

WLAN 802.11ad Measurements

Application Note

Products:

- R&S®FSW67/85
- R&S®FSW-K95
- R&S®FSW-B2000
- R&S®RTO-2044
- R&S®SMW200A
- R&S®SMW-K141
- R&S®SZU100A

The amendment 802.11ad to the WLAN standard defines the MAC and PHY layers for very high throughput (VHT) in the 60 GHz range.

This application note provides a brief examination of key 802.11ad parameters, describes the required measurements and test setups and contains several important recommendations for over-the-air (OTA) measurements.

Note:

Visit our homepage for the most recent version of this application note (www.rohde-schwarz.com/appnote/1MA260).

WLAN 11ad Measurements – 1MA260_1e

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1 Introduction

Digital wireless communications will always demand more throughput than is available. To meet this need, the 802.11ad specification for wireless transmission of data (originally for video streams) in the 60 GHz band provides speeds in the multi-Gigabit range.

The amendment 802.11ad to the WLAN standard defines the MAC and PHY layers for very high throughput (VHT) in the 60 GHz range.

Tests and measurements of this standard create new challenges for users. On one hand, 11ad requires a combination of very high frequencies (60 GHz) and a high modulation bandwidth. On the other, it is typically not possible to directly establish a line-based connection for measurements in this frequency range.

This application note provides a brief examination of key 802.11ad parameters, describes the required transmitter (Tx) and receiver (Rx) measurements and test setups and contains several important recommendations for over-the-air (OTA) measurements.

Table 1-1: Covered 802.11ad Tests

Chapter	Test	
21.3.2	Transmit mask	✓
21.3.3.3	Center Frequency Tolerance	
	- General	✓
	- Center Frequency Convergence	✗
21.3.3.4	Symbol Clock Tolerance	✓
21.3.3.5	Transmit Center Frequency Leakage	✓
21.3.3.6	Transmit Ramp Up and Down	✓
21.3.3.9	Receiver Sensitivity	✓
21.3.10	Received Channel Power Indicator (RCPI) Measurement	✓
21.4.4.1.2 (Control PHY) 21.6.4.1.1 (SC PHY)	Transmit EVM	✓

The following abbreviations are used in this Application Note for Rohde & Schwarz test equipment:

- The R&S®FSW spectrum analyzer is referred to as the FSW.
- The R&S®RTO spectrum analyzer is referred to as the RTO.
- The R&S®SMW vector signal generator is referred to as the SMW.
- The R&S®SZU upconverter is referred to as the SZU.

2 WLAN 802.11ad

The 11ad physical layer was added as an amendment, chapter 21 of the 802.11-2012 standard. It is called "Directional Multi-Gigabit (DMG) PHY". This sections provides a brief overview. You can find a detailed description under [1].

2.1 Key features

802.11ad includes the following key features:

- Support for data rates of up to 7 Gbit/s, divided into
 - a mode with simple, robust modulation, but lower data rates (single carrier),
 - an energy-saving mode for battery-operated devices (single carrier low power)
 - and a high-performance mode with OFDM technology for very high throughput
- Use of the 60 GHz unlicensed band
 - provides global availability
 - avoids the overcrowded 2.4 GHz and 5 GHz bands
 - uses short wavelengths (5 mm at 60 GHz), making compact and affordable antennas or antenna arrays possible
- Beamforming
 - optimizes power at the receiver.
 - provides necessary antenna gain to compensate high free space pass loss
 - overcomes interference (e.g. changes in the channel conditions caused by obstacles) during the transmission in realtime
- is fully integrated in the WLAN universe
 - "triband" devices: across both bands 2.4 GHz and 5 GHz, plus 11ad in the 60 GHz range
 - Seamless use of 802.11a,b,g,n: "fast session transfer"

Typical applications for 11ad are:

- Wireless Display
- Distribution of HDTV content (e.g. in residential living rooms)
- Wireless PC connection to transmit huge files quickly
- Automatic sync applications (e.g. uploading images from a camera to a PC, "kiosk" applications)

2.2 Channels

The nominal channel bandwidth is 2.16 GHz. The useful ISM band around 60 GHz (57 GHz to 66 GHz) is regulated differently in various regions of the world. Four channels are defined for this band, but they are not universally available. Channel 2 (center fre-

quency 60.48 GHz) is available in all regions and is therefore used as the default channel.

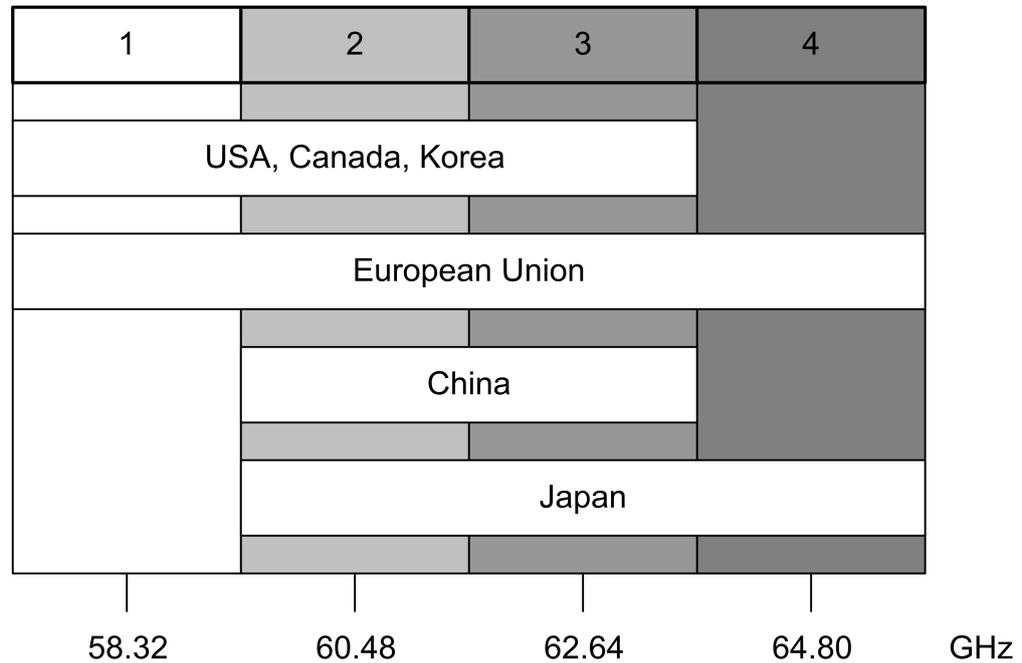


Figure 2-1: Channels in the 60 GHz band. Top: channel numbers, bottom: center frequencies

2.3 Directional multi-Gigabit (DMG): Three different PHYs.

In principle, three different modulation modes are available. They make it possible to fulfill differing requirements (such as high throughput or robustness). Not all three modes need to be supported by every implementation:

Table 2-1: Three different PHYs.

PHY	Purpose
Control PHY	Exchange of signaling and/or control messages in order to establish and monitor connections (mandatory).
Single carrier PHY (SC PHY)	Robust transmission mode. Additional low power mode (optional)
OFDM PHY	High data rate mode (optional)

All DMG PHYs use the same packet structure, but they differ in how the individual fields are defined as well as in the coding and modulation that is used.

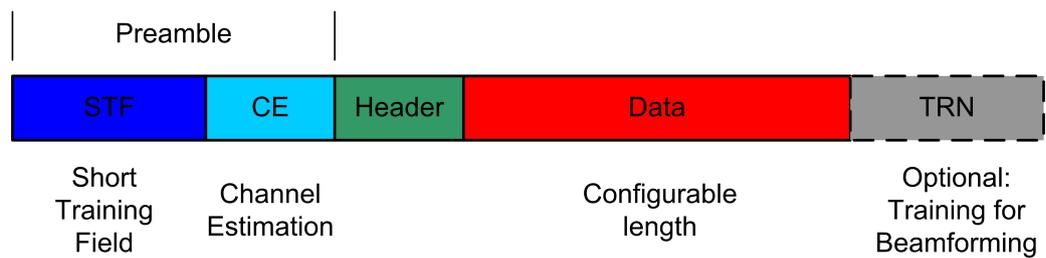


Figure 2-2: General structure of a packet in 11ad.

A packet is made up of the following common parts:

- **Preamble**
The preamble consists of the short training field (STF) and the channel estimation (CE) field. It is required in every packet. It supports the receiver during automatic gain control (AGC), when recognizing the packet and in estimating the frequency offset, and it displays the type of PHY that is used (SC or OFDM). The receiver can also use the known CE field to estimate the channel.
- **Header**
The header is different for every PHY and contains additional important information for the receiver, such as the modulation and coding scheme (MCS), the length of the data field and a checksum.
- **Data**
This part is used to transmit the actual user data with different modulations (MCS). The length of the field varies (number of bytes/octetets).
- **TRN**
This field is optional and can be appended to all packets. It allows to optimize beamforming settings

The following table shows an overview of the most important parameters.

Directional multi-Gigabit (DMG): Three different PHYs.

PHY	MCS	Preamble		Header		Data			Datarate (Mbit/s @MCS)
		STF (Golay (T_c))	CE (Golay (T_c))	Mod.	Length (bits)	Mod.	Coder (rate)	Length (octets)	
Control									
CPHY	0	G_b 128 6400	G_u+G_v 1152	$\pi/2$ -DBPSK	40	$\pi/2$ -DBPSK	LDPC $1/2$	14...1023	27.5
Single Carrier									
SC PHY	1...12	G_a 128 2176	G_u+G_v 1152	$\pi/2$ -DBPSK	64	$\pi/2$ -DBPSK $\pi/2$ -QPSK 16QAM	LDPC $1/2$ $5/8$ $3/4$ $13/16$	1...262143	385 (1) 1115 (4) 4620 (12)
Low Power SC PHY	25...31					$\pi/2$ -DBPSK $\pi/2$ -QPSK	RS Block		625 (25) 2503 (31)
Orthogonal Frequency Division Modulation									
OFDM PHY	13...24	G_a 128 2176	G_v+G_u 1152	QPSK	64	SQPSK QPSK 16QAM 64QAM	LDPC $1/2$ $5/8$ $3/4$ $13/16$	1...262143	693 (13) 6756 (24)

Figure 2-3: Overview of different PHYs. For more information on the parameters see [1]

3 Measurements Over-The-Air (OTA)

Measurements in the mm-wave range typically feature no conducted coaxial interface. Instead, they are performed on radiated emissions and called over-the-air (OTA) for simplicity.

OTA measurements lead to high attenuations, which must be considered in the RF link budget. This section describes the parameters that need to be taken into account.

Parameters such as wavelength, far-field condition, antenna form factor and polarization as well as free space conditions and loss calculation are introduced here.

If you are familiar with these topics, you can skip this section.

3.1 Wavelength

The wavelength of a sinusoidal waveform travelling at constant speed is given by [2]:

$$\lambda = \frac{v}{f} \text{ with } v = \text{velocity of light in vacuum} = 299\,792\,458 \text{ m/s}$$

Equation 3-1: Wavelength

For example, the wavelength of 802.11ad channel 2 is

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8 \frac{\text{m}}{\text{s}}}{60.48 \cdot 10^9 \text{ Hz}} = 0.00496 \text{ m} = 4.96 \text{ mm}$$

3.2 Near/Far-Field Conditions

In order to make use out of the calculations made in the next paragraphs, one need to understand why it is important to measure in the far-field region. It is not the intention of this section to go to details, rather to give an example of the far-field region of the 60 GHz transmission and receiving antenna.

In respect to the near field, the far-field distance is the distance at which the radiation pattern does not change with distance although the power density decreases by $1/\text{radius}^2$. [Figure 3-1](#) shows the property that from the far-field and beyond the radiation pattern does not change.

To reach this property, you can monitor the field strength over distance or you calculate it.

The distance from an antenna where far-field conditions are met depends on the dimensions of the antenna in respect to the wavelength. For smaller antennas (e.g. a half-wave dipole), the wave fronts radiated from the antenna become almost parallel at a much closer distance than for electrically large antennas. [2]

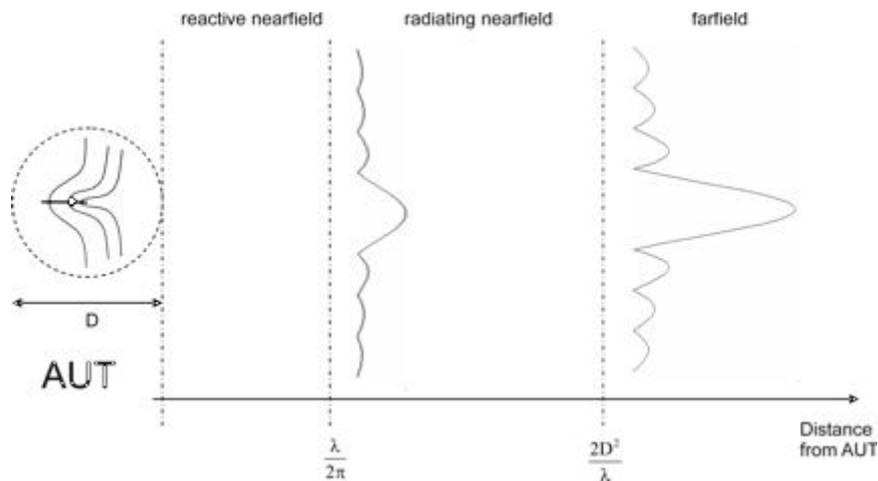


Figure 3-1: Far field of antenna under test (AUT) (<http://www.ihf.uni-stuttgart.de/>).

For larger antennas (i.e. reflector antennas or array antennas), where the antenna diameter (D) dimensions are significantly larger than the wavelength ($D \gg \lambda$), the following approximation applies to the radiating far-field distance:

$$\text{Range} = r = \frac{2D^2}{\lambda} \text{ with } D = \text{Diameter [m]}$$

Equation 3-2: Far field.

Note that you have to calculate not only the transmitting antenna rather also the receiving antennas far field values and take the highest value.

Example:

For 802.11ad frequencies of 60.48 GHz (channel 2) and DUT patch antenna elements with a diameter D of 4 mm, the far field would begin at:

$$r = \frac{2 * (0.004 \text{ m})^2}{4.96 * 10^{-3} \text{ m}} = 0.0065 \text{ m} = 6.5 \text{ mm}$$

For the receiving test antenna (rectangle horn antenna) with a diameter D of 43 mm

$$r = \frac{2 * (0.043 \text{ m})^2}{4.96 * 10^{-3} \text{ m}} = 0.75 \text{ m}$$

In this case we need at least 75 cm to assume to be in the far field of both antennas.

3.3 Free Space Loss (FSPL) Calculation

This section explains the formula used to calculate OTA decibel loss.

In order to calculate OTA loss, you must take into account all of the parameters introduced above. This is an approximate loss calculation and does not cover loss due to reflections, multipath and scattering effects.

$$FSPL = 20 \log_{10}(d) + 20 \log_{10}(f) + 20 \log_{10}\left(\frac{4\pi}{c}\right)$$

Equation 3-3: Free space loss.

Where:

- d = distance [m]
- f = frequency [MHz]
- c = speed of light = 299 792 458 m/s

Example

The table below shows examples for several distances of 802.11ad channel 2:

Table 3-1: Example of free space loss for channel 2

Distance [m]	FSPL [dB]
0.65	64.34
0.75	65.58
1.0	68.08
1.5	71.60

3.4 Polarization

This section deals with the practical impact of mismatched antenna polarization. The polarization of an antenna is determined by the direction of the electric field $E \rightarrow$.

A distinction must be made between the following types of polarizations:

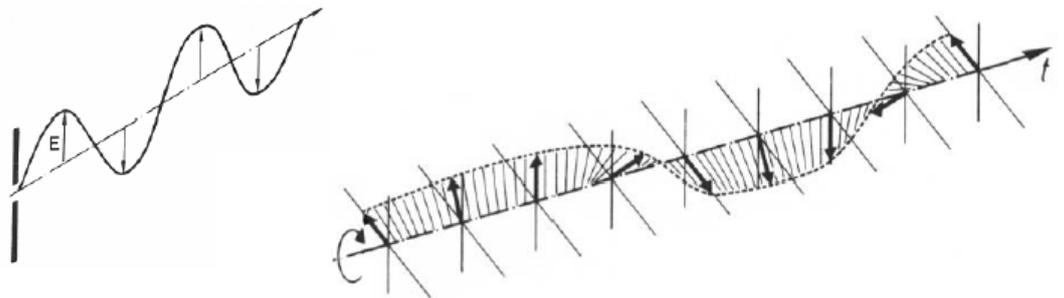


Figure 3-2: Linear (vertical) polarization and right-hand circular polarization. [2]

- Linear polarization: The $E \rightarrow$ field vector changes in magnitude only.
- Circular polarization: The magnitude of the $E \rightarrow$ field vector is constant, but the direction changes and rotates around the direction of propagation.
- Elliptical polarization: The magnitude and the direction of the $E \rightarrow$ field vector changes and its peak position can be described by an elliptical equation.

Polarization mismatch occurs when the polarization of the receiving antenna is not equal to that of the incoming wave. Figure 3-3 gives an overview of polarization mis-

match and the associated loss imposed on the received signal. Note that V means vertical, H horizontal, LHC left-hand circular and RHC right-hand circular polarization.

		Antenna polarization			
		↑	→	↻	↻
E vector of incoming signal	V	0 dB	∞	3 dB	3 dB
	H	∞	0 dB	3 dB	3 dB
	RHC	3 dB	3 dB	0 dB	∞
	LHC	3 dB	3 dB	∞	0 dB

Figure 3-3: Mismatch polarization table [2].

The losses that occur when trying to receive a linearly polarized signal with a circularly polarized antenna amounts to 3 dB (same vice versa) – this can usually be tolerated. Most critical is when an orthogonal antenna polarization is used, as the attenuation can theoretically increase beyond all limits. In practice, however, most antennas have a limited polarization decoupling, so that the loss will never reach infinity [2].

Example

The picture below shows the signal level difference when the rectangular horn antenna used is not adequately set to match the incoming wave polarization. The difference here is ~ 3 dB.



Figure 3-4: Example of different levels for incoming wave polarization.

3.5 Antenna Gain Calculation

This section briefly explains the gain or loss contribution of the antenna. The below example uses the gain of the rectangle horn antenna.

Typically the gain is mentioned in the specification of the used antenna.

Example:

For using a rectangle horn antenna, there is a general calculation. With an aperture of $a = 30 \text{ mm}$ and $b = 37 \text{ mm}$, the horn antenna will produce a gain of:

$$\text{Gain} = 10 * \log\left(\frac{4\pi A}{\lambda^2} e_A\right) = 10 * \log\left(\frac{4\pi (0.03\text{m} * 0.037\text{m})}{(4.88 * 10^{-3}\text{m})^2} 0.5\right) [\text{dBi}] = 24.75 \text{ dBi}$$

Equation 3-4: Horn antenna calculation example.

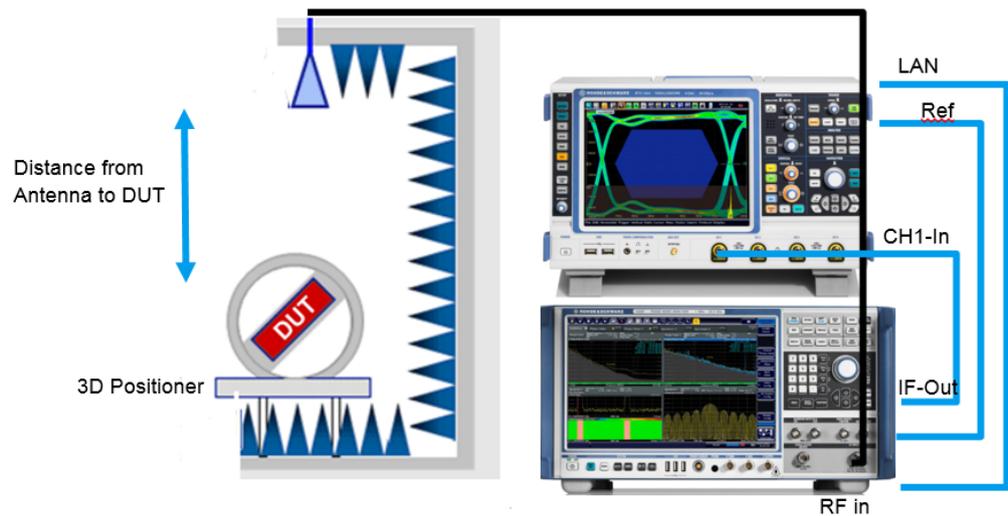
3.6 Practical Approach to OTA Measurements

3.6.1 Measurements with DST-B160 Positioner

This section summarizes the calculations made in the subjects above, in order to calculate the expected power levels at the RF frontend of the FSW.

Note that the below [Equation 3-5](#) refers only for the far field region covered in [Chapter 3.2, "Near/Far-Field Conditions"](#), on page 8

The Example used here is for the following OTA setup:



Example:

With an 802.11ad module distance of 0.75 m, patch antenna gain 5.5 dBi and an output level of 5 dBm continuous wave transmission power, the expected RF power level at the FSW input is approximately -35 dBm. The equation is described in [Equation 3-5](#)

$$P_{RX} = P_{TX}[dbm] + G_{TX}[dBi] + G_{RX}[dbi] - FSPL [dB] - CL$$

Equation 3-5: Receive power level over-the-air.

Where:

- P_tx [dbm] = transmitted power 5 dBm
- G_tx [dBi] = DUT patch antenna transmission gain = 5.5 dBi
- FSPL [dB]- Free space loss = 75 cm = 65.71 dB (see [Table 3-1](#))
- G_rx [dbi] = receive horn antenna gain = 24.75 dBi (see [Chapter 3.5, "Antenna Gain Calculation"](#), on page 12)
- CL = cable loss = 5 dB

$$P_{RX} = 5 \text{ dBm} + 5.5 \text{ dB} + 24.75 \text{ dB} - 65.71 \text{ dB} - 5 \text{ dB} = -35.46 \text{ dBm}$$

Note that this is an approximation.

[Figure 3-5](#) shows the measurement outcome of this example. The peak value is at -34.27 dBm.

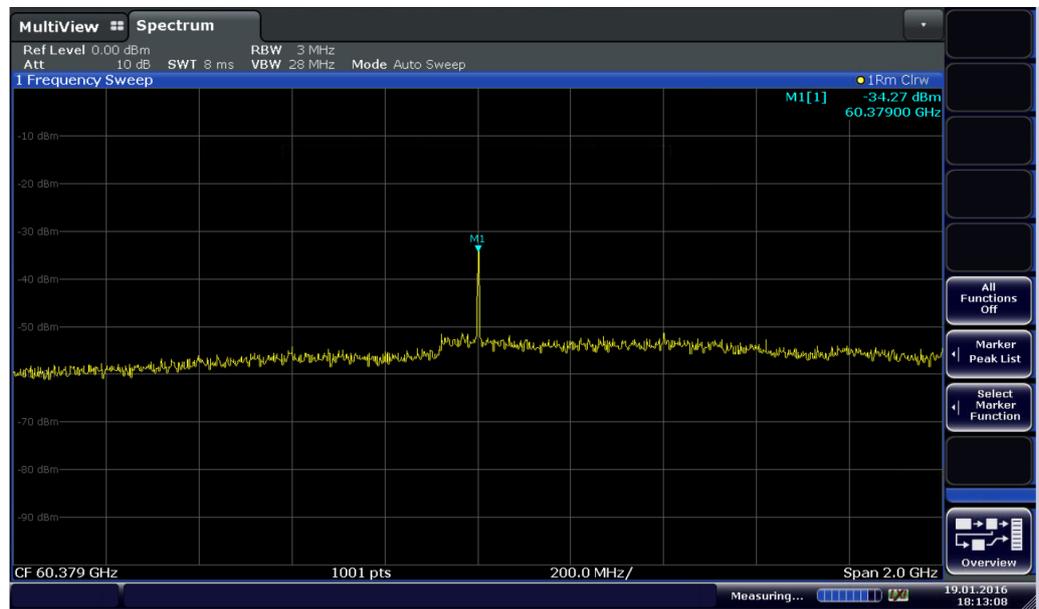


Figure 3-5: Over-the-air CW measurement with DUT Marker value = -34.27 dBm.

Rohde & Schwarz offers an application note with a downloadable calculator tool [9].

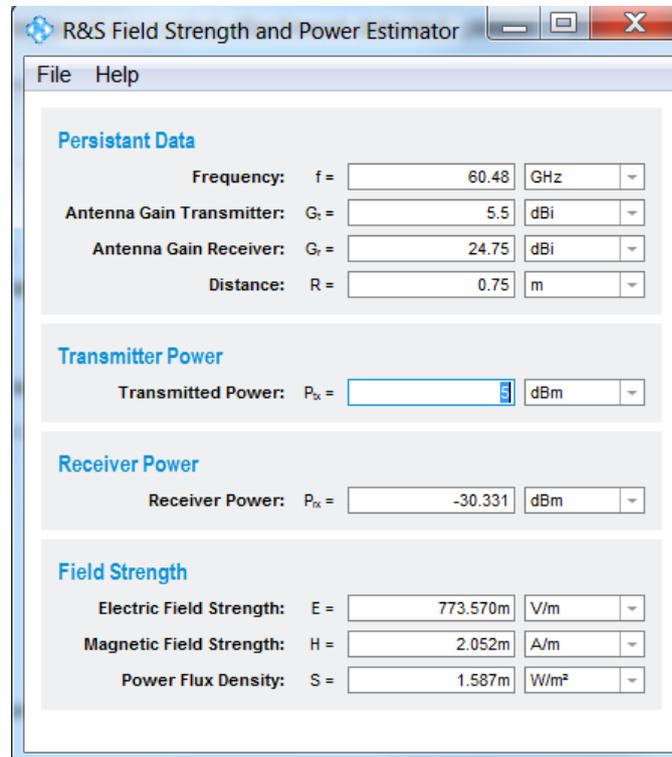


Figure 3-6: 1MA85 field strength and power estimator.

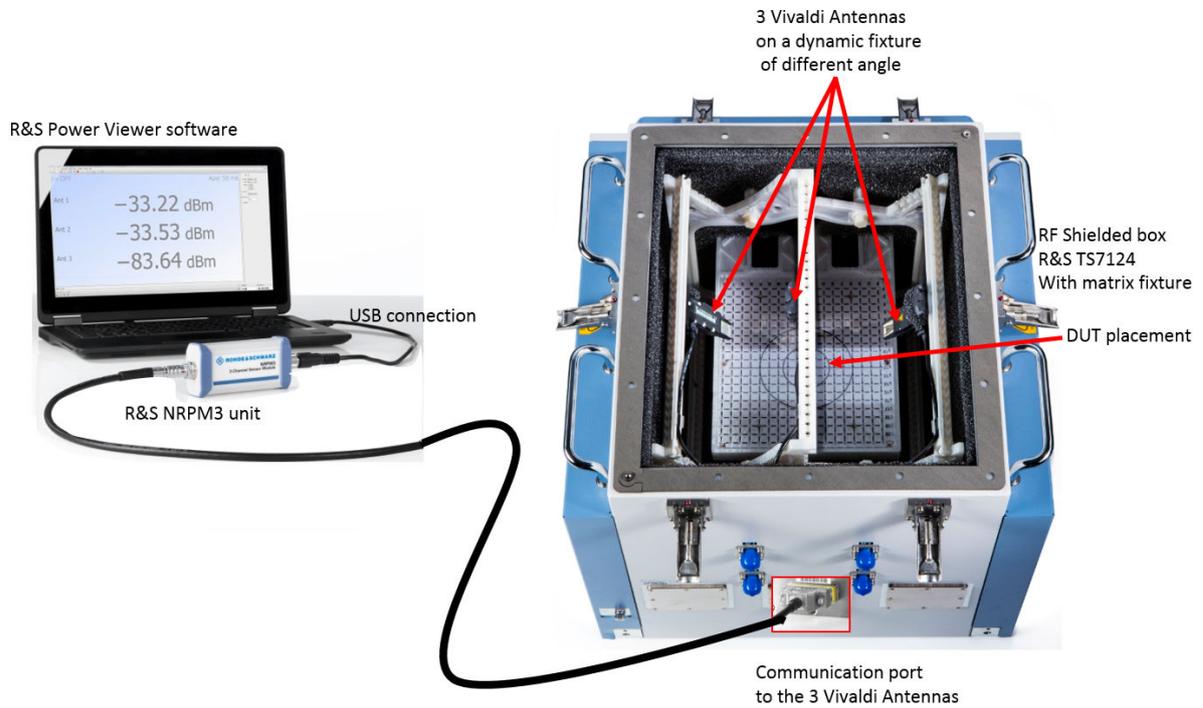
3.6.2 Power Meter Measurements in a TS7124 Shield Box

In comparison to the turning DUT from prior chapter, here the DUT is fixed and the power is measured on several points on a grid, thus considerably decreasing the measurement time in the near-field compared to stepped measurements. This approach allows to sample several beamforming modes versus a “golden device” to perform a fast pass fail criteria for the production line. In contrary to the example above, here only average power is measured with the power meter software [Power Viewer Plus](#) and the power sensor NRPM3.

For the 802.11ad DUT each NRPM3 communication unit can handle 3 Single-Polarized antenna module, with integrated diode detector from 57 GHz to 66 GHz and the TS7124 RF Shielded box chamber up to three communication ports, yielding a capability of up to 9 antennas on the antenna holder. The PowerViewerPlus sw can then display 9 power values, one per antenna.

With this approach the user can test many different beamforming activities in a split of a second.

The Figure below shows the setup with 3 antennas to test a beamforming mode of a DUT,



The NRPM3 is the first OTA power meter with an Antenna. The power is measured and the analog signal already on the RF frontend (NRPM-A66) so only the logic is being transferred to the NRPM3 unit. On the fixture the antennas can be adjusted according to the user's need. See the youtube video on this link : <https://www.youtube.com/watch?v=nljwtkdHAYw>

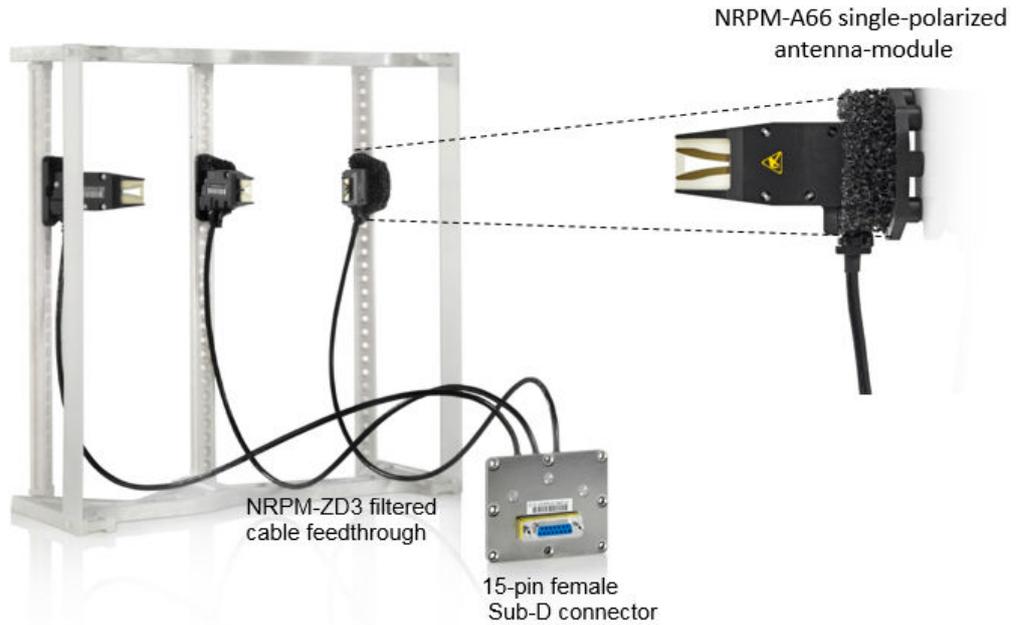


Figure 3-7: NRPM-A66 antenna module with arc fixture

The example measurement is described and simplified in figure [Figure 3-8](#)

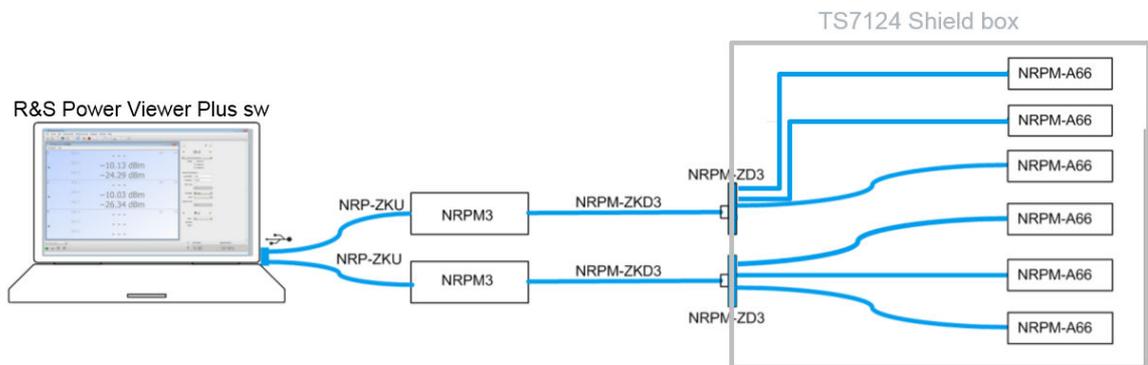


Figure 3-8: Example measurement setup

A Dut 802.11ad rf module is placed in the middle of the chamber’s matrix and six antenna modules are scattered on the grid (named Ant 1.1-3 and Ant 2.1-3) as seen on figure [Figure 3-9](#)

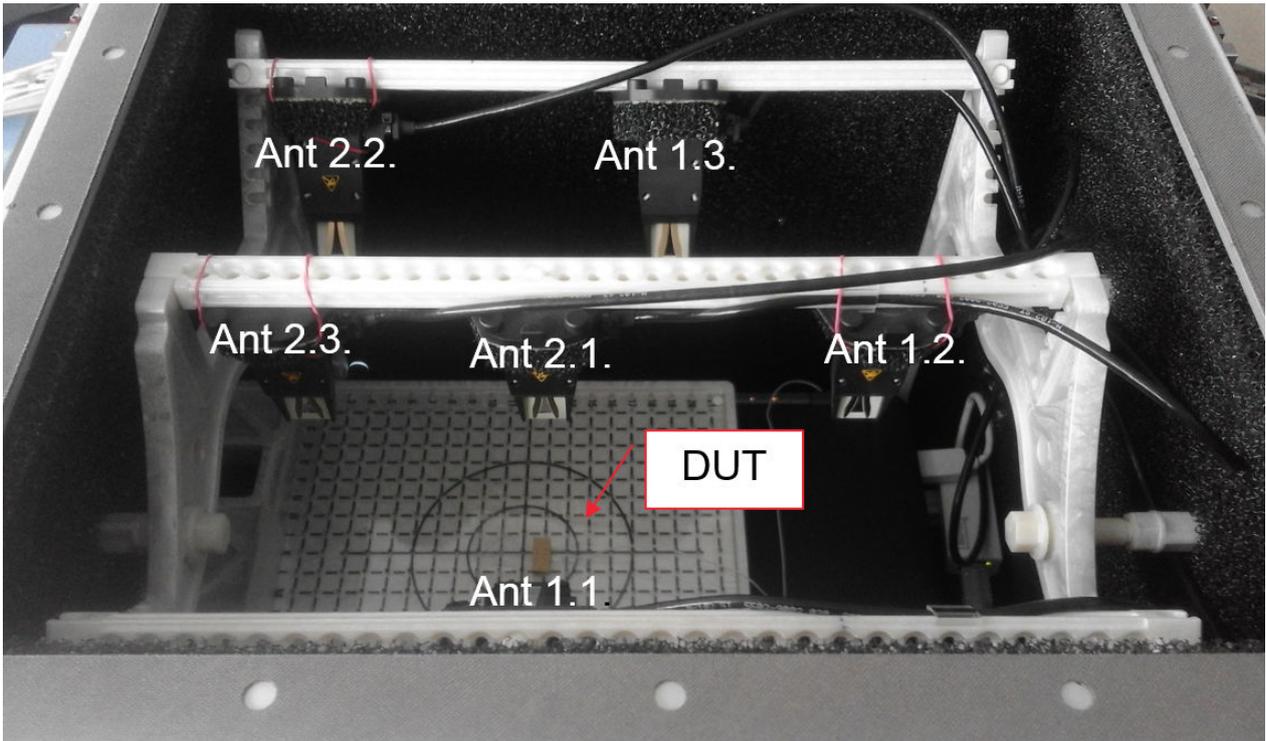


Figure 3-9: DUT inside the shield box with six antenna sensors

The measurement outcome is verified on the Power Viewer Plus sw as seen on figure Figure 3-10

OTA Multi Sensor RUNNING		Boresight transmission	No Transmission
Resolution	Unit		
1	Irabxe	Ant 1.1: -44.11 dBm	-71.95 dBm
		Ant 2.2: -29.60 dBm	-66.89 dBm
		Ant 3: -53.29 dBm	-78.15 dBm
		Ant 1.3: -53.29 dBm	-78.15 dBm
2	DemoPool	Ant 2.1: -50.14 dBm	-81.05 dBm
		Ant 2.1: -59.57 dBm	-96.85 dBm
		Ant 3: -57.04 dBm	-89.97 dBm
		Ant 2.3: -57.04 dBm	-89.97 dBm

Figure 3-10: Boresight vs. no transmission

Several beam forming modes have been applied during the measurement and a trace can be saved for later postprocess see figure Figure 3-11.

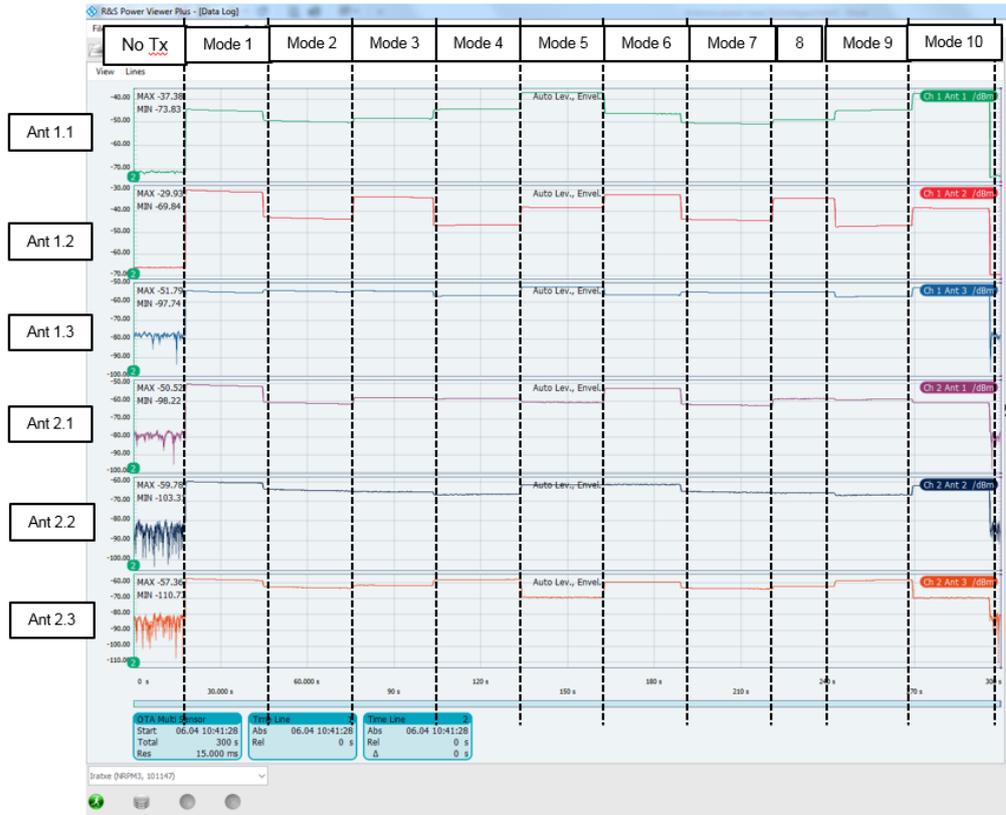


Figure 3-11: Power Viewer Plus Data Log during several modes

As can be seen that several changes of beam forming modes can be verified within a short time. For this example approx. 30 s between each mode has been applied for visualization purposes.

For a power level calibration and 3D beamforming test, this approach allows in a short time to verify the best modes applied to the antenna elements of the DUT against the values of a golden device.

For a power level calibration, having one single-polarized antenna module in a chamber pointing directly to the DUT can verify the total transmitted power of the DUT relative a “golden device”.

4 Transmitter Measurements

The FSW spectrum and signal analyzer uses the **WLAN 802.11ad** software option (FSW-K95) to carry out measurements on DUT transmitters.

First the test setup is described below, followed by a general description of the measurement option. Specification-based descriptions of the individual measurements are provided as well. The K95 option currently supports measurements in the control PHY and the single carrier PHY only.

4.1 Test Setup

DUTs generally consist of a baseband/IF chip and an RF transceiver. Three different tests and associated setups can be derived from this:

- Measurements of the BB/IF chip
The IF frequency is relatively low and measurements can be carried out via cable.
- Measurements of the RF transceiver
The RF frequency in this case is in the 60 GHz range and measurements must be carried out OTA. A suitable input signal is also required for the IF side.
- Measurements of the entire chip
The RF frequency in this case is in the 60 GHz range and measurements must be carried out OTA.

The FSW (67 GHz or 85 GHz) mixes the DUT's RF signal down to an IF signal with 2 GHz bandwidth (hardware option B2000), which comes out the IF OUT 2 GHz port on the rear panel. The RTO samples this IF signal. The FSW controls the RTO transparently via LAN, and therefore the RTO does not require additional control input. All control input takes place on the FSW, and the system behaves as a single test and measurement instrument. The FSW processes the data recorded by the RTO and displays the measurement results.

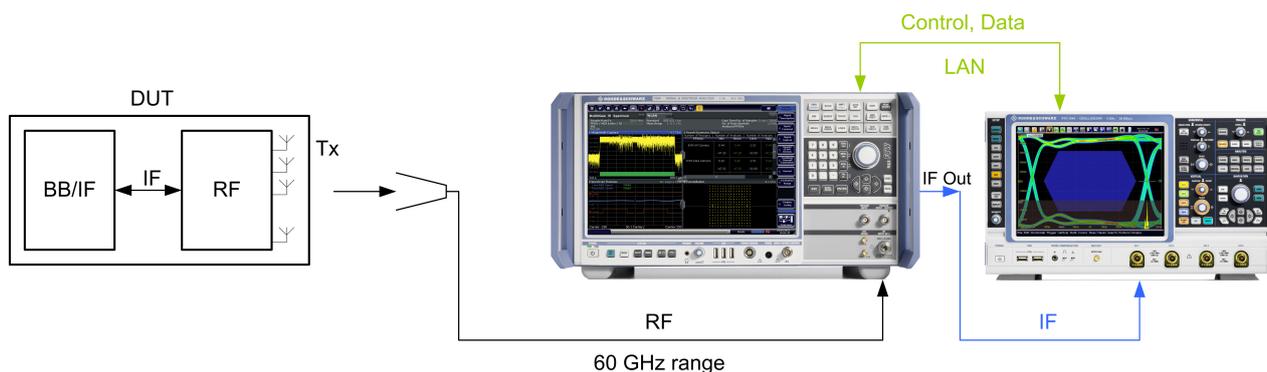


Figure 4-1: General TX test setup.

The setup consists of the following instruments and options:

- FSW67 or FSW85
- FSW-B24 preamplifier (possibly)

- best EVM with FSW new RF frontend
- 2 GHz analysis bandwidth: FSW-B2000
- FSW-K95 software option: WLAN 802.11ad measurements
- RTO2044 digital oscilloscope

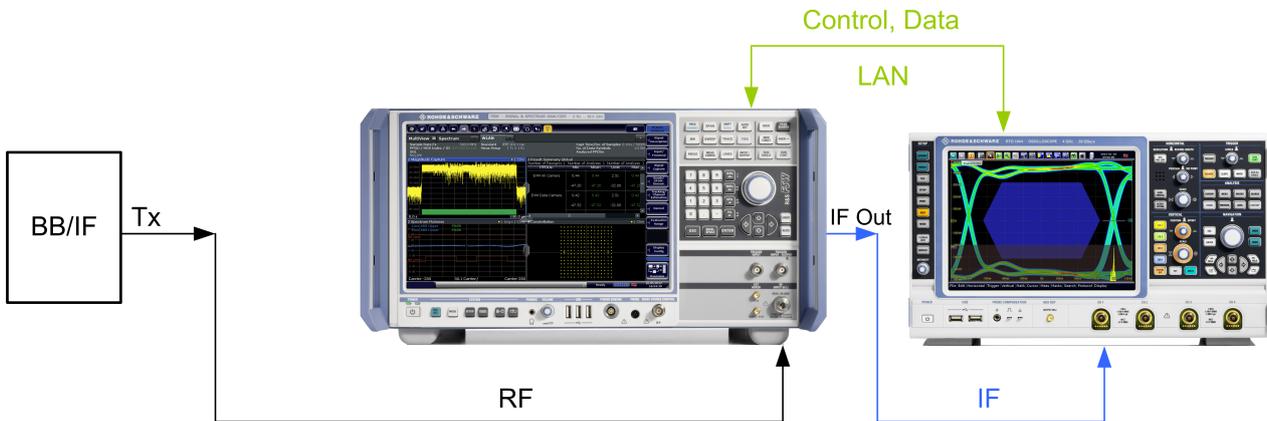


Figure 4-2: TX test setup on the BB/IF chip – in principle, the same as the overall setup. However, a cable connection can be used thanks to the lower IF frequency of the BB chip.

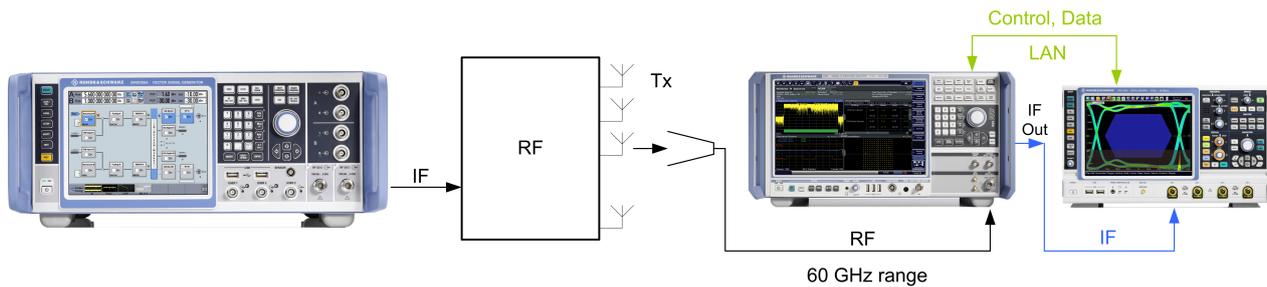


Figure 4-3: TX test setup on an RF transceiver – in principle, the same as the overall setup. In this case, however, the SMW provides the IF input signal.

4.2 Connections and Alignment

This section guides you through the B2000 setup and alignment.

Connections

- Connect both the RTO and the FSW to your local network or via direct Ethernet connection.
- Connect the FSW 10 MHz Reference OUT to the RTO 10 MHz Reference IN
- NOTE: You do not need to connect the FSW IF OUT to RTO CH1 at this time. You will connect it after the alignment.

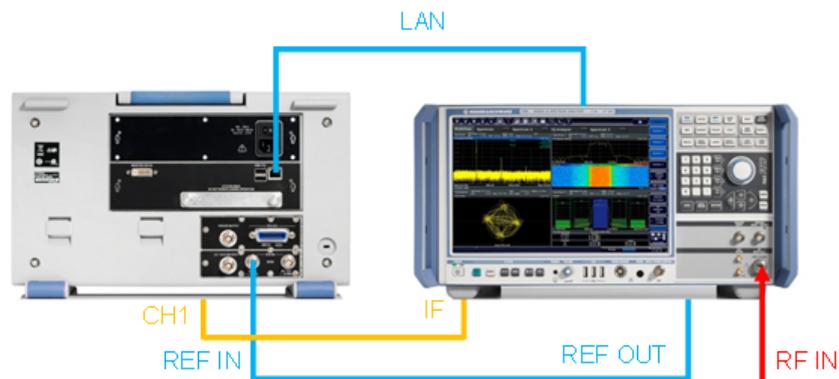


Figure 4-4: Connection setup with RTO rear panel.

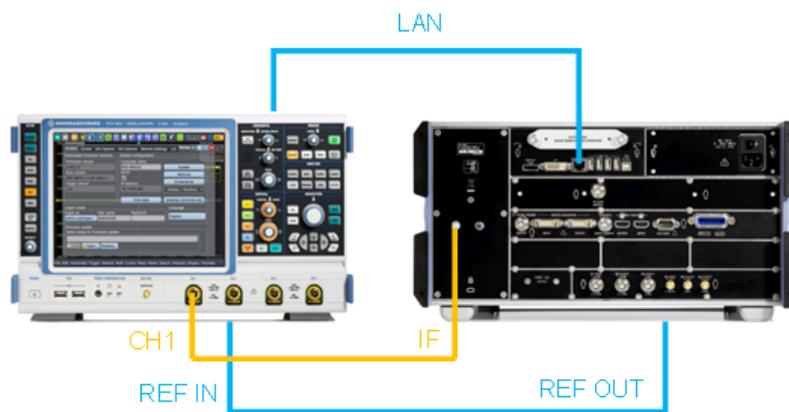


Figure 4-5: Connection setup with FSW rear panel.

Alignment

Before connecting the IF output of the FSW to the RTO Channel 1 input as depicted above, the combination of FSW and RTO has to be configured and aligned in the software.

As the FSW acts as a master and controls the RTO via LAN, the FSW needs to know the IP address of the RTO. Therefore, note the IP address of your RTO oscilloscope. Press the **Setup** hardkey to enter the SYSTEM menu. The IP address can be found in the defined field as shown in the figure below.

1. Setup: System (HARDKEY or FILE|SETUP).
2. Note the RTO IP address or computer name (in this example: 10.85.0.77).

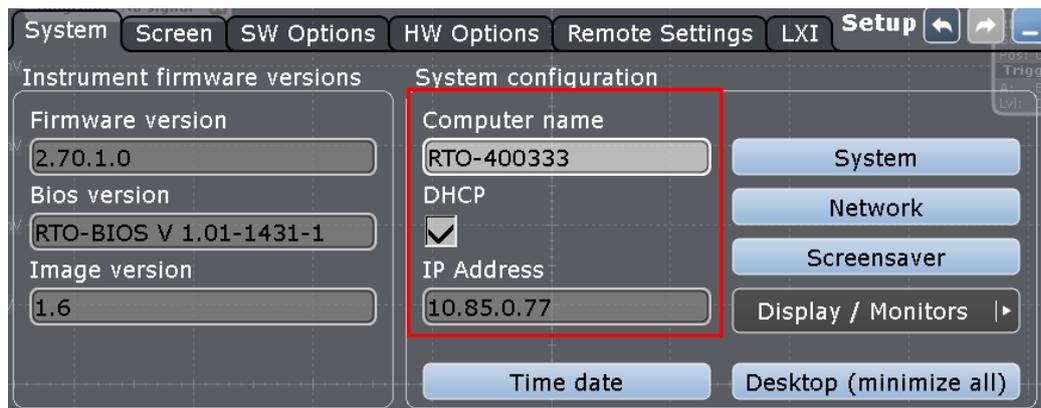


Figure 4-6: RTO IP address.

Now move to the FSW.

The wideband analysis function has to be activated and set up as INPUT/OUTPUT of the FSW. The setup procedure outlined below applies to all options supporting the B2000.

First, set up the B2000. Press the MODE hardkey and select the 802.11ad option. Select the B2000 as an Input Source.

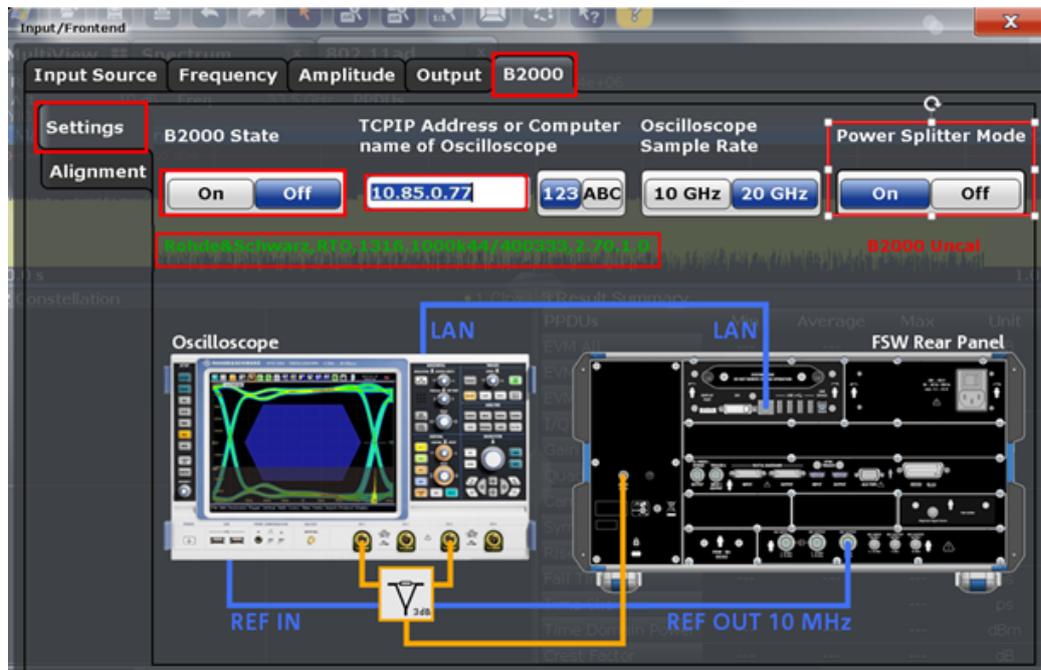


Figure 4-7: B2000 settings.

As shown in Figure 4-7, the connection status and the calibration status are indicated in the B2000 Settings tab. If the connection status is green, it indicates a successful connection to the RTO. Since FSW firmware 2.60 there is a possibility to improve the EVM effectively by 2.5 dB when the signal goes through an external splitter to the RTO, so the signal is distributed to two independent A/D converters. The alignment

status is actually drawn in red and shows “B2000 Uncal,” an unaligned RTO-FSW setup.

In this case, it is necessary to start the alignment and calibrate the RTO-FSW connection.

The alignment is carried out only once per RTO and takes few seconds to finish only. A wizard guides you through the entire process and stores calibration files automatically on the RTO hard disk, enabling different RTOs to be used with a single FSW.

Switch to the **Alignment** tab.

1. Connect the RTO Channel 1 to the REF OUT 640 MHz connector at the rear panel of the FSW as depicted in [Figure 4-8](#)
2. Press **Alignment**.

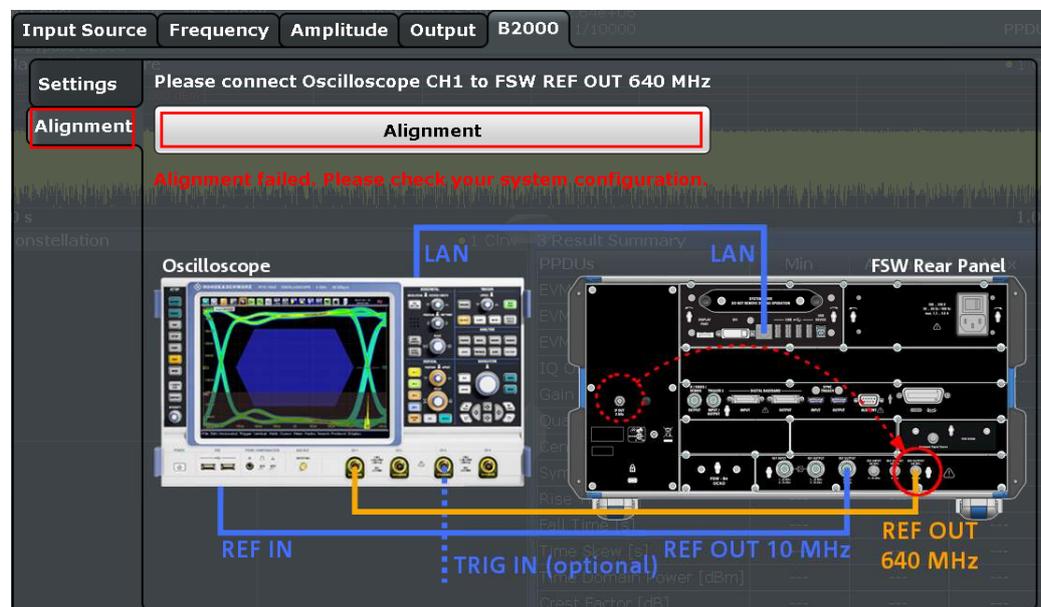


Figure 4-8: First step of alignment with REF OUT 640 MHz signal.

1. The wizard shows you the second IF cable reconnection where you connect the RTO Channel 1 to the B2000 Alignment Signal Source.
2. Press **Continue Alignment**.

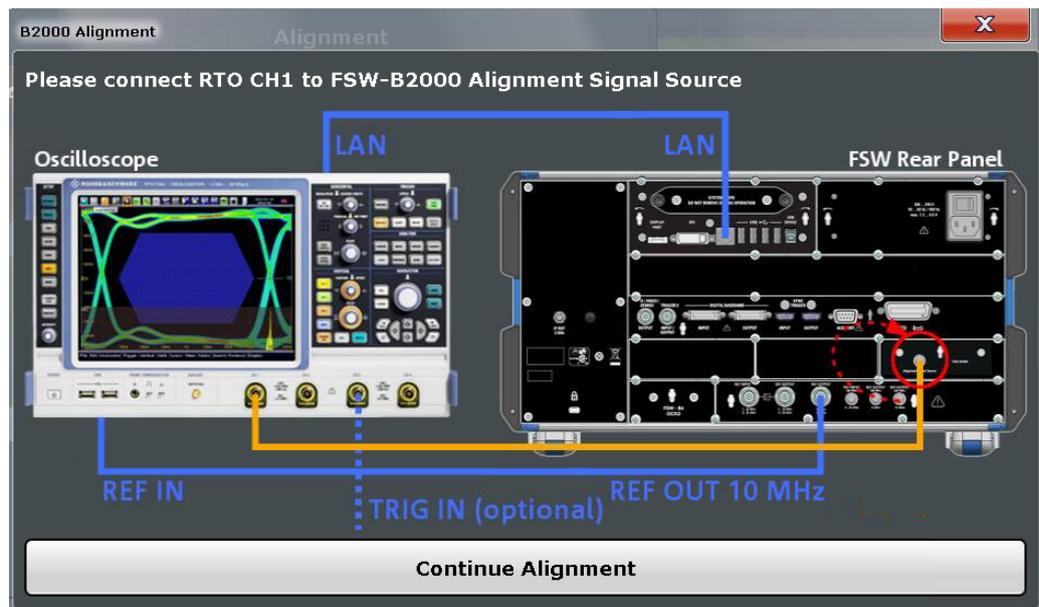


Figure 4-9: Second step of alignment with B2000 alignment source signal.

1. After successful alignment, you can reconnect the RTO Channel 1 to the IF Output output.(Figure 4-10)
2. Press Continue to finish the wizard.

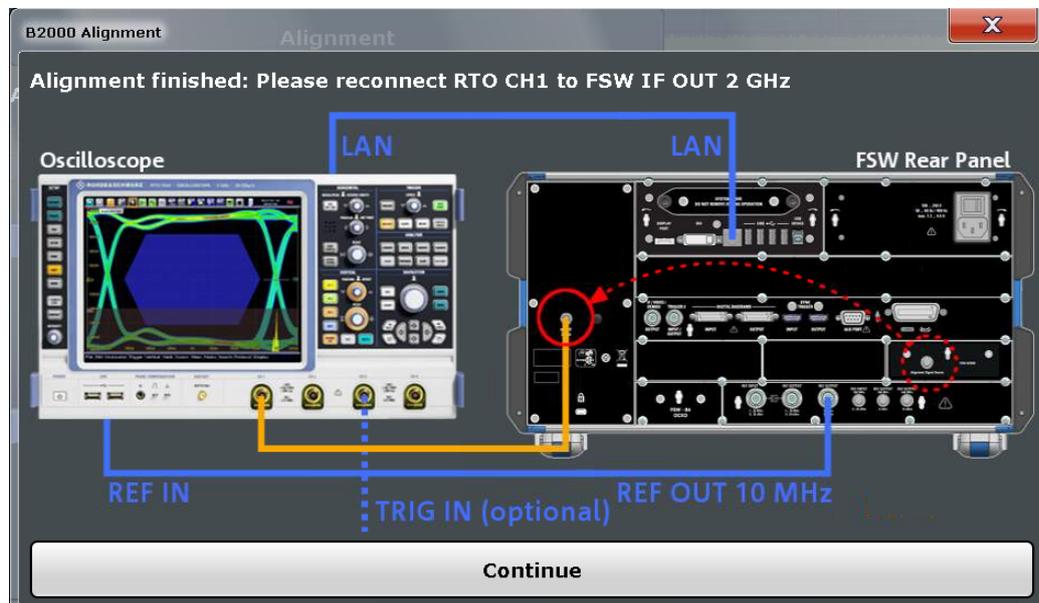


Figure 4-10: Alignment finished – reconnect with the B2000 IF signal.

The B2000 status will appear in green in the **Settings** tab and display calibration information and the last calibration date.

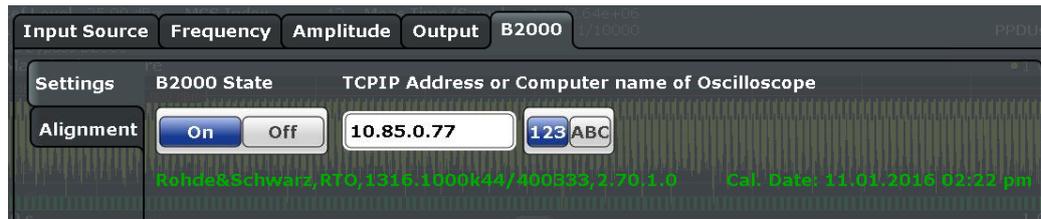


Figure 4-11: Successful alignment is shown in green.

4.3 Approach for Optimum EVM Measurement OTA

This section provides an approach to the step-by-step procedure for an optimal EVM measurement OTA. It presumes that the DUT transmits a 16QAM 802.11ad signal in the distance of 75 cm (far field distance as described in [Chapter 3.2, "Near/Far-Field Conditions"](#), on page 8) from the receiving horn antenna connected to the FSW.

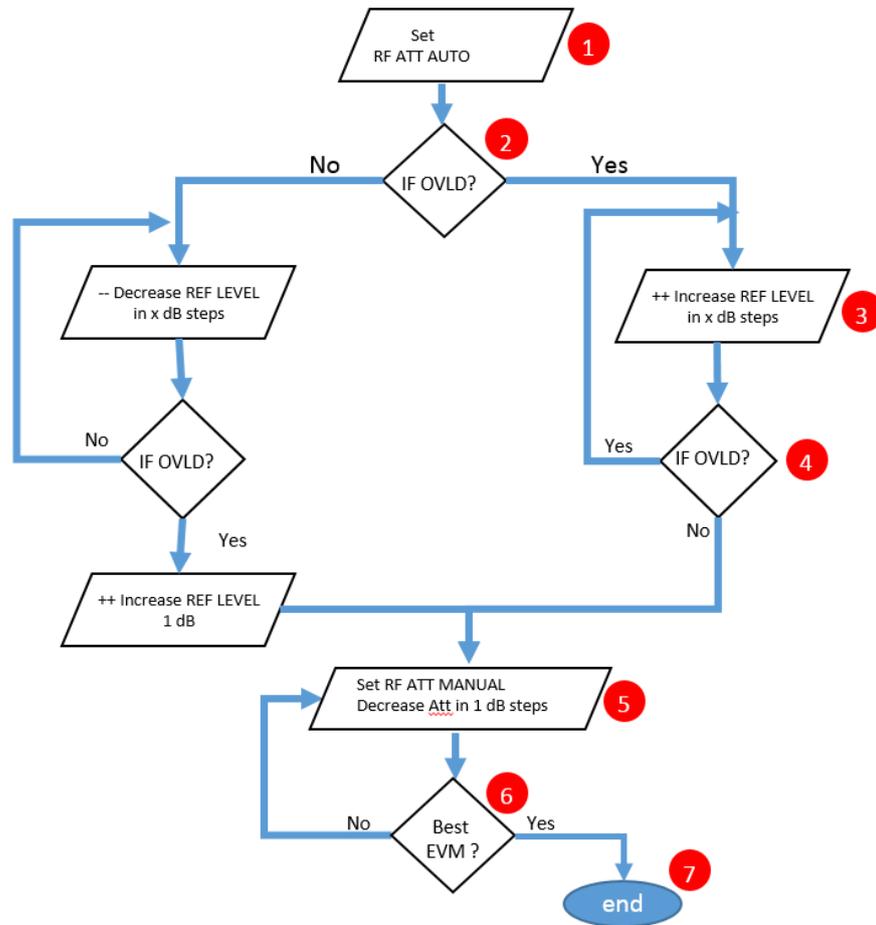


Figure 4-12: Suggested Algorithm for optimal EVM

Step by step description of the block diagram

The prerequisites are:

- The 802.11ad (K95) is the active channel (see [Figure 4-13](#))
- The B2000 is switched on (see [Figure 4-7](#))
- 802.11ad signal on RF input

1. Click **AMPT** button and set the **RF Atten Auto** (see [Figure 4-13](#)).
2. Verify if the **IFOVLD** indication appears in the indication bar (see figure below).

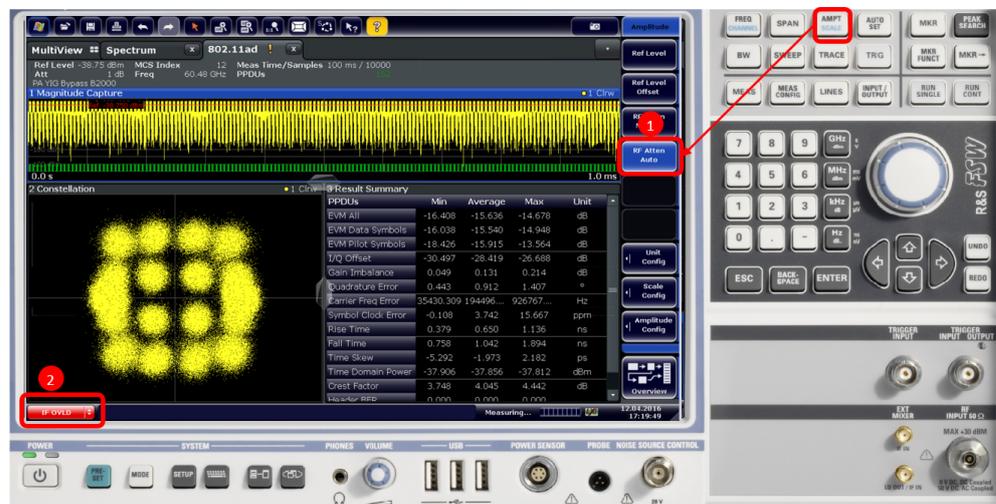


Figure 4-13: Default View of 802.11ad signal

3. Increase the **Ref Level** by 1 dB steps (see [Figure 4-14](#)).
4. Follow step 3 until the **IFOVLD** indication disappears. Note, to wait the defined measurement time (in here 1 ms) for each change. (see figure below)

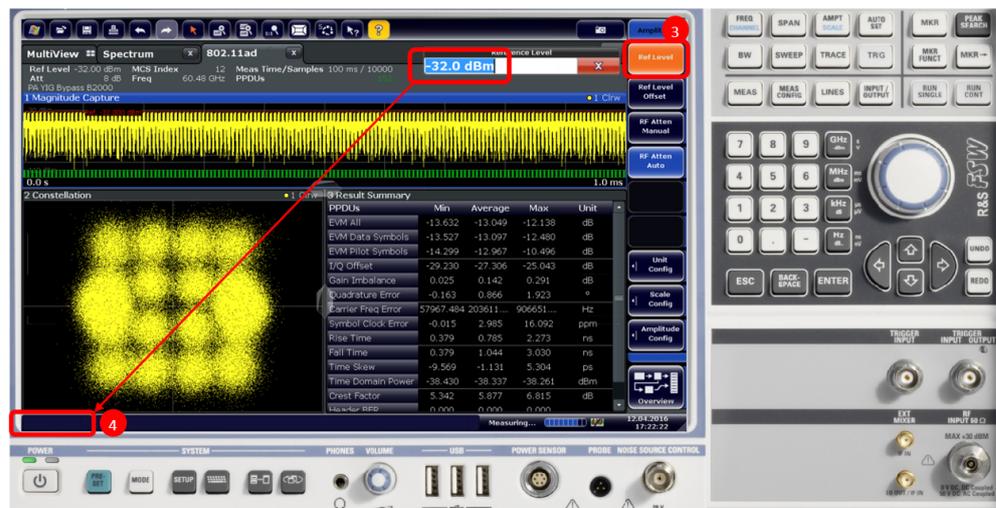


Figure 4-14: IFOVLD disappear

- Set RF attenuation to manual under **AMPLITUDE/RF Atten Manual**. (see Figure 4-15)
- Start decreasing the Attenuation by 1 dB. (see figure below)
- Verify the EVM improves, follow step 6 until reached best EVM (see figure below)

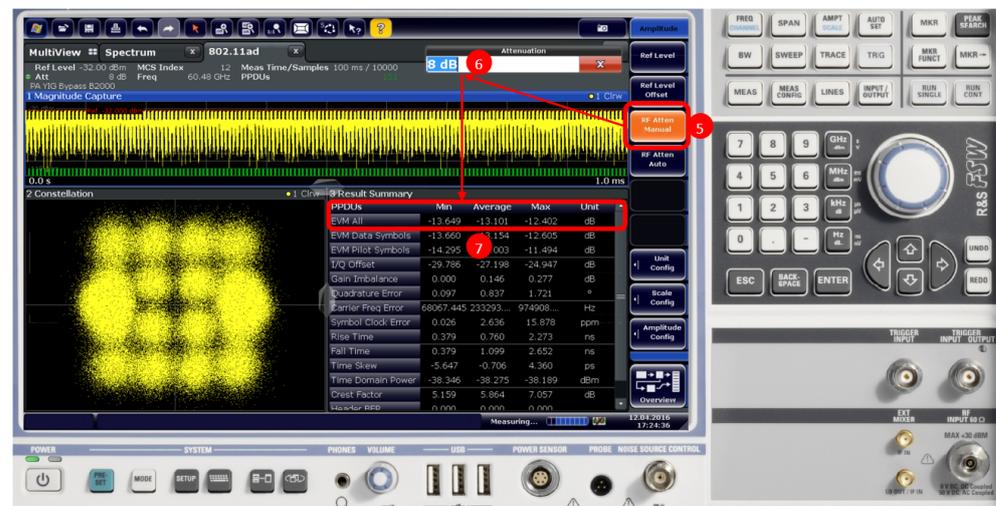


Figure 4-15: 802.11ad Mode

- In case the time domain power is below -5 dBm a PreAmplifier is to be turned on and repeat steps 1-7. (see figure below). In the example above it is always on since the DUT is in OTA and is below -5 dBm Time domain power.



Figure 4-16: PreAmplifier on

4.4 TX Measurements According to Specification

The K95 option is started by pressing the **MODE** hardkey and selecting WLAN 802.11ad.

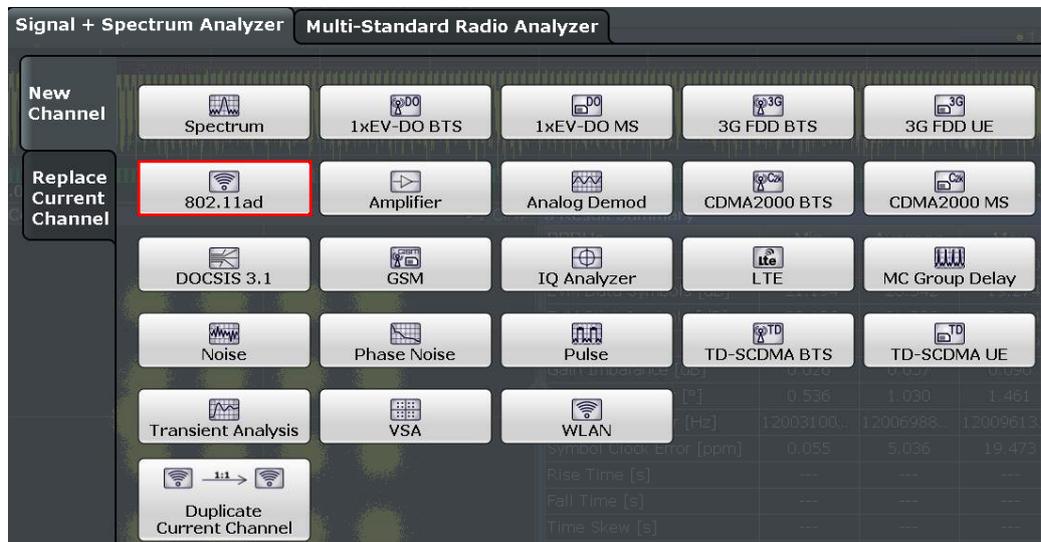


Figure 4-17: Starting the K95 option – all measurements are carried out within the software option.

Measurements of DUT transmitters can be divided into two groups:

- In-spectrum measurements (spectrum emission mask (SEM))
- Measurements with demodulation (e.g. error vector magnitude, frequency error, etc.)

MEAS hardkey is used to switch between measurements:

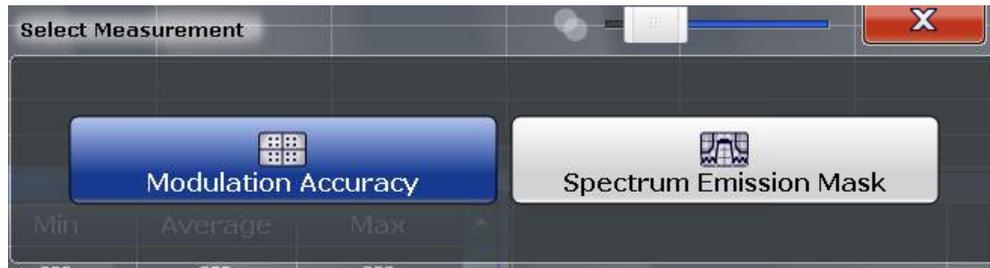


Figure 4-18: Switch between modulation and spectrum measurements.

Figure 4-19 provides an overview of modulation accuracy measurement for an example OTA measurement. The MCS (automatically detected) is shown in the top part of the display.

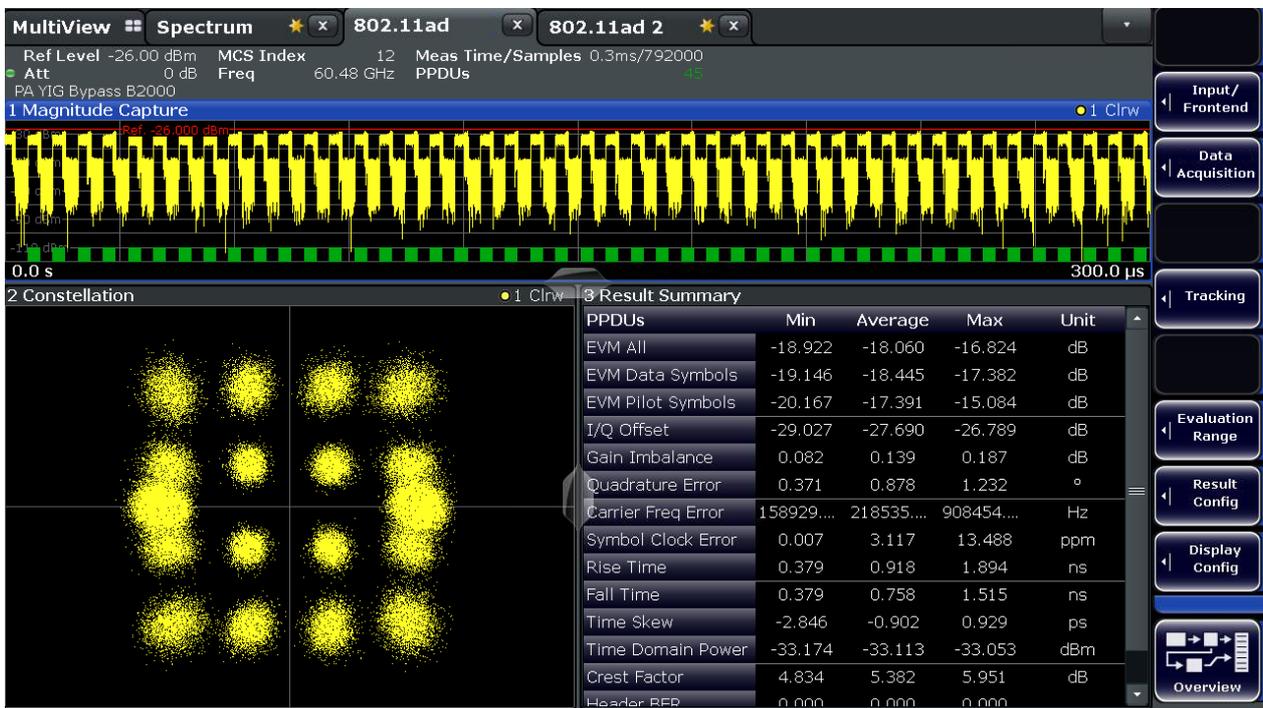


Figure 4-19: Modulation accuracy overview.

3 Result Summary				
PPDUs	Min	Average	Max	Unit
EVM All	-19.135	-18.243	-16.781	dB
EVM Data Symbols	5 -19.462	-18.566	-17.605	dB
EVM Pilot Symbols	-19.841	-17.671	-14.814	dB
I/Q Offset	3 -28.585	-27.695	-26.881	dB
Gain Imbalance	0.073	0.138	0.210	dB
Quadrature Error	0.469	0.854	1.191	°
Carrier Freq Error	1 116236.781	245342.156	908295.500	Hz
Symbol Clock Error	2 0.021	2.903	14.397	ppm
Rise Time	0.379	0.976	2.273	ns
Fall Time	4 0.379	0.800	1.894	ns
Time Skew	-3.426	-0.918	0.941	ps
Time Domain Power	-32.979	-32.907	-32.827	dBm
Crest Factor	4.653	5.400	5.863	dB
Header BER	0.000	0.000	0.000	
Payload BER	0.000	0.001	0.002	

Figure 4-20: The result summary shows scalar measurement values . The red numerics are referenced in the following sections.

4.4.1 Transmit Mask (21.3.2)

The transmitted signal shall adhere to the transmit spectrum mask shown in [Figure 4-21](#)

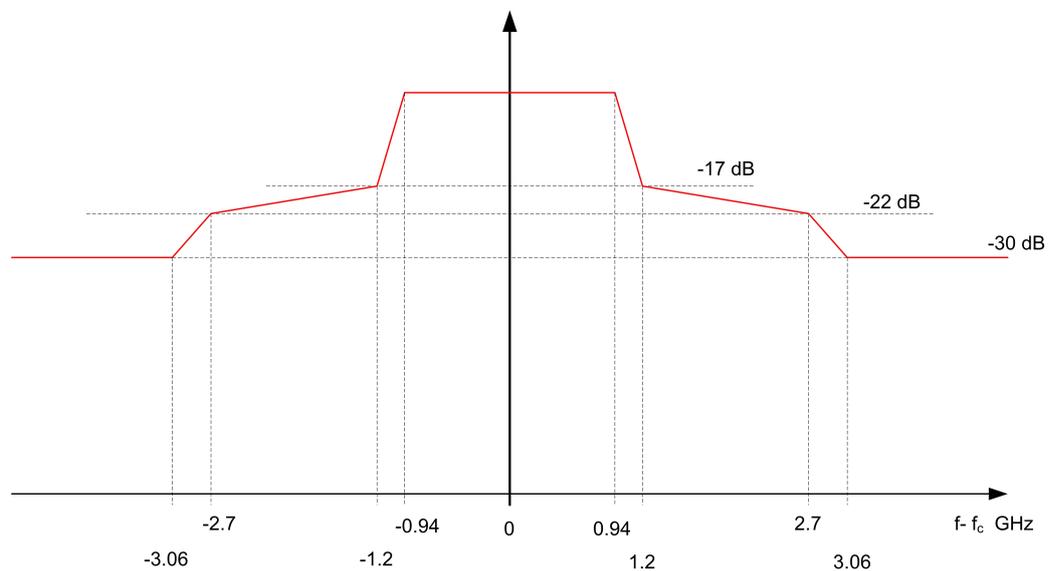


Figure 4-21: Transmit mask – the limits are relative to the power in the actual channel (± 0.94 GHz). At ± 1.2 GHz, it is -17 dB; at ± 2.7 GHz, it is -22 dB; and starting at ± 3.06 GHz, it is -30 dB.

The limits apply relative to the nominal power (maximum spectral density). The measurements are taken with a resolution bandwidth (RBW) of 1 MHz. The FSW automatically applies the right limits.

The Tx Mask mask is measured in the spectrum domain. The 802.11ad packets are bursts, thus the measured power may be too low. Increase the duty cycle of the DUT as much as possible.

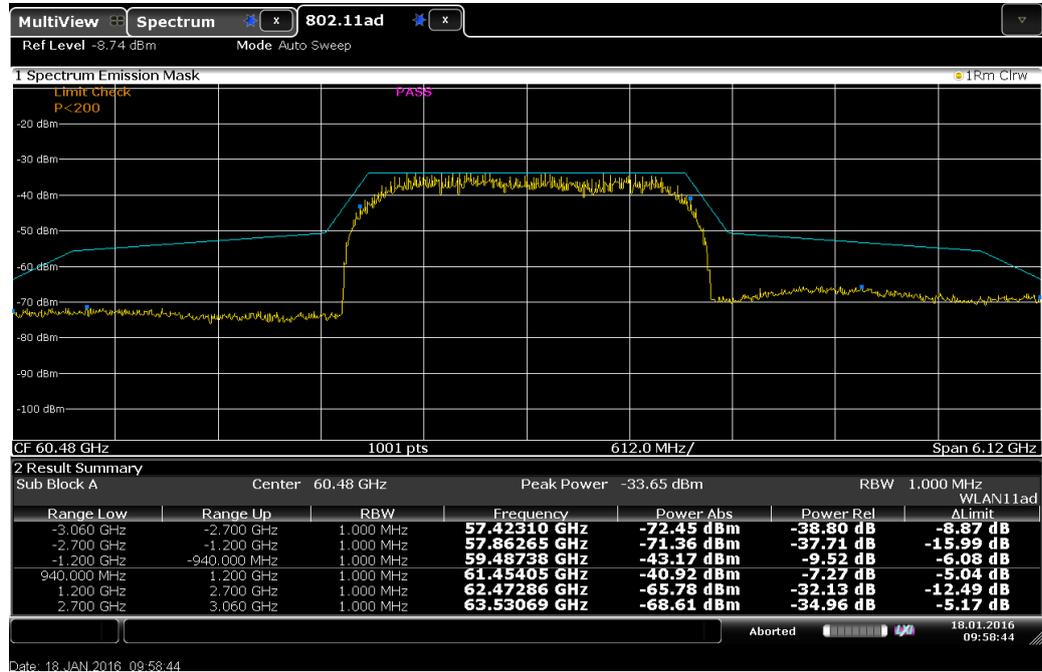


Figure 4-22: The TX mask measurement in 802.11ad.

4.4.2 Center Frequency Tolerance (21.3.3.3)

The transmitter center frequency tolerance shall be ± 20 ppm maximum [1]. For example, this is 60.48 GHz * 20E-6 = 1.2096 MHz for channel 2.

The measurement is carried out in the modulation accuracy. The option shows the result as the **Center Frequency error** in Hertz (marked with the red 1 in Figure 4-20). To get the result in ppm, just divide the result by the channel center frequency and multiply by 1E6.

$$\text{Tolerance} = \frac{\text{Center Frequency error}}{\text{nominal Center Frequency}} \cdot 1 * 10^6$$

In addition, the transmitter center frequency shall converge to within 1 ppm of its final value within 0.9 μs from the start of the packet [1]. This test will be implemented in the firmware option later.

4.4.3 Symbol Clock Tolerance (21.3.3.4)

The symbol clock frequency tolerance shall be ± 20 ppm maximum. The measurement is carried out in the modulation accuracy and directly shown as the **Symbol Clock Error** (marked with the red 2 in [Figure 4-20](#)).

4.4.4 Transmit Center Frequency Leakage (21.3.3.5)

For SC-PHY, the transmitter center frequency leakage shall not exceed -23 dB relative to the overall transmitted power. The measurement is shown as the **IQ Offset** (marked with the red 3 in [Figure 4-20](#)).

4.4.5 Transmit Rampup and Rampdown (21.3.3.6)

Both the rampup and the rampdown times (10 % to 90 %) shall be less than 10 ns. The measurements are shown as **Rise Time** and **Fall Time** (marked with the red 4 in [Figure 4-20](#)).

4.4.6 Error Vector Magnitude (EVM) (Control-PHY 21.4.4.1.2, SC-PHY 21.6.4.1.1)

The requirements for the transmit EVM depend on the PHY and/or MCS. In the case of the low-power SC PHY, no limits are specified.

Table 4-1: Transmit EVM requirements

PHY	MCS	Modulation	EVM [dB]
Control PHY	0	DPSK	- 6
Single carrier PHY	1	$\pi/2$ -PSK	- 6
	2		- 7
	3		- 9
	4		- 10
	5		- 12
	6	$\pi/2$ -QPSK	- 11
	7		- 12
	8		- 13
	9		- 15
	10	$\pi/2$ -16QAM	- 19

PHY	MCS	Modulation	EVM [dB]
	11		- 20
	12		- 21

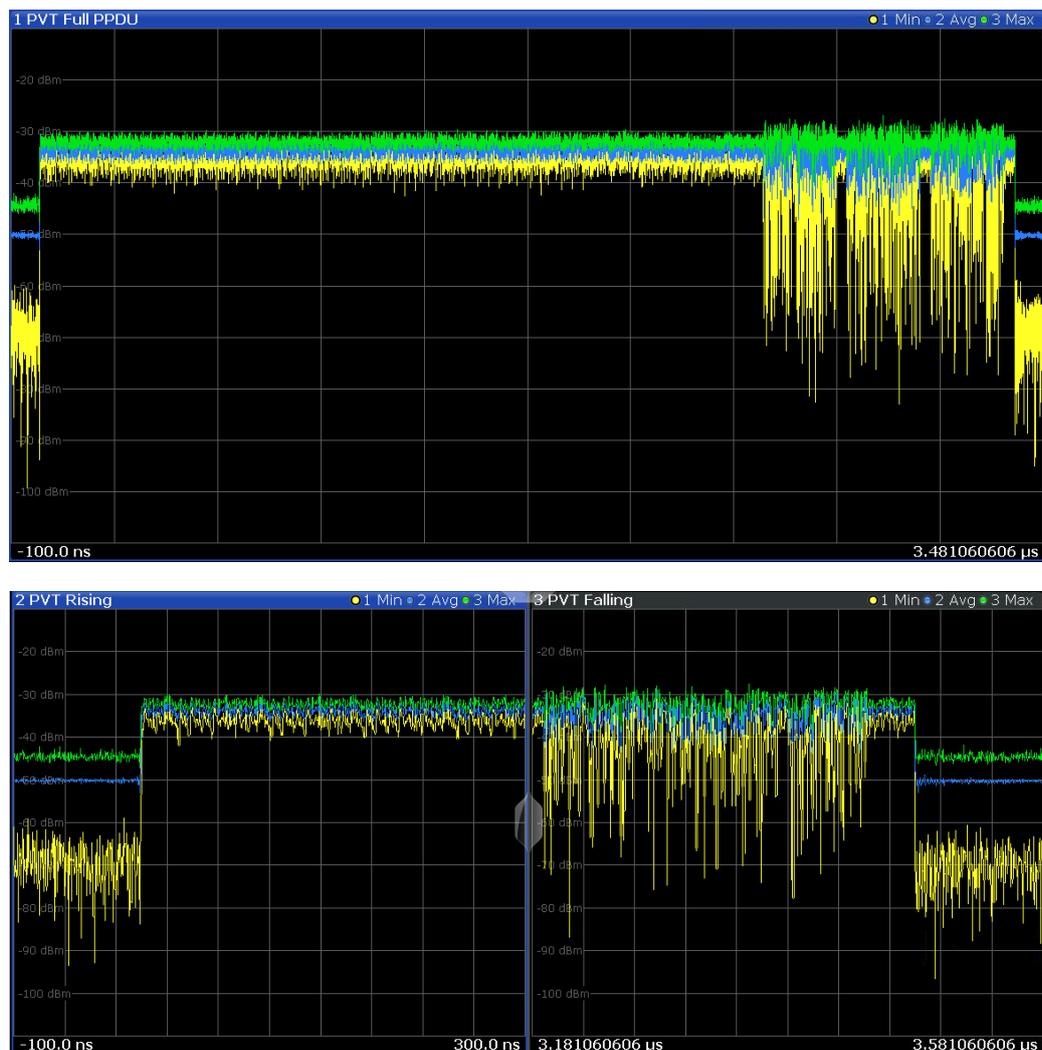
The measurement is carried out in the modulation accuracy. It shows the EVM on the pilot symbols as well as on the data symbols. The EVM on all symbols is shown (EVM All) as well (marked with the red 5 in [Figure 4-20](#)).

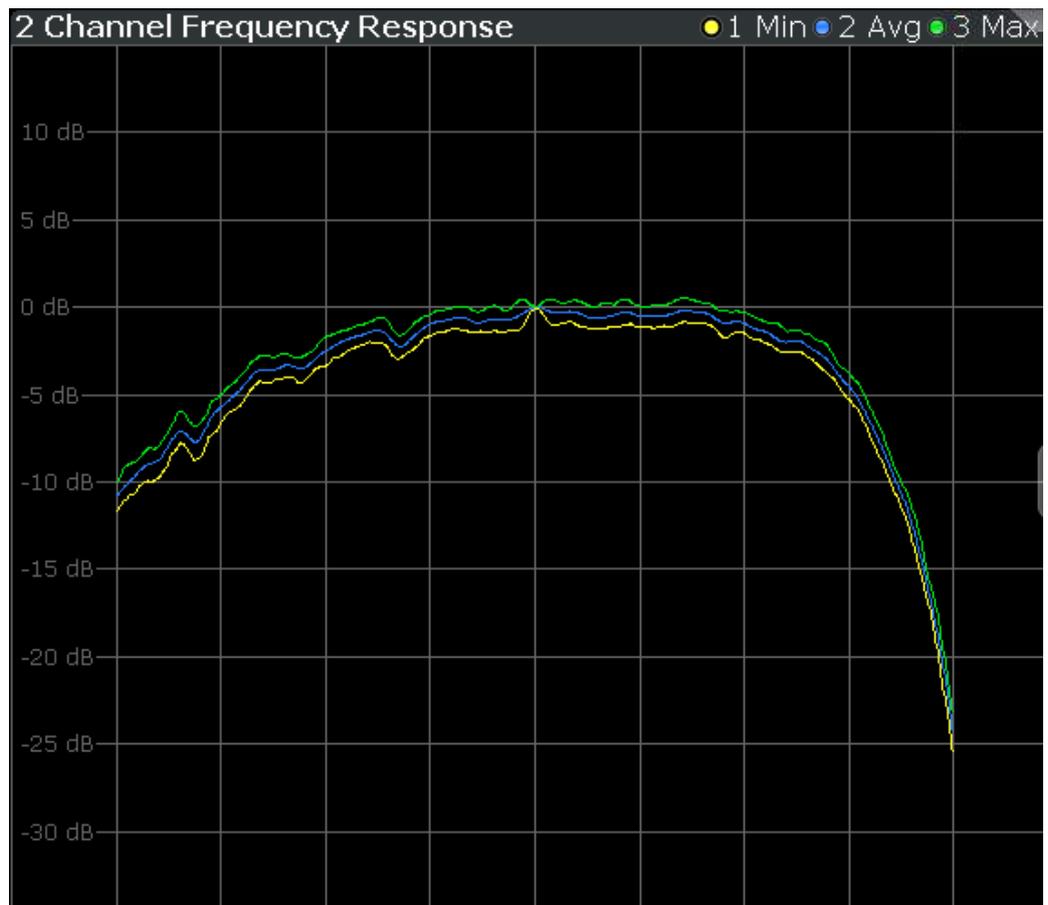
4.4.7 Additional Measurements

The software option K95 offers other useful measurements and display formats in addition to those described above.

Users can benefit from features such as the ability to display complete packages versus time as well as rampup and rampdown areas.

See [5] for detailed information.





The option also displays the decoded header or bitstream (raw and decoded).

4 Header Information					
	DMG PHY Type	MCS A1st	Length	Training Length	HCS
PPDU 1	SC	0011 12	500	15	1110110101011001 0x1001101010110111
PPDU 2	SC	0011 12	500	15	1110110101011001 0x1001101010110111
PPDU 3	SC	0011 12	500	15	1110110101011001 0x1001101010110111
PPDU 4	SC	0011 12	500	15	1110110101011001 0x1001101010110111
PPDU 5	SC	0011 12	500	15	1110110101011001 0x1001101010110111
PPDU 6	SC	0011 12	500	15	1110110101011001 0x1001101010110111
PPDU 7	SC	0011 12	500	15	1110110101011001 0x1001101010110111
PPDU 8	SC	0011 12	500	15	1110110101011001 0x1001101010110111

2 Bitstream Header Decoded

PPDU	Octet Index	
0	0	00010100 00011011 00010100 111001
	9	01000100 10001110 11010001 101110
	18	10101110 01110110 11001011 011000
	27	00010100 11101010 10011110 110111
	36	00101001 00001011 00011101 100100
	45	00011011 10000011 00100010 100101
	54	11110100 00110100 11011000 001001
	63	11101101 00010100 00011011 000101
	72	10100110 10111011 01110001 001011
	81	00000011 01010001 10001001 001101
	90	01000010 11101011 00010101 011000
	99	00010011 11010110 11110100 111000
	108	01011100 11100100 01111100 110111
	117	10010101 00001011 11001011 001001
	126	01000110 00010010

5 Receiver Measurements

The SMW vector signal generator employs the **WLAN 802.11ad** software option (SMW-K141) to provide signals for DUT receiver assessments. The upconverter SZU extends the SMW in the frequency range from 58.32...64.8 GHz.

For measurements on RF transceivers with the FSW, please refer to section [Chapter 4, "Transmitter Measurements"](#), on page 19.

First the test setup is described below, followed by a general description of the software option. Specification-based descriptions of the individual measurements are provided as well.

5.1 Test Setup

DUTs generally consist of a baseband/IF chip and an RF transceiver. Three different tests and associated setups can be derived from this:

- Measurements of the BB/IF chip
The IF frequency is relatively low and measurements can be carried out via cable. An upconverter is not required with the SMW for the 20 GHz frequency range, for example
- Measurements of the RF transceiver
The RF frequency in this case is in the 60 GHz range and measurements must be carried out OTA. The signal quality is evaluated on the IF side (e.g. FSW) as well.
- Measurements of the entire chip
The RF frequency in this case is in the 60 GHz range and measurements must be carried out OTA.

The SMW uses the SMW-K141 software option to generate a WLAN 802.11ad signal and outputs it at the wideband IQ out connectors. The SMW also generates a CW signal as a local oscillator (LO) for the V-band upconverter (SZU). The upconverter multiplies the LO-signal into the 60 GHz range and modulates it with the 802.11ad IQ-signal. Thus a 802.11ad signal in the 60 GHz range is generated. The SMW controls the SZU via USB, thus the setup behaves like one single instrument.

Automatic frequency response compensation

Rohde & Schwarz fully characterizes every SZU during the production process and programs it with appropriate correction values. During operation, the SMW applies these corrections automatically without requiring any special user interaction. At every level and every frequency, the SZU always offers a flat frequency response of < 2.0 dB over 2 GHz bandwidth, although typically the SZU is even better. This eliminates the need for time-consuming external calibration procedures that are required prior to every measurement with conventional mixer setups.

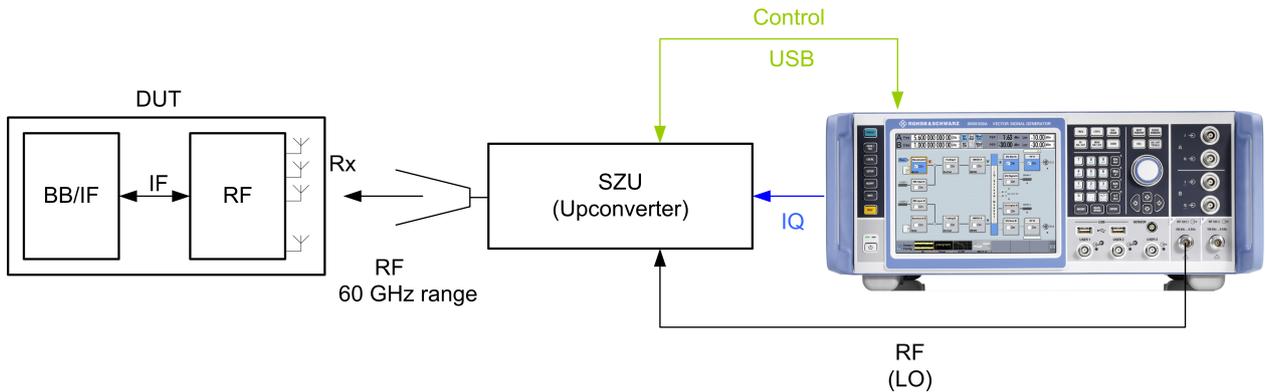


Figure 5-1: RX test setup.

The setup consists of the following instruments and options:

- SMW200A
 - One RF path with 3 GHz (20 GHz or 40 GHz, if IF signals are needed)
 - Baseband with 2 GHz bandwidth (up to 2 basebands possible)
 - SMW-K141 software option
- V-band upconverter SZU.



Figure 5-2: RX test setup on the BB/IF chip – in principle, the same as the overall setup. However, a cable connection can be used thanks to the lower IF frequency of the BB chip and no upconverter is needed. The RF path needs the 20 GHz or 40 GHz option

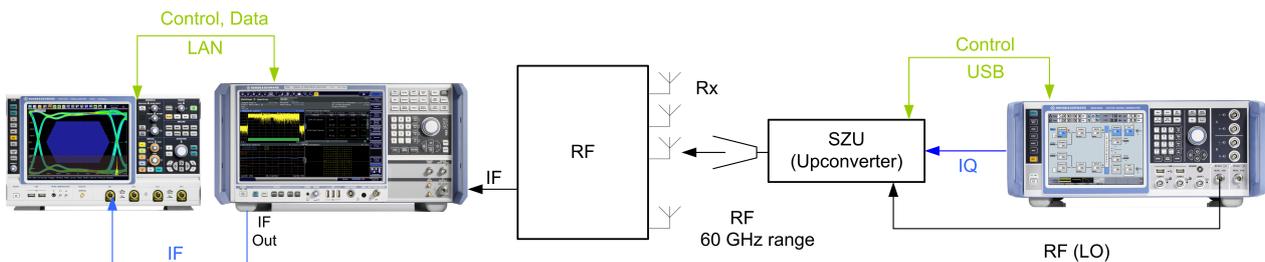


Figure 5-3: RX test setup on an RF transceiver – in principle, the same as the overall setup. In this case, however, the FSW measures the performance (e.g. EVM) on the IF (see also section 4).

5.2 Connection and Setup of the SZU

For measurements in the 60 GHz range, the combination of the SMW and the SZU is the ideal test setup. The SMW controls the SZU directly via the USB connection. The

SMW GUI contains all relevant parameters (one-box-feeling). The SZU provides levels between +5 dBm and -80 dBm. It needs a LO input of around 2 GHz, which is supplied by the SMW even with the 3 GHz option. The SZU supports all common mountable test port adapters and provides high-level stability and harmonic suppression.



For more information on the SZU, please refer to the manual [10].

5.2.1 Hardware Connection

1. SMW is powered on and running.
2. Connect the analog baseband output (single ended or differential I/Q) of the SMW with the **BB IN** of the SZU. The I/Q cable of the SZU uses a color coding to simplify the setup.
3. Connect the **RF A** output of the SMW with the **LO IN** of the SZU
4. Connect the SMW and the SZU with the USB cable
5. Connect the SZU with the power supply and switch it on

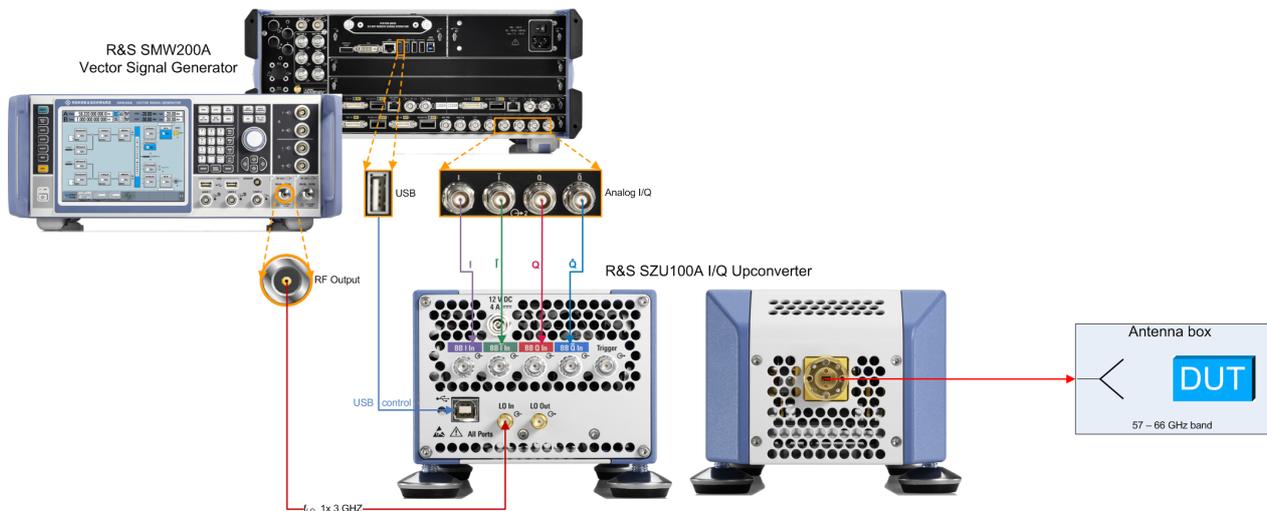


Figure 5-4: Hardware connection SMW and SZU

5.2.2 Configuration in the SMW Firmware

1. Goto **System Configuration** -> **External RF and IQ**
2. Click Config in row **I/Q OUT 1**

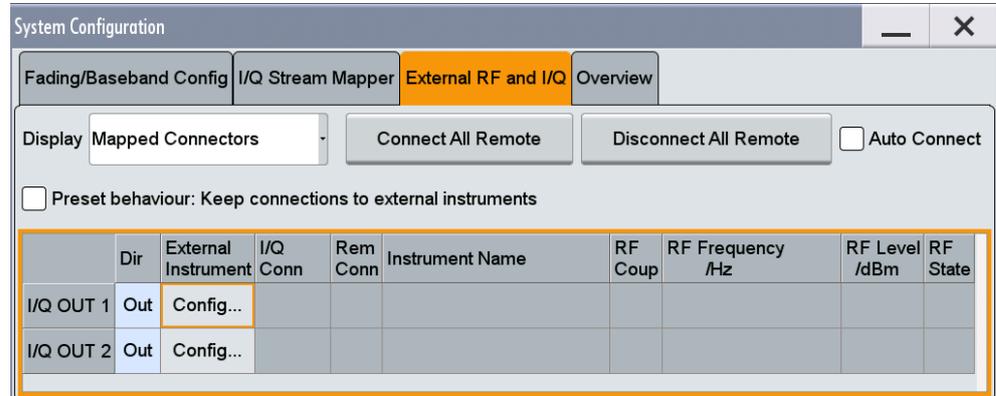


Figure 5-5: SMW: External I/Q connection

3. Scan for SZU and select the connected instrument from the list.
4. Set **I/Q Output Type** to *Differential*

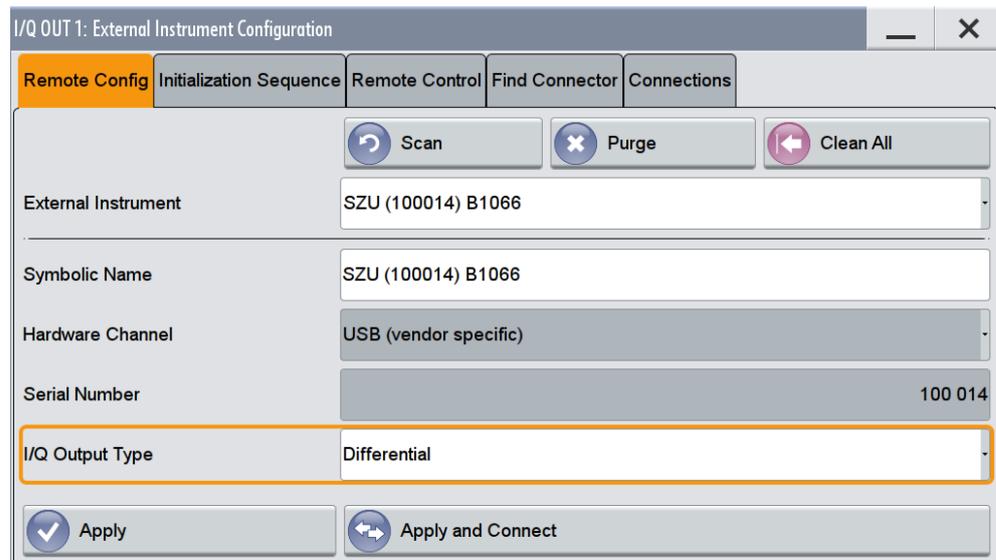


Figure 5-6: The SZU is connected to the SMW via USB. Differential I/Q Output allows a better noise suppression.

5. Click **Apply & Connect**.
6. Check the connection under **Overview**

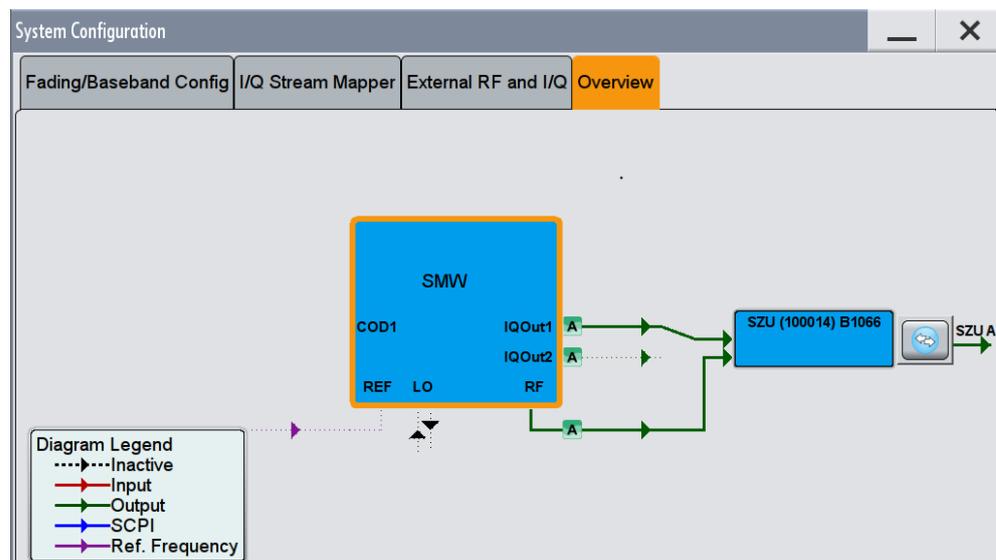


Figure 5-7: Overview of the connections in the System Configuration

Figure 5-8 shows the complete SMW overview with a connected SZU

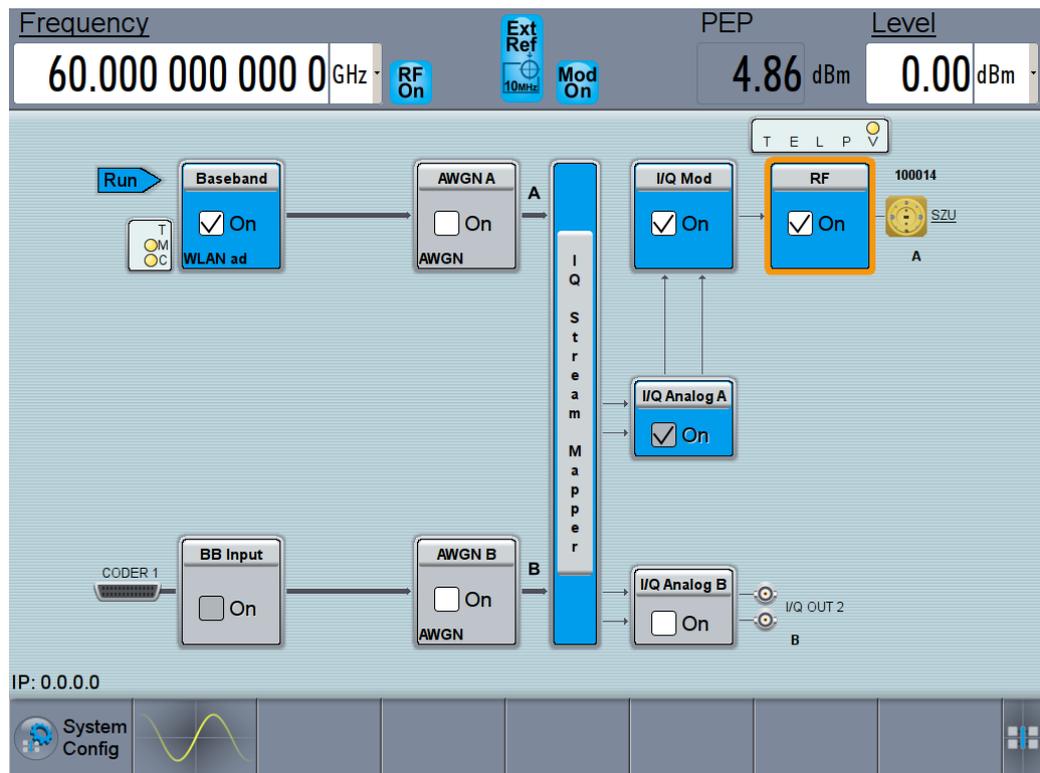


Figure 5-8: SMW with a connected SZU: The frequency and level are at the SZU output.

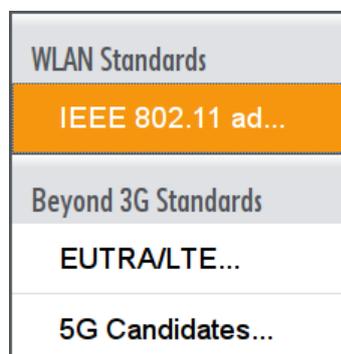
5.3 RX Measurements According to Specification

This section describes the settings on the SMW.

The first part introduces general settings of the WLAN 802.11ad solution in the SMW. The second part describes the tests according to the specification.

5.3.1 The WLAN 802.11ad Software Option

Start the **WLAN 802.11ad** firmware option K141 in the baseband of the SMW:



Select a **DMG PHY mode**.

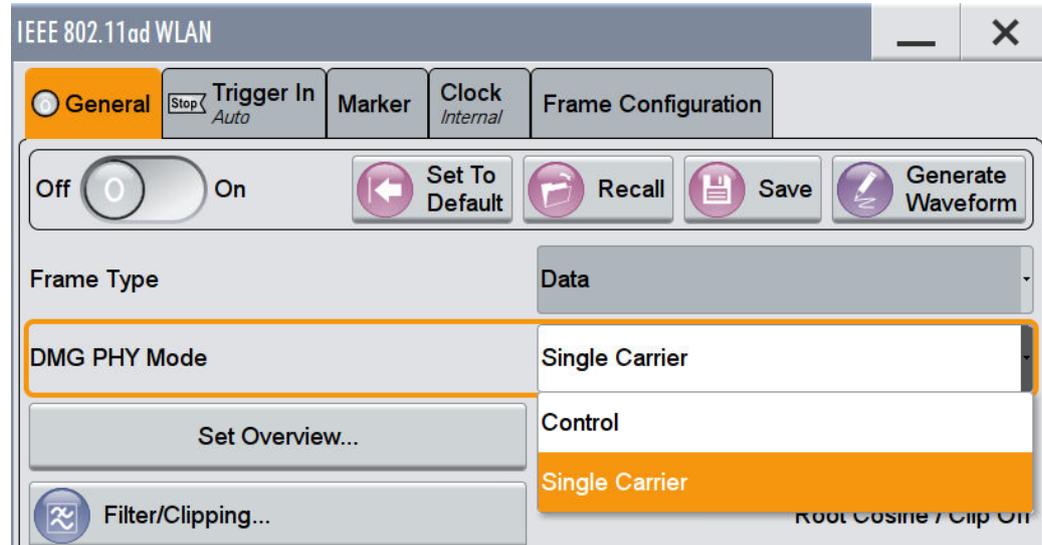


Figure 5-9: The SMW supports the Control PHY and the Single Carrier PHY modes

The SMW supports a **Sequence Length** of up to 360 (different) frames. You can also set the **Idle Time**, that means the time between two 802.11ad packets. Click **PPDU Configuration** to set further details of the signal.

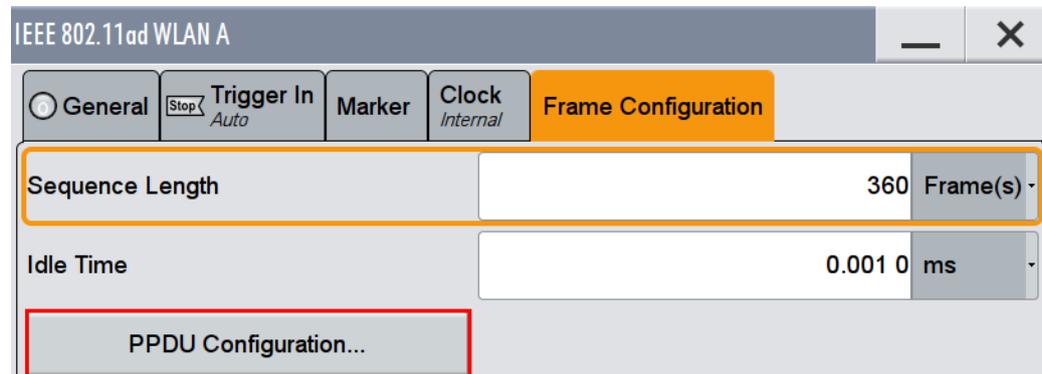


Figure 5-10: The 802.11ad frame configuration supports up to 360 frames.

The tab **General** in the **PPDU Configuration** contains the settings of the Modulation and Coding Scheme (MCS). The SMW sets the modulation automatically according to the selected MCS. In addition you can set the Coding and the Scrambler. The SMW indicates also the resulting **Data Rate**.

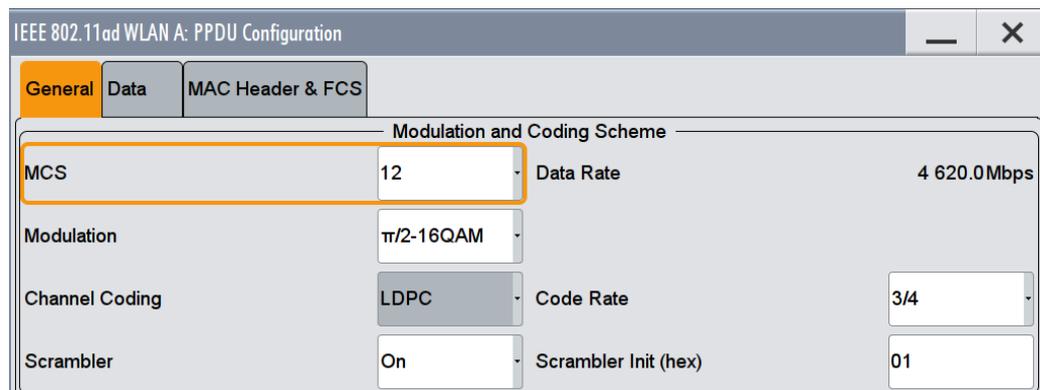


Figure 5-11: General PDU Configuration: Modulation and Coding Scheme.

The tab **Data** contains the settings for the data and the header. The data length can be in single carrier PHY up to 262107 bytes. The SMW shows also a graphical overview of the configured packet.

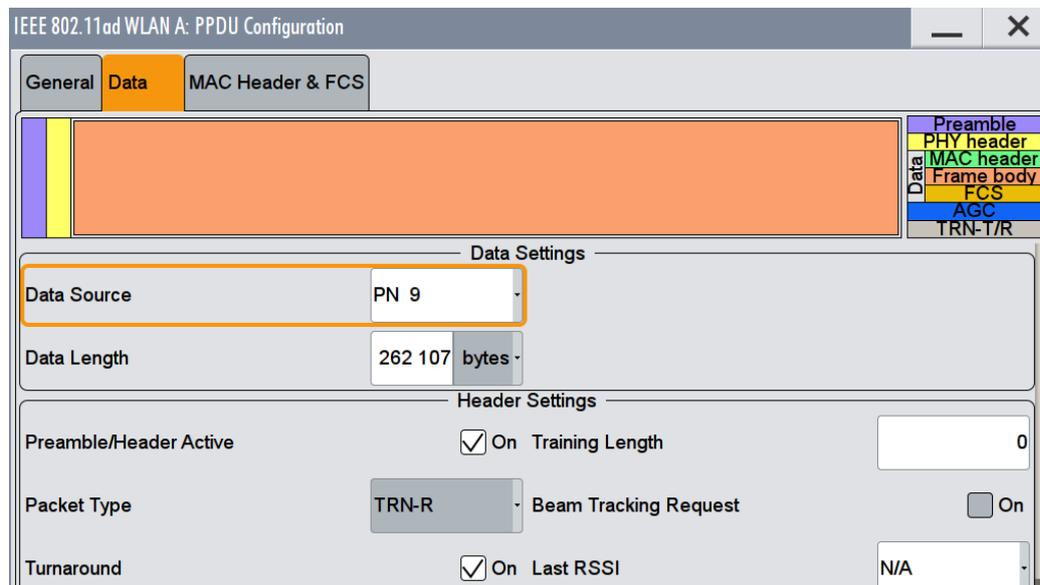


Figure 5-12: Data PDU Configuration: Data and Header settings

The SMW supports different sources like pseudo random sequences with different lengths (PNx) as well as free settable patterns or user data. Configuration of multiple A-MPDU's is supported, too.

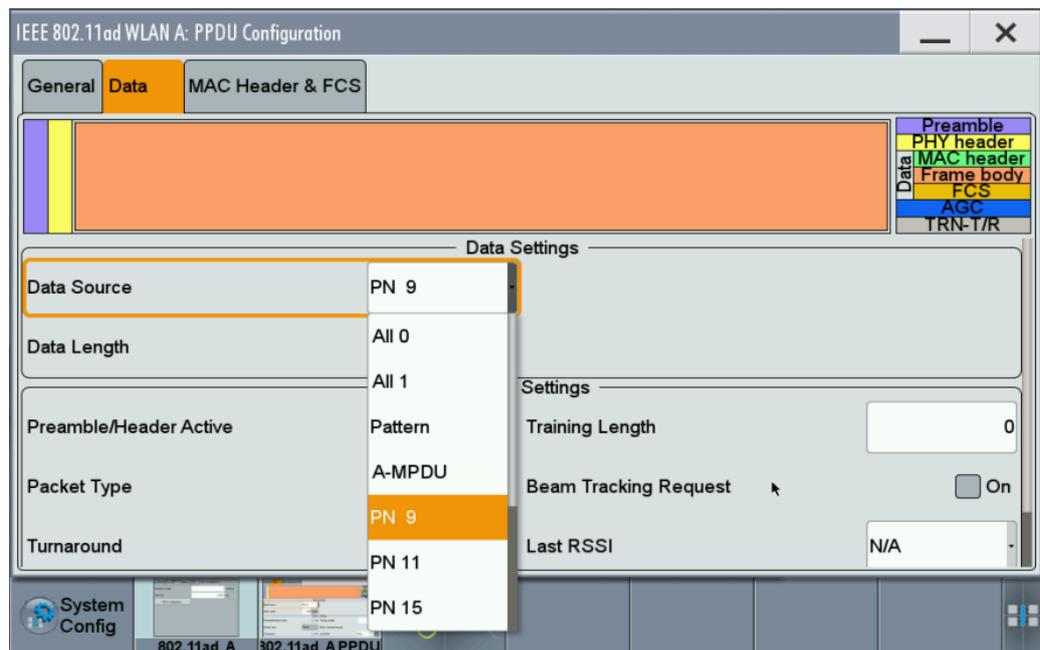


Figure 5-13: Data Source.

In the section **Header Settings** you can control the optional beamforming training. If the **Training Length** is set to 0, no beamforming training is transmitted in the packet (Figure 5-14). If the length > 0, the beamforming training is transmitted. Here you can select in addition the **Packet type** (Figure 5-15). The SMW may transmit the **LAST RSSI** as fixed values.

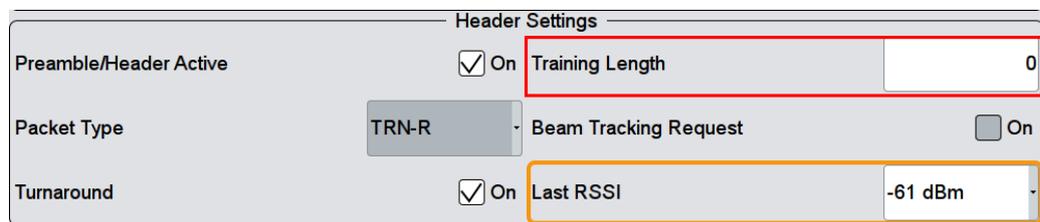


Figure 5-14: Data PDU Configuration: Header settings

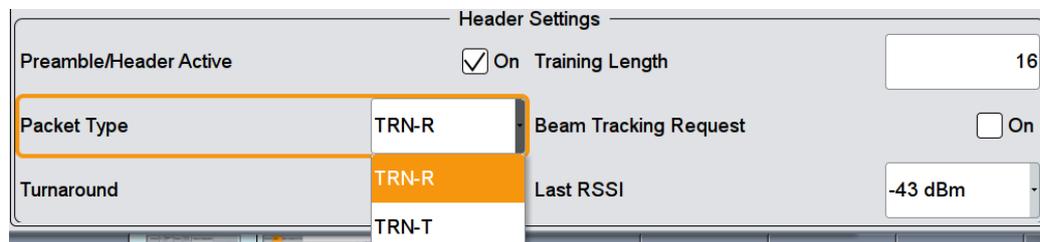


Figure 5-15: Data PDU Configuration: Header settings with beamforming training enabled.

The tab **MAC Header & FCS** allows you to enable MAC header information and the FCS checksum. Both are disabled by default.

IEEE 802.11ad WLAN A: PDU Configuration

General Data **MAC Header & FCS**

MAC Header On FCS (checksum) On

Field	Value	Size
Frame Control (hex)	0000	2 bytes
Duration / ID (hex)	0000	2 bytes
Address 1 (hex)	0000 0000 0000	6 bytes
Address 2 (hex)	0000 0000 0000	6 bytes
Address 3 (hex)	0000 0000 0000	6 bytes
Seq Control	Enable <input type="checkbox"/>	4 bit
Address 4 (hex)	0000 0000 0000	6 bytes
QoS Ctrl(hex)	0000	2 bytes
Frame Body	0 - 262107	bytes
FCS		4 bytes

Start Number (hex) 0 Start Number (hex) 000
Incremented Every 1 packet(s) Incremented Every 1 packet(s)

MAC Frame Control Field

Field	Value	Size
Protocol Version	00	2 bits (LSB)
Type	00	2 bits
Subtype	0000	4 bits
To DS	0	1 bit
From DS	0	1 bit
More Frag	0	1 bit
Retry	0	1 bit
Pwr Mgt	0	1 bit
More Data	0	1 bit
Protcl Frm	0	1 bit
Order	0	1 bit (MSB)

Figure 5-16: MAC Header & FCS

5.3.2 Receiver Sensitivity (21.3.3.9)

The Receiver sensitivity test is determined by the packet error rate (PER). The limits are:

PHY	Limit
Control Phy	< 5%
SC PHY	< 1%
Low Power SC PHY	< 1%

for the levels mentioned in the following table:

Table 5-1: Receiver Sensitivity

PHY	MCS	Modulation	Sensitivity Level [dBm]
Control PHY	0	DPSK	- 78
Single carrier PHY	1	$\pi/2$ -PSK	- 68
	2		- 66
	3		- 65
	4		- 64
	5		- 62
	6	$\pi/2$ -QPSK	- 63
	7		- 62
	8		- 61
	9		- 59

PHY	MCS	Modulation	Sensitivity Level [dBm]
	10	$\pi/2$ -16QAM	- 55
	11		- 54
	12		- 53
Low Power SC PHY	25	$\pi/2$ -BPSK	- 64
	26		- 60
	27		- 57
	28	$\pi/2$ -QPSK	- 57
	29		- 57
	30		- 57
	31		- 57

The SMW generates a signal at the specified level. The PER is determined in the receiver chip (baseband).

Set the following parameters at the SMW:

- DMG PHY
- MCS
- Channel (Frequency)
- Level

Please note, that the mentioned level is the input level at the DUT. You can compensate the attenuation inside the SMW (see also [Chapter 3.6, "Practical Approach to OTA Measurements"](#), on page 12).

5.3.3 Received Channel Power Indicator (RCPI) Measurement (21.3.10)

The RCPI indicates the received RF power by a value in the range between 0 and 255 in the power range between 0 dBm and -110 dBm in 0.5 dB steps. For more details, see [1].

The RCPI difference to the actual power shall be at maximum ± 5 dB.

The SMW generates a signal at wanted levels. The RCPI is calculated in the receiver chip (baseband).

Set the following parameters at the SMW:

- DMG PHY
- MCS
- Channel (Frequency)
- Level

6 Appendix

6.1 Literature

- [1] IEEE: **Wireless LAN MAC and PHY Specifications // Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band.** - 2012.
- [2] Rohde & Schwarz: **Antenna Basics**, Application Note 8GE01.
- [3] Rohde & Schwarz: **Fundamentals of Spectrum Analysis.** Book // ISBN: 978-3-939837-01-5
- [4] Rohde & Schwarz: **Intermodulation Measurements on Modern Spectrum Analyzers.** Application Note 1EF79 // 2012
- [5] Rohde & Schwarz: **R&S®FSW-K95 802.11ad Measurements**, User Manual.
- [6] Rohde & Schwarz: **802.11ad - WLAN at 60 GHz**, White Paper 1MA220 // 2015.
- [7] Wikipedia https://en.wikipedia.org/wiki/Horn_antenna.
- [8] Rohde & Schwarz: **Wideband mm - Wave Signal Generation and Analysis** , Application Note 1MA257 // 2015.
- [9] Rohde & Schwarz: **Field Strength and Power Estimator**, Application Note 1MA85 // 2016.
- [10] Rohde & Schwarz: **R&S®SZU100A IQ Upconverter 58.32-64.8 GHz**, User Manual.

6.2 Additional Information

Please send your comments and suggestions regarding this white paper to TM-Applications@rohde-schwarz.com

6.3 Ordering Information

Spectrum & Signal Analyzer		
FSW 67 GHz	R&S®FSW67	1312.8000K67
FSW 85 GHz	R&S®FSW85	1312.8000K85
2 GHz Analysis Bandwidth	R&S®FSW-B2000	1325.4750.02
IEEE802.11ad Measurements	R&S®FSW-K95	1313.1639.02
Digital oscilloscope 4 GHz	R&S®RTO2044	1329.7002.44

Vector Signal Generator		
SMW200A	R&S®SMW200A	1412.0000.02
100 kHz to 3 GHz ¹	R&S®SMW-B103	1413.0004.02
Baseband Main Module	R&S®SMW-B13XT	1413.8005.02
Wideband Baseband Generator	R&S®SMW-B9	1413.7350.02
Baseband Extension to 2 GHz BW	R&S®SMW-K526	1413.9318.02
ARB memory extension to 2 GS ²	R&S®SMW-K515	1413.9360.02
Low Phase Noise + FM/PhiM ³	R&S®SMW-B22	1413.2207.02
Wideband Differential I/Q Outputs	R&S®SMW-K17	1414.2346.02
IEEE802.11ad	R&S®SMW-K141	1414.1333.02
IQ Upconverter 58.32...64.8 GHz	R&S®SZU100A	1425.3110.02
57GHz TO 66GHz, WR15	R&S®SZU-B1066	1425.3110.02

Power Sensor		
Three-Channel Sensor Module, for R&S®NRP OTA antenna modules	R&S®NRPM3	1425.8563.02
Single-Polarized Antenna-Module, with integrated diode detector from 57 GHz to 66 GHz	R&S®NRPM-A66	1425.8740.02
Filtered Cable Feedthrough, for anechoic chamber	R&S®NRPM-ZD3	1425.8786.02
Interface Cable, between R&S®NRPM3 sensor module and R&S®NRPM-ZD3 feedthrough module	R&S®NRPM-ZKD3	1425.8770.02
USB Interface Cable, different lengths	R&S®R&S®NRP-ZKU	1419.0658.0x
Six-Pole Interface Cable, different lengths	R&S®NRP-ZK6	1419.0664.0x
RF Shielded Box, manual version, RF 4 × N, without front feed-throughs	R&S®TS7124M	1525.8564.02
RF Shielded Box, automatic version, RF 4 × N, without front feed-throughs	R&S®TS712AS	1525.8587.02
Antenna Ring	R&S®TS-F24-AR	1525.8906.02
Absorber Kit für mmW	R&S®TS-F24ABS2	1530.1012.02
DUT Holder	R&S®TS-F24P1	1525.8664.02

1. If also IF frequencies are needed, an RF path with 20 GHz or 40 GHz is necessary.
2. The SMW-K515 memory extension is optional if very long signal sequences are to be generated.
3. The SMW-B22 can be used to improve the already excellent SSB phase noise of the standard SMW even further. This option is recommended for achieving best EVM.

7 Rohde & Schwarz

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