and its limitations

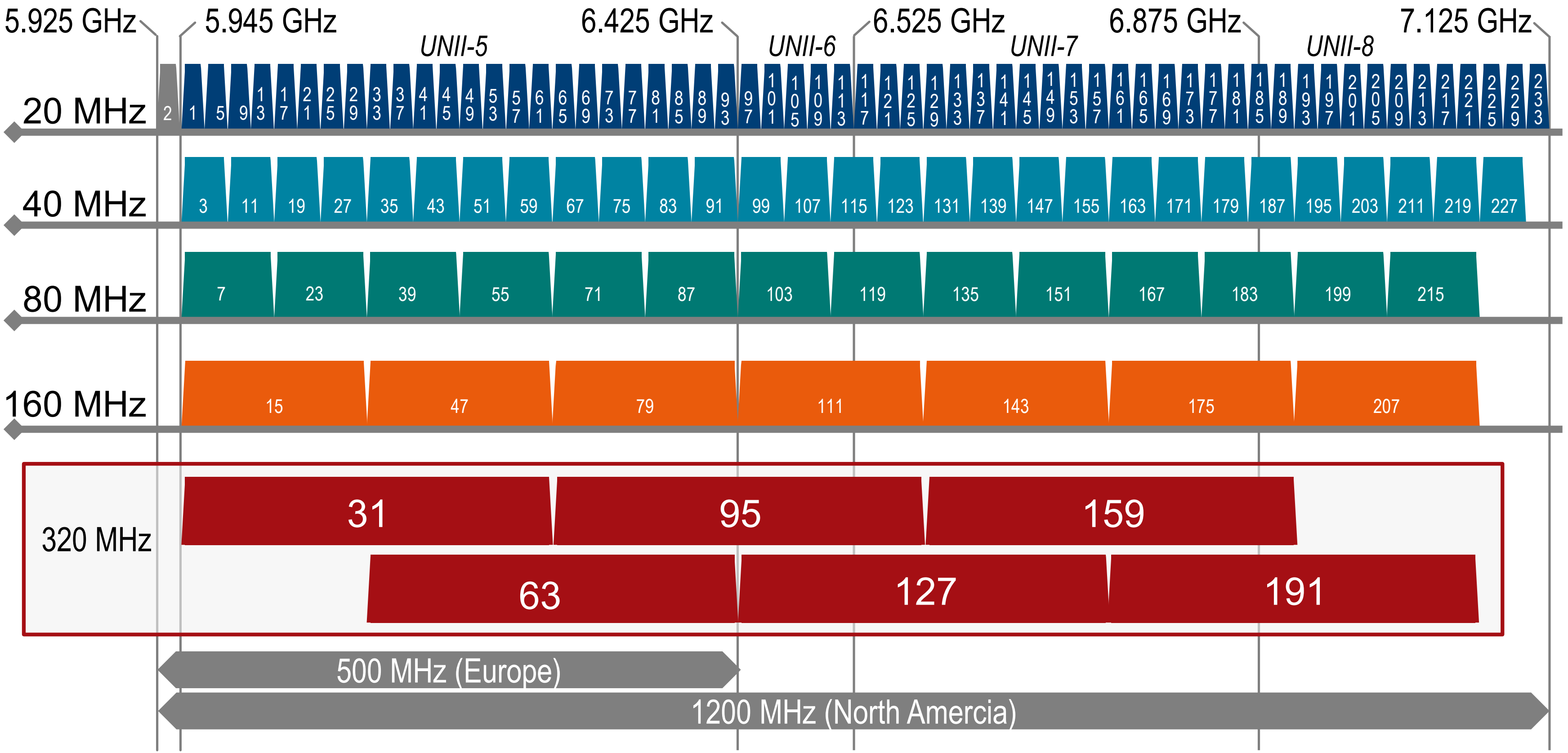
Data rate = # data subcarrier x bits per symbol x # SS / symbol-time



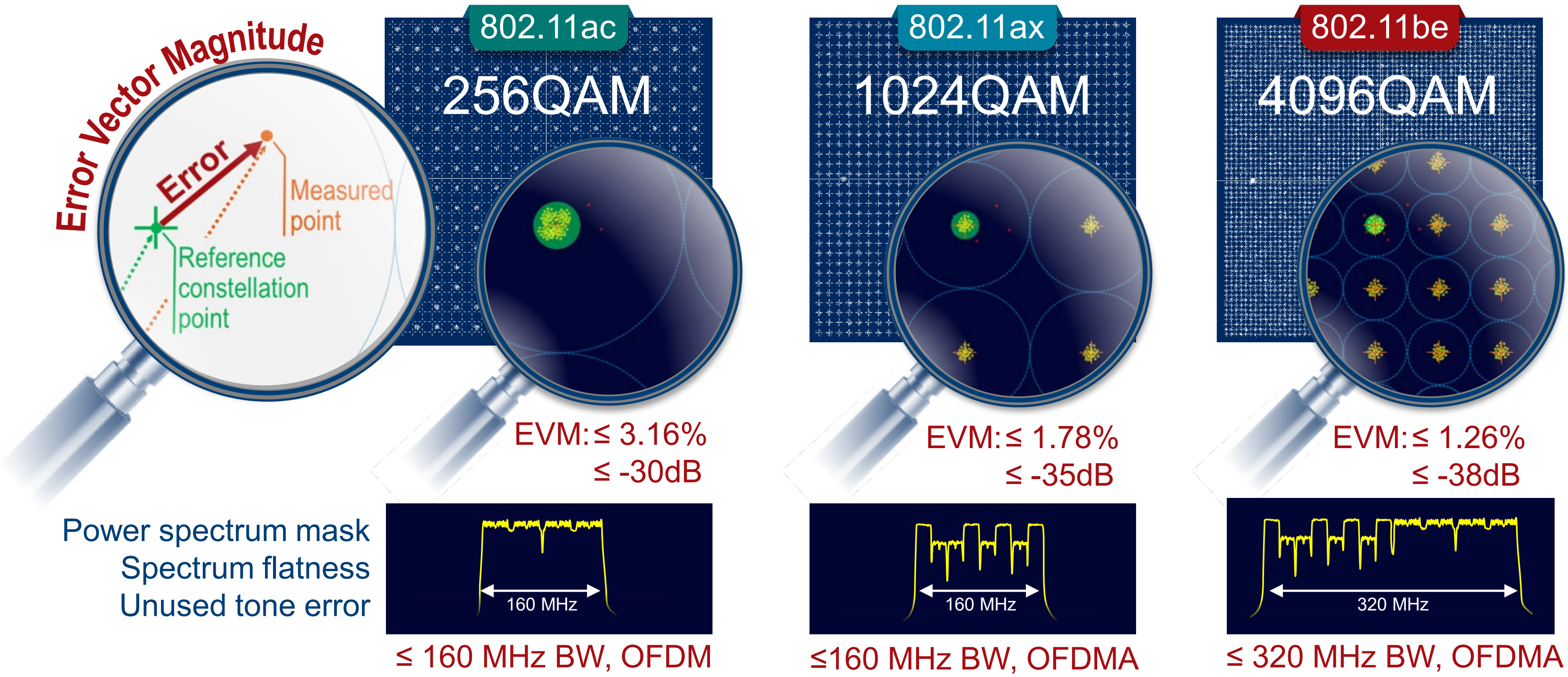


46 871 Mbps (16x16, 4096QAM, 320 MHz)

A few overlapping 320 MHz channels in the 6 GHz band



Wi-Fi 7 pushes RF performance requirements to the next level

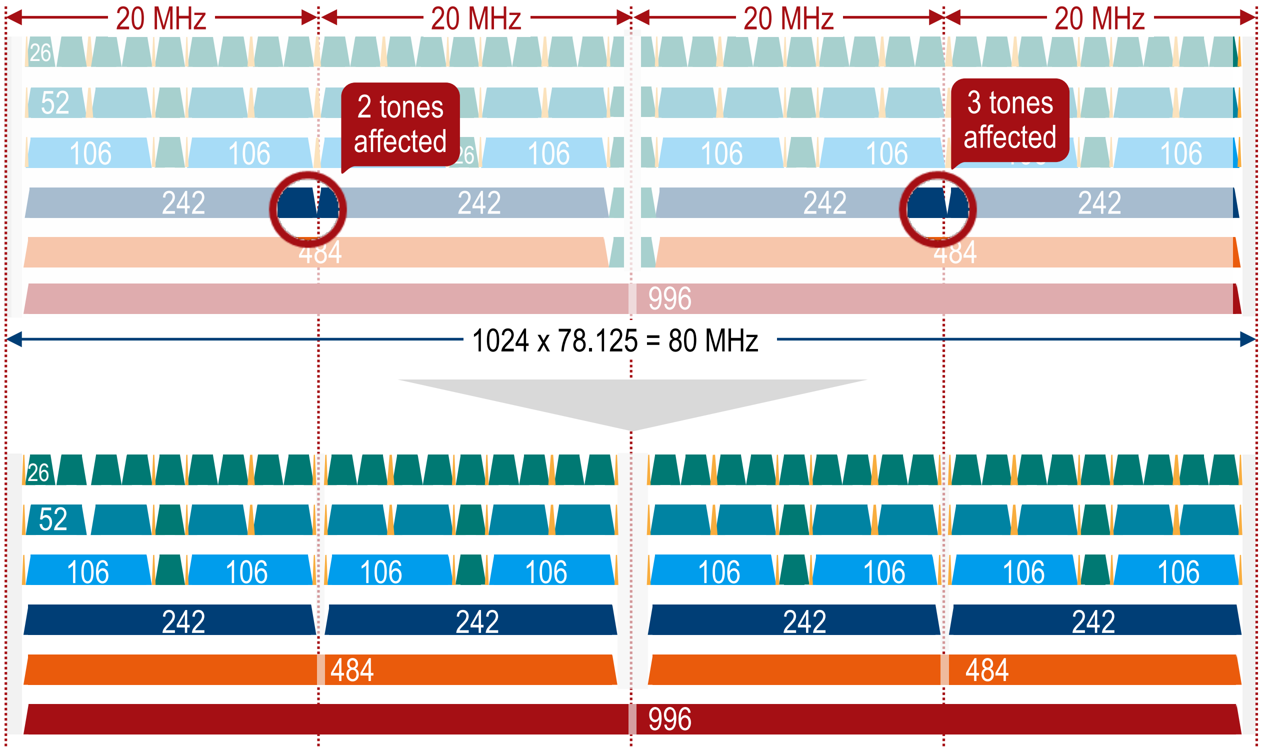


Over two generation a sixfold increase of max throughput

	Wi-Fi 5 (802.11ac) *Very High Throughput (VHT)*	Wi-Fi 6E (802.11ax) *High Efficiency (HE)*	Wi-Fi 7 (802.11be) *Extreme High Throughput (EHT)*
Supported bands	5 GHz	2 GHz, 5 GHz, **6 GHz**	2 GHz, 5 GHz, 6 GHz
Channel bandwidth (MHz)	20, 40, 80, 80+80, 160	20, 40, 80, 80+80, 160	20, 40, 80, 160, **320**
Transmission scheme	OFDM	OFDM, OFDMA	OFDM, OFDMA
Subcarrier spacing	312.5 kHz	78.125 kHz	78.125 kHz
Guard interval	0.4 µs, 0.8 µs	0.8 µs, 1.6 µs, 3.2 µs	0.8 µs, 1.6 µs, 3.2 µs
Spatial streams	8x8 (incl. DL-MU-MIMO)	8x8 (incl. MU-MIMO)	**16x16** (incl. MU-MIMO)
Modulation (highest)	256QAM (8 bit)	1024QAM (10 bit)	**4096QAM (12 bit)**
Max. data rate*	*6.9 Gbps*	*9.6 Gbps*	*46 Gbps*

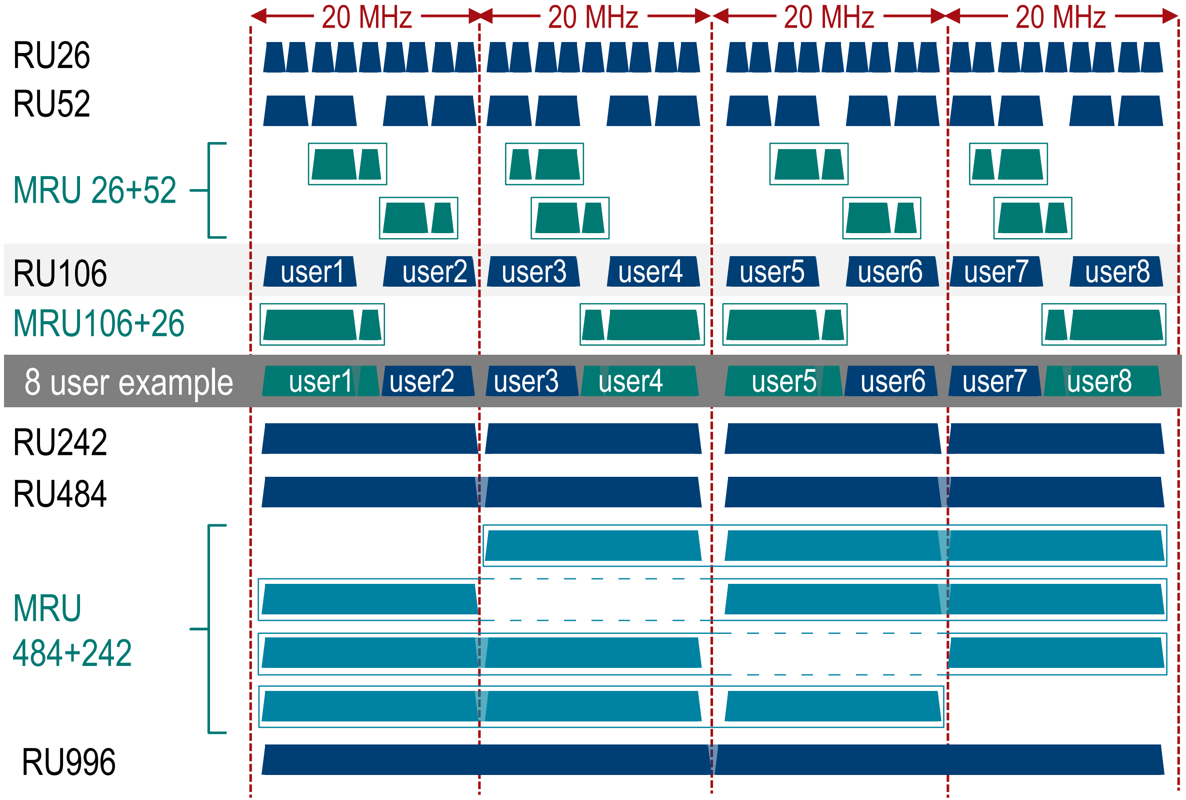
** dependent on configuration (GI) and incl. signaling overhead*

Modified tone-plan ≥ 80 MHz



- 802.11be tone plan is based on 20/40 MHz PPDU 11ax tone plan
- 802.11be modifies the HE80 MHz OFDMA tone plan to fix the problems with regulation and puncturing (20 MHz boundery)
- The 80 MHz OFDMA design applies to any RU < 996 for all modes of transmission, SU, DL MU, TB PPDU, with and without puncturing.

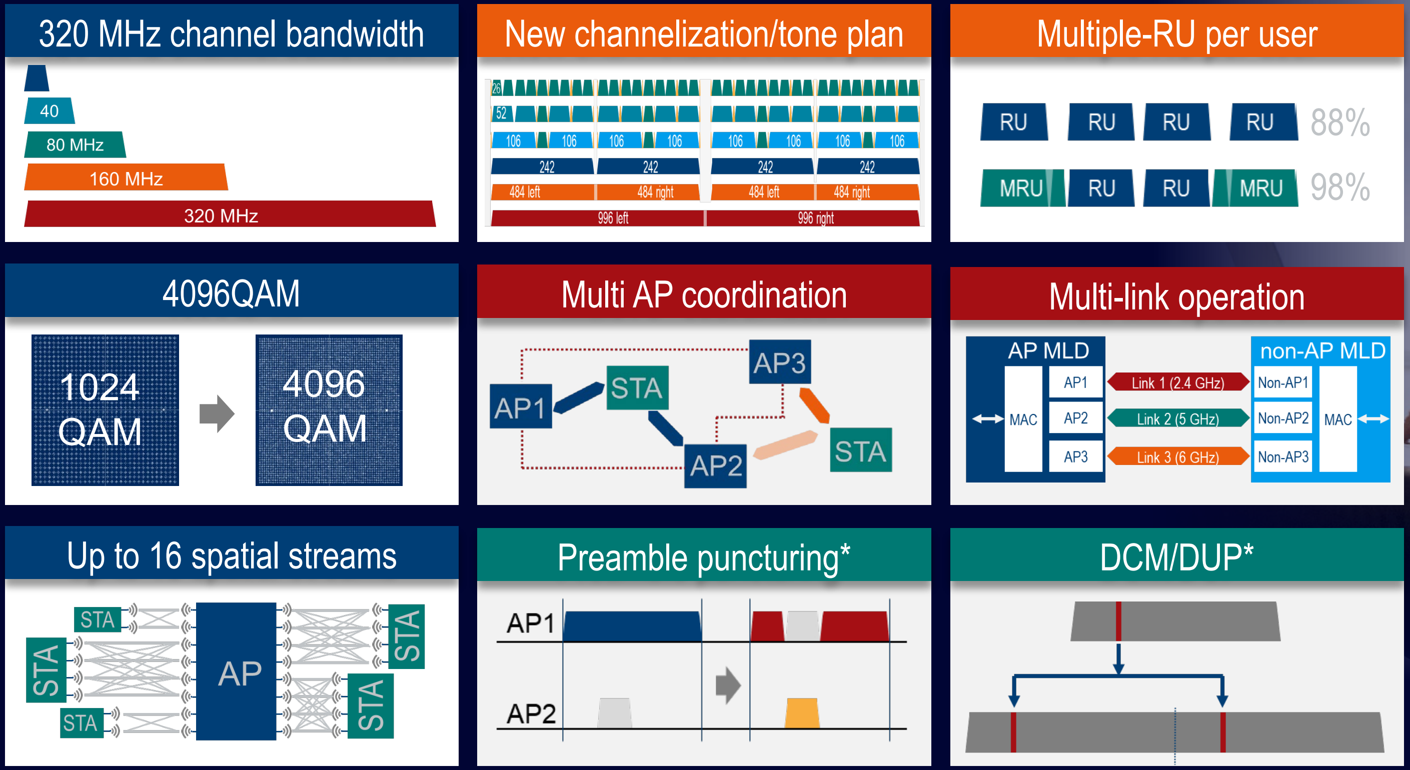
Multiple Resource Units (MRU) per user for efficiency



A **small size MRU** (i.e. 26, 52, 106 tone) can only be combined for **efficiency** with another small size RU to form an MRU. RUs in the MRU need to be contiguous and within a 20 MHz channel boundary

The permitted **large size MRU** (i.e. 242, 484, 996 tone) combinations allow additional aggregated bandwidth options (e.g. 60 MHz) per user that don't need to be continuous.

Wi-Fi 7 features that are of importance for test & measurement



* Wi-Fi 6 features

Wi-Fi test solutions for today and tomorrow

Conformance

R&S®TS8997

RF performance

R&S®CMW500/270

R&S®CMP180

Production

R&S®TS7124

R&S®DST200

R&S®CMW100

R&S®CMP180

R&S®ZNA

R&S®FSW

R&S®SMM100A

RF design and compliance

R&S®NGU

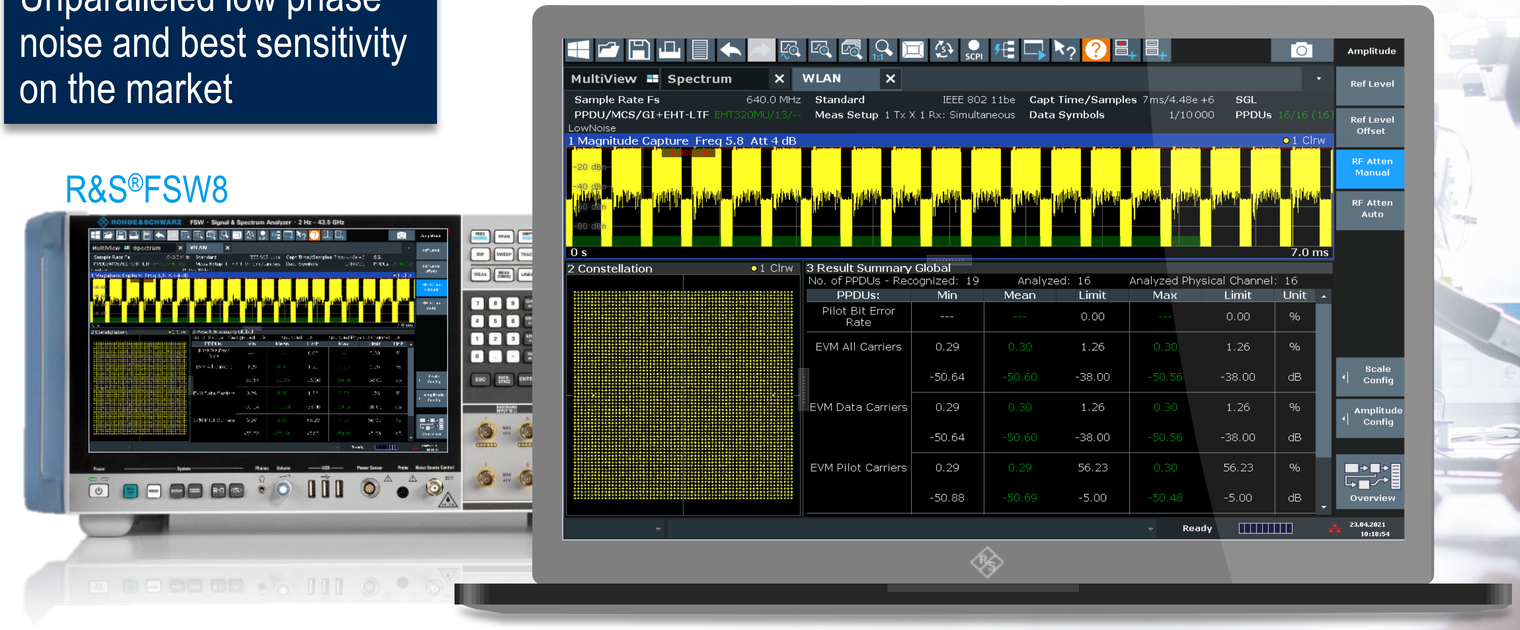
R&S®RTP

Embedded design & power

Measurements* of 802.11be signals with the R&S®FSW signal and spectrum analyzer

Unparalleled low phase noise and best sensitivity on the market

R&S®FSW8

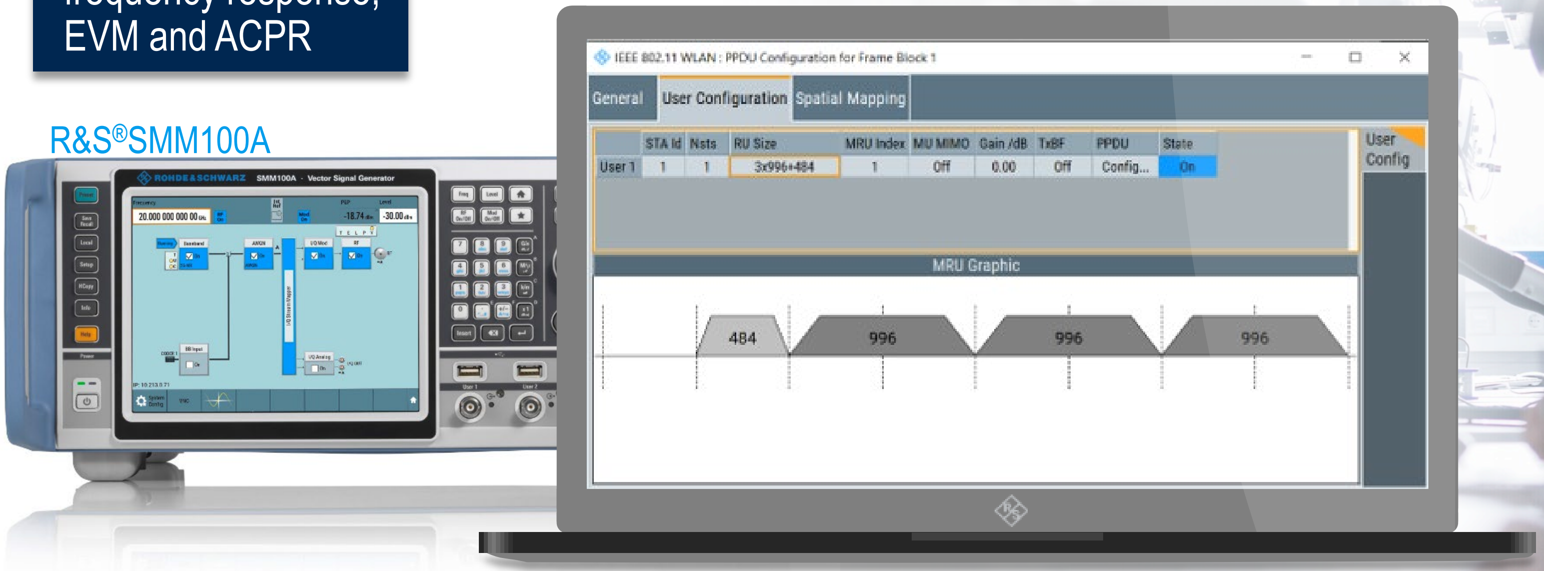


**Based on actual draft specification of IEEE 802.11be*

Generation* of 802.11be signals with the R&S®SMM100A vector signal generator

Excellent modulation frequency response, EVM and ACPR

R&S®SMM100A



*Based on actual draft specification of IEEE 802.11be

R&S®CMP180 - The future integrated.

Enhanced frequency and bandwidth for the next wireless generation

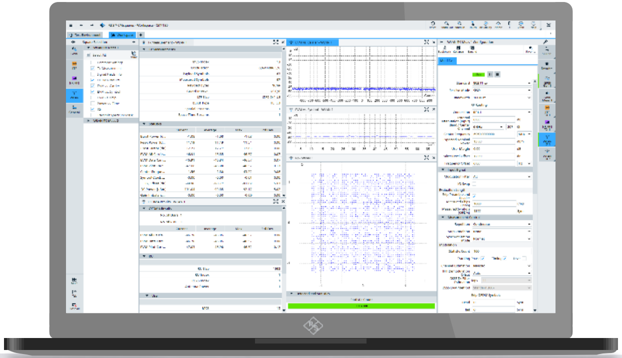
Futureproof design
- 400 MHz up to 8 GHz
- Up to 500 MHz bandwidth
- High output power

Compact (2 HU x 19”)
- 2x 8 RF (in/out) ports
- 2 VSA + 2 VSG
- Build-in controller

Advanced testing
- 5G FR1 devices
- Wi-Fi 6E/7 STAs & APs
- BLE and many more

Common platform
- Linux OS
- R&S®CMsquares
- Systemwide license

R&S®CMP180



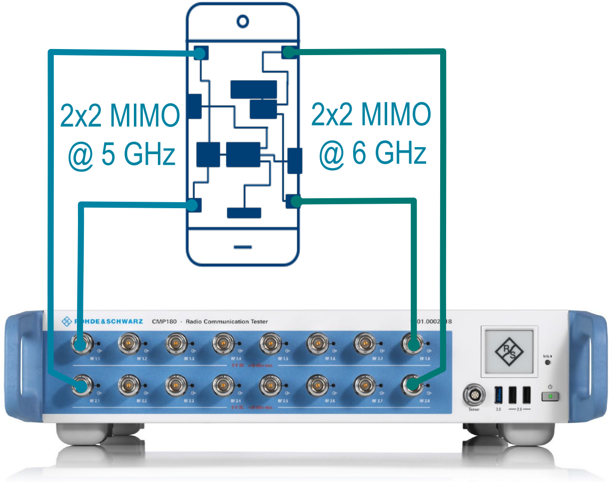
The ideal solution for comprehensive RF testing in engineering validation (EVT), design validation (DVT) and prototyping

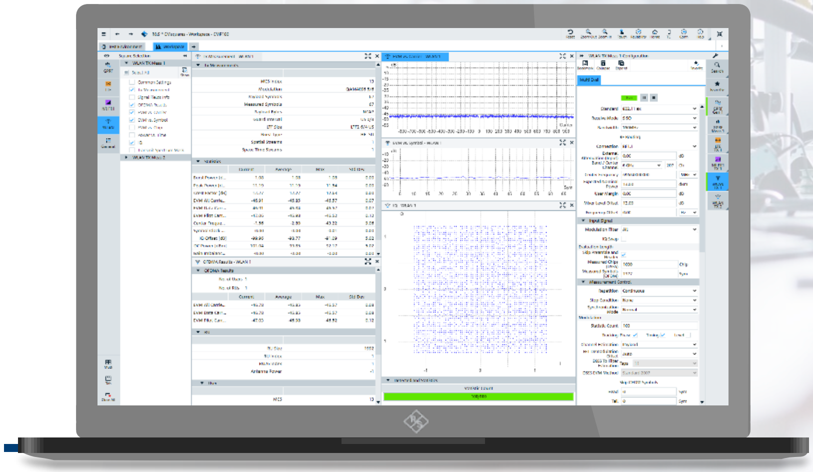
R&S®CMP180

Excellent RF performance combined with flexibility, speed and broad technology support.

R&S®CMsquares

Powerful control center with an intuitive web based user interface and graphical sequencer.

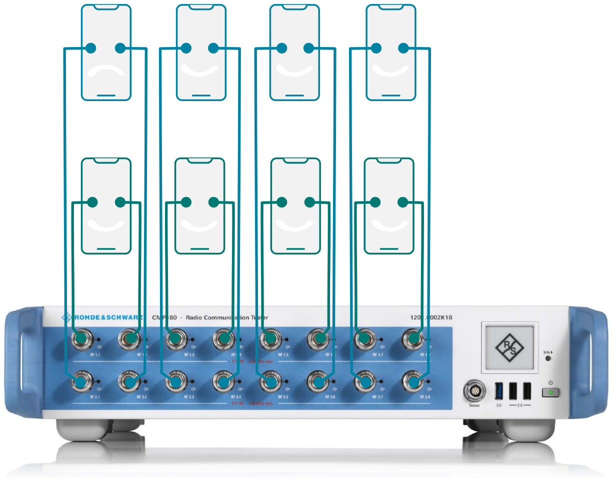




After CMW100 and CMP200, this is the next member of the family of wireless device testers for validation and production

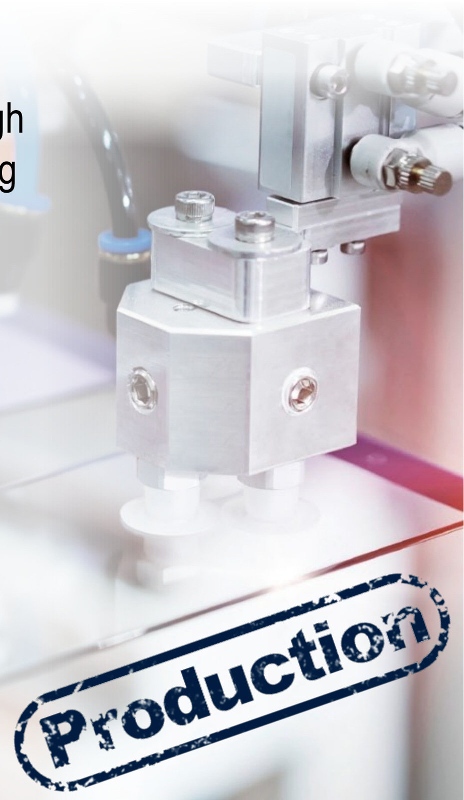
R&S®CMP180

Parallel testing on up to 16 RF ports and R&S®SmartChannel support for optimized test performance

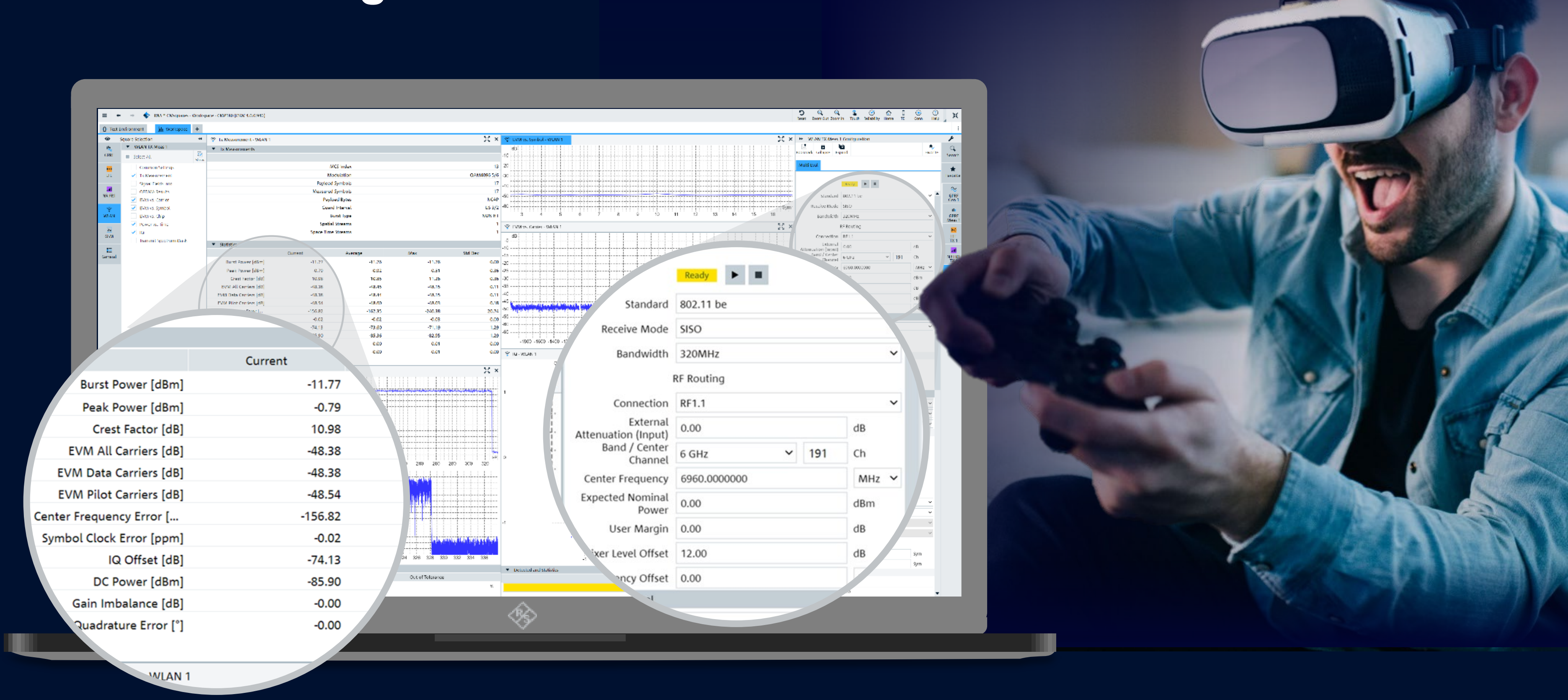


Wireless Manufacturing Test (WMT)

Modular software framework tailored for high volume production testing and non-signaling R&D applications.



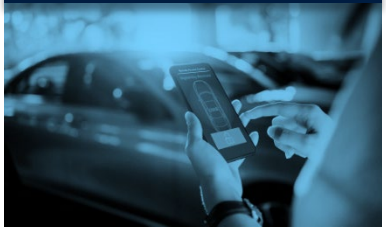
One more thing ….. Wi-Fi 7 on the R&S®CMP180



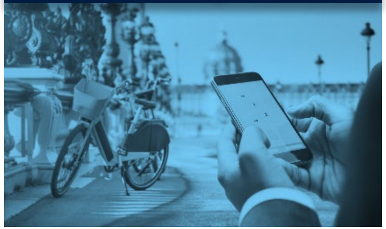
Immersive customer experience needs more wireless technologies than 5G – Wi-Fi, UWB and more

The *return* of UWB on *mobile devices* with precise ranging and secure low-power communication

Hands-free access



Asset finding



Navigation

Mobile payment

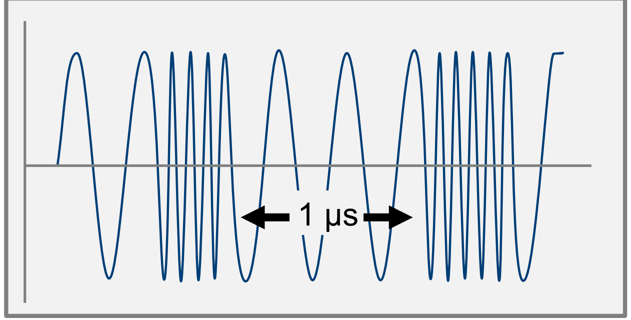
Mobile sharing

AR/VR anchor

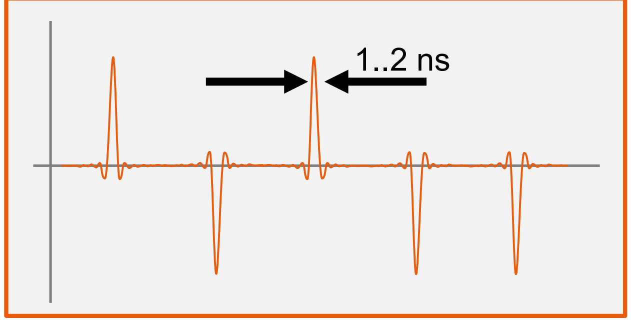
Smartphone vendors provide UWB functionalities: e.g. Apple: iPhone 11/12, HomePod mini, AirTags, Samsung: Watch S6, Galaxy 20/21, Galaxy SmartTag, Google, Xiaomi and others

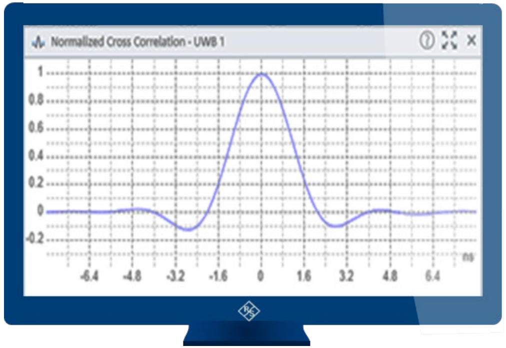
Ultra-wideband (UWB) :
Low-power short signal pulses over a broad spectrum

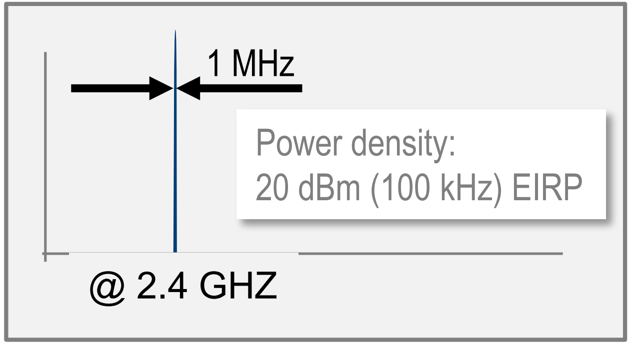
NB/WB e.g. Bluetooth GFSK

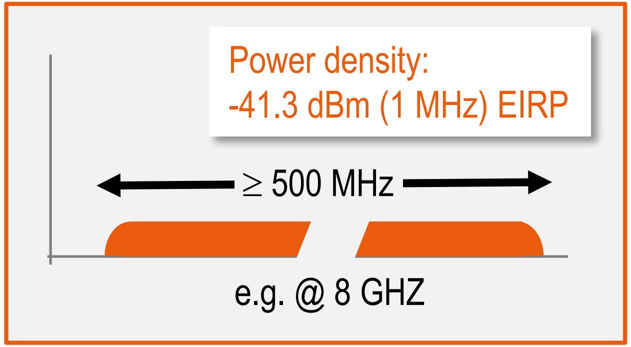


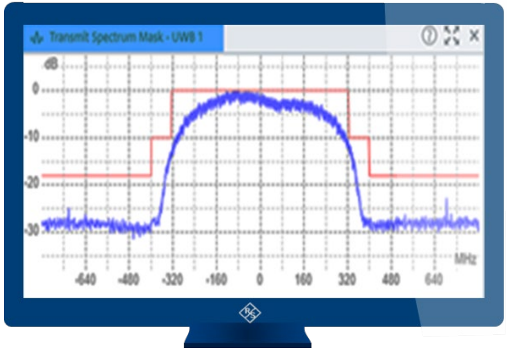
UWB pluse – Phase shift keying



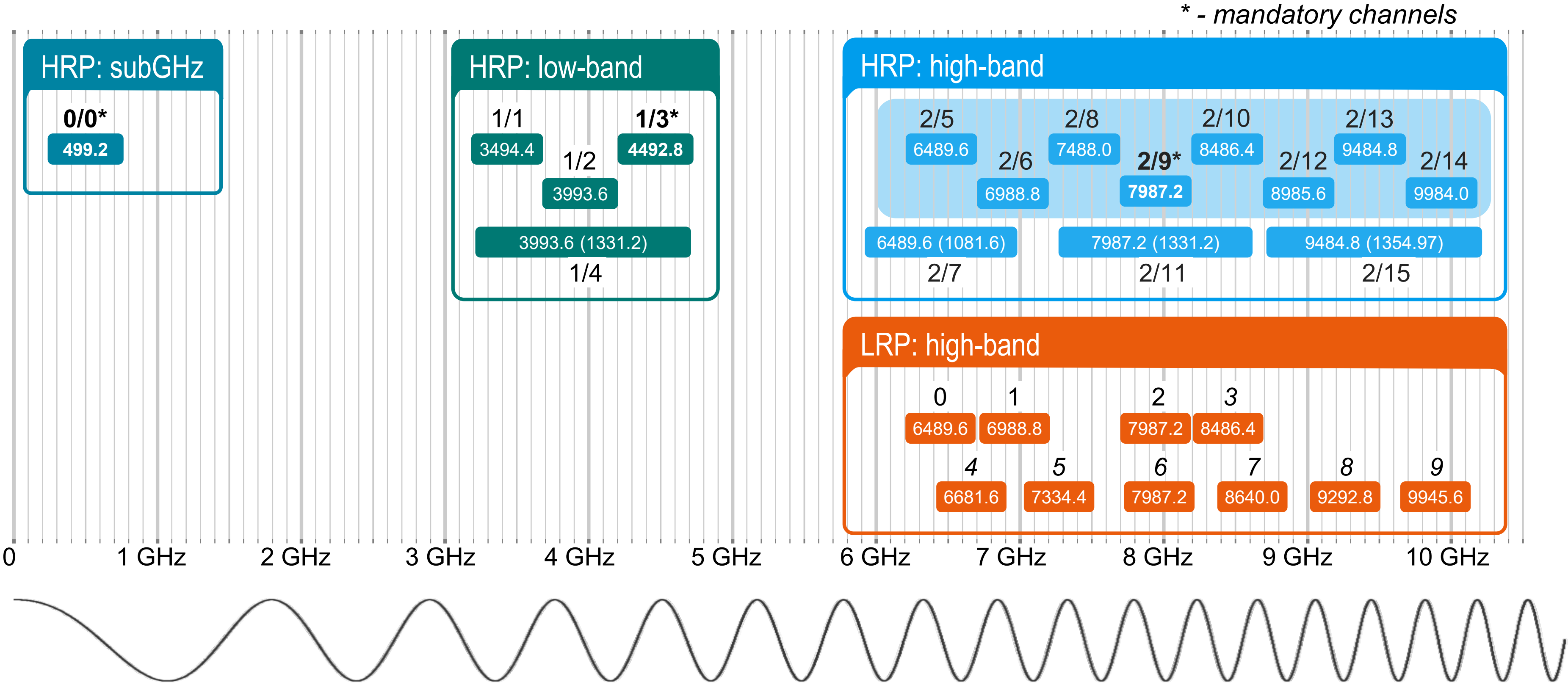








UWB channel allocation based on 802.15.4z



Impulse radio ultra-wideband (UWB) standardization: IEEE 802.15.4 (groups a, f, z)

HRP UWB PHY High Rate Pulse repetition frequency			**LRP UWB PHY** Low Rate Pulse repetition frequency					
RDEV	ERDEV		RDEV			ERDEV		
base	BPRF	HPRF	base	extend	long-range	DF	enh. DF	DF w/ EPC
Modulation BPM-BPSK **Pulse Rate:** 3.9 MHz 15.6 MHz 62.4 MHz	**Modulation** BPM-BPSK **Pulse Rate:** 62.4 MHz	**Modulation** BPSK **Pulse Rate:** 124.8 MHz 249.6 MHz	**Modulation** OOK **Pulse Rate:** 1 MHz	**Modulation** OOK **Pulse Rate:** 1 MHz	**Modulation** PPM **Pulse Rate:** 2 MHz	**Modulation** PBFSK **Pulse Rate:** 1 MHz 2 MHz 4 MHz	**Modulation** PBFSK **Pulse Rate:** 1 MHz 2 MHz 4 MHz	**Modulation** PBFSK-PPM **Pulse Rate:** 1 MHz 2 MHz
802.15.4a/z	802.15.4z		802.15.4f/z			802.15.4z		

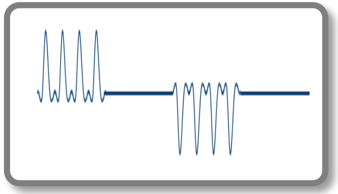
RDEV: Ranging device
ERDEV – Enhanced Ranging Device
BPM - burst position modulation

BPRF – Base pulse repetition frequency
HPRF – High pulse repetition frequency
PBFSK – Pulsed binary frequency shift keying

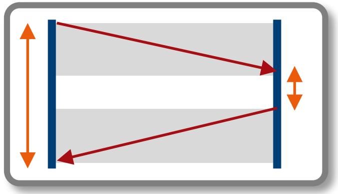
PPM – Pulse Positioning Modulation
EPC – enhanced Payload capacity
BPSK - binary phase shift keying

DF – Dual frequency
OOK: On-Off Keying

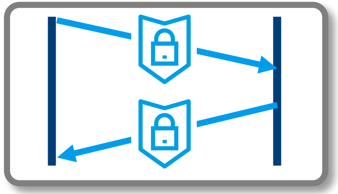
802.15.4z: Ensure interoperability for secure fine ranging applications with lower power consumption at higher range



Higher pulse repetition rates improve power consumption and allow reliable communication to ranges of up to 100 m



Single sided two-way ranging (SS-TWR) and **simultaneous ranging** save battery live time
Ranging for **UWB-LRP** (low rate repetition)

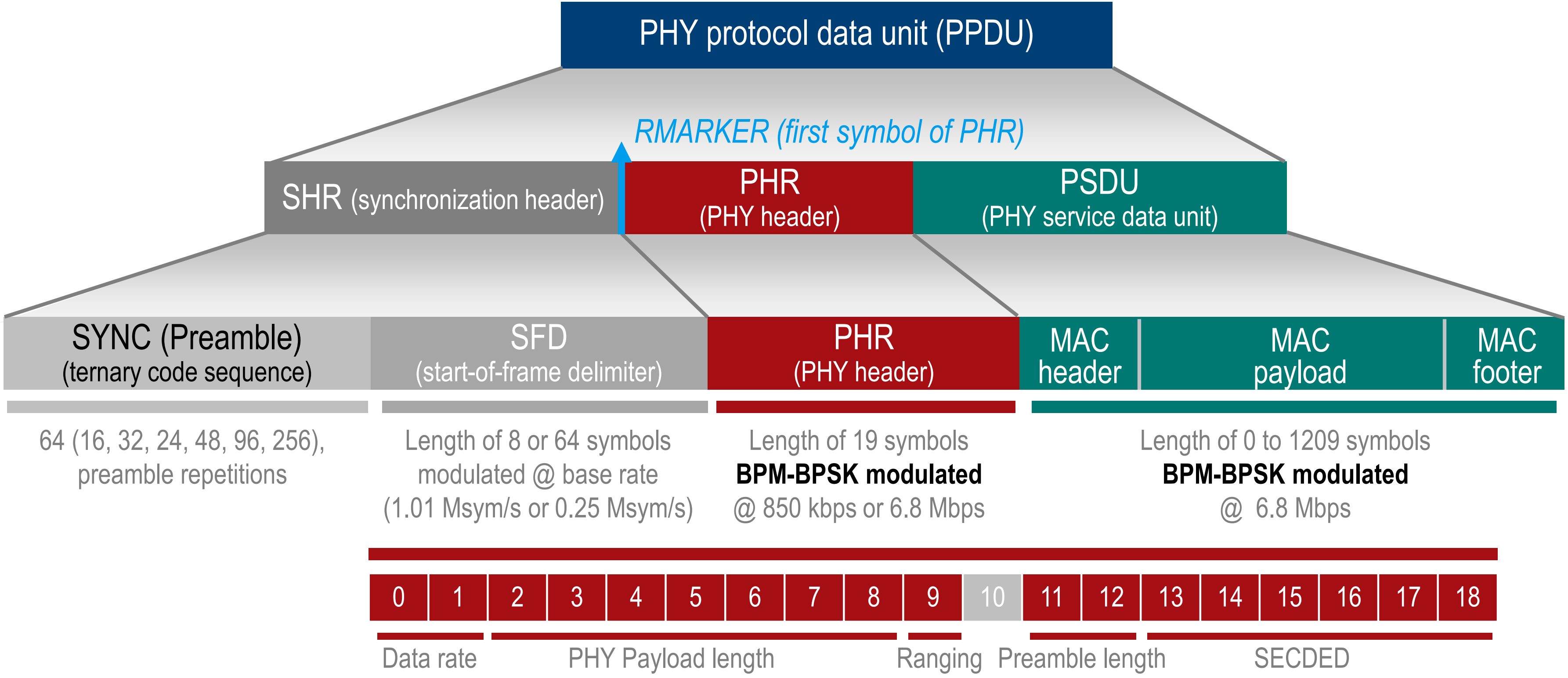


Secure ranging by cryptographic and random number generation used for scrambled timestamp sequence (STS)

HRP Enhanced Ranging DEVice (ERDEV) based on 802.15.4z

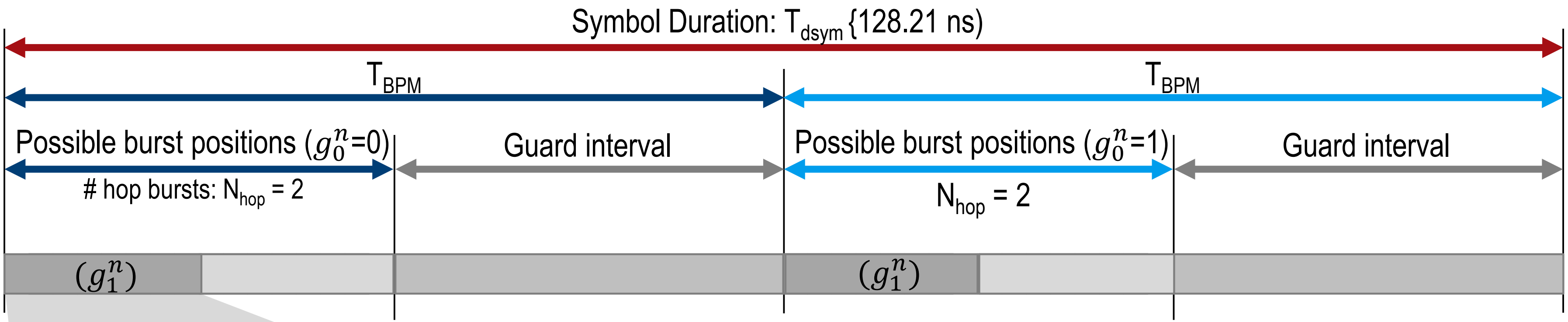
HRP UWB PHY High Rate Pulse repetition frequency			**LRP UWB PHY** Low Rate Pulse repetition frequency					
RDEV	ERDEV		RDEV			ERDEV		
base	BPRF	HPRF	base	extend	long-range	DF	enh. DF	DF w/ EPC
Modulation BPM-BPSK **Pulse Rate:** 3.9 MHz 15.6 MHz 62.4 MHz	**Modulation** BPM-BPSK **Pulse Rate:** 62.4 MHz	**Modulation** BPSK **Pulse Rate:** 124.8 MHz 249.6 MHz	**Modulation** OOK **Pulse Rate:** 1 MHz	**Modulation** OOK **Pulse Rate:** 1 MHz	**Modulation** PPM **Pulse Rate:** 2 MHz	**Modulation** PBFSK **Pulse Rate:** 1 MHz 2 MHz 4 MHz	**Modulation** PBFSK **Pulse Rate:** 1 MHz 2 MHz 4 MHz	**Modulation** PBFSK-PPM **Pulse Rate:** 1 MHz 2 MHz

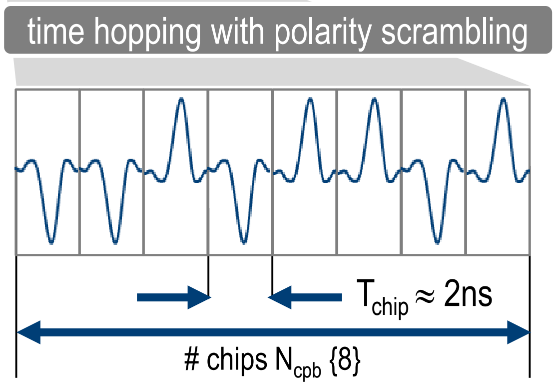
HRP-EREDV BPRF-Mode: SP0-PPDU encoding (802.15.4z)

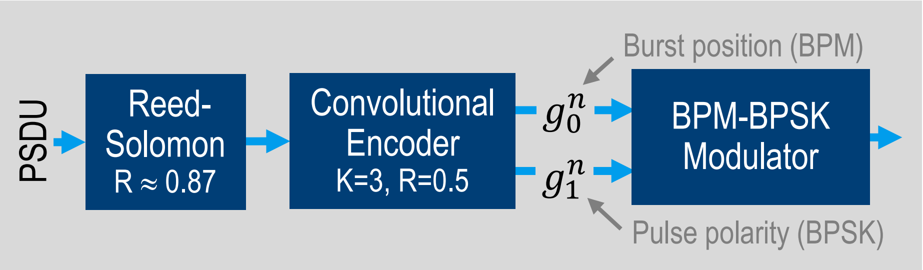


SECDED -single error correct, double error detect

HRP-ERDEV BPRF-Mode: BPM-BPSK modulation of PSDU



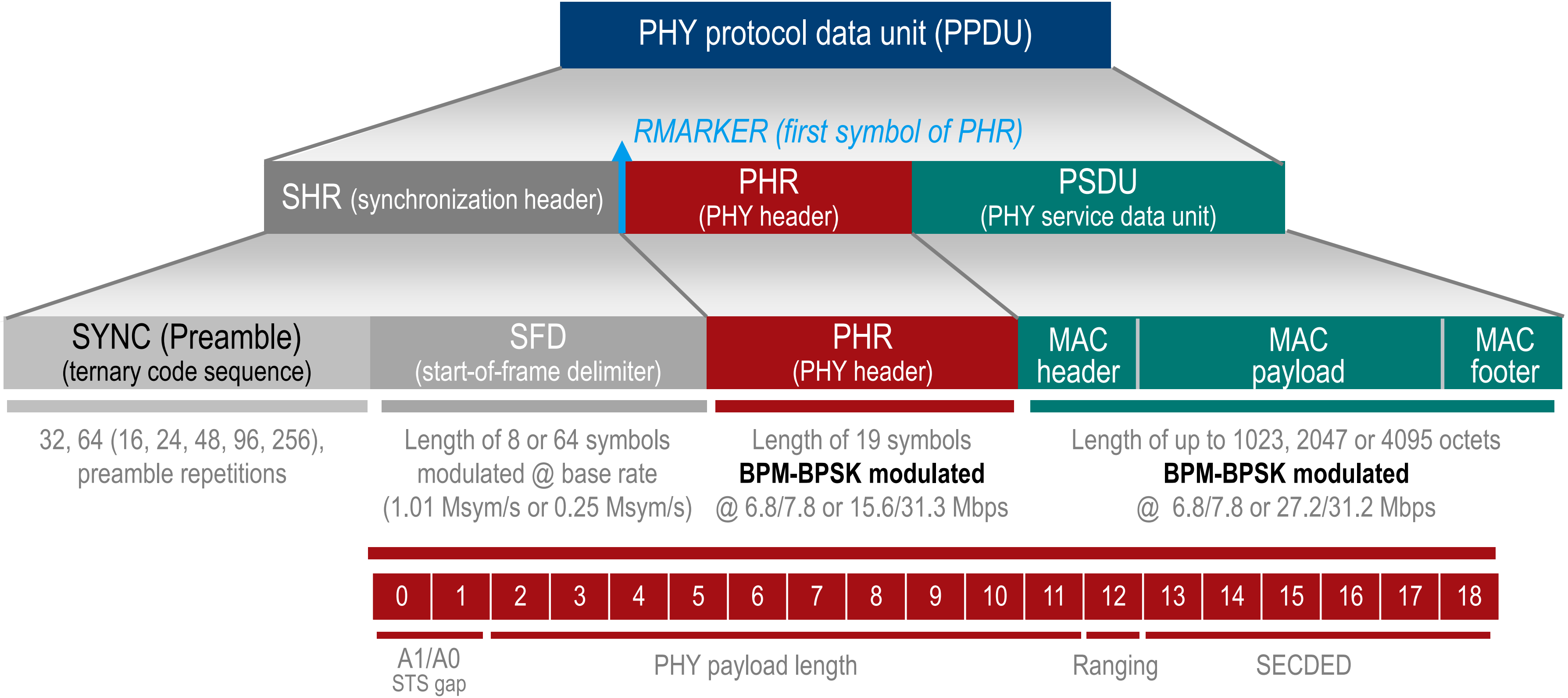




Peak PRF	Chips per symbol	Pulses per burst	FEC	Bitrate	Mean PRF
499.2 MHz	64	8	0.435	6.8 Mbps	62.4 MHz

SECDED -single error correct, double error detect

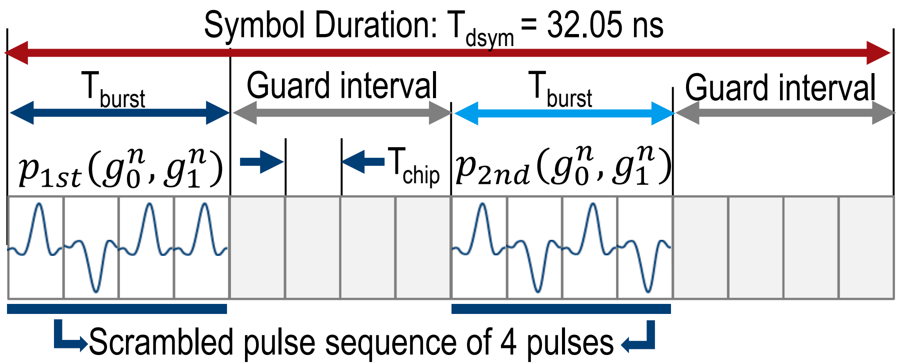
HRP-ERDEV HPRF-Mode: SP0-PPDU encoding (802.15.4z)



SECDED -single error correct, double error detect

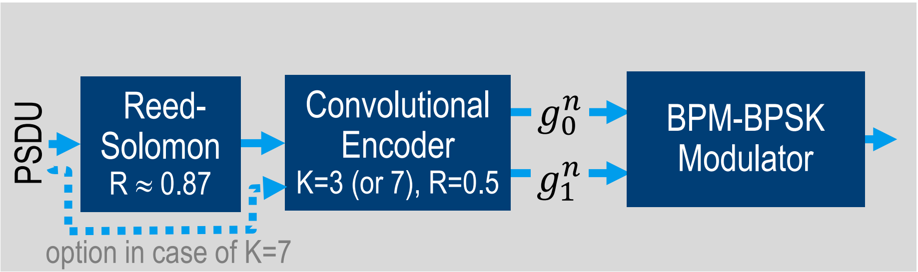
HRP-EREDV HPRF-Mode: BPSK modulation (802.15.4z)

HPRF PSDU modulation @ Mean PRF of 249.6 MHz



g_0^n , g_1^n mapping to the burst bit patterns

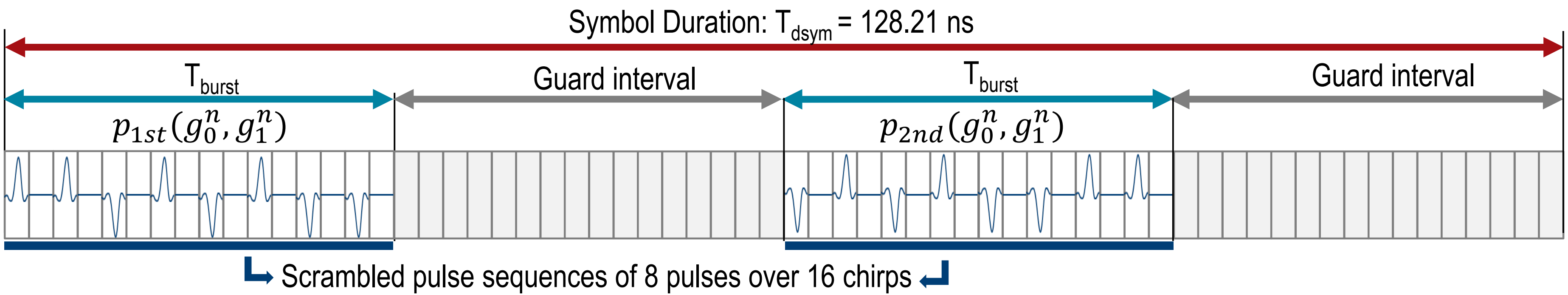
g_0^n	g_1^n	$p_{1st}(g_0^n, g_1^n)$	$p_{2nd}(g_0^n, g_1^n)$
0	0	0 0 0 0	0 0 0 0
1	0	1 1 1 1	0 0 0 0
0	1	1 1 1 1	1 1 1 1
1	1	0 0 0 0	1 1 1 1

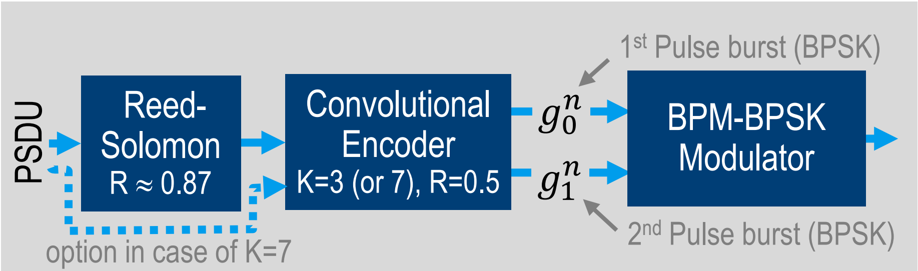


Peak PRF	Chips per symbol	Pulses per burst	FEC	Bitrate	Mean PRF
499.2 MHz	16	4	0.435	27.2 Mbps	249.6 MHz
499.2 MHz	16	4	0.500	31.2 Mbps	249.6 MHz

HRP-EREDV HPRF-Mode: BPSK modulation (802.15.4z)

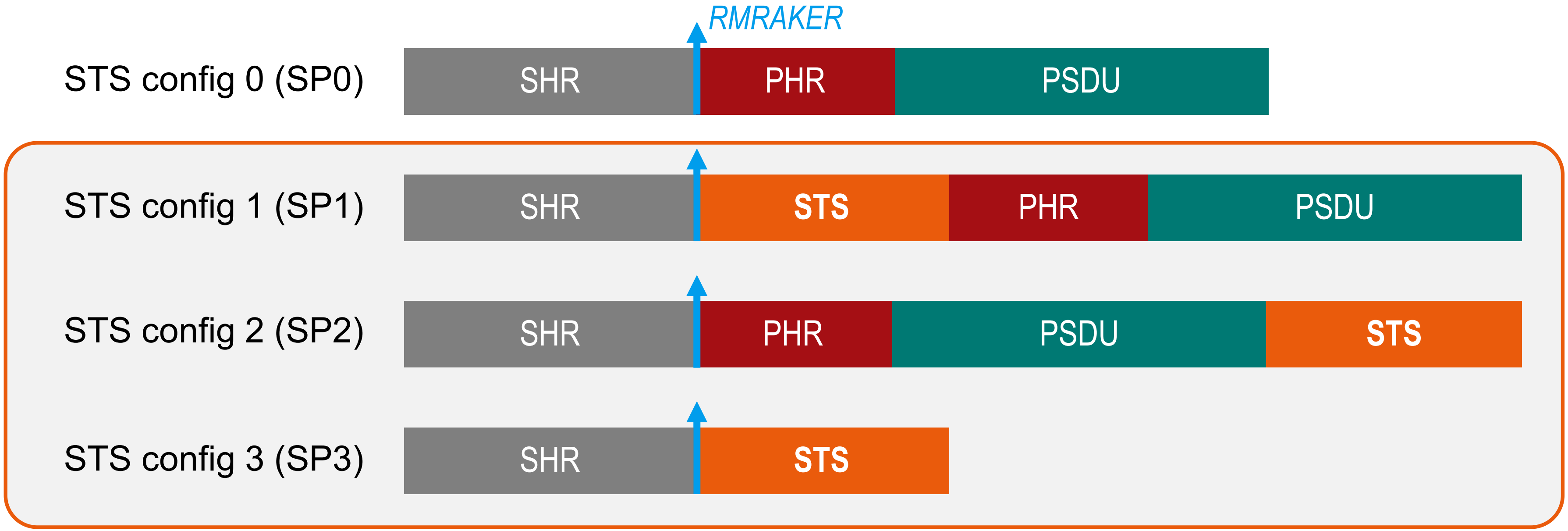
HPRF PSDU modulation @ Mean PRF of 124.8 MHz



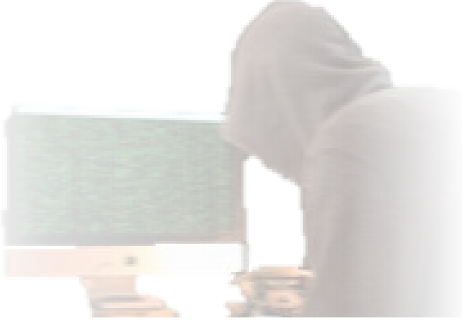


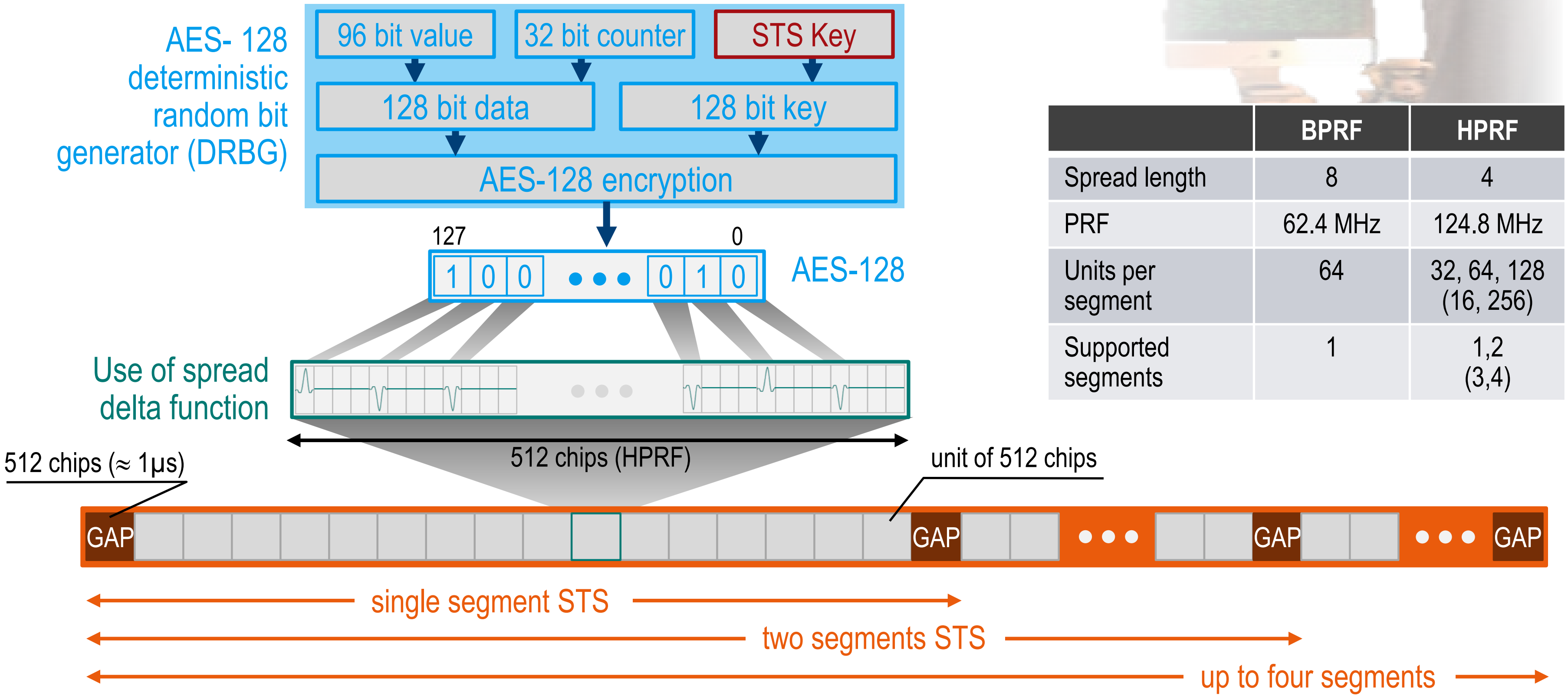
Peak PRF	Chips per symbol	Pulses per burst	FEC	Bitrate	Mean PRF
249.6 MHz	64	8	0.435	6.8 Mbps	124.8 MHz
249.6 MHz	64	8	0.500	7.8 Mbps	124.8 MHz

Introduction of a scrambled timestamp sequence (STS) generated by AES-128 based deterministic random bit generator



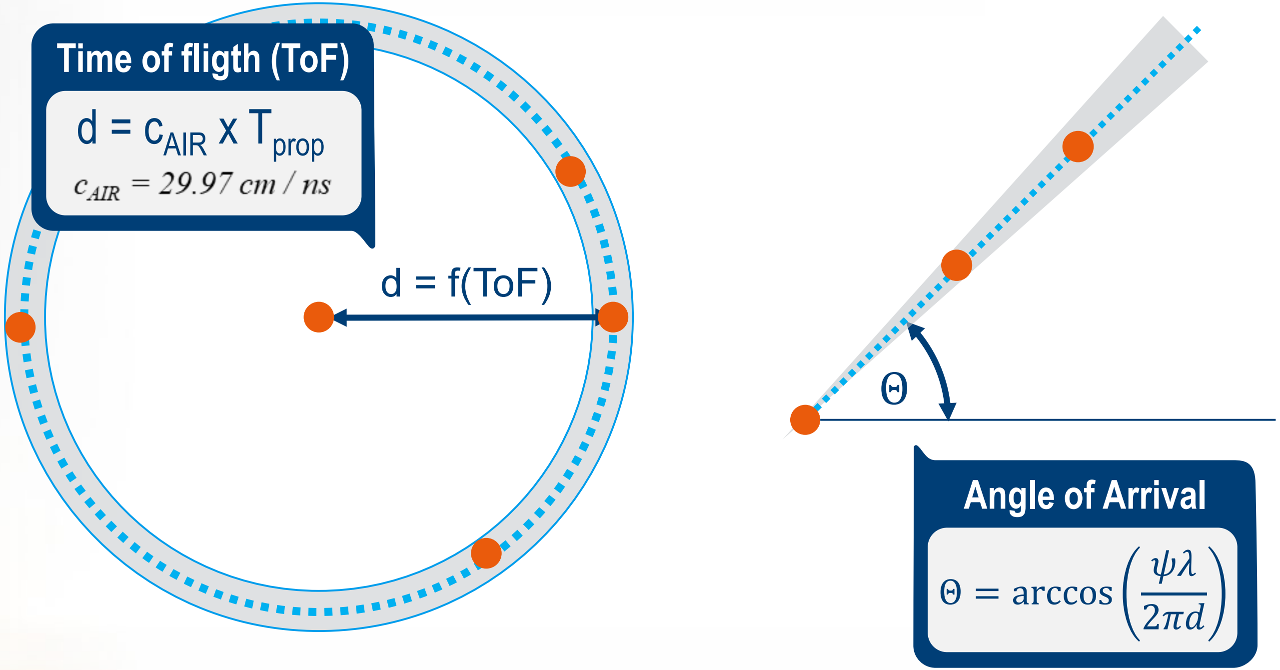
GENERATION OF STS SEGMENTS





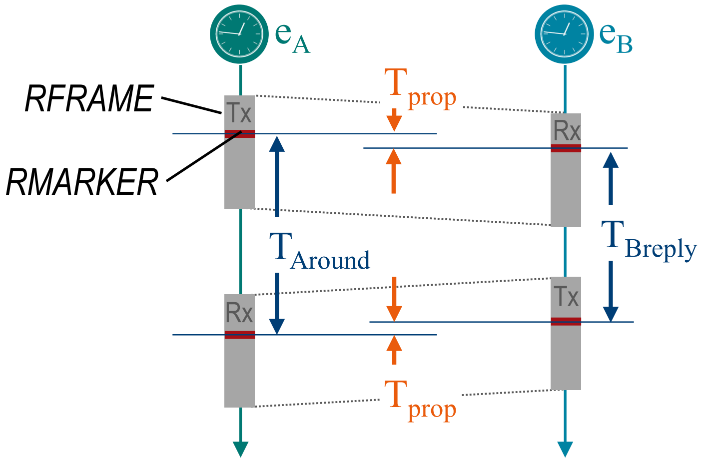
	BPRF	HPRF
Spread length	8	4
PRF	62.4 MHz	124.8 MHz
Units per segment	64	32, 64, 128 (16, 256)
Supported segments	1	1,2 (3,4)

Fine ranging/positioning with UWB



Ranging estimation based on two-way ToF estimation

SS-TWR: single-sided two-way ranging

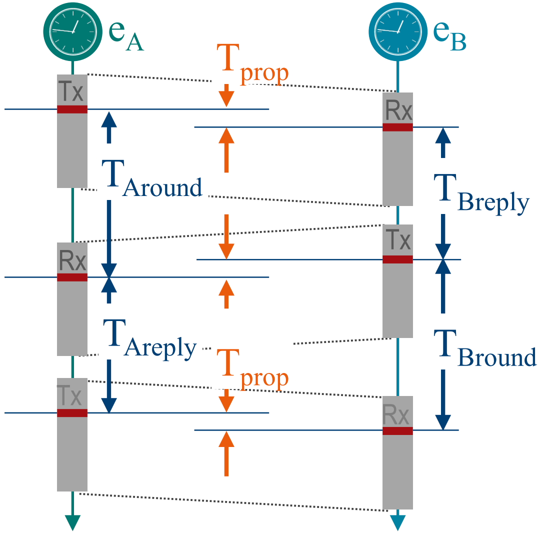


$$T_{prop} = \frac{(1+e_A) \times T_{Around} - (1+e_B) \times T_{Breply}}{2}$$

error $= 0.5\,(e_B \times T_{Breply} - e_A \times T_{Around})$

$e_B; e_A$ – clock offset error

DS-TWR: double-sided two-way ranging

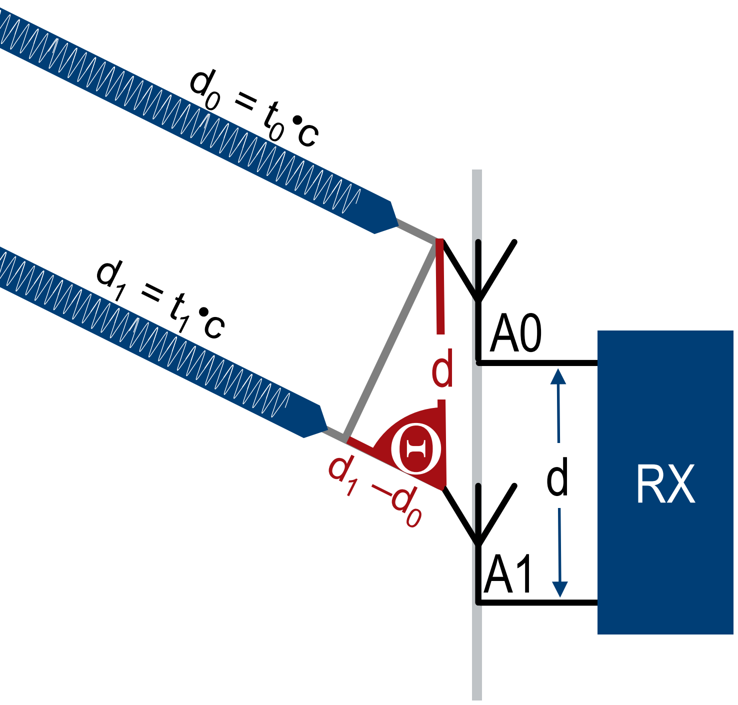


$$\hat{T}_{prop} = \frac{T_{Around} \times T_{Bround} - T_{Areply} \times T_{Breply}}{T_{Around} + T_{Bround} + T_{Areply} + T_{Breply}}$$

$$Distance = c_{AIR} \times T_{prop}$$

$$c_{AIR} = 29.97\ cm / ns$$

Angle of Arrival (AoA) based on time or phase difference



Time difference

c: speed of light

d: Antenna distance

$$\cos\Theta = \frac{d_0 - d_1}{d}$$

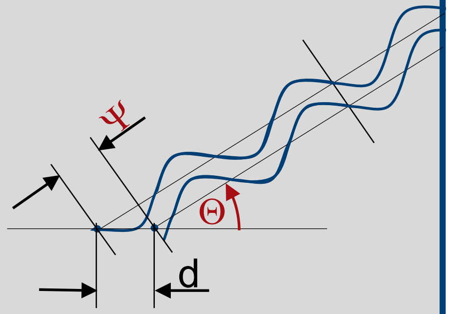
$d_0 = t_0 \cdot c$

$d_1 = t_1 \cdot c$

$d_0 - d_1 = (t_0 - t_1) \cdot c$

$$\Theta = \arccos\left(\frac{\Delta tc}{d}\right)$$

Phase difference Ψ



λ: Wavelength

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

Ψ: Phase difference

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

UWB Conformance

IEEE Standard 802.15.4

UWB Physical Layers (PHYs) and Associated Ranging Techniques – 802.14.4z

15.4 RF requirements

15.4.1 Operating frequency bands
15.4.2 Channel assignments
15.4.3 Regulatory compliance
15.4.4 Baseband impulse response
15.4.5 Transmit PSD mask
15.4.6 Chip rate clock and chip carrier alignment
14.4.7 TX-to-RX turnaround time
14.4.8 RX-to-TX turnaround time
14.4.9 Transmit center frequency tolerance
14.4.10 Receiver maximum input level of desired signal
14.4.11 Receiver energy detection (ED)
14.4.12 Link quality indicator (LQI)
14.4.13 Clear channel assessment (CCA)

Regulatory Conformance

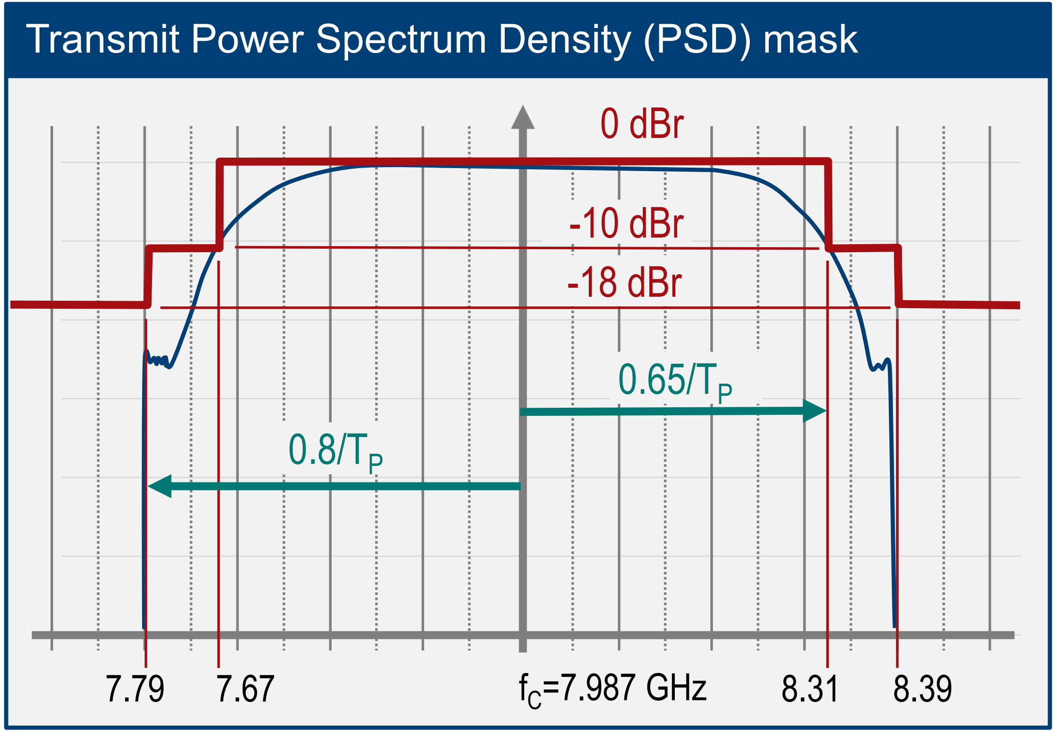
ETSI EN 303 883
Short Range Devices (SRD) and Ultra Wide Band (UWB);

ETSI EN 302 065
Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB)

FCC CFR 47 Part 15.250
Operation of wideband systems within the band 5925-7250 MHz

FCC CFR 47 Part 15.5xx
Technical requirements and measurement techniques ….

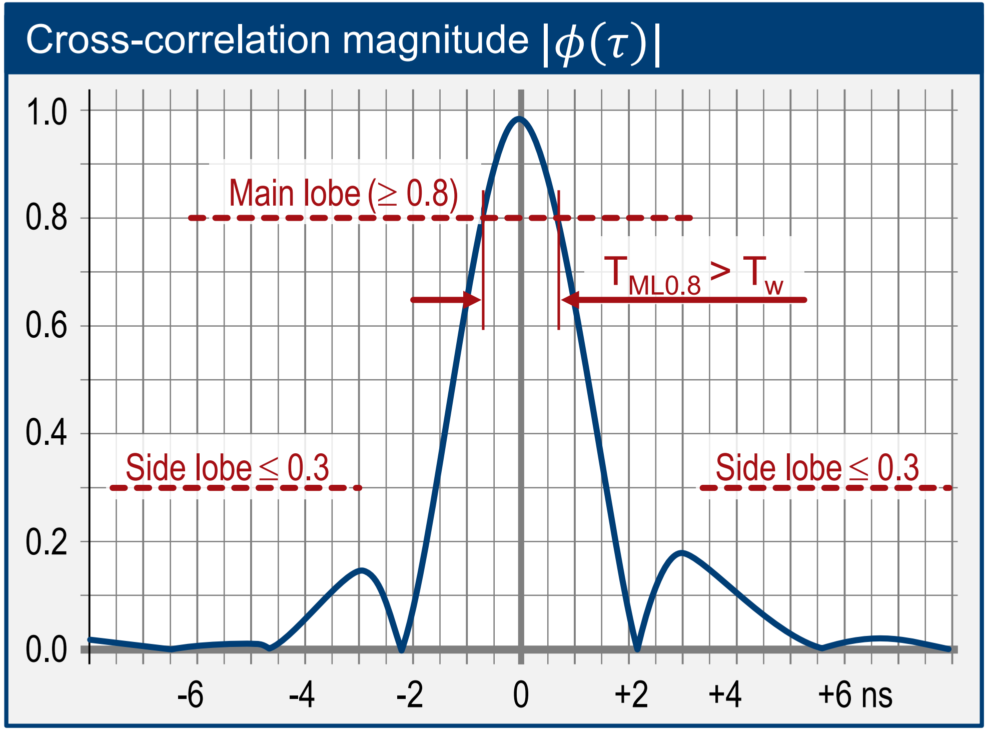
Transmit power spectrum density (PSD)



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	$\|f_c – f\|$ -10 dBr	$\|f_c – f\|$ -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



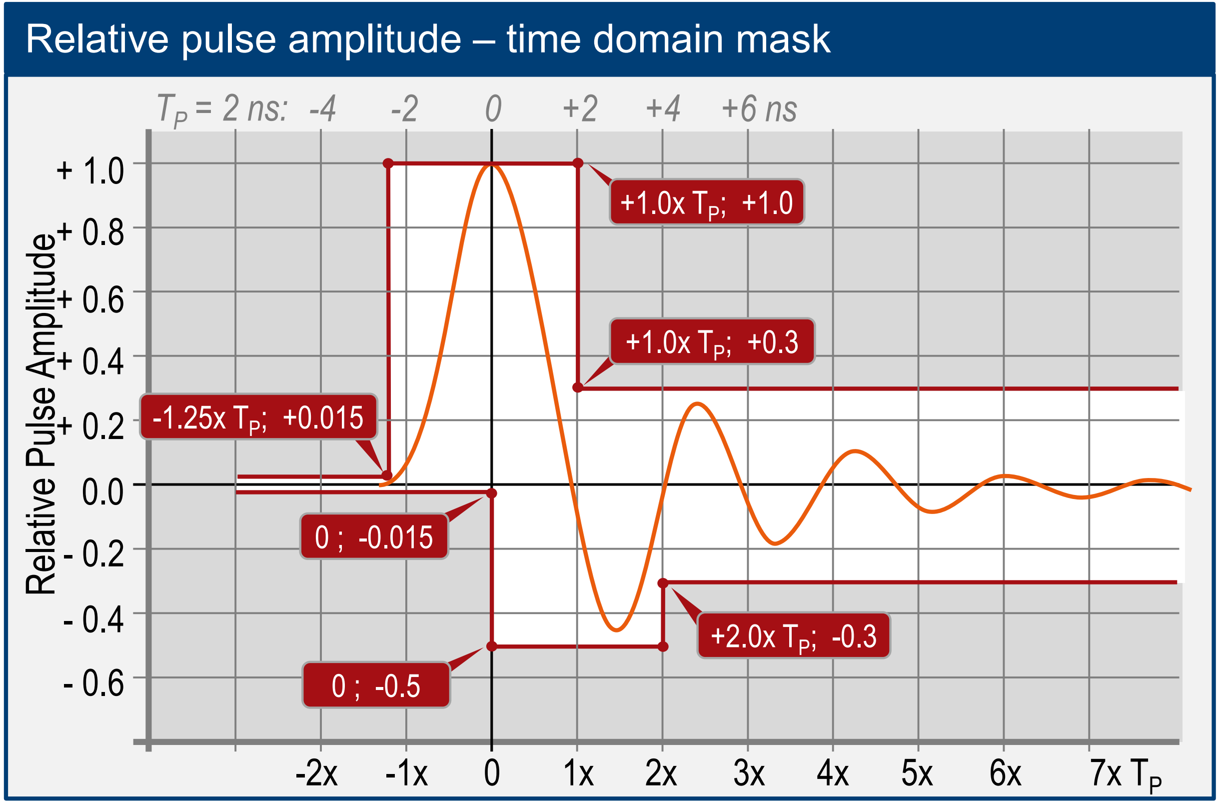
The transmitted pulse shape p(t) shall be constrained by the shape of its cross-correlation function with a standard reference pulse, r(t), which is a root raised cosine pulse with a roll-off factor of β = 0.5.

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

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



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)

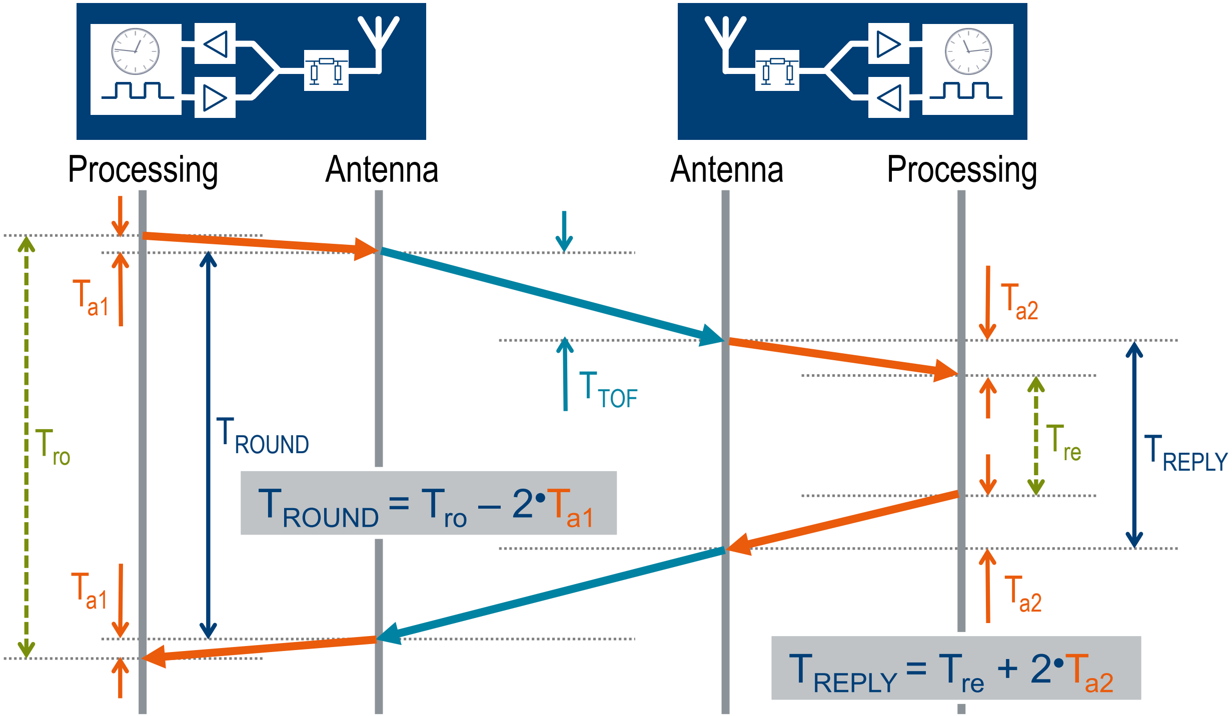
Certification testing
(by authorized test labs)

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

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

EVERYTHING YOU NEED FOR UWB TESTING

UWB Signal Generation

R&S®SMW200A

R&S®SMM100A

Embedded design and power

R&S®NGM200

R&S®RTM3000

R&S®FPC1500

R&S®FSW26

R&S®RTP

UWB Spectrum & signal analysis

R&S®CMP200

R&S®TS7124

UWB non-signaling tests incl. ToF

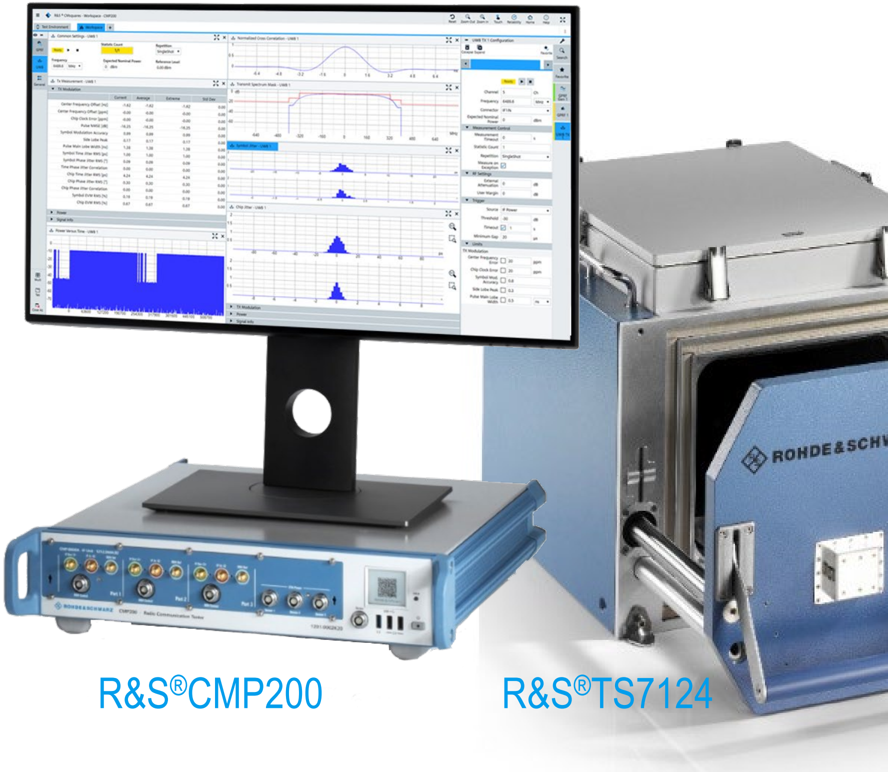
R&S®CMP200 – Wideband non-signaling test for 5G and more

CMP200 features

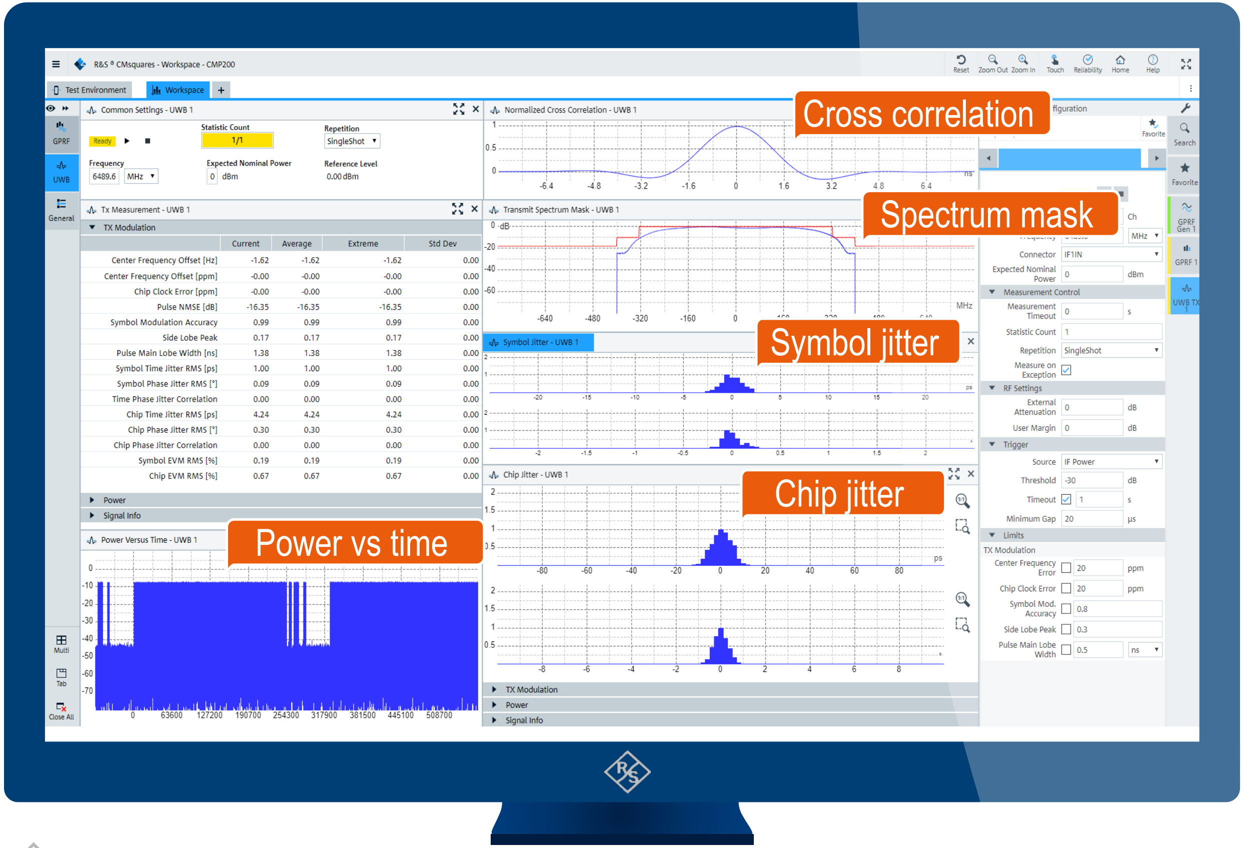
- One general purpose analyzer
  Frequency range: 4 to 20 GHz
- One ARB generator
  Replay of predefined waveforms (-100 dBm)
  Frequency range: 6 to 20 GHz
- Three switchable ports, 1 GHz bandwidth

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

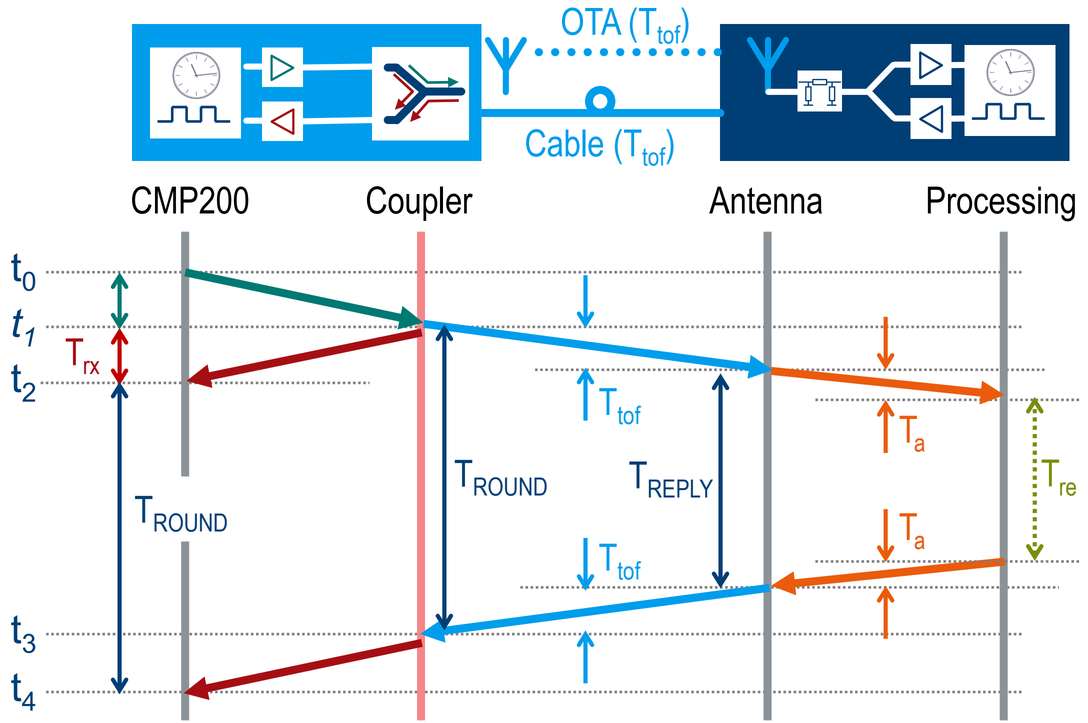


HRP UWB transmitter measurements with R&S®CMP200



R&S®CMP200

ToF measurement setup with R&S®CMP200



- Coupler is used as reference point
- Connection from coupler to DUT via cable (length, velocity factor) or over the air (distance)

ToF Verification

$T_{ROUND} = T_{REPLY} + 2 \cdot T_{tof}$

$T_{ROUND} = t_3 - t_1$

$t_1 = t_2 - T_{rx}$; $t_3 = t_4 - T_{rx}$

$T_{ROUND} = t_4 - t_2$

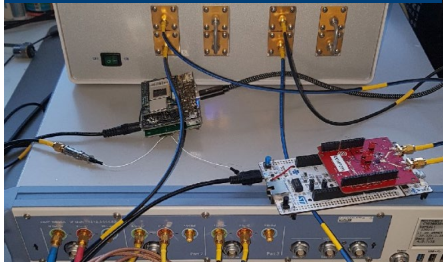
ToF Calibration

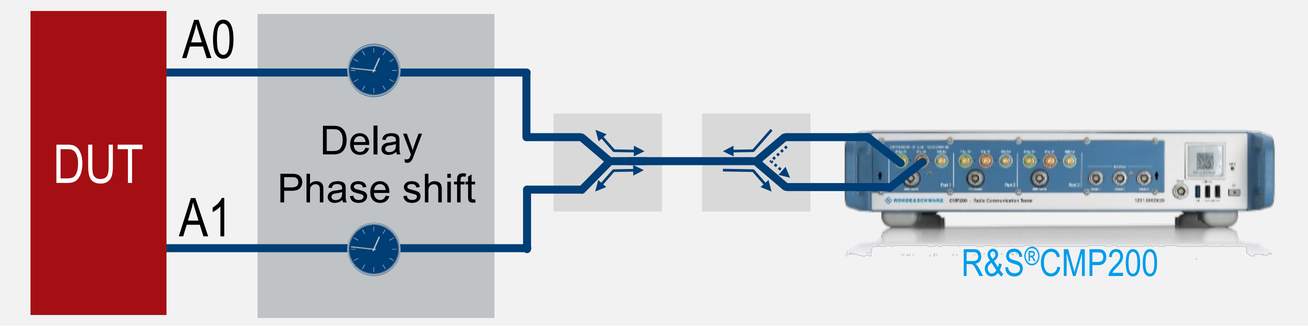
$T_{ROUND} = T_{re} + 2 \cdot T_a + 2 \cdot T_{tof}$

$T_a = [\, t_4 - t_2 - T_{re} - 2 \cdot T_{tof} \,] / 2$

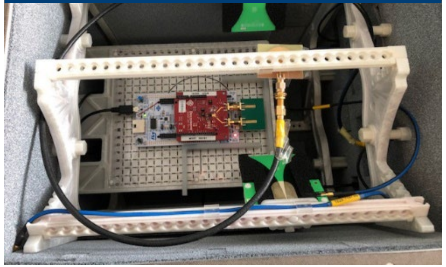
Verification and calibration of Angle of Arrival (AoA)

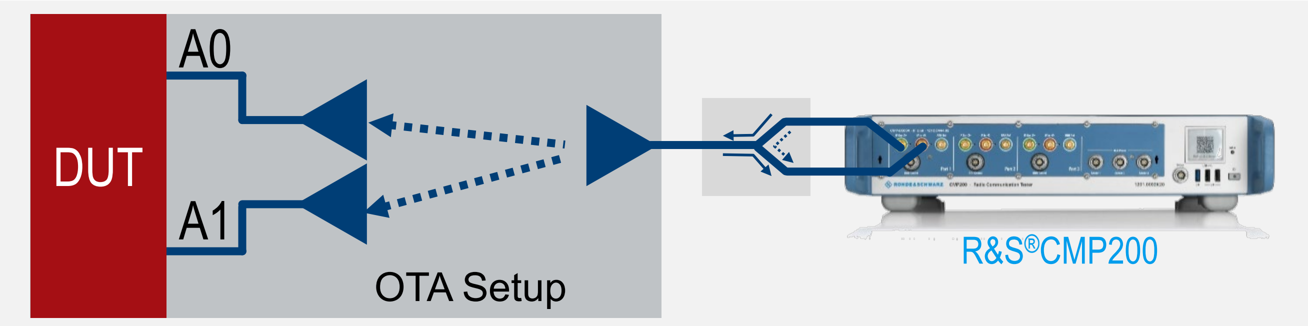
Conducted Mode





Over-the-air Mode





Empowering the mobile device experience with Wi-Fi6E/7 and UWB

ROHDE&SCHWARZ

Make ideas real