Generating Signals for WLAN 802.11ac

Application Note

Products:

R&S®SMW200A	R&S®AMU200A
R&S®SMU200A	R&S®AFQ100A
R&S®SMATE200A	R&S®AFQ100B
R&S®SMBV100A	R&S®WinIQSIM2™
R&S®SMJ100A	
R&S®SGS100A	

Rohde & Schwarz signal generators can generate standard-compliant WLAN IEEE 802.11ac signals up to 160 MHz bandwidth with excellent EVM performance.

This application note demonstrates the generator test solutions and explains step-by-step how to configure a test signal. Several measurements are presented to illustrate EVM performance.

Application Note

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ROHDE&SCHWARZ

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1 Introductory Note

The following abbreviations are used in this application note for Rohde & Schwarz products:

- The R&S®SMW200A vector signal generator is referred to as SMW
- The R&S®SMU200A vector signal generator is referred to as SMU
- The R&S®SMATE200A vector signal generator is referred to as SMATE
- The R&S®SMBV100A vector signal generator is referred to as SMBV
- The R&S®SMJ100A vector signal generator is referred to as SMJ
- The R&S®AMU200A baseband signal generator and fading simulator is referred to as AMU
- The R&S®AFQ100A I/Q modulation generator is referred to as AFQ A
- The R&S®AFQ100B UWB signal and I/Q modulation generator is referred to as AFQ B
- The AFQ A and the AFQ B are also referred to as AFQ, if the differentiation is not important
- The R&S®SGS100A SGMA RF source is referred to as SGS
- The R&S®WinIQSIM2™ simulation software is referred to as WinIQSIM2
- The R&S®FSW signal and spectrum analyzer is referred to as FSW
- The R&S®SMW200A , R&S®SMU200A, R&S®SMATE200A, R&S®SMBV100A and R&S®SMJ100A are collectively referred to as SMx

The WLAN IEEE 802.11ac standard is referred to as WLAN 11ac or 802.11ac.

2 Introduction

Rohde & Schwarz signal generators can generate standard-compliant, fully coded WLAN 11ac signals up to 160 MHz bandwidth with excellent EVM performance. This application note demonstrates the generator test solutions (section 3) and explains step-by-step how to configure a test signal (section 4). Several measurements are presented in this application note to illustrate EVM performance and to explain how the signal quality can be optimized for certain setups (sections 5 and 6).

For technical background on the WLAN 11ac standard, see the “802.11ac Technology Introduction” white paper (1MA192).

3 WLAN 11ac Test Setup

3.1 Overview

The 802.11ac standard supports higher data rates and wider RF signal bandwidths than its predecessor standards. Besides 20 MHz and 40 MHz channels (as used in the 802.11n standard), the 802.11ac standard also supports 80 MHz, 80 MHz + 80 MHz and 160 MHz channels. For the 80 MHz + 80 MHz channel, two transmission modes are possible: contiguous mode and noncontiguous mode. The table below summarizes and illustrates the different 802.11ac bandwidths.

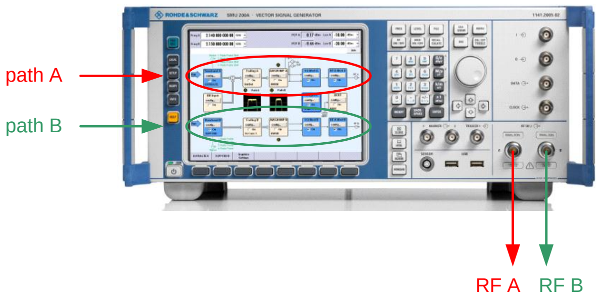
The application relevant Rohde & Schwarz signal generators support the following RF bandwidths:

Overview of Rohde & Schwarz signal generators for WLAN 802.11ac applications			
Instrument	**Generator type**	**Maximum RF bandwidth**	**Maximum RF frequency**
SMW	RF vector signal generator	160 MHz (internal I/Q) 2000 MHz (external I/Q upconversion)[1]	6 GHz (first RF path) 6 GHz (second RF path)
SMU	RF vector signal generator	80 MHz (internal I/Q) 200 MHz (external I/Q upconversion)	6 GHz (first RF path) 3 GHz (second RF path)
SMATE	RF vector signal generator	80 MHz (internal I/Q) 200 MHz (external I/Q upconversion)	6 GHz (first RF path) 6 GHz (second RF path)
SMJ	RF vector signal generator	80 MHz (internal I/Q) 200 MHz (external I/Q upconversion)	6 GHz
SMBV	RF vector signal generator	160 MHz (internal I/Q) 528 MHz (external I/Q upconversion)	6 GHz
AFQ A	Baseband signal generator	200 MHz (internal I/Q)	---
AFQ B	Baseband signal generator	528 MHz (internal I/Q)	---
SGS	RF signal generator	1000 MHz (external I/Q upconversion)	6 GHz

The SMU and SMATE have a two-path architecture that effectively combines two complete vector signal generators in a single instrument. The SMW is even more powerful and has a multi-path architecture with two RF outputs.

[1] RF frequency dependent value. See SMW data sheet for details.

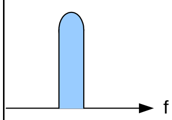
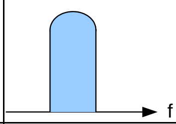
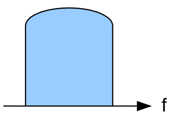
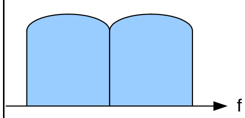
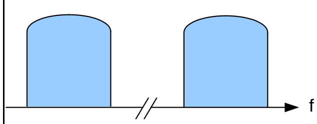
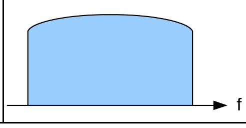
SMU



The SMU can be equipped with a 2.2 GHz, 3 GHz, 4 GHz or 6 GHz RF path and a second 2.2 GHz or 3 GHz RF path. The SMW and SMATE can be equipped with a 3 GHz or 6 GHz RF path and a second 3 GHz or 6 GHz RF path.

All RF signal generators listed in the above table can be used for upconversion of external I/Q signals.

The following table summarizes and illustrates the different 802.11ac channels and the required instruments for standard-compliant WLAN 11ac RF signal generation.

WLAN 802.11ac bandwidths and generator solutions		
Channel bandwidth	**Channel bandwidth illustration**	**Required instruments for RF signal generation**
20 MHz		one SMx or one AFQ + upconverter (e.g. SGS)
40 MHz		one SMx or one AFQ + upconverter (e.g. SGS)
80 MHz		one SMx or one AFQ + upconverter (e.g. SGS)
80 MHz + 80 MHz contiguous mode		one SMW (one-path) or one SMBV or one SMATE (two-path) or two SMJs or one AFQ + upconverter (e.g. SGS)
80 MHz + 80 MHz noncontiguous mode		one SMW (two-path) or one SMATE (two-path) or two SMBVs/SMJs (or one AFQ B + upconverter (SGS or SMBV))
160 MHz		one SMW (one-path) or one SMBV or one AFQ + upconverter (e.g. SGS)

Instrument recommendations

Mid-range:

To cover the 20/40/80/160 MHz and 80+80 MHz (contiguous) channel bandwidths, the recommended solution is:
One SMBV 6 GHz signal generator.

To cover the 20/40/80/160 MHz and 80+80 MHz (noncontiguous) channel bandwidths, the recommended solution is:
Two SMBV 6 GHz signal generators.

High-end:

To cover all channel bandwidths (20/40/80/160 MHz, contiguous and noncontiguous 80+80 MHz), the recommended solution is:
One SMW 6 GHz signal generator (two RF paths).

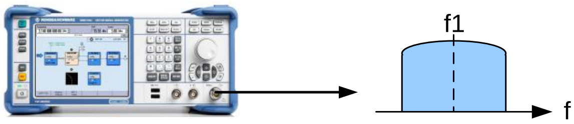
3.2 Setups

This section shows some examples of setups for WLAN 11ac signal generation. Note, however, that not all possible instrument setups are shown. For a complete overview, refer to the “WLAN 802.11ac bandwidths and generator solutions” table in the previous section.

3.2.1 20 MHz, 40 MHz, 80 MHz, 160 MHz Channels

3.2.1.1 SMBV and SMW

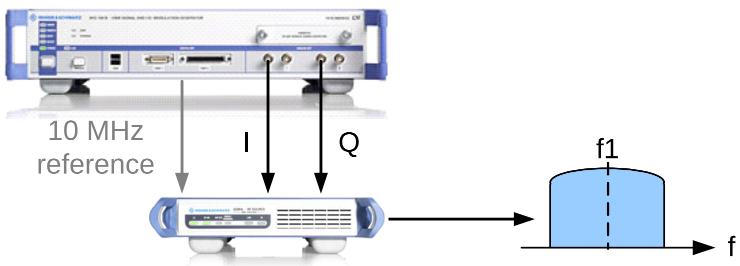
A single SMBV or SMW can generate 802.11ac signals with 20 MHz, 40 MHz, 80 MHz, 80 MHz + 80 MHz (contiguous), and 160 MHz channel bandwidths.



3.2.1.2 AFQ A and B

802.11ac signals with 20 MHz, 40 MHz, 80 MHz, 80 MHz + 80 MHz, and 160 MHz channel bandwidths can be generated using a combination of AFQ A or B and SGS.

The AFQ generates the 802.11ac signal and the SGS upconverts the analog I/Q baseband signal to the RF. The SGS is small, cost-efficient and offers outstanding signal quality. It is therefore the perfect match for the AFQ. (However, other RF vector signal generators could be used as well for upconversion.)



Note that there is a bandwidth limitation of 528 MHz for generating the noncontiguous 80 MHz + 80 MHz channel.

As a general rule, to connect the AFQ to the upconverter, use cables of the same type that are exactly equal in length. This is important, since otherwise a delay between the I and the Q signal is introduced, which degrades signal quality significantly.

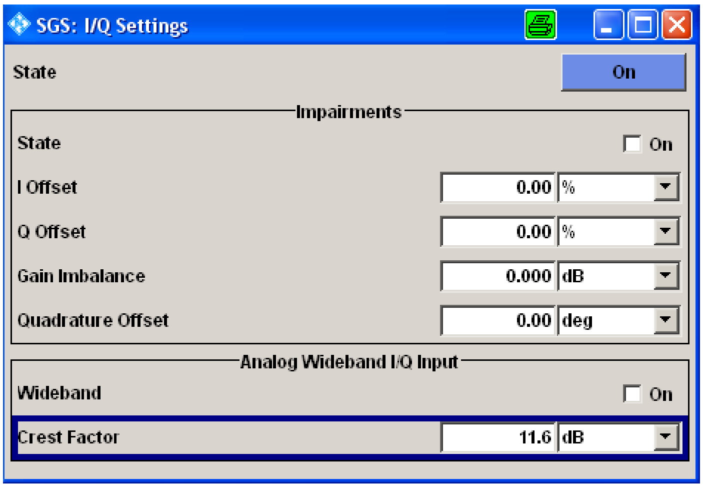
Since the AFQ has no display, the instrument is controlled via a standard remote desktop connection from a PC (see reference [1] for details). The SGS has no display and is controlled via the SGMA GUI software running on a PC.

To obtain the correct RF output power at the SGS, the following settings are important. The SGS expects an input amplitude of 500 mV peak at its analog I/Q input. The corresponding analog I/Q output amplitude settings of the AFQ are shown in the following table:

AFQ analog I/Q output amplitude settings		
AFQ A	**AFQ B**	**Display**
1000 mV (balanced output)	1000 mV (balanced output) with bias amplifier enabled	
500 mV (unbalanced output)	---	

The crest factor of the ARB waveform is displayed in the header of the AFQ.

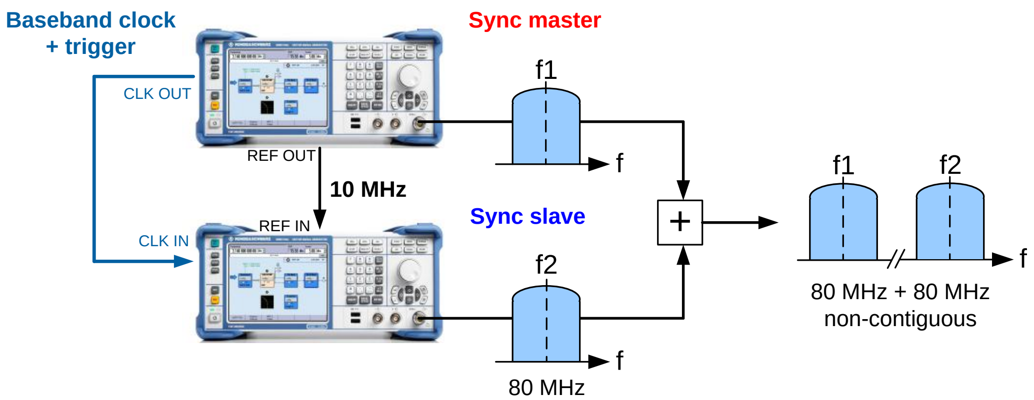
This crest factor needs to be entered in the SGS. The I/Q Settings menu of the SGS contains a corresponding parameter.



Since the signal is fed in from external and is thus unknown to the SGS, the user needs to provide information about the crest factor of the input signal. The SGS can determine the RMS level of the signal from the peak amplitude (500 mV expected) and the entered crest factor value. This enables the instrument to level its RF output correctly which is important if the channel power of the WLAN 11ac signal is to be measured.

3.2.2 80 MHz + 80 MHz Noncontiguous Channels

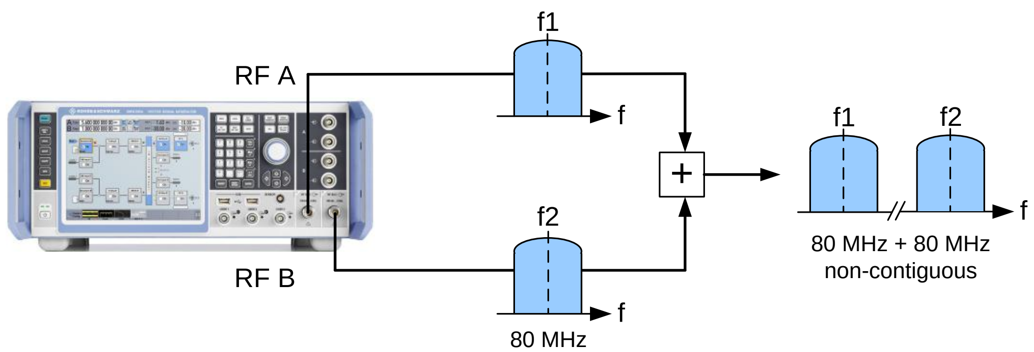
To generate the 80 MHz + 80 MHz noncontiguous channels, two SMBVs can be used. Each SMBV generates one 80 MHz signal with appropriate RF frequency. The two RF output signals are added using a suitable RF combiner. To ensure that signal generation starts synchronously in both instruments, the SMBV master-slave setup is used.



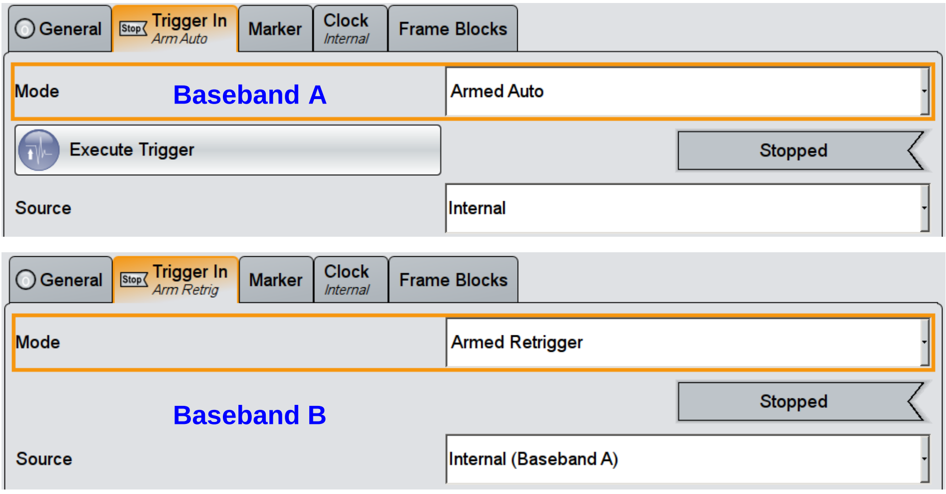
One SMBV acts as master instrument and supplies all necessary synchronization signals to the slave instrument via just two connection cables. The master-slave setup is simple, easy to configure and provides highly synchronized test signals. It is described in detail in the application note “Time Synchronous Signals with Multiple R&S SMBV100A Vector Signal Generators” (1GP84).

To obtain the desired RF power at the combiner output, the following points should be taken into account. Adding two signals with equal RF levels theoretically increases the signal level at the output by 3 dB. However most combiners exhibit a specified loss (typically 3 dB for hybrid and 6 dB for resistive combiners) that reduces the theoretical signal level.

Alternatively, a two-path SMW can be used to generate the 80 MHz + 80 MHz noncontiguous channels. Each RF path generates one 80 MHz signal with appropriate RF frequency. The two RF output signals are added using a suitable RF combiner. To ensure that signal generation starts synchronously in both basebands, baseband A is used to trigger baseband B.



To synchronize both basebands, the following trigger settings are needed on the SMW:



To actually start both basebands simultaneously, click the “Execute Trigger” button in baseband A.

4 Signal Configuration

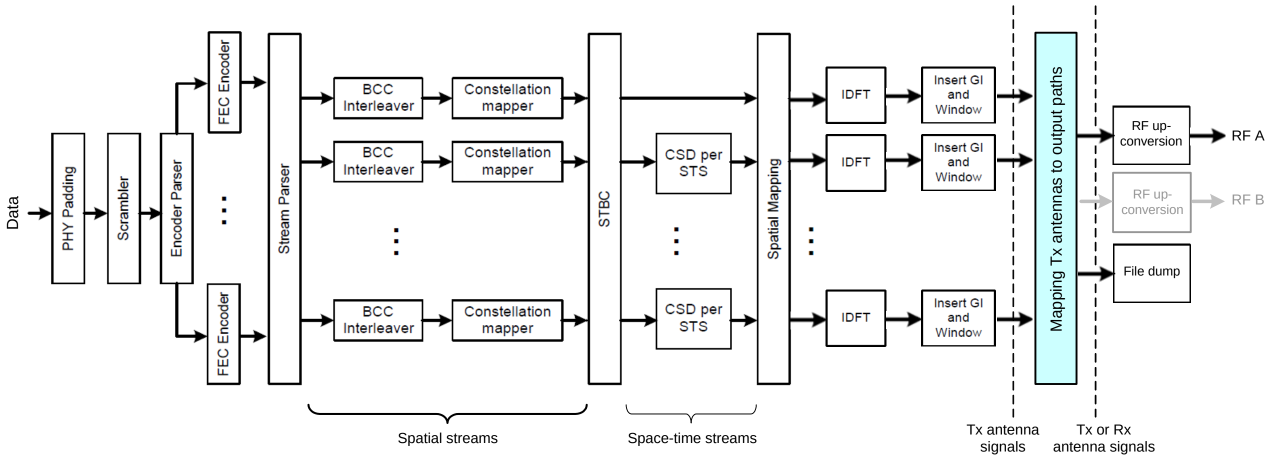
4.1 Overview

Rohde & Schwarz signal generators can generate standard-compliant WLAN 802.11ac signals with excellent EVM performance (see section 5). The corresponding options are listed in the following table:

Options for WLAN IEEE 802.11ac				
Instrument	**Internal option**	**Prerequisite internal option**	**WinIQSIM2 option**	**Prerequisite WinIQSIM2 option**
SMW	SMW-K86	SMW-K54	SMW-K286	SMW-K254
SMU	SMU-K86	SMU-K54	SMU-K286	SMU-K254
SMATE	SMATE-K86	SMATE-K54	---	---
AMU	AMU-K86	AMU-K54	AMU-K286	AMU-K254
SMBV	SMBV-K86	SMBV-K54	SMBV-K286	SMBV-K254
SMJ	SMJ-K86	SMJ-K54	SMJ-K286	SMJ-K254
AFQ	---	---	AFQ-K286	AFQ-K254

The K86 (802.11ac) and K54 (802.11n) options are needed to generate WLAN 802.11ac signals via the instrument's internal baseband generators. In order to play back WLAN 802.11ac ARB waveforms generated with the WinIQSIM2 software, the K286 (802.11ac) and K254 (802.11n) options are needed.
For generating 160 MHz channels, the SMW and the SMBV need the K522 baseband extension (to 160 MHz RF bandwidth) option.

The following block diagram shows the signal generation chain as implemented in the Rohde & Schwarz signal generators. This diagram serves as a guideline for the following sections.

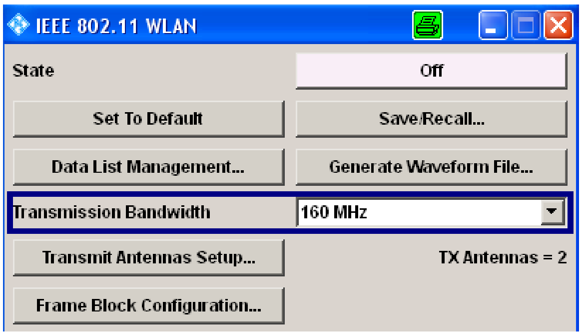


Signals are generated in multiple steps. First, the user data is scrambled, encoded and distributed to up to eight spatial streams. Each spatial stream is interleaved, and an individual modulation mapping (BPSK, QPSK, 16QAM, 64QAM, 256 QAM) is applied. Afterwards, space time block coding (STBC) is optionally applied for adding redundancy. Out of two spatial streams, for example, four space time streams can be generated using STBC, which makes the transmission more robust. After applying a cyclic shift to the space time streams for decorrelation, the space time streams are subject to spatial mapping. Spatial mapping can be interpreted as the distribution of the precoded data bits onto the different OFDM carriers. In the real world, a WLAN 11ac transmitter tries to optimize the spatial mapping depending on the channel conditions by means of the channel sounding information received. Therefore, there is a spatial mapping matrix for every OFDM carrier. Additionally, spatial expansion is possible, which means that, for example, three space time streams can be effectively distributed to e.g. 4 Tx antennas. Each Tx signal is derived by applying a spatial mapping matrix to the space time streams, performing an inverse discrete Fourier transformation (IDFT), and adding a guard interval. The Tx antenna signals are then mapped to the baseband output. It is possible to map either a single Tx signal or multiple Tx signals to the baseband output. The next step is the upconversion of the baseband signal to the RF. Depending on the mapping, either a Tx signal or an Rx signal (i.e. multiple superimposed Tx signals) is output as RF signal.

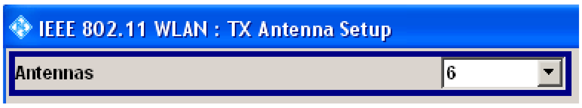
4.2 Configuring a WLAN11ac Signal

4.2.1 Basic Settings

To generate a WLAN 11ac signal, first select the transmission bandwidth, e.g. 160 MHz, in the WLAN main menu.

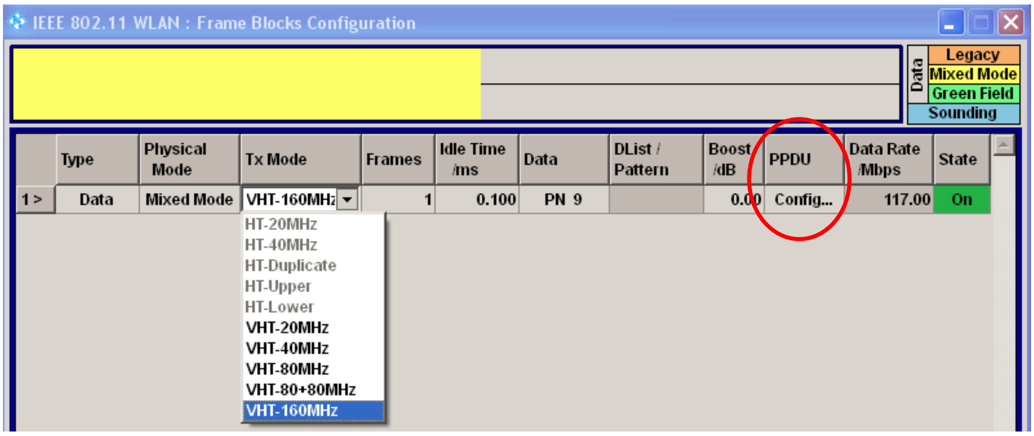


Click the “Transmit Antennas Setup…” button to open the TX Antenna Setup menu. Set the “Antennas” parameter to the desired number of Tx antenna signals to be generated.



4.2.2 Frame Block Configuration

In the main menu, click the “Frame Block Configuration…” button. In the Frame Blocks Configuration menu, the user can define the very high throughput (VHT) channel to use, e.g. the VHT 160 MHz channel. The entry for “Physical Mode” must be set to “Mixed Mode” (default setting). The user can also select the number of frames to be generated and the idle time.

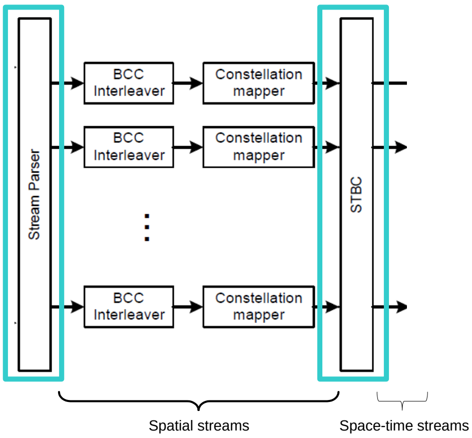


4.2.3 PPDU Configuration for Frame Block

Click “Config…” in the Frame Blocks Configuration table to open the PPDU Configuration menu.

4.2.3.1 Stream Settings

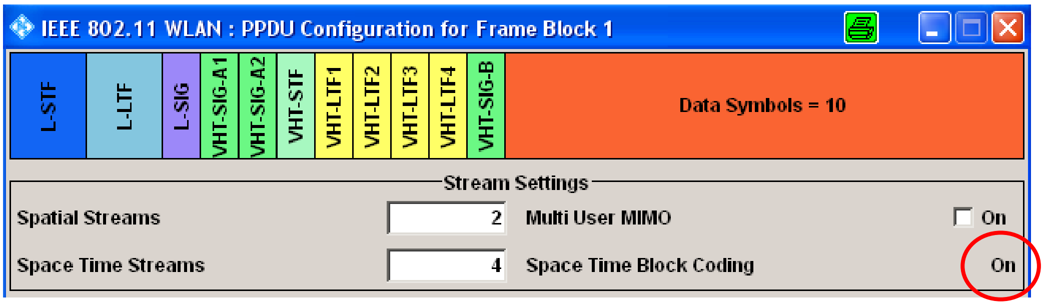
This section briefly describes the settings needed to configure the highlighted part of the signal generation chain:



The scrambled and encoded data is distributed to one, two, three, four, five, six, seven or eight spatial streams.

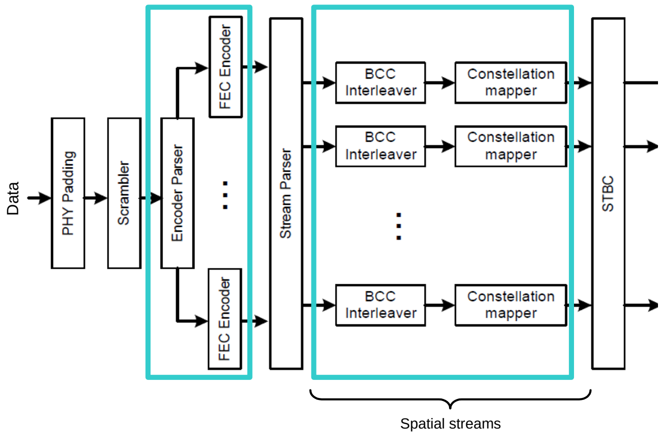
Space time block coding (STBC) is optionally applied for adding redundancy. Out of two spatial streams, for example, three or four space time streams can be generated using STBC, which makes the transmission more robust.

Select the number of spatial streams that shall be generated. The maximum number that can be entered depends on the selected number of Tx antennas (configured in section 4.2.1). Select the number of space time streams that shall be generated. The number that can be entered is equal to or greater than the number of spatial streams. The maximum number depends on the selected number of Tx antennas. If the entered number of space time streams is greater than the number of spatial streams, STBC is automatically applied.

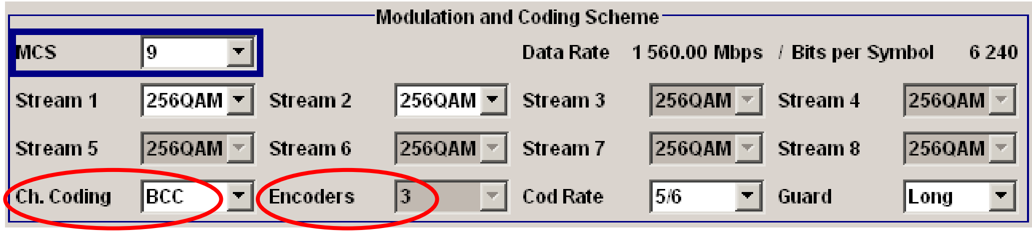


4.2.3.2 Modulation and Coding Scheme

This section briefly describes the settings needed to configure the following part of the signal generation chain:

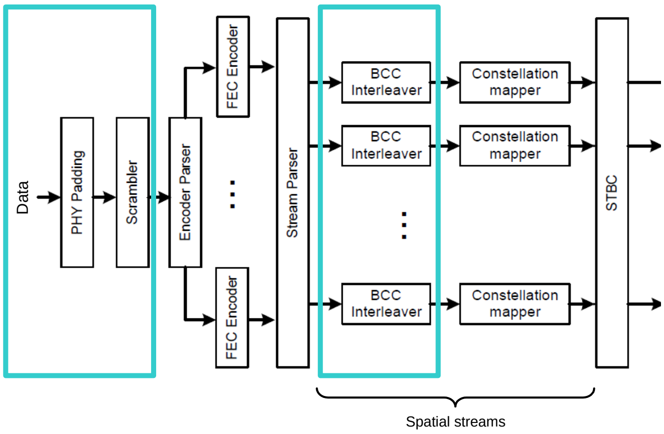


Choose a modulation and coding scheme (MCS). All related parameters are set automatically. Alternatively, you can select the modulation type (BPSK, QPSK, 16QAM, 64QAM, 256QAM) to be applied to the spatial streams. The binary convolution coding (BCC) is enabled by default. Low density parity check (LDPC) coding is also supported. Depending on the selected MCS, the number of forward error correction (FEC) encoders to use is set automatically.

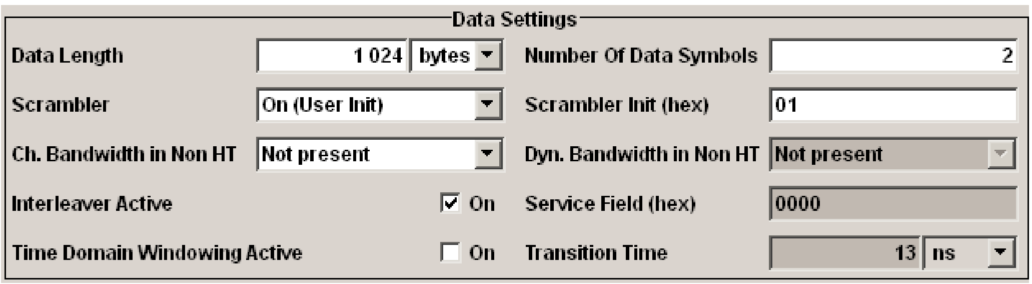


4.2.3.3 Data Settings

This section briefly describes the settings needed to configure the highlighted part of the signal generation chain:

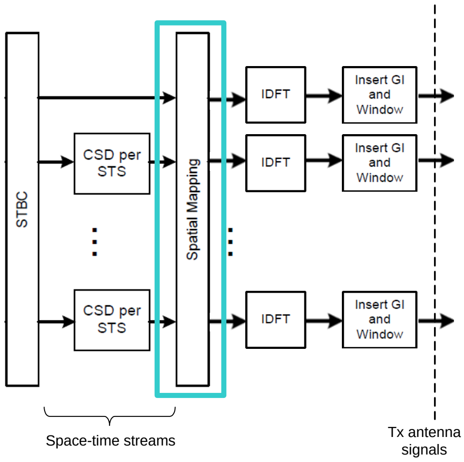


You can define the size of the data field or alternatively the number of data symbols. The scrambler uses either a fixed, selectable initialization value or a random initialization value that is different for each frame. The interleaver is enabled by default.



4.2.4 Spatial Mapping for Frame Block

This section briefly describes the settings needed to configure the highlighted part of the signal generation chain:

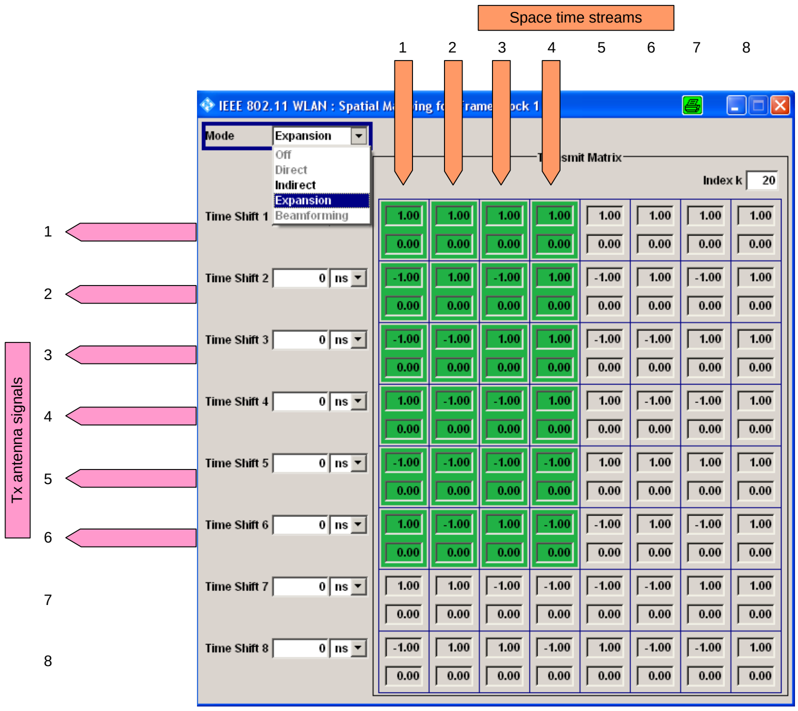


Spatial mapping can be interpreted as the distribution of the precoded data bits onto the different OFDM carriers. In the real world, a WLAN 11ac transmitter tries to optimize the spatial mapping depending on the channel conditions by means of the channel sounding information received. Therefore, there is a spatial mapping matrix for every OFDM carrier. Additionally, spatial expansion is possible, which means that, for example, four space time streams can be effectively distributed to e.g. six Tx antennas.

In the PPDU Configuration menu, click the “Spatial Mapping” button to open the Spatial Mapping menu. Select the spatial mapping mode. The available choices depend on the number of space time streams (configured in section 4.2.3.1) and the number of Tx antennas (configured in section 4.2.1). If the number of space time streams equals the number of Tx antennas, all three choices for the spatial mapping matrix are possible: Direct, Indirect, and Expansion. The corresponding matrix is displayed in the menu. Note that the shown matrix is only for illustration, it is not editable. If the number of space time streams is less than the number of Tx antennas, it is not possible to choose “Direct”. Since a spatial mapping matrix exists for every OFDM carrier, the “Index k” parameter can be used to view the spatial mapping matrix of a particular OFDM carrier. Depending on the mapping mode, the spatial mapping matrix is:

- a CSD matrix, i.e. a diagonal matrix with complex values that represent cyclic time shifts (direct mode)
- the product of a CSD matrix and a Hadamard unitary matrix (indirect mode)
- the product of a CSD matrix and a square matrix defined in the standard specification (expansion mode)

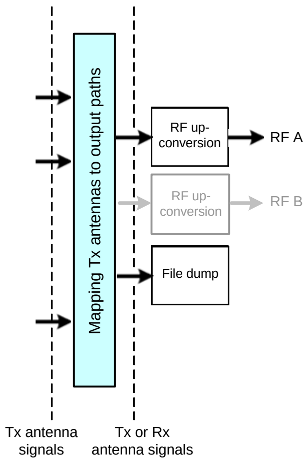
Whereas the Hadamard and the square matrix are predetermined, the CSD matrix can be configured by the user. The CSD matrix is diagonal and causes a time delay for the individual Tx antenna signals. Therefore, it can be configured by setting the “Time Shift x” parameters.



In this example, four space time streams are mapped to six Tx antennas by spatial expansion.

4.2.5 Transmit Antennas Setup

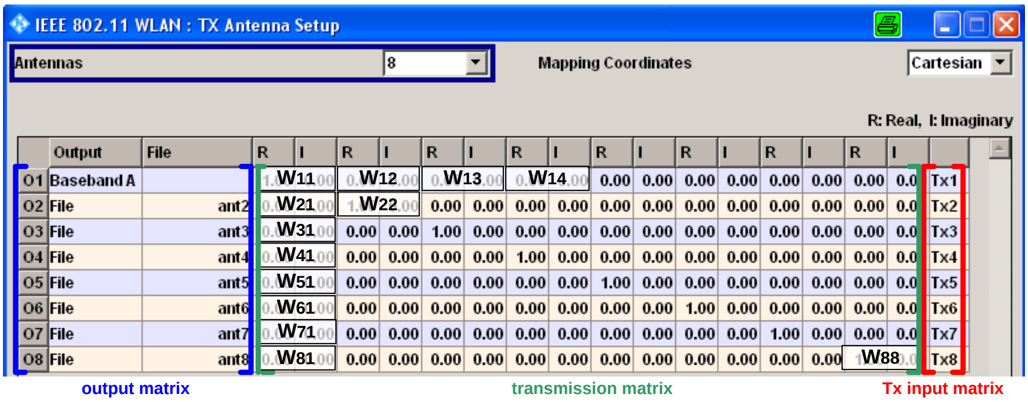
This section describes the settings needed to configure the following part of the signal generation chain:



The Tx antenna signals (Tx1 to Tx8) are mapped to the baseband output. The mapping determines if a single Tx signal or multiple superimposed Tx signals are present at the output of the baseband. By mapping multiple Tx signals to the baseband output, these signals are combined and form an Rx signal that can be used for MIMO testing (see section 4.2.5.2 for background information).

In the WLAN 11 main menu, click the “Transmit Antennas Setup…” button to open the TX Antenna Setup menu. This menu is used to map the Tx antenna signals to the baseband output. The signals are mapped using simple matrix algebra: Multiplying the transmission matrix by the Tx input matrix gives the output matrix.

[output matrix] = [transmission matrix] · [Tx input matrix]

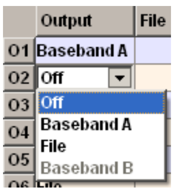


This calculation yields the following possible output signals (O1 to O8):

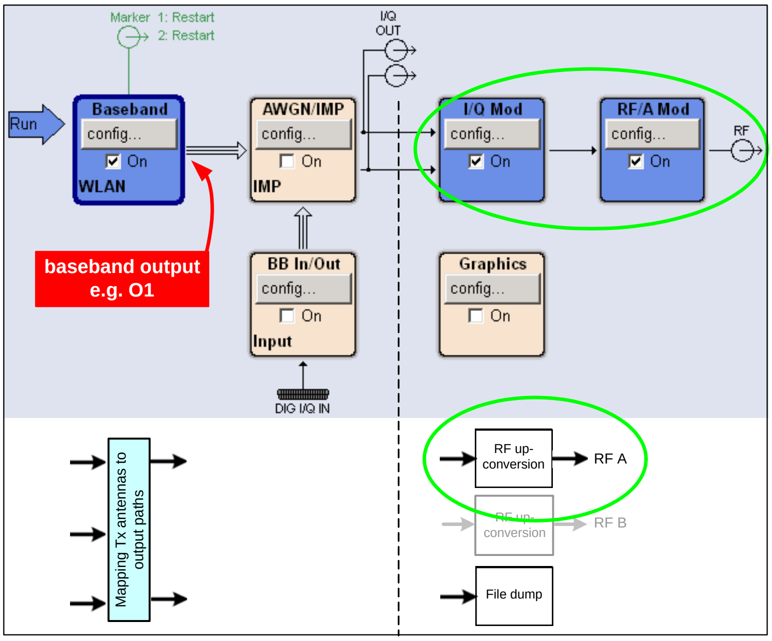
O1 = w_{11}·Tx1 + w_{12}·Tx2 + w_{13}·Tx3 + w_{14}·Tx4 + w_{15}·Tx5 + w_{16}·Tx6 + w_{17}·Tx7 + w_{18}·Tx8
O2 = w_{21}·Tx1 + w_{22}·Tx2 + w_{23}·Tx3 + w_{24}·Tx4 + w_{25}·Tx5 + w_{26}·Tx6 + w_{27}·Tx7 + w_{28}·Tx8
O3 = w_{31}·Tx1 + w_{32}·Tx2 + w_{33}·Tx3 + w_{34}·Tx4 + w_{35}·Tx5 + w_{36}·Tx6 + w_{37}·Tx7 + w_{38}·Tx8
…
O8 = w_{81}·Tx1 + w_{82}·Tx2 + w_{83}·Tx3 + w_{84}·Tx4 + w_{85}·Tx5 + w_{86}·Tx6 + w_{87}·Tx7 + w_{88}·Tx8

The elements of the transmission matrix (complex numbers w_{11}, w_{12}, …, w_{88}) can be used to configure the output signals (O1 to O8) by weighting the Tx signals accordingly.

The output signals can be routed to a baseband output or saved to a file.



For example, the output signal O1 is routed to “Baseband A”. The following figure illustrates this example.



For example, the output signal O2 is routed to “File”. The signal is saved to the hard drive by entering a file path and name in the “File” column for O2.

	Output	File
01	Baseband A	
02	File	ant2

The saved signal can be transferred to another instrument, e.g. with a USB stick, and played back via the ARB generator of this instrument for MIMO testing.

4.2.5.1 Generating Tx Antenna Signals

By default, the diagonal elements of the transmission matrix (w_{11}, w_{22}, …, w_{88}) are set to 1, while all other matrix elements are set to 0.

IEEE 802.11 WLAN : TX Antenna Setup

Antennas: 8 | Mapping Coordinates: Cartesian

R: Real, I: Imaginary

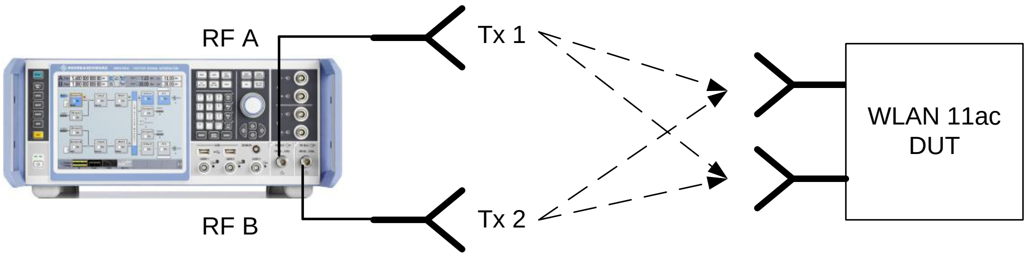
	Output	File	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	
01	Baseband A		1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx1
02	File	ant2	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx2
03	File	ant3	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx3
04	File	ant4	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx4
05	File	ant5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx5
06	File	ant6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	Tx6
07	File	ant7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	Tx7
08	File	ant8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	Tx8

In this case, the above formulas reduce to

O1 = Tx1
O2 = Tx2
O3 = Tx3
…
O8 = Tx8

One of these signals can be routed to the baseband output by selecting “Baseband A” as output. After upconversion of the baseband signal, the selected Tx signal is present at the RF output. For example, to generate the Tx1 signal, set O1 to “Baseband A”.

If a two-path signal generator, i.e. the SMW, is used, one more signal can be routed to the second baseband output by selecting “Baseband B” as output. After upconversion of the baseband signal, the selected Tx signal is present at the second RF output. For example, to generate the Tx2 signal in the second instrument path, set O2 to “Baseband B”.

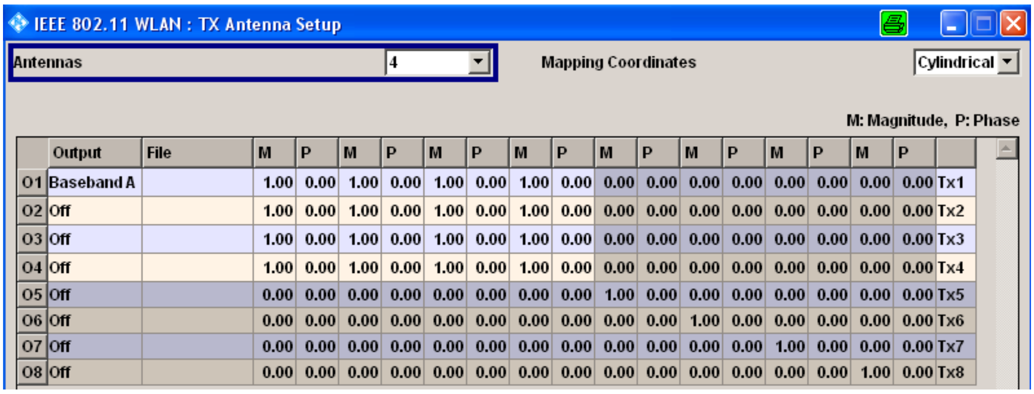


The remaining Tx signals cannot be routed directly to a baseband output but can be saved to a file by selecting “File” as output. The generated waveform files can then be played back via the internal ARB generators of further instruments. For example, to generate the Tx signals Tx3 to Tx8, e.g. six SMBVs are needed. Each SMBV plays back one of the generated waveform files and outputs the corresponding Tx signal at the RF output.

4.2.5.2 Generating Rx Antenna Signals

In MIMO systems with transmit diversity or spatial multiplexing, multiple Tx signals are transmitted. The receiver sees a superposition of these Tx signals. Such a composite signal is termed Rx signal in this application note. The WLAN 11ac option makes it possible to generate Rx signals as a weighted combination (amplitude and phase) of up to eight Tx signals (in the following, only amplitude weighting is considered). Note that this static weighting of Tx signals is not equivalent to a time-varying statistical channel simulation. However, for many applications static weighting is already sufficient for basic diversity and MIMO receiver testing. (For more demanding MIMO tests with true channel emulation a realtime MIMO fading simulator, such as the SMW, is required. Please see references [6] and [2] for details.)

The Tx signals can be combined by setting the elements of the transmission matrix (w_{11}, w_{12}, …, w_{88}) to nonzero values. In the following example, four Tx antennas are used.



	Output	File	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	
01	Baseband A		1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx1
02	Off		1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx2
03	Off		1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx3
04	Off		1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx4
05	Off		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Tx5
06	Off		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	Tx6
07	Off		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	Tx7
08	Off		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	Tx8

If all matrix elements are set to 1 (no weighting), the above formulas give the following output signals (O1 to O4):

O1 = Tx1 + Tx2 + Tx3 + Tx4 = Rx1
O2 = Tx1 + Tx2 + Tx3 + Tx4 = Rx2
O3 = Tx1 + Tx2 + Tx3 + Tx4 = Rx3
O4 = Tx1 + Tx2 + Tx3 + Tx4 = Rx4

In this case, the signals Rx1 to Rx4 are all equal. If all matrix elements are set to values different than 1 (weighting), the above formulas give the following output signals (O1 to O4):

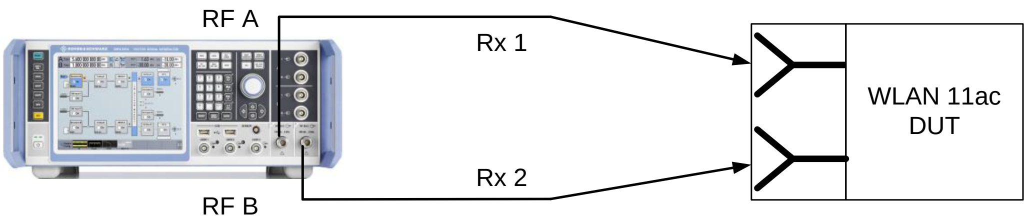
Example:
O1 = Tx1 + 0.5·Tx2 + Tx3 + 0.2·Tx4 = Rx1
O2 = 0.8·Tx1 + Tx2 + 0.2·Tx3 + Tx4 = Rx2
O3 = 0.7·Tx1 + 0.5·Tx2 + 0.4·Tx3 + Tx4 = Rx3
O4 = 0.2·Tx1 + Tx2 + 0.8·Tx3 + 0.6·Tx4 = Rx4

M	P	M	P	M	P	M	P
1.00	0.00	0.50	0.00	1.00	0.00	0.20	0.00
0.80	0.00	1.00	0.00	0.20	0.00	1.00	0.00
0.70	0.00	0.50	0.00	0.40	0.00	1.00	0.00
0.20	0.00	1.00	0.00	0.80	0.00	0.60	0.00

In this case, the signals Rx1 to Rx4 differ. For example, signal Rx1 simulates the situation where the antenna signals Tx1 and Tx3 reach the Rx antenna with full signal strength while only 50 % of antenna signal Tx2 and 20 % of Tx4 are received.

One of the Rx signals can be routed to the baseband output by selecting “Baseband A” as output. After upconversion of the baseband signal, the selected Rx signal is present at the RF output. For example, to generate the Rx1 signal, set O1 to “Baseband A”.

If a two-path signal generator, i.e. the SMW, is used, one more signal can be routed to the second baseband output by selecting “Baseband B” as output. After upconversion of the baseband signal, the selected Rx signal is present at the second RF output. For example, to generate the Rx2 signal in the second instrument path, set O2 to “Baseband B”.

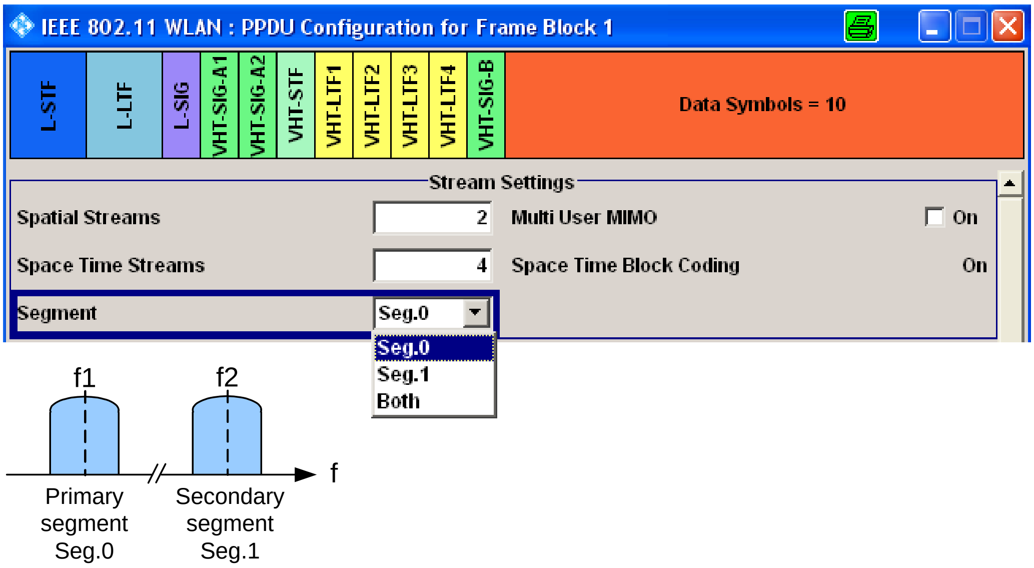


The remaining Rx signals cannot be routed directly to a baseband output but can be saved to a file by selecting “File” as output. The generated waveform files can then be played back via the internal ARB generators of further instruments. For example, to generate the Rx signals Rx3 and Rx4, e.g. two SMBVs are needed. Each SMBV plays back one of the generated waveform files and outputs the corresponding Rx signal at the RF output.

Note that the required number of instruments (or more precisely, the number of baseband generators/RF outputs) depends on the number of receive antennas at the DUT that shall be tested simultaneously with different Rx signals. For example, if four Tx antennas shall be simulated but only one Rx antenna at a time needs to be tested, only one baseband/RF output, e.g. one SMBV, is needed. However, this sequential testing of the Rx antennas is not real MIMO testing. To test four Rx antennas simultaneously with different Rx signals, four basebands/RF outputs, e.g. four SMBVs, are needed.

4.2.6 Special Case: Configuring an 80 MHz + 80 MHz Signal

For the 80 MHz + 80 MHz channel, there is an additional setting parameter in the PPDU Configuration menu: Segment.



To generate the primary segment of the 80 MHz + 80 MHz signal, select “Seg.0”. To generate the secondary segment, select “Seg.1”. Selecting “Both” is only possible if the transmission bandwidth is set to 160 MHz in the main menu. The two segments are generated contiguously in this case.

4.2.6.1 Generating an 80 MHz + 80 MHz Signal with the AFQ

Contiguous
To generate the two 80 MHz segments contiguously, set the “Segment” parameter to “Both”.

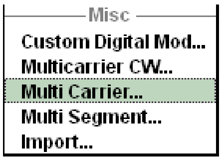
Noncontiguous
To generate the two 80 MHz segments noncontiguously, perform the following steps in WinIQSIM2:

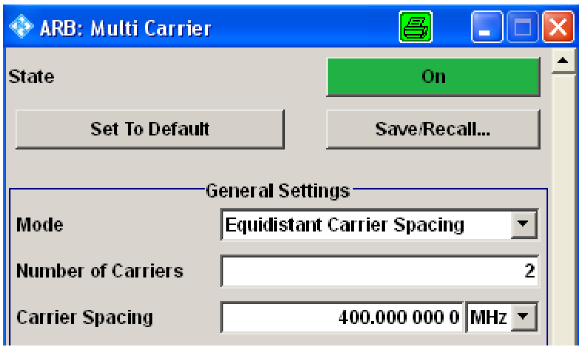
1. Generate the primary segment and the save signal as a waveform file
2. Generate the secondary segment and the save signal as a waveform file
3. Combine both waveforms using the ARB multi carrier function

Step 1: Set the “Segment” parameter to “Seg.0” and configure the signal as desired. Click the “Generate Waveform File” button [2] in the main menu to save the signal (e.g. as “primary_seg.wv”).

Step 2: Return to the PPDU Configuration menu and set the “Segment” parameter to “Seg.1”. Again, click the “Generate Waveform File” button in the main menu to save the signal (e.g. as “secondary_seg.wv”).

Step 3: Open the ARB Multi Carrier menu and set the number of carriers to “2”. Enter the desired carrier spacing, e.g. 400 MHz. Click the “Carrier Table” button.





In the carrier table, set the “State” to “On” for both carriers. For carrier 0, select the primary segment waveform as “File”. For carrier 1, select the secondary segment waveform as “File”.

	State	Carrier Freq [MHz]	Gain [dB]	Phase [deg]	Delay [ns]	File	Info
0	On	-200.000 00	0.00	0.00	0	SIM2/Waveforms/primary_seg	Info...
1	On	200.000 00	0.00	0.00	0	2/Waveforms/secondary_seg	Info...

In the main menu, set the “State” to “On” and transfer the multi carrier signal (i.e. the 80 MHz + 80 MHz signal) to the AFQ B for playback.

---

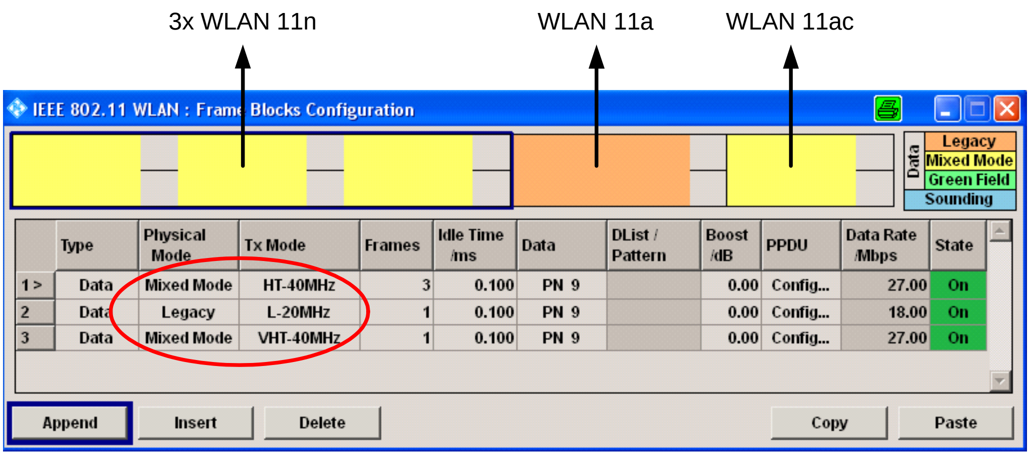
[2] This button saves the baseband output signal that is routed to “Baseband A” in the “TX Antenna Setup” menu.

Note that the AFQ A is not suitable for noncontiguous 80 MHz + 80 MHz signal generation. For the AFQ B, the maximum (meaningful) carrier spacing of the two segments is 400 MHz.

4.3 Configuring WLAN Multistandard Signals

WLAN 11ac devices must be able to communicate with earlier generation devices operating in the 5 GHz band using the predecessor standards, WLAN 11a and 11n. For cross-standard testing, the user can define realistic multistandard signals via the Frame Blocks Configuration menu.

Open this menu by clicking the “Frame Block Configuration…” button in the main menu. Use the “Append” button to add new frame blocks (i.e. new lines) to the list and create a sequence of frame blocks in this way. Each frame block can be configured individually. For example, the number of frames within this block can be set. Also the PPDU settings are configured individually for each block. To generate WLAN 11n and 11ac frames, choose “Mixed Mode” as “Physical Mode” and define the high throughput (HT) or VHT channel to use. To generate WLAN 11a frames, choose “Legacy” as “Physical Mode” and define the channel to use.



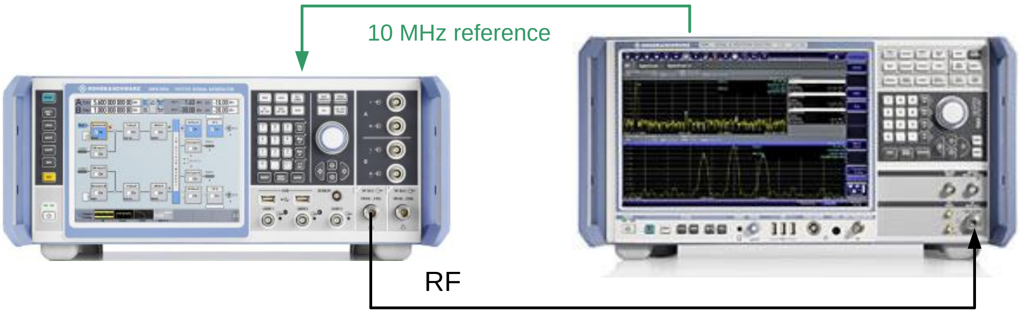
As shown in the above figure, switching between different WLAN signals is easy to do, making multistandard testing straightforward.

5 Verification Measurements

Rohde & Schwarz signal and spectrum analyzers can analyze WLAN 11ac transmitter signals in two different ways:

- Analysis using the R&S®FSx-K96 general purpose OFDM analysis software. This method is described in the application note “Measurement of WLAN 802.11 ac signals” (1EF82).
- Analysis using the on-instrument WLAN application R&S®FSx-K91ac. This method is recommended for analysis and used in this application note to perform measurements.

The verification measurements presented in this application note were performed using an FSW with an analysis bandwidth of 160 MHz in the following setup:



5.1 EVM Measurement

To obtain optimal EVM results, the following settings should be made:

Generator:

- The “Time Domain Windowing Active” parameter in the PPDU Configuration menu is disabled by default. Leave this parameter disabled.

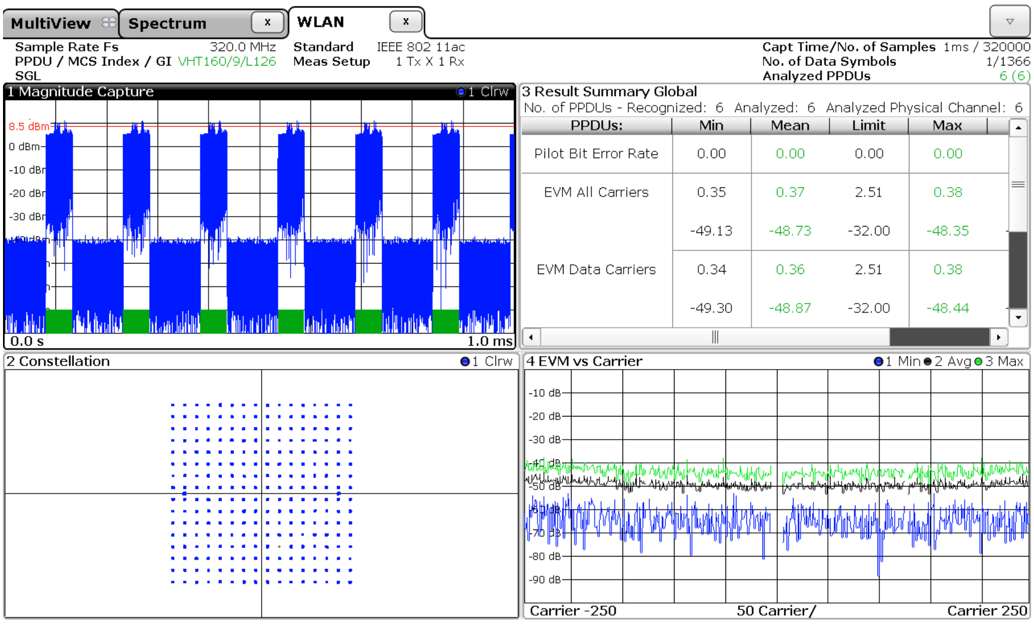
- When using an AFQ setup, optimize the EVM as described in section 6.1.

Analyzer:

- Set the “Channel Estimate” parameter to “Payload” in the Tracking/Channel Estimation menu. (All EVM measurements presented in this application note are performed with payload-based channel estimation.)
- Adjust the RF attenuation.
- Optimize the reference level such that the R&S®FSx is about to show the IF overload warning.

For example, an SMW is used to generate a 160 MHz signal. The RF level is set to 0.0 dBm. On the FSW, the RF attenuation is set to 10 dB. The reference level is adjusted to 8.5 dBm. (At 8 dBm the FSW shows the “IF OVLD” warning.) The following result is obtained:

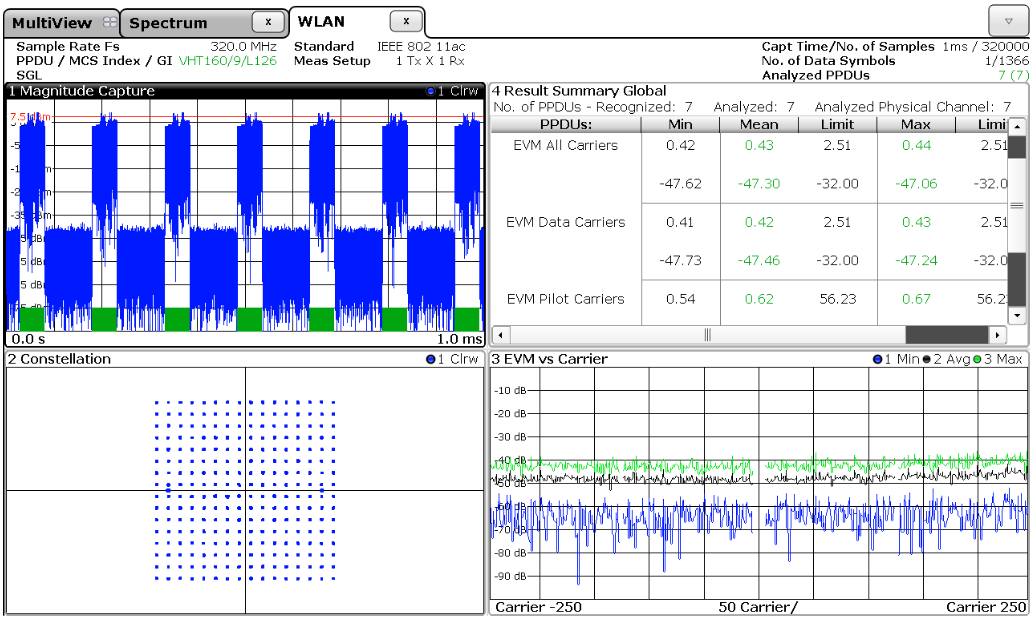
SMW



The measured EVM is –48.7 dB (0.37 %) for a 160 MHz signal with 256 QAM modulation.

For comparison, an SMBV is used to generate the 160 MHz signal. The RF level is set to 0.0 dBm. On the FSW, the RF attenuation is set to 10 dB. The reference level is adjusted to 8.5 dBm. (At 8 dBm the FSW shows the “IF OVLD” warning.) The following result is obtained:

SMBV



The measured EVM is –47.3 dB (0.43 %) for a 160 MHz signal with 256 QAM modulation.

5.2 Channel Power Measurement

When performing a channel power measurement of a WLAN Tx signal, one needs to take into account that there are signal gaps between the WLAN frames if the “Idle Time” parameter is set to nonzero values in the Frame Blocks Configuration menu. The measured average RF power will thus be lower than the RF level set at the generator, as the latter relates only to the “frame active” part of the signal. To obtain a correct channel power measurement, the following settings should be made:

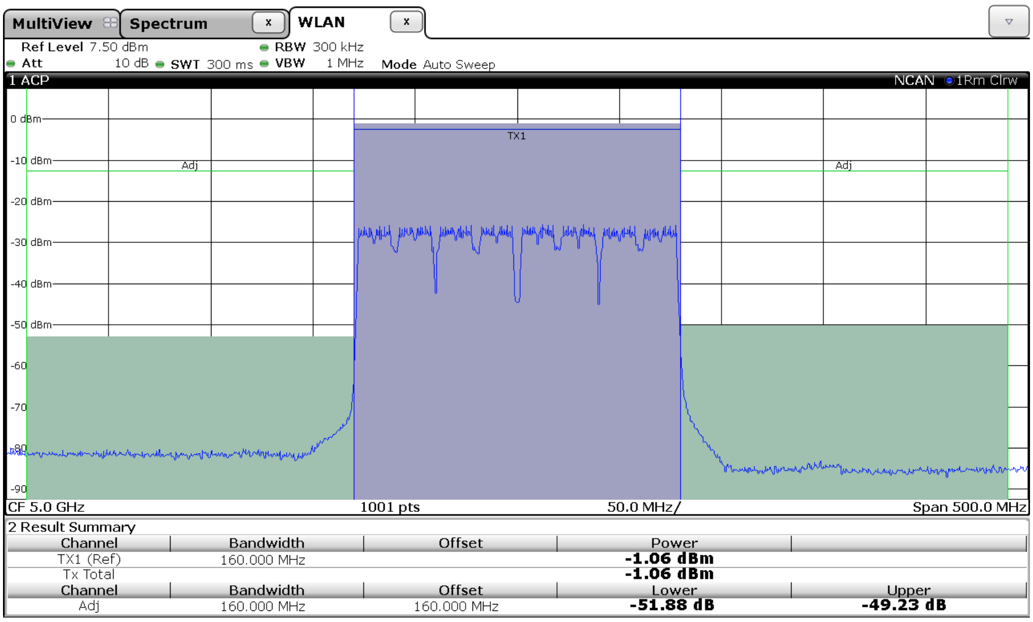
Generator:

- When using an AFQ setup, do not forget to adjust the “Crest factor” parameter in the upconverter for correct leveling as described in section 3.2.3.
- When using a combiner in the setup, consider the specified insertion loss.

Analyzer:

- Use a gated trigger to measure the signal only during bursts. Use “IF Power” as trigger source and adjust the trigger level. Set the gate length such that only the burst is captured and not the gap.

For example, an SMW is used to generate a 160 MHz signal. The RF level is set to 0.0 dBm. The following result is obtained.

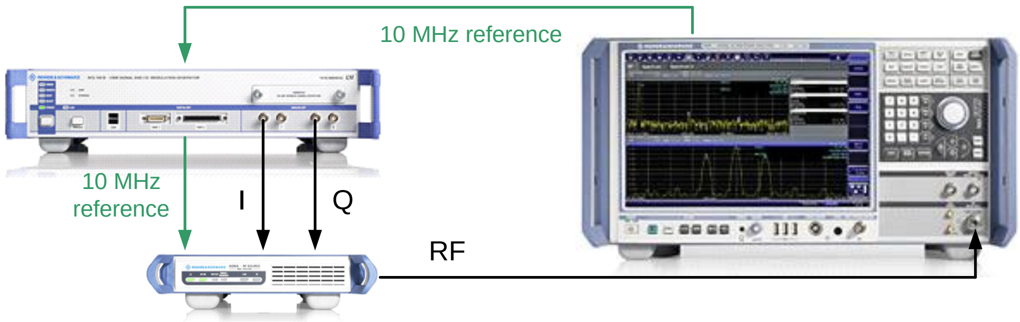


The measured channel power is –1.1 dBm. The result matches (apart from cable loss) the RF level set at the SMW.

6 Optimizing Signal Quality for AFQ Setups

If the WLAN 11ac signal is generated with an AFQ and an upconverter, the signal quality is very good but the external cabling is a potential source of impairment. The cabling can lead to I/Q imbalances and consequently to image OFDM carriers in the RF signal. These overlay and thus impair the actual OFDM carriers, resulting in a suboptimal EVM. Therefore, due to the external cabling, the signal quality of an AFQ setup may not be as good as it could be. Even if achieving better signal quality for testing is not relevant to your application, we nevertheless want to explain in this section how to configure the AFQ setup to attain optimal performance. For the optimization, it does not matter which Rohde & Schwarz signal generator is used for upconversion (although the best results are achieved with the SGS).

As an example, the AFQ-SGS setup is used for the measurements presented in this section. They were performed using an FSW with an analysis bandwidth of 160 MHz.

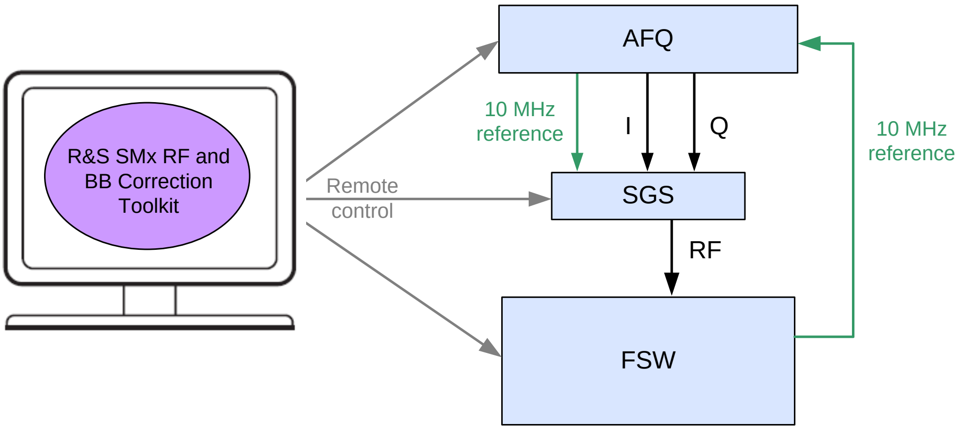


6.1 Optimizing EVM Performance

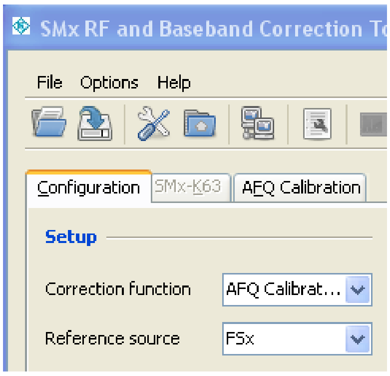
6.1.1 Optimization Tool

A software tool that can be used to optimize the EVM result for AFQ setups is available free of charge. The software can be downloaded from the Rohde & Schwarz website: Products → Signal Generators → Baseband → AFQ → Downloads → Software → R&S SMx RF and BB Correction Toolkit

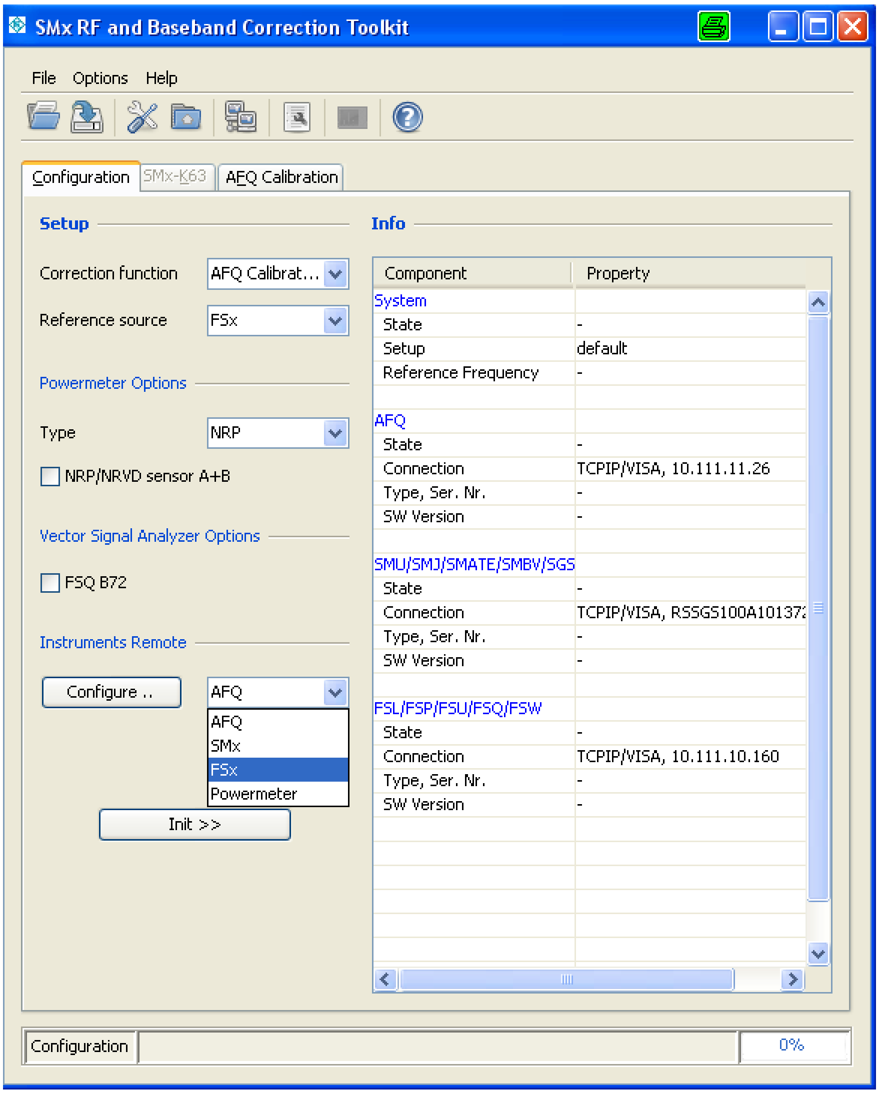
As mentioned above, the external cabling can lead to image OFDM carriers that impair the signal and degrade EVM performance. The provided software automatically configures the equalizer of the AFQ to compensate the image carriers. The necessary measurement is performed with the connected upconverter (e.g. SGS) and a spectrum analyzer.



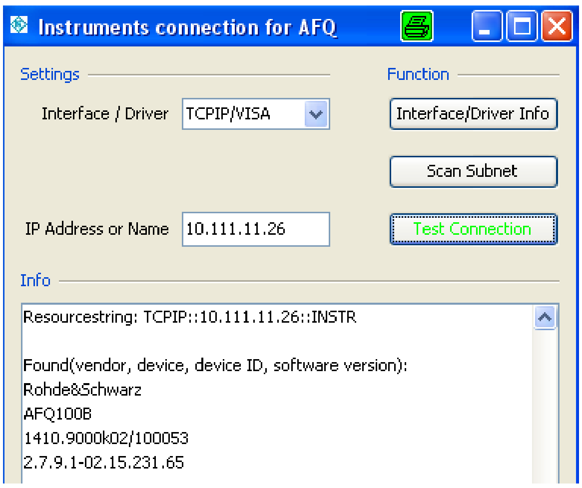
Open the software and select “AFQ Calibration” under the “Configuration” tab. Select the 10 MHz reference source.



Next, configure the three instruments of the setup: AFQ, SGS (or SMx) and R&S®FSx. Select the instrument and click the “Configure..” button.



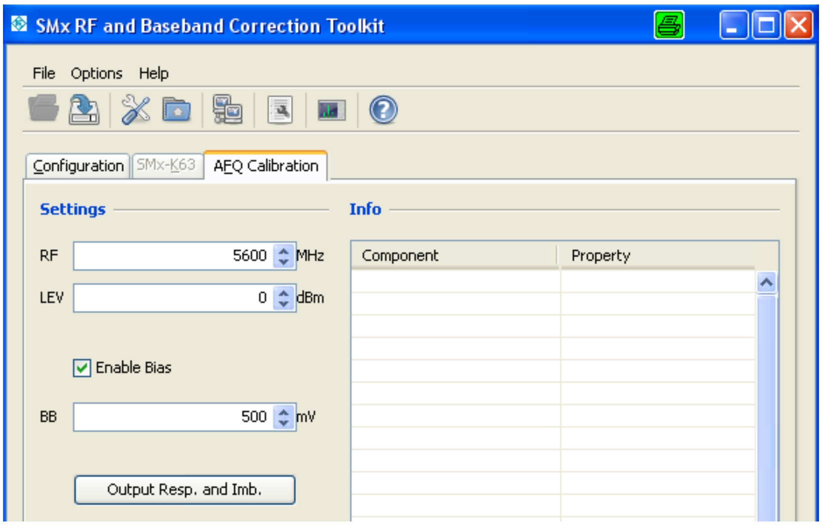
Select the remote interface, e.g. "TCPIP/VISA". Connect the instrument via LAN to the control PC and enter the IP address of the instrument. Use the "Test Connection" button to quickly test the remote connection.



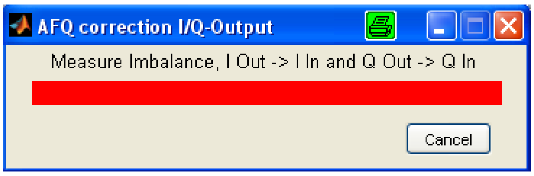
Under the “Configuration” tab in the main menu, press the “Init >>” button. If the software reports “Initializing instruments ok.”, switch to the “AFQ Calibration” tab. Select the RF frequency and RF level to be used for calibration and later for testing. Select the single-ended baseband output level of the AFQ. Use the following values:

- AFQ A: 500 mV
- AFQ B: 500 mV with “Enable Bias” checkbox enabled (recommended)
- AFQ B: 350 mV with “Enable Bias” checkbox disabled

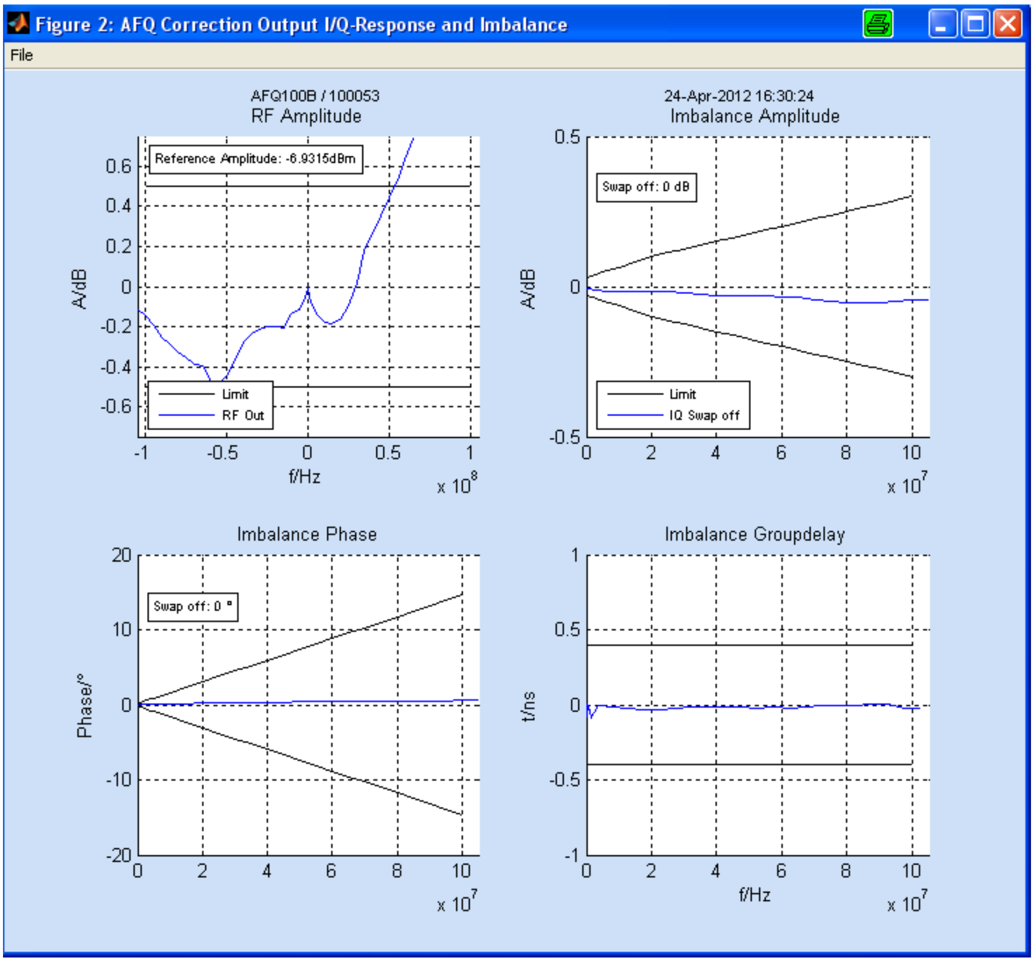
If the bias amplifier of the AFQ B is not enabled, the EVM result is slightly better than with amplification, since every amplifier introduces a certain degree of distortion. However, the output level of the AFQ B is then limited to 700 mV (balanced output), and consequently the RF level at the SGS is no longer correct (see section 3.2.3 for background). The actual RF level is 3.1 dB lower than the set/displayed level on the SGS (or SMx).



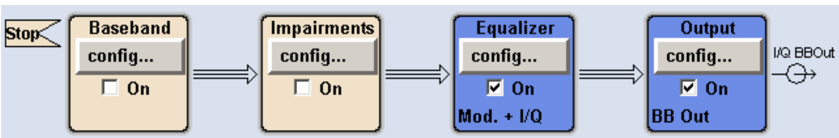
Start the calibration by pressing the “Output Resp. and Imb.” button. While the calibration is running, the following window is displayed:



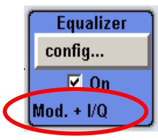
If the software reports “Correction ok.”, the calibration is completed and the following result summary is displayed:



On the AFQ, click the “Local“ icon in the toolbar to switch from remote to local operation. The AFQ block diagram looks like this:



Note that the software configures both equalizers of the AFQ: “Modulator” and “I/Q”.



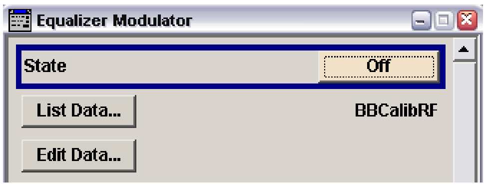
- The equalizer “Modulator” is used to compensate the RF frequency response of the upconverter (e.g. SGS).
- The equalizer “I/Q” is used to compensate I/Q imbalances and thus the image carriers.

When operating the AFQ B with 350 mV and inactive bias amplifier, the following error message may appear on the AFQ B:

*** Err -300 Output unleveled: Gain Control on Upper Limit**

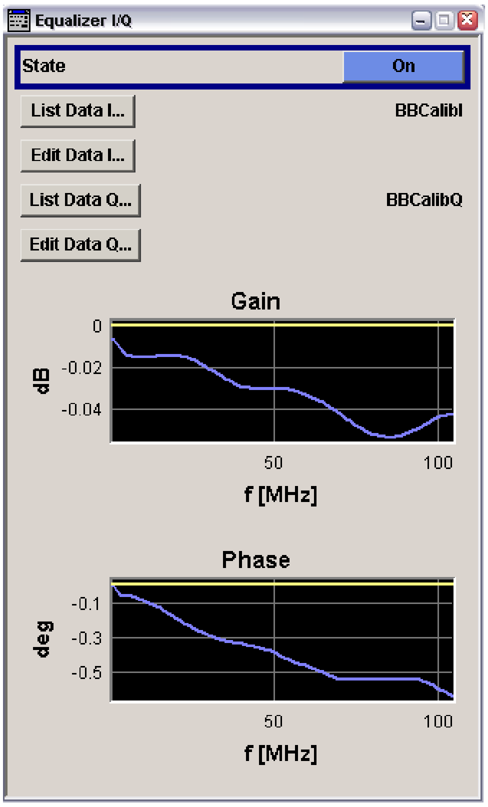
There are two ways to remove this error:

- Click the “config” button in the “Equalizer” block and select “Modulator”. Set the “State” to “Off”. This disables the RF frequency response correction which is not necessarily needed, because the DUT (like the FSW) can equalize the frequency response of the received signal through channel estimation.



- Alternatively, leave the RF frequency response correction enabled. Slightly reduce the baseband output level of the AFQ (amplitude setting) until the error message vanishes. Be aware that the actual RF level differs from the set/displayed level on the SGS (or SMx) by slightly more than 3.1 dB in this case.

Click the “config” button in the “Equalizer” block and select “I/Q”. The “State” must be “On”, i.e. the baseband I/Q correction must be enabled. The “BBCalibI” and “BBCalibQ” files are generated and loaded automatically by the software tool.



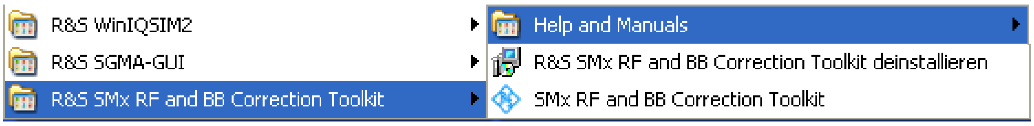
The last step is to load the wanted WLAN waveform and activate the ARB.

Compared with the RF frequency response correction (which can be disabled), the baseband I/Q correction is more robust against RF frequency and level changes on the SGS (or SMx). However, for optimal performance the calibration should be repeated if

- the RF frequency and level changes
- the AFQ baseband output level changes

If the setup changes, e.g. if the cables are exchanged or swapped, the calibration must be repeated.

Refer also to the software manuals that come with the installation of the software.



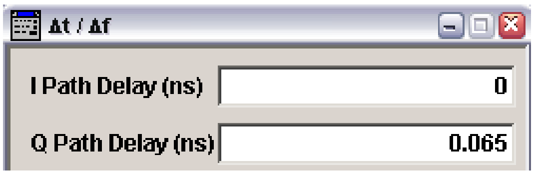
The following screenshots show the EVM measured before and after the calibration.

The measured EVM for a 160 MHz signal with 256 QAM modulation is –44 dB before and –47 dB after the calibration.

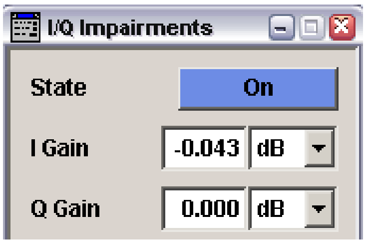
6.1.2 Manual EVM Optimization

To optimize the EVM, it is strongly recommended to use the software tool, since the equalizer of the AFQ compensates I/Q imbalances frequency-selectively. However, the EVM can also be optimized manually, e.g. in case there is no R&S®FSx available. Slightly unequal electrical cable lengths introduce a delay between the I and Q signals. This delay leads to image OFDM carriers and is the biggest contribution to a degraded EVM.

The delay can be compensated by adjusting the I and Q path delay of the Δt / Δf settings on the AFQ.



In addition, the I and Q signals may have small amplitude imbalances. They can be compensated by adjusting the I and Q gain of the I/Q impairments settings on the AFQ.



The following screenshots show the EVM measured before and after adjusting the I and Q path delay such that the initial delay between the I and Q signals is cancelled.

The measured EVM for an 80 MHz signal with 256 QAM modulation is –45 dB before and –47 dB after the adjustment.

Note that this manual optimization method does not use the equalizer of the AFQ and is thus not frequency-selective.

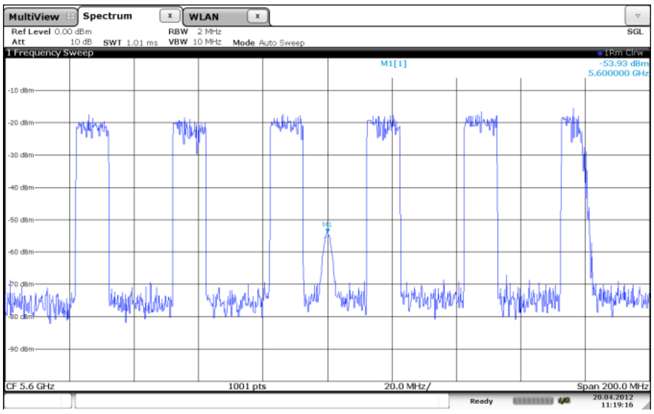
6.2 Minimizing Carrier Leakage

6.2.1 Optimization Tool

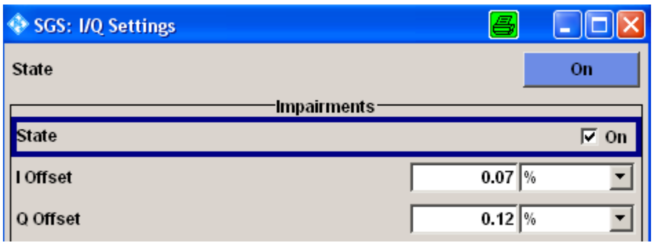
The software tool described in section 6.1.1 also minimizes the carrier leakage automatically during the calibration.

6.2.2 Manual Carrier Leakage Optimization

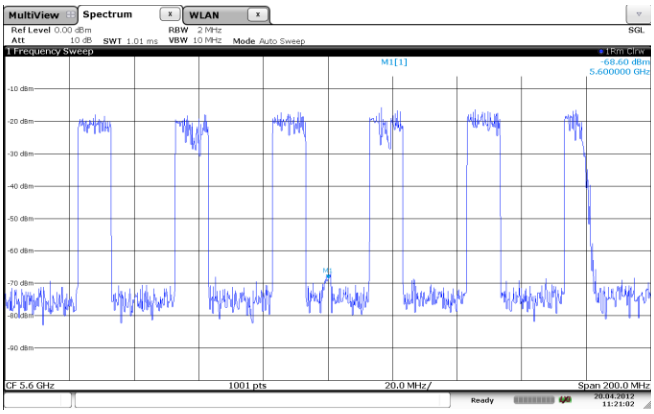
The following figure shows the spectrum of a WLAN 11ac signal. The sweep time setting on the analyzer was chosen such that the spectrum reveals the carrier leakage in the RF signal.



The carrier leakage is caused by a DC component in the I/Q signal. It can be suppressed by adjusting the I and Q offset of the I/Q impairments settings in the upconverter.



The following figure shows the spectrum after adjusting the I and Q offset such that the center carrier is optimally suppressed.



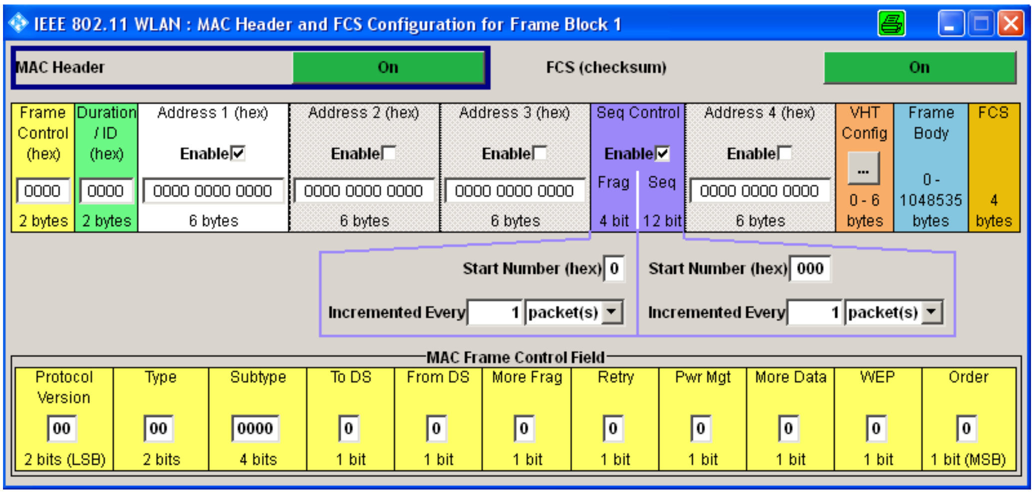
Note that the carrier leakage has no effect on the measured EVM of the WLAN 11ac signal (since there is no OFDM carrier at the carrier frequency).

7 PER Testing

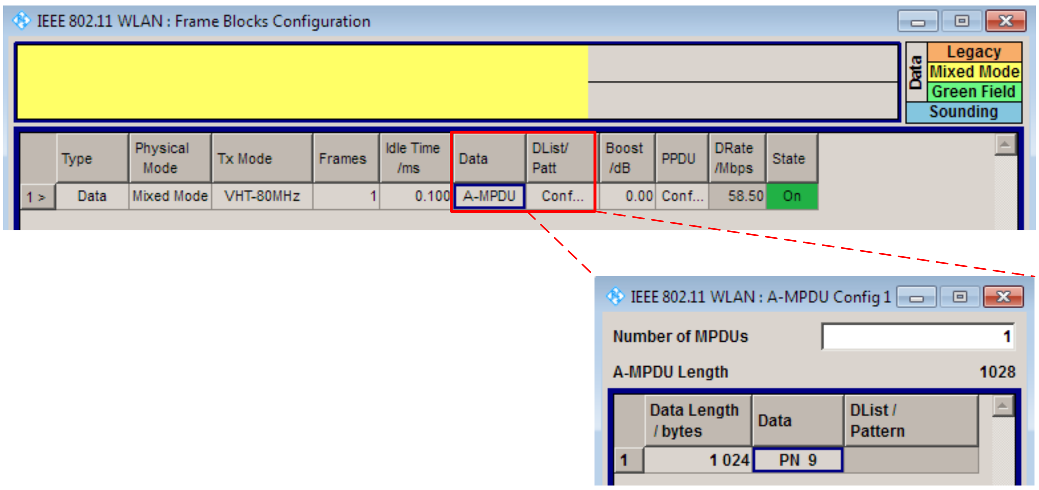
The Rohde & Schwarz WLAN 11ac test solution supports packet error rate (PER) testing via the nonsignaling mode. It is possible to generate standard-compliant test signals including MAC header.

To configure the MAC header, click the “Configure MAC Header and FCS…” button in the PPDU configuration menu.

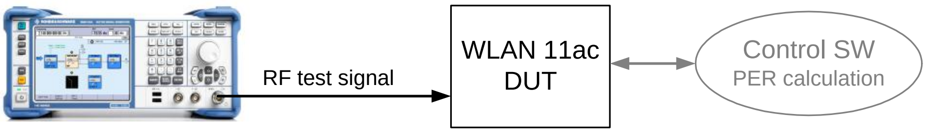
Activate the MAC Header and the frame check sequence (FCS) and optionally enable the sequence control field.



In addition, activate frame aggregation as this is mandatory for WLAN 11ac. To activate frame aggregation, select “A-MPDU” from the dropdown list of the “Data” column in the frame block configuration menu. The settings for the aggregated MAC protocol data unit (A -MPDU) can be made in the corresponding A-MPDU configuration menu.



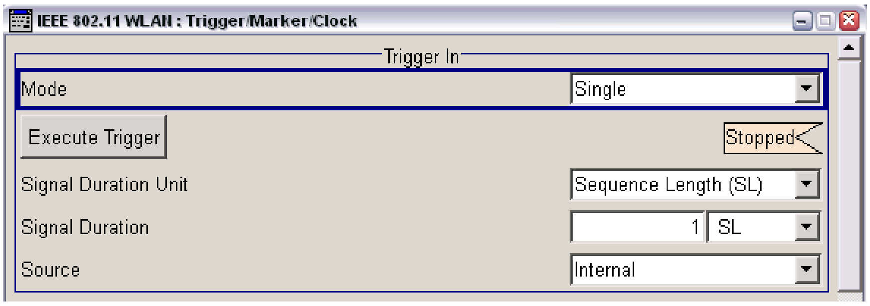
To perform nonsignaling PER measurements, the MAC header settings do not need to be configured but can be left at their default values. This generally works fine. The user's equipment[3] analyzes the transmitted FCS to evaluate if packets sent from the generator to the DUT were received error-free. All erroneous packets are counted and a PER (ratio between erroneous packets and total number of packets) is calculated. The user's equipment can further determine missing or retransmitted frames by evaluating the sequence control field.



For PER measurements, e.g. 1000 frames are generated and evaluated. Set the desired number of frames in the frame blocks configuration menu.

	Type	Physical Mode	Tx Mode	Frames	Idle Time /ms	Data	DList/ Patt	Boost /dB	PPDU	DRate /Mbps	State
1 >	Data	Mixed Mode	VHT-80MHz	1 000	0.100	A-MPDU	Conf...	0.00	Conf...	58.50	On

On the instrument, use the "Single" trigger mode to output the 1000 frames exactly once. The trigger menu can be opened by clicking the "Trigger/Marker…" button in the main menu of the WLAN option or the ARB.



[3] The control and evaluation software is generally provided by the WLAN device manufacturer.

8 MIMO Testing

Test signals

Standard-compliant signals for testing MIMO devices can be easily generated. Up to eight Tx antenna signals can be created. It is even possible to generate different Rx antenna signals. See section 4.2.5 for details.

Realtime fading

Fading can be applied to the test signals by using the SMW, SMU and AMU signals generators. These instruments support realtime fading for true channel simulation. In particular, the SMW is ideally suited for WLAN 11ac MIMO testing because it supports 3x3 MIMO fading simulation in a single instrument. Please see references [6] and [2] for details.

Synchronizing multiple instruments

Multiple SMBVs can be synchronized with ultrahigh precision using the master-slave mode of the instrument. See reference [4] for details.

Multiple AFQs can be synchronized with ultrahigh precision using the master-slave mode of the instrument. The master AFQ must be triggered externally. See reference [5] for details.

The two internal baseband generators in a single SMW/SMU/SMATE/AMU can be synchronized with very high precision by using the first baseband generator to trigger the second one. See section 3.2.2 for details.

Multiple SMUs/SMATEs/SMJs/AMUs can be synchronized with very high precision by triggering all internal baseband generators with a common external trigger signal. See reference [2] for details.

9 Abbreviations

A-MPDU	Aggregated MAC protocol data unit
ARB	Arbitrary waveform generator
BCC	Binary convolution coding
CSD	Cyclic shift delay
DUT	Device under test
EVM	Error vector magnitude
I/Q	In-phase/quadrature
IDFT	Inverse discrete Fourier transformation
LDPC	Low density parity check
MAC	Media access control
MIMO	Multiple input multiple output
MCS	Modulation and coding scheme
OFDM	Orthogonal frequency-division multiplexing
PER	Packet error rate
PLCP	Physical layer convergence protocol
PPDU	PLCP protocol data unit
RF	Radio frequency
RMS	Root mean square
Rx	Receive
STBC	Space time block coding
SW	Software
Tx	Transmit
VHT	Very high throughput
WLAN	Wireless local area network

10 References

[1] Rohde & Schwarz Application Note, “Connectivity of Rohde & Schwarz Signal Generators” (1GP72)

[2] Rohde & Schwarz Application Note, “Guidelines for MIMO Test Setups – Part 2” (1GP51)

[3] Rohde & Schwarz White Paper, “802.11ac Technology Introduction” (1MA192)

[4] Rohde & Schwarz Application Note, “Time Synchronous Signals with Multiple R&S®SMBV100A Vector Signal Generators” (1GP84)

[5] Rohde & Schwarz, R&S®AFQ100B Operating Manual

[6] Rohde & Schwarz Application Note, “Higher Order MIMO Testing with the R&S®SMW200A Vector Signal Generator” (1GP97)

11 Ordering Information

Please visit the Rohde & Schwarz product websites at www.rohde-schwarz.com for comprehensive ordering information on the following Rohde & Schwarz signal generators:

- R&S®SMW200A vector signal generator
- R&S®SMU200A vector signal generator
- R&S®SMATE200A vector signal generator
- R&S®SMBV100A vector signal generator
- R&S®SMJ100A vector signal generator
- R&S®AMU200A baseband signal generator and fading simulator
- R&S®AFQ100A I/Q modulation generator
- R&S®AFQ100B UWB Signal and I/Q modulation generator
- R&S®SGS100A SGMA RF source

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- Energy-efficient products
- Continuous improvement in environmental sustainability
- ISO 14001-certified environmental management system

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ISO 9001

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