KEYSIGHT WORLD 2020

802.15.4/4z UWB Technology Challenges and Test Solutions

Project Manager / Keysight Technologies

TIM HUANG

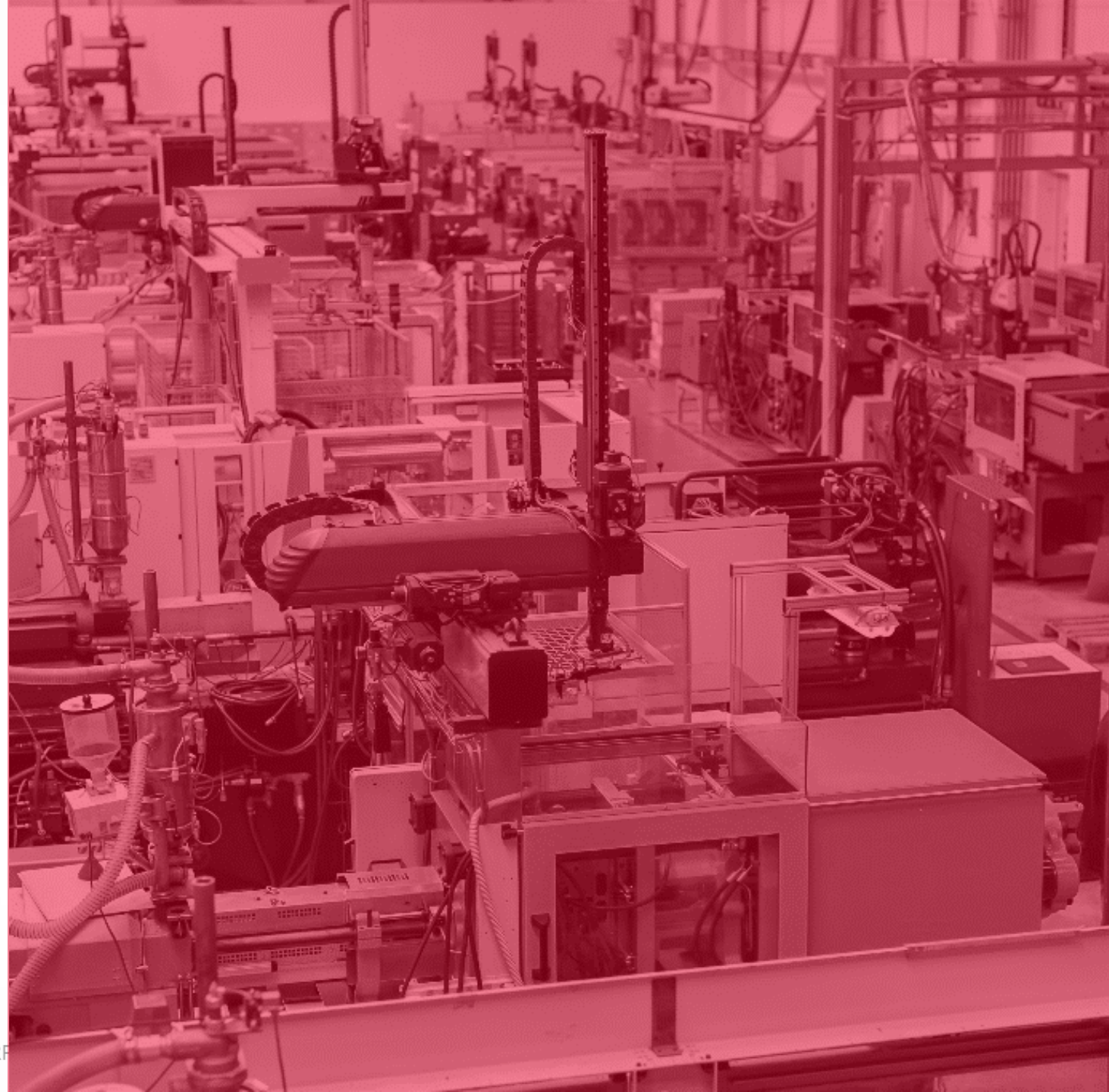
Agenda

802.15.4/4z UWB TECHNOLOGY

01 *Ultra Wide-Band Standard Evolution & Ecosystem*

02 *Overview of IEEE 802.15.4/4z*

03 *UWB Test Challenges and Solutions*



KEYSIGHT TECHNOLOGIES

Indoor Positioning / Wayfinding Technologies

WI-FI, BLUETOOTH, RFID AND UWB

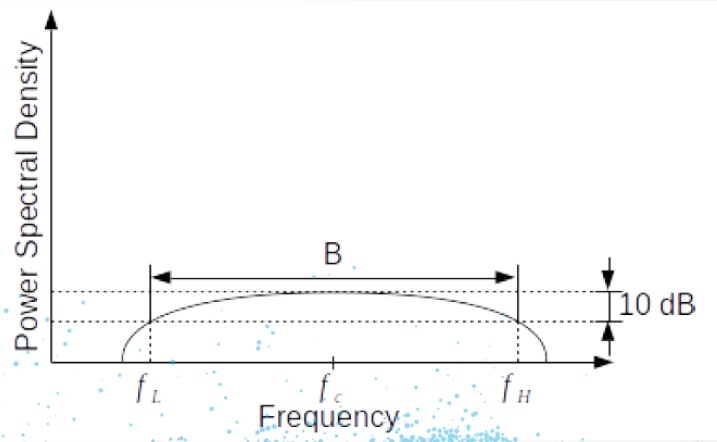
Technologies	802.11az (Wi-Fi based)	Bluetooth LE (4.0/5.1)	RFID	UWB
Standards	IEEE WLAN 802.11	Bluetooth SIG	EPC/ISO	IEEE WPAN 802.15.4/4z
Positioning Technology	Intensity of the received signal (RSSI)	RSSI (Mesh) AoA or AoD	Remote coupling	AoA or ToF
Secure	Under relay attack threat	Under relay attack threat	HIGH Security	HIGH Security
Frequency	2.4, 5, 6 GHz	2.4 GHz	125 KHz to 5.8 GHz	Sub-GHz Low band (3.1 to 4.8 GHz) High band (6 to 10.6 GHz)
Modulation	OFDM	GFSK	ASK/2FSK/OOK	BPM+BPSK (802.15.4) HRP-ERDEV (BPRF, HPRF)
Trans. Range	< 150 meters	< 75 meters	< 1 meter	< 100 meters
Accuracy	< 15 meters	< 1 meter (BT 5.1) < 8 meters (BT 4.0)	Presence detection only	< 30 cm (objects down to less than 10 cm in line of sight)
Power Consumption	High	Low	Passive powered	Medium / Low
Cost	$$$	$$	$	$$$

The benefit of UWB, is in its low-power pulses, which help to ensure security and allow for highly accurate location data

What is UWB?

ULTRA WIDE-BAND

- **FCC Definition:**



  - An intentional radiator that has either:
    - ✓A fractional bandwidth (B_{frac}) greater than 0.20 where $B_{frac} = BW / fc$
    - ✓A bandwidth greater than or equal to 500 MHz

  The frequency upper and lower bounds (F_H and F_L respectively) are the points that are 10 dB below the highest radiated power part of the band.

  $B = (F_H - F_L)$

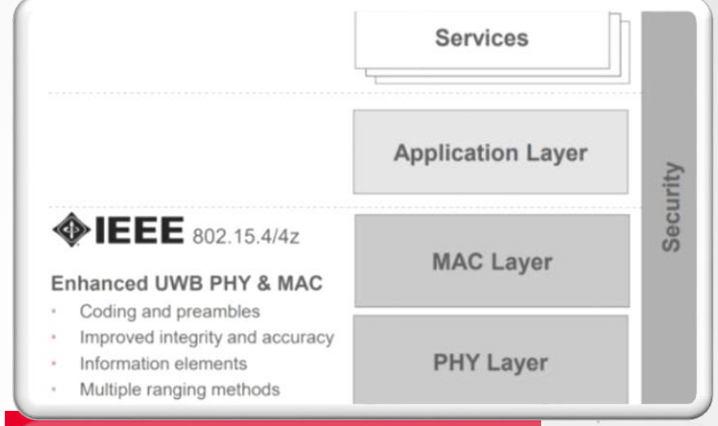
  $Fc = 1/2 * (F_H + F_L)$

  $B_{frac} = B / Fc = 2*(F_H - F_L)/ (F_H + F_L)$

  - In an unlicensed band with a very strict power spectral density of -41.3 dBm/MHz

Meet the New UWB - Standard Evolution

DEFINED IN IEEEE 802.15.4/4Z



802.15.4a – 2007

- Completed in Aug., 2007
- 1st standardization of UWB
- Evolved from OFDM-based to use impulse radio (UWB-IR), 2ns pulse width
- Indoor positioning for WSN or IIoT

802.15.4 – 2011

- Completed in Sep., 2011
- Decawave chipset based on this spec on market

802.15.4 – 2015

- Completed in Dec., 2015
- 2 UWB PHY Defined:

(1) HRP (High Rate Pulse) from 802.15.4a/802.15.4-2011

(2) LRP (Low Rate Pulse) as 802.15.4f-2012 (aka Active RFID)

802.15.4z – 2019

- Active working group (TG4z)
- Enhancements of Security extension to HRP & LRP UWB PHYs & MAC
- Introduce ERDEV (Enhanced Ranging Device) mode including BPRF or HPRF

HRP UWB Ecosystem

CHIPSET, DEVICE, APPLICATION, CONSORTIUM

Chipsets / Modules

- USA
- Europe
- Korea
- China

Devices

- Mobile Phone
- Car Key
- Car
- More coming

Applications

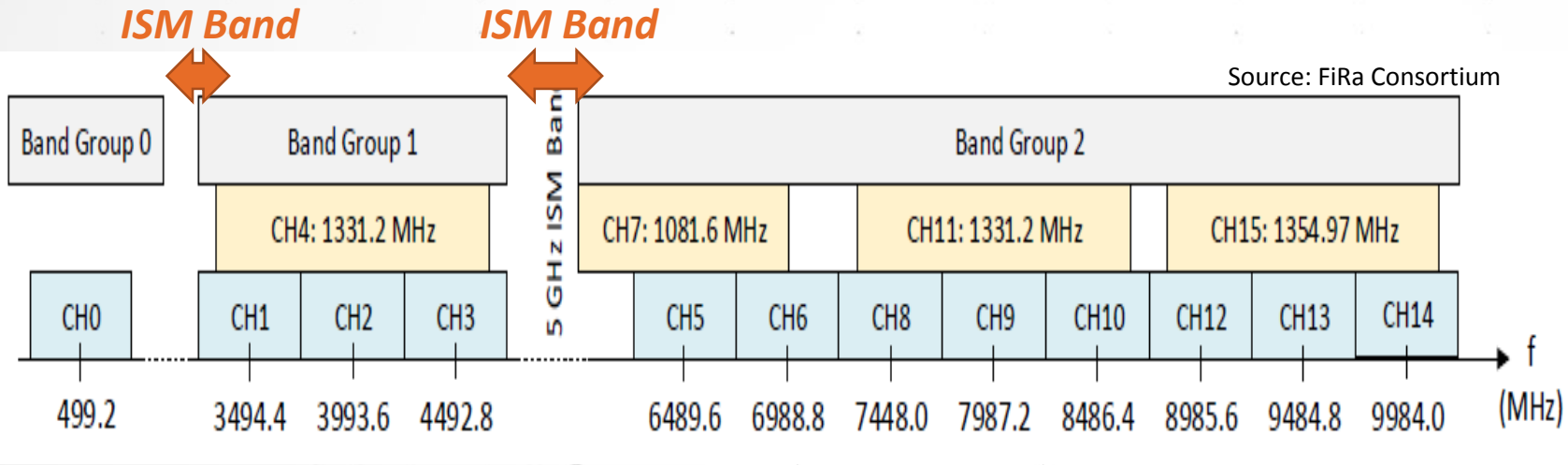
- Smart Home
- Mobile Payment
- Keyless/ Car Entry
- Indoor navigation

Consortiums

- UWB Alliance
  formed in Dec., 2018
- FiRA
  formed in Aug., 2019

Frequency and Channel Assignments

802.15.4-2015 HRP UWB PHY



IEEE 802.15.4-2015 - HRP PHY band allocation (blue channels have 499.2 MHz bandwidth, others as noted

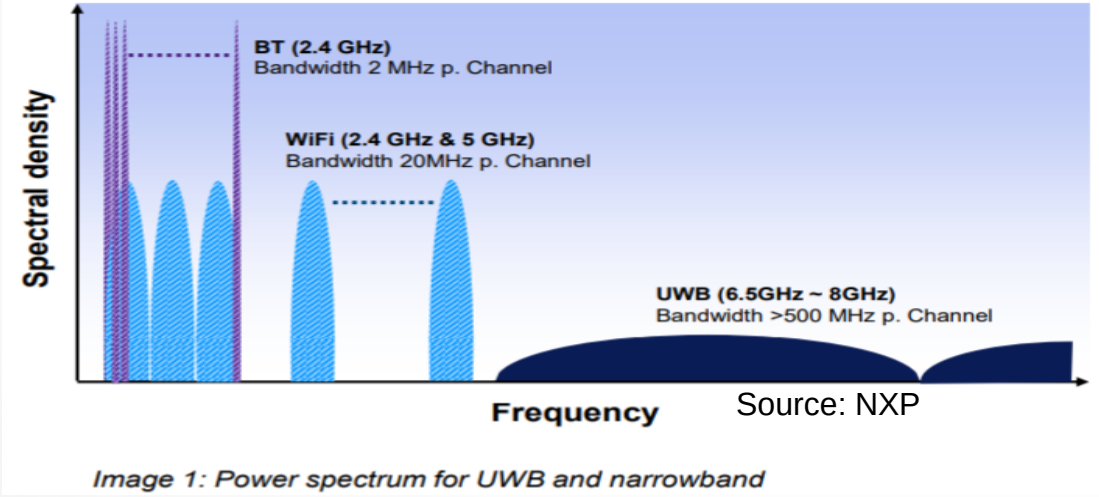


Image 1: Power spectrum for UWB and narrowband

- Sub-GHz band: 249.6 MHz to 749.6 MHz
  - 1 channel with 500MHz BW
  - Channel #0 as mandatory
- Low band: 3.1 GHz to 4.8 GHz
  - 4 channels
  - 3 channels with 500MHz BW
  - 1 channel with 1.3GHz BW
  - Channel #3 as mandatory
- High band: 6.0 GHz to 10.6 GHz
  - 11 channels
  - 8 channels with 500MHz BW
  - 1 channel with 1.1GHz BW
  - 2 channels with 1.3GHz BW
  - Channel #9 as mandatory

Frequency and Channel Assignments

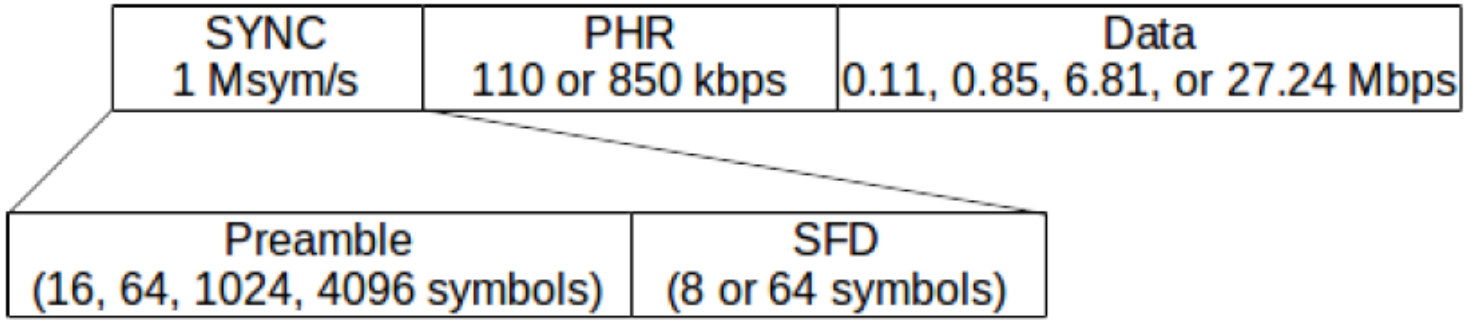
802.15.4-2015 HRP UWB PHY

Band Group	Channel Number	Center Freq (MHz)	Bandwidth (MHz) (-3dB BW)	Mandatory/Optional
0 (Sub-GHz)	0	499.2	499.2	Mandatory below 1GHz
1 Low band (3.1 GHz to 4.8 GHz)	1	3494.4	499.2	Optional
	2	3993.6	499.2	Optional
	3	4492.8	499.2	Mandatory in low band
	4	3993.6	1331.2	Optional
2 High band (6 GHz to 10.6 GHz)	5	6489.6	499.2	Optional
	6	6988.8	499.2	Optional
	7	6489.6	1081.6	Optional
	8	7488.0	499.2	Optional
	9	7987.2	499.2	Mandatory in high band
	10	8486.4	499.2	Optional
	11	7987.2	1331.2	Optional
	12	8985.6	499.2	Optional
	13	9484.8	499.2	Optional
	14	9984.0	499.2	Optional
	15	9484.8	1354.97	Optional

PHY Overview

802.15.4-2015 HRP UWB PHY

Physical frame is composed of three parts: ***SYNC field, physical header (PHR) and Payload (data Field)***. SYNC field is further split into two parts: the preamble and start of frame delimiter (SFD).



802.15.4 UWB physical frame structure

Transmitted at different rates:

- SHR: base rate 1MSym/s (16/64MHz PRF), 0.25MSym/s (4MHz PRF)
- PHR: 110kbps, 850kbps
- Data: information data rate (110/850kbps, 6.81/27.24Mbps)

What is 802.15.4z HRP-ERDEV?

ERDEV(ENHANCED RANGING-CAPABLE DEVICE)

- ✓This amendment enhances the UWB PHYs with additional coding and preamble options, improvements to existing modulations to increase the integrity and accuracy of the ranging measurements, additional information element definitions to facilitate ranging information exchange.
- ✓It also enhances the MAC to support control of time of flight ranging procedures and exchange ranging related information between the participating ranging devices.

- ***To reduce air-time for higher density/lower power operation***
- ***To increase the integrity and accuracy of ranging measurement timestamps***
- ***Typical range of the radio is up to 100 meters***

ERDEV

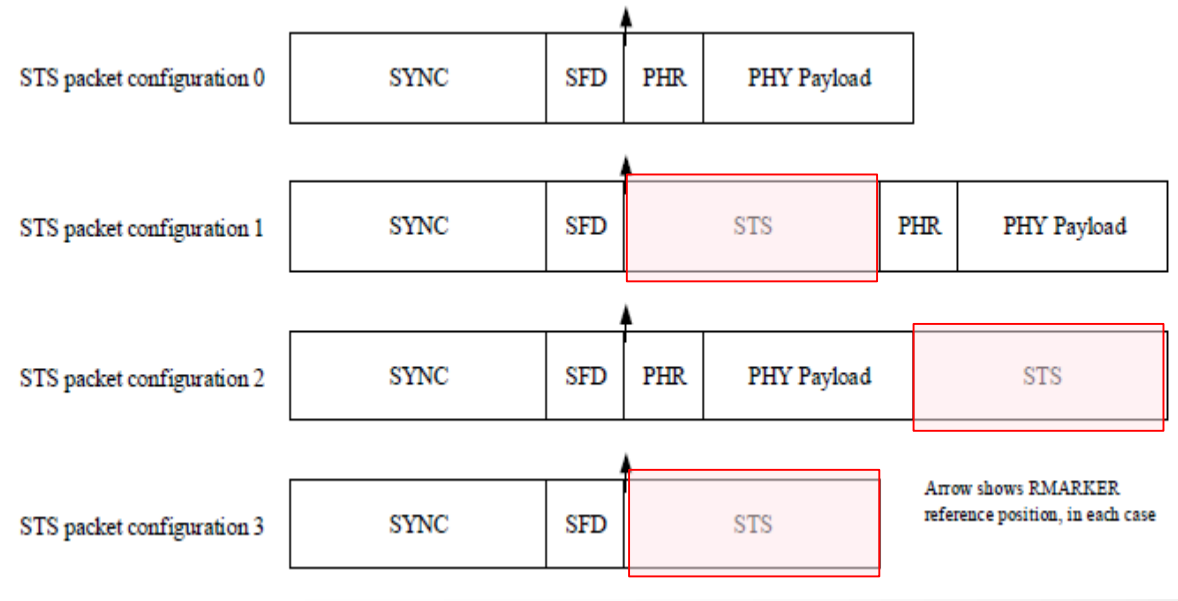
- BPRF mode (Base PRF mode, nominal 64MHz PRF)
- HPRF mode(256MHz PRF, 128MHz PRF)

HRP-ERDEV PPDU Configurations

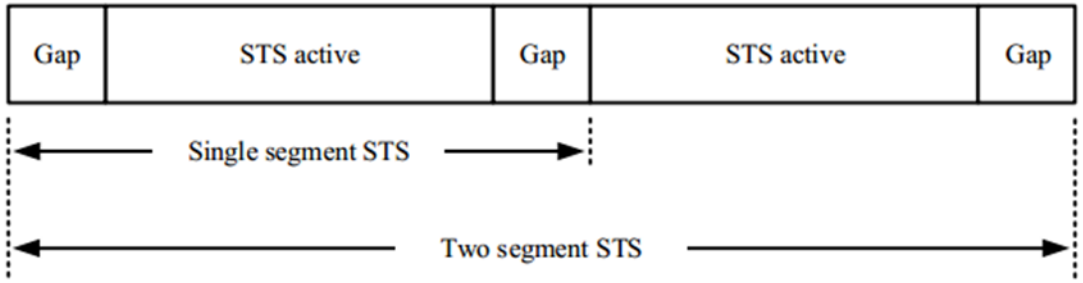
802.15.4z HRP-ERDEV FORMATS

An HRP UWB PHY based ERDEV which includes **STS (Scrambled Timestamp Sequence)** to increase the integrity and accuracy of ranging measurements.

STS packet configuration specifier value (see note)	Selected the position of the STS in the PPDU	Support
0	There is no STS field included in the PPDU.	Mandatory
1	The STS field is placed immediately after the SFD field and before the PHR field.	Mandatory
2	The STS field is placed after the PHY Payload field.	Optional
3	The STS field is placed immediately after the SFD field and no PHR or Data fields are included.	Mandatory



The 128 pulses of the STS are generated from **AES-128. :** It will only be correctly received (correctly correlated in the receiver) when both TX and RX parties know the keys. It is secure against both accidental interference and intentional malicious attack

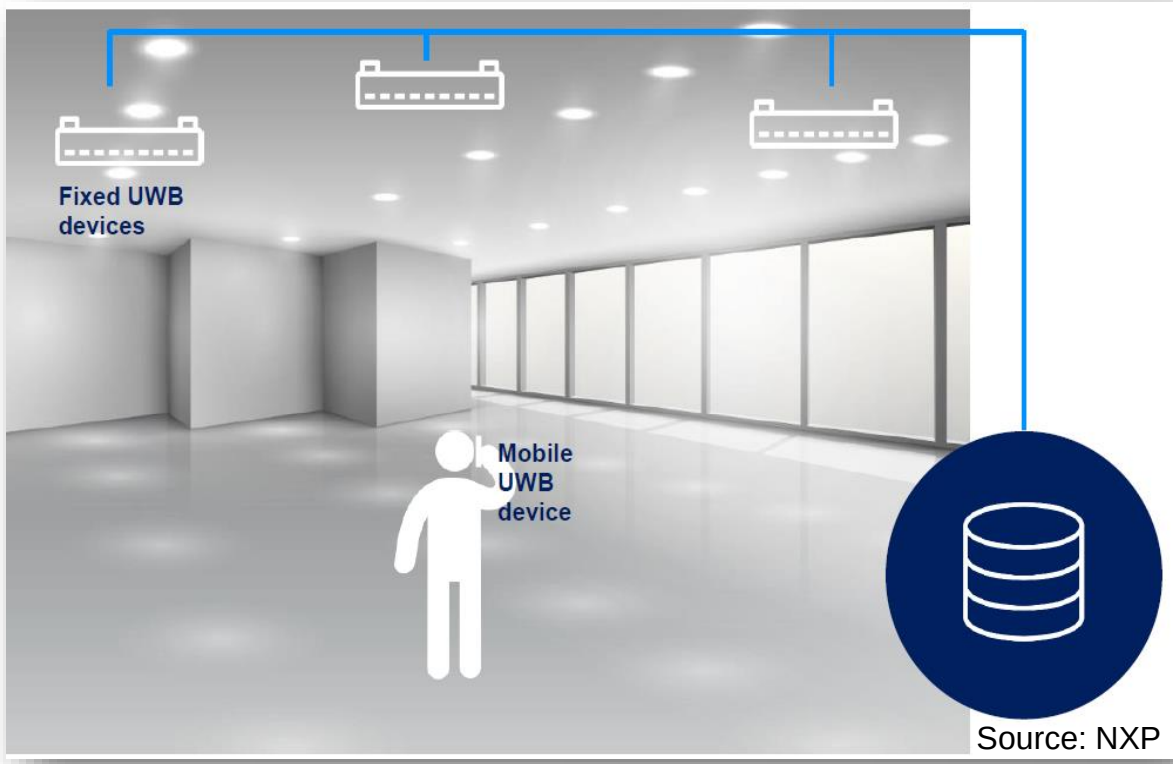


Why ToF (Time of Flight) ?

INDOOR POSITIONING SERVICES

Security

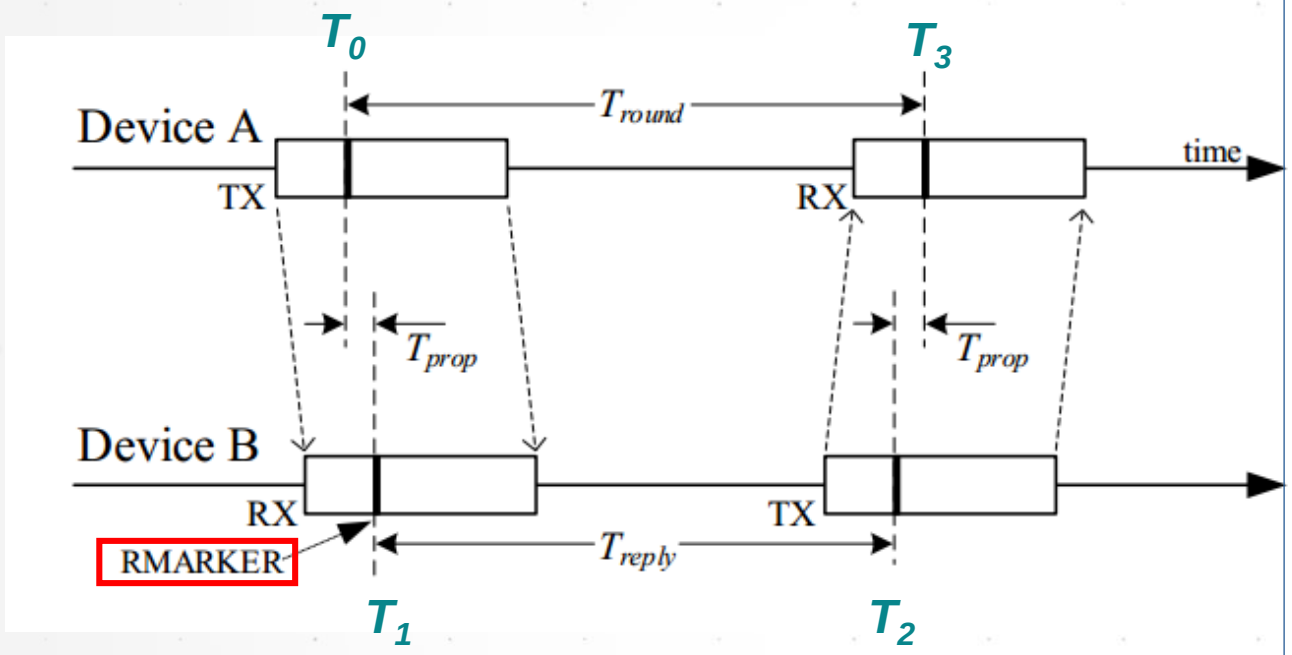
- UWB offers a high-precision positioning, even in crowded, multipath signal environments, and can pass obstacles.
- Positioning with RSSI can be hacked and encryption can be broken.
  Time of Flight technique is difficult to “fake” time.
- Advantage:
  highest precision and positional stability
- How it works:
  The anchors send UWB signals, the sensors return them. The distance is calculated based on the time it takes the pulses between sending and receiving.



Source: NXP

Improved Ranging - Time of Flight (TOF)

SINGLE-SIDED TWO-WAY RANGING(SS-TWR)



$$\hat{T}_{prop} = ½ (T_{round} - T_{reply})$$

Distance = *Tprop x Speed of light*

- A initiates the exchange and device B responds.
- Each device precisely timestamps the **transmission** and **reception** time of the message frames, and so can calculate times T_{round} and T_{reply} by simple subtraction.
- Time of Flight T_{prop} is the propagation time of the **RMARKER** between the devices.
- For the TOF to be calculated at device A, device A **needs the reply time T_{reply} employed by device B.**

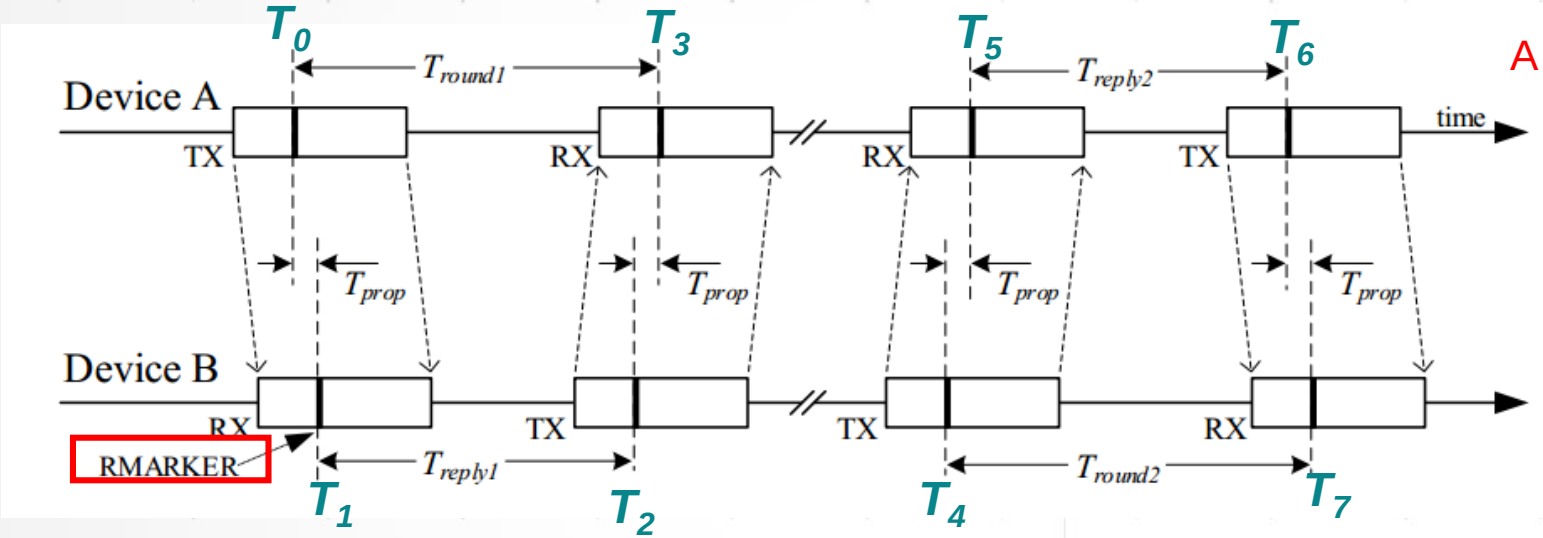
  a. When is determined by device B after its transmission, an additional message is necessary to bring this value to device A.

  b. When can be accurately predicted by device B before its transmission, the value can be embedded in the reply message itself.

Advanced TOF ranging method

DS-TWR

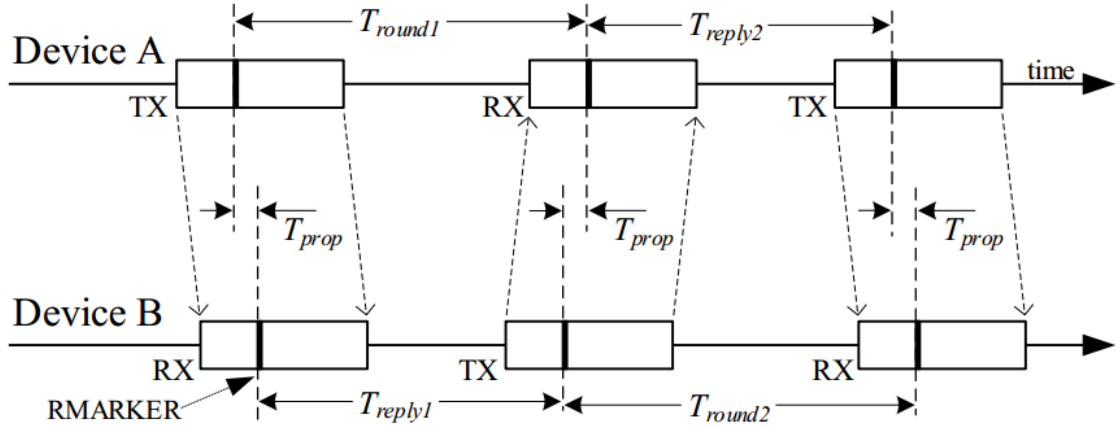
➢ *Double-sided two-way ranging (DS-TWR) with four messages*



A initiates -> B responds -> B initiates ->A responds

$$\hat{T}_{prop} = \frac{(T_{round1} \times T_{round2} - T_{reply1} \times T_{reply2})}{(T_{round1} + T_{round2} + T_{reply1} + T_{reply2})}$$

➢ *Double-sided two-way ranging (DS-TWR) with three messages*



What is the HRP UWB Test Challenges?

REQUIREMENTS

> 6GHz Frequency

High band operating in 6GHz to 10.6 GHz

> 500 MHz BW

Wide bandwidth at least 500 MHz, up to 1.3GHz

IEEE 802.15.4/4z

Meet RF requirements in 802.15.4 PHY Spec

UWB Signal Generation and Analysis Solutions

Required HRP UWB Transmitter Measurements

DEFINED IN IEEE 802.15.4

IEEE 802.15.4 Chapter #	Transmitter Test	89601BHTC HRP UWB Modulation Analysis
16.4.1	**Operating frequency bands** Channel 0 is mandatory for sub-gigahertz; Channel 3/9 is mandatory for low/high band	**Supports all channel 0 to 15**
16.4.2	**Channel assignment** support at least two complex channels for one of the mandatory band	**Supports all channels**
16.4.3	**Tx maximum allowable output PSD** comply to regulatory requirements (FCC: <-41.3dBm/MHz @3-10GHz)	**Spectrum**
16.4.4	**Tx maximum temperate range** 0° to 40°C	**N/A**
16.4.5	**Baseband impulse response** the transmitted pulse p(t) shall have a magnitude of the cross-correlation function $\|\phi(\tau)\|$ whose main lobe is greater than or equal to 0.8 for a duration of at least Tw (See IEEE 802.15.4 Table 16-12 for Tw value), and any sidelobe shall be no greater than 0.3	**RRC Correlated** **Syms/Errs (Main Lobe Width and Side Lobe Pk, with Pass/Fail Indication)**
16.4.6	**Tx transmit PSD mask** Less than –10 dB relative to the maximum spectral density of the signal for $0.65/T_p < \|f - fc\| < 0.8/T_p$ Less than –18 dB for $\|f - fc\| > 0.8/T_p$ T_p is the inverse of the chip frequency The measurements shall be made using a 1 MHz resolution bandwidth and 1 kHz video bandwidth	**Transmit Mask (with auto-generated limit lines)**
16.4.7	**Chip rate clock and chip carrier alignment** UWB transmitter with an accuracy of $\pm 20 \times 10^{-6}$.	**Syms/Errs (Chip Clock Error)**
16.4.10	**Transmit center frequency tolerance** The HRP UWB PHY transmit center frequency tolerance shall be $\pm 20 \times 10^{-6}$.	**Syms/Errs (Frequency Error)**

- Tx Maximum allowable output PSD – comply to regulatory requirements (FCC: <-41.3dBm/MHz @3-10GHz)

- Tx Transmit PSD mask:
  - Less than –10 dB relative to the maximum spectral density of the signal for $0.65/T_p < |f - fc| < 0.8/T_p$
  - Less than –18 dB for $|f - fc| > 0.8/T_p$
  - T_p is the inverse of the chip frequency.

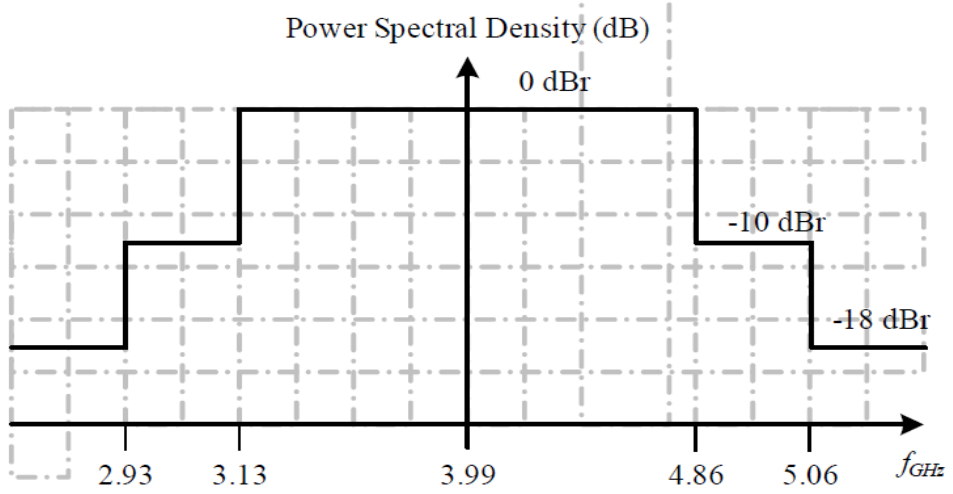


Figure 16-14—Transmit spectrum mask for band 4

E7760A Wideband Transceiver

E7760A Wideband Transceiver

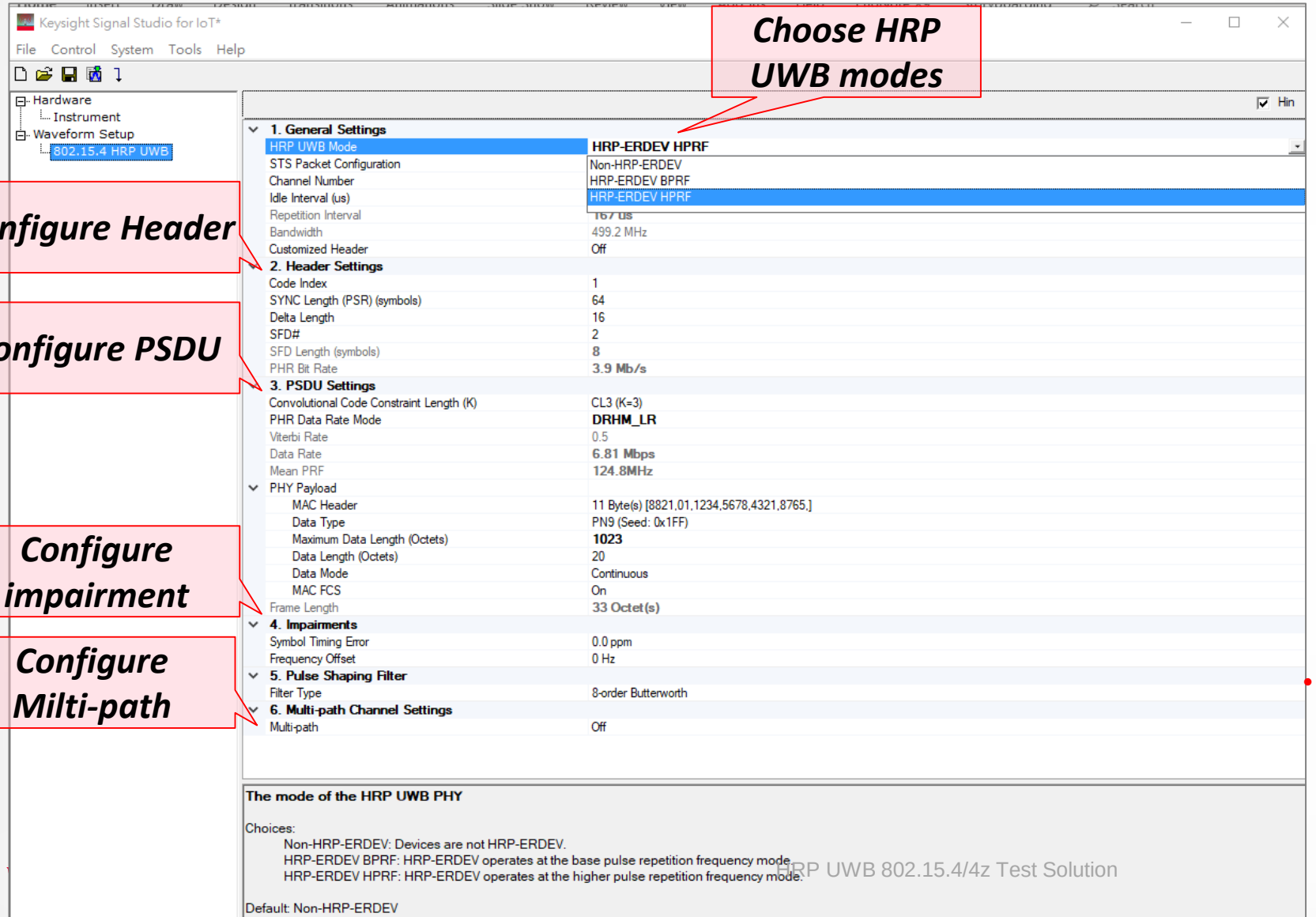
- ✓ 1 VSA, 1 VSG in 2U form factor saves precious rack space
- ✓ **Analysis and Generation Bandwidth: 2GHz**
- ✓ **2** x **IFIO ports** (SMA): 2 – 18 GHz
- ✓ 6x **RF** ports (Type N): 55 - 68GHz for mmWave Transceivers (M1650A)
- ✓ Built-in Windows PC controller
- ✓ Signal Studio Waveform Playback (E7760A-CG1 is required)
- ✓ Connectivity with 89601 VSA

Performance

- Analyzer amplitude range -90 dBm to +10 dBm.
- Generator settable output power range: -60 dBm to +7 dBm
- Linearity: +/-0.5 dB
- IQ data capture depth and ARB waveform memory: 1G Samples

Keysight IoT Signal Studio -N7610C

HRP UWB SIGNAL GENERATION



HRP-UWB support (IoT 2020):

- Support ***Non-HRP-ERDEV (802.15.4)***, ***HRP-ERDEV BPRF and HPRF (802.15.4z)***
- Support all channel 0-15
- Header settings: preamble code index, symbols, Delta length
- PSDU settings with Viterbi Rate, Hop Bursts, Chirp Per Burst and Physical payload settings
- Impairment settings: Symbol timing error and freq offset

Supported hardware:

- E7760A wideband transceiver
- PXIe VXG M9383B/M9384B
- AWG M8190A + PSG E8267D

802.15.4/4z HRP UWB Receiver Testing Hardware

E7760A, X-SERIES N90X0B XSA

E7760A Wideband Transceiver

- One-Box Tester Platform for both DVT or MFG signal generation and analysis
- Cover 2 IF input/output ports from 2 to 18 GHz and up to RF input/output ports from 55 to 68 GHz connecting the M1650A mmWave transceiver
- Internal analysis bandwidth up to 2GHz
- Connectivity with 89600 VSA and support UWB signal analysis (option 89601BHTC)

M9383B/M9384B

- Microwave signal generators
- Dual-channel 1 MHz to 44 GHz VSG with up to 2 GHz bandwidth.
- M9384B is an integrated box with touch-front panel
- M9383B is the PXIe modular without front-panel

AWG M8190A + PSGE8267D

- AWG M8190A as the baseband signal generator with variable sample rate from 125 MSa/s to 8/12 GSa/s and spurious-free-dynamic range (SFDR) up to 90 dBc (typ.)
- AWG M8190A has up to 2 GSa arbitrary waveform memory per channel and analog bandwidth up to 5GHz
- Vector PSG as the up-converter up to to 44 GHz with 80 MHz internal BW and 4GHz BW as external I/Q input

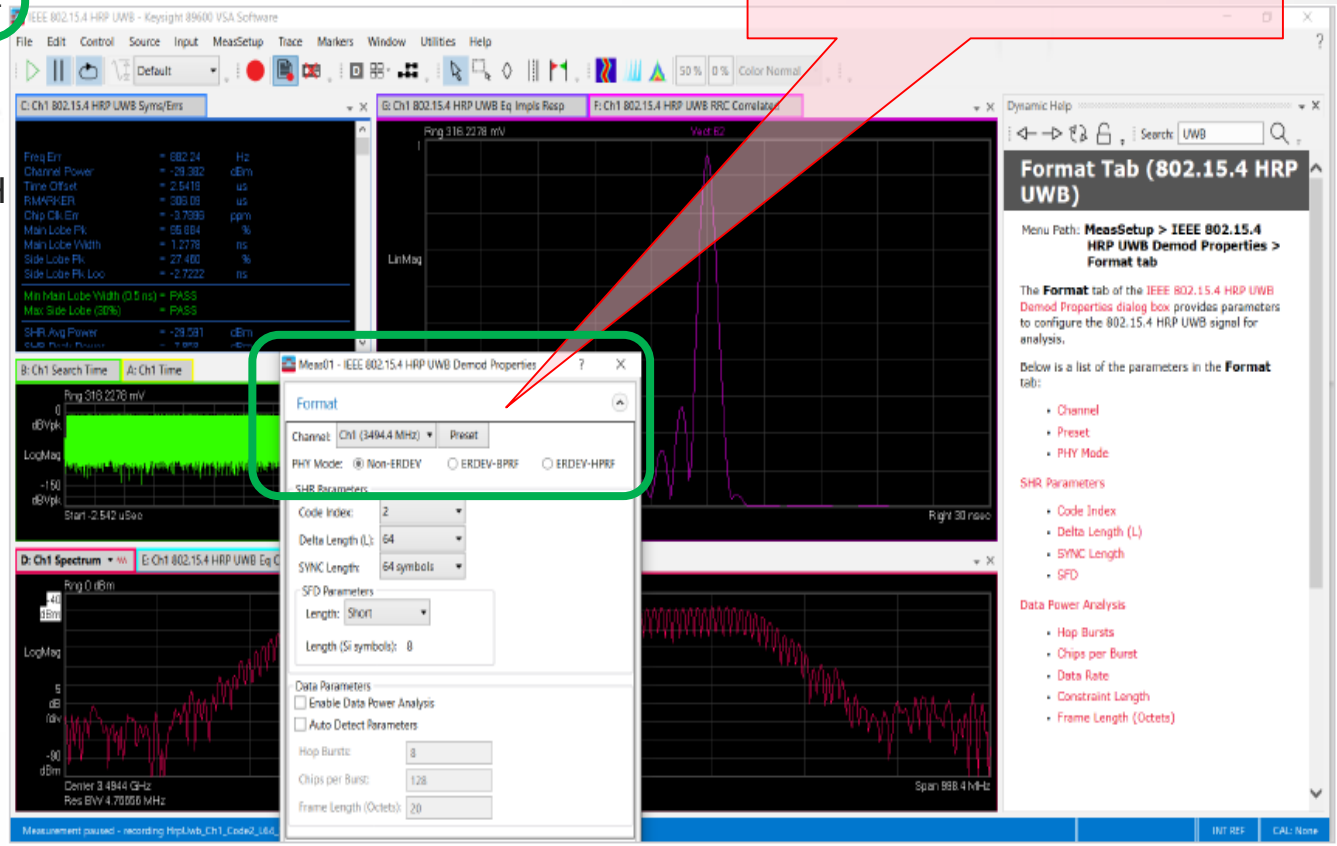
HRP UWB 802.15.4/4z Signal Analysis

89600 VSA 2020 RELEASE

- **89600 VSA supports all modes:**
  - Non-HRP-ERDEV in IEEE 802.15.4-2015
  - HRP-ERDEV-BPRF and HRP-ERDEV-HPRF in IEEE 802.15.4z

- **Key features**
  - Support sub-GHz, L-band (3.1-4.8 GHz) and H-band (6-10.6 GH
  - Support all bandwidth: 499.2, 1081.6, 1331.2 or 1354.97 MHz
  - Modulation BPM-BPSK (burst position modulation - BPSK)
  - Measurement Results
    - RRC Correlated trace and Main Lobe/Side Lobe metrics (with pass/fail)
    - RMARKER location relative to beginning of recording (for calculating Time of Flight)
    - Eq Channel Impulse Response and Frequency Response
    - Transmit Mask (including pass/fail indication)
    - Frequency Error/Chip Clock Error
    - Peak/Average Power for SHR, STS, and Data (PHR/PSDU)

Format Tab to select :
Non-HRP-ERDEV
HRP-ERDEV-BPRF
HRP-ERDEV-HPRF



HRP UWB 802.15.4/4z Signal Analysis

89600 VSA 2020 RELEASE

- **89600 VSA supports all modes:**
  - Non-HRP-ERDEV in IEEE 802.15.4-2015
  - HRP-ERDEV-BPRF and HRP-ERDEV-HPRF in IEEE 802.15.4z

- **Key features**
  - Support sub-GHz, L-band (3.1-4.8 GHz) and H-band (6-10.6 GHz)
  - Support all bandwidth: 499.2, 1081.6, 1331.2 or 1354.97 MHz
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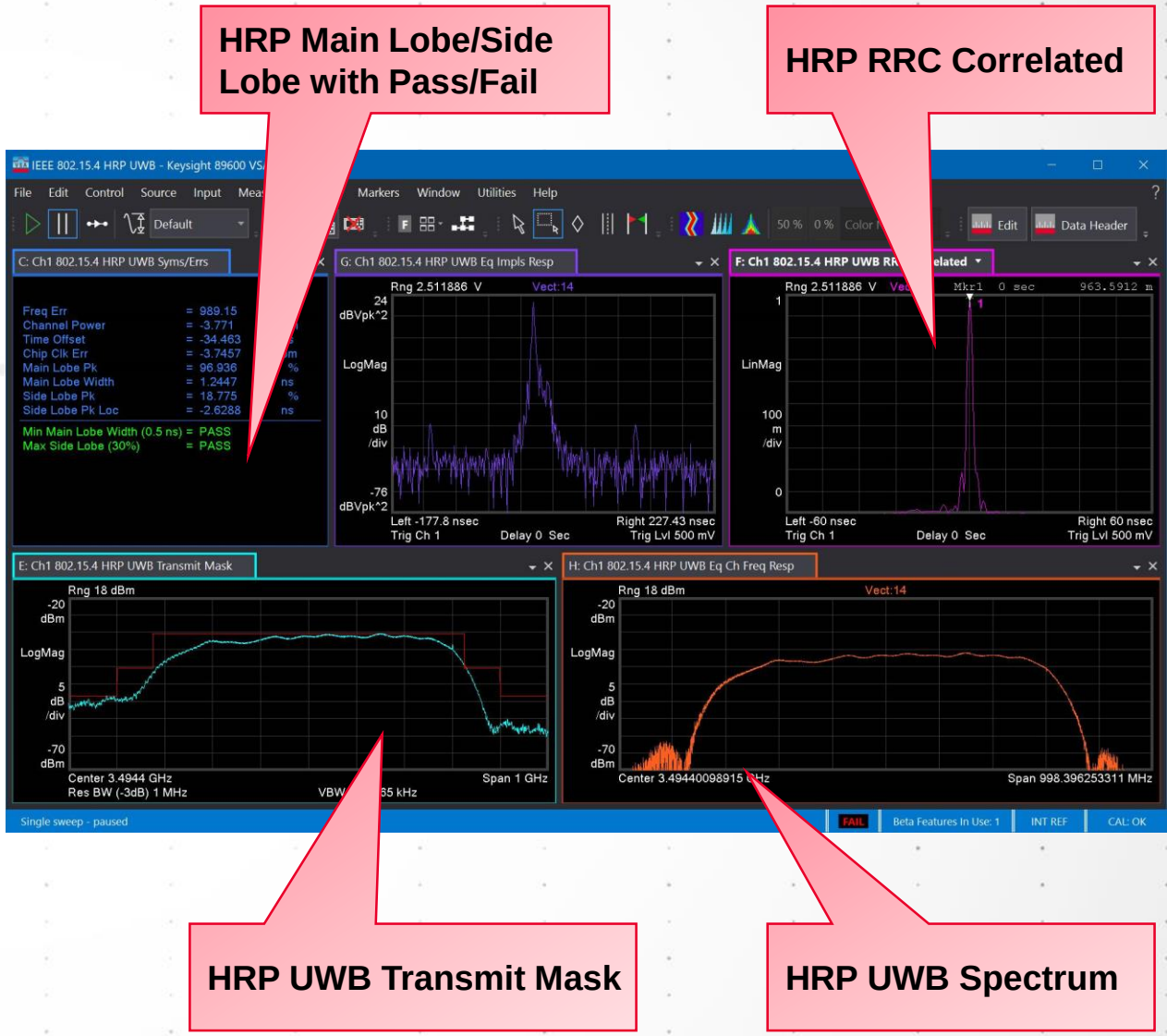


802.15.4/4z HRP UWB Transmitter Testing Hardware

E7760A, X-SERIES N90X0B XSA, UXR

E7760A Wideband Transceiver

- DVT or Mfg for HRP UWB both signal generation and analysis
- Cover 2 IF input/output ports from 2 to 18 GHz and up to RF input/output ports from 55 to 68 GHz connecting the M1650A mmWave transceiver
- Internal analysis bandwidth up to 2GHz
- Connectivity with 89600 VSA and support UWB signal analysis with option 89601BHTC

N9040B/N9041B SA

- Wide-open performance
- Frequency range: 2 Hz to 8.4, 13.6, 26.5, 44 and 50 GHz
- Analysis bandwidth up to 510 MHz BW or 1 GHz (only with 50 GHz UXA)
- Connectivity with 89600 VSA and support UWB signal analysis with option 89601BHTC

UXR-Series Oscilloscope

- 13 to 110 GHz of bandwidth, with the most comprehensive set of probing, analysis applications, and measurements for advanced technologies
- Most accurate oscilloscope at any bandwidth – lowest noise, highest ENOB, and 10 bit vertical resolution enable you to see the truest representation of your signal
- Solve problems faster with hardware-accelerated measurements and analysis (DDC)
- EVM performance for wideband mmWave meas that rivals even the best signal analyzers
- Connectivity with 89600 VSA and support UWB signal analysis with option 89601BHTC

IOT8700 Series IoT Wireless Test Solutions

FOR IOT END DEVICE TESTING

X8721A IoT wireless test set

Key Features

- Over-the-air signaling test capability
- Multi-format radio support
- Ease of use with SW automation
- Deep radio control
- Fast test time
- 1-up to 16-up multi-device configuration

Key specifications

- Freq: 2.4-2.48GHz and 4.8-6GHz
- DL power: -25 to -100 dBm
- TX power meas: +20 to -50 dBm
- Accuracy ~1dB (typical)

A cost-effective over-the-air signaling test solution that can test IoT / smart devices in actual operation modes and in its final form. It enables comprehensive channel based TX and RX measurements, ensuring device quality and performance, and simplifies test development.

IOT8700 Series IoT Wireless Test Solutions

2 MODELS

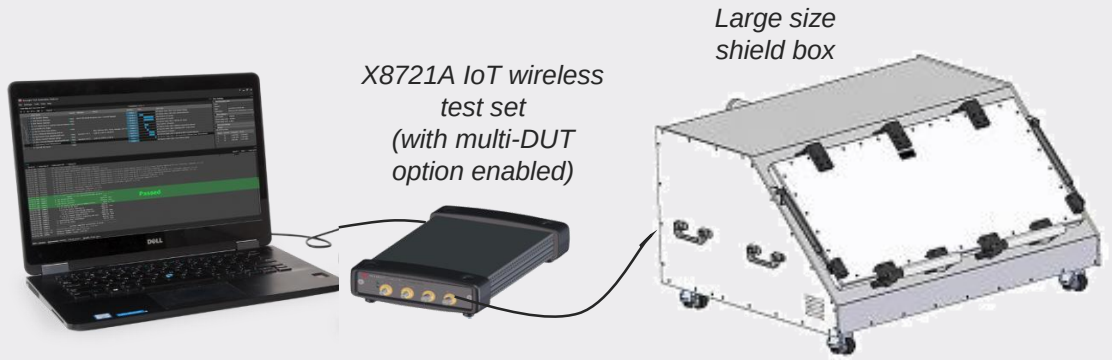
IOT8720A IoT Wireless Test Solution

(Single DUT configuration)

Only one DUT inside the shield box

IOT8740A IoT Wireless Multi-Device Test Solution

(Multi-DUT configurations – 4-DUT, 8-DUT, 16-DUT)



Possible to put up to16 DUTs into the shield box for simultaneous measurements of all DUTs

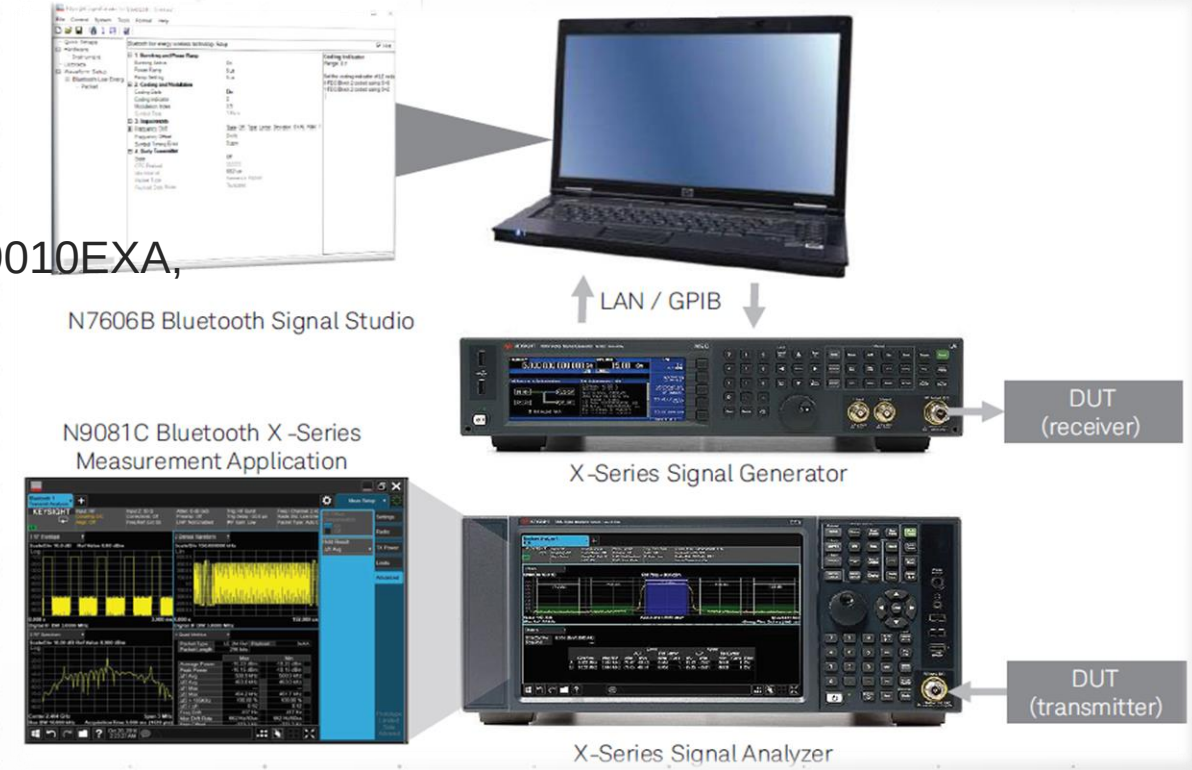
Keysight BT 5.1 Test Solutions

SW AND HW PLATFORMS

- Signal generation for receiver test
  - Software: N7606C Signal Studio for Bluetooth
    - Bluetooth waveform generation with different configurations
    - Pre-distortions: AWGN, Frequency error, Sampling clock error
  - Hardware: Vector Generator(N5182B MXG, N5182B MXG, N5172B EXG, or N5166B CXG), E6640A EXM Transceiver, N9421A VXT Transceiver

- Signal Analysis for transmitter test
  - Software: N/V9081A X-App for Bluetooth
  - Hardware: X-series Signal Analyzer, e.g, N9020B MXA, N9010EXA, N9000 CXA, E6640A EXM Transceiver, N9421A VXT Transceiver

One-Box Tester E6640A



KEYSIGHT TECHNOLOGIES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