Application Note

AUTOMOTIVE UWB DEVICE TESTING OVER THE AIR

Calibration and Verification Solution

Products:

- ► R&S®CMP200
- ► R&S®CMQ200 HS
- ► R&S®CMQ500
- ► R&S®WMT
- ► R&S®WinIQSIM2
- ► R&S®CM-Z300A

Yong Shi | 1SL394 | Version 0e | 04.2023

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Abstract

The UWB (Ultra-Wideband) technology is a short range wide-band radio technology specified for device to device communication operating in unlicensed spectrum. It is an RF positioning technology that enables accurate and secure peer-to-peer ranging between mobile devices with robust resistance to interference while consuming very low energy and coexisting well with other radio communication systems. UWB is used for a variety of different applications, such as asset tracking, secure payment, personal tracker, real time location services and keyless access and start of a vehicle etc. According to ABI Research forecasts, there will be well over 1 billion UWB annual device shipments by 2026. Almost every smart phone shipped in 2026 will support UWB services [1].

Talking about testing aspect of a UWB device, in general two test methodologies can be adopted as other wireless products, either the traditional testing mode (so-called conducted test mode) with wired RF connection between the test measurement equipment and device under test (DUT) or over the air (OTA) test mode in an OTA anechoic chamber. Sometimes, it is not always possible or necessary to perform the tests under conducted mode due to the limiting factors, e.g. cost, space, complexity and direct access to the RF connectors of the product. In this case, OTA testing is then becoming a non-evitable approach. Moreover, OTA testing reflects the usage of DUT in a real condition.

In this application note, R&S® OTA test solution covering transmitter (Tx), receiver (Rx) and Time of Flight (ToF) testing in Wireless Automated Testing (WMT) environment is described. The measurement results throughout the whole document are based on NXP Trimension™ NCJ29D5 UWB automotive IC.

Testing of a UWB device in conducted mode can be referred in [2] and more automotive vehicle access control test solutions from R&S® can be found under this Link.

The remaining of this document is organized in the following way:

Chapter 1 outlines the UWB fundamentals

Chapter 2 briefly introduces the OTA basics

Chapter 3 describes the UWB OTA test solution in great details, incl. hardware/software requirements of the test solution, insight of Tx, Rx and ToF testing

In Appendix, some useful information in association with the described test solution are provided for further reference.

The following abbreviations are used for R&S® products throughout this application note:

R&S®CMP200 radio communication tester is referred to as CMP200

R&S®CMQ200 High Shielding (HS) shielding cube is referred to as CMQ200

R&S®CMQ500 shielding cube is referred to as CMQ500

R&S®CM-Z300A accessory kit for UWB Time of Flight (ToF) measurements for CMP200 is referred to as ToF Kit

R&S®SP6T RF connection kit is referred to as RF switch

R&S®WinIQSIM2 signal generation software is referred to as WinIQSIM

It is assumed that the reader of this application note has fundamental understanding of UWB PHY. If not, then please refer to the UWB white paper [3] for more detailed overview on the fundamentals, testing and certification or UWB IEEE 802.15.4 [4] / IEEE 802.15.4z standard [5].

Acknowledgements

R&S® would like to express sincere thanks to the NXP® Customer Application Support for the valuable technical contributions to this document.

1 UWB Fundamentals

This chapter describes the fundamentals of UWB technology.

1.1 Standards

High rate pulse repetition (HRP) UWB PHY is standardized by IEEE802.15.4, a task working group within the IEEE 802.15 family. In that standard, the HRP UWB PHY protocol data unit (PPDU), modulation, RF requirements (incl. operating frequency bands, channel assignments, baseband impulse response, transmit power spectrum density PSD mask etc.) are defined.

IEEE802.15.4z standard is an amendment to IEEE802.15.4 where enhanced ranging device (ERDEV) based on HRP UWB PHY, so-called HRP-ERDEV, is specified. HPR-ERDEV can be operated in two modes, i.e. base pulse repetition frequency (BPRF) and higher pulse repetition frequency (HPRF) mode, at a nominal 64 MHz and 124.8 MHz or 249.6 MHz pulse repetition frequency (PRF), respectively.

For automotive industry, global automotive industry organization Car Connectivity Consortium® (CCC) was founded in 2011. It standardizes interface to provide consistently great user experiences across light vehicles and mobile devices. Through CCC Digital Key standard, it makes widespread adoption of smartphones as vehicle keys possible. The latest Digital Key Release 3.0 adds hands-free, location-aware keyless access and location-aware features by adopting UWB secure ranging technology based on IEEE 802.15.4z standard in combination with standard Bluetooth®Low Energy connectivity [6].

FiRa® Consortium was founded in 2019 and is an organization dedicated to expand the UWB ecosystem by ensuring interoperability between multiple devices through compliance and certification programs.

In the remaining of this application note, 802.15.4 and 802.15.4z are the respective synonym of IEEE 802.15.4 and IEEE 802.15.4z standard.

1.2 UWB Frequencies and Channels

The UWB channel allocation based on 802.15.4 [4] is summarized in Table 1-1.

HRP UWB PHY operates 16 channels in three band groups, i.e. subgigahertz (subGHz), low band and high band, denoted as band group 0, 1 and 2, respectively.

Band group	Frequency range	Channel number	Center frequency (MHz)	Bandwidth (MHz)	Mandatory (M) / Optional (O)
0 (subGHz)	249.6 MHz to 749.6 MHz	0	499.2	499.2	M
1 (Low band)	3.1 to 4.8 GHz	1	3494.4	499.2	O
		2	3993.6	499.2	O
		3	4492.8	499.2	M
		4	3993.6	1331.2	O
2 (High band)	6.0-10.6 GHz	5	6489.6	499.2	O
		6	6988.8	499.2	O
		7	6489.6	1081.6	O
		8	7488	499.2	O
		9	7987.2	499.2	M
		10	8486.4	499.2	O
		11	7987.2	1331.2	O
		12	8985.6	499.2	O
		13	9484.8	499.2	O
		14	9984	499.2	O

Band group	Frequency range	Channel number	Center frequency (MHz)	Bandwidth (MHz)	Mandatory (M) / Optional (O)
		15	9484.8	1354.97	O

Table 1-1 HRP UWB PHY channel allocation

Each channel spans 500 MHz bandwidth except channel 4, 7, 11 and 15. Supporting of channel 0, 3 and 9 is mandatory for UWB implementation in the related bands. The majority of the UWB products on the market as of today focus on the high band group, operating in channel 5 and 9 particularly.

For example, NXP Trimension™ NCJ29D5 device operates in high band from 6 GHz to 8.5 GHz.

1.3 UWB Physical Layer Signal Properties

1.3.1 UWB Waveform

A mandatory Root Raised Cosine (RRC) pulse shaping with roll-off factor β = 0.5 has to be applied as a reference pulse (see Equation 1-1). It's impulse response r(t) is as follows:

$$r(t) = \frac{4\beta}{\pi\sqrt{T_p}} \frac{\cos\left[(1+\beta)\pi t/T_p\right] + \dfrac{\sin\left[(1-\beta)\pi t/T_p\right]}{4\beta t/T_p}}{1-\left(4\beta t/T_p\right)^2}$$

Equation 1-1 UWB impulse response

Where T_p is the pulse duration, measured in nanoseconds.

1.3.2 Frame Structure

HRP ranging-capable devices (HRP-RDEV) facilitate the ranging function based on physical layer implementations in line with 802.15.4 [4].

The PHY protocol data unit (PPDU) frame configuration of an HRP-RDEV is composed of the synchronization header (SHR), physical layer header (PHR) and physical layer service data unit (PSDU) as shown in Figure 1-1

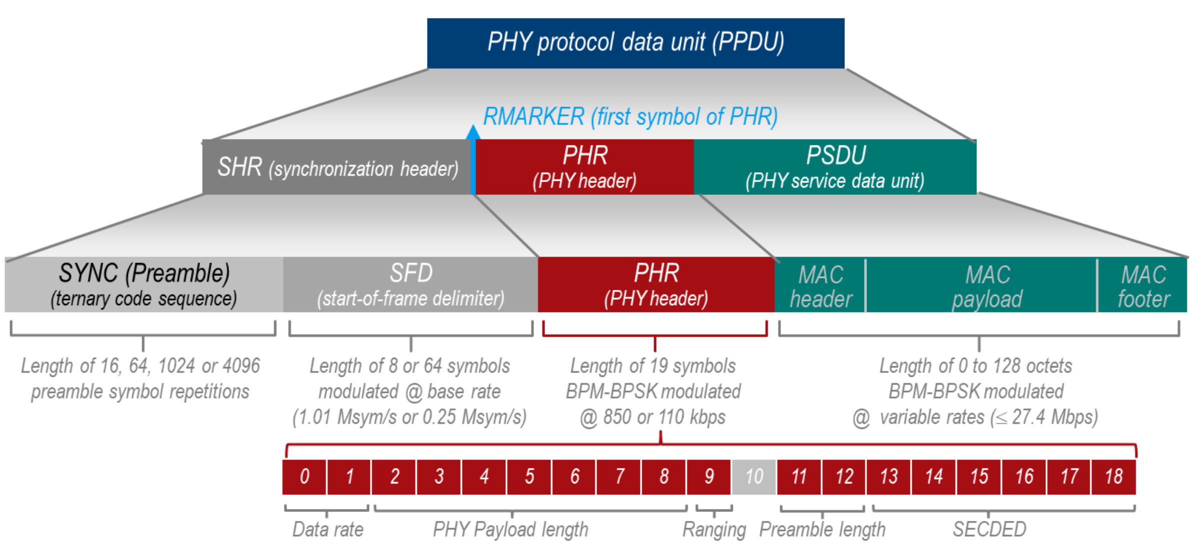


Figure 1-1 PPDU of UWB HRP-RDEV (802.15.4)

As a supplement to the 802.15.4 standard, 802.15.4z meets the eve-increasing demands of highly secure and precise ranging. The key enhancements are:

► Inclusion of the scrambled timestamp sequence (STS) field in the HRP PPDU format

► PRF increment applied for preamble and data field

Devices supporting these enhancements are called HRP enhanced ranging devices (HRP-ERDEV). Two mandatory functions must be supported:

► Operation in base pulse repetition frequency (BPRF) mode at a nominal PRF of 64 MHz

► Operation in higher pulse repetition frequency (HPRF) mode at a higher PRF of 124.8 MHz or 249.6 MHz

1.3.3 Synchronization Header (SHR)

Synchronization header (SHR) consists of preamble and start-of-frame delimiter (SFD)

1.3.3.1 Preamble

Preamble Code Index

The preamble portion of the SHR is used for timing synchronization, packet detection, and carrier frequency offset recovery.

Each preamble symbol consists of a predefined preamble code sequence drawn from a ternary alphabet {–1,0,1}. 802.15.4 [4] specifies mandatory length-31 (mandatory) and optional length-127 preamble code sequences. In Table 1-2, the channel dependent length-31 preamble code sequences are listed with an individual index (1 to 8).

Index	Code Sequence C_i	Channel Number[i]
1	- 0 0 0 0 + 0 - 0 + + + 0 + - 0 0 0 + - + + + 0 0 - + 0 - 0 0	0, 1, 8, 12
2	0 + 0 + - 0 + 0 + 0 0 0 - + + 0 - + - - - 0 0 + 0 0 + + 0 0 0	0, 1, 8, 12
3	- + 0 + + 0 0 0 - + - + + 0 0 + + 0 + 0 0 - 0 0 0 0 - 0 + 0 -	2, 5, 9, 13
4	0 0 0 0 + - 0 0 - 0 0 - + + + + 0 + - + 0 0 0 + 0 - 0 + + 0 -	2, 5, 9, 13
5	- 0 + - 0 0 + + + - + 0 0 0 - + 0 + + + 0 - 0 + 0 0 0 0 - 0 0	3, 6, 10, 14
6	+ + 0 0 + 0 0 - - - + - 0 + + - 0 0 0 + 0 + 0 - + 0 + 0 0 0 0	3, 6, 10, 14
7	+ 0 0 0 0 + - 0 + 0 + 0 0 + 0 0 0 + 0 + + - - - 0 - + 0 0 - +	4, 7, 11, 15
8	0 + 0 0 - 0 - 0 + + 0 0 0 0 - - + 0 0 - + 0 + + - + + 0 + 0 0	4, 7, 11, 15

Table 1-2 Length-31 ternary preamble code sequence [4]

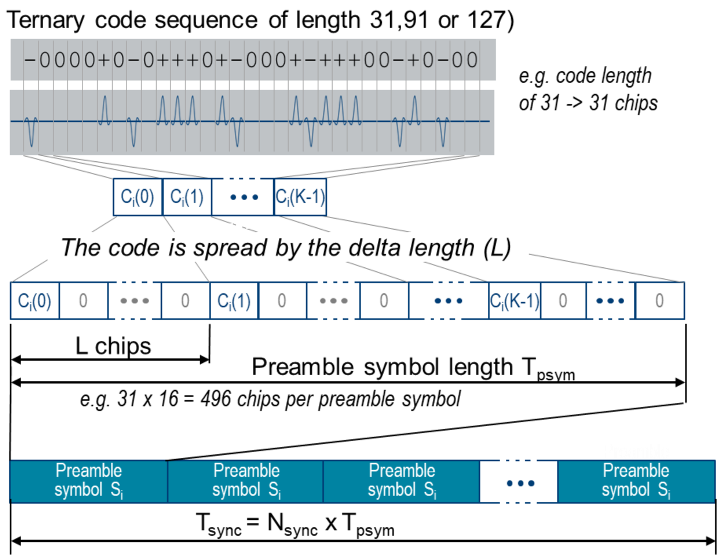
The use of length-127 ternary preamble code sequences is optional. In total, 16 length-127 ternary sequences indexed from 9 to 24 are specified. Similar to length-31 preamble code sequence, the applicable preamble index is also channel dependent. The complete length-127 preamble code sequence can be referred in Table 15-7 of 802.15.4 [4].

For HRP-ERDEV, it is mandatory to support length-91 ternary preamble code sequences in addition which has code index ranged between 25 and 32. Unlike length-31 and length-127, the selection of length-91 code index is not bounded to channel. Complete length-91 preamble code sequence is listed in Table 15-7a of 802.15.4z [5].

Preamble Length

[i] Code index 1 to 6 may also be used for HRP UWB channel 4, 7, 11, 15 (channel bandwidth > 500 MHz) if inter-channel communication is desired.

The preamble code is spread to construct a preamble symbol, and the resultant preamble symbol is then repeated to constitute the SYNC field portion of the SHR as shown in the example in Figure 1-2. The SYNC field contains simple repetitions of the preamble symbol and the number of preamble symbol repetitions are 16, 64, 1024 and 4096 as defined in 802.15.4 [4]. In HPRF mode (PRF > 64 MHz), the HRP-ERDEV shall support 32 and 64 preamble symbol repetitions with optional values being 16, 24, 48, 96, 128 and 256 as defined in 802.15.4z [5].



$C_i()$	Preamble code sequence with code index i
K	Preamble code sequence length. 31, 127 or 91 (only for HRP ERDEV)
L	Spreading factor (Length of delta function δ_L)
S_i	Preamble symbol after spreading containing K*L chips

Figure 1-2 Construction of a preamble symbol S_i by spreading [4]

Preamble length (16, 32, 64, 1024, 4096) refers to the number of preamble symbol repetitions.

1.3.3.2 Start of Frame Delimiter (SFD)

The SFD signals the end of the preamble and start of the PHY header (PHR).

SFD Type

SFD supports mandatory 8 symbols (short) and optional 64 symbols (long) as shown in Table 1-3, depending on the subsequent transmitted data rate for HRP-RDEV [4].

SFD Length	Applicability	Support
64 symbols (Long)	For low data rate (110kbps)	Optional
8 symbols (Short)	For other data rates	Mandatory

Table 1-3 SFD sequence of HRP-RDEV (802.15.4)

The SFD type for HRP-ERDEV is given in Table 1-4 [5].

SFD Type	SFD Length	Mode	Support
0	8[II]	BPRF	Mandatory
1	4	HPRF	Mandatory
2	8	BPRF / HPRF	Mandatory

[II] Equivalent to short SFD sequence (8 symbol length) of HRP-RDEV (802.15.4) (cf. Table 1-3)

SFD Type	SFD Length	Mode	Support
3	16	HPRF	Mandatory
4	32	HPRF	Optional

Table 1-4 SFD sequence for HRP-ERDEV (802.15.4z)

1.3.4 PHY Header (PHR) and PHY Service Data Unit (PSDU)

As per specification [4] [5], data rate of PHR and PSDU are predefined depending on the PHR data rate mode in use. Refer to Table 1-5 for HRP-RDEV, Table 1-6 and Table 1-7 for HRP-ERDEV to know the corresponding PHR bit rate and associated PSDU bit rate.

PHR Data Rate Mode	PHR Bit Rate (Mb/s)	PSDU Bit Rate (Mb/s)
DRMDR	0.85 or 0.11	0.11 / 0.85 / 6.8 / 27.2

Table 1-5 PHR and PSDU data rate in HRP-RDEV (802.15.4)

PHR Data Rate Mode	PHR Bit Rate (Mb/s)	PSDU Bit Rate (Mb/s)
DRBM_LP	0.85	6.8
DRBM_HP	6.8	6.8

Table 1-6 PHR and PSDU data rate in HRP-ERDEV BPRF mode (802.15.4z)

PHR Data Rate Mode	Viterbi Constraint Length	PHR Bit Rate (Mb/s)	PSDU Bit Rate (Mb/s)	Mean PRF (MHz)
DRHM_LR	CL3	3.9	6.8	124.8
DRHM_LR	CL7	7.8	7.8	124.8
DRHM_HR	CL3	15.6	27.2	249.6
DRHM_HR	CL7	31.2	31.2	249.6

Table 1-7 PHR and PSDU data rate in HRP-ERDEV HPRF mode (802.15.4z)

1.3.5 Scrambled Timestamp Sequence (STS)

802.15.4z [5] introduced a new frame structure by incorporating a scrambled timestamp sequence (STS) to enhance the data integrity which is basically a cryptographically generated sequence of pulses using the AES-128 algorithm that is then added to the HRP UWB PHY frame structure.

STS Packet Structure (0, 1, 2, 3)

Depending on the position of STS portion in the frame, four STS packet structures are defined (see Figure 1-3). In each STS packet configuration, the RMARKER plays the same role as it does for legacy RDEV, i.e. it serves as a reference point for frame timestamping.

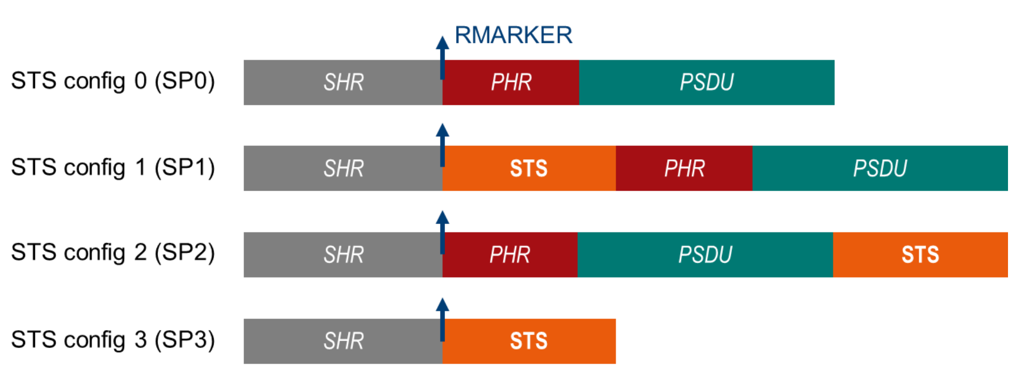


Figure 1-3 Scrambled Timestamp Sequence (STS) packet configurations

Please be noted, SP3 does not contain PHR and PSDU. Therefore, if measurements on data part are required, then SP3 should be avoided.

The generation of the STS is illustrated below in Figure 1-4.

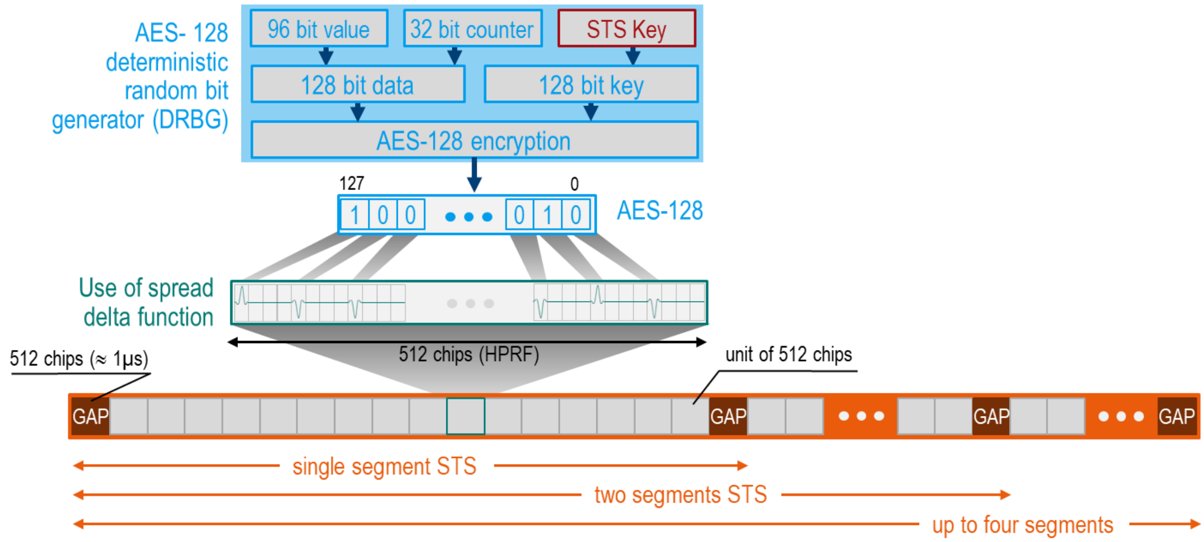


Figure 1-4 STS generation (by spread length 4, HPRF)

STS parameters associated with each HRP-ERDEV mode are given in Table 1-8.

HRP-ERDEV Mode	Spread Length L	Pulse Spacing (Chips)	Mean PRF (MHz)	STS Length in Unit of 512 chips	Number of Supported Segment
BPRF	8	8	62.4	64	1
HPRF	4	4	124.8	32, 64, 128, 16[III], 256[III]	1, 2, 3[III], 4[III]

Table 1-8 STS parameters

STS Index

Index of the STS for waveform generation, it can be any integer between 0 and 2^{32}

STS Length

STS length refers to the length of each STS segment in unit of 512 chips. It varies between 16, 32, 64, 128 and 256 as given in Table 1-8.

STS Segment Count

STS segment count specifies the total number of the segments in STS field. For HPRF, it can support up to 4 segments (refer to Table 1-8).

1.4 Time of Flight (ToF)

UWB technology adopts ToF method for distance ranging. ToF is basically the signal's traveling time in free space between the initiator (Tag) and responder (Anchor). Its estimation is based on the reliable and robust ranging timestamp.

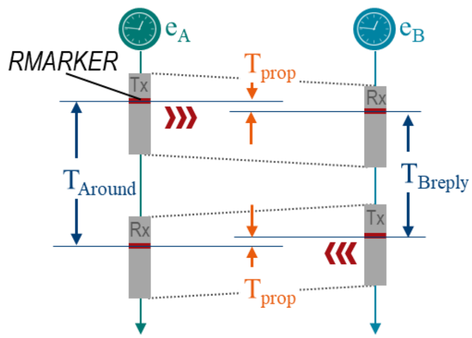
Two-way ranging (TWR) is a common method to measure the distance between two UWB devices particularly when clock synchronization between them is absent. In other words, each device uses its own clock reference to perform the measurements independently. By knowing the ToF between the two devices, the distance can be easily calculated as the ToF multiplied by the speed of light.

There are two different TWR flavors described in the subsequent sections, single-sided two-way ranging (SS-TWR) and double-sided two-way ranging (DS-TWR). With the amendment in [5], the ranging capability is

[III] Optional

further enhanced to support secure ranging by including STS (see 1.3.5) to prevent distance fraud attacks in which an attacker manipulates the distance estimation process.

1.4.1 Single-sided Two-Way Ranging (SS-TWR)



$$T_{prop} = \frac{T_{Around} - T_{Breply}}{2}$$

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

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

Figure 1-5 Single-sided two-way ranging

As depicted in Figure 1-5, device A (Tag) wants to determine its distance to device B (Anchor) by estimating the ToF. It sends a poll message in a ranging frame (RFRAME flag is set in PHR) to device B and receives the response message returned by device B in the end. RMARKER is defined to be the time when the beginning of the first symbol of the PHR of the RFRAME is at the local antenna. It functions like a stopwatch to measure the round-trip time of a message.

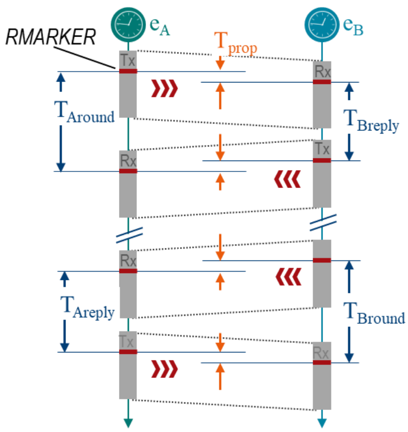
Several time differences are measured or calculated. T_{prop} is the propagation time over the air. The times T_{Around} and T_{Breply} are the processing time measured independently by device A and B using their own local clock. The measured T_{Breply} is piggy-backed in the response message from device B to A. By knowing T_{Around} and T_{Breply}, device A calculates its ToF using formula $T_{prop} = \frac{T_{Around} - T_{Breply}}{2}$. The distance equals to $c_{AIR} \times T_{prop}$ where c_{AIR} is the speed of light, i.e. 29.97 cm/ns

SS-TWR does not require a synchronized clock on both transmitter and receiver side. But, in reality, due to the clock jitter or clock offset error on both sides caused by the imperfection of the clock oscillator, the ToF estimation error is caused. The reply time T_{Breply} is the dominant factor of the distance estimation error in SS-TWR method.

In this document, we focus on SS-TWR.

1.4.2 Double-sided Two-Way Ranging (DS-TWR)

Like SS-TWR, DS-TWR is an asymmetrical ranging method, meaning no need for response times on both devices to be the same. It is a combination of two SS-TWR procedures that differs in the direction of the initiation.



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

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

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

Figure 1-6 Double-sided two-way ranging

The principle of DS-TWR is illustrated in Figure 1-6. The whole procedure is initiated by device A (Tag) towards device B (Anchor). Device B then sends response to device A, and in the same way, device B initiates second round SS-TWR towards device A. The whole procedure is completed after device B receives the response from device A. Usually, the poll message and response message from device B towards device A can be combined into one message. Therefore, DS-TWR involves practically three messages in total.

The resultant ToF estimation $T_{prop} = \frac{T_{Around} \times T_{Bround} - T_{Areply} \times T_{Breply}}{T_{Around} + T_{Bround} + T_{Areply} + T_{Breply}}$

By knowing the ToF estimation T_{prop}, the distance can then be calculated according to the same principle as in the SS-TWR case, i.e. estimated ToF is multiplied by the speed of light to determine the distance.

Compare to SS-TWR, the impact of clock offset on the ToF estimation is significantly reduced. The estimation error in DS-TWR solely depends on the ToF, but not on T_{Breply} as in SS-TWR the case [7].

2 OTA Basics

2.1.1 Far Field

The electromagnetic wave propagation and radiation around an antenna can be classified into three regions, i.e. reactive near field, radiative near field and far field (FF) as illustrated in Figure 2-1.

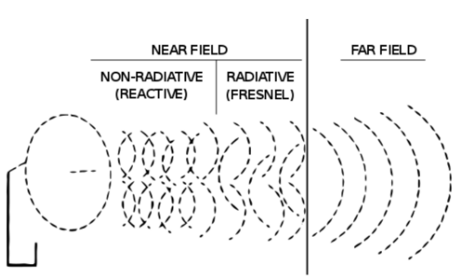


Figure 2-1 Wave propagation regions around an antenna (source: wikipedia)

Basically, in OTA test environment, far field is of high importance. Because in that region the electromagnetic wave is assumed to have predominantly plane wave character. Measurements conducted in FF provides higher measurement reliability. The minimum distance at which FF is assumed is a so-called Fraunhofer distance (FHD) r_{Fr} . It is denoted as

$$r_{Fr} = \frac{2D^2}{\lambda}$$

Equation 2-1 Fraunhofer distance

where D stands for the radiating aperture size of the antenna, λ is the wavelength of the carrier frequency.

FHD is necessary to be respected if the whole antenna pattern is concerned. However, if only the main lobe of the antenna transmission pattern is considered which is the case for UWB applications here, then the FHD can be relaxed by Derat distance r_{De} as given in Equation 2-2.

$$r_{De} = \lambda \left(\frac{\pi D}{\lambda}\right)^{0.8633} \left[0.1673 \left(\frac{\pi D}{\lambda}\right)^{0.8633} + 0.1632\right]$$

Equation 2-2 Derat distance

With this consideration, the footprint of the OTA chamber can be reduced, yet without having negative impact on the measurement performance [8].

The OTA solution described in this document utilizes Vivaldi antenna shown in Figure 3-8 as measurement/feed antenna. A study on the FHD and Derat distance of UWB channel 5 and 9 by utilizing Vivaldi antenna with 70 mm antenna aperture is given in Table 2-1. It shows that FF distance is reduced significantly by considering the Derat distance r_{De}.

	r_{Fr} (mm)	r_{De} (mm)
UWB Channel 5 (6.4896) GHz	~210	~140
UWB Channel 9 (7.9872) GHz	~260	~160

Table 2-1 Comparison of r_{Fr} vs. r_{De} of a Vivaldi antenna radiating at UWB channel 5 and 9

Distance between Vivaldi antenna and DUT antenna should be no less than Derat distance r_{De} in order to ensure that the FF condition is met in the downlink direction, i.e. from tester to DUT. This condition is particularly recommended to be fulfilled for an Angle of Arrival (AoA) test scenario where phase deviation should be kept at a lower level.

2.1.2 Quiet Zone (QZ)

A quiet zone D defines the area in which deviation of the amplitude and phase from the plane wave criteria is limited [9]. At the FHD, the amplitude difference is negligible over the surface D with a phase deviation Δφ of up to 22.5° [10]. Figure 2-2 illustrates the determination of a quiet zone size.

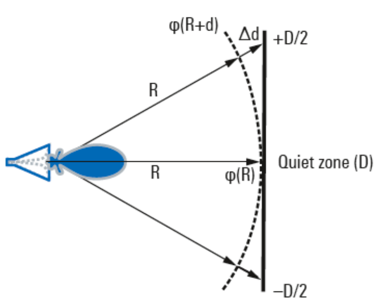


Figure 2-2 Determination of quiet zone size

Quiet zone size limits the maximum size of the tested DUT size (or DUT antenna size in case white box approach) and reflects the size of the chamber as well. The bigger the quiet zone is, the larger the chamber size has to be. As a result, a DUT with larger antenna size can be tested.

As we already know from the previous section, as long as the DUT antenna is at least in Derat distance r_{De} to Vivaldi antenna, then we are testing in QZ in downlink direction.

Whereas in the opposite direction (uplink), from DUT perspective, assuming white-box approach is adopted (details see 2.1.3), given the DUT antenna size and carrier frequency, we can derive Derat distance $\boldsymbol{r_{De}}$. If the derived r_{De} does not exceed the chamber size (max 300mm for CMQ200/CMQ500), then uplink testing in QZ is also guaranteed.

2.1.3 White-box and Black-box Approach

Testing in OTA environment has basically two approaches, namely, white-box and block-box approach.

The white-box approach is suitable in the case where the antenna position of the DUT is known exactly. This approach can be typically adopted by R&D and production application.

Whereas for black-box approach, the position of the DUT antenna is unknown. Therefore, up to the maximum DUT dimension has to be considered for the determination of the FHD or Derat distance which in turn requires larger chamber size. The black-box approach has a significant importance for the DUT conformance testing or testing at service stage.

In compare to black-box approach, white-box approach leads to small floor space of the OTA chamber. Since the DUT used for testing in this application note is based on NXP chipset with prior knowledge of the antenna position, white-box approach is the focus of this document.

3 UWB OTA Test Solution

3.1 System Overview and Preparations

UWB OTA test solution with shielding chamber CMQ200 HS is shown in Figure 3-1. Alternatively, the shielding chamber CMQ500 can be facilitated for UWB testing as well.

Figure 3-1 R&S UWB Over the Air test setup with CMQ200 HS

In this document, two setup variants (system variant 1 and variant 2) are addressed that differ in the number of the mounted Vivaldi antenna in the shielding chamber and the associated RF connection to the chamber.

The setup block diagram (system variant 1) shown in Figure 3-2 is equipped with a single Vivaldi measurement antenna in the chamber which is connected with an RF feedthrough. This setup can well cover UWB Tx, Rx and ToF measurements.

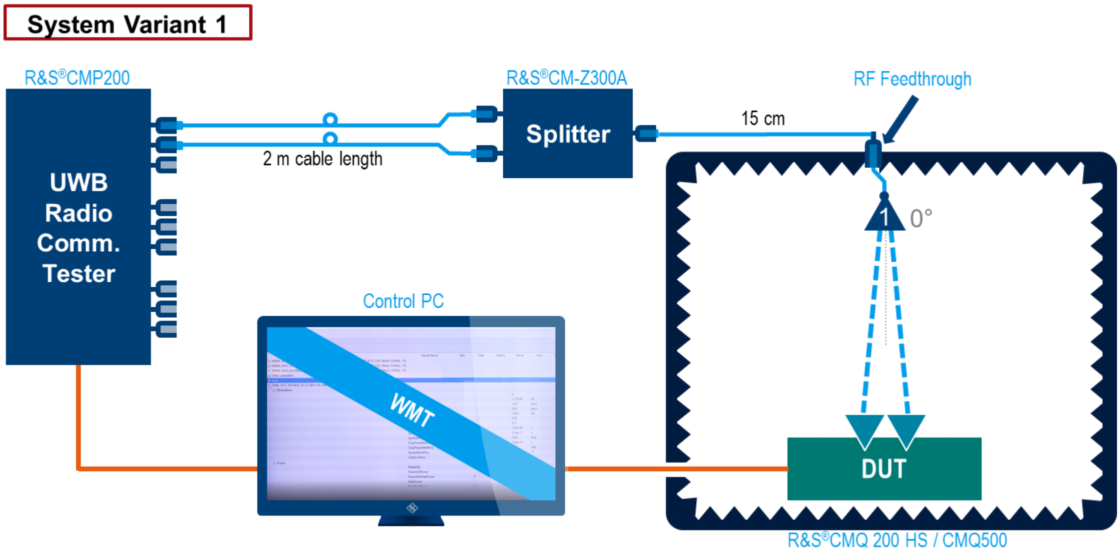


Figure 3-2 Block diagram of system variant 1: UWB OTA testing environment with RF feedthrough for Tx, Rx and ToF measurement (single Vivaldi antenna)

For ease of verifying the AoA from different impingement angle, test solution with multiple Vivaldi antennas is recommended. To allow the RF path switching, an RF switch (R&S SP6T) has to be adopted here as illustrated in Figure 3-3 (system variant 2).

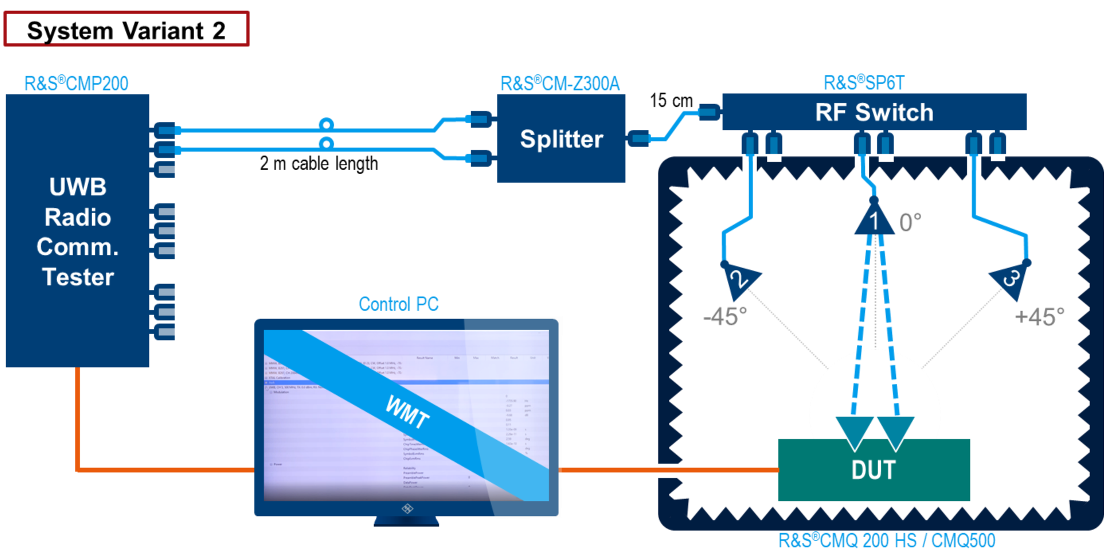


Figure 3-3 Block diagram of system variant 2: UWB OTA testing environment with RF switch for Tx, Rx, ToF and AoA measurement (multiple Vivaldi antennas)

3.1.1 Hardware Requirements

Hardware requirements of the solution include:

- Device Under Test (see 3.1.1.1)
- Radio Communication Tester CMP200 (see 3.1.1.2)
- UWB ToF Kit R&S CM-Z300A (see 3.1.1.3)
- Shielding chamber CMQ500 or CMQ200 with High Shielding (HS) option (see 3.1.1.4)
- Linear polarized Vivaldi antenna CMQ-725A (Antenna kit 5, UWB) (see 3.1.1.5)

► RF connection kit: RF switch CMQ-B744A or RF feedthrough CMQ-B742A (see 3.1.1.6)

► Control PC (a PC with Microsoft Windows® OS)

3.1.1.1 Device Under Test (DUT)

In this document, following NXP evaluation boards are used for testing:

► For UWB Tx, Rx and ToF testing, NXP Trimension™ NCJ29D5 Evaluation Board for Automotive Ultra-Wideband [11] (Figure 3-4).

Figure 3-4 NXP Trimension™ NCJ29D5 evaluation board

UWB tests conducted in this application note are based on the DUT version information as given in Table 3-1 below.

UCI Version	UCI CCC Version	CCC Version	Firmware Version	Device Version
1.0	1.5	0.2.6	2.0.0	22.0

Table 3-1 DUT's version information

► AoA measurements shall be possible with the next generation NXP Trimension™ NCJ29D6 chipset. This chipset is under development at the release time of this document.

3.1.1.2 Radio Communication Tester CMP200

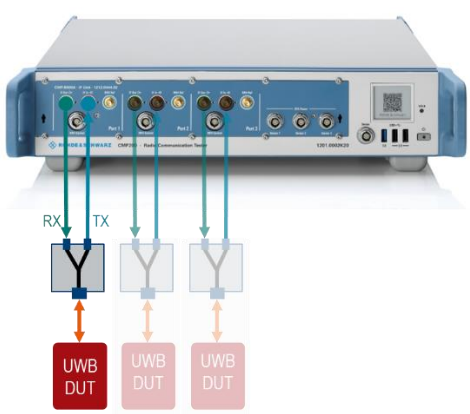


Figure 3-5 R&S CMP200 with multiple switchable ports

CMP200 is a one-box mobile radio tester (MRT) suitable for UWB and 5G FR2 testing in non-signaling mode. It contains general purpose analyzer covering frequency range from 6 to 20 GHz and ARB generator. It supports replay of predefined waveforms (-100 dBm) with frequency range from 6 to 20 GHz. Three switchable ports with 1 GHz bandwidth each accelerate the measurement speeds.

Follow the Link here for further reading.

3.1.1.3 UWB ToF Kit R&S CM-Z300A

UWB Time of Flight (ToF) Kit CM-Z300A is a collection of accessories that provides a fixed group delay (GD) and insertion loss (IL) over the signal path. This is important for the antenna delay calibration as well as the pathloss calibration of the system. See 3.3.1 and 3.3.2.3 for more detailed information.

ToF Kit Z300A (Figure 3-6) contains:

- Power splitter (Model: Minicircuit ZFRSC-183+) (cf. data sheet in Appendix A)
- Attenuator (6 dB, 10 dB, 20 dB, 30 dB)
- RF cables (2 x 2 m)
- RF cable (1 x 15 cm)

Figure 3-6 UWB ToF kit CM-Z300A

The attenuator (6 dB, 10 dB, 20 dB or 30 dB) in the ToF kit can be optionally inserted in the signal path so that the receive power level at CMP200 IFin port can be varied. This is sometimes required for stable signal detection. More details about the power level adjustment for ToF testing is given in Appendix D.

3.1.1.4 Shielding Chamber

CMQ200 HS or CMQ500 are ideal shielding chambers for UWB OTA testing featuring

- Operating frequency range CMQ200 HS 0.3 to 14 GHz / CMQ500 0.7 to 77 GHz
- High shielding effectiveness > 80 dB
- Perfectly suited for multi-antenna setups required for instance for UWB AoA measurements

Figure 3-7 Front and rear view of OTA chamber CMQ200 HS (upper) and CMQ500 (lower)

In general, OTA shielding chamber can be flexibly configured according to customer's testing needs, e.g. door open-close mechanism, table layouts, fixture layouts, feedthroughs (RF, USB, other connections) etc. For more details about the chamber configurations, please refer to [12] or contact your local R&S representative.

In this document, the used DUT in the chamber is powered and controlled by USB. Therefore, an USB feedthrough is a must-to-have accessory to be used here. Besides that, either RF feedthrough or RF switch (see 3.1.1.6) needs to be equipped.

Further readings on R&S website: CMQ200 product page and CMQ500 product page.

3.1.1.5 Antenna Kit

The antenna kit (CMQ-B725A) contains standardized components for UWB testing in OTA chamber. It eliminates the measurement uncertainties caused by the unequal length of RF cables that are in use. It includes the antenna that covers the required frequency range for UWB measurements.

Included components are:

► Vivaldi antenna

  single linear broadband ultra-wideband antenna with a directive pattern and high gain that covers the frequency range from 2.4 to 18 GHz. Figure 3-8 shows Vivaldi antenna with open aperture size of 70 mm.

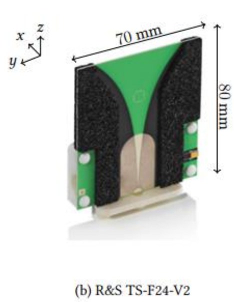


Figure 3-8 R&S TS-F24-V2 (Vivaldi Antenna) with 70 mm aperture size

► 55 cm RF cable which interconnects the Vivaldi antenna with the RF switch or RF feedthrough of the OTA chamber

► Vivaldi antenna fixation accessories: 3D fixture and 45° adapter

3.1.1.6 RF Connection Kit

Two RF connection kits (either RF feedthrough or RF switch) can be chosen. Both RF connection kits cover the frequency range up to 40 GHz.

Single Vivaldi antenna is connected through an RF feedthrough (CMQ-B742A) in the chamber (system variant 1).

The optional RF switch RS SP6T (CMQ-B744A) (see Figure 3-9) is only required when multiple Vivaldi antennas need to be installed in the OTA chamber, e.g. for AoA measurement (system variant 2).

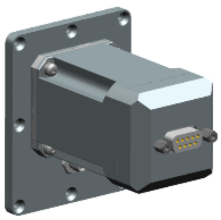


Figure 3-9 RF switch module SP6T

RF switch RS SP6T possesses 6 switch ports. Its port numbering from front view is highlighted in Figure 3-10.

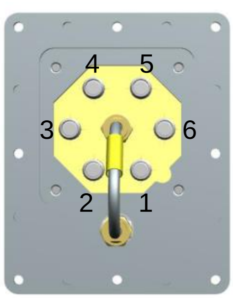


Figure 3-10 RF Switch (SP6T) port numbering from front view

In multi-antenna setup, the changing of RF switch position is controlled via remote interface of CMQ which is fully integrated in the WMT software. This is only possible when the connection of RF switch port and Vivaldi antenna is properly configured in the test configuration `testconfig.ini` file.

In Figure 3-11, a configuration example is given. Three Vivaldi antennas are connected to RF switch that is then connected to Port1.IFin port of CMP200. In this constellation, the last digit of mnemonic 'relay' in `testconfig.ini` file reveals the RF switch port number with which the Vivaldi antenna is connected. Figure 3-12 is the configuration in `testconfig.ini` file that the Vivaldi antenna #1 (the one in the middle) can be applied.

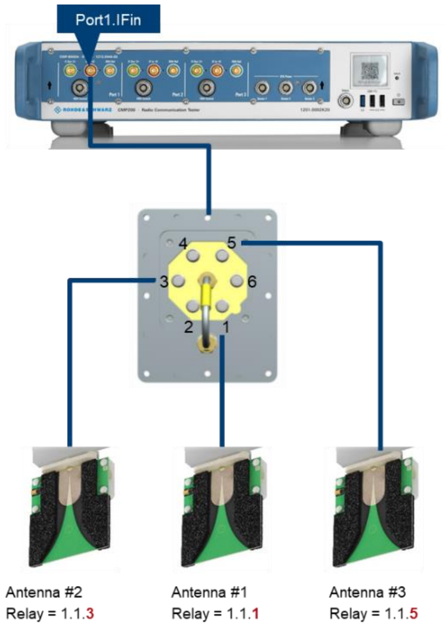


Figure 3-11 RF switch port number configuration

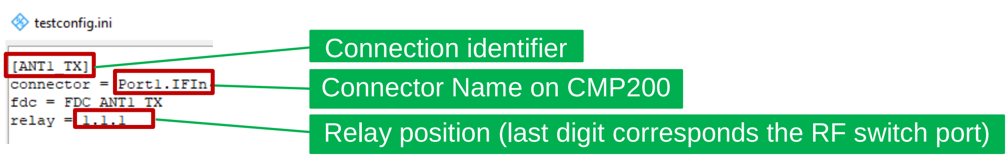


Figure 3-12 Relay configuration in `testconfig.ini`

Details of `testconfig.ini` file can be referred in Appendix C.

3.1.2 Software Requirements

This chapter outlines the software requirements of the test solution.

3.1.2.1 CMP200 Firmware

3.1.2.1.1 General

CMP200 firmware is required to be installed on CMP200. It is responsible for the signal generation and analysis, allows remote access of the instrument via Web-based GUI CMsquares. In terms of the licenses, please make sure following licenses are in place for UWB testing:

- ► UWB measurement option KM300
- ► WinIQSIM2 option KW300 for ARB generation (waveform file generation)
- ► Smart channel software option CMP-K103 enables 3 DUT parallel testing to speed up the testing time (optional)

In Figure 3-13, it represents the UWB measurements in CMsquares[IV] of the CMP200. CMsquares is accessible from any PC by entering the IP address of the CMP200 in the address field of a Web browser given that both PC and CMP200 are on the same IP subnet (see IP settings in 3.1.4).

Figure 3-13 UWB measurements in CMsquares on CMP200

3.1.2.1.2 Installation

Check in the Gloris[V] (https://gloris.rohde-schwarz.com/) and make sure that the latest software is installed on the CMP200. If not, please proceed the following steps to update the software.

1. Download the CMP200 software installer (setup_cmp200_xyz[VI].exe) from Gloris to the control PC
2. Execute the installer remotely on control PC and follow the steps below
    a) Double click on the installer will launch the software distributor. From there, select 'Remote Installation' and press 'Next' to proceed (Figure 3-14). This will allow the software to be installed on CMP200 remotely.

[IV] CMsquares denotes the web-based graphic user interface (GUI) of the CMP200
[V] Gloris represents a self-service customer portal of R&S
[VI] xyz is a placeholder for CMP200 software version

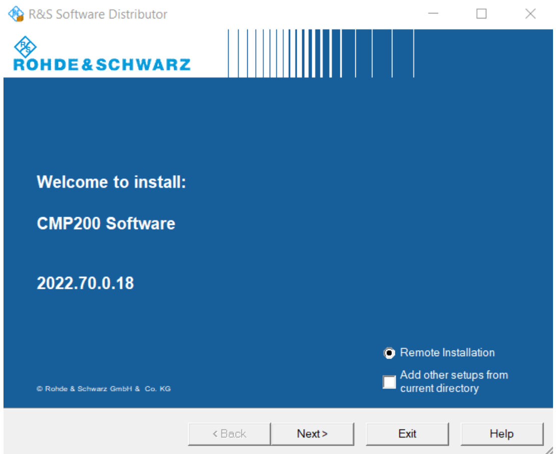


Figure 3-14 Launch software distributor

b) Accept the license agreement and press 'Next' to proceed (Figure 3-15)

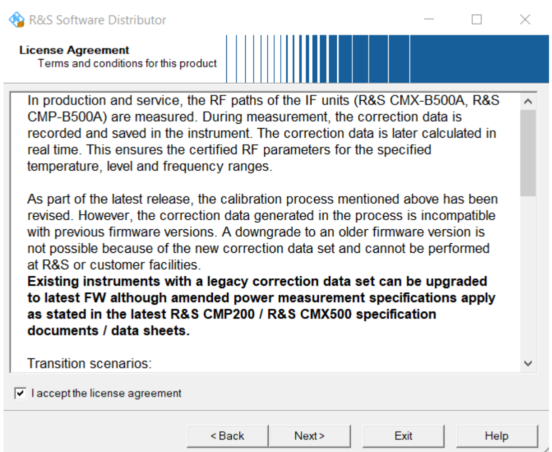


Figure 3-15 Accept the license agreement

c) Select all the packages to install and press 'Next' to proceed (Figure 3-16).

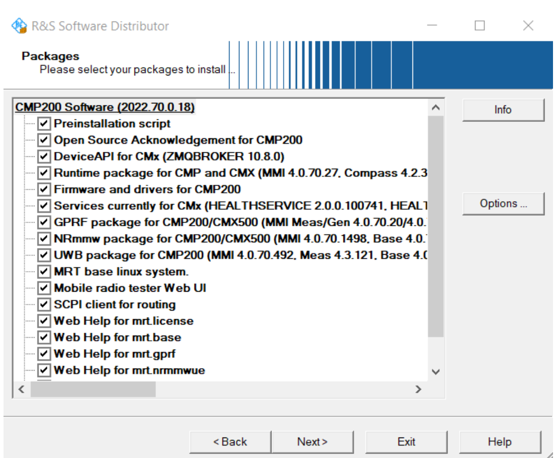


Figure 3-16 Select the packages to install

d) Choose the CMP200 unit in the 'Device List' where the software is going to be installed remotely and press 'Install' to start the installation process (Figure 3-17).

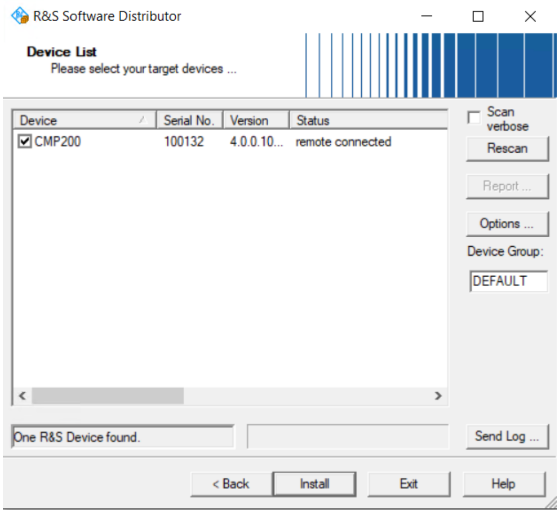


Figure 3-17 Select the CMP200 unit

e) Wait few minutes until text 'Ready: see report for details' appears in 'Status' column. Click 'Report' to make sure that the installation is successful.

f) Click 'Exit' to exit the software distributor.

g) Reboot CMP200.

h) After CMP200 start-up and firmware update process is completed, enter the IP address of the CMP200 in the control PC browser (IP configuration of the setup, see 3.1.4), CMP200 GUI (CMsquares) will be loaded (Figure 3-18).

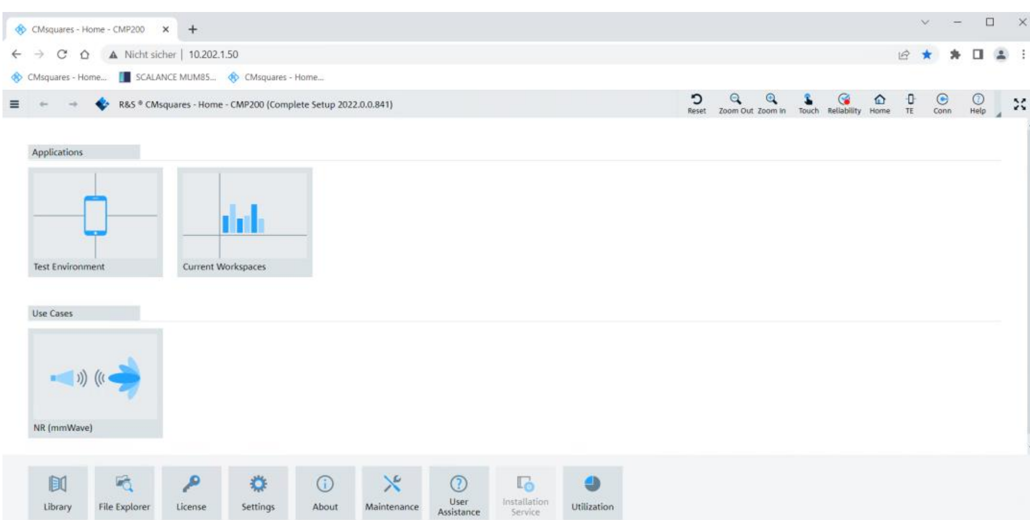


Figure 3-18 Load CMsquares

3.1.2.2 WinIQSIM

3.1.2.2.1 General

WinIQSIM is a Windows based signal generation software that creates digitally modulated signal waveforms including UWB waveform. The generated waveform files contain the same test signal settings for repeatable tests.

In our application here, WinIQSIM generates the UWB test signal in a form of waveform file for the UWB receiver test on control PC. The waveform file is then transferred and played back on the CMP200.

Figure 3-19 shows the WinIQSIM main GUI window.

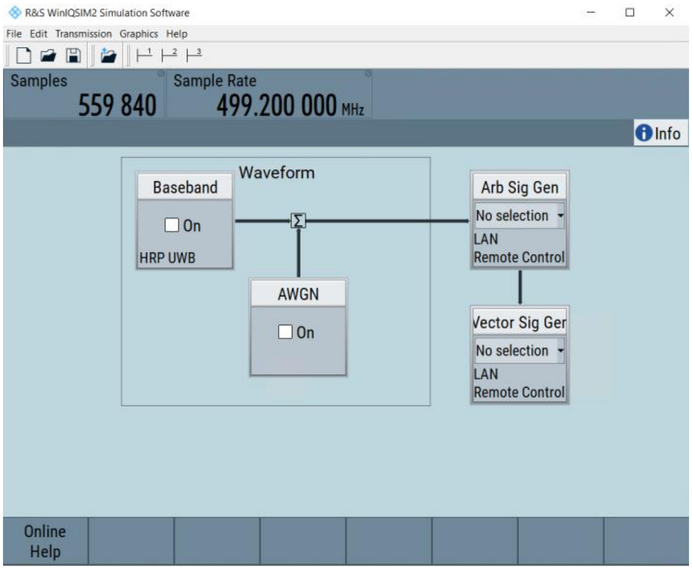


Figure 3-19 WinIQSIM main GUI window

3.1.2.2.2 Installation

1. Visit https://www.rohde-schwarz.com/us/software/winiqsim2/ to get the latest WinIQSIM software and install it on control PC. The software is distributed as a windows installer.
2. Launch the WinIQSIM software and let it run in the background (WMT will take control of WinIQSIM). This is only required when a new waveform file has to be generated. If the required waveform file already exists on CMP200, then WinIQSIM will not be needed, hence, it is not required to have it run in the background.

3.1.2.3 Wireless Automated Testing (WMT) Tool

3.1.2.3.1 General

WMT is a Python based software solution for chipset and module RF testing of 5G NR, Wi-Fi, Bluetooth and UWB (including UWB Tx, Rx, ToF and AoA testing) etc. It is tailored for high volume production testing and R&D applications. A modular architecture enables the flexible integration and minimizes time-to-market of a product.

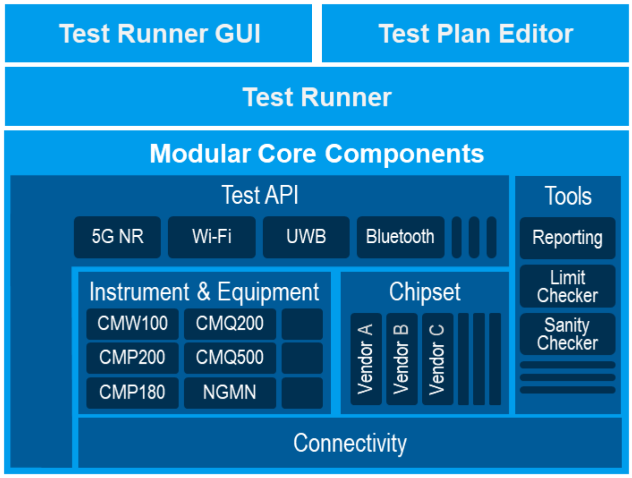


Figure 3-20 WMT Architecture

As illustrated in Figure 3-20, WMT is installed on control PC featuring instrument control (e.g. CMP200), communicating with OTA chamber (e.g. CMQ200/CMQ500), DUT control (UCI communication with UWB DUT), testcase execution, limit check and report collection.

The controlling part herein contains following functionalities:

► Controlling the CMP200 through the SCPI remote interface using a TCP/IP raw socket connection

► For CMQ200/CMQ500 chamber, setting RF switch position is required to select the different used measurement antennas in multiple antenna case, e.g. for AoA testing. This is controlled through the remote interface using a TCP/IP raw socket connection

► Controlling the DUT using standard FiRa or NXP proprietary UCI command communication through the control interface (COM port)

Two GUIs are provided by WMT, namely, WMT Test Plan Editor and WMT Test Runner. In the following text, we use Test Plan Editor and Test Runner as the synonym of WMT Test Plan Editor and WMT Test Runner, respectively.

In Test Plan Editor (Figure 3-21), as the name already implied, a test plan can be newly created or the existing one can be modified. In each test plan, it is possible to include multiple test routines with individual parameter settings (see 3.3 and 3.4 for more details).

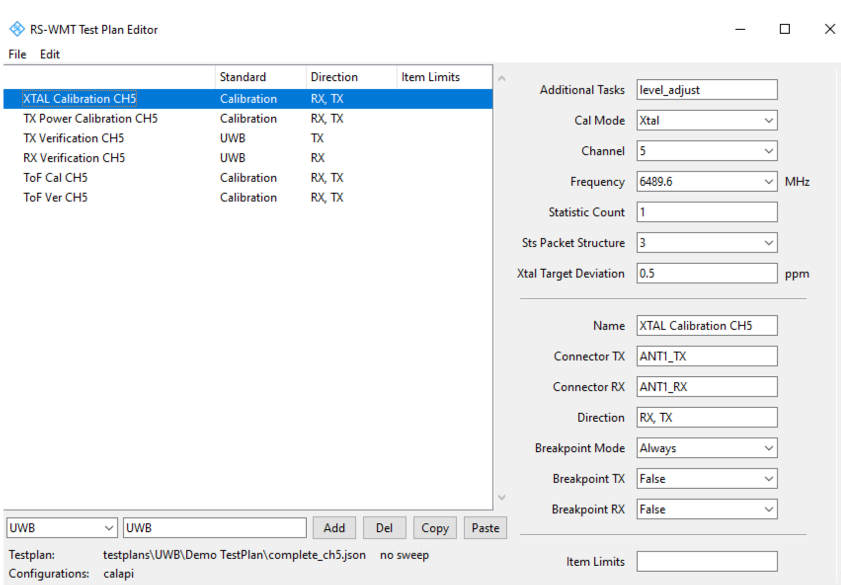


Figure 3-21 WMT Test Plan Editor GUI

Test Runner (Figure 3-22) provides the environment for test execution of a selected test plan as well as multi-DUT parallel testing. After each test plan is executed, test report can be inspected. Debug log associated to the test run can be checked in Test Runner, if required.

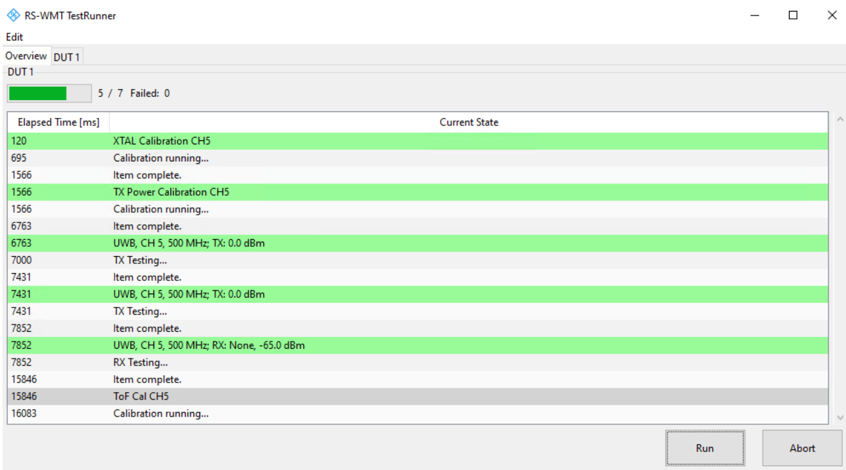


Figure 3-22 WMT Test Runner GUI

Follow the link here for further reading.

3.1.2.3.2 Installation

Distribution of the WMT software is in form of a windows installer, e.g. for NXP Trimension™ NCJ29D5 chip, execute the installer `NXP_NCJ29D5D_UCI_Custom-Custom.1.0.0.7.msi` and go through the installation steps as follows:

1. Confirm the welcome page by pressing 'Next' button

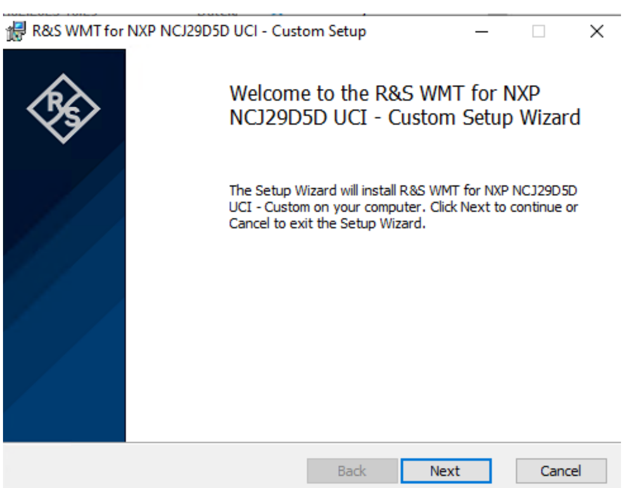


Figure 3-23 Welcome page

2. Confirm the license agreement by pressing 'Next' button

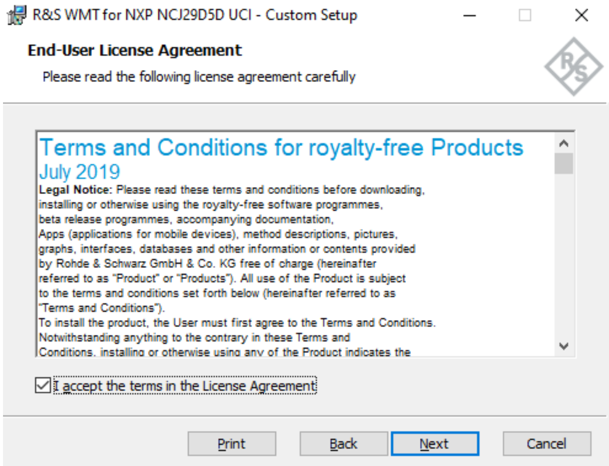


Figure 3-24 Accept license agreement

3. Specify an installation folder on the control PC and press 'Next' key to proceed

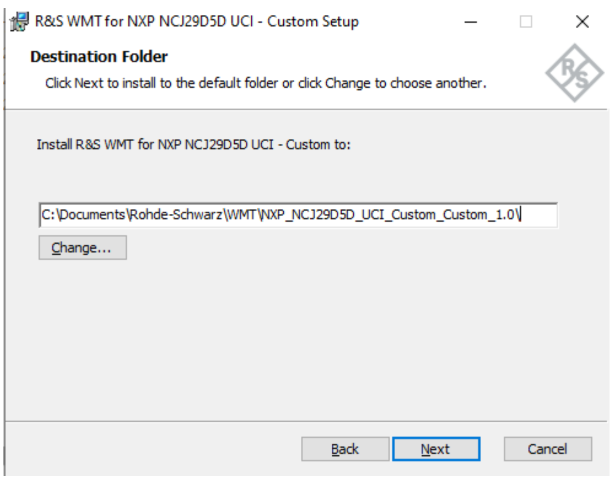


Figure 3-25 Specify the destination folder

4. Press 'Install' button to start the installation

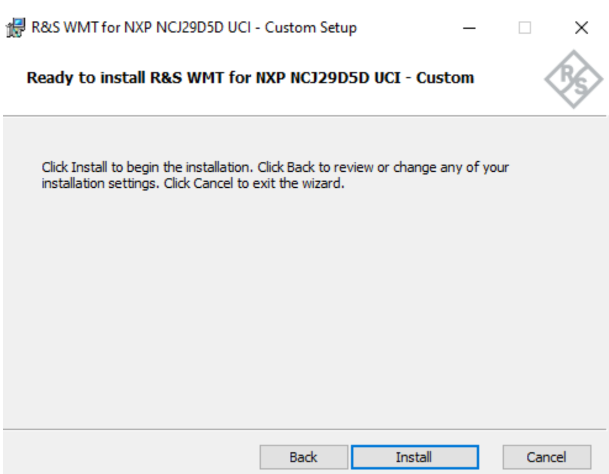


Figure 3-26 Confirm installation

5. Wait until the installation process is completed, then press 'Finish' button to exit

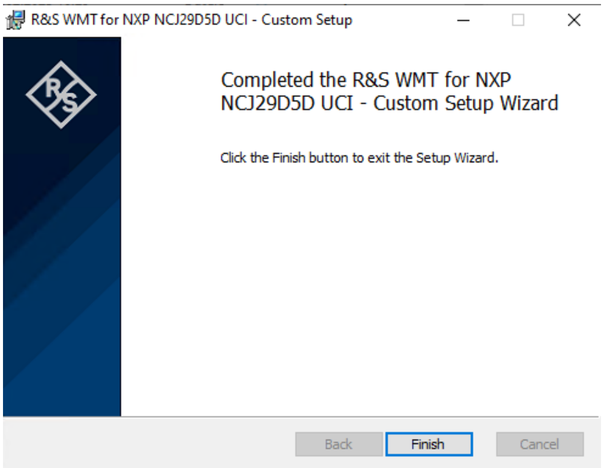


Figure 3-27 Completion of the installation

After successful installation, the folder structure under the WMT installation folder is created (see Figure 3-28). From there, Test Plan Editor (`testplan_editor.exe`) and Test Runner (`testrunner_gui.exe`) can be called. Create sub-folder 'testplans' under the installation folder to place test plans if it does not exist.

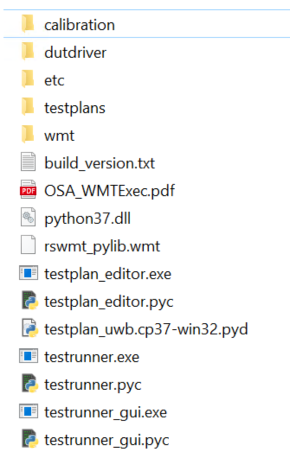


Figure 3-28 Folder structure under the installation folder

3.1.2.4 DUT USB Driver

For Evaluation board NXP Trimension™ NCJ29D5, an USB driver needs to be installed on control PC. Visit https://www.pemicro.com/opensda/ to obtain USB driver installer (`PEDrivers_install.exe`).

3.1.3 Cabling

System cablings on the test setup are shown below in Figure 3-29, Figure 3-30 and Figure 3-31.

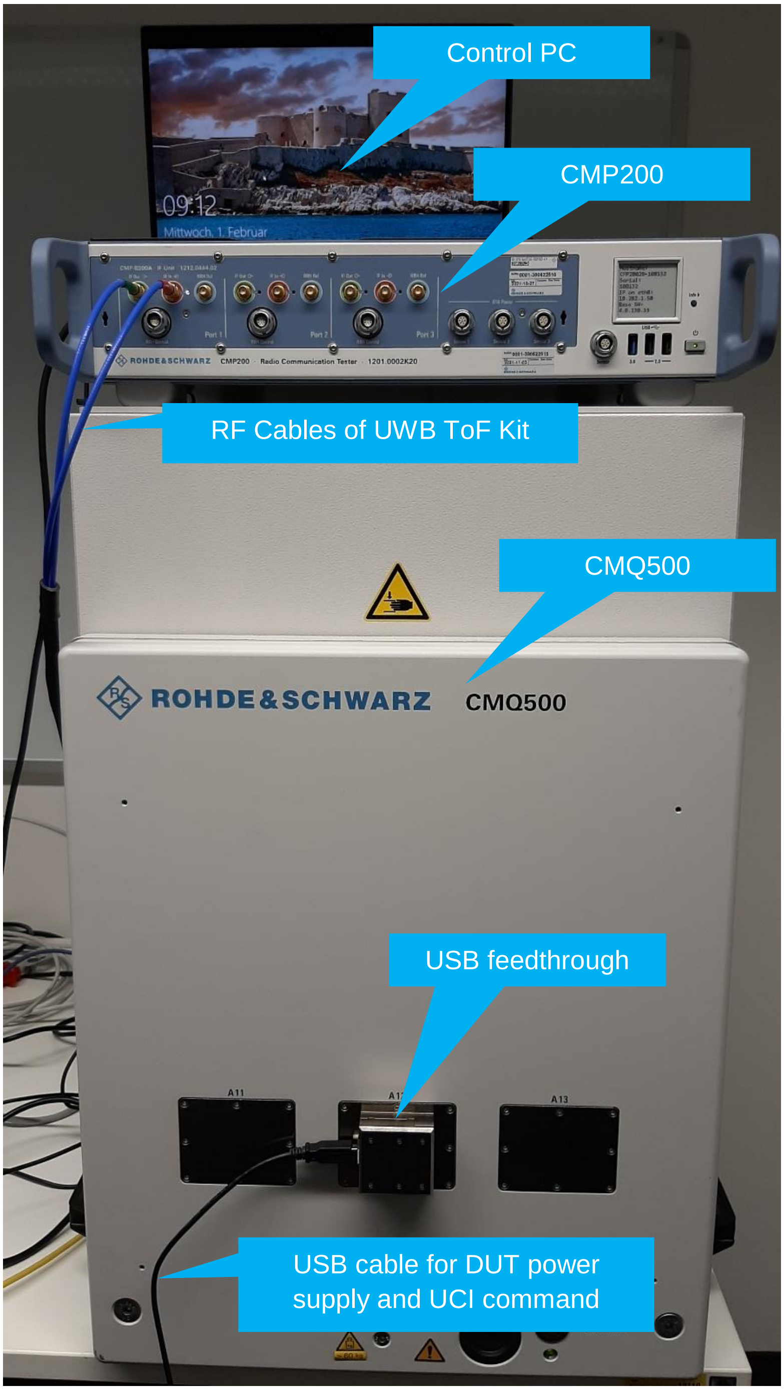


Figure 3-29 Front view of setup with cabling

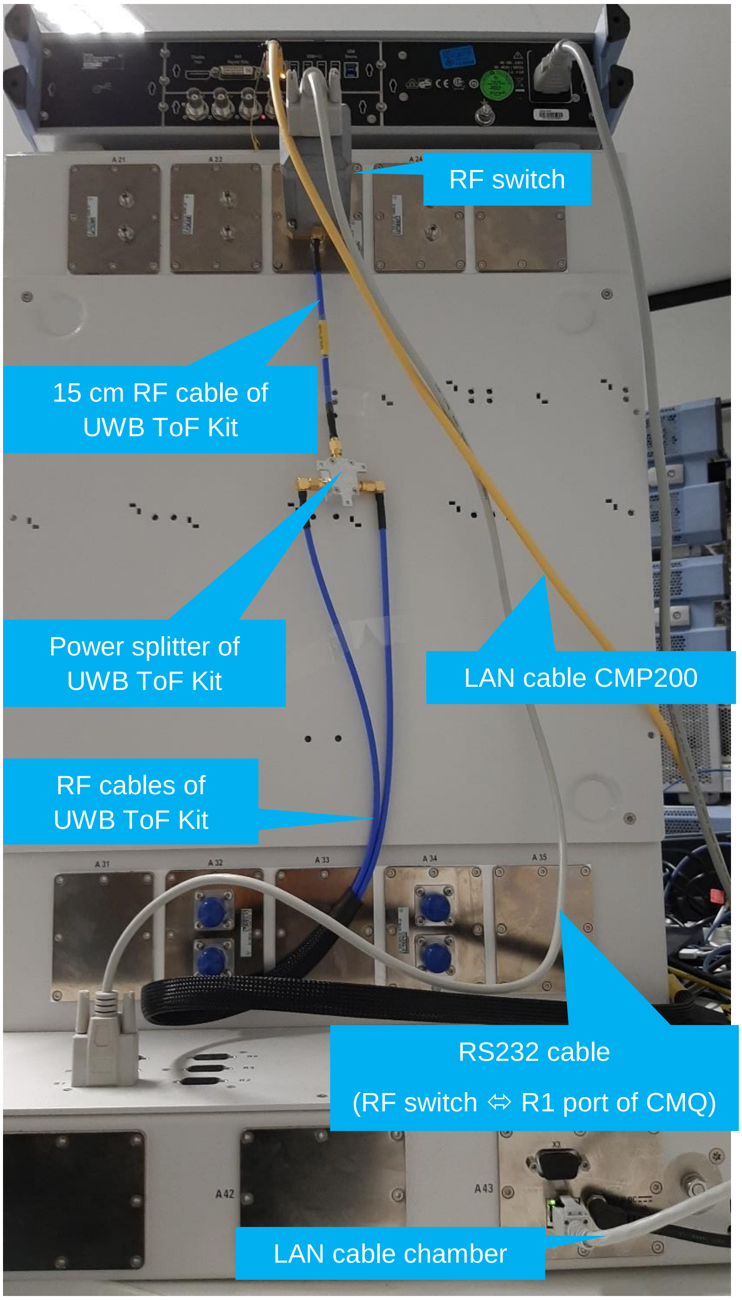


Figure 3-30 Rear view of setup with cabling

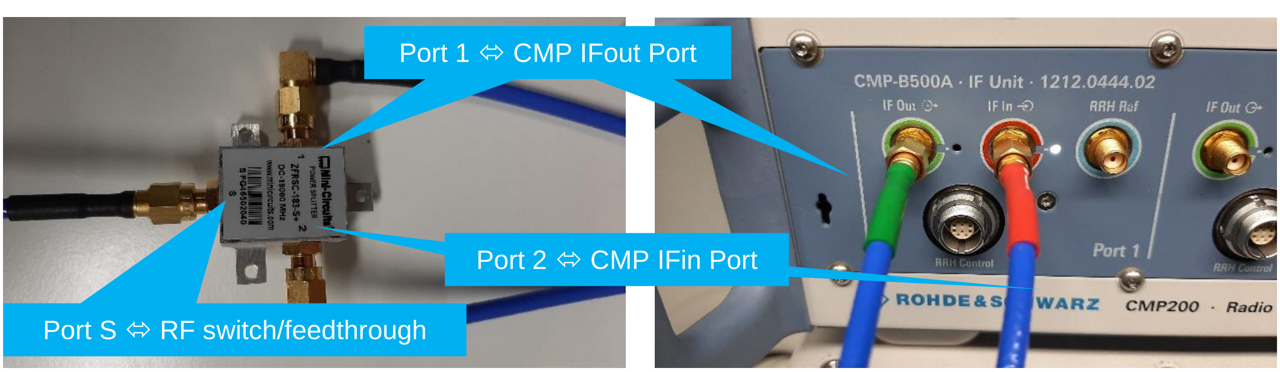


Figure 3-31 Cabling of power splitter and its connections to RF ports of CMP200

3.1.4 IP Configuration

CMP200 and control PC should possess the IP address in the same IP segment. This can be done either through automatic IP assignment through DHCP or static IP assignment.

► Automatic IP address assignment via DHCP

Both CMP200 and control PC are connected via LAN to the network where DHCP server is presented for assigning the IP address to each connected device automatically. This is normally the case when CMP200 and control PC are connected to company network.

The CMQ200/CMQ500 chamber has however a fixed IP address 192.168.178.41. Most probably, the IP address of the control PC and CMP200 will have the different IP subnet assignment by DHCP server, e.g. on subnet 10.202.1.*. In this deployment scenario, since control PC needs to be operated on both networks to have functional control of CMP200 and chamber, two network interfaces are required on control PC as shown in Figure 3-32.

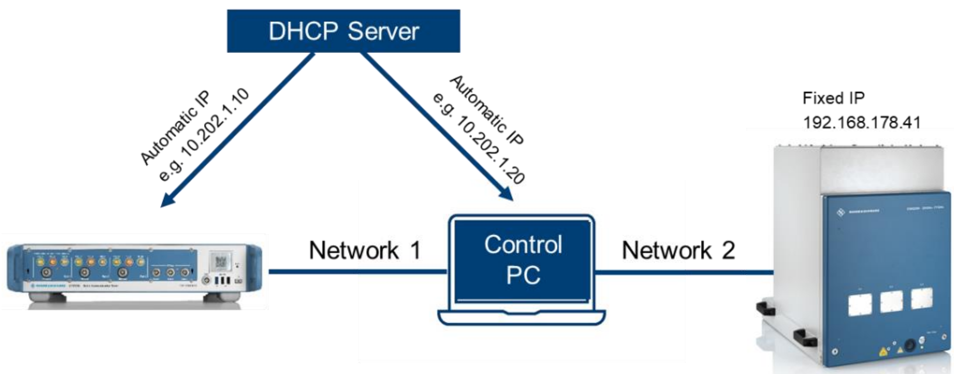


Figure 3-32 Two network interfaces on control PC when IP of CMP200 and control PC are assigned automatically by DHCP server

► Manual IP address configuration (static IP)

Set the static IP address on both CMP200 and control PC. This is usually the case for standalone operation of the setup.

Unlike in the automatic case described above, for manual IP address configuration, user can simply configure the control PC and CMP200 IP address in such a way that both of them are allocated in the same subnet as the fix IP of the chamber, i.e. 192.158.178.*. With that, one network interface on control PC is sufficient.

Further read in Chapter 6.8.1 of [13] to get more detailed instruction especially on the manual IP settings on CMP200.

Hint:

The CMP200 IP address can be read out directly in LED display on the instrument front panel after the successful reboot.

3.1.5 DUT Positioning in CMQ200/CMQ500

As mentioned earlier in 2.1.3, we focus on white-box approach in the OTA chamber in this document assuming the physical location of the DUT antenna is known.

For the measurements in OTA chamber, it is crucial to know the free space distance between the Vivaldi measurement antenna and DUT's antenna. The distance hat influence on the signal pathloss and signal propagation delay (see more details about the calibration in 3.3).

CMQ200/CMQ500 offers one of the two table layouts, inner or drawer table layout as listed in Table 3-2. The type of the table layout is part of the chamber configuration when the order is placed.

Table Layout	Option	Description	Remark
Inner table layout	R&S®CMQ-B701A	Table is mounted inside of the CMQ	User-defined table height position is possible
Drawer table layout	R&S®CMQ-B702A	Table is mounted on front drawer of CMQ	Two fixed mounting positions

Table 3-2 Table layouts of CMQ

For drawer table layout (see Figure 3-33), one of the two fixed mounting positions (lower position 1 and upper position 2) can be chosen to place the table. The two positions are 135 mm apart. Moreover, if the Vivaldi antenna is mounted in the chamber with the ordered antenna fixation accessories from R&S (see antenna kit 3.1.1.5), then the distance between drawer table position 1 and Vivaldi antenna has a fixed 313 mm (see Figure 3-34). These reference values can be used later on to determine the free space distance between Vivaldi antenna and DUT.

Since the table is attached to the door, it is convenient for DUT loading/unloading. This brings advantages in the production application for instance when robotic arm is adopted.

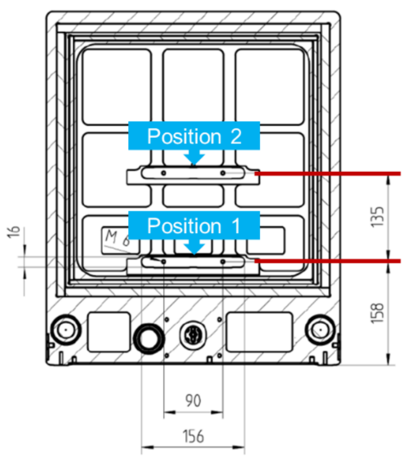


Figure 3-33 Two fixed positions in CMQ200/CMQ500 chamber with drawer table layout

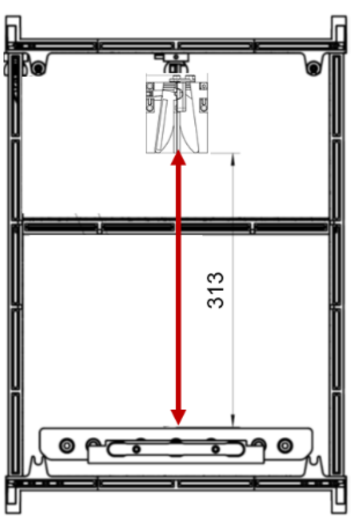


Figure 3-34 Distance between drawer table position 1 and Vivaldi antenna (313 mm)

While with inner table layout, the table can be mounted at any height position in the chamber. This offers of course more freedom of DUT position.

Independent of the table layout selected, the free space distance needs to be determined. It is the distance between the aperture of the Vivaldi measurement antenna and DUT's antenna. With the help of the cradle (fixing frame with scaler) in the CMQ200/CMQ500, the Vivaldi measurement antennas and DUT antenna can be aligned on the same plane in y-axis. The free space distance in x-axis is determined with the help of the cradle and by taking DUT's antenna geometric situation into account. The minimum distance between the DUT and aperture of the Vivaldi antenna on the x-axis needs to fulfil at least the Derat distance as given in Table 2-1. For example, for testing channel 5, it should have minimum 14 cm apart.

Figure 3-35 (inner table layout) shows recommended DUT position and three Vivaldi antenna positions in the chamber for all UWB tests, including AoA testing. The impinging angle of the Vivaldi antenna opposed to the DUT antenna can be adjusted in 22.5° step size with the help of the antenna adaptor. The example shown in Figure 3-36 has the antenna fixed at 45° on the antenna adaptor.

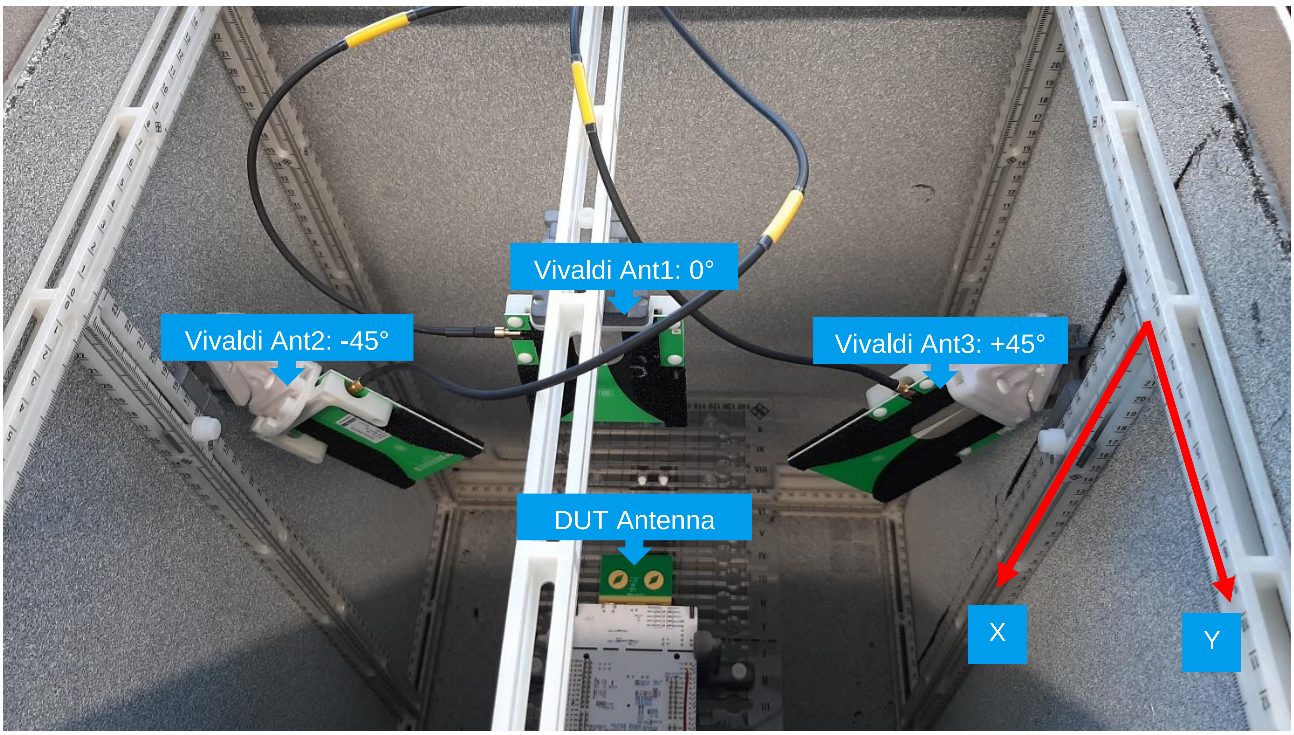


Figure 3-35 Positioning of UWB DUT and measurement antennas (Vivaldi) in a CMQ200 chamber for UWB AoA testing

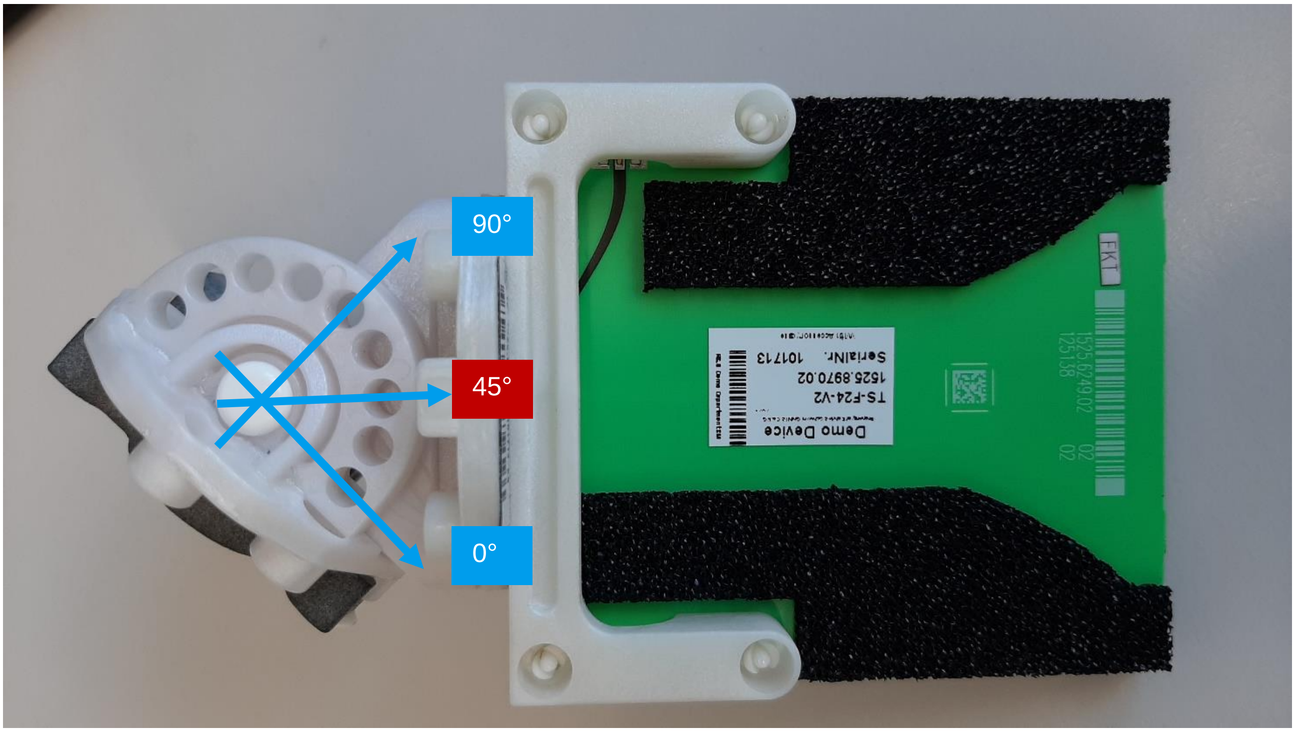


Figure 3-36 Angle adjustment of the Vivaldi antenna with the adaptor (45°)

3.2 Test Procedures

3.2.1 Operations in WMT Test Plan Editor

Create new UWB test plan or configure an existing one in Test Plan Editor.

1. In WMT installation folder, double click on '`testplan_editor.exe`' to launch Test Plan Editor
2. In Test Plan Editor, new test plan can be created (main menu > File > New…) or the existing test plan can be inspected or modified if desired (main menu > File > Open…). See Figure 3-37.

   The test plan can include test routines for transmitter, receiver, ToF tests.

Figure 3-37 Create a new test plan / Open an existing test plan in Test Plan Editor

An example test plan is shown in Figure 3-38 below. Further details about the creation of calibration and verification routine together with its configurations can be referred further in chapter 3.3.2 and 3.4, respectively.

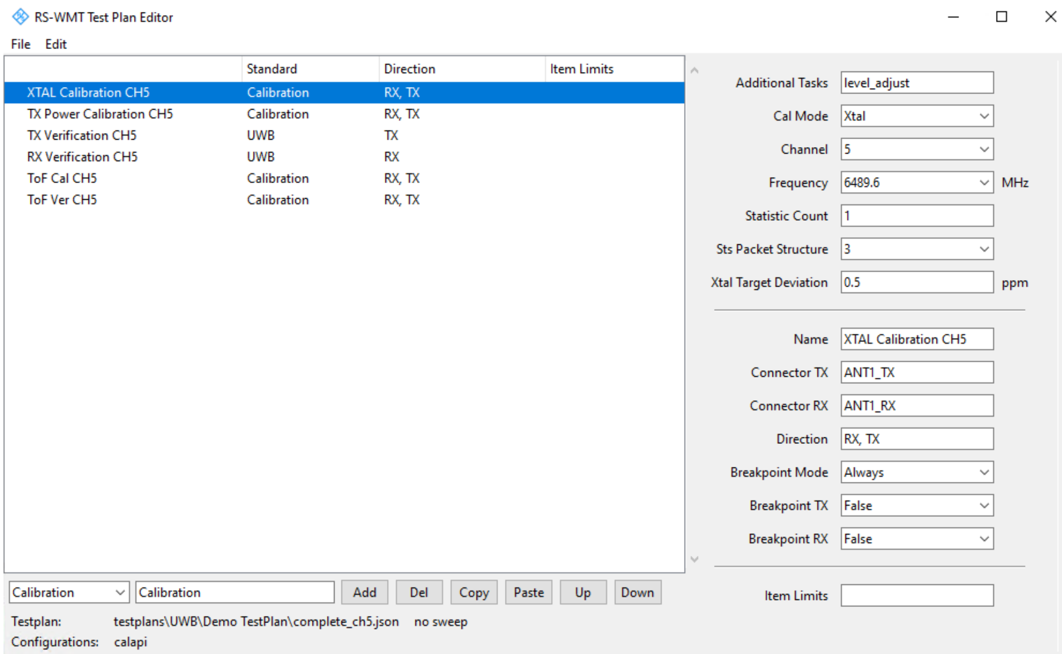


Figure 3-38 An example UWB test plan in Test Plan Editor

3.2.2 Operations in WMT Test Runner

Follow the steps below to execute a test plan in Test Runner:

1. In WMT installation folder, double click on '`testrunner_gui.exe`' to launch Test Runner GUI
2. In Test Runner GUI, a test configuration file (`testconfig.ini`) should be made available. As shown in Figure 3-39, it is accessible from Test Runner main menu> Edit > Settings, there are three operation options available:
   - Edit: edit a test configuration file in a text editor
   - Open: open an existing test configuration file under the sub-folder `\etc` in WMT installation folder
   - New: create a new test configuration file with pre-defined configuration structure

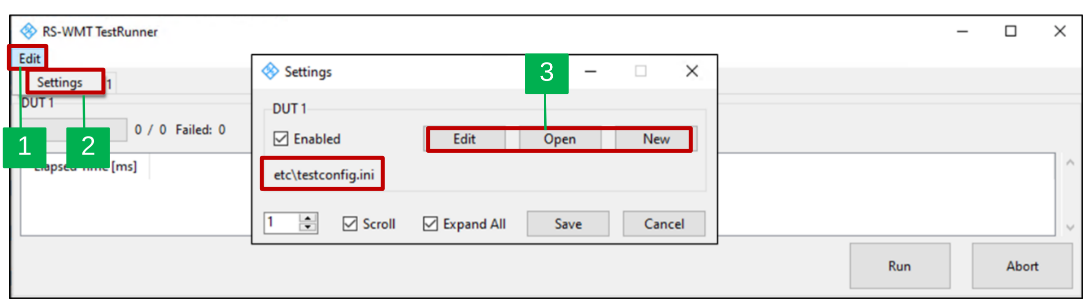


Figure 3-39 Access to test configuration file 'testconfig.ini' in Test Runner

3. Configure the '`testconfig.ini`' file. Figure 3-40 shows the most important settings to be went through
   - activate a test plan (only one test plan is allowed to be activated at a time, the activation is done by removing the semi-colon symbol in front of the test plan in question
   - specify the virtual serial port on your control PC for DUT control (for UCI communication), e.g. COM3
   - enter the IP address of the CMP200

– enable ARB generator, if it is required

– define the connection (name, physical connector on CMP200 and the FDC[VII] of the associated connection)

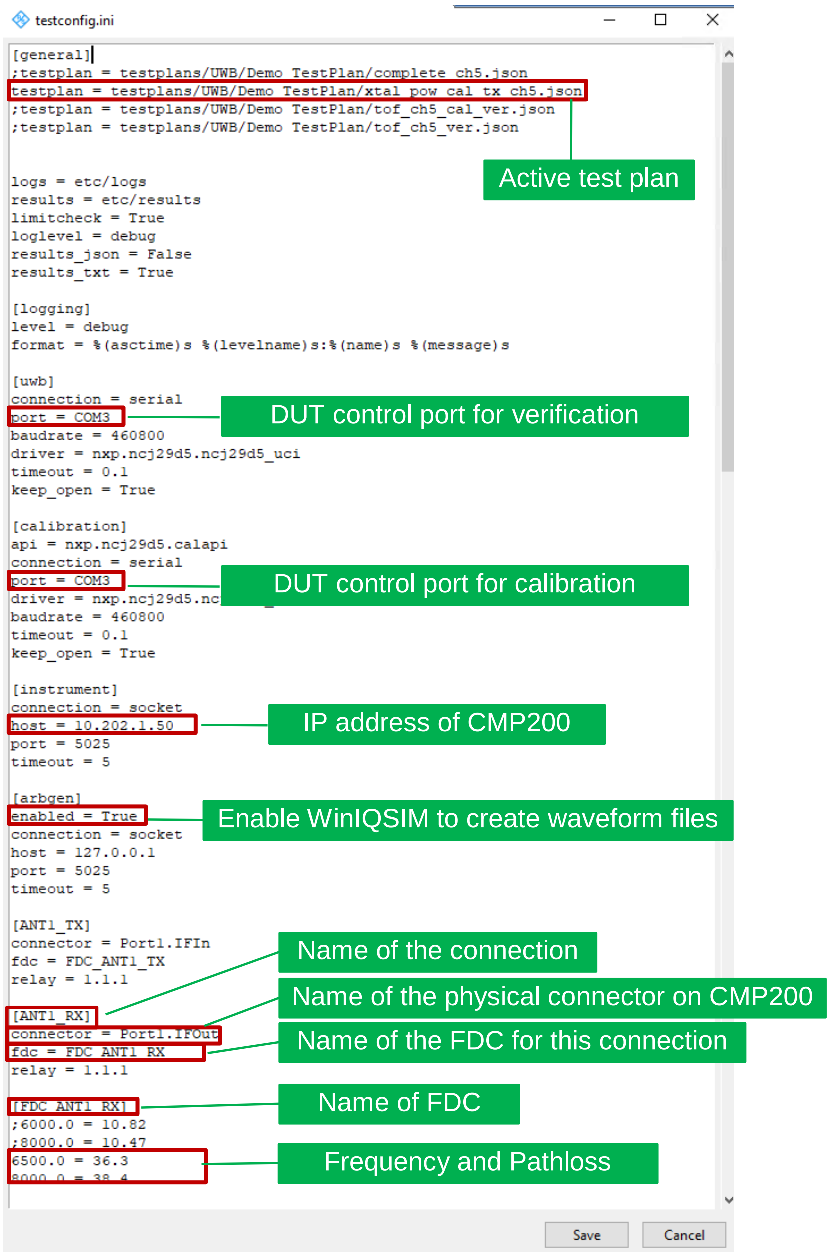


Figure 3-40 Most important settings in 'testconfig.ini' file

Some hints on the configurations in Figure 3-40

– The DUT control port (virtual serial port) entered in the '`testconfig.ini`' file can be checked in Device Manager of the Windows OS. As example shown in Figure 3-41 indicates that COM3 port is assigned.

– IP address of the instrument can be easily read out from the LED display located on CMP200's front panel

[VII] FDC = Frequency Dependent Correction

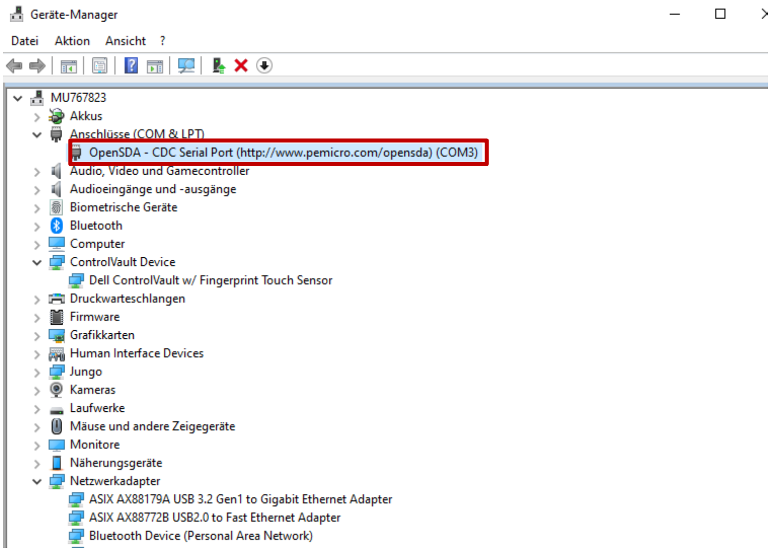


Figure 3-41 Check assigned DUT control port in Windows Device Manager

4. Confirm the changes in '`testconfig.ini`' by pressing 'Save' button (Figure 3-40) and press 'Save' button (Figure 3-39) in the setting window to quit

5. Click 'Run' button in main window of Test Runner GUI to execute the test plan (see Figure 3-42). The progress of the test plan execution is updated in the Test Runner GUI and the actual test results can be checked in the 'DUTx[VIII]' tab of the GUI

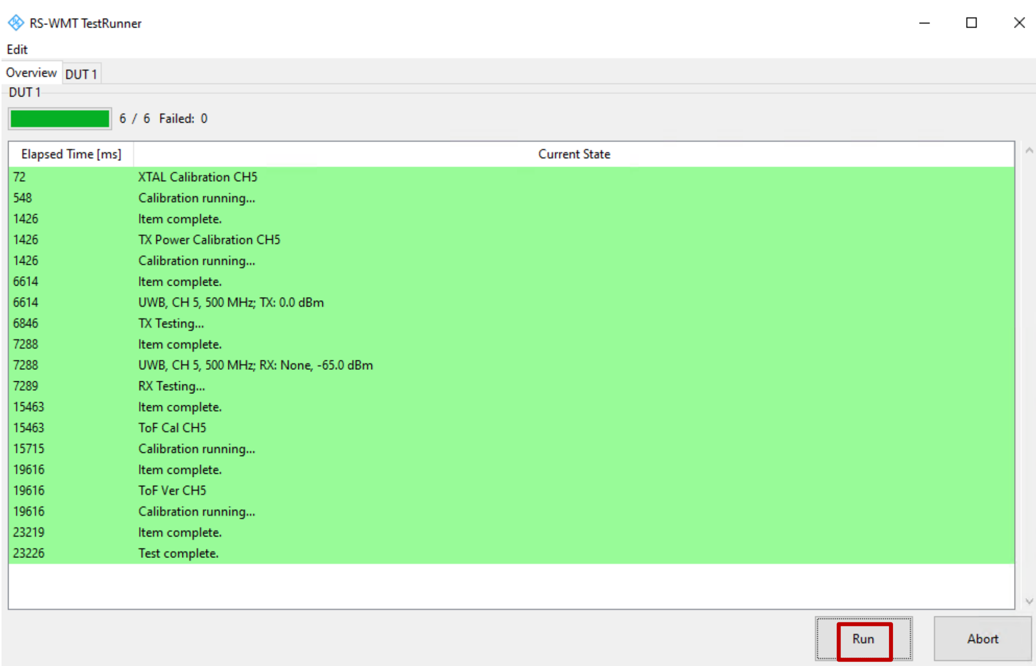


Figure 3-42 WMT Test Runner Overview

6. After the test plan execution is completed, the whole test results are shown in 'DUTx' (see Figure 3-43). If desired, activate the check box 'View Log' to check the detailed log (Figure 3-44) which serves quite well for debugging purposes.

[VIII] x is a suffix in the DUT identifier. Suffix is increased by 1 when a new DUT instance is added.

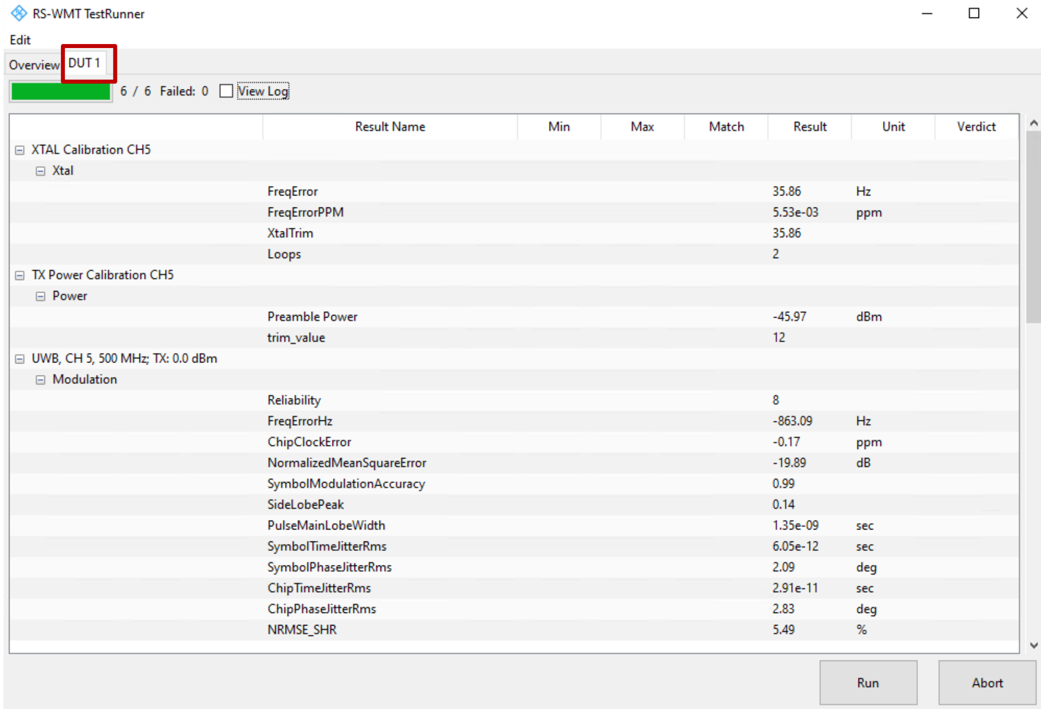


Figure 3-43 Test Runner result page

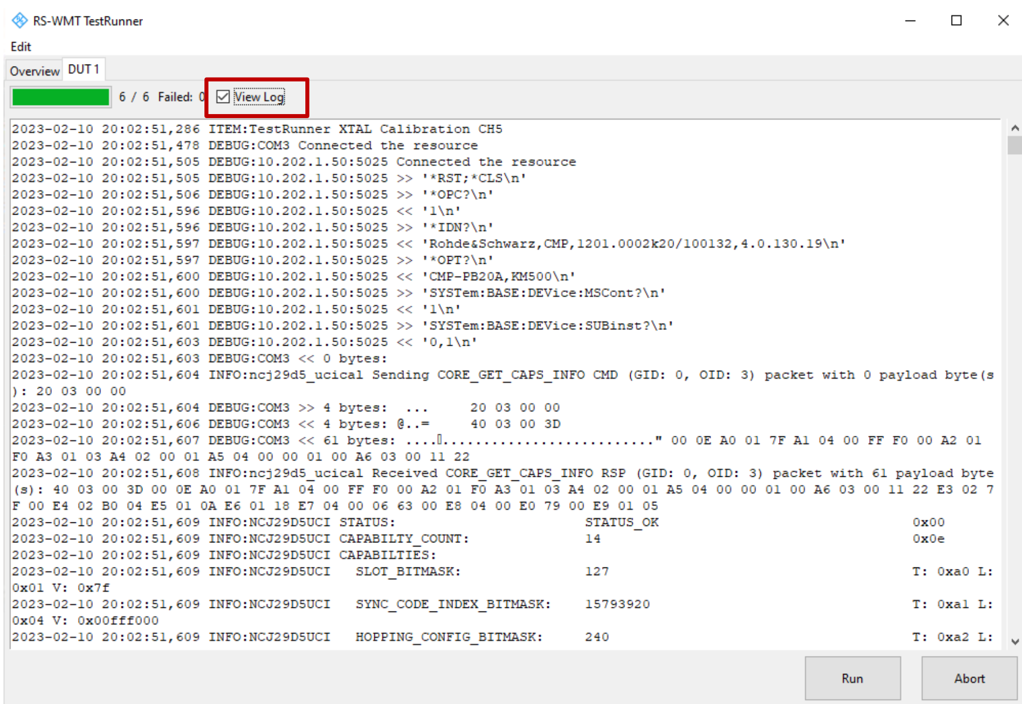


Figure 3-44 Test Runner log view

7. If needed, navigate to sub-folder `etc/results/DUTx/` and `etc/logs/DUTx/` under the WMT installation folder to fetch the saved test result file and logfile

3.3 Calibrations

In this chapter, we are going to tackle the calibration from two aspects, OTA test system pathloss calibration and device calibration.

3.3.1 OTA Test System Pathloss Calibration

OTA test system pathloss calibration is necessary to ensure accurate measurement through power level compensation. This includes the insertion losses (IL) that occur on the involved components throughout the signal propagation chain and signal power level loss over the free space in the chamber, a so-called free space path loss (FSPL) which is usually the predominant power loss in an OTA system.

As mentioned earlier in 3.1, two system variants are considered here, a chamber with RF feedthrough (variant 1) and with RF switch (variant 2). Figure 3-45 shows that the PL of both setup variants contains the fixed IL portion caused by the known components (ToF Kit, RF feedthrough/RF switch and Vivaldi antenna, see 3.1.1.3, 3.1.1.5 and 3.1.1.6) and FSPL which is distance and frequency dependent.

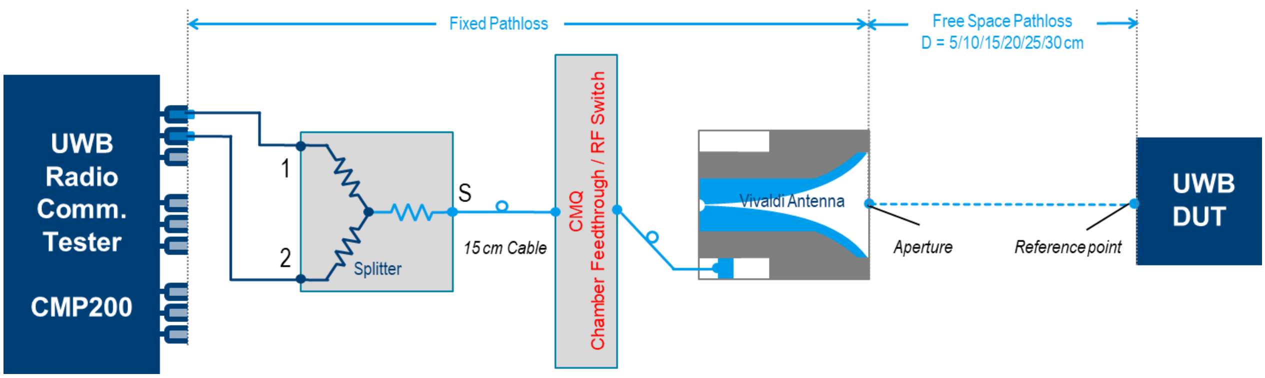


Figure 3-45 Sketch of overall pathloss consists of fixed insertion loss on the signal path plus distance and frequency dependent free space pathloss

A lookup table given in Table 3-3 indicates the overall pathloss from CMP200 output port to DUT antenna without attenuator from the ToF kit (see 3.1.1.3) in the signal path. If an attenuator is desired to be connected in the signal path, then additional pathloss (6, 10, 20 or 30 dB) has to be added on top of the pathloss of the lookup table, accordingly.

OTA setup	Frequency	Pathloss from CMP output to DUT with different free space distance					
		5 cm	10 cm	15 cm	20 cm	25 cm	30 cm
Variant 1 (RF feedthrough)	**6.5 GHz**	-30.0 dB	-33.6 dB	-36.1 dB	-38.1 dB	-39.8 dB	-41.4 dB
	8 GHz	-32.1 dB	-35.6 dB	-38.1 dB	-40.1 dB	-41.6 dB	-42.9 dB
Variant 2 (RF switch)	**6.5 GHz**	-30.2 dB	-33.8 dB	-36.3 dB	-38.3 dB	-40.0 dB	-41.6 dB
	8 GHz	-32.4 dB	-35.9 dB	-38.4 dB	-40.4 dB	-41.9 dB	-43.2 dB

Table 3-3 Overall pathloss between CMP output port and DUT antenna at 6.5 GHz and 8 GHz without attenuator inserted

With lookup table approach, it is an easy and fast way to obtain the signal pathloss of the system. The overall pathloss is determined by OTA setup variant (with RF feedthrough or RF switch), operating frequency and free space distance between Vivaldi antenna and DUT antenna. For example, a setup with RF switch, operating at 6.5 GHz with 15 cm distance between Vivaldi antenna and DUT should apply -36.3 dB PL.

The PL value has to be maintained in the test plan configuration file `testconfig.ini` (more info, see 3.2 or Appendix C) prior to the test execution in WMT. Figure 3-46 indicates that 36.3 dB[IX] PL at 6.5 GHz is assigned for both frequency dependent corrections FDC_ANT1_RX and FDC_ANT1_TX. They are the FDCs applied to physical connectors Port1.IFOut and Port1.IFIn of the CMP200 which are identified by connector name 'ANT1_RX' and 'ANT1_TX', respectively. In Test Plan Editor, only the connector name as an identifier has to be configured, e.g. ANT1_RX, ANT1_TX.

[IX] In `testconfig.ini` file, the pathloss value is entered as positive value.

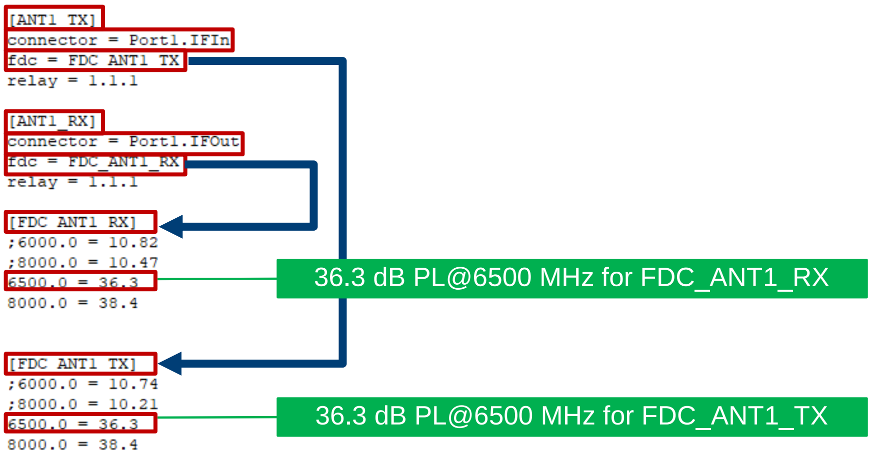


Figure 3-46 Pathloss entries in `testconfig.ini` file in WMT

3.3.2 Device Calibration Routines

On a UWB device, it is required to perform some internal calibration routines prior to the verification. This refers to the crystal calibration, Tx power calibration and ToF calibration.

3.3.2.1 Crystal (XTAL) Calibration

Crystal (XTAL) calibration is required to reduce the Center Frequency Offset (CFO) error of DUT within the specified limit. It is not channel dependent. Figure 3-47 shows the steps to create a crystal calibration routine and its important settings in Test Plan Editor.

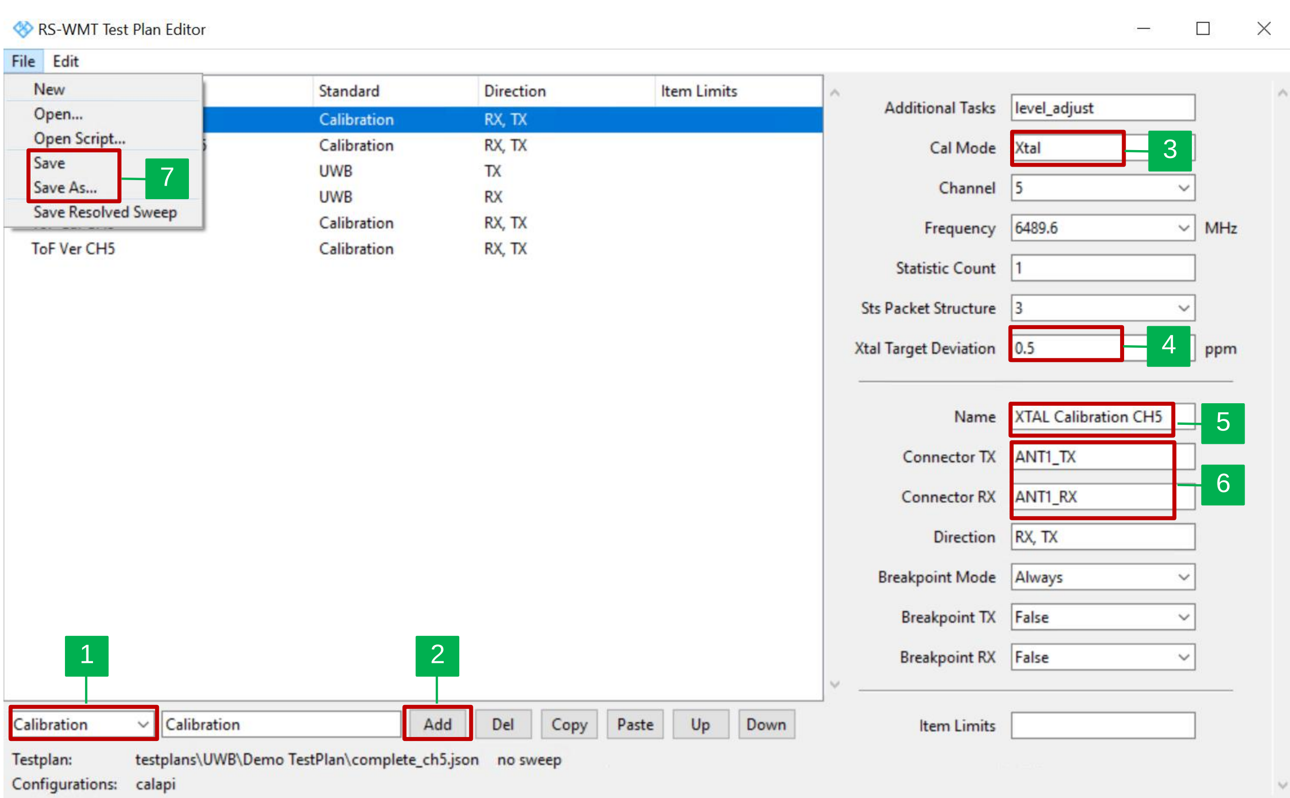


Figure 3-47 Create and configure a XTAL calibration routine in Test Plan Editor

1. In Test Plan Editor, choose 'Calibration' in the standard selection field

2. Press 'Add' to add the calibration routine
3. Choose 'Xtal' as calibration mode
4. Define the Xtal deviation limit, the default value 0.5 ppm can be kept, unless otherwise specified
5. Name the calibration routine, e.g. 'XTAL Calibration CH5'
6. Specify the connector name for both connectors in Tx and Rx direction, e.g. 'ANT1_TX', 'ANT1_RX'. The specified connector name should match the one in the `testconfig.ini` file (cf. 3.3.1 to get to know the association between FDC and connector)
7. Under main menu bar, go to File > Save/Save As … to save the test plan

After the XTAL calibration routine is run in Test Runner (cf. 3.2.2), the calibration results are presented as shown in Figure 3-48 where FreqErrorPPM shows 0.06 ppm which is within the limit of 0.5 ppm defined for this routine. The Trim parameter FREQ_DIFF on DUT is updated with the corresponding XTAL trim value 418,09 Hz.

	Result Name	Min	Max	Match	Result	Unit	Verdict
⊟ XTAL Calibration CH5							
⊟ Xtal							
	FreqError				418.09	Hz	
	FreqErrorPPM				0.06	ppm	
	XtalTrim				418.09		
	Loops				2		

Figure 3-48 XTAL calibration results in Test Runner

3.3.2.2 Power Calibration

FCC mandates the UWB device to transmit the power with maximum power spectral density to be lower than -41.3 dBm/MHz. Power calibration routine is required to ensure that the UWB DUT meets this power requirement. The calibration needs to be done for each channel and antenna.

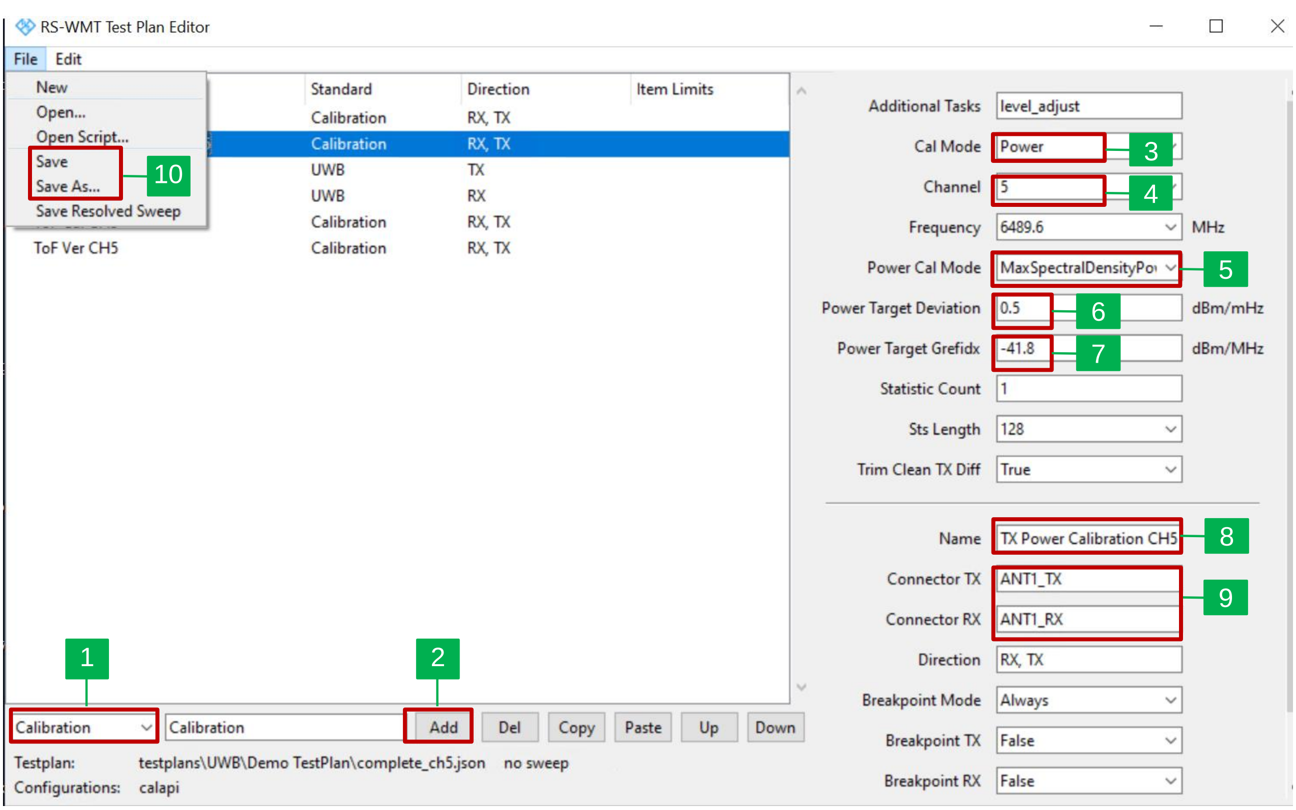


Figure 3-49 Create and configure a Tx power calibration routine in Test Plan Editor

1. In Test Plan Editor, choose 'Calibration' in the standard selection field
2. Press 'Add' to add the calibration routine
3. Choose 'Power' as calibration mode
4. Select the UWB channel, e.g. Channel 5
5. Select 'MaxSpectralDensityPower' for Power Calibration Mode
6. Define power deviation target, e.g. the default value 0.5 dBm/MHz
7. Specify the power target '-41.8 dBm/MHz' (a worst case is considered here, i.e. it takes max power deviation 0.5 dBm/MHz into account to ensure that the Tx power is within the FCC limit -41.3 dBm/MHz)
8. Name the calibration routine, e.g. 'Tx Power Calibration CH5'
9. Specify the connector name for both connectors in Tx and Rx direction, e.g. 'ANT1_TX', 'ANT1_RX'. The specified connector name should match the one in the `testconfig.ini` file (cf. 3.3.1 to get to know the association between FDC and connector)
10. Under main menu bar, go to File > Save/Save As … to save the test plan

After the Tx power calibration routine is run in Test Runner (cf. 3.2.2), the calibration results are presented as shown in Figure 3-50 where the Trim parameter TX_POWER_DIFF (difference between received and expected Tx power) of value 12 is set on the DUT. As per NXP® UCI specification [14], this trim value corresponds to +3 dB.

Figure 3-50 Tx power calibration results in Test Runner

3.3.2.3 ToF Calibration

To have precise ranging, excessive internal time delay or antenna delay between the analog antenna frontend and digital processing unit on a UWB device has to be determined and as a result to be compensated in the subsequent ranging session. The antenna delay occurs in both Tx and Rx direction. In Figure 3-51, the depicted time delays T_{TX} and T_{RX} on DUT side needs to be calculated which is exactly the task of the ToF calibration described in this section.

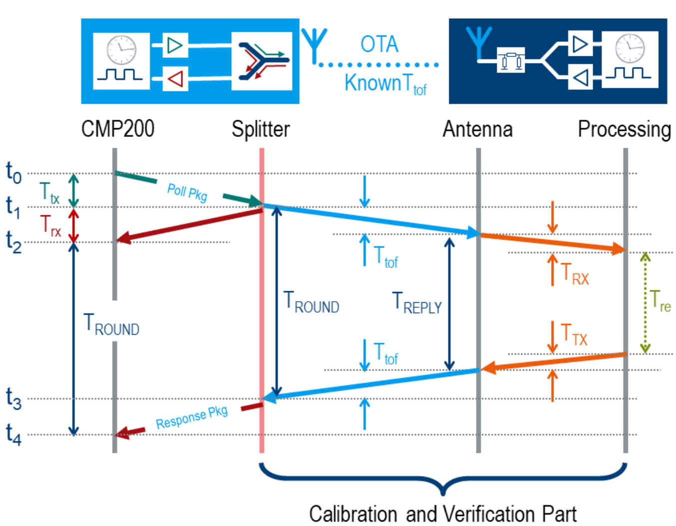


Figure 3-51 Principle of antenna delay calibration and ToF verification (cf. Table 3-4)

Designation	Description
t_0	Time of origin of the poll packet
t_1	Time instance when the poll packet arrives at splitter
t_2	Time instance when the poll packet routed back from the splitter to CMP200
t_3	Time instance when the DUT response packet arrives at splitter
t_4	Time instance when the DUT response packet arrives at CMP200
T_{tx}	Travelling time of poll packet from CMP200 to splitter (t_1-t_0)
T_{rx}	Travelling time of poll packet routed back from splitter to CMP200 (t_2-t_1)
T_{ROUND}	Time difference between t_4 and t_2 (t_4-t_2). It equals the time difference between t_3 and t_1 (t_3-t_1).
T_{tof}	Time of Flight
T_{REPLY}	DUT response time (T_{RX}+T_{re}+T_{TX})
T_{RX}	DUT internal antenna delay on the receiver path
T_{TX}	DUT internal antenna delay on the transmission path
T_{re}	DUT internal packet possessing time

Table 3-4 Timings of antenna delay calibration (cf. Figure 3-51)

The principle of antenna delay calibration is explained as follows:

As illustrated in Figure 3-51, T_{ROUND} represents the time interval between the RMARKER of the poll packet routed back from the splitter at t_2 and the DUT's response packet arriving at CMP200 analyzer side at t_4. T_{ROUND} is also the time difference of t_3 and t_1 at the splitter. The travelling time of packets from the splitter to CMP200 is the same, thus $T_{ROUND} = t_3 - t_1 = t_4 - t_2$. Therefore, only the right-hand side of the splitter is included in the time calculation during the ToF calibration and verification.

Equation 3-1

$$T_{ROUND} = T_{re} + 2T_{tof} + T_{RX} + T_{TX}$$

where $T_{RX} + T_{TX}$ represents the two-way antenna delay.

Equation 3-2

$$T_{RX} + T_{TX} = T_{ROUND} - T_{re} - 2T_{tof} = t_4 - t_2 - T_{re} - 2T_{tof}$$

where t_2 and t_4 are the time stamps on the RMARKER of the packet measured at CMP200, T_{re} is response time reported by DUT. For ToF calibration, T_{tof} is a known ToF (details of known ToF value determination is shown in Figure 3-52 and Figure 3-53 below). The result of Equation 3-2 is actually the calibration outcome. The half of $T_{RX} + T_{TX}$ is the antenna delay that will be set as a trim value on the DUT in the end of the calibration routine. As a result, this updated trim value will then be adopted during the ToF verification routine (cf. 3.4.3).

In OTA test solution described in this document, T_{tof} is broken down into two parts, namely, the fixed group delays (GD) occurring on the components of the system and the signal traveling time over the air. By adopting ToF kit, UWB Antenna Kit, and RF feedthrough or alternatively RF switch, the fixed GD from middle of splitter to the aperture of the Vivaldi antenna has a total value of 4.08 nanoseconds and 4.51 nanoseconds for the setup with RF feedthrough (system variant 1) and RF switch (system variant 2), respectively. Details of GD contribution of each component in the signal path are listed below in Table 3-5.

Items	Group Delay (ns)		Description	Comment
	$T_{tof\_fix\_feedthrough}$	$T_{tof\_fix\_Switch}$		
T_{gs}	0.12	0.12	Splitter (from middle to SUM port)	Included in ToF kit option CM-Z300A
T_{ga}	0.10	0.10	Attenuator[X]	Included in ToF kit option CM-Z300A
T_{cable1}	0.78	0.78	15 cm RF cable	Included in ToF kit option CM-Z300A
T_{switch}	n.a.	0.48	RF Switch SP6T	Included in Antenna kit option CMQ-B744A

[X] The maximum group delay fluctuation among different attenuators (6, 10, 20 and 30 dB) from the ToF kit is about 15 ps. This group delay only applies when attenuator is connected.

Items	Group Delay (ns)		Description	Comment
$T_{feedthr}$	0.05	n.a.	RF feedthrough	Included in CMQ200/CMQ500 standard configuration
T_{cable2}	2.55	2.55	55 cm RF cable	Included in Antenna kit option CMQ-B725A
$T_{antenna}$	0.48	0.48	From RF feed to the aperture of the Vivaldi antenna	Included in Antenna kit option CMQ-B725A
SUM	**4.08**	**4.51**		

Table 3-5 List of fixed group delay with 6 dB attenuator in the signal path

Figure 3-52 and Figure 3-53 show ToF calculation examples of system variant 1 and variant 2. In both cases, DUT's antenna (reference point) is placed 0.15 m away from the Vivaldi antenna that creates free space signal traveling time $T_{air} = \frac{D}{c*\upsilon} = 0.50\ ns$, where D denotes the distance between the aperture of the Vivaldi antenna and reference point of the DUT in meter. Constant c is the speed of light in m/ns, i.e. 0.3 m/ns. Velocity factor υ in the air equals to 1. By adding the fixed GD of 4.08 ns and 4.51 ns, the total ToF is now 4.58 ns and 5.01 ns for system variant 1 with RF feedthrough and system variant 2 with RF switch, respectively.

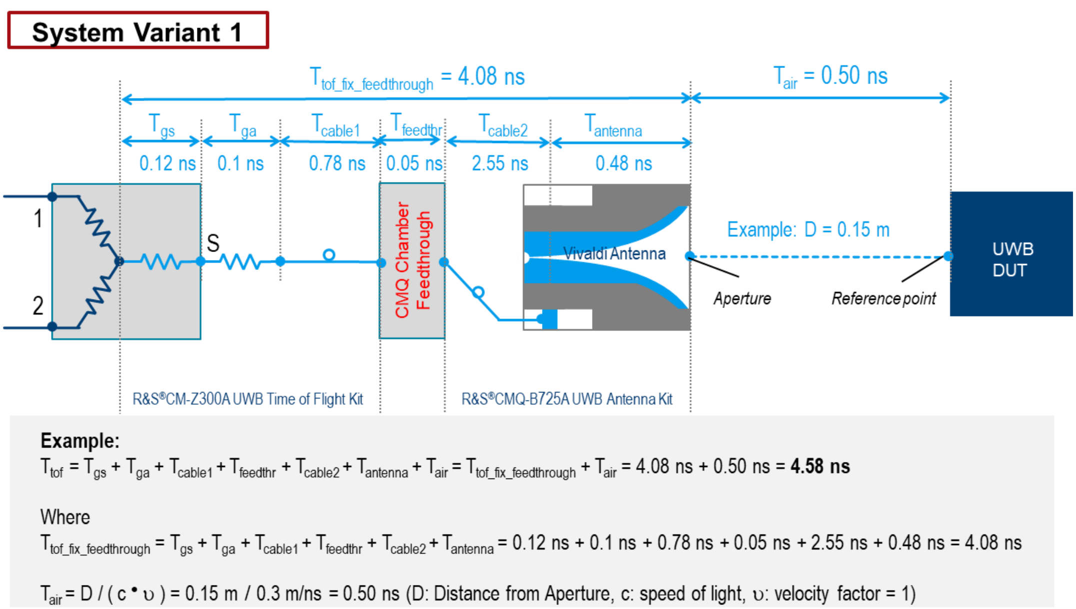
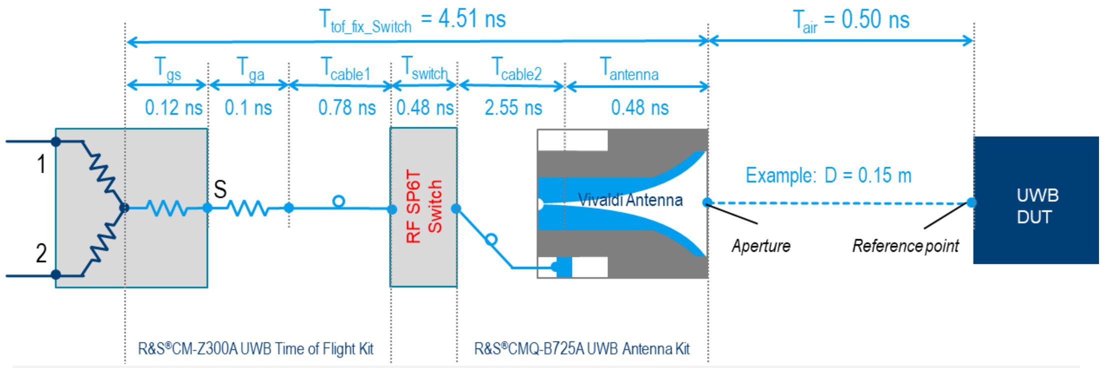


Figure 3-52 An example of ToF calculation for RF feedthrough (system variant 1) with 0.15 meter OTA distance

System Variant 2



Example:

$T_{tof} = T_{gs} + T_{ga} + T_{cable1} + T_{switch} + T_{cable2} + T_{antenna} + T_{air} = T_{tof\_fix\_switch} + T_{air} = 4.51\ ns + 0.50\ ns = \mathbf{5.01\ ns}$

Where

$T_{tof\_fix\_switch} = T_{gs} + T_{ga} + T_{cable1} + T_{switch} + T_{cable2} + T_{antenna} = 0.12\ ns + 0.1\ ns + 0.78\ ns + 0.48\ ns + 2.55\ ns + 0.48\ ns = 4.51\ ns$

$T_{air} = D / (c \cdot \upsilon) = 0.15\ m / 0.3\ m/ns = 0.50\ ns$ (D: Distance from Aperture, c: speed of light, υ: velocity factor = 1)

Figure 3-53 An example of ToF calculation for RF Switch (system variant 2) with 0.15 meter OTA distance

Both fixed GD on the components ($T_{tof\_fix\_feedthrough}$ or $T_{tof\_fix\_switch}$) and T_{air} need to be configured in the ToF calibration routine.

As required by the test routine configuration, the fixed GD $T_{tof\_fix\_feedthrough} = 4.08\ ns$ or $T_{tof\_fix\_switch} = 4.51\ ns$ needs to be converted in distance by applying Equation 3-3

Equation 3-3

$$Path\ Delay\ in\ meter = T_{tof\_fix} * c * \upsilon$$

Where $\upsilon = 0.71$ is velocity factor used for calculation, speed of light $c = 0.3\ m/ns$

Thus, $T_{tof\_fix\_feedthrough}$ and $T_{tof\_fix\_switch}$ are equivalent of 0.87 m and 0.96 m in distance, correspondingly.

Figure 3-54 shows the procedure of ToF calibration routine creation and its configurations.

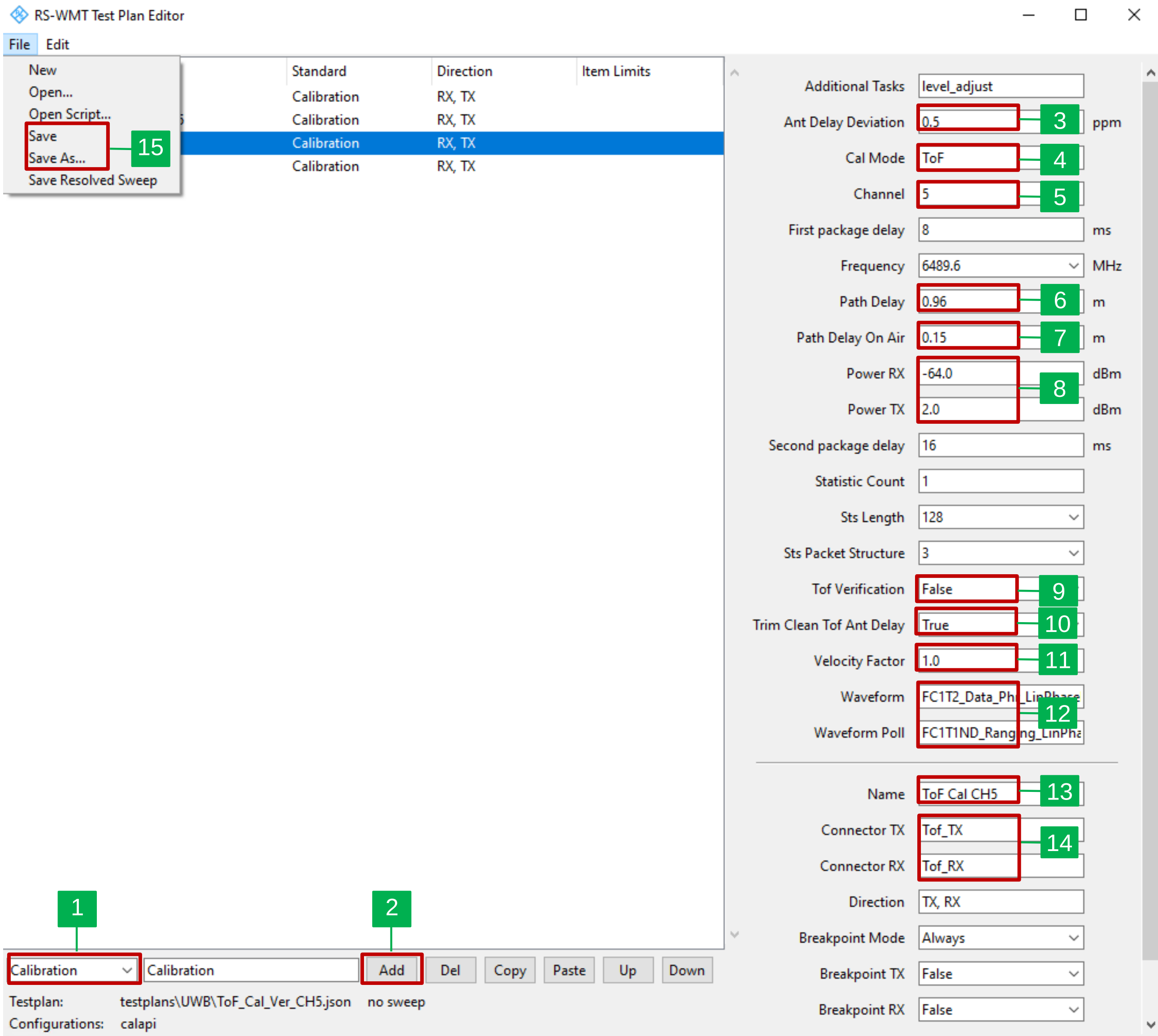


Figure 3-54 Create and configure a ToF calibration routine in Test Plan Editor

1. In Test Plan Editor, choose 'Calibration' in the standard selection field
2. Press 'Add' to add the calibration routine
3. Define antenna delay deviation value, e.g. the default value 0.5 ppm
4. Choose 'ToF' as calibration mode
5. Select the UWB channel, e.g. Channel 5
6. Enter the fixed group delay, 0.96 m ($T_{tof\_fix\_switch}$ for system variant 2) or 0.87 m ($T_{tof\_fix\_feedthrough}$ for system variant 1)
7. Enter the free space distance between Vivaldi antenna and DUT antenna, e.g. 0.15 m
8. Enter proper DUT Rx Power and Tx Power level. Refer to Appendix D on page 68 to learn more about the determination of both power levels (**Attention:** improper power level might lead to unstable signal detection at CMP200)
9. Set ToF Verification to 'False' to indicate this is a calibration routine

10. Set Trim Clean ToF Ant Delay flag to 'True' to indicate that the antenna delay trim value on the DUT needs to be cleaned when this routine starts
11. Set Velocity Factor to '1' as the signal propagates in air
12. Keep the default waveform file name.

    Two waveform files should be uploaded to CMP200 before the test starts (waveform file handling, see Appendix E on page 69). Both waveform files are played back on CMP200 in 8 ms time interval (Figure 3-55) that is required by DUT (NCJ29D5).

    – Waveform file #1 (Pre_Poll packet):

      `FC1T2_Data_Phr_LinPhaseRRC0p45_waveform_1_resample.wv`

    – Waveform file #2 (Poll packet):

      `FC1T1ND_Ranging_LinPhaseRRC0p45_waveform_2_resample.wv`

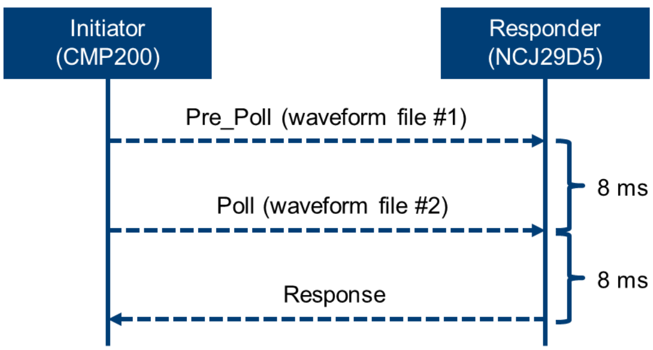


Figure 3-55 Ranging message flow of NXP NCJ29D5

13. Name ToF calibration routine, e.g. 'ToF Cal CH5'
14. Specify the connector name for both connectors in Tx and Rx direction for ToF calibration, e.g. 'ToF_TX', 'ToF_RX'. The specified connector name should match the one in the `testconfig.ini` file (cf. 3.3.1 to get to know the association between FDC and connector)
15. Under main menu bar, go to File > Save/Save As … to save the test plan

After the ToF calibration routine is executed in Test Runner (cf. 3.2.2), the antenna delay of the DUT in nanosecond is determined and the corresponding trim value is then set on the DUT under the trim parameter ANTENNA_DELAY. As example shown in Figure 3-56, the antenna delay is 4.13 ns that is translated in trim value 263 with 15.65 ps resolution granularity.

⊟ ToF Cal CH5			
⊟ ToF			
	Distance	123.76	cm
	Antenna Delay	4.13	ns
	Trim Value	263	
	CMP TIME	7846264.70	ns
	DUT TIME	7846257.21	ns
	FREQ ERR	0.23	ppm
	ToF_E	9.26	ns

Figure 3-56 ToF calibration results in Test Runner

3.4 Verification

In this chapter, verification routines for transmitter, receiver and ToF in WMT are introduced and the results are presented.

A holistic view of the recommended UWB test items for automotive NXP® chip (NXP Trimension™ NCJ29D5) on CMP200 is given in Table 3-6.

Category	Measurement Item (Chapter)	Needed R&S Equipment and Option
Tx / Power	Preamble Power (3.4.1.1)	CMP200, KM300 UWB
Tx / Power	Data Power (3.4.1.2)	CMP200, KM300 UWB
Tx / Modulation	Frequency Error (3.4.1.3)	CMP200, KM300 UWB
Tx / Modulation	Chip Clock Error (3.4.1.4)	CMP200, KM300 UWB
Tx / Pulse Mask Margin	Pulse Mask (3.4.1.5)	CMP200, KM300 UWB
Tx / Modulation	SHR/PHR/PSDU/STS NRMSE (3.4.1.6)	CMP200, KM300 UWB
Tx / Pulse Level	AVG PHR/PSDU/STS Pulse Level, relative to SHR (3.4.1.7)	CMP200, KM300 UWB
Tx / Mask	Transmit Spectrum Mask (3.4.1.8)	CMP200, KM300 UWB
Tx / Power	Max Spectral Power [dBm/MHz] (3.4.1.9)	CMP200, KM300 UWB
Tx / Power	Max Peak Spectral Power [dBm/50MHz] (3.4.1.10)	CMP200, KM300 UWB
Rx	RX Sensitivity (3.4.2)	CMP200, ARB Generator UWB SW Option
ToF	Ranging DS-TWR / SS-TWR (3.4.3)	CMP200, ARB Generator + KM300 + ToF Kit

Table 3-6 Measurement items for NXP Trimension™ NCJ29D5 on CMP200

3.4.1 Transmitter

Transmitter tests are about power, pulse level, pulse mask and transmit spectrum mask measurements.

The SP3 is considered in all transmitter tests. Therefore, all the measurements on the data portion (PHR/PSDU) of the UWB frame are not available. Otherwise, SP0 should be configured.

Follow the steps shown in Figure 3-57 to create and configure transmitter verification routine.

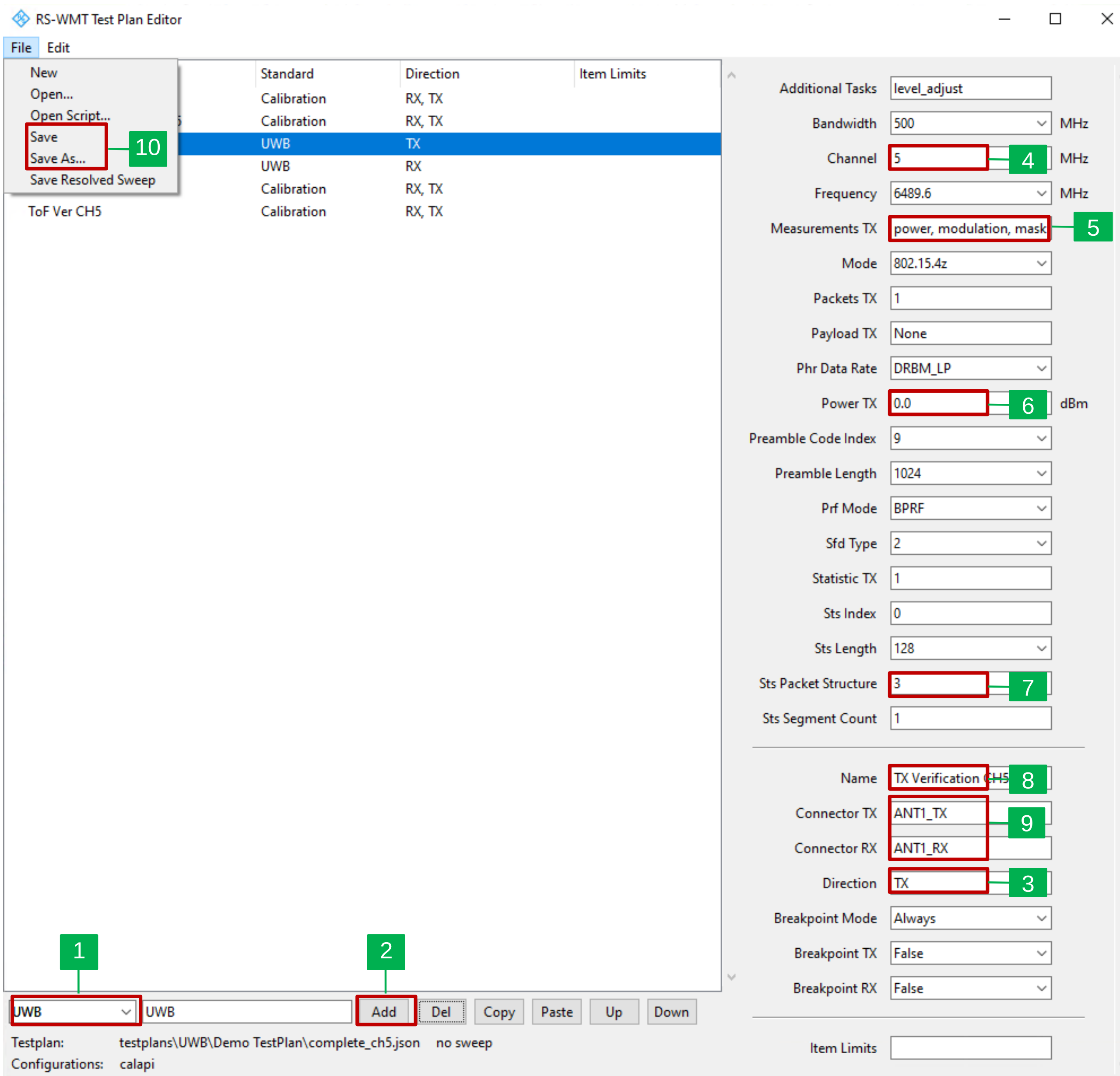


Figure 3-57 Create and configure a Tx verification routine in Test Plan Editor

1. In Test Plan Editor, choose 'UWB' in the standard selection field
2. Press 'Add' to add the verification routine
3. Choose 'Tx' direction
4. Select the UWB channel, e.g. Channel 5
5. Select Tx measurements from the list (see Figure 3-58), e.g. Power, Modulation, Mask

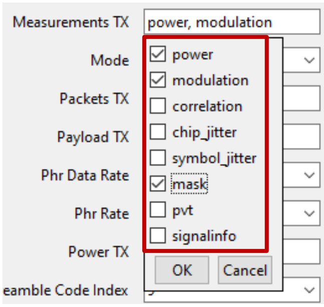
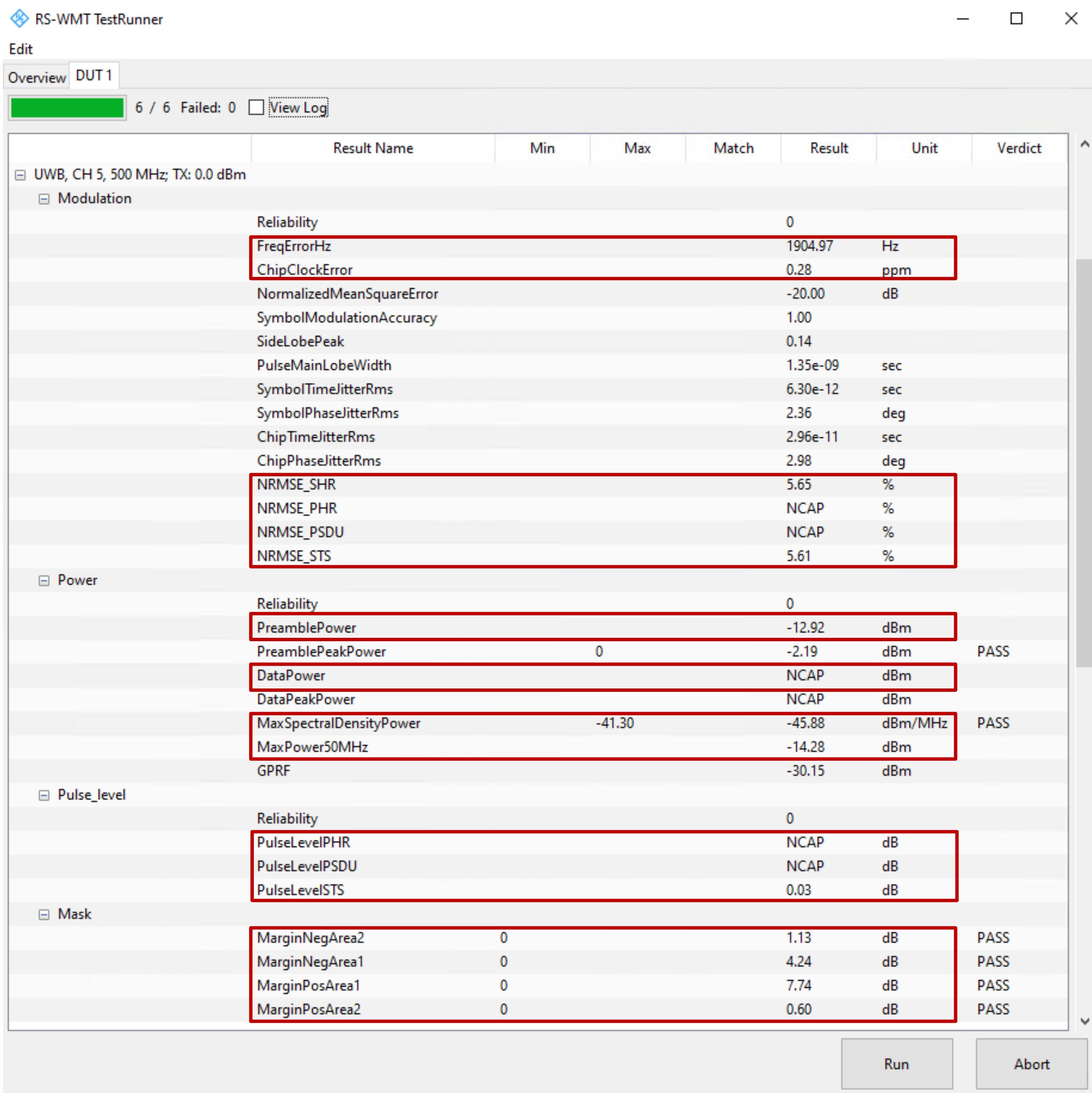


Figure 3-58 Tx measurement items

6. Set Power TX to '0'
7. Set STS packet structure to '3'
8. Name the verification routine, e.g. 'Tx Verification CH5'
9. Specify the connector name for both connectors in Tx and Rx direction, e.g. 'ANT1_TX', 'ANT1_RX'. The specified connector name should match the one in the `testconfig.ini` file (cf. 3.3.1 to get to know the association between FDC and connector)
10. Under main menu bar, go to File > Save/Save As … to save the test plan



Result Name	Min	Max	Match	Result	Unit	Verdict
UWB, CH 5, 500 MHz; TX: 0.0 dBm						
Modulation						
Reliability				0		
FreqErrorHz				1904.97	Hz	
ChipClockError				0.28	ppm	
NormalizedMeanSquareError				-20.00	dB	
SymbolModulationAccuracy				1.00		
SideLobePeak				0.14		
PulseMainLobeWidth				1.35e-09	sec	
SymbolTimeJitterRms				6.30e-12	sec	
SymbolPhaseJitterRms				2.36	deg	
ChipTimeJitterRms				2.96e-11	sec	
ChipPhaseJitterRms				2.98	deg	
NRMSE_SHR				5.65	%	
NRMSE_PHR				NCAP	%	
NRMSE_PSDU				NCAP	%	
NRMSE_STS				5.61	%	
Power						
Reliability				0		
PreamblePower				-12.92	dBm	
PreamblePeakPower		0		-2.19	dBm	PASS
DataPower				NCAP	dBm	
DataPeakPower				NCAP	dBm	
MaxSpectralDensityPower		-41.30		-45.88	dBm/MHz	PASS
MaxPower50MHz				-14.28	dBm	
GPRF				-30.15	dBm	
Pulse_level						
Reliability				0		
PulseLevelPHR				NCAP	dB	
PulseLevelPSDU				NCAP	dB	
PulseLevelSTS				0.03	dB	
Mask						
MarginNegArea2	0			1.13	dB	PASS
MarginNegArea1	0			4.24	dB	PASS
MarginPosArea1	0			7.74	dB	PASS
MarginPosArea2	0			0.60	dB	PASS

Figure 3-59 Tx verification results with SP3 in WMT Test Runner

Figure 3-59 shows the transmit test results in Test Runner after the Tx verification routine is executed (cf. 3.2.2).

In the subsequent chapters, description of each transmitter test and the applied pass criteria is given.

3.4.1.1 Preamble Power

Preamble power is the mean power of the preamble portion of the UWB PPDU.

3.4.1.2 Data Power

Data power is the mean power of the PHY payload of the UWB PPDU.

3.4.1.3 Frequency Error

As specified in Chapter 15.4.9 of [4], the HRP UWB PHY transmit center frequency tolerance shall be ± 20 × 10^{-6}. The tolerance on the chipping clock given in 3.4.1.4 takes precedence over this requirement.

3.4.1.4 Chip Clock Error

As specified in Chapter 15.4.6 of [4], an HRP UWB transmitter shall be capable of chipping at the peak PRF of 499.2 MHz with an accuracy of ± 20 × 10^{-6}. In addition, for each HRP UWB PHY channel, the center of transmitted energy shall be within the values listed in Table 1-1 also with an accuracy of ± 20 × 10^{-6}. The measurements shall be made using a 1 MHz resolution bandwidth and a 1 kHz video bandwidth.

3.4.1.5 Pulse Mask

As specified in Chapter 15.4.4 of [5], for a UWB device electing to use a pulse with precursor, it is recommended that the transmitted pulse follows mathematical formula (Equation 1-1) of the reference root raised cosine pulse r(t) with a roll-off factor of β = 0.45, over at least ±3 chip periods. If the transmitted pulse follows the minimum precursor pulse recommendation, the transmitted pulse shape p(t) should be constrained by the time domain mask of Figure 3-60, where the peak of the pulse is normalized to a magnitude of 1 and t = 0 ns. scaled to a value of one, and the time unit is T_p, defined in Table 3-7.

Channel Number	Pulse Duration T_p (ns)	Main Lobe Width T_w (ns)
{0:3, 5:6, 8:10, 12:14}	2.00	0.5
7	0.92	0.2
{4, 11}	0.75	0.2
15	0.74	0.2

Table 3-7 Reference pulse durations in each UWB channel (Table 15-12 in [4])

The pulse should monotonically rise to a first peak amplitude; the first peak amplitude is defined as the maximum amplitude of the pulse before it first drops more than 1.25%.

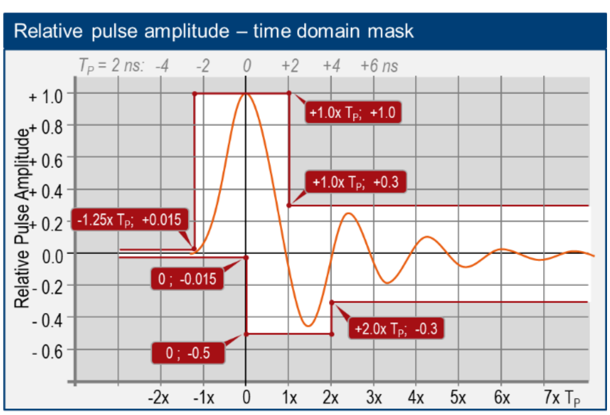


Figure 3-60 Time domain mask of HRP UWB PHY pulse with 2 ns T_p

Designation	Time Interval x T_p (X-axis)	Limit Value (Y-axis)
Area 1 (Lower)	[-3, 0]	-0.015
Area 2 (Lower)	[0, 2]	-0.5
Area 3 (Lower)	[2, 3]	-0.3
Area 1 (Upper)	[-3, -1.25]	0.015
Area 2 (Upper)	[-1.25, 1]	1.0
Area 3 (Upper)	[1, 3]	0.3

Table 3-8 Limit line definition of pulse amplitude mask

The result shown in Figure 3-59 gives the result in margin value, that means

$Margin = Limit\ Value - Measured\ Value$

So, if the margin value is > 0, then the measured value is within the mask, otherwise, the measured value exceeds the defined limit.

3.4.1.6 SHR/PHR/PSDU/STS NRMSE

Normalized Root Mean Square Error (NRMSE) measurements over SHR/PHR/PSDU/STS is based on Fira specification in chapter "Transmit Signal Quality"

For SHR and STS: NRMSE < 25%

For PHR and PSDU: NRMSE < 30%

3.4.1.7 AVG PHR/PSDU/STS Pulse Level, relative to SHR

Average PHR/PSDU/STS pulse level relative to SHR is based on Fira specification in chapter "Transmit Signal Quality". It should be no larger than ± 2dB.

3.4.1.8 Transmit Spectrum Mask

As specified in Chapter 15.4.5 of [4], the transmitted spectrum shall be less than –10 dB relative to the maximum spectral density of the signal for $0.65/T_p < |f - f_c| < 0.8/T_p$ and –18 dB for $|f - f_c| > 0.8/T_p$, where f_c is the center frequency of the channel, T_p is pulse duration of the associated channel. The measurements shall be made using a 1 MHz resolution bandwidth and a 1 kHz video bandwidth.

Table 3-9 gives an overview of the limit lines of the transmit PSD mask with respect to different pulse durations.

Channel Number	Pulse Duration T_p (ns)	$\|f - f_c\|$	
		-10 dB	-18 dB
{0:3, 5:6, 8:10, 12:14}	2.00	325 MHz	400 MHz
7	0.92	705 MHz	870 MHz
{4, 11}	0.75	867 MHz	1067 MHz
15	0.74	878 MHz	1081 MHz

Table 3-9 Transmit spectrum mask limit lines

For example, channel 9 operates at 7.987 GHz (f_c) and has 2 ns pulse duration. The transmit spectrum mask for channel 9 is therefore shown as in Figure 3-61.

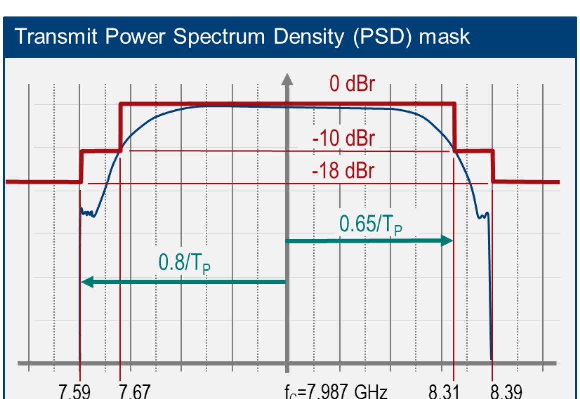


Figure 3-61 Transmit spectrum mask for channel 9

Designation	Frequency Range (X-axis)	Limit Value (Y-axis)
Area 1	$[0.65/T_p, 0.8/T_p]$	-10 dB
Area 2	$> 0.8/T_p$	-18 dB

Table 3-10 Limit line definition of transmit spectrum mask

The result evaluation is based on margin, where

$$Margin = Limit\ Value - Measured\ Value$$

So, if the margin value is > 0, then the measured value is within the mask, otherwise, the measured value exceeds the defined limit.

3.4.1.9 Max Spectral Power [dBm/MHz]

The maximum mean spectral power measured with 1 MHz resolution bandwidth (RBW). The power is measured over the PPDU or over 1 ms starting with the PPDU [15]. According to FCC requirement, max spectral power density should be lower than -41.3 dBm/MHz.

3.4.1.10 Max Peak Spectral Power [dBm/50MHz]

The maximum peak spectral power measured with 50 MHz resolution bandwidth (RBW) [15]. According to FCC section 15, it should be lower than 0 dBm/50 MHz

3.4.2 Receiver Sensitivity

Receiver sensitivity is the lowest receive signal power level at which the DUT achieves the packet error rate (PER) ≤ 1%. It is based on Fira specification in chapter "Packet Reception Sensitivity".

Follow the steps shown in Figure 3-62 to create and configure Rx sensitivity test routine.

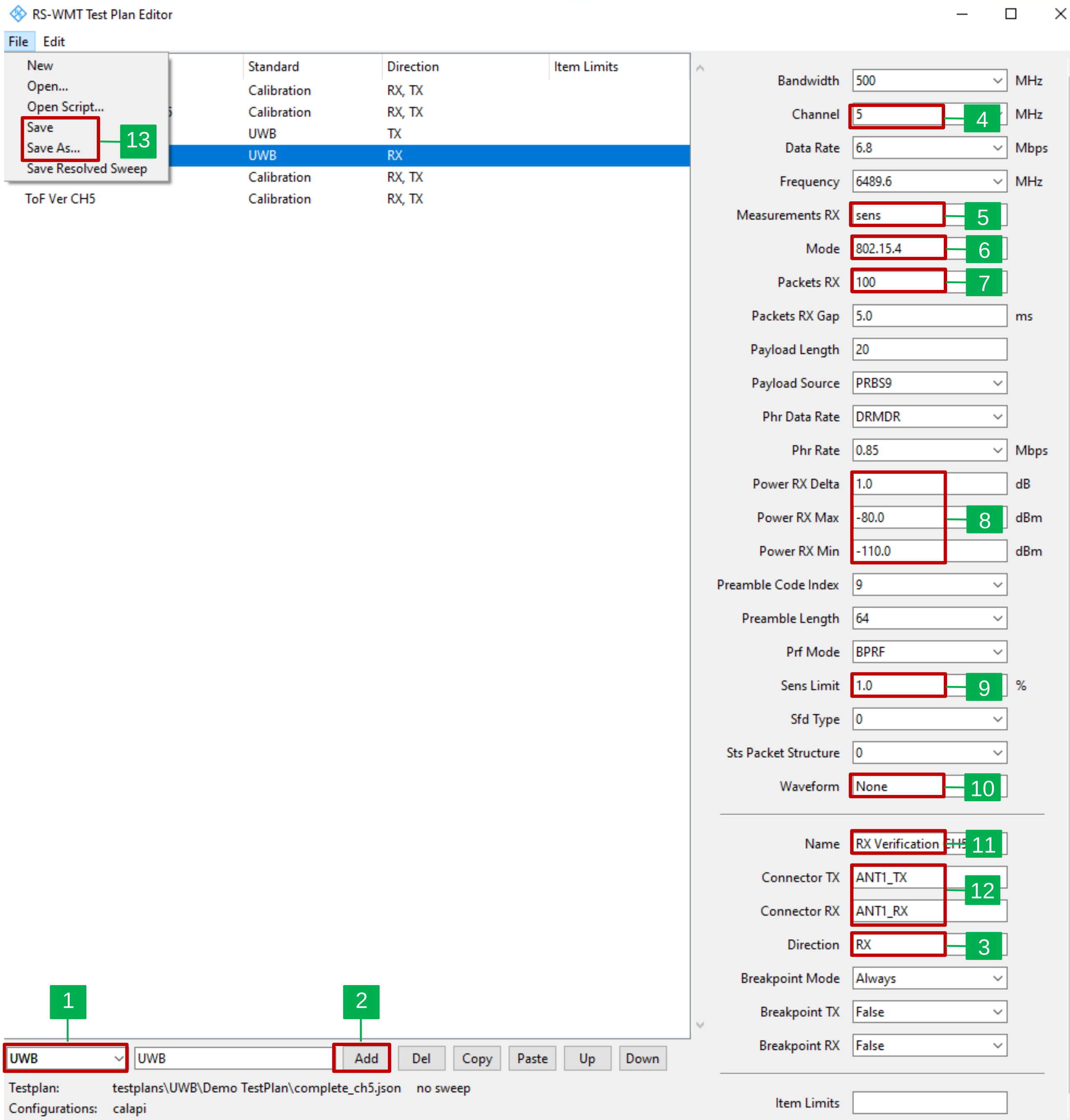


Figure 3-62 Create and configure a Rx verification routine in Test Plan Editor

1. In Test Plan Editor, choose 'UWB' in the standard selection field
2. Press 'Add' to add the verification routine
3. Choose 'Rx' direction
4. Select the UWB channel, e.g. Channel 5
5. Select 'Sens' Rx measurements from the list (see Figure 3-58)

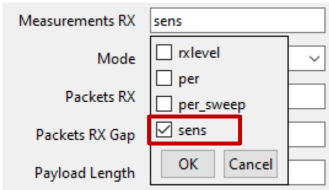
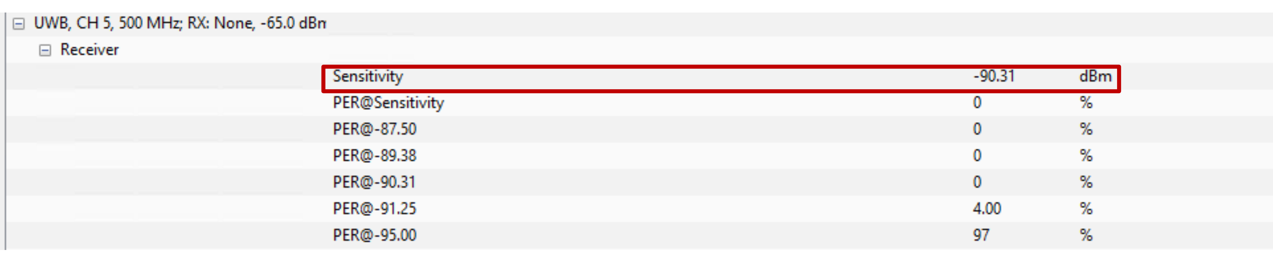


Figure 3-63 Select 'Sens' from Rx measurement items

6. Select the UWB standard
7. Specify the number of receive packets
8. Define the initial receiver power level range (max, min) and delta value for terminating the sensitivity search, default settings Power Rx Max -80 dBm, Power Rx Min -110 dBm, delta 1 dB can be kept. Refer to Appendix F on page 70 to get insight of receiver sensitivity search
9. Specify the receiver sensitivity limit, default setting 1% may be kept
10. Use default value 'None' in waveform field. The waveform file will be generated on the fly via WinIQSIM.
11. Name the verification routine, e.g. 'Rx Verification CH5'
12. Specify the connector name for both connectors in Tx and Rx direction, e.g. 'ANT1_TX', 'ANT1_RX'. The specified connector name should match the one in the `testconfig.ini` file (cf. 3.3.1 to get to know the association between FDC and connector)
13. Under main menu bar, go to File > Save/Save As … to save the test plan



UWB, CH 5, 500 MHz; RX: None, -65.0 dBm
Receiver

Sensitivity	-90.31	dBm
PER@Sensitivity	0	%
PER@-87.50	0	%
PER@-89.38	0	%
PER@-90.31	0	%
PER@-91.25	4.00	%
PER@-95.00	97	%

Figure 3-64 Rx verification results in Test Runner

After the execution of the Rx verification routine in Test Runner (cf. 3.2.2), the result in Figure 3-64 shows that the PER achieves 0% (< 1% limit) at when receiver power level is at -90.31 dBm. The receiver sensitivity of this DUT is -90.31 dBm.

3.4.3 ToF Ranging (SS-TWR)

The same principle as ToF calibration shown in Figure 3-51 is considered here. However, in ToF ranging verification routine, the task here is to verify the ranging distance D or equivalently the ToF between the Vivaldi antenna and DUT antenna given that the DUT internal antenna delay $T_{RX} + T_{TX}$ is known after the ToF calibration routine (cf. 3.3.2.3).

Follow the steps indicated in Figure 3-65 to create and configure ToF verification routine.

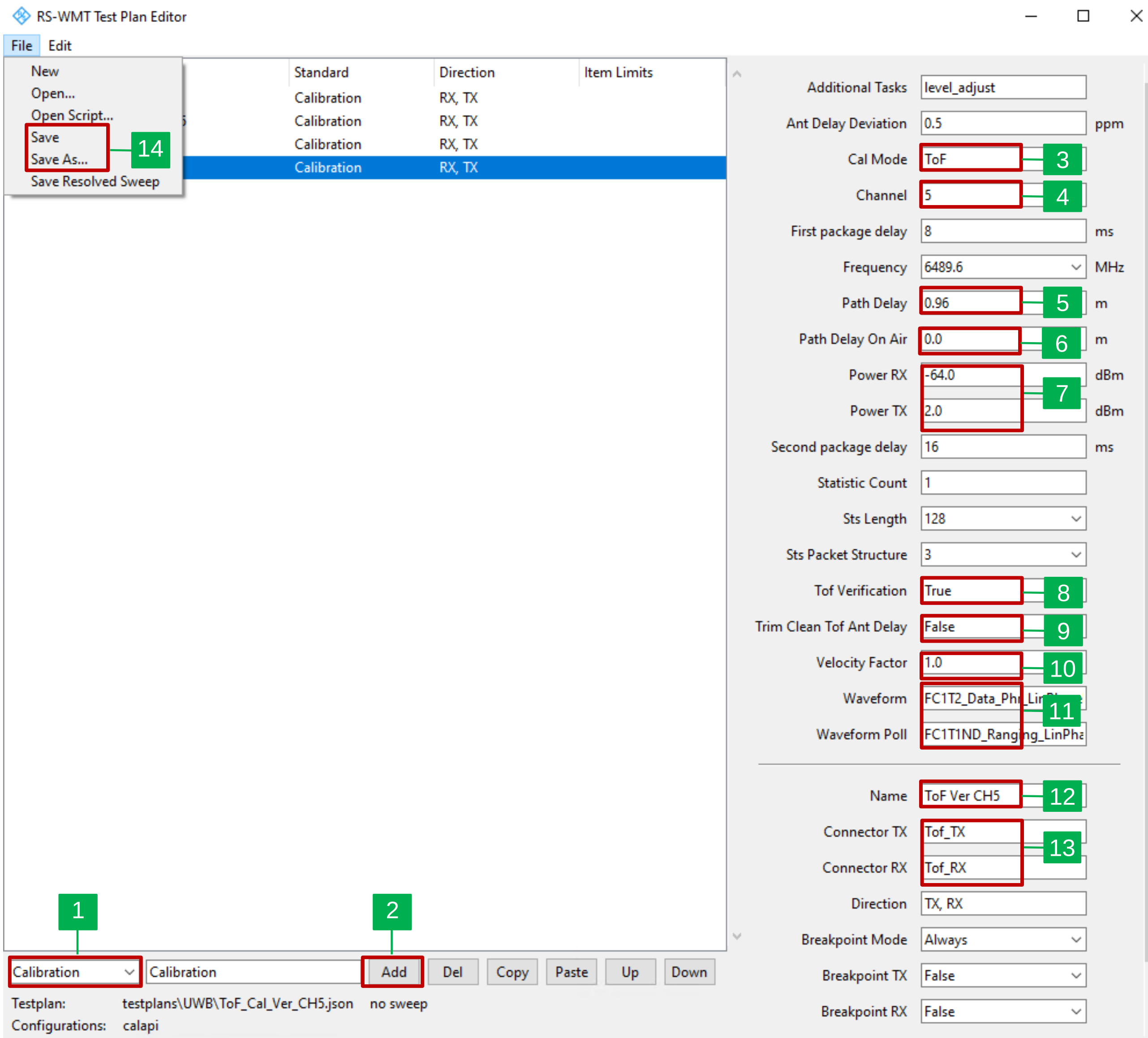


Figure 3-65 Create and configure a ToF verification routine in Test Plan Editor

1. In Test Plan Editor, choose 'Calibration' in the standard selection field
2. Press 'Add' to add the calibration routine
3. Choose 'ToF' as calibration mode
4. Select the UWB channel, e.g. Channel 5
5. Enter the fixed group delay, 0.96 m ($T_{tof\_fix\_switch}$ for system variant 2) or 0.87 m ($T_{tof\_fix\_feedthrough}$ for system variant 1) (cf. 3.3.2.3)
6. Enter '0' in path delay for verification purpose
7. Enter proper DUT Rx Power and Tx Power level. Refer to Appendix D on page 68 to learn more about the determination of both power levels (**Attention:** improper power level might lead to unstable signal detection at CMP200)
8. Set ToF Verification to 'True' to indicate this is a verification routine
9. Set Trim Clean ToF Ant Delay flag to 'False' to indicate to keep the antenna delay trim value on the DUT
10. Set Velocity Factor to '1' as the signal propagates in air

11. Keep the default waveform file name.

    Two waveform files should be uploaded to CMP200 before the test starts (waveform file handling, see Appendix E on page 69)

    – Waveform file #1 (Pre_Poll packet):

      `FC1T2_Data_Phr_LinPhaseRRC0p45_waveform_1_resample.wv`

    – Waveform file #2 (Poll packet):

      `FC1T1ND_Ranging_LinPhaseRRC0p45_waveform_2_resample.wv`

12. Name ToF calibration routine, e.g. 'ToF Ver CH5'
13. Specify the connector name for both connectors in Tx and Rx direction for ToF calibration, e.g. 'ToF_TX', 'ToF_RX'. The specified connector name should match the one in the `testconfig.ini` file (cf. 3.3.1 to get to know the association between FDC and connector)
14. Under main menu bar, go to File > Save/Save As … to save the test plan

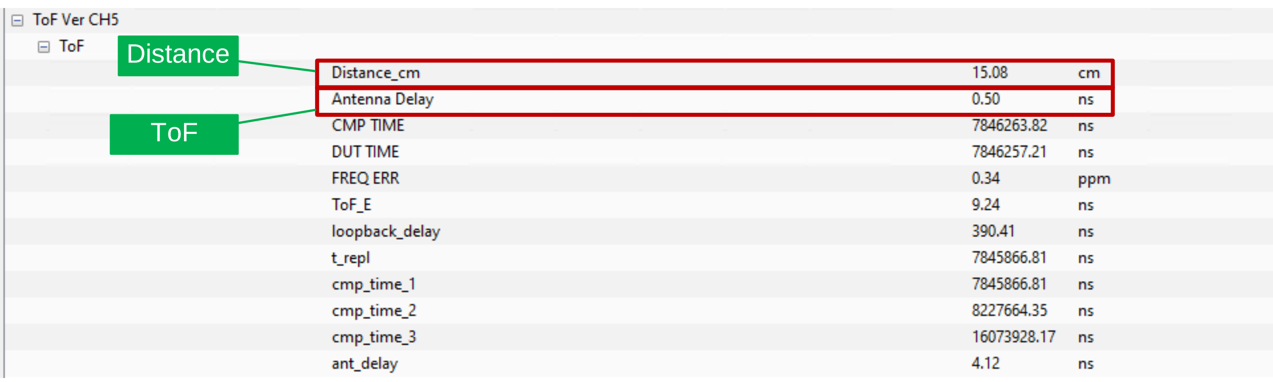


Figure 3-66 ToF verification results in Test Runner

After the ToF verification routine is executed in Test Runner (cf. 3.2.2), the verification result indicates the measured distance between Vivaldi antenna and DUT antenna in centimeter and the corresponding ToF in the air. In the result example shown in Figure 3-66, the ranging result is 15.08 cm which is quite precise (the physical distance between Vivaldi antenna and DUT antenna is 15 cm).

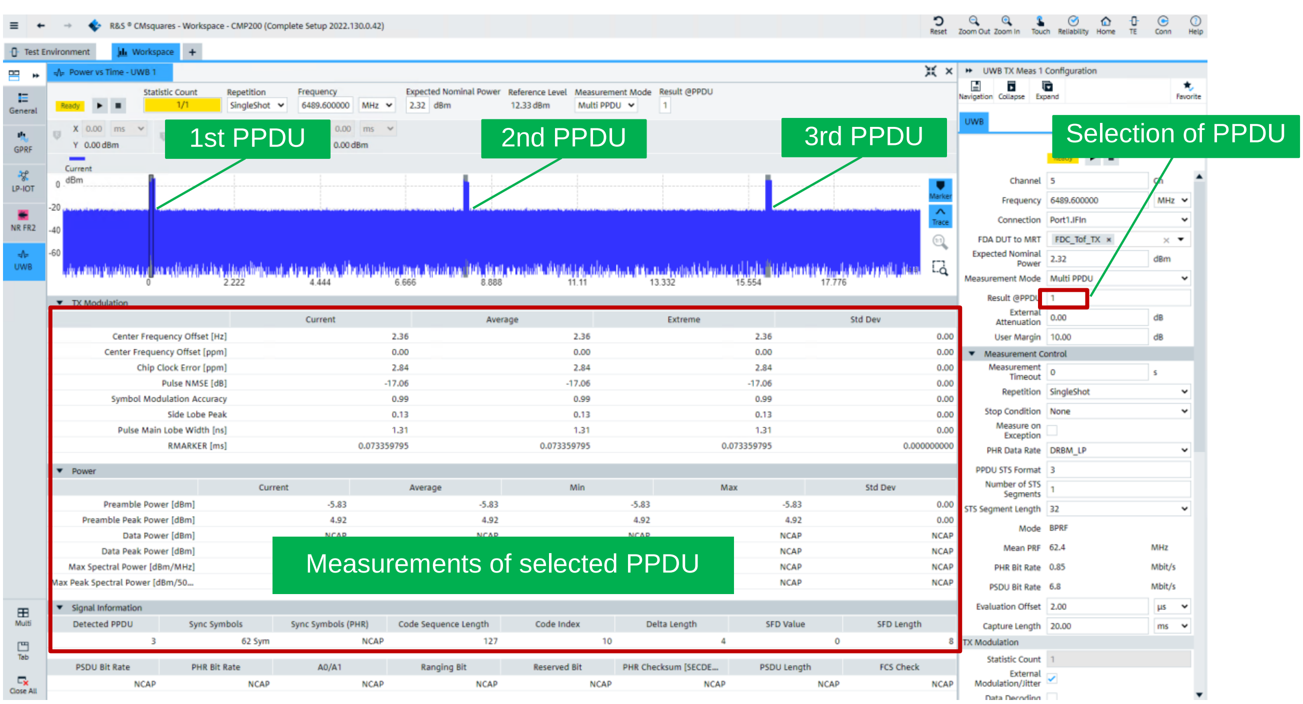


Figure 3-67 Measurements on PPDU of a ToF session

In addition to WMT, CMP200 Power vs. Time (PvT) square of CMsquares delivers an overview of the ToF session with measurement on each PPDU that is detected by CMP200. As shown in Figure 3-67, altogether 3 PPDUs are detected during the whole ToF session. By selecting the PPDU number in the UWB measurement configuration, the measurement details of the selected PPDU are presented.

4 Literature

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[13] R&S®, "R&S®CMP200 Radio Communication Tester User Manual".

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[15] R&S®, "R&S®CMP200 UWB Tx Measurements User Manual".

5 Appendix

A Data Sheet of Mini-circuits Power Splitter/Combiner ZFRSC-183+

Typical Performance Data

Frequency (MHz)	Total Loss[1] (dB)		Amplitude Unbalance (dB)	Isolation (dB)	Phase Unbalance (deg.)	VSWR S	VSWR 1	VSWR 2
	S-1	S-2						
500.00	6.05	6.07	0.01	6.05	0.01	1.02	1.01	1.01
1000.00	6.07	6.08	0.02	6.06	0.08	1.02	1.02	1.02
2000.00	6.09	6.13	0.04	6.08	0.26	1.02	1.01	1.01
3000.00	6.19	6.22	0.02	6.26	0.28	1.06	1.04	1.04
4500.00	6.27	6.34	0.07	6.36	0.05	1.06	1.04	1.01
6000.00	6.30	6.36	0.07	6.22	0.01	1.07	1.12	1.09
7500.00	6.37	6.39	0.03	6.38	0.08	1.06	1.07	1.06
9000.00	6.34	6.44	0.10	6.67	0.22	1.15	1.03	1.05
10500.00	6.51	6.62	0.11	6.82	0.10	1.17	1.06	1.03
12000.00	6.76	6.82	0.05	6.58	0.91	1.16	1.03	1.06
13500.00	6.82	6.87	0.05	6.47	0.18	1.06	1.15	1.16
15000.00	7.37	7.32	0.05	7.57	0.01	1.12	1.32	1.29
16500.00	7.25	7.04	0.21	7.35	0.78	1.34	1.40	1.25
17000.00	6.79	6.59	0.19	6.84	0.59	1.29	1.34	1.18
18000.00	6.07	5.91	0.15	6.32	0.57	1.07	1.19	1.13

1. Total Loss = Insertion Loss + 6dB splitter loss.

Table 5-1 Mini-circuits Power Splitter/Combiner ZFRSC-183+ Performance Data (Source: Mini-circuits)

B Parameters in WMT Test Plan Editor

B.1 Common Settings

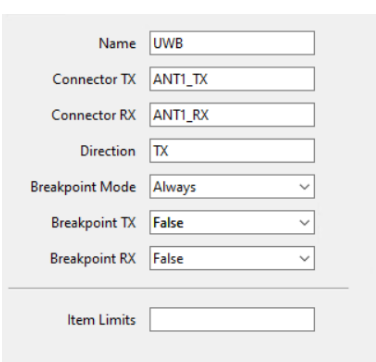

Figure 5-1 Common settings

Parameter	Description	Setting
Name	The name of the test routine	Any
Connector TX	Connector identifier of DUT transmission path, i.e. from DUT to CMP200	The name should match the corresponding section name in `testconfig.ini` file (cf. 3.3.1)
Connector RX	Connector identifier of DUT receiver path, i.e. from CMP200 to DUT	The name should match the corresponding section name in `testconfig.ini` file (cf. 3.3.1)
Direction	Specify the direction from DUT's point of view	TX and/or RX
Breakpoint Mode	Enable the breakpoint mode so that the test routine is halted that allows the user to start and check the	Always / On Failure

Parameter	Description	Setting
	measurements in CMsquares manually given that the test routine supports the breakpoint feature. This is mainly required for debugging purposes	
Breakpoint TX	Turn on/off the breakpoint for Tx test routine	True / False
Breakpoint RX	Turn on/off the breakpoint for Rx test routine	True / False

Table 5-2 Common settings of a test plan in Test Plan Editor

B.2 Configurations of Transmitter Tests

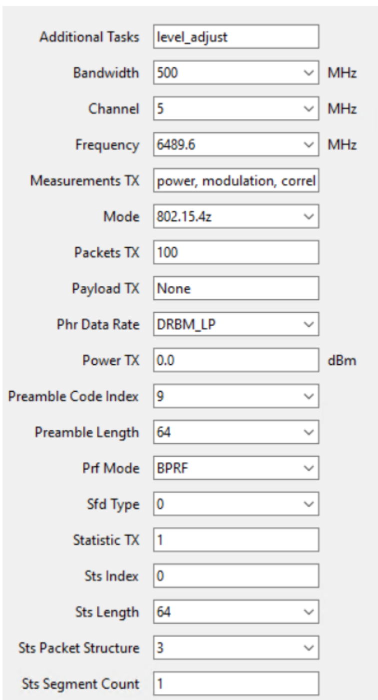

Figure 5-2 Configurations of transmitter tests with STS packet structure 3 (SP3)

Parameter	Description	Setting
Additional Tasks	Automatic level adjustment (auto ranging)	Enable / Disable
Bandwidth	UWB channel bandwidth	See Table 1-1
Channel	UWB channel	See Table 1-1
Data Rate	PSDU bit rate (cf. 1.3.4). The field is hidden if STS packet structure 3 is chosen.	See Table 1-5, Table 1-6 and Table 1-7
Frequency	Channel center frequency	See Table 1-1
Measurement Tx	Transmitter test items	Power / Modulation / Correlation / Chip Jitter / Symbol Jitter / Mask / PvT / Signal Info
Mode	UWB standard	802.15.4 / 802.15.4z
Packets Tx	Number of the transmitted packets	0…5000
Payload Tx	Payload for transmitter test, only required if SP0	SP0: Mandatory, e.g. 0x01,0x02,0x03 SP3: None
PHR Data Rate	PHR data rate mode (cf. 1.3.4).	802.15.4: DRMDR 802.15.4z: DRBM_LP / DRBM_HP / DRHM_LR / DRHM_HR
PHR Rate	PHR bit rate (cf. 1.3.4). The field is hidden if STS packet structure 3 is chosen.	See Table 1-5, Table 1-6 and Table 1-7
Power Tx	The nominal Tx power setting	-12 dBm to +14 dBm (Resolution: 0.25 dBm)
Preamble Code Index	Set the preamble code index	See 1.3.3.1
Preamble Length	Number of preamble symbol repetitions (cf. 1.3.3.1)	16 / 32 /64 / 1024 / 4096
PRF Mode	Specify the PRF Mode	BPRF / HPRF
SFD Type	Specify SFD type (cf 1.3.3.2)	0 / 1 / 2 / 3 / 4 (see Table 1-4)

Parameter	Description	Setting
Statistic Tx	Number of repetitions of the measurements	>0
STS Index	Specify current STS index (cf 1.3.5). The field is hidden if STS packet structure 0 is chosen	See Table 1-8
STS Length	Specify STS length (cf 1.3.5). The field is hidden if STS packet structure 0 is chosen	See Table 1-8
STS Packet Structure	STS packet structure defined in 802.15.4z (cf. 1.3.5)	0 / 1 / 2 / 3[XI]
STS Segment Count	Specify STS segment count (cf 1.3.5). The field is hidden if STS packet structure 0 is chosen	See Table 1-8

Table 5-3 Settings of Tx test in Test Plan Editor

B.3 Configurations of Receiver Tests

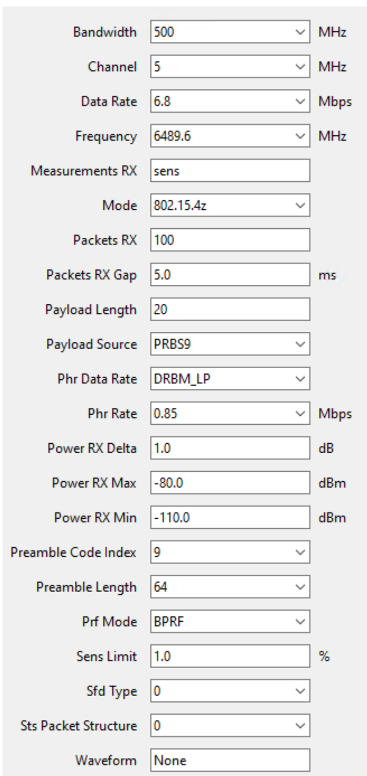

Figure 5-3 Configuration of receiver tests with STS packet structure 0 (SP0)

Parameter	Description	Setting
Bandwidth	UWB channel bandwidth	See Table 1-1
Channel	UWB channel	See Table 1-1
Data Rate	PSDU bit rate (cf. 1.3.4). The field is hidden if STS packet structure 3 is chosen.	See Table 1-5, Table 1-6 and Table 1-7
Frequency	Channel center frequency	See Table 1-1
Measurement Rx	Select the types of receiver tests	RxLevel / PER / PER Sweep / Sens
Mode	UWB standard	802.15.4 / 802.15.4z
Packets Rx	Number of receive packets	0…5000
Packets Rx Gap	Idle time between two consecutive packets sent to the DUT	0…100 ms

[XI] NXP NCJ29D5 UCI Specification Rev. 1.16 - 7 July 2021 only supports SP0 and SP3

Parameter	Description	Setting
Payload	Payload for receiver tests. The payload should be specified here only if payload source is set to 'List'. The field is hidden if STS packet structure 3 is chosen.	0x618801CADE9A555352434E35EC65270AB591
Payload Length	Payload length. It is not required to be set if payload source is set to 'List'. The field is hidden if STS packet structure 3 is chosen.	0..127
Payload MAC FCS	Activates / Deactivates the MAC Frame Check Sequence (FCS) field. This parameter setting is only required if payload source is set to 'List'. The field is hidden if STS packet structure 3 is chosen.	True / False
Payload Source	Select the data source List: A binary file PRBS9: Pseudo-random binary sequence (PRBS) with word length of 9 bits All0: internally generated sequence containing all 0 data All1: internally generated sequence containing all 1 data The field is hidden if STS packet structure 3 is chosen.	List / PRBS9 / All0 / All1
PHR Data Rate	PHR data rate mode (cf. 1.3.4).	802.15.4: DRMDR 802.15.4z: DRBM_LP / DRBM_HP / DRHM_LR / DRHM_HR
PHR Rate	PHR bit rate (cf. 1.3.4). The field is hidden if STS packet structure 3 is chosen.	See Table 1-5, Table 1-6 and Table 1-7
Power Rx Delta	Specify the power difference between maximum receive power level and minimum receive power (cf. Appendix F)	e.g. 1 dB
Power Rx Max	Specify the initial maximum receive power level (cf. Appendix F)	e.g. -80 dBm
Power Rx Min	Specify the initial minimum receive power level (cf. Appendix F)	e.g. -110 dBm
Preamble Code Index	Set the preamble code index	See 1.3.3.1
Preamble Length	Number of preamble symbol repetitions (cf. 1.3.3.1)	16 / 32 /64 / 1024 / 4096
PRF Mode	Specify the PRF Mode	BPRF / HPRF
Sens Limit	Specify the receiver sensitivity limit	e.g. 1%
SFD Type	Specify SFD type (cf 1.3.3.2)	0 / 1 / 2 / 3 / 4 (see Table 1-4)
STS Index	Specify current STS index (cf 1.3.5). The field is hidden if STS packet structure 0 is chosen	See Table 1-8
STS Length	Specify STS length (cf 1.3.5). The field is hidden if STS packet structure 0 is chosen	See Table 1-8
STS Packet Structure	STS packet structure defined in 802.15.4z (cf. 1.3.5)	0 / 1 / 2 / 3 (see footnote XI on page **Fehler! Textmarke nicht definiert.**)
STS Segment Count	Specify STS segment count (cf 1.3.5). The field is hidden if STS packet structure 0 is chosen	See Table 1-8
Waveform	Specify the waveform filename used for playback on the CMP200. If text 'None' is given, then the waveform file is generated on the fly with the parameter settings given in the configuration fields above.	'None' or enter the waveform filename that has been uploaded in CMP200. See Appendix E for more details about waveform file handling.

Table 5-4 Settings of Rx test in Test Plan Editor

B.4 Configurations of ToF

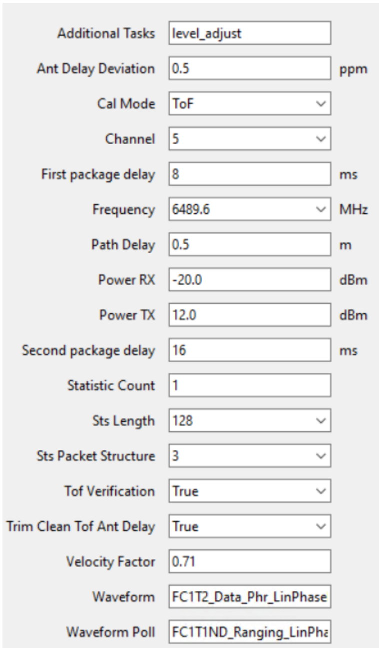

Figure 5-4 Configurations of ToF tests with STS packet structure 3 (SP3)

Parameter	Description	Setting
Additional Tasks	Level adjustment	Enable / Disable
Ant Delay Deviation	Specify the deviation of antenna delay	e.g. 0.5 ppm
Cal Mode	Select the calibration mode	ToF
Channel	UWB channel	See Table 1-1
First Package Delay	Fix value of NXP chip (NXP NCJ29D5)	8
Frequency	Channel center frequency	See Table 1-1
Path Delay	Fix path delay from the splitter to Vivaldi antenna aperture	0.87 for system variant 1 (with RF feedthrough)[XII] 0.96 for system variant 2 (with RF switch)
Path Delay On Air	Free space distance in meter /	ToF calibration routine: enter free space distance in meter between Vivaldi antenna and DUT antenna ToF verification routine: 0
Power Rx	DUT receive power level	See Appendix D
Power Tx	DUT transmit power level	See Appendix D
Second Package Delay	Fix value of NXP chip (NXP NCJ29D5)	16
Statistic Count	Number of the measurement repetitions	>1
STS Length	Specify STS length (cf 1.3.5).	See Table 1-8
STS Packet Structure	Packet structure defined in 802.15.4z (cf. 1.3.5) containing STS portion	1 / 2 / 3 (see footnote XI on page **Fehler! Textmarke nicht definiert.**)
ToF Verification	Indicate if this is a ToF verification routine	True / False
Trim Clean TOF Ant Delay	Reset ToF antenna delay trim value on the device	True / False
Velocity Factor	Specify the velocity factor in the air	1
Waveform	Waveform file for pre-poll (NXP specific)	'FC1T2_Data_Phr_LinPhaseRRC0p45_waveform_1_resample.wv'

[XII] The calculated value includes the group delay on a 6 dB attenuator. For calculation details, please refer to chapter 3.3.2.3

Parameter	Description	Setting
Waveform Poll	Waveform file for poll message (NXP specific)	'FC1T1ND_Ranging_LinPhaseRRC0p45_waveform_2_resample'

Table 5-5 Settings of ToF test in Test Plan Editor

C Test Plan Configuration File (`testconfig.ini`)

To execute a test plan in Test Runner, a test configuration file needs to be assigned to each test run.

The test configuration is a plain text file with `.ini` as file extension and located in sub-folder `\etc` under the WMT installation directory. As per default, the configuration file is called `testconfig.ini`. The filename can of course be user defined.

Table 5-6 below lists the entries in an example `testconfig.ini` configuration file. The mnemonics in the square brackets indicates the beginning of a configuration section.

Test Configuration	Comment
[general]	
testplan = testplans/UWB/test_UWB_TX_CH5.json	Selected test plan
;testplan = testplans/UWB/test_UWB_RX_PER_65_CH5.json	De-selected test plan started with semi-colon in front of the line
logs = etc/logs	Logfile location
results = etc/results	Result file location
limitcheck = True	Enable limit check
loglevel = debug	Define log level (debug / info)
results_json = False	Result file in JSON format
results_txt = True	Result file in text format
[logging]	
level = debug	Level definition (debug / info)
format = %(asctime)s %(levelname)s:%(name)s %(message)s	Logging format
[uwb]	
connection = serial	Defines the connection type of DUT used by UWB verification routine
port = COM3	Specify the virtual COM port of the connected DUT. Check Windows device manager to obtain the used COM port.
baudrate = 460800	Defines the baud rate of the serial connection
driver = nxp.ncj29d5.ncj29d5_uci	Specify DUT's UCI control driver in WMT which is part of the WMT installation. The driver itself is located in the sub-folder `dutdriver\` under the WMT installation directory
timeout = 0.1	Serial communication time out value
keep_open = True	Keep serial port open
[calibration]	
api = nxp.ncj29d5.calapi	Specify the DUT calibration API which is part of the WMT installation. The API is located in the sub-folder `calibration\` under the WMT installation directory
connection = serial	Defines the connection type of DUT used by UWB calibration routine
port = COM3	Specify the virtual COM port of the connected DUT. Check Windows device manager to obtain the used COM port.
driver = nxp.ncj29d5.ncj29d5_uci	Specify DUT's UCI control driver in WMT which is part of the WMT installation. The driver itself is located in the sub-folder `dutdriver\` under the WMT installation directory

Test Configuration	Comment
baudrate = 460800	Defines the baud rate of the serial connection
timeout = 0.1	Serial communication time out value
keep_open = True	Keep serial port open
[instrument]	
connection = socket	Defines remote control interface of CMP200. A socket connection is used.
host = 10.202.1.50	Specify the IP address of CMP200
port = 5025	Specify the port number of socket connection. Port 5025 is the VISA default port for a raw socket connection.
timeout = 10	Defines the remote port timeout timer
[arbgen]	
enabled = True	Activate the ARB generator by using WinIQSIM2 software
connection = socket	Defines socket connection to the ARB generator
host = 127.0.0.1	Specify the IP address of ARB generator. Local host IP 127.0.0.1 is used here, meaning the WinIQSIM2 software runs on the same PC as the WMT
port = 5025	Specify the port number of socket connection. Port 5025 is the VISA default port for a raw socket connection.
timeout = 5	Defines the remote port timeout timer
[relay]	
enabled = True	Activate the control of RF switch on CMQ chamber
connection = socket	Defines remote control interface of CMQ. A socket connection is used.
host = 192.168.178.41	Specify the IP address of CMQ. This is a fixed IP.
port = 5000	Specify the port number of socket connection. Port 5000 is a fixed port number for CMQ chamber
timeout = 5	Defines the remote control timeout timer
termchar = \r	Define the termination character of the remote control command
driver = wmt.equipment.cmq	Specify CMQ control driver which is part of the WMT installation. The driver is located in sub-folder `wmt\equipment` under WMT installation directory. A driver named cmq is used in this example
[ANT1_TX]	Section name ANT1_TX can be user defined. This is the identifier of the connection. The name should match the one entered in Connector TX field of the common setting part of the Test Plan Editor (see Table 5-2)
connector = Port1.IFIn	Specify the Port1.IFIn connector on CMP200 according to the physical cable connection
fdc = FDC_ANT1_TX	Specify the FDC table name that is associated to this connection
relay = 1.1.1	Specify the relay position in CMQ (cf. 3.1.1.6)
[ANT1_RX]	Section name ANT1_RX can be user defined. This is the identifier of the connection. The name should match the one entered in Connector RX field of the common setting part of the Test Plan Editor (see Table 5-2)
connector = Port1.IFOut	Specify the Port1.IFOut connector on CMP200 according to the physical cable connection
fdc = FDC_ANT1_RX	Specify the FDC table name that is associated to this connection
relay = 1.1.1	Specify the relay position in CMQ (cf. 3.1.1.6)
[FDC_ANT1_RX]	FDC named FDC_ANT1_RX
6500.0 = 36.3	Frequency in MHz, attenuation in dB (see Table 3-3)
8000.0 = 38.4	Frequency in MHz, attenuation in dB (see Table 3-3)
[FDC_ANT1_TX]	FDC named FDC_ANT1_TX

Test Configuration	Comment
6500.0 = 36.3	Frequency in MHz, attenuation in dB (see Table 3-3)
8000.0 = 38.4	Frequency in MHz, attenuation in dB (see Table 3-3)

Table 5-6 Example of a `testconfig.ini` file

D Power Level Settings for ToF Testing

As illustrated in Figure 3-51, when performing ToF calibration/verification, CMP200 receives two packets at time instance t_2 and t_4 on which the T_{ROUND} calculation is based. The power level of these two packets at the CMP200 IFin port should fulfill following criteria to ensure the stable signal detection:

1. absolute power level of both detected packets $P_{CMP\_IFin\_P1}$ and $P_{CMP\_IFin\_P2}$ arriving at t_2 and t_4 at CMP200 IFin port should be no less than -50 dBm, respectively, where $P_{CMP\_IFin\_P1}$ is the power level of the poll packet routed back from the splitter, $P_{CMP\_IFin\_P2}$ is the power level of the DUT's response packet.
2. the relative power level difference between $P_{CMP\_IFin\_P1}$ and $P_{CMP\_IFin\_P2}$ should be no larger than 10 dB

In case the criteria are not fulfilled, the attenuators coming along with the UWB ToF Kit (R&S CM-Z300A) can be added in the signal path to adjust the power level.

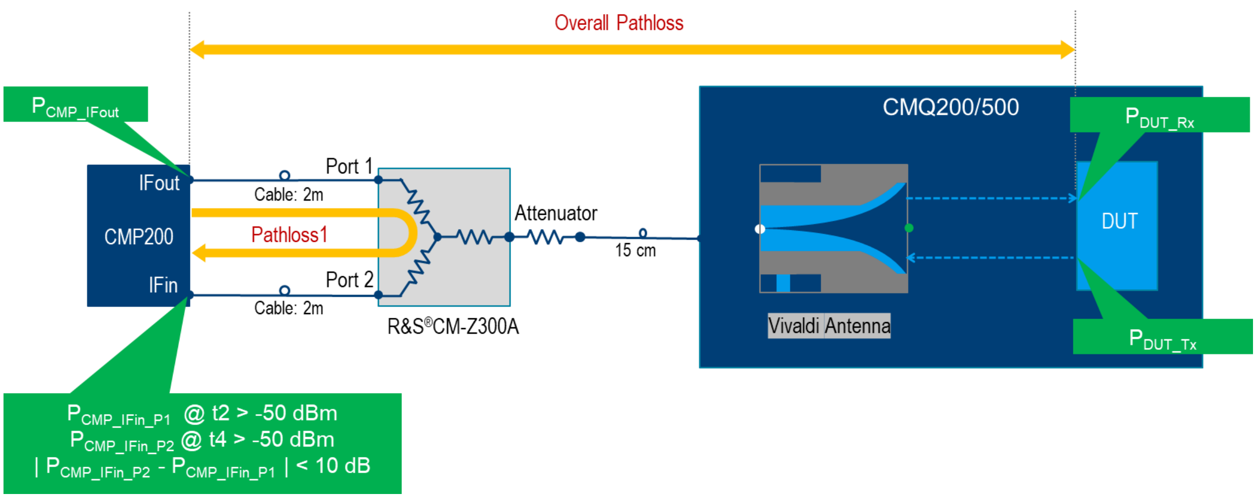

Figure 5-5 Power level consideration for ToF calibration/verification

Hereafter are the equations that are used for the power level calculations.

Equation 5-1

$$P_{DUT\_Rx} = P_{CMP\_IFout} - Overall\ Pathloss$$

where overall pathloss on the signal path is given in Table 3-3. P_{DUT_Rx} is the DUT receive power that needs to be entered (power RX, cf. Chapter 3.3.2.3, Chapter 3.4.3 and Appendix B.4) in Test Plan Editor for the ToF calibration/verification routine. P_{CMP_IFout} is the output power level at the IFout port of CMP200.

Equation 5-2

$$P_{DUT\_Tx} < 14\ \text{dBm}$$

P_{DUT_Tx} is the DUT transmit nominal power that needs to be entered (power TX, cf. Chapter 3.3.2.3, Chapter 3.4.3 and Appendix B.4) in Test Plan Editor for the ToF calibration/verification routine. This is the value specified by DUT vendor. In our example here, it is defined by NXP in [14].

Equation 5-3

$$P_{CMP\_IFin\_P1} = P_{CMP\_IFout} - Pathloss1$$

where pathloss1 denotes the loss on 2 cables (2 meter of each) connected between CMP200 and splitter, and isolation between port1 and port2 of the splitter. Typical pathloss on a cable is about 2.2 dB. The exact isolation of the splitter in the operation frequency can be found in the datasheet of the splitter in Appendix A.

Equation 5-4

$$P_{CMP\_IFin\_P2} = P_{DUT\_Tx} - Overall\ Pathloss$$

After the DUT power RX P_{DUT_Rx} and power TX P_{DUT_Tx} are configured for the ToF calibration/verification routine, all power levels at CMP200 side P_{CMP_IFout}, $P_{CMP\_IFin\_P1}$ and $P_{CMP\_IFin\_P2}$ are determined by applying the equations given above. Check the mentioned two criteria at the beginning of this chapter to see if the criteria are fulfilled, if not, try to go another iteration by adjusting the different P_{DUT_Rx} and P_{DUT_Tx} value until the criteria are met.

In the following example, DUT is positioned 15 cm apart from Vivaldi measurement antenna. The chamber is equipped with RF switch (system variant 2). No attenuator is connected in the signal path. The tested UWB channel is 5 (6.5 GHz). With this setup and configuration, the power level and pathloss applied for the level calculation are listed in Table 5-7 below.

Power Level/Pathloss	Value	Remark
P_{DUT_Rx}	-64 dBm	DUT Rx power level configured in WMT
P_{DUT_Tx}	2 dBm	DUT Tx power level configured in WMT
$Overall\ Pathloss$	36,3	Lookup Table 3-3 (system variant 2, with 6 dB attenuator)
P_{CMP_IFout}	-27.7 dBm	Apply Equation 5-1
$P_{CMP\_IFin\_P2}$	-34.3 dBm	Apply Equation 5-4, > -50 dBm
$Pathloss1$	10.62 dB (2 x 2.2 dB on cable + 6.22 dB isolation)	Fixed value
$P_{CMP\_IFin\_P1}$	-38.32 dBm	Apply Equation 5-3, > -50 dBm
$\lvert P_{CMP\_IFin\_P1} - P_{CMP\_IFin\_P2} \rvert$	4.02 dB	< 10 dB

Table 5-7 Example of power level settings for ToF calibration/verification

With the settings given in this example, the power level criteria are fulfilled, i.e. $P_{CMP\_IFin\_P1}$ and $P_{CMP\_IFin\_P2}$ are higher than -50 dBm. And difference of them is 4.02 dB which is lower than 10 dB. The calculation confirms that P_{DUT_Rx} and P_{DUT_Tx} values entered in WMT Test Plan Editor are valid.

A calculator called 'UWB Power Level Calculation' is available in Gloris (https://gloris.rohde-schwarz.com/) for download. With this tool, the determination of P_{DUT_Rx} and P_{DUT_Tx} is becoming much easier.

E Waveform File Handling

Waveform file or ARB file are required for receiver or ToF tests. Before the test routine is started, make sure that required waveform file is available on CMP200. If this is not the case, then the waveform file (.wv) needs to be uploaded to CMP200 via CMsquares beforehand.

The upload operation in CMsquares is shown in Figure 5-6.

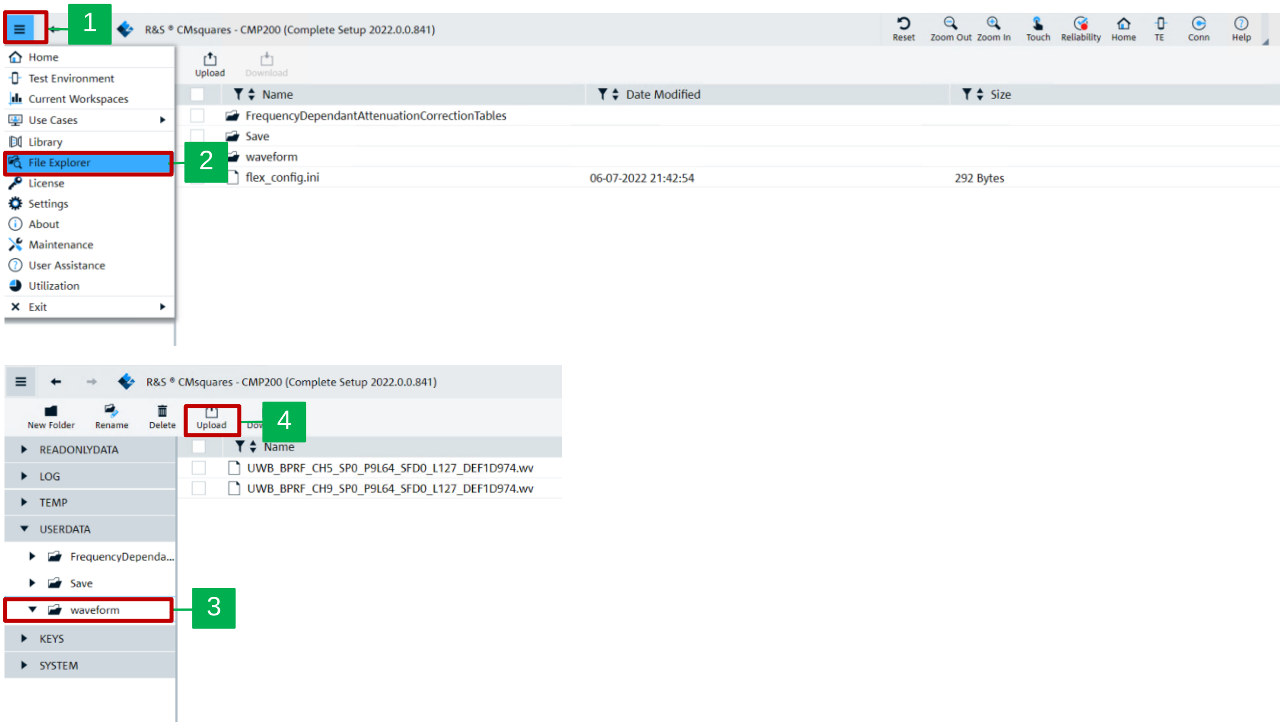

Figure 5-6 Upload waveform file on CMP200 from CMsquares

1. Access to CMsquares by entering the CMP200's IP address in the Web browser on the control PC. After the CMsquares (Web interface of CMP200) is loaded, click on the burger menu
2. In the drop-down menu, select 'File Explorer'
3. Navigate to 'waveform' folder in the opened file explorer in CMsquares
4. Select the waveform file that is intended to be uploaded and press 'Upload' button.

For the receiver tests, there is an alternative way to handle the waveform file. If no ARB file is explicitly specified in Test Plan Editor of the test routine ('None' is set in Waveform parameter configuration field), then the ARB file will be generated on the fly by WinIQSIM2 software on the local control PC based on the parameter settings of receiver test in the Test Plan Editor. The generated ARB file will be transferred to CMP200 afterwards during the test execution. For doing that, WinIQSIM2 needs to be launched and running in the background before test routine is executed.

F Receiver Sensitivity Search

Figure 5-7 illustrates the flow chart of receiver sensitivity search. The initial maximal receiver power level P_Max and minimum receiver power level P_Min, as well as the $Delta$ value are the parameters that need to be configured in the receiver sensitivity routine as described in 3.4.2 and Appendix B.3.

The sensitivity search starts with receiver power level at $(P\_Max + P\_Min)/2$. During the search, the P_Max and P_Min will be changed dynamically based on the measured PER and comparison with the target sensitivity limit. The iteration keeps on running till both P_Max and P_Min values converge somehow with a power difference of $Delta$ dB.

Parameter settings of P_Max , P_Min and $Delta$ can influence the speed and accuracy of the receiver sensitivity search.

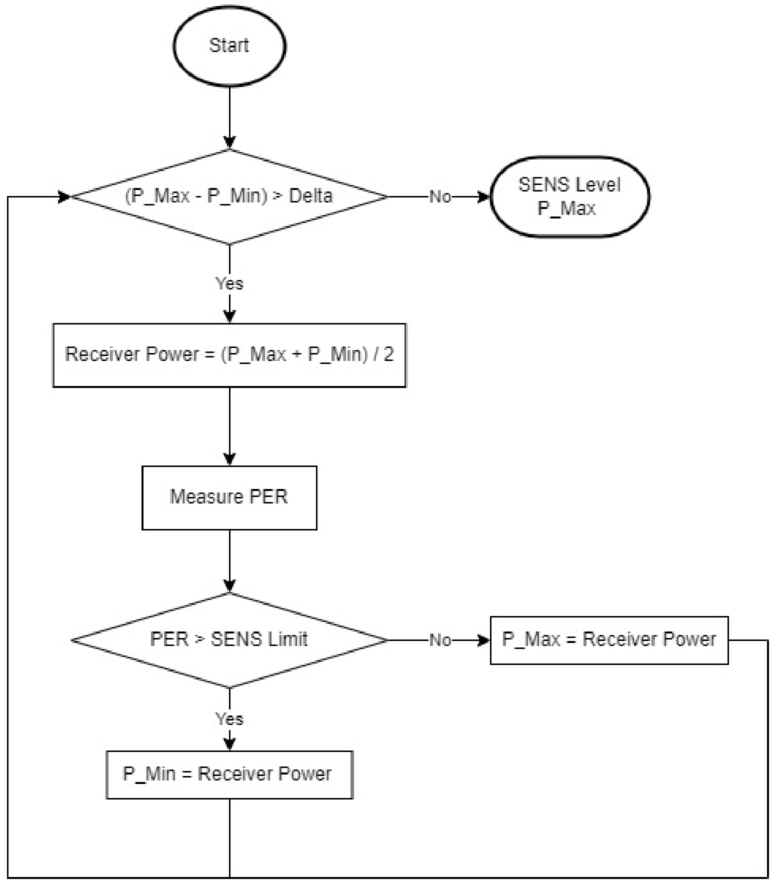

Figure 5-7 Flow chart of receiver sensitivity search

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