LTE Downlink MIMO Verification

with R&S®SMW200A and R&S®FSW

Application Note

Products:

R&S®SMW200A	R&S®FSW
R&S®SMU200A	R&S®FSQ
R&S®SMATE200A	R&S®FSV
R&S®AMU200A	R&S®RTO

Multiple Input Multiple Output (MIMO) is an integral part of LTE. Rohde & Schwarz vector signal generators and signal & spectrum analyzers support LTE tests with up to 4 antenna paths.

This Application Note mainly covers 2x2 MIMO in the LTE downlink. Simplicity of programming for remote controlled tests is demonstrated by example scripts used with R&S®, a free-of-charge scripting tool. One of these tests demonstrates a 4x4 MIMO LTE downlink scenario by using the R&S® RTO Oscilloscope.

ROHDE&SCHWARZ

Application Note

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

- The R&S®SMW200A vector signal generator is referred to as the SMW.
- The R&S®SMATE200A vector signal generator is referred to as the SMATE.
- The R&S®SMU200A vector signal generator is referred to as the SMU.
- The R&S®AMU200A baseband signal generator and fading simulator is referred to as the AMU.
- The R&S®FSW signal analyzer is referred to as the FSW.
- The R&S®FSQ signal analyzer is referred to as the FSQ.
- The R&S®FSV spectrum analyzer is referred to as the FSV.
- The R&S®RTO digital oscilloscope is referred to RTO.
- SMW, SMATE and SMU are referred to as SMx.
- FSW, FSQ and FSV are referred to as FSx.

1 Introduction

Advanced radio communications standards, such as WLAN, WiMAX™, HSPA+, and LTE, must be able to handle the demand for faster data transmission. One way to achieve higher data rates is to use multiple antenna systems. Antenna configurations with two or more antennas are called Multiple Input Multiple Output (MIMO). Most important terms Spatial Multiplexing and TX Diversity are described in detail in [7].

LTE as of Release 8 supports MIMO with up to four antennas. The Rohde & Schwarz solutions not only permit LTE signals to be generated with up to four antenna paths (pre-coding and realtime MIMO fading), but also allow analysis and demodulation.

This Application Note describes the physical downlink structure of MIMO in LTE with two antennas. A small, free-of-charge test sequencer software named "R&S®FORUM" is included to show the necessary remote control commands and to run all LTE tests for demonstration and evaluation. It also shows the most important LTE MIMO settings for manual operation.

2 LTE Downlink MIMO

This section gives a short overview of the LTE downlink structure.

2.1 Downlink Physical Structure

Figure 1 shows the basic block diagram for the downlink as defined by 3GPP specification [1].

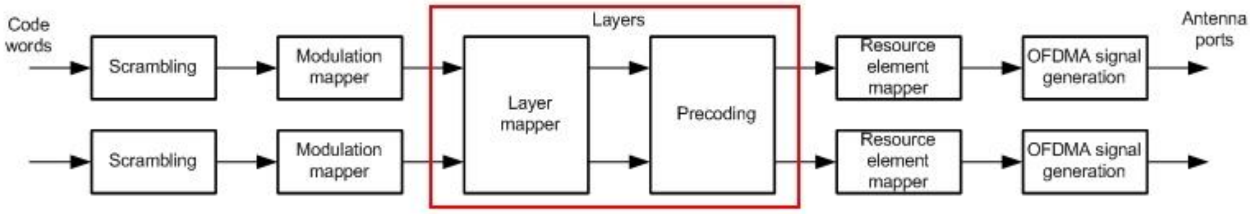

Figure 1: Downlink physical structure

One or two code words (or streams) are scrambled and modulated (QPSK, 16QAM or 64QAM) and then mapped on up to four layers. The pre-coding maps the layers to the antennas (up to four) and is known on the receiver side as well.

This section concentrates on the steps from the code words to the layers (layer mapping) and from the layers to the antennas (pre-coding).

In the simple case of one antenna (SISO), there is only one code word and only one layer. All symbols are forwarded to the antenna 1:1.

The following scenarios apply to two transmit antennas, with a distinction being made between spatial multiplexing and TX diversity.

2.2 Spatial Multiplexing with Two Antennas

Figure 2 shows the typically spatial multiplexing antenna setup for two antennas.

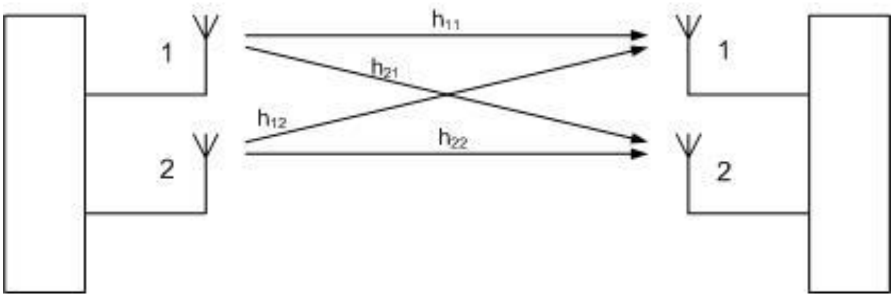

Figure 2: 2x2 MIMO

Layer mapping

The block modulation mapper assigns a modulation to every code word; in other words, all of the symbols associated with a code word are modulated the same. For two layers, all of the symbols from the first code word are mapped to layer 0 and all of the symbols from the second code word are mapped to Layer 1.

Pre-coding

The layers (symbols) are multiplied by a predefined matrix based on the codebook index provided in Table 1 and then distributed to the individual resource blocks (OFDMA signals) and thus to the antennas.

Spatial multiplexing LTE		
Codebook index	Number of layers υ	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Table 1: Codebook for spatial multiplexing with two antennas

Examples

Figure 3 shows a simple configuration with one code word, one layer, and two antennas. The individual symbols of the code word are mapped directly to the individual layer: The pre-coding distributes the symbols 1:1 to the antenna paths; i.e., both antennas transmit the same signal. One FSx is sufficient for demodulation, and the two antennas can be measured sequentially.

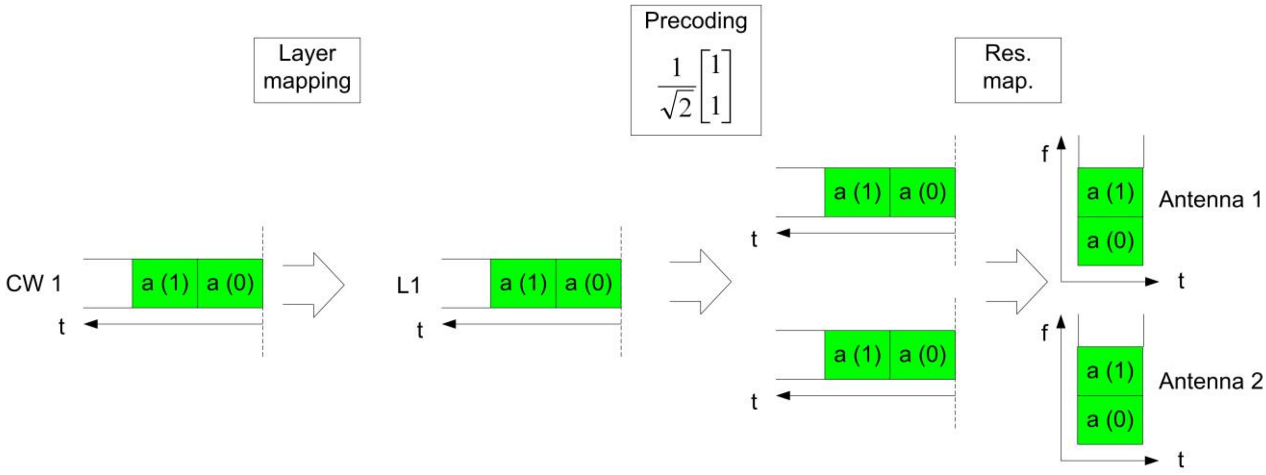

Figure 3: Pre-coding one CW, one layer, index 0

Figure 4 shows two (differently) modulated code words, (1) QPSK and (2) 16QAM. The code words are mapped directly to the two layers. The pre-coding based on codebook index 0 distributes the layers directly to the antennas; i.e., antenna 1 transmits the user data with QPSK modulation in the PDSCH, while antenna 2 is modulated with 16QAM. One FSx is also sufficient for demodulation in this case because the two layers are not mixed.

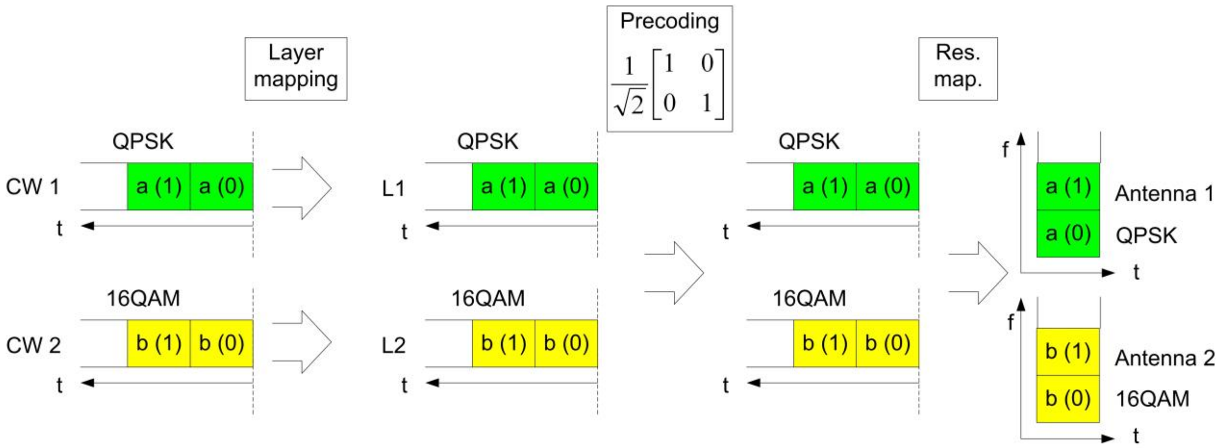

Figure 4: Pre-coding two CWs, two layers, index 0

Figure 5 shows two (differently) modulated code words, (1) QPSK and (2) 16QAM. The code words are mapped directly to the two layers. The pre-coding based on codebook index 1 distributes the mixed layers to the antennas, and the antennas transmit a mixed modulation. Two FSx units are required to demodulate the signal because the two layers are mixed by the pre-coding.

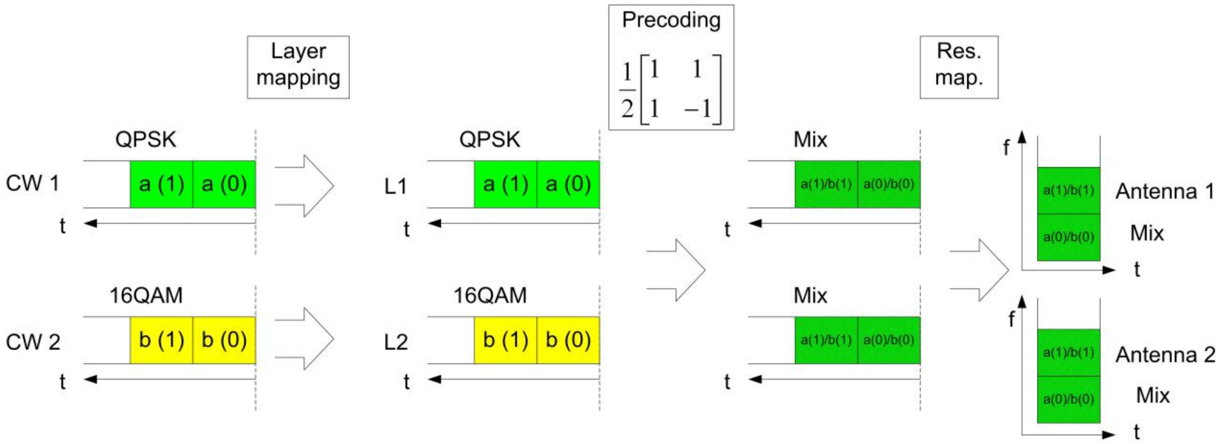

Figure 5: Pre-coding two CWs, two layers, index 1

Cyclic delay diversity (CDD)

Cyclic Delay Diversity (CDD) mode is also provided for spatial multiplexing. In this case, multiplication with matrices D(i) and U is carried out in addition to pre-coding matrix W as per Table 2.

Number of layers υ	U	$D(i)$
1	$[1]$	$[1]$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & e^{-j2\pi/2}\end{bmatrix}$	$\begin{bmatrix}1 & 0\\ 0 & e^{-j2\pi i/2}\end{bmatrix}$

Table 2: CDD pre-coding with two antennas

The additional multiplication mixes the two layers, and the second layer is additionally phase-rotated. With this shifting additional multi-path is added on the channel. Because the two layers are mixed, two FSx units are required for demodulation.

2.3 TX Diversity with Two Antennas

Figure 6 shows the typically antenna setup for two TX Diversity antennas.

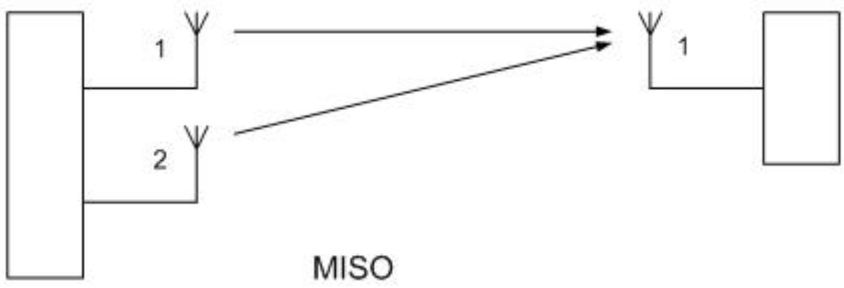

Figure 6: TX Diversity

Layer mapping and Pre-coding
In the case of TX diversity with two antennas, one code word is mapped to two layers. The pre-coding multiplies the two layers. As a result, antenna 1 transmits the 'original' code word and antenna 2 transmits the same data, but with complex conjugate symbols (Figure 7).

Example

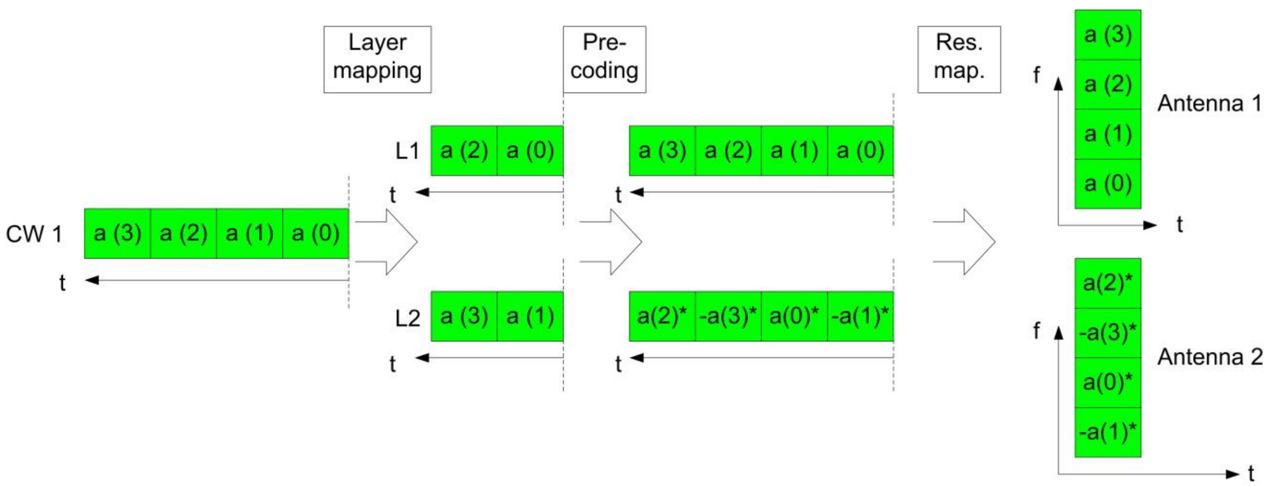

Figure 7: TX diversity with one CW, two layers

One FSx is also sufficient for demodulation in this case because the two layers are not mixed.

3 Base station Transmitter MIMO Tests

In this section the usage of the Rohde & Schwarz analyzers for MIMO tests on the base station transmitter (Tx) is shown. The most important settings in manual control are shown and remote control examples are provided.

LTE Base stations can use four antennas in the downlink (release 8), four FSx can be used to measure simultaneously. In this Application Note up to two antennas are covered (two FSx).

The number of FSx needed for the demodulation of the signals depends on the number of layers and the codebook index which is used. Table 3 shows again the pre-coding matrices for 2 antennas. All matrices used with only one layer need only on FSx (marked in green). The yellow marked indices need two FSx (indices 1 and 2 for two layers). The blue index (index 0 for two layers) needs one FSx when CDD is disabled, two FSx when CDD is enabled.

Spatial multiplexing LTE		
Codebook index	**Number of layers** υ	
	1	**2**
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Table 3: LTE codebook index. One FSx, two FSx units required.

3.1 Instruments and test setup

Testing requires a signal/spectrum analyzer (FSW, FSQ or FSV) with the following software options:

- FS-K100 (LTE Downlink FDD)
- FS-K102 (LTE MIMO)
- FS-K104 (LTE Downlink TDD)

Please note that for tests with two units FSx, the PC version of the LTE software has to be used:

- FS-K100PC (LTE Downlink FDD)
- FS-K102PC (LTE MIMO)
- FS-K104PC (LTE Downlink TDD)

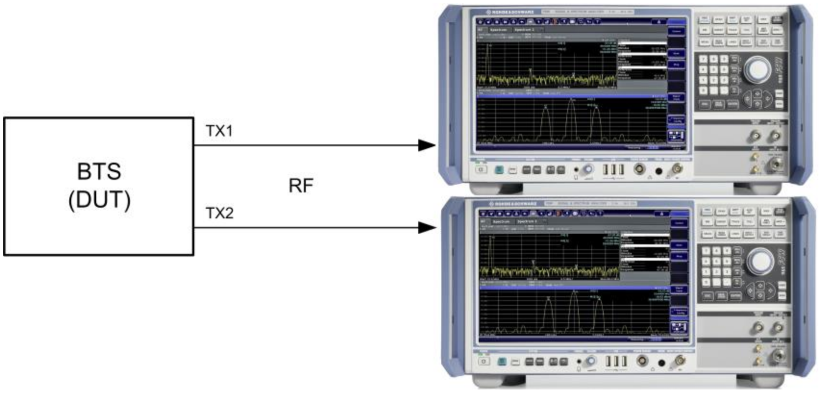

Figure 8: General test setup for base station tests. For two transmit antennas up to two Analysers are required.

For demonstration purpose the remote control examples provided with this application note also allow to replace the BTS DUT by a signal generator. The demo setup is shown in Figure 50 in the appendix.

3.2 Manual Settings for the LTE Analysis SW, Overview

This part shows the most important parameters of the LTE Analysis SW for MIMO in manual control. Basic knowledge about LTE and the general usage of the analyzers are required.

In the main window of the Analysis Software you can find two buttons for configuration:

- general settings (Figure 9 button “1”)
- demodulation settings (Figure 9 button “2”).

Figure 9: LTE Analysis Software - Main window

General settings

Click on the button **General settings** to configure basic parameters. Make sure that the folder *General* is active.

In the section **Signal Characteristics** (Figure 10) you can select between FDD and TDD mode via the field *Duplexing*. To measure the MIMO TX part of a base station, select *Downlink* via the *Link Direction*.

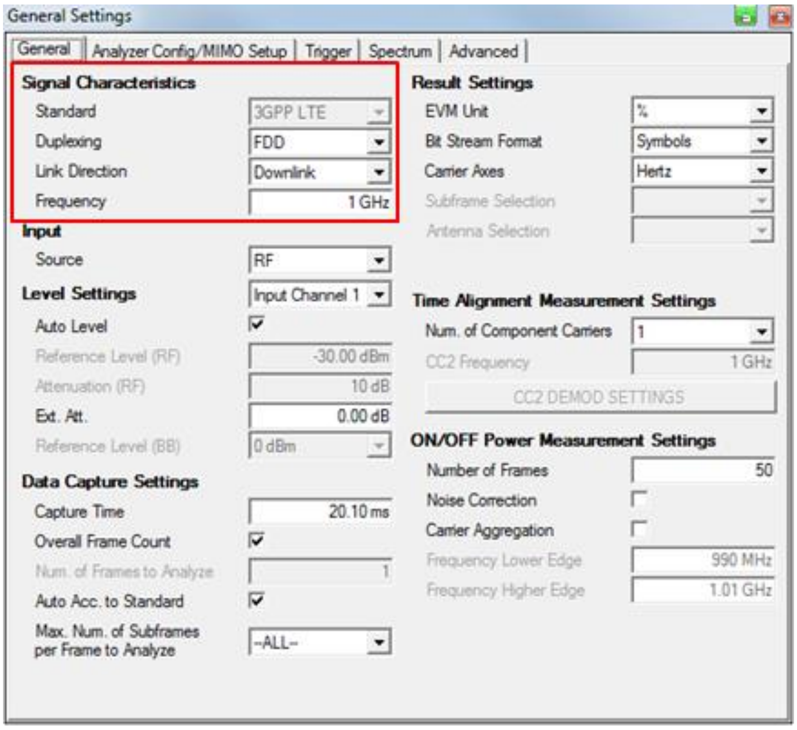

Figure 10: General Settings - Signal characteristics

Trigger Settings

To measure two or more antennas in parallel, all used analyzers must sample at the same time. Therefore set the **Trigger Mode** to *External* (Figure 11).

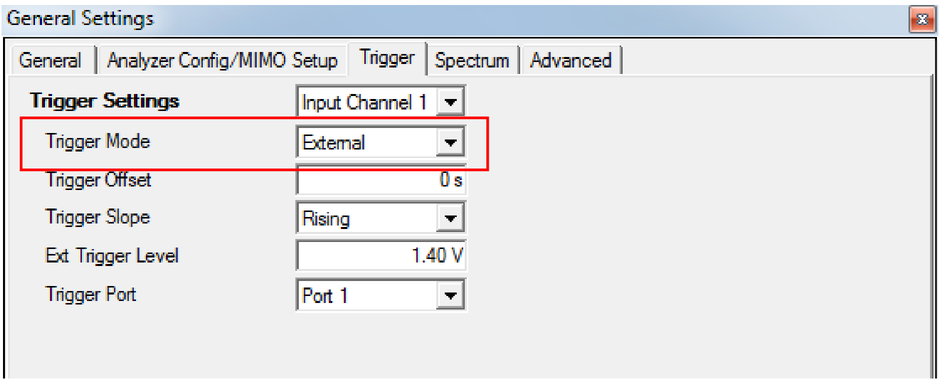

Figure 11: Trigger Settings: An external trigger is necessary to sample on more analyzers at the same time

Demodulation Settings

Click on the button **Demodulation settings** to configure basic parameters. Make sure that the folder *Downlink Signal Characteristics* is active.

In the section MIMO Configuration (Figure 12) set the number of used antennas (in this Application Note 2 two antennas are covered).

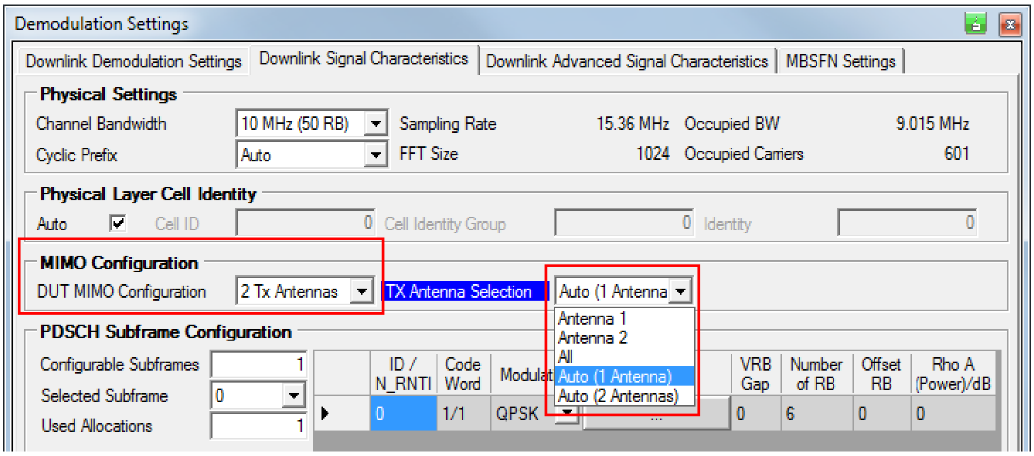

Figure 12: Downlink Signal Characteristics

Under **Antenna Selection** you can select how to measure the antennas. Antenna 1/2 selects a single antenna. Select “Antenna 1 “ or “Antenna 2” for a setup with one FSx. Select **All** to test two antennas simultaneously using two FSx units. If **All** is used both antennas are measured at the same time. You can switch between the results of the antennas by changing the *Antenna Selection* in the section *Result Settings* in the window **General Settings** (
Figure 13).

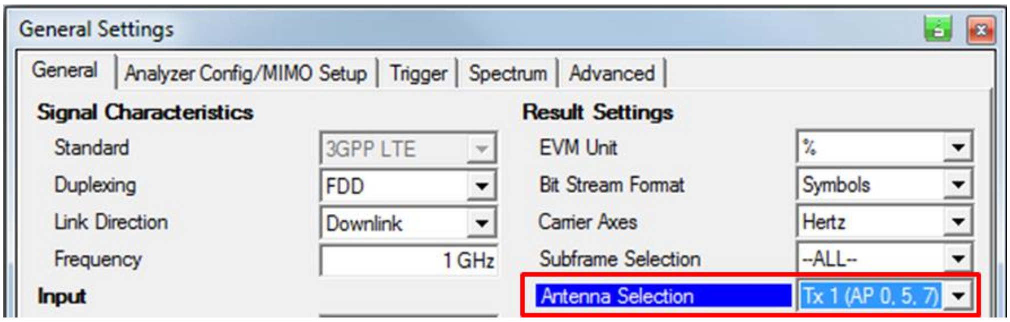

Figure 13: Antenna Selection

PDSCH

In the section **PDSCH Subframe Configuration** (Figure 14) you can set the number of Configurable subframes (1 in the example) and for each subframe the individual allocations. Click at the button in column *Enhanced Settings* (see Figure 14) to open the **Enhanced Settings** of a allocation**.**

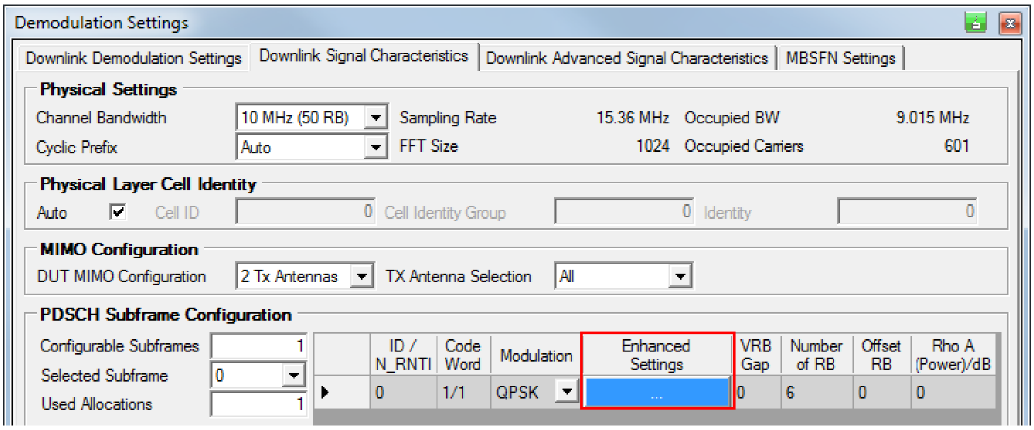

Figure 14: PDSCH Subframe Configuration window and Enhanced Settings frame

In the **Enhanced Settings** window (Figure 15) select the pre-coding (example: Spatial Multiplexing), the codeword to layer mapping (example 2/2) and the used codebook index (example 1).

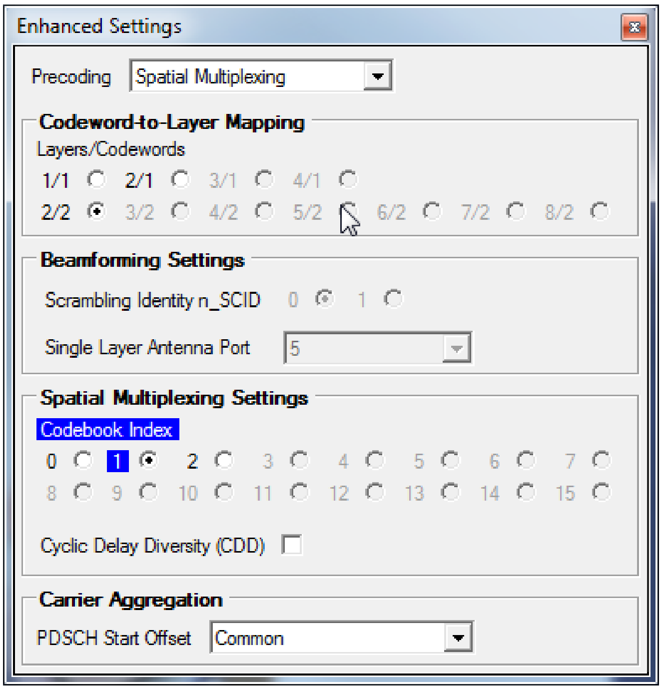

Figure 15: Setup for allocation 1

With the above settings two layers will be used in the allocation part (Figure 16). Set the remaining parameters like *Modulation*, *Number of RB* and *Offset RB* according to the signal to be measured.

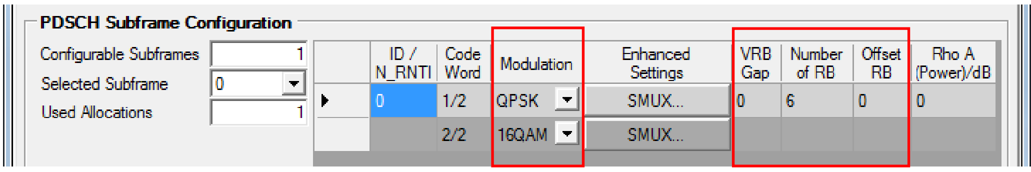

Figure 16: PDSCH Subframe Configuration in the example Spatial Multiplexing with 2 Codewords / Layers is used

In the folder **Downlink Demodulation Settings** (Figure 17) disable the *Auto PDSCH Demodulation* checkbox if not done yet and also set the *Detection* to **Off.**

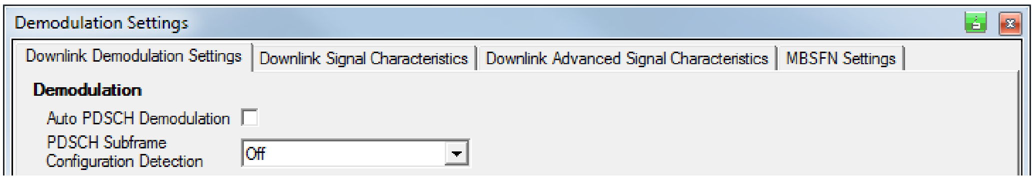

Figure 17: Demodulation Settings, Downlink Demodulation Settings

Measurements

After setting the parameters you can start a measurement. Using FSx (and Analysis Software) you can make following measurements:

- Numeric demodulation measurements, such as error vector magnitude (EVM)
- Graphical output of demodulation measurements (both antenna 1 and antenna 2)
  - EVM vs. carrier
  - EVM vs. symbol
  - EVM vs. subframe
  - Frequency error vs. subframe
- Spectrum measurements
  - Spectrum mask
  - ACP
  - Power spectrum
  - Channel flatness
- Constellation diagram
- Bitstream

Besides the measurements on every antenna like EVM or spectrum, for MIMO measurements the constellation diagram and the allocation overview are useful, because here the different layers and the pre-coding influences the results.

Constellation diagram (Constell button)
Constellation diagram is a graphical representation of a signal in the complex (IQ) plane.

It can be shown direct on the individual antennas (Before MIMO/CDMA decoder (antenna)), where the different layers are possibly mixed depending on the pre-coding. It also shows the decoded signal of all MIMO layers (After MIMO/CDMA decoder).

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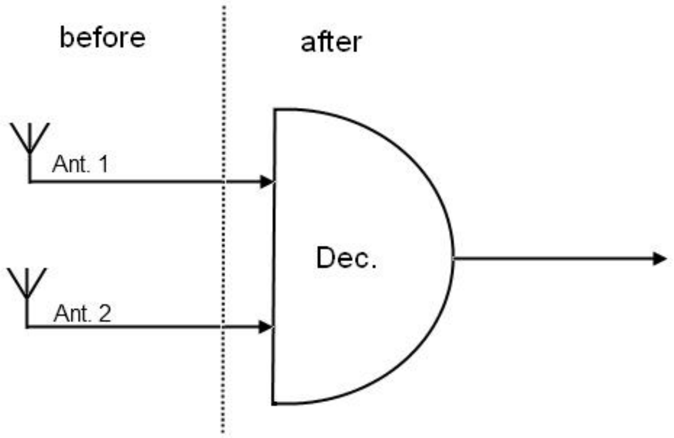


Figure 18: MIMO decoder: possible mixed layers can be decoded

Figure 19 shows an example constellation diagram before decoding with the following channels:

- Primary synchronization signal P-SYNCH (CAZAC)
- Secondary synchronization signal S-SYNCH (RBPSK)
- PBCH (QPSK)
- PDSCH 0 (MIXTURE)

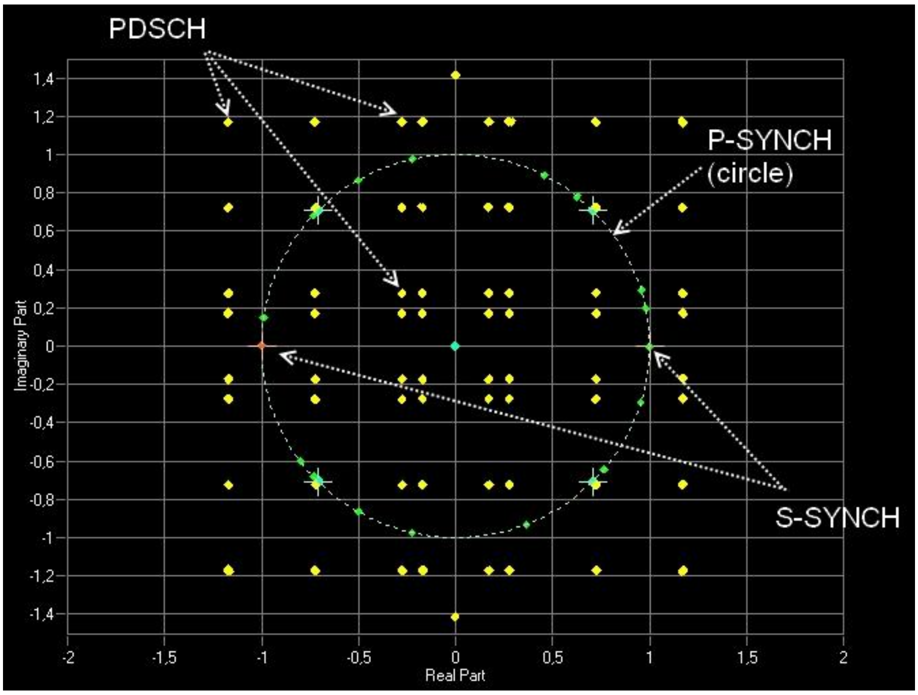


Figure 19: Example Constellation Diagram before decoder for MIMO 2x2 signal captured with two FSW. The PDSCH is a mixture of two layers.

The PDSCH in Figure 19 consist of two layers, two codewords (QPSK and 16QAM with 6 RB) and uses codebook index 1. In effect you can see mixed constellation diagram for PDSCH.

After the MIMO decoder you can see in constellation diagram both parts of the PDSCH allocation (see Figure 20 and Figure 21). Via Codeword it is also possible to shown the constellation diagram of one codeword only.

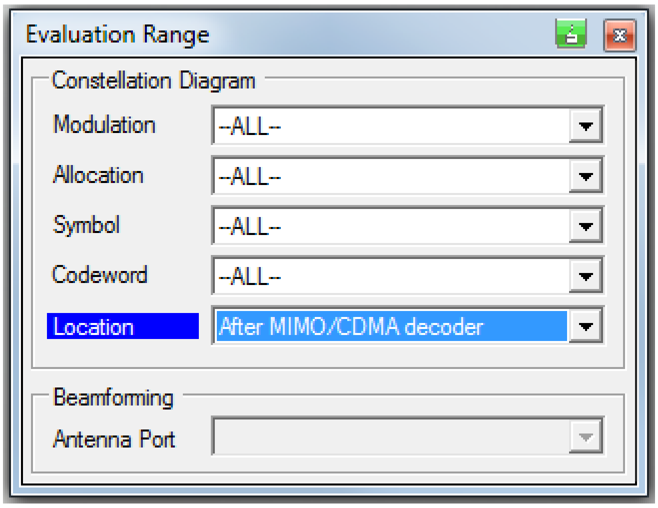


Figure 20: Evaluation Filter, allocation possible after decoding

In Figure 21 you can see constellation diagram for the same signal as in Figure 19 but after MIMO decoder:

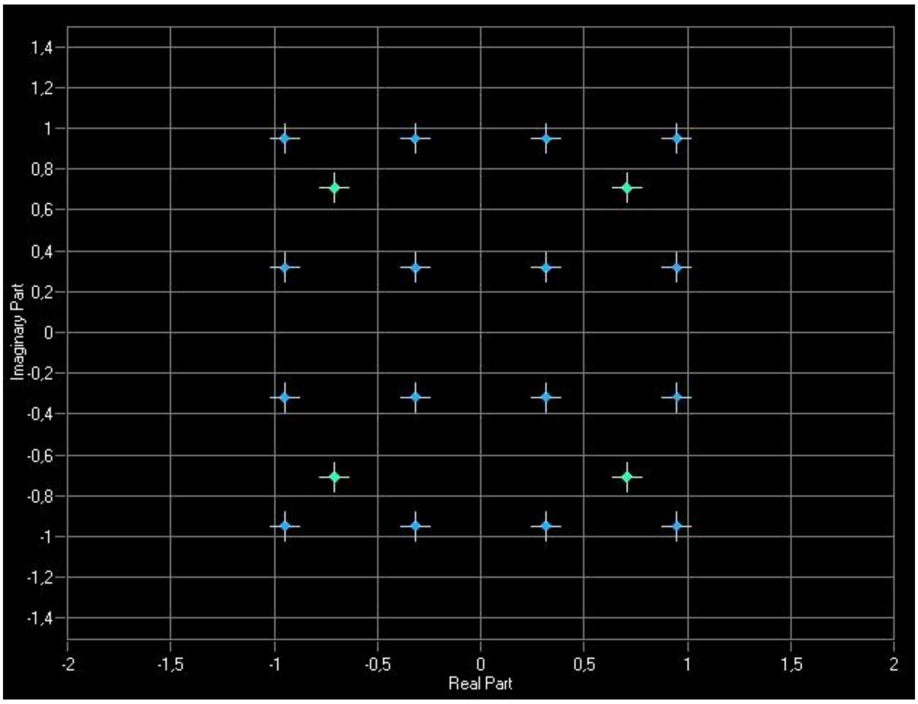


Figure 21: Example Constellation Diagram after MIMO decoder for PDSCH allocation, two codewords (16QAM –blue points, QPSK –green points)

Result Summary

An overview of the numerical results can be shown by click on the button **Display** Figure 22.

Figure 22: Result summary list, overview of numerical results

It is also possible to show an Allocation Summary and the demodulated bitstream (Figure 23).

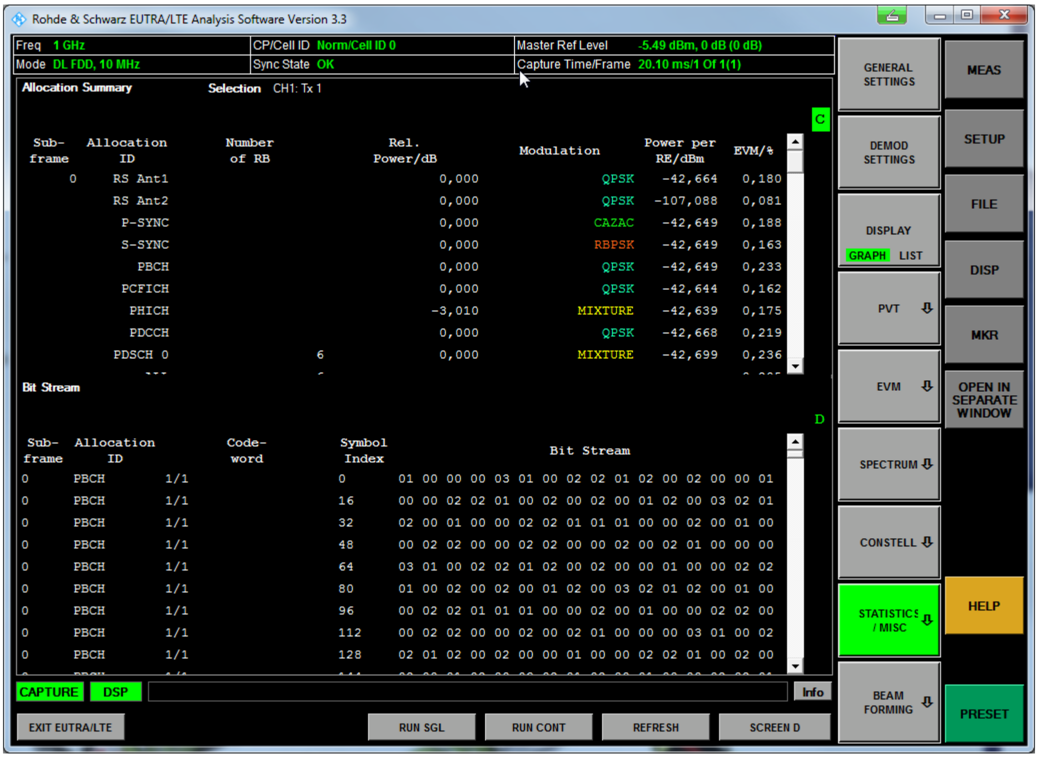


Figure 23: Allocation summary (upper half) and bitstream (lower half) of the demodulated signal

Time Alignment measurement

To find the time alignment error between muliple antennas, the following setup must be used. Both transmit antennas must be connected to an FSx via a combiner (Figure 24).

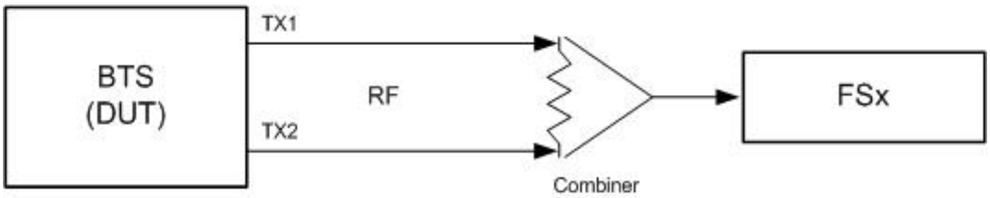


Figure 24: Test setup for time alignment measurements

Ensure that the antenna selection is not set to ALL (because the signals are fed to one FSx). On the FSx, set **Compensate MIMO Crosstalk** to ON (see Figure 25). This function enables the channel estimation for the ’cross’ channels between Tx antenna 1 and Rx antenna 2 and between Tx antenna 2 and Rx antenna 1. Note that the time alignment measurement only uses the reference signal and therefore ignores any PDSCH settings (e.g. it does not have an influence on this measurement if the PDSCH MIMO scheme is set to transmit diversity or spatial multiplexing). The EVM will usually be very high for this measurement. This does not effect the accuracy of the time alignment error measurement result.

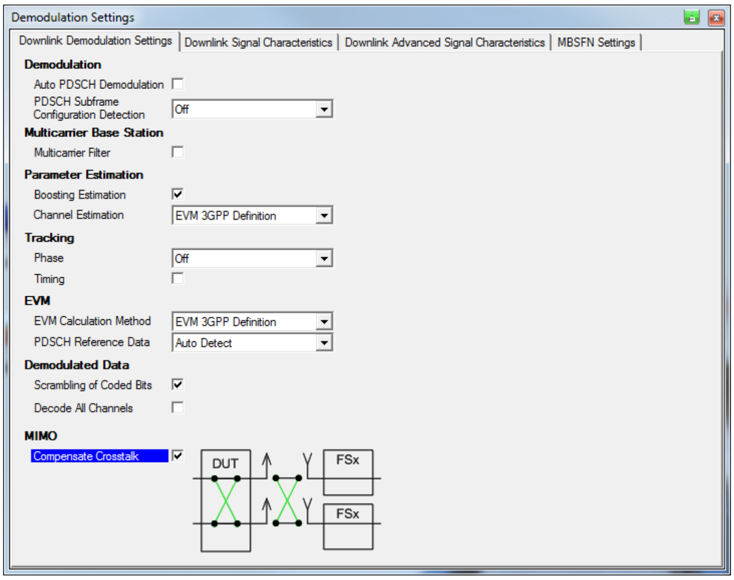


Figure 25: Enabling the Compensate Crosstalk feature

In the FSx test results list, the result (always with reference to antenna 1) is now displayed (Figure 26).

Figure 26: Results of the time alignment measurement. The software can measure up to four antennas. Here the antenna 2 trnasmits 0.56 ns later then antenna 1.

3.3 Remote Control Examples

3.3.1 Tests with one FSx

Test setup

Figure 27 shows the setup with one FSx. Only one FSx is needed to measure both antennas individually, one after the other.

Figure 27: BTS transmitter test with one FSx

Examples in Forum

The following setups are provided as example remote control scripts for BTS transmitter tests with one FSx:

1. Example: **BTS Transmitter TX Diversity**
   – FDD: TX Diversity, 2 Antenna, 2 Layers
   – Bandwidth: 10 MHz
   – CDD Off
   – 2 Allocations (PDSCH), 1 Codeword
   a. QPSK, 25 Resource Blocks
   b. 16QAM, 25 Resource Blocks

2. Example: BTS **Transmitter 1 Layer Code 0**
   – FDD: Spatial Multiplexing: 2 Antenna, 1 Layer, Codebook index 0
   – Bandwidth: 10 MHz
   – CDD Off
   – 3 Allocations (PDSCH), 1 Codeword
   a. QPSK, 10 Resource Blocks
   b. 16QAM, 20 Resource Blocks
   c. 64QAM, 20 Resource Blocks

3. Example: BTS **Transmitter 2 Layer Code 0**
   – FDD: Spatial Multiplexing: 2 Antenna, 2 Layers, Codebook index 0
   – Bandwidth: 10 MHz
   – CDD Off
   – 2 Allocations (PDSCH), 2 Codewords
   a. 1.1: 64QAM, 25 Resource Blocks
   b. 1.2: QPSK, 25 Resource Blocks
   c. 2.1: 16QAM, 25 Resource Blocks
   d. 2.2: QPSK, 25 Resource Blocks

4. Example: **BTS Transmitter 2 Layer Code 0 TDD**
   - TDD: Spatial Multiplexing: 2 Antenna, 2 Layers, Codebook index 0
   - Bandwidth: 10 MHz
   - CDD Off
   - 1 Allocation (PDSCH), 2 Codewords
   a. 1.1: 16QAM, 50 Resource Blocks
   b. 1.2: QPSK, 50 Resource Blocks

3.3.2 Tests with two FSx

Test setup

Figure 28 shows the test setup with two FSx units. Two FSx units are needed to measure the two antennas in parallel. In this case, the DUT must also generate a trigger signal so that the two FSx units can record the signal simultaneously. With this test setup, all codebook indices can be measured as defined in Table 1.

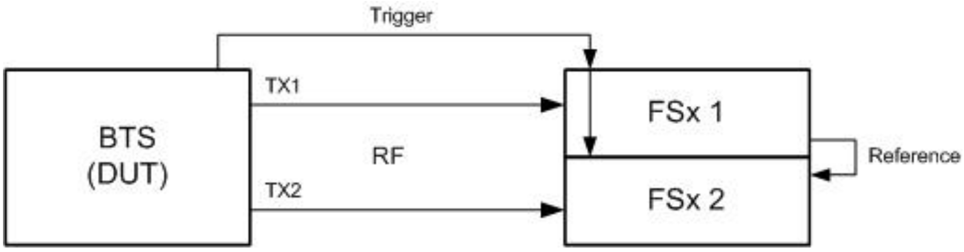


Figure 28: BTS transmitter test with two FSx units

Examples in Forum

The following setups are provided as example remote control scripts for BTS transmitter tests with one FSx.

5. Example: **BTS Transmitter 2 Layer Code 0 with CDD**
   - FDD: 2 Antenna, 2 Layers, Codebook index 0 with CDD
   - Bandwidth: 10 MHz
   - CDD On
   - 2 Allocations (PDSCH), 2 Codewords
   a. 1.1: 64QAM, 25 Resource Blocks
   b. 1.2: QPSK, 25 Resource Blocks
   c. 2.1: 16QAM, 25 Resource Blocks
   d. 2.2: QPSK, 25 Resource Blocks

6. Example: **BTS Transmitter 2 Layer Code 1**
   - FDD: 2 Antenna, 2 Layers, Codebook index 1
   - Bandwidth: 10 MHz
   - CDD Off
   - 2 Allocations (PDSCH), 2 Codewords
   a. 1.1: QPSK, 25 Resource Blocks
   b. 1.2: 64QAM, 25 Resource Blocks
   c. 2.1: QPSK, 25 Resource Blocks
   d. 2.2: 64QAM, 25 Resource Blocks

3.3.3 Tests with RTO (4x4 MIMO)

Test setup

Figure 29 shows the test setup with one RTO. A four channel RTO is needed to measure four antennas in parallel. With this test setup, all codebook indices can be measured as defined in Table 1.

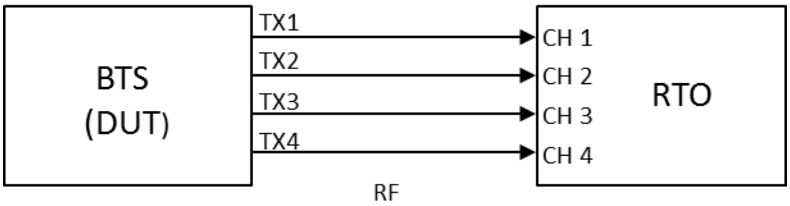


Figure 29: 4x4 MIMO BTS transmitter test with one RTO

Example in Forum

The following setup are provided as example remote control scripts for BTS transmitter tests with the 4 channel Oscilloscope RTO 1014/1024 or 1044:

7. Example: **BTS Transmitter 2 Layer Code 1**
   - FDD: 4 Antenna, 4 Layers, Codebook index 0
   - Bandwidth: 10 MHz
   - CDD Off
   - 2 Allocations (PDSCH), 2 Codewords

   e. 1.1: QPSK, 25 Resource Blocks
   f. 1.2: 64QAM, 25 Resource Blocks
   g. 2.1: QPSK, 25 Resource Blocks
   h. 2.2: 16QAM, 25 Resource Blocks

3.3.4 Time Alignment Error

Test setup

To find the time alignment error between the antennas, the following setup must be used. Both transmit antennas must be connected to an FSx via a combiner (Figure 30).

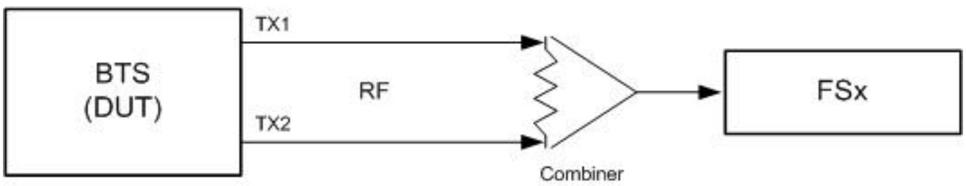


Figure 30: Test setup Time Alignment Error

Example in Forum

The following setup is provided as example remote control scripts for time alignment error measurement in Forum:

8. Example: **BTS Transmitter Timing Measurement**
   - FDD: Timing Measurement
   - Bandwidth: 10 MHz
   - Spatial Multiplexing
   - 2 Layers, Codebook index 1
   - CDD Off
   - 1 Allocation (PDSCH), 2 Codewords
   a. 1.1: QPSK, 50 Resource Blocks
   b. 1.2: 64QAM, 50 Resource Blocks

Note:
In this example, focus is on time alignment error. For demodulation measurement of the signal, two FSx would be needed according to Table 3.

4 UE Receiver Test

4.1 Test setup

For the UE receiver test, the SMW generates the signal of one base station with two antennas and also simulates 2x2 MIMO, LTE fading for four channels (AA, AB, BA and BB) and can add AWGN (Figure 31).

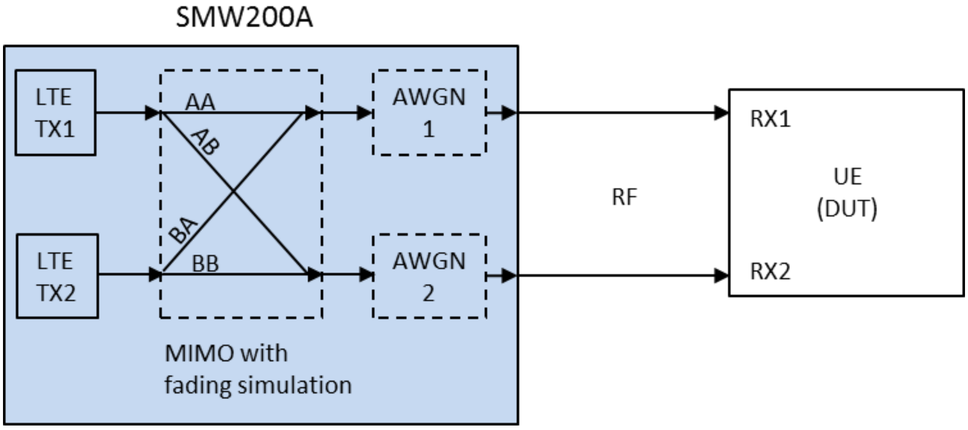


Figure 31: UE receiver test

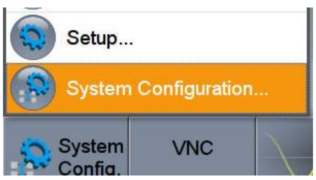
If it is necessary to emulate higher-order MIMO configurations such as 3x3, 4x4, and 8x2 see the application note 1GP97 “Higher Order MIMO Testing with the R&S®SMW200A Vector Signal Generator” (www.rohde-schwarz.com/appnote/1GP97)

In order to perform MIMO measurements up to 4x4 the R&S®RTO can be used instead of several signal analyzers. For more details the application note 1EF86 “Testing LTE MIMO Signals using a R&S®RTO Oscilloscope” (www.rohde-schwarz.com/appnote/1EF86)

4.2 Manual settings for LTE MIMO with 2 Antennas, Overview

This part shows the most important parameters for MIMO in manual control. Basic knowledge about LTE and the general usage of the generators are required.

For the MIMO configuration press the *System Config.* Button and select *System Configuration* as shown in the Figure below:



In the *Fading/Baseband* Tab make the following setting:

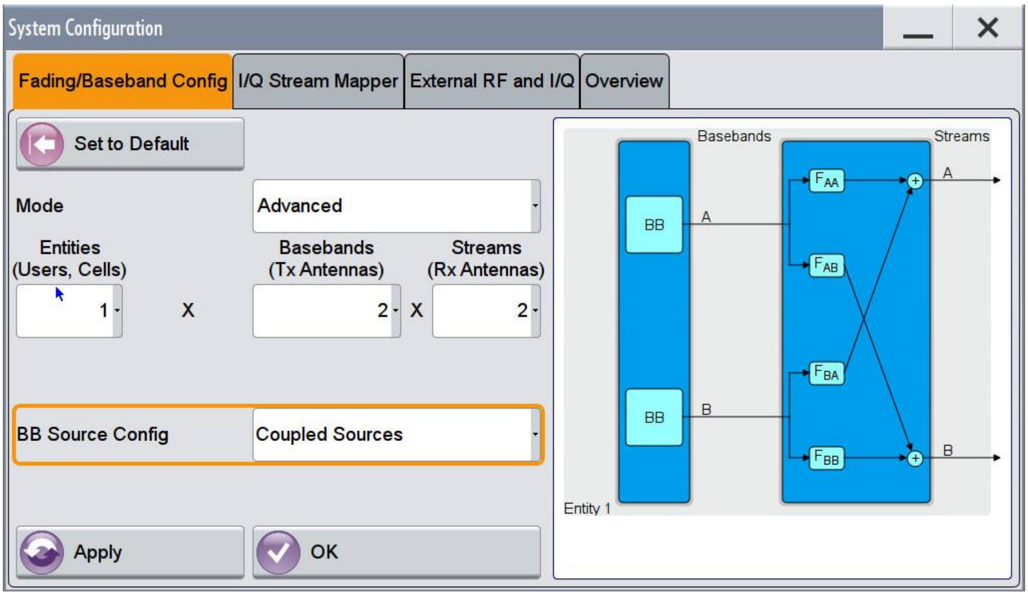


Figure 32: MIMO Settings

In order to take over the settings press the *Apply* button. The block diagramm shows the resulting signal routing of 2x2 MIMO. The baseband Path B is now coupled to path A. The SMW automatically sets all parameters for path B (Figure 31).

Press *OK* and select the Baseband button and choose the LTE Standard:

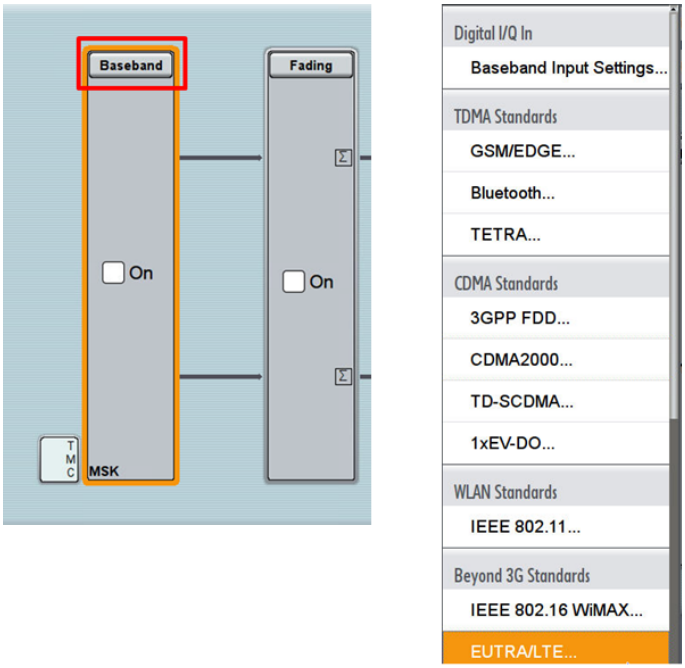


Figure 33: Baseband A generates the first, baseband B the second transmit (Tx) signal. The internal real-time fading simulators simulate the four fading channels.

In the LTE window, you can choose between FDD and TDD mode (33).

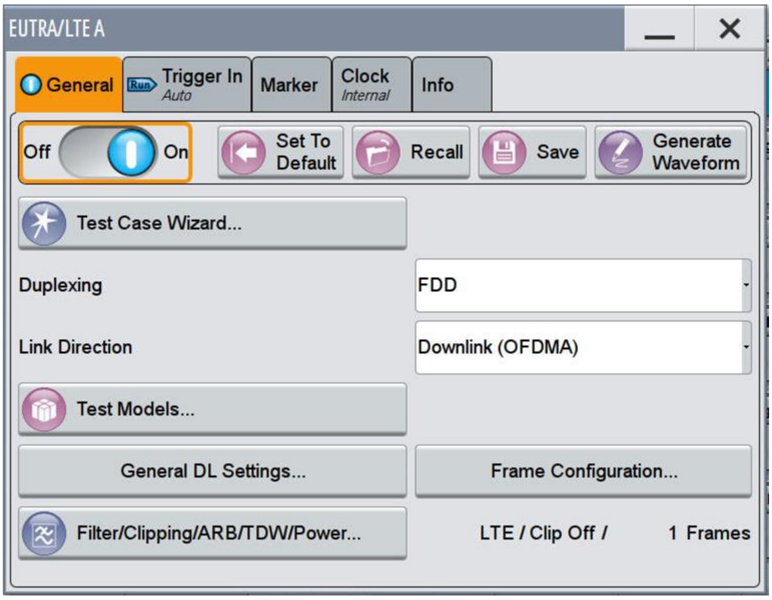


Figure 34: SMW duplexing FDD/TDD

In the **LTE General DL Settings** window, two antennas in the Antenna Ports section are selected and assign path A to antenna 1 and path B to antenna 2 automatically (Figure 34).

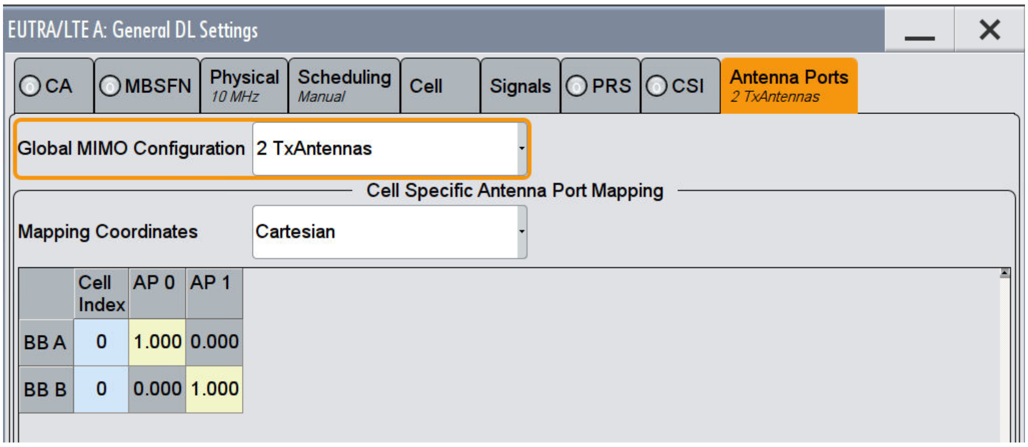
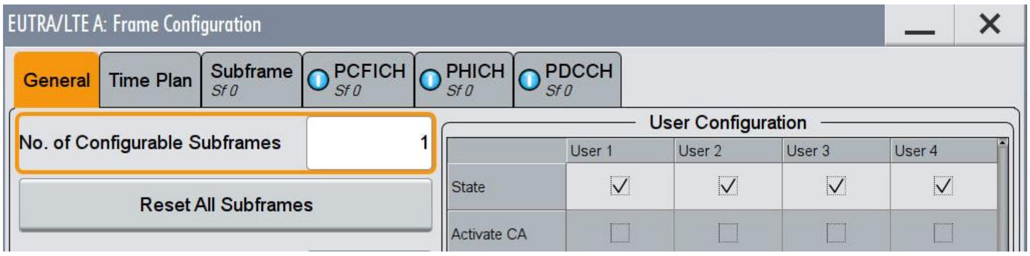


Figure 35: SMW LTE with two antennas

In the **LTE Frame Configuration** window, select the value 1 as the number of configurable subframes:



This way, only one subframe has to be set, and the SMW will copy the first subframe into the other subframes and automatically set the correct control channels (Figure 36). The SMx always set and shows at least 10 subframes (one frame). The PBCH is already enabled as a default setting so only the PDCCH has to be enabled explicitly.

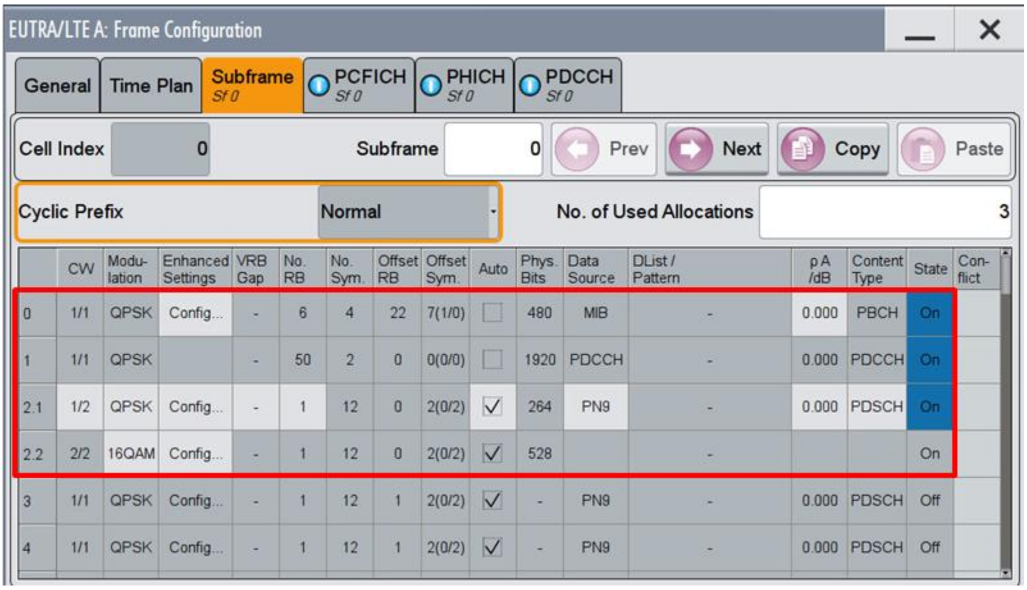


Figure 36: Frame configuration, example1 (SMW)

You can set different additional allocations (PDSCHs). For each allocation you can setup:

- Modulation (QPSK, 16QAM or 64QAM)
- Number of Resource Blocks

Please note that if two codewords are used the allocation will be shown in two lines numbered x.1 and x.2.

Use the **Config** button for the individual allocations to open the Enhanced Settings (Figure 37):

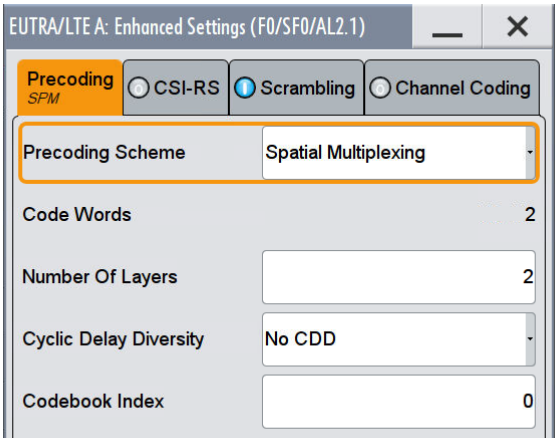


Figure 37: Enhanced settings, example (SMW)

Here you can set the pre-coding Scheme to spatial multiplexing or TX Diversity, the number of layers, the codebook index and the cyclic delay diversity setting. You also can enable Scrambling and Channel Coding.

Under Configure **PCFICH**, **PHICH** and **PDCCH** you can edit these three channels (Figure 38).

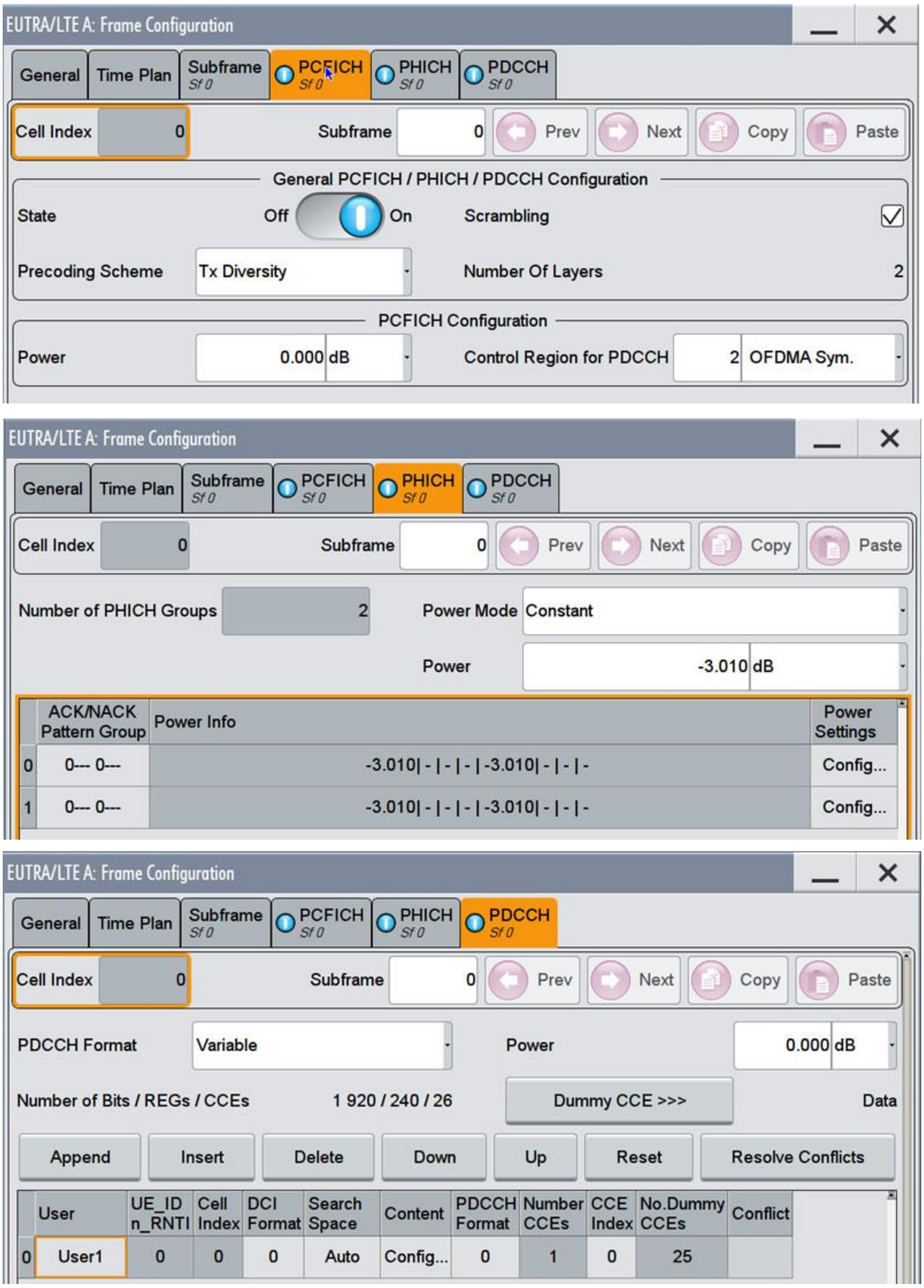


Figure 38: Configure PCFICH, PHICH and PDCCH

Figure 39 shows the first subframe of the generated signal and the individual allocations. The reference and synchronization signals are inserted automatically. Figure 40 shows all ten subframes. A synchronization signal is automatically inserted into subframe 5.

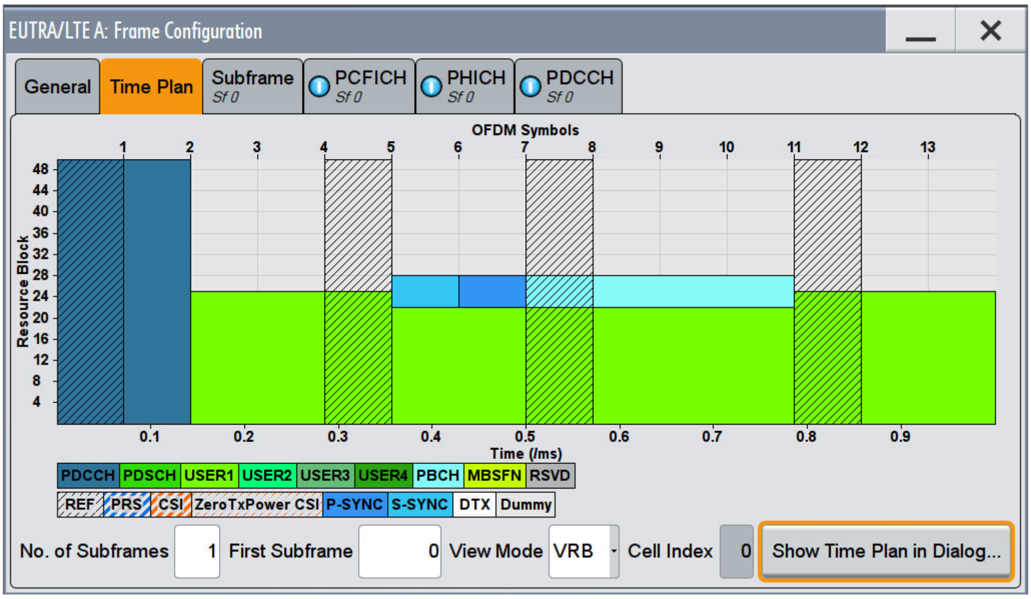


Figure 39: Time plan, example (one subframe)

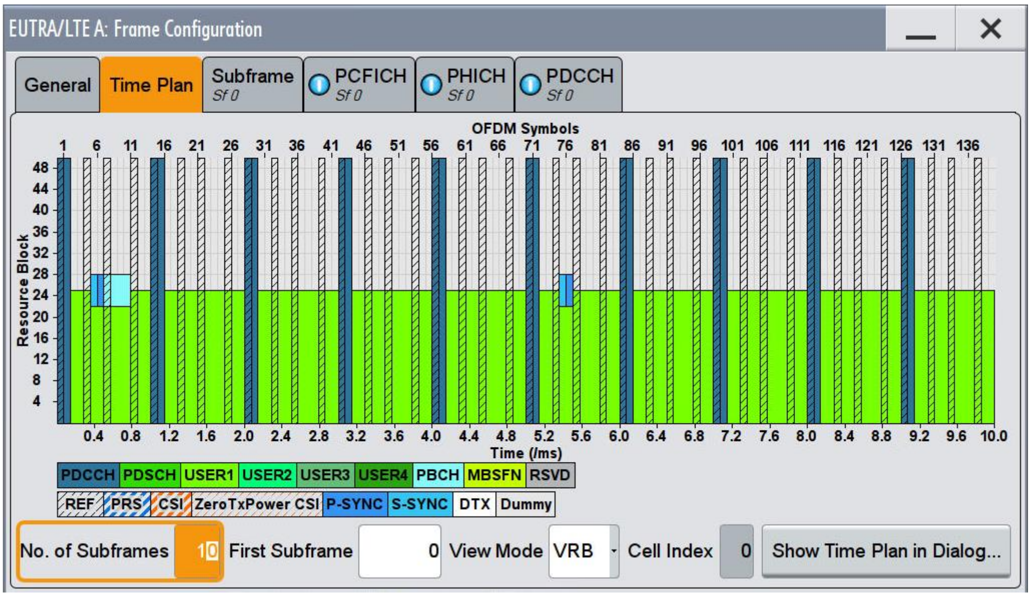


Figure 40: Time plan, example (all sub frames)

If the signal should not be faded it is necessary to bypass the fading simulator (Figure 41).

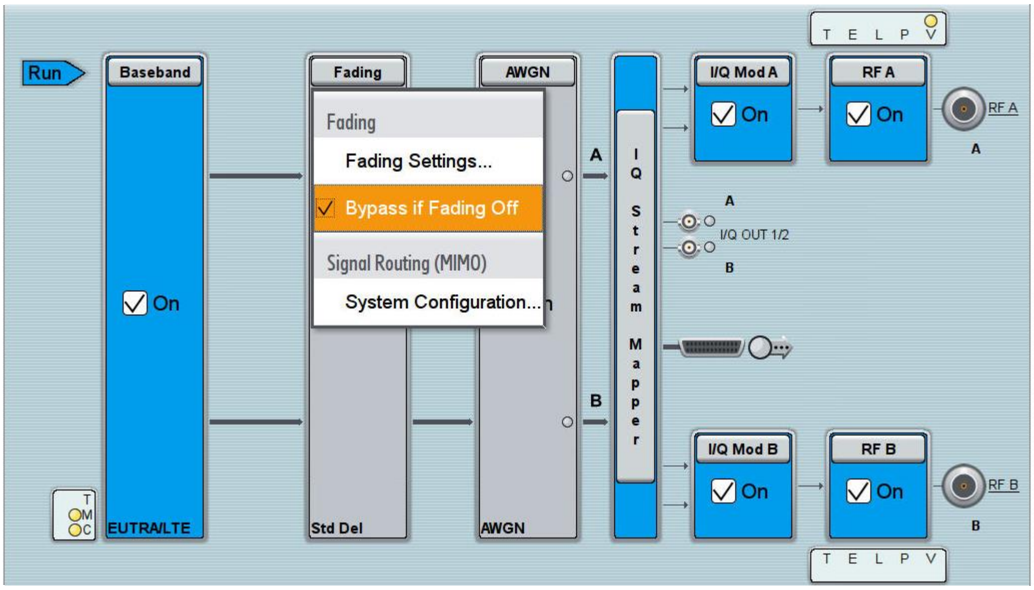


Figure 41: Bypass the fading simulator if it is not needed

After activating LTE, the Baseband A generates the first, baseband B the second transmit (Tx) signal. The resulting streams A and B correspond to the marked signals in the following block diagram (Figure 42)

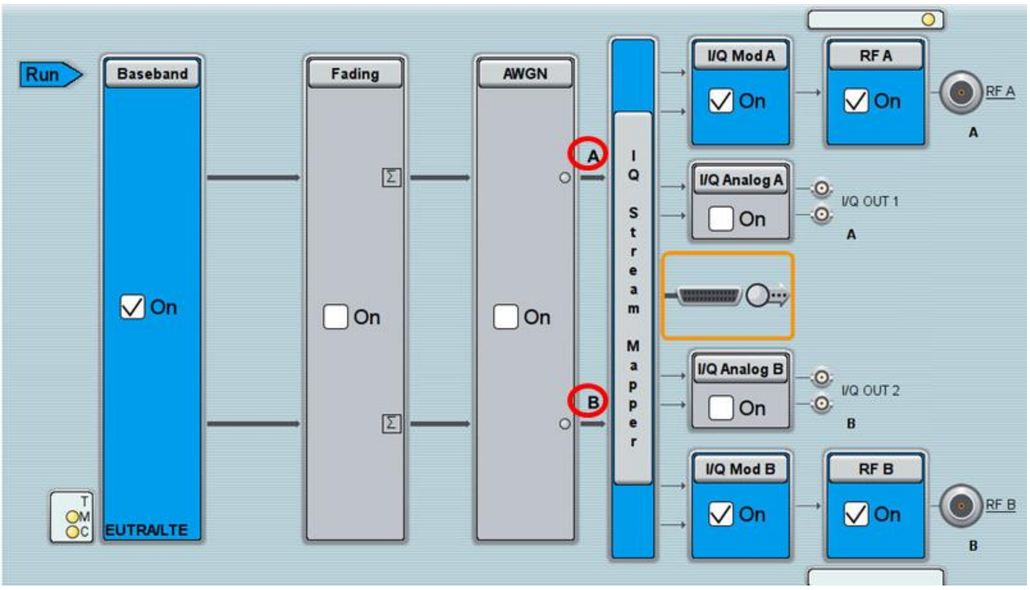


Figure 42: Block diagram on the SMW with stream A (TX1) and stream B (TX2)

Additional settings for UE Receiver tests
For the UE receiver tests general settings (besides the LTE specific) like MIMO, fading and AWGN can be done.

MIMO + Fading
For UE receiver tests, the SMW can be used to simulate the MIMO configuration with fading.
To do this, select the configuration using the Fading button and then select *Fading Settings…*(Figure 43).

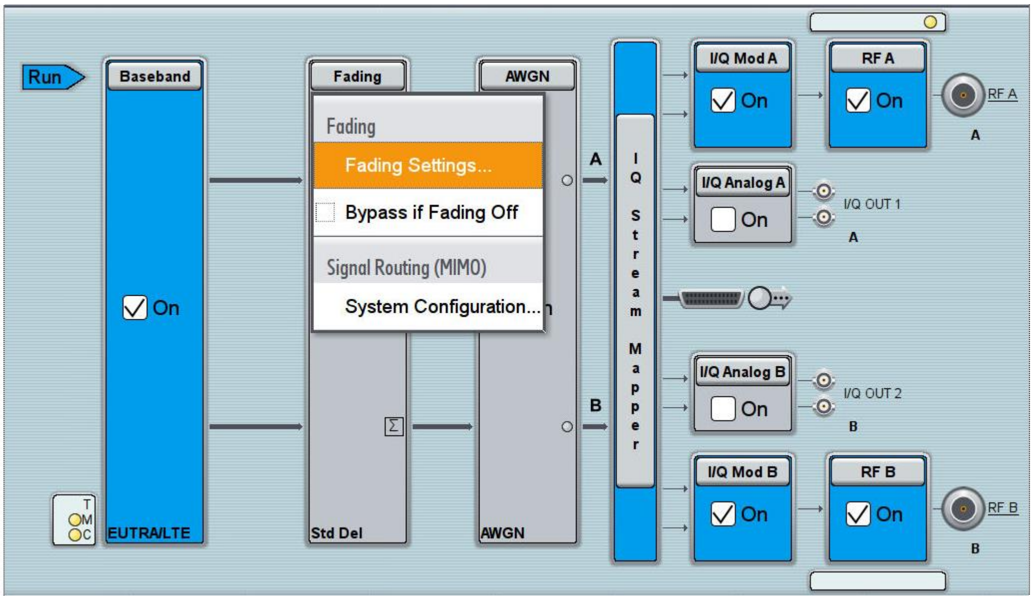


Figure 43: SMW Fading setting selection

In order to use one of the various predefined fading scenarios select *Standard* in the *General* tab (Figure 44). These predefined settings are in accordance with test scenarios stipulated in modern mobile radio standards. Table 5 shows available fading profiles specified for LTE:

LTE fading profiles			
Predefined			
Profile	**5 Hz**	**70 Hz**	**300 Hz**
EPA	X		
EVA	X	X	
ETU		X	X

Table 4: LTE MIMO fading profiles

Added to this are the correlation matrices LOW, MID and HIGH for each possible profile. All profiles defined in the specification are provided in the SMW as predefined profiles. Specifics regarding the fading profiles and settings are found in [5].

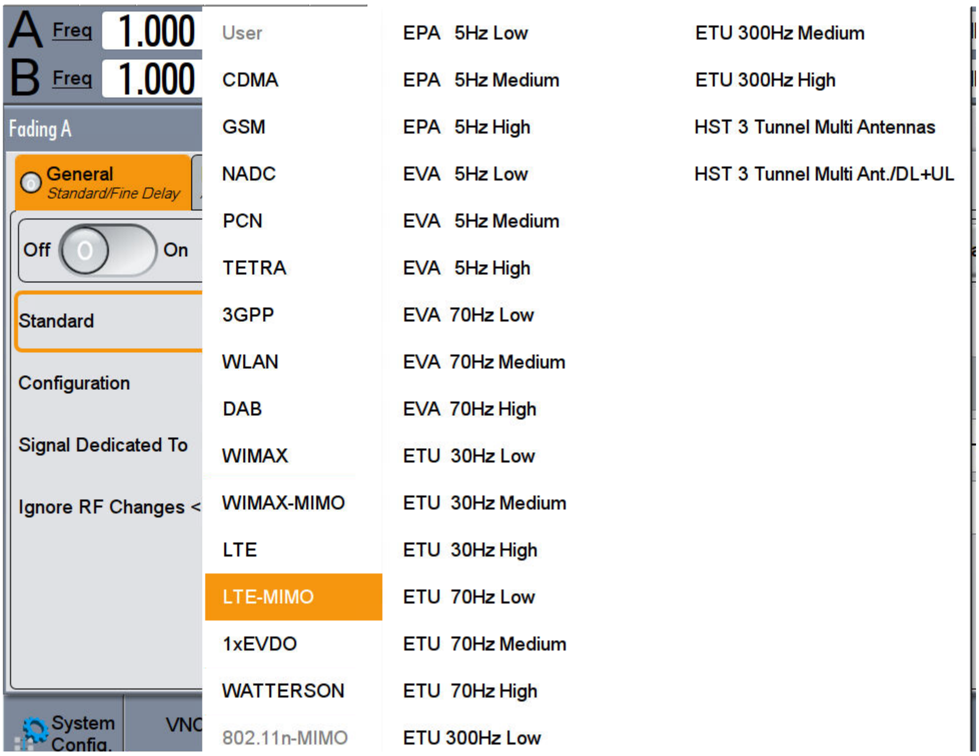


Figure 44: List of predefined fading scenarios for LTE-MIMO

The selected fading scenario can be shown graphically as power delay profile in the "Path Graph" tab (Figure 45).

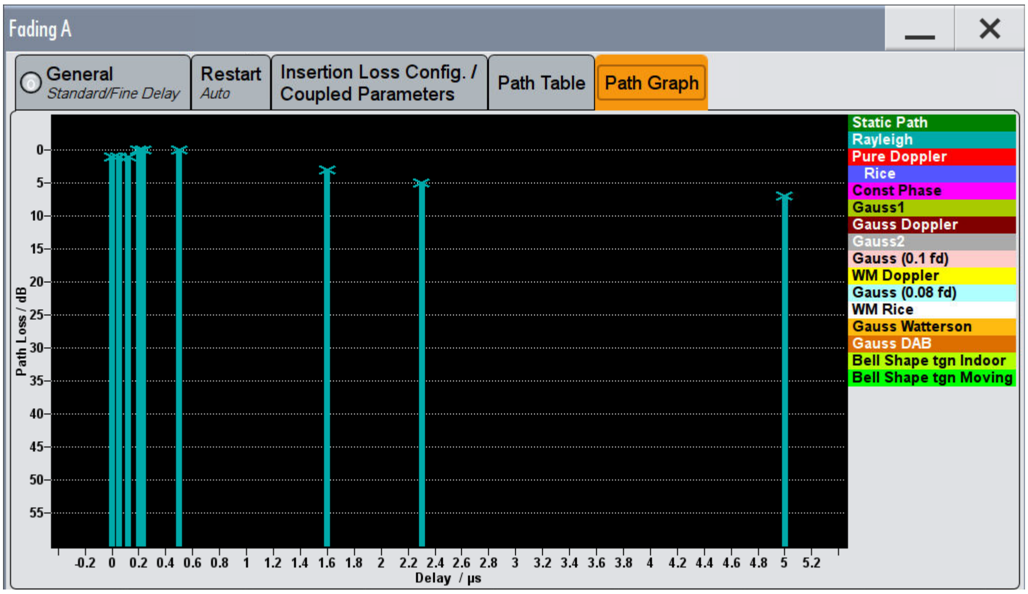


Figure 45: Power delay path graph of the LTE-MIMO fading scenario

Instead of using a predefined fading scenario, the user can also configure a custom scenario. In the *Path Table* tab, the user can specify the number of active fading paths, their delay and attenuation, the fading profile to be used (e.g. Rayleigh), as well as all path related settings (Figure 46).

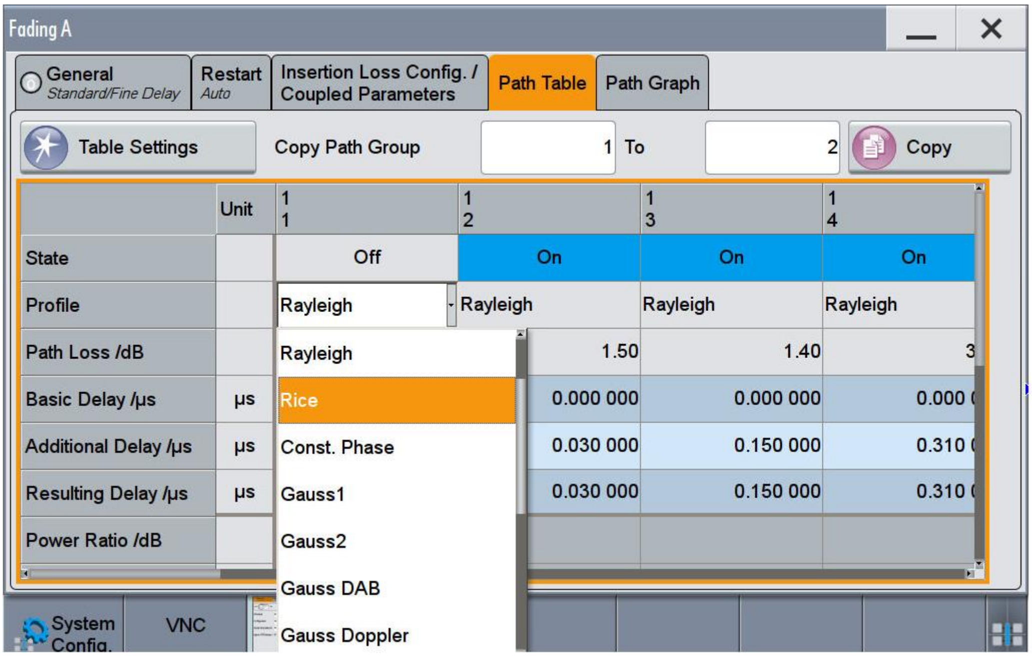


Figure 46: Power delay path graph of the LTE-MIMO fading scenario

To test MIMO receivers under real-world conditions, a certain degree of correlation between the fading channels has to be simulated. The correlation is quantified in terms of a matrix. For 2x2 MIMO this correlation matrix is a 4x4 matrix representing the correlation of the four fading channels (AA, AB, BA, BB).

The correlation between two fading channels is defined by a correlation coefficient that is a measure for the similarity of the two signals. The correlation coefficient is a complex quantity expressed as a pair of numbers in either Cartesian form (real-imaginary) or polar form (magnitude-phase). The polar form is more descriptive, since it directly gives the magnitude and phase relationship of the two signals.

In the path table under *Coefficient* press on *Matrix* (Figure 47) open the correlation matrix menu (Figure 48).

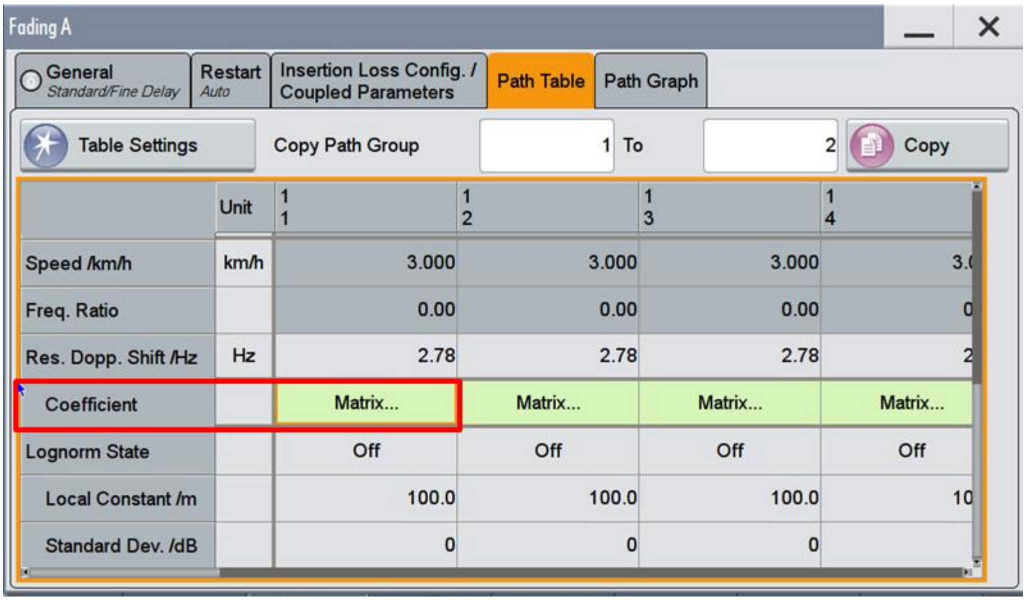


Figure 47: Open the correlation matrix

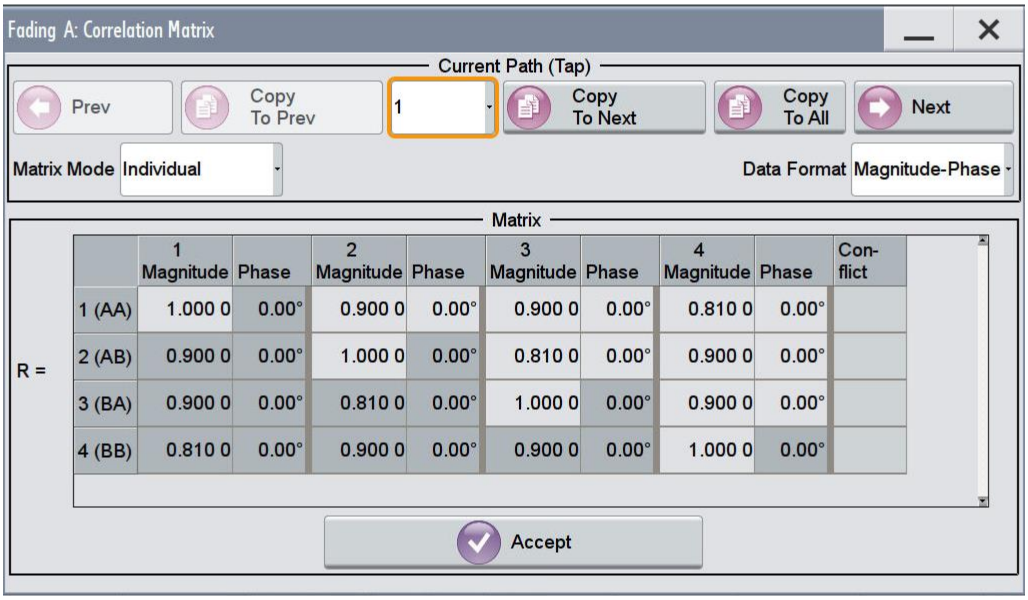


Figure 48: Correlation matrix

Perfect correlation is achieved when magnitude = 1 and phase = 0, whereas magnitude = 0.00 (and phase = 0)5 gives absolutely no correlation. To simulate ideal conditions for MIMO, i.e. no correlation between the fading channels, set all correlation coefficients to zero (default setting) except for the diagonal matrix elements. They represent the correlation of one fading channel with itself and are therefore usually set to magnitude = 1. To create real-world conditions, set the off-diagonal elements to nonzero values to simulate a certain degree of correlation between the fading channels. For more details see the application note 1GP97 "Higher Order MIMO Testing with the R&S®SMW200A Vector Signal Generator" (www.rohde-schwarz.com/appnote/1GP97)

MIMO + Fading + AWGN

An additive white Gaussian noise (AWGN) signal with selectable system bandwidth can be added to the streams after fading simulation (Figure 49). For example, the AWGN signal can be used for simulating a certain signal-to-noise ratio at the receiver to test the receiver sensitivity.

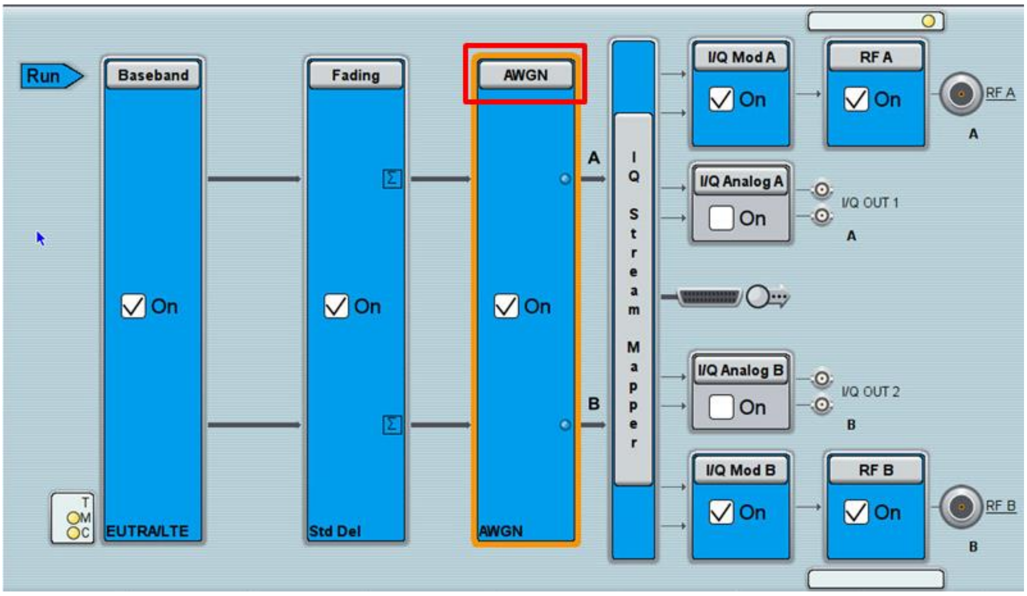


Figure 49: Adding white Gaussian noise

It is possible to specify the AWGN independently for each stream. If the “Coupled Mode” parameter is enabled, the same AWGN settings are used for each stream. In any case, the AWGN is statistically independent for each stream. The settings are not described in more detail here.

4.3 Remote Control Example

Example in Forum

The following setup is provided as example remote control script for UE receiver test.

9. Example: UE **Receiver 2 Layer Code 1 2x2 AWGN**
   – FDD: 2 Antenna, 2 Layers Codebook index 1, 2x2 Fading, AWGN
   – Bandwidth: 10 MHz
   – CDD Off
   – Channel Coding On
   – Scrambling On
   – 1 Allocation (PDSCH), 2 Codewords
   a. 1.1: QPSK, 50 Resource Blocks
   b. 1.2: 64QAM, 50 Resource Blocks
   – 2x2 MIMO
   – predefined LTE fading profile: EPA 5 Hz Medium
   – AWGN with C/N 1 dB

Appendix

4.4 Demo-Setup

Testing typically requires a signal/spectrum analyzer (FSW, FSQ or FSV) for base station (eNodeB) transmitter tests and a signal generator (SMW200A, SMU200A or combination of SMATE200A and AMU200A) for User Equipment receiver tests.

For demonstration purpose the remote control examples provided with this application note also allow to replace the BTS DUT by a signal generator and the UE DUT by signal/spectrum analyzers. The demo setup is shown in Figure 50 .

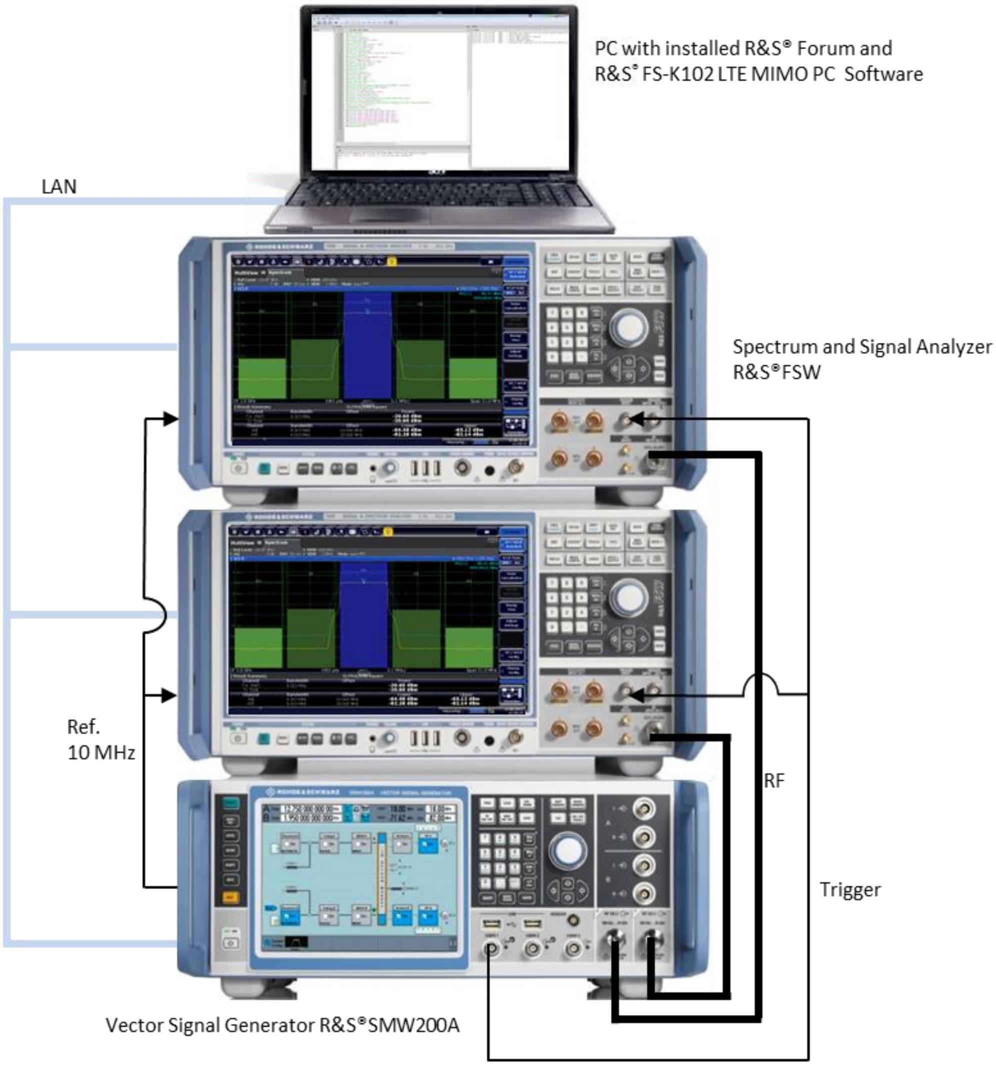


Figure 50: Setup with SMW and two FSW for demonstration

For demonstrating the, in Example 7 described 4x4 MIMO Scenario, it is necessary to increase the number of available SMW RF outputs beyond two. This can be done by connecting external RF sources such as the R&S® SGS or the R&S®SMBV100A to the SMW. These instruments are upconverting the SMW's analog I/Q baseband signals to the RF. The external SGS can be controlled directly from the SMW via LAN or USB. Instead of four signal/spectrum analyzers one RTO oscilloscope with four channels can be used. The RTO is also supported by the R&S® FS-K102 LTE MIMO PC software. An example setup with two SGS and one RTO is shown in Figure 51.

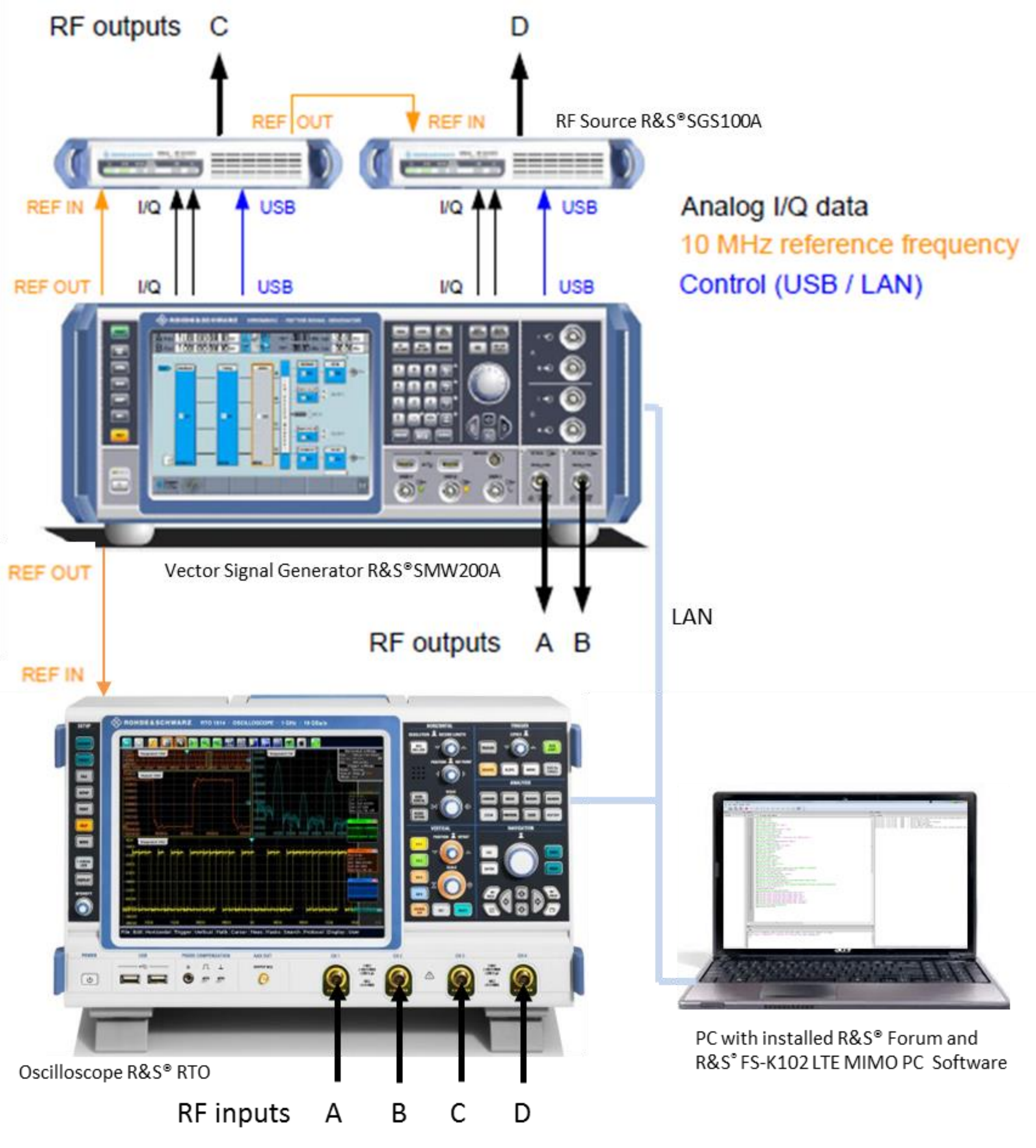


Figure 51: Setup with SMW, SGS and RTO for 4x4 MIMO demonstration

R&S®SGS Configuration Procedure:

- Connect the cables for analog I/Q (the analog I/Q output signals of the SMW are connected to the analog I/Q inputs of the SGS: I → I, Q → Q), reference frequency, and control as shown in Figure 51 above.
- Establish a remote connection to SGS (LAN or USB)
- Per default, “RF coupling” is enabled, i.e. RF frequency, level and “RF State” of the SGS are set automatically via the corresponding SMW settings. Alternatively, set the RF frequency and level directly and turn on the RF output by enabling the “RF State**”.**

Please note:
Use cables of the same type that are exactly equal in length to feed the analog I/Q signals to the SGS. This is important, since otherwise a delay between the I and the Q signal is introduced, which can degrade signal quality significantly. Also, use high quality adapters and do not accumulate adapters.

The settings for the SGSs are made in the “External RF and I/Q” tab of the “System Configuration” menu. Set the “Display” parameter to “Output Connectors” to display only the available output connectors. The outputs “I/Q OUT 1” and “I/Q OUT 2” are relevant for the SGS (Figure 52)

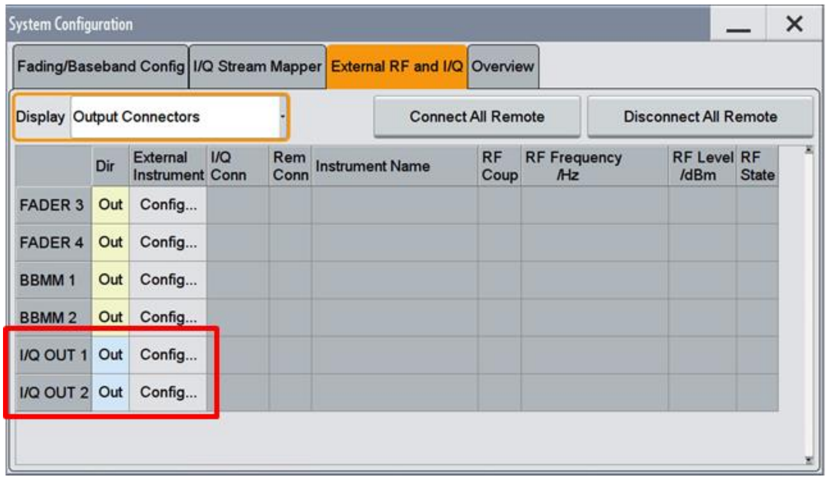


Figure 52: Setup with SMW, SGS and RTO for 4x4 MIMO demonstration

After pressing the Config… Button press the “Scan” button to scan the network (and the USB interfaces) for connected devices. The found devices are listed under the “External Instrument” parameter. Select the target SGS from the drop down list. It is possible to enter a symbolic name for the SGS. The IP address is automatically displayed. Since the SGS is not a two path instrument the “RF Path” parameter is fixed to “A” (Figure 53).

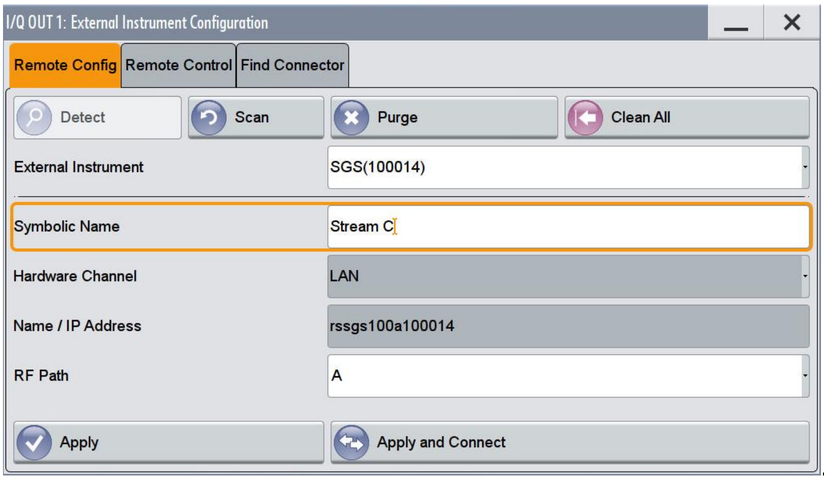


Figure 53: Configuration of the external RF source R&S® SGS

To connect a second SGS repeat the steps described above for the “ I/Q OUT 2” connector.

Back in the “System Configuration” menu, the connected SGS is displayed with its symbolic name. The “Remote Connection” button indicates the connection state and can be used to toggle the state on and off (Figure 54).

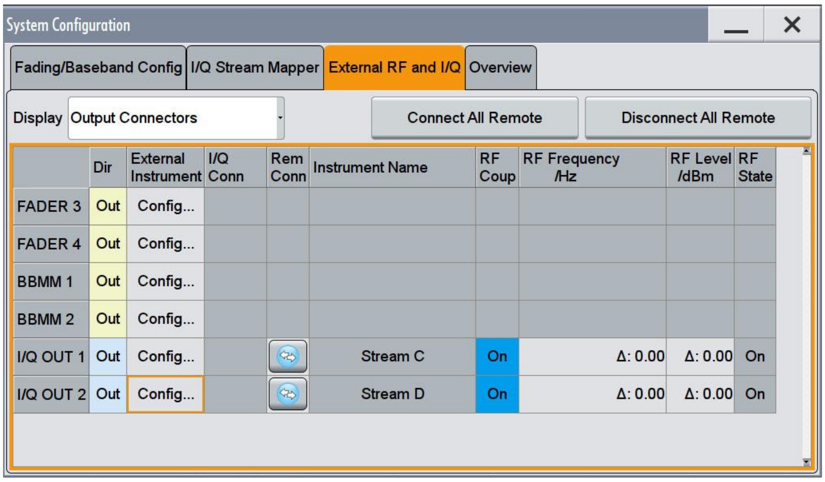


Figure 54: Two SGS are now connected to the SMW “I/Q Out 1” and “I/Q Out 2”

Configuration of the FSK-K102 LTE MIMO PC Software

Figure 55 shows the general Analayzer configuration for the RTO. Select 4 Tx Antennas, and four Channels for the RTO.

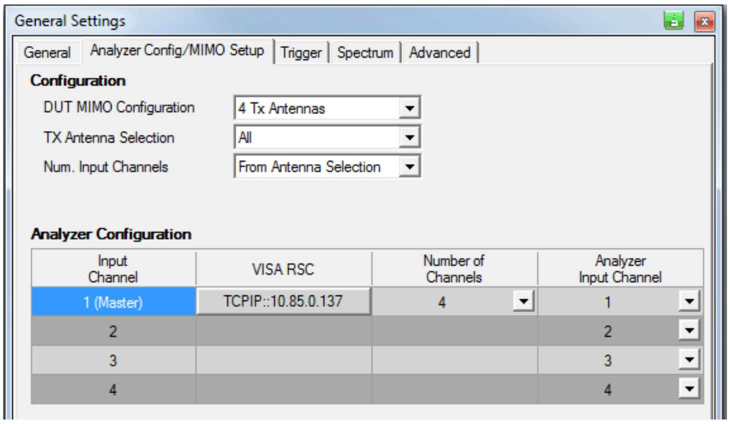


Figure 55: configuration of the FSK-K102 LTE MIMO PC Software by using the 4 channel Oscilloscope RTO.

4.5 Minimum SMW, SGS and RTO Configuration

Table 5 and table 6 shows the minimum configuration of an SMW in order to cover all examples. Please note that it is also possible to combine an AMU and an SMATE.

Minimum SMW configuration (for LTE 2x2 MIMO)		
Option	**Designation**	**Number of options**
SMW-B103	1^{st} path 3 GHz	1
SMW-B203	2^{nd} path 3 GHz	1
SMW-B10	Baseband Generator with ARB (64 Msample) and Digital Modulation (real time), 120 MHz RF bandwidth	2
SMW-B13T	Signal Routing and Baseband Main Module, two I/Q paths to RF	1
SMW-B14	Fading Simulator	2
SMW-K74	MIMO Fading/Routing	1
SMU-K55	Digital standard LTE/EUTRA	2

Table 5: Minimum SMW configuration for LTE 2x2 MIMO measurements

Minimum SMW, SGS and RTO configuration (for LTE 4x4 MIMO)		
Option	**Designation**	**Number of options**
SMW-B103	1st path 3 GHz	1
SMW-B203	2nd path 3 GHz	1
SMW-B10	Baseband Generator with ARB (64 Msample) and Digital Modulation (real time), 120 MHz RF bandwidth	2
SMW-B13T	Signal Routing and Baseband Main Module, two I/Q paths to RF	1
SMW-B14	Fading Simulator	4
SMW-K74	MIMO Fading/Routing	1
SMU-K55	Digital standard LTE/EUTRA	2
SGS-B106V	SGMA RF Source	2
SGS-B26	1 MHz to 6 GHz, I/Q (with vector modulation)	2
SGS-B1	Electronic Step Attenuator	2
RTO-B4	10 MHZ OCXO	1
RTO-K11	I/Q Software Interface	1

Table 6: Minimum SMW, SGS and RTO configuration for LTE 4x4 MIMO measurements

4.6 Remote Control Examples (Program R&S®Forum)

R&S®Forum is a powerful tool for remote control of R&S®Instruments. It allows users to run and edit example script sequences and to write their own script files. Script files can range from simple command sequences (Winbatch syntax) to complex programs using the programming language Python. R&S®Forum application uses the VISA interface, which allows remote control of instruments via LAN, GPIB and USB. R&S®Forum runs on Windows® XP, Vista, 7, 8. For more detailed information see the application note 1MA196 (http://www.rohde-schwarz.com/appnote/1MA196).

R&S®Forum Key Features:

- Stand-alone tool with installer
- Multiple remote connections are supported.
- Python shell prompt for interactive remote control.
- Integrated Debugger: Breakpoints, stepping through source code, inspecting variables.
- Macros: Assign code snippets to buttons in the GUI.
- Window manager: Docking windows allow for user-defined window layout.

- Easy integration of custom python libraries.
- Graphics: matplotlib and numpy are integrated.

Installation
This application note comes with an installer, which includes the:

- Forum application
- Python interpreter

1. Execute the R&S®Forum installation program and select the installation directory.
2. Save the script files provided with the Application Note in a directory on your PC.

Please note:
For communication with instruments, R&S®Forum application uses VISA interface, which is not included in the installer. National Instruments VISA, available on the National Instruments® homepage (www.ni.com/visa), is recommended.
The Python interpreter is installed locally and used for Forum only. An eventually already installed Python version is not used or touched and remains unchanged for normal use.

Each test described in this Application Note can be executed quickly and easily using the demo script files. Results and test times can be evaluated with a single mouse click.The individual remote control commands are commented to make it easy to customize all examples.

In the examples all FSx units are switched to external reference frequency and synchronize to a reference frequency (10 MHz) (provided for demo by the SMx).
It is also possible to set the level and the frequency.

Getting started
After the start, the R&S®Forum user interface will come up:

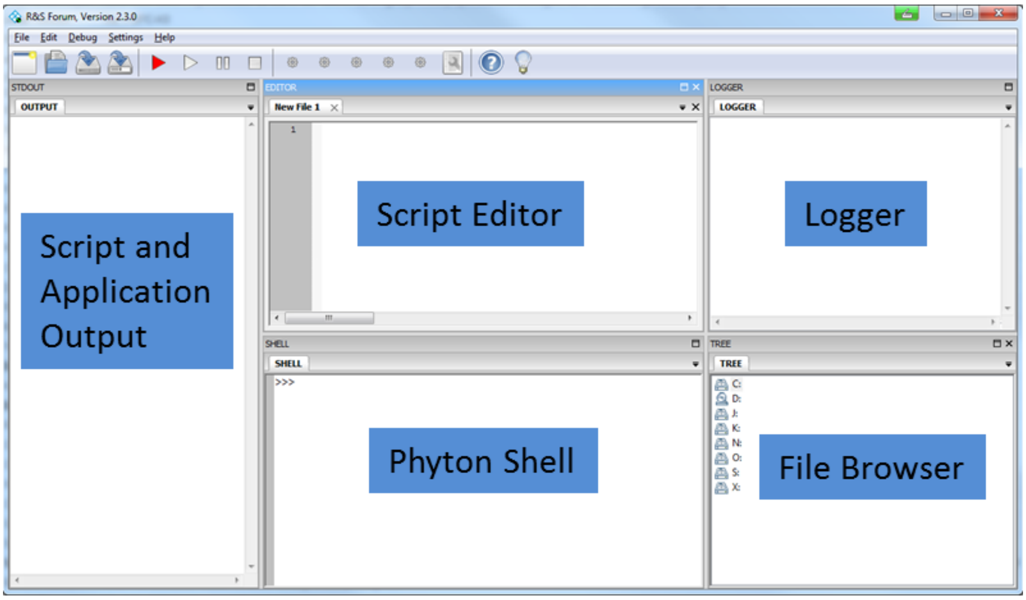


Figure 56: Forum overview

The generator, signal analyzer and the K10xPC EUTRA/LTE analysis software are connected to R&S®Forum via its Visa Resource in the Instrument Configuration file as shown below. As the K10xP EUTRA/LTE analysis software runs on the computer which controls all instruments you have to enter as the resource name **localhost**.

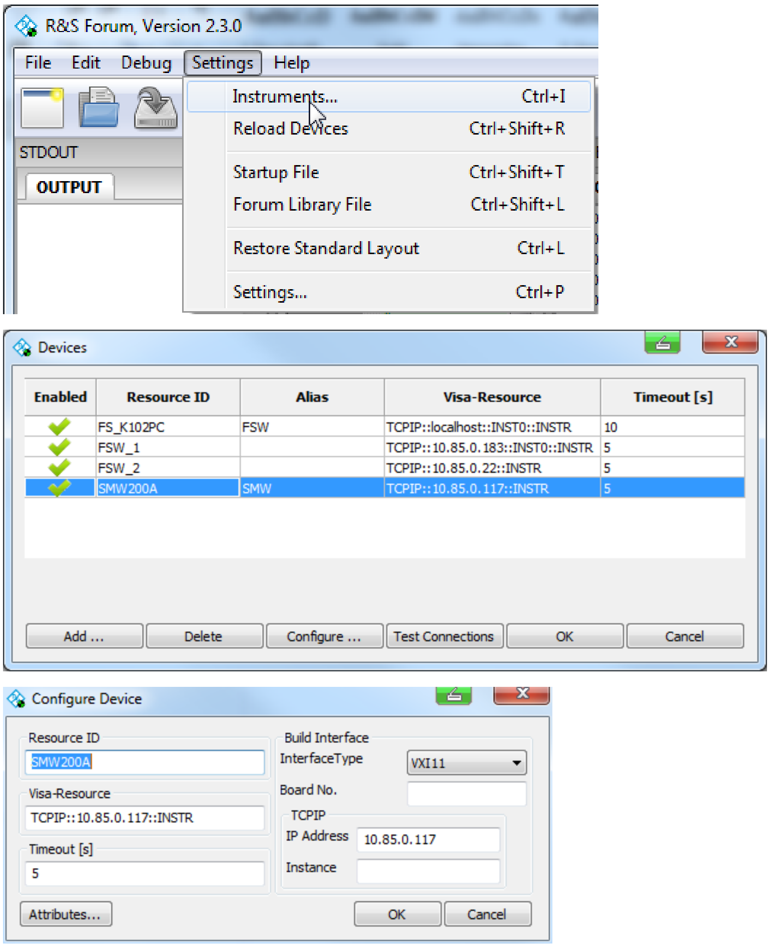


Figure 57: Configuration of the used remote control devices

- Each test described in this Application Note is one txt file.
  Just load a test case via **Open File**
- Test runs are divided into generator (as demo) and measurement part for Tx tests.
- Demos with the SMx can be skipped with Demo = 0
- Results and messages are displayed in the **Output** frame.

If scripts measures two antennas sequentially, the script pauses and Forum waits for the user (8).

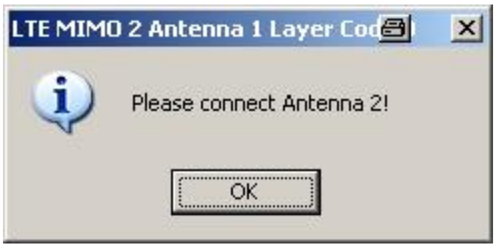


Figure 58: Forum connect antenna 2

Figure 59 shows a typically measurement results in the Forum report.

```
 DATA FOR ANT1
12:00:14.720          FS_K102PC:               INIT:IMM
12:00:14.720          FS_K102PC:               *OPC?
12:00:16.270          FS_K102PC:  1551.2 ms    ['1']
12:00:16.270          FS_K102PC:               FETC:SUMM:POW?
12:00:16.280          FS_K102PC:     3.8 ms    ['-20.6659532722']
12:00:16.280          FS_K102PC:               FETC:SUMM:FERR?
12:00:16.280          FS_K102PC:     1.2 ms    ['-1.59285824338']
12:00:16.280          FS_K102PC:               FETC:SUMM:EVM?
12:00:16.280          FS_K102PC:     1.2 ms    ['0.277908495627']
12:00:16.280          FS_K102PC:               FETC:SUMM:EVM:DSQP?
12:00:16.280          FS_K102PC:     0.8 ms    ['0.276901316829']
12:00:16.280          FS_K102PC:               FETC:SUMM:EVM:DSST?
12:00:16.280          FS_K102PC:     0.7 ms    ['0.280901254155']
12:00:16.280          FS_K102PC:               FETC:SUMM:CRES?
12:00:16.290          FS_K102PC:     0.7 ms    ['11.0552834314']
12:00:48.273          FS_K102PC:               CONF:DL:MIMO:ASEL ANT2
 DATA FOR ANT2
12:00:48.273          FS_K102PC:               INIT:IMM
12:00:48.273          FS_K102PC:               *OPC?
12:00:49.062          FS_K102PC:   787.8 ms    ['1']
12:00:49.062          FS_K102PC:               FETC:SUMM:POW?
12:00:49.062          FS_K102PC:     0.8 ms    ['-20.6728921893']
12:00:49.062          FS_K102PC:               FETC:SUMM:FERR?
12:00:49.062          FS_K102PC:     0.8 ms    ['0.0566992025597']
12:00:49.062          FS_K102PC:               FETC:SUMM:EVM?
12:00:49.062          FS_K102PC:     0.8 ms    ['0.212337798439']
12:00:49.062          FS_K102PC:               FETC:SUMM:EVM:DSQP?
12:00:49.072          FS_K102PC:     0.8 ms    ['0.2095263917']
12:00:49.072          FS_K102PC:               FETC:SUMM:EVM:DSST?
12:00:49.072          FS_K102PC:     0.7 ms    ['0.213155872189']
12:00:49.072          FS_K102PC:               FETC:SUMM:CRES?
12:00:49.072          FS_K102PC:     0.8 ms    ['10.8603929675']
```

Figure 59: Forum Report of example 1: BTS Transmitter TX Diversity

4.7 References

[1] 3GPP **TS 36.211 V8.4.0**; Physical Channels and Modulation (Release 8)

[2] Rohde & Schwarz: **UMTS Long Term Evolution (LTE) Technology Introduction**, Application Note 1MA111

[3] Rohde & Schwarz: **RF Chipset Verification for UMTS LTE with SMU200A and FSQ**, Application Note 1MA138

[4] Rohde & Schwarz: **E-UTRA Base Station Testing acc. to 3GPP TS 36.141**, Application Note 1MA134

[5] Rohde & Schwarz: **Manual: Vector Signal Generator SMW200A**,

[6] Rohde & Schwarz: **Forum**, Application Note 1MA196

[7] Rohde & Schwarz: **Introduction to MIMO**, Application Note 1MA142

[8] Rohde & Schwarz: **Higher Order MIMO Testing with the R&S® SMW200A**, Application Note 1GP97

4.8 Additional Information

Please send your comments and suggestions regarding this application note to

TM-Applications@rohde-schwarz.com

4.9 Ordering Information

Ordering Information		
Vector Signal Generator		
R&S®SMW200A	Vector Signal generator	**1412.0000.02**
R&S®SMW-B10	Baseband Generator with ARB (64 Msample) and Digital Modulation (real time), 120 MHz RF bandwidth	1141.7007.02
R&S®SMW-B13T	Signal Routing and Baseband Main Module , two I/Q paths to RF	1413.3003.02
R&S®SMW-B14	Fading Simulator	1413.1500.02
R&S®SMW-B10x	RF path A (3, 6, 12.75 or 20 GHz)	
R&S®SMW-B20x	RF path B (3, 6, 12.75 or 20 GHz)	
R&S®SMW-K62	AWGN (optional)	1413.3484.02
R&S®SMW-K55	Digital Standard LTE/EUTRA	1413.5235.02
R&S®SMW-K74	MIMO Fading/Routing	1413.3632.02
External RF Source (for 4x4 MIMO)		
R&S®SGS100A	SGMA RF Source	1416.0505.02
R&S®SGS-B106V	1 MHz to 6 GHz, I/Q (with vector modulation)	1416.2350.02
R&S®SGS-B26	Electronic Step Attenuator	1416.1353.02

Ordering Information		
R&S®SGS-B1	Reference Oscillator OCXO	1416.2408.02
Signal Analyzers, Spectrum Analyzers, Oscilloscope		
R&S®FSW	**Up to 8, 13 or 67 GHz**	**1312.8000.xx**
R&S®FSQ	**Up to 3, 8, 26, 31 or 40 GHz**	**1155.5001.xx**
R&S®FSV	**Up to 4, 7, 13, 30 or 40 GHz**	**1321.3008.xx**
R&S®FSx-K100	EUTRA/LTE Downlink	1308.9006.02
R&S®FSx-K102	EUTRA/LTE Downlink, MIMO	1309.9000.02
R&S®FSx-K104	EUTRA/LTE Downlink, TDD	1309.9422.02
R&S®FS-K100PC	PC SW EUTRA/LTE Downlink	1309.9916.06
R&S®FS-K102PC	PC SW EUTRA/LTE Downlink, MIMO	1309.9939.06
R&S®FS-K104PC	PC SW EUTRA/LTE Downlink, TDD	1309.9951.06
R&S®RTO1014	Digital Oscilloscope 1 GHz, 4 channels	**1316.1000.14**
R&S®RTO1024	Digital Oscilloscope 2 GHz, 4 channels	**1316.1000.24**
R&S®RTO1044	Digital Oscilloscope 4 GHz, 4 channels	**1316.1000.44**
R&S®RTO-B4	10 MHZ OCXO	1304.8305.02
R&S®RTO-K11	I/Q Software Interface	1317.2975.02

xx stands for the different frequency ranges (e.g. 1312.8000.26 up to 26 GHz)

Note: Available options are not listed in detail .The use of the SMATE vector generator is also possible (SMATE does not support fading).
Please contact your local Rohde & Schwarz sales office for further assistance.

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