Guidelines for MIMO Test Setups – Part 2
Application Note

Products:

- R&S®SMU200A
- R&S®AMU200A
- R&S®SMATE200A
- R&S®SMBV100A
- R&S®AMU-Z7

Multiple antenna systems, known as MIMO systems, form an essential part of today's wireless communications standards. The multi-antenna technology efficiently boosts the data throughput without requiring additional bandwidth or transmit power and has thus become a key technology.
Rohde & Schwarz offers compact and versatile MIMO test solutions with realtime fading including simulation of channel correlations. This application note explains how to set up Rohde & Schwarz signal generators for 2x2, 4x2 and 2x4 MIMO tests with a focus on signal routing, synchronization of the generators, and leveling.

Application Note

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ROHDE&SCHWARZ

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1 Introductory Note

This application note is part 2 of a pair of application notes.

- Part 1 describes how to set up Rohde & Schwarz signal generators for MIMO scenarios without fading: “Guidelines for MIMO Test Setups – Part 1” (1GP50)
- Part 2 (i.e. this application note) describes how to set up Rohde & Schwarz signal generators for MIMO scenarios with realtime fading: “Guidelines for MIMO Test Setups – Part 2” (1GP51)

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

- The R&S®SMU200A vector signal generator is referred to as SMU
- The R&S®AMU200A baseband signal generator and fading simulator is referred to as AMU
- 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®AMU-Z7 analog I/Q combiner is referred to as I/Q combiner

2 Overview

Frequency bandwidth is a limited resource. To make best use of it, today’s wireless communications standards implement multiple antennas at the transmitter and receiver end. This multi-antenna technology is called MIMO (multiple input, multiple output). MIMO efficiently increases the data throughput without requiring additional bandwidth or transmit power. MIMO is used in mobile communications (3GPP release 8, EURATEL/LTE) as well as in wireless local area networks (WLANn) and regional radio networks (WiMAX).

An NxM MIMO system, consisting of N transmit and M receive antennas, involves NxM fading channels, since there is one channel from each transmitting to each receiving antenna. The higher the statistical independence of the channel characteristics, the better the achievable data transfer rate. For MIMO tests, it is therefore absolutely essential to simulate these channel characteristics. Under real operating conditions, the channel characteristics are not independent of each other, due to the geometric arrangement of the antennas. As a result, the individual channels must be correlated with each other to achieve a realistic simulation of the entire transmission path.

For tests on MIMO systems up to 2x2, only one R&S®SMU200A signal generator is needed. The generator provides frequencies up to 3 GHz. For frequencies up to 6 GHz, only one R&S®AMU200A signal generator in combination with an R&S®SMATE200A signal generator is needed. The R&S®SMU200A and R&S®AMU200A generators include four logical fading simulators which can be correlated via a settable correlation matrix. Settable correlations are important, since for MIMO systems the benefit depends on the degree of correlation. The lower the correlation of the transmission paths, the greater the multi-path propagation benefit to be achieved by the receiver.
If the number of antennas is higher (e.g. with 2x4 MIMO), the number of required channel simulators also increases. For example, for 2x4 MIMO eight logical fading simulators are needed. For such, more complex scenarios, two R&S®SMU200A or two R&S®AMU200A signal generators are needed.
This application note explains how to set up signal generators from Rohde & Schwarz for 2x2, 4x2 and 2x4 MIMO testing with a focus on signal routing, synchronization of the generators, and leveling.

Besides this pair of application notes, several other MIMO-related application notes can be downloaded from the Rohde & Schwarz website:

- “Introduction to MIMO” (1MA142) covers the basics of MIMO technology including data precoding, spatial diversity, spatial multiplexing and beamforming.
- “Phase Adjustment of Two MIMO Signal Sources with Option B90” (1GP67) explains how to adjust the RF phases of two or more signal generators and provides the PhaseTracker PC software, which makes it possible to achieve optimal phase coherence/alignment.
- “LTE Downlink MIMO (2x2) with R&S®SMU200A and R&S®FSQ” (1MA143) describes how to perform tests on LTE MIMO signals (downlink) using an SMU and an FSQ for signal generation and signal analysis, respectively.

3 Brief Introduction to MIMO

This section gives a brief introduction to MIMO systems. A more detailed description of the MIMO technology is given in the application note “Introduction to MIMO” (1MA142).

3.1 Fading

Under real-world conditions, the signal of one transmit antenna arrives at a receive antenna not only via the direct line of sight but via multiple propagation paths. This multi-path propagation is called fading. Especially in urban environments the transmitted signal is reflected from objects such as buildings. As a result, the transmitter signal travels along different reflection paths to the receiver (Fig. 1). The receiver detects all these signals, which typically have different time delays, levels, phases and even frequency shifts due to Doppler effects (caused by moving transmitters or receivers). In a MIMO system a complex fading channel exists between each transmit and receive antenna pair. While the performance of a single input, single output (SISO) system with only one transmit and one receive antenna is degraded by the fading process, MIMO systems work best under multi-path conditions, i.e. in environments with strong fading. Fading is an essential component in MIMO systems, since sufficiently different – i.e. in the best case, uncorrelated – fading channels are required to distinguish the data streams coming from the different transmit antennas.

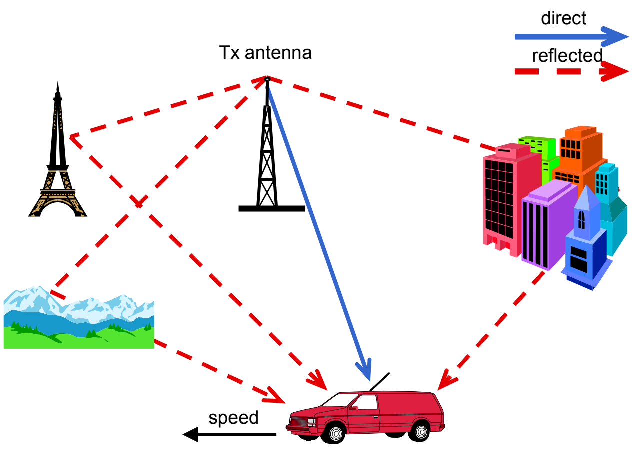

Fig. 1: Fading principle.

Uncorrelated fading channels are, however, only a best-case scenario. Under real operating conditions, the different fading channels are not fully independent of each other, due to the geometric arrangement of the antennas. For MIMO tests, it is therefore essential to simulate variable correlations between the different fading channels. Only by correlating the individual channels with each other a realistic simulation of the entire MIMO system can be achieved. This is important, since for MIMO systems the benefit depends on the degree of channel correlation, i.e. the higher the statistical independence of the different fading channels, the better the achievable data transfer rate.

3.2 MIMO Systems

When discussing MIMO systems, one has to distinguish between spatial diversity systems and spatial multiplexing systems.

Spatial diversity is a MIMO technique that uses multiple transmit and receive antennas to increase the robustness of data transmission and thus indirectly the effective data rates. *Spatial diversity* means transferring essentially the *same* data stream simultaneously on the same frequency such that the receive antennas obtain replicas of the signal. Typically, an additional antenna-specific coding is applied to the signals before transmission to increase the diversity effect. This means that each antenna transmits the same information stream, but with different coding. Often, space-time coding according to Alamouti is used. On the receiver side, the signal of the transmit antennas is received by the antennas over different, ideally uncorrelated propagation paths. This mitigates fading effects, because it is unlikely that the signals are affected the same way by fading processes along the different propagation paths. Therefore, the signal-to-noise ratio at the receiver side and thus the robustness of data transmission is improved. Transmit diversity (multiple input, single output – MISO) and receive diversity systems (single input, multiple output – SIMO) are both special types of spatial diversity systems (Fig. 2).

Spatial multiplexing or “true” MIMO is a different MIMO technique that is used to significantly increase data rates or channel capacity. *Spatial multiplexing* means transferring *different* data streams simultaneously on the same frequency by using multiple transmit and receive antennas, i.e. fully exploiting the spatial dimension of the radio channel. In contrast to spatial diversity, no redundant data is transmitted. The data stream to be transmitted is split up into independent data streams, which are sent via the different transmit antennas. Spatial multiplexing thus increases the data rate of a single user or the overall capacity in the case of multiple users. For single-user (SU) MIMO, the transmitted data streams belong to one user only, thus increasing the data rate of this single user. For multi-user (MU) or collaborative MIMO, the transmitted data streams belong to different users sharing the same radio channel. In this case, the overall capacity of the radio channel is increased, while the data rate of an individual user remains unchanged. Also, the user equipment (UE) has to be equipped with just one transmit antenna (Fig. 2).

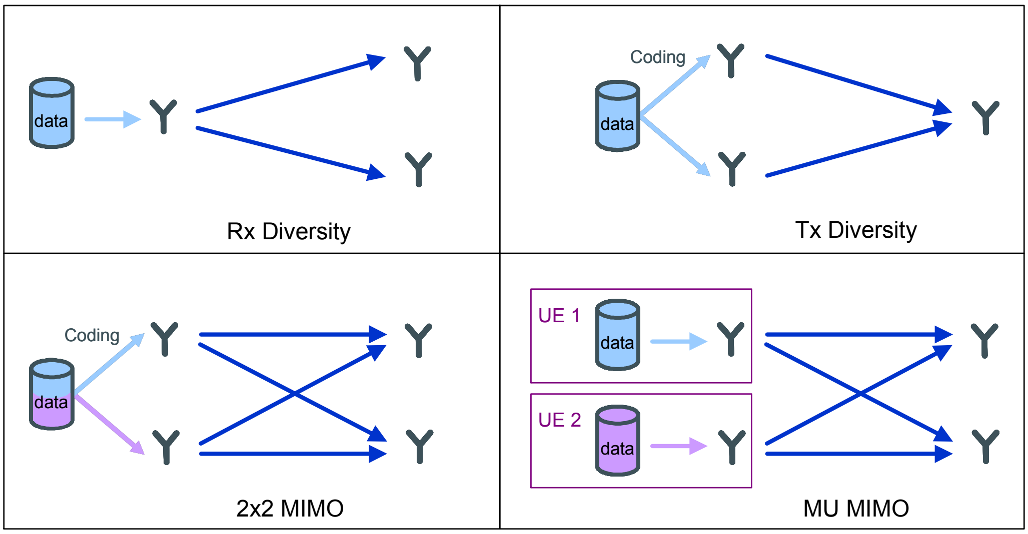

Fig. 2: Schematics of receive diversity (upper left), transmit diversity (upper right), “true” 2x2 MIMO (lower left), and multi-user MIMO (lower right).

3.3 Testing MIMO Systems

A good test solution for MIMO must be able to provide data precoding and realtime channel simulation including channel correlations. The R&S®SMU200A and the R&S®AMU200A allow standard-compliant SISO, transmit diversity and “true” MIMO signal generation (up to four Tx antennas) for modern communications standards such as LTE, HSPA+, WiMAX and WLANn, i.e. they provide diversity and spatial multiplexing data precoding for the named digital standards. In addition, the instruments offer integrated realtime fading for realistic channel simulation including the possibility to specify channel correlations. Compared to precalculated fading processes, realtime fading is beneficial not only due to the fact that no time-consuming recalculation is necessary when changing any fading parameter, but mainly because only realtime fading processes provide reliable statistical results.

3.3.1 Testing without Fading

A first step in testing MIMO systems might be to run performance tests without applying fading to the transmitter signals, i.e. leaving out realistic channel simulation but applying data precoding only. For these basic tests, basically any modern vector signal generator from Rohde & Schwarz (R&S®SMU200A, R&S®SMATE200A, R&S®SMJ100A, R&S®SMBV100A, etc.) can be used, since all generators offer data precoding for the different digital standards and are hence able to generate the MIMO transmitter signals. The application note "Guidelines for MIMO Test Setups – Part 1" focuses on these test configurations and explains how to set up the signal generators for MIMO scenarios without fading. For the digital standard LTE, an application note is available that explains how to perform tests on LTE MIMO signals (downlink) using an SMU and an FSQ for signal generation and signal analysis, respectively. Most examples described in this application note (titled "LTE Downlink MIMO (2x2) with R&S®SMU200A and R&S®FSQ" – 1MA143) are test scenarios for receiver and transmitter tests without fading.
In early test stages, it might be useful to operate with phase-coherent RF signals in order to create well-defined conditions for the device under test (e.g. the MIMO receiver). The R&S®SMU200A, R&S®SMATE200A, R&S®SMJ100A, and R&S®SMBV100A vector generators offer an option (B90) that makes it possible to obtain two or more phase-coherent signals for early stage MIMO tests. Of course, these tests are also performed without fading, since the fading process would change the phase relations of the signals and destroy any phase coherence. The application note "Phase Adjustment of Two MIMO Signal Sources with Option B90" (1GP67) explains how to adjust the RF phases of two or more signal generators for achieving optimal phase coherence. For example, phase-coherent signals are essential for testing beamforming applications which represent a special type of MIMO systems. Beamforming systems use multiple transmit antennas to create a radiation lobe by constructive interference of the transmitted signals. The resulting beam can be steered by adjusting the individual RF phases of the signals and weighting the signal amplitudes. In contrast to spatial multiplexing applications, beamforming is a direct line-of-sight technique, i.e. fading processes are unwanted.

3.3.2 Testing with Fading

After testing a MIMO system under static conditions, i.e. without applying fading to the transmitter signals, a next step will be to simulate real-world conditions. Modern digital standards stipulate sensitivity tests under multi-path conditions to ensure that the MIMO receiver is able to cope with these propagation conditions. As already pointed out above, the R&S®SMU200A and the R&S®AMU200A signal generators are ideally suited for simulating the complex fading channels between the transmit and receive antennas. These generators provide MIMO data precoding and realistic channel simulation (realtime fading), both of which are important features offered by high-quality test equipment. Therefore, this application note focuses on these two instruments in spatial multiplexing configurations with applied realtime fading.

4 2x2 MIMO

The simplest ("true") MIMO setup is a 2x2 MIMO system consisting of two transmit and two receive antennas. This antenna configuration involves four fading channels.

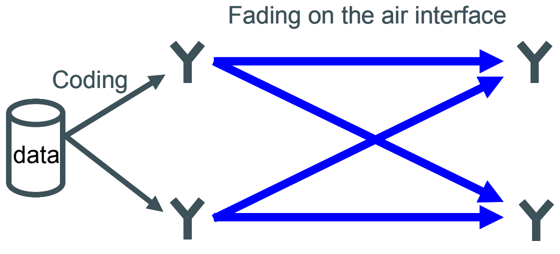

Fig. 3: Schematic of 2x2 MIMO.

This MIMO system can be implemented with either of the two following instrument setups:

- R&S®SMU200A for MIMO signals up to 3 GHz (section 4.1)
- R&S®AMU200A and R&S®SMATE200A for MIMO signals up to 6 GHz (section 4.2)

4.1 2x2 MIMO with SMU

Rohde & Schwarz offers a powerful one-box solution for testing 2x2 MIMO systems: The R&S®SMU200A vector signal generator equipped with two baseband generators and two RF paths provides realtime fading on all four propagation channels and is thus a stand-alone test solution for 2x2 MIMO.

Required options for the R&S® SMU200A (minimum instrument configuration):

- 1x R&S®SMU200A Vector signal generator
- 2x R&S®SMU-B11 Baseband generator (16 Msamples)
- 2x R&S®SMU-B13 Baseband main module
- 1x R&S®SMU-B14 Fading simulator
- 1x R&S®SMU-B15 Fading simulator extension
- 1x R&S®SMU-K74 MIMO fading
- 1x R&S®SMU-B103 Frequency range 100 kHz to 3 GHz, 1st path
- 1x R&S®SMU-B203 Frequency range 100 kHz to 3 GHz, 2nd path

4.1.1 Signal Routing

Configuring the SMU to simulate the four fading channels necessary for 2x2 MIMO is easily done by clicking on the Fading function block and selecting “2x2 MIMO” from the list (Fig. 4).

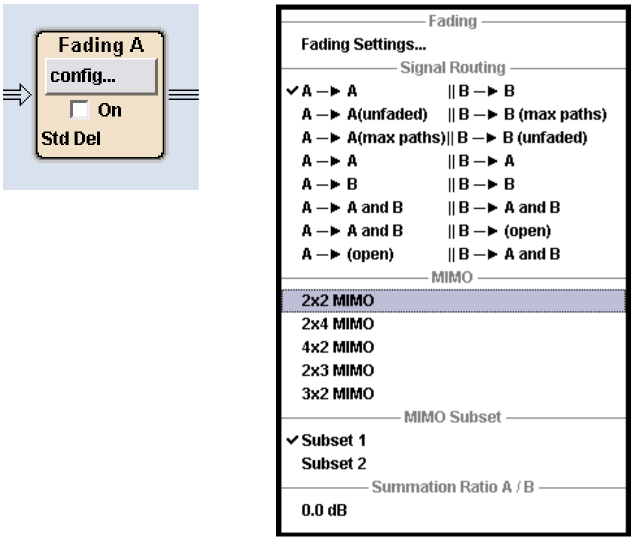

Fig. 4: Signal routing and MIMO options.

The SMU is automatically configured for 2x2 MIMO with the following signal routing representing the four fading channels (highlighted in colors for the sake of clarity):

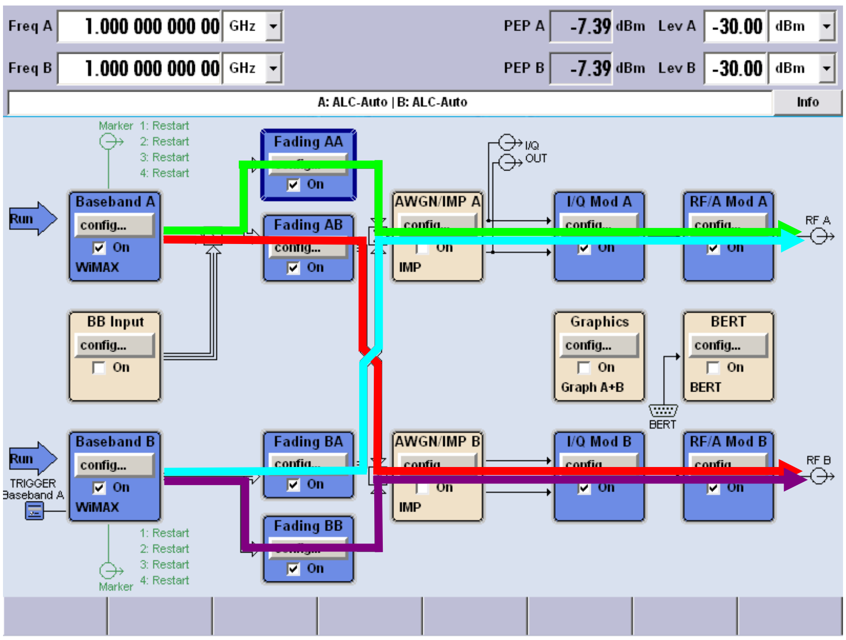

Fig. 5a: Signal routing of the SMU for 2x2 MIM

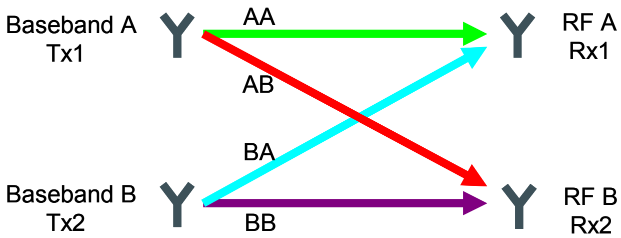

Fig. 5b: Schematic of the signal routing of the SMU for 2x2 MIMO.

4.1.2 Baseband Signal

As a key technology for the future, MIMO is intrinsic to many modern communications standards. Equipped with the internal options, the SMU supports MIMO precoding for the 3GPP LTE, WiMAX, WLAN 802.11n and HSPA+ standards. For these standards MIMO precoding as defined by the individual standards is implemented. MIMO Precoding is done in the baseband section of the instrument and means distributing the data onto the transmitters using spatial coding algorithms. The internal options for 3GPP LTE, WiMAX, WLAN 802.11n and HSPA+ make it possible to generate standard-compliant MIMO (and SISO) signals. Besides using the internal options, also custom-built baseband signals can be generated via the arbitrary waveform generator (ARB) of the instrument.

2x2 MIMO is implemented by setting up two transmitter signals in the baseband sections of the SMU; the signals differ in only a few parameters (see following subsections). Each of the two basebands acts as a transmit antenna. Baseband A represents the first antenna (Tx1) and baseband B represents the second antenna (Tx2). In order to start both baseband generators simultaneously, which is essential for MIMO, baseband B is triggered internally by baseband A. The trigger settings can be accessed via the Digital Standards menu by clicking the “Trigger/Marker” button.

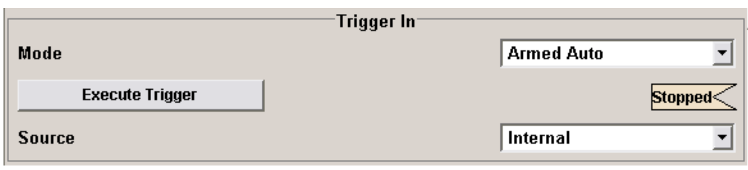

Fig. 6: Trigger settings for baseband A.

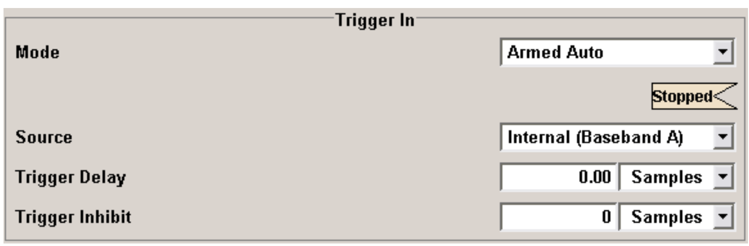

Fig. 7: Trigger settings for baseband B.

Both baseband generators are activated simultaneously by clicking the "Execute Trigger" button in baseband A.
Alternatively, an external trigger source can be used to start both baseband generators simultaneously. In this case, the trigger signal is connected to the TRIGGER 1 input connector of the SMU and the trigger settings of baseband A and baseband B are configured identically as shown in Fig. 8.

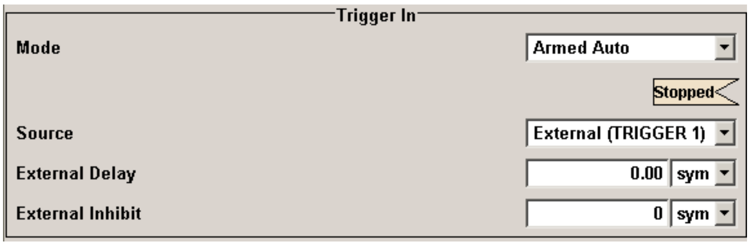

Fig. 8: Trigger settings for basebands A and B when using an external trigger signal.

4.1.2.1 LTE

An LTE signal for 2x2 MIMO is generated by making the following settings in the "General DL Settings" menu of baseband A: Global MIMO Configuration is set to "2 TxAntennas", Simulated Antenna Path A is set to "Antenna 1" and Simulated Antenna Path B is set to "Antenna 2" (Fig. 9). The Simulated Antenna Path B setting activates path coupling, and the appropriate configurations of baseband B are set automatically (i.e. the signal generated by baseband B will have identical parameters as specified for baseband A and the parameters of the downlink reference signal are set accordingly). Additionally, triggering is done automatically, i.e. if baseband A is activated both basebands start synchronously.

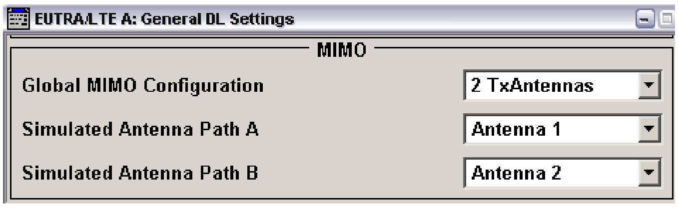

Fig. 9: LTE – MIMO settings for both instrument paths.

The precoding settings are configured in the following way: In the DL Frame Configuration menu, click on "Config…" in the Allocation Table to open the Enhanced Settings menu for the selected allocation, and then set the Precoding Scheme to "Spatial Multiplexing" (Fig. 10). (More details on how to configure the LTE baseband signal can be found in the application note "LTE Downlink MIMO (2x2) with R&S®SMU200A and R&S®FSQ" (1MA143).)

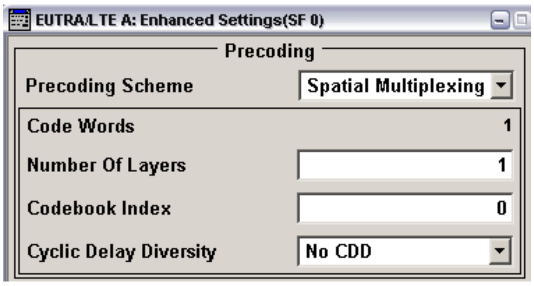

Fig. 10: LTE – Precoding setting for a single allocation.

4.1.2.2 HSPA+

An HSPA+ downlink signal for 2x2 MIMO is generated by making the following settings in baseband A: In the configuration menu of the selected base station (e.g. BS1), set the Diversity/MIMO parameter to “Antenna 1 Of 2”.

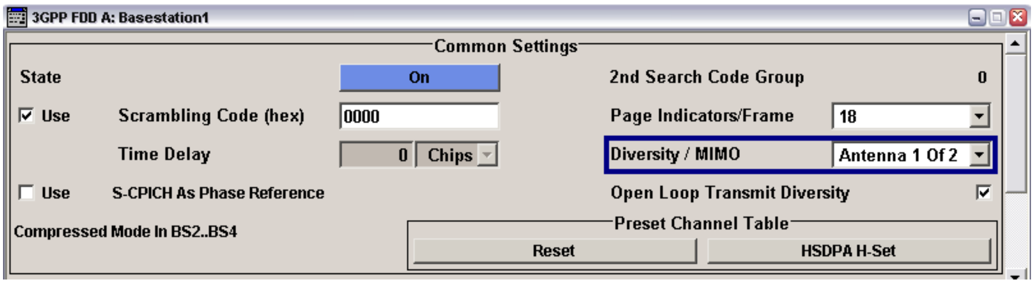

Fig. 11: HSPA+ – MIMO settings for baseband A.

A single MIMO channel with spatial multiplexing precoding can be created by selecting Channel Type “HS-PDS.MIMO”. Clicking on “Config…” in the Channel Table opens the Enhanced HSDPA Settings menu for the selected channel. Here, the precoding weight parameter w2 can be set. The weight parameters w1, w3 and w4 are automatically calculated.

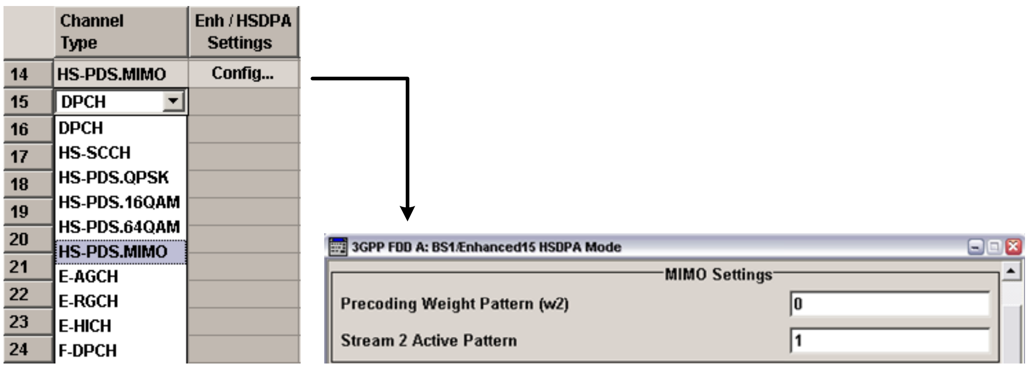

Fig. 12: HSPA+ – channel configuration for MIMO precoding.

MIMO channels with precoding and channel coding can be created by selecting Channel Type “HS-SCCH” and selecting HSDPA-Mode “H-Set” in the Enhanced HSDPA Settings menu (Fig. 13). The HS-SCCH Type must be set to “Type 3 (MIMO)”.

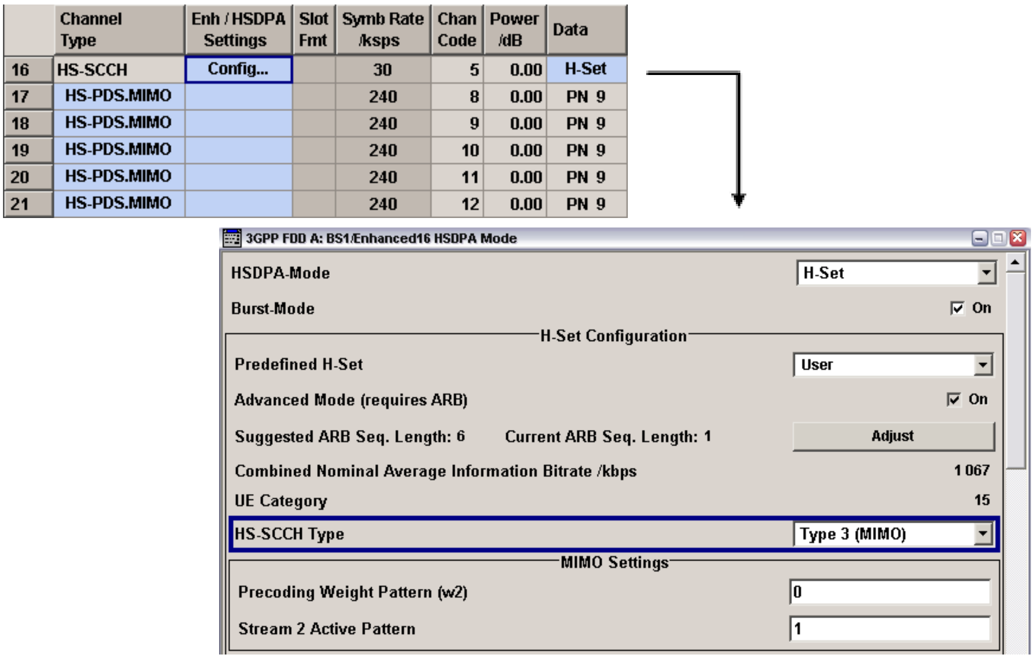

Fig. 13: HSPA+ – configuration of MIMO channels with precoding and channel coding.

The settings for baseband B are the same as for baseband A, except that the Diversity/MIMO parameter must be set to “Antenna 2 Of 2” in the configuration menu of the selected base station. For this digital standard, there is no path coupling available, but the settings of baseband A can be saved and then recalled from baseband B. Afterwards, only the Diversity/MIMO parameter needs to be adjusted.

4.1.2.3 WiMAX

2x2 MIMO for a WiMAX OFDMA signal is implemented by making the following settings in baseband A: The Space-Time Coding Mode is “2 Antennas, Matrix B” (coding algorithm for spatial multiplexing) and the Space-Time Coding Antenna is “Antenna 0”.

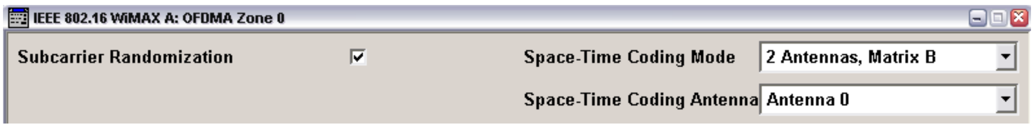

Fig. 14: WiMAX – MIMO settings for baseband A.

The submenu for making these settings (Fig. 14) can be called from the Digital Standards menu, i.e. the WiMAX menu, by clicking the “Frame Configuration” button and then clicking on “Config…” in the Zone Table. In order to simplify matters, baseband B is configured via baseband A by checking “Configure Baseband B from Baseband A” in the WiMAX menu.

Fig. 15: WiMAX – automatic configuration of baseband B.

This automatically sets the appropriate configurations for baseband B (i.e. baseband B will automatically run an identical configuration, but the Space-Time Coding Antenna is “Antenna 1” and the preamble is omitted). Additionally, triggering is done automatically – i.e. if baseband A is activated, both basebands start synchronously such that both basebands are aligned in time.

4.1.3 Fading Settings

Fading performance for 2x2 MIMO					
Fading channels	**Fading paths**	**Fading configuration**	**RF bandwidth**	**Time resolution**	**Required options**
4	10	Standard Delay	80 MHz	10 ns	K74
4	6	Fine Delay 30 MHz	30 MHz	0.01 ns	K74 & K71*
4	4	Fine Delay 50 MHz	50 MHz	0.01 ns	K74 & K71*

* fading option R&S® SMU-K71 (dynamic fading and enhanced time resolution)

Terminology:

- Fading channel:
  For 2x2 MIMO there are four fading channels between the transmit and the receive antennas.

- Fading path:
  Each fading channel consists of several fading paths. The number of fading paths within one fading channel depends on the fading configuration. For example, for the “Standard Delay” fading configuration, up to 10 different fading paths can be configured.

Note:
All four fading channels run with the same fading configuration (e.g. “Standard Delay”) and the same path configuration (e.g. up to 10 differently configured fading paths). The fading paths can be configured via each of the four fading function blocks and apply to all four fading channels.

Clicking on any of the fading function blocks and selecting “Fading Settings” opens the Fading menu [1] (Fig. 16).

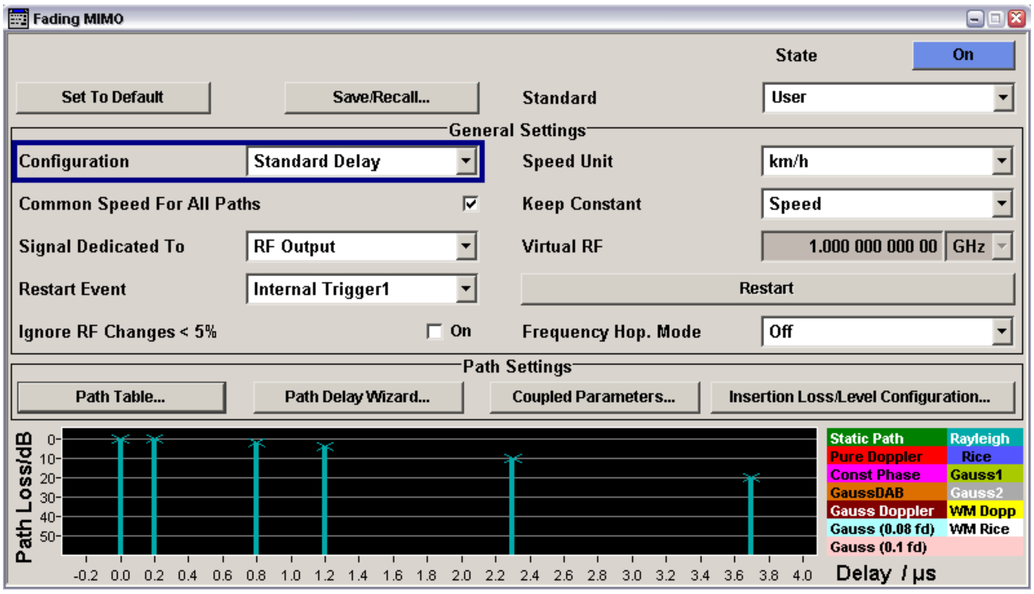

Fig. 16: Fading menu.

Here, the fading configuration can be set. Clicking the “Path Table” button opens a submenu for configuring the path settings.

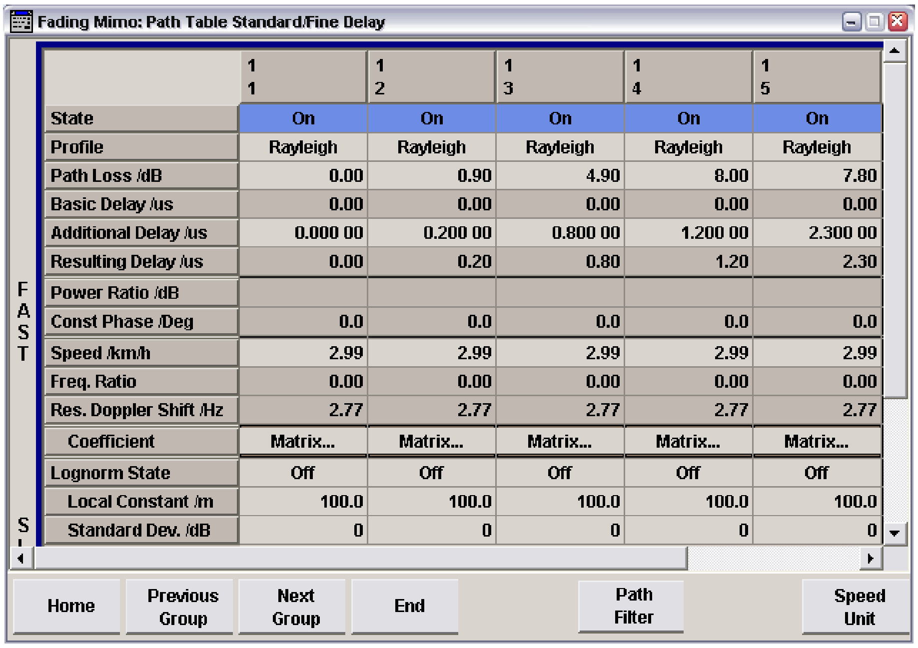

Fig. 17: Path table.

4.1.3.1 Correlation Matrix

In order to test MIMO receivers under real-world conditions, a certain degree of correlation between the fading channels has to be simulated. Channel correlation defines the coupling relationship between the signals transmitted over of the individual fading channels. This coupling is quantified in terms of a correlation matrix. For 2x2 MIMO this correlation matrix is a 4x4 matrix representing the coupling of the four fading channels (AA, AB, BA, BB).

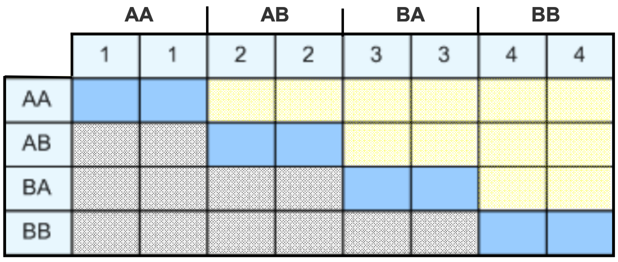

Fig. 18: Schematic of correlation matrix for 2x2 MIMO.

The correlation between two fading paths is defined by a complex correlation coefficient that is a measure for the similarity of the two signals. The complex correlation coefficient is expressed as a pair of numbers in either Cartesian form (Real-Imag) or polar form (Ratio-Phase). The polar form is more descriptive, since it directly gives the amplitude and phase relationship of the two signals. Perfect correlation means Ratio = 1.00 and Phase = 0.00, whereas Ratio = 0.00 and Phase = 0.00[1] means absolutely no correlation. In order to simulate ideal conditions for MIMO, i.e. no correlation between the fading channels, all correlation coefficients are set to zero except for the diagonal matrix elements which represent the correlation of one fading channel with itself. For real-world scenarios, the off-diagonal elements are set to nonzero values for simulating a certain degree of correlation between two individual fading channels. Fig. 19 illustrates graphically the effect of nonzero Ratio and Phase values. In simple terms, the more the values differ from Ratio = 0.00, the higher the correlation is and hence the less efficient the MIMO system is.

[1] In principle, for Ratio = 0 the Phase is not a definite value, i.e. it could be any arbitrary real value. If R = 0, it is common practice to define Phase = 0.

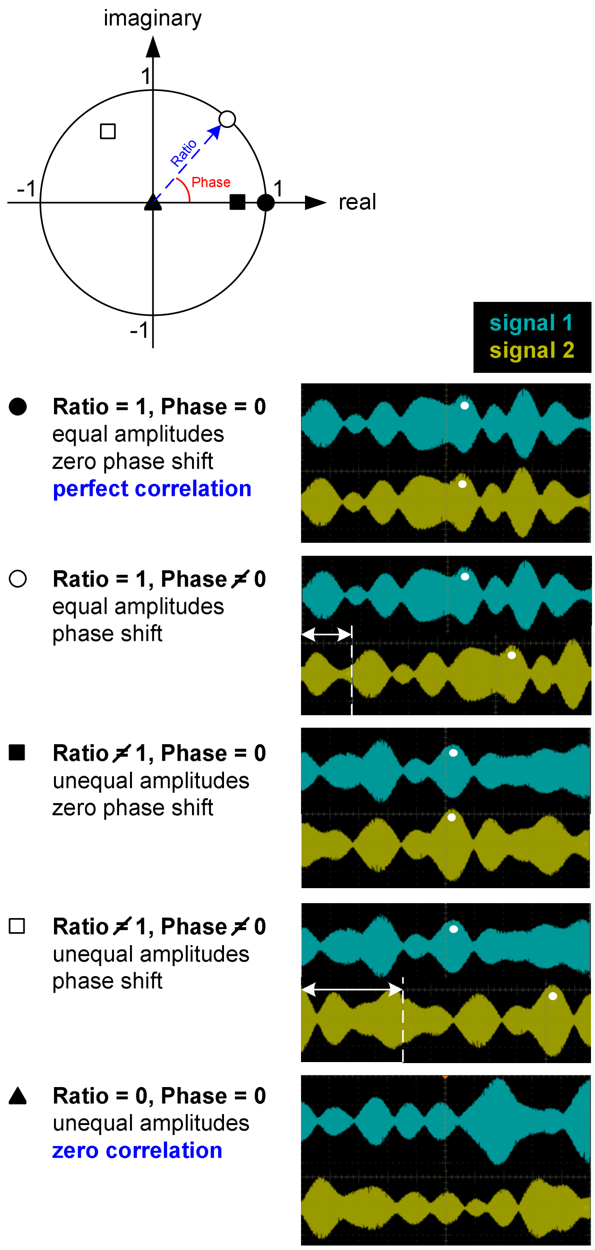

Fig. 19: Illustration of the complex correlation coefficient in polar form (Ratio and Phase). Five example correlation coefficients are depicted. The corresponding correlations between two test signals are shown.

For MIMO fading the Path Table includes a “Coefficient” row. Clicking the “Matrix” button opens the Correlation Matrix table. The correlation matrix can be defined individually for each fading path and applies to the selected path only.

The matrix entries for one path can be copied to the adjacent fading paths using the “Copy To Prev” or “Copy To Next” button.

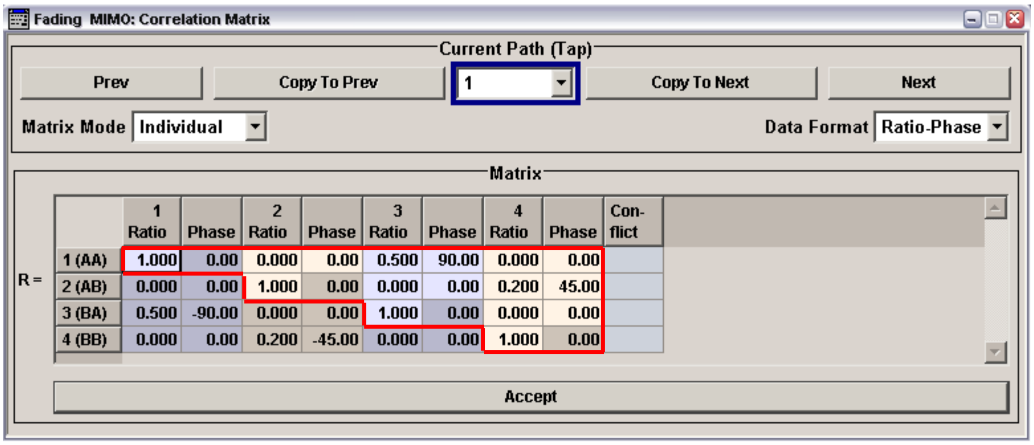

Fig. 20: Correlation matrix for 2x2 MIMO in Individual mode.

The user can choose between two Matrix Modes: Individual Mode and Kronecker Mode.

- Individual Mode:
  Basically, this mode allows the user to define the correlation coefficients. For example, the value of matrix element [BB,AB] describes the coupling between channels AB and BB. But the matrix structure is such that this coupling relationship is also described by the value of matrix element [AB,BB]. Thus, the value of matrix element [BB,AB] defines the value of matrix element [AB,BB] and vice versa, since both describe the coupling between channels AB and BB. As a consequence, only the matrix elements marked in red need to be set manually, as they already fully describe the correlations among the four fading channels (Fig. 20). The remaining matrix elements are determined automatically by exploiting the complex conjugate symmetry across the diagonal.

- Kronecker Mode:
  This mode is based on the Kronecker assumption of separable transmit and receive correlations. Using the Kronecker mode simplifies the configuration of the matrix. Only the Tx (transmitter) and Rx (receiver) correlation coefficients need to be specified. All matrix elements are automatically calculated on the basis of the entered values for Tx and Rx correlation. Setting a Tx correlation correlates the fading of path AA with BA as well as the fading of path AB with BB, i.e. the two transmitter signals Tx1 and Tx2 are faded in a correlated way (Fig. 22). Accordingly, setting an Rx correlation correlates the fading of path AA with AB as well as the fading of path BA with BB, i.e. the two receiver signals Rx1 and Rx2 exhibit the specified correlation (Fig. 23).

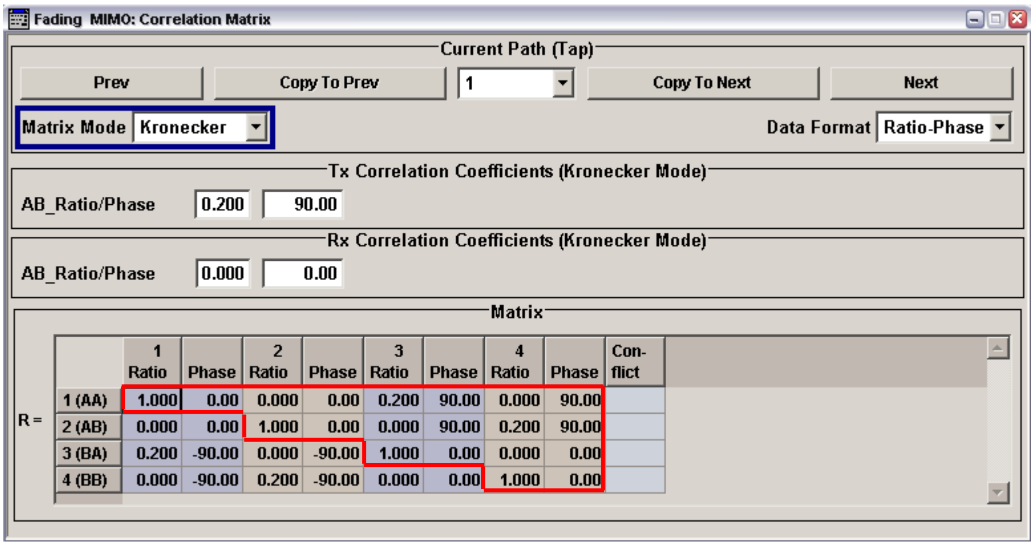

Fig. 21: Correlation matrix for 2x2 MIMO in Kronecker mode.

4.1.3.2 Correlation Matrix – Kronecker Mode

When using the Kronecker mode, a Tx correlation and an Rx correlation can be specified. For example, setting a Tx correlation coefficient of 1.00 (Ratio) means perfect correlation of the two transmitter signals. This case is shown in Fig. 22. The spectrum on the left corresponds to the signal at the first receiver (Rx1), while the spectrum on the right corresponds to the signal at the second receiver (Rx2). The spectra are snapshots of the Rx signals, both measured at the same point in time. In order to distinguish the two transmit signals (Tx1 and Tx2) in the spectrum, a frequency offset of 10 MHz has been applied to Tx2. Note that in real MIMO applications the two Tx signals are transmitted at the same center frequency. The frequency offset is just needed here for demonstration purposes. Fig. 22 shows that the two transmit signals are faded in a perfectly correlated way, while the two receiver signals differ (Rx correlation coefficient is set to 0.00).

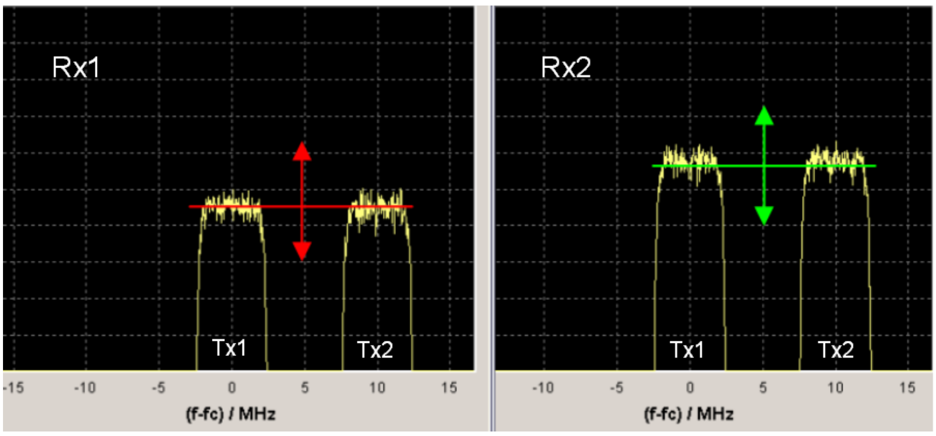

Fig. 22: Perfect Tx correlation.

For example, to simulate perfect Rx correlation and no Tx correlation, the Rx correlation coefficient is set to 1.00 (Ratio) and the Tx correlation coefficient is set to 0.00 (Ratio). This case is shown in Fig. 23. Now, Tx1 and Tx2 are faded independently, while the Rx signals are perfectly correlated.

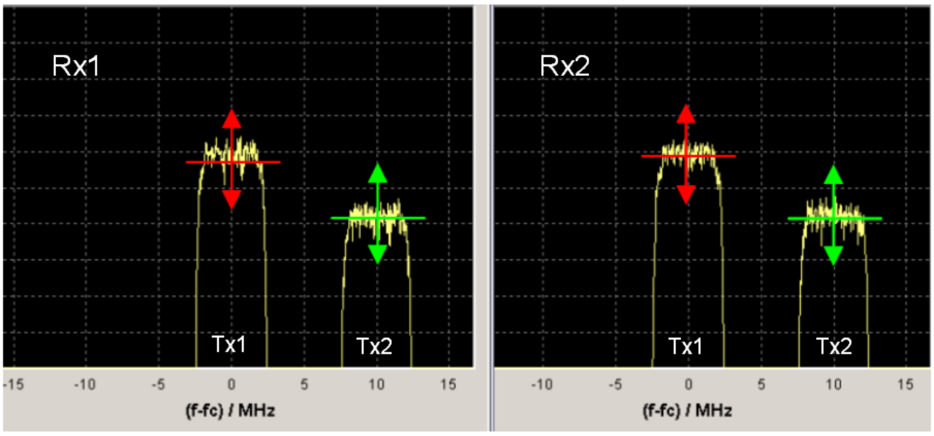

Fig. 23: Perfect Rx correlation.

4.1.3.3 Steering Matrix

In the correlation matrix, the off-diagonal matrix elements determine the correlations between the fading channels. In contrast, the diagonal matrix elements determine the power levels of the individual fading channels relative to each other. By default, all values of the diagonal matrix elements are set to Ratio = 1.00 to simulate equal power levels. By entering values smaller than Ratio = 1.00, it is possible to simulate antennas or channels with different power levels. Such a correlation matrix with diagonal elements different from Ratio = 1.00 is called a “steering matrix”. For example, reducing the power level of a fading channel or path can be used to simulate attenuation along this channel/path. Another example would be the simulation of a directed beam, i.e. simulating full signal strength along a specific direction (e.g. towards one receive antenna) while simulating low signal strengths elsewhere (e.g. towards the second receive antenna). Fig. 24 shows an example of simulating channels with different power levels by configuring the diagonal elements of the correlation matrix.

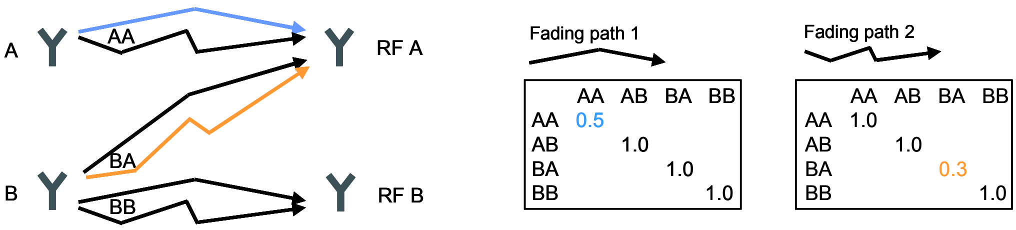

Fig. 24: Simulation of path attenuation via a steering matrix.

Fig. 24 shows three channels (for the sake of clarity, the fourth channel is not shown) with two fading paths each. In the correlation matrix of path 1, the diagonal element representing channel AA is set to Ratio = 0.5 to simulate signal attenuation along this individual path. Similarly, for path 2 the diagonal element representing channel BA is set to Ratio = 0.3 for simulating an even stronger signal attenuation along this individual path. Overall, this results in different power levels for the individual fading channels: The level of channel BB is highest, while the level of channel BA is lowest.

Information on how to calculate the resulting power levels of the two RF output signals (RF A, RF B) is given in section 4.1.6.

Note that it is possible to configure diagonal and off-diagonal elements of a correlation matrix at the same time. Setting the diagonal elements to values smaller than Ratio = 1.00 does not interfere with the channel correlations specified via the off-diagonal elements.

4.1.3.4 Predefined Fader Settings for Radio Standards

Besides the possibility of creating user-specified correlation matrixes, one can also choose from predefined fader settings that are in accordance with test scenarios stipulated in modern mobile radio standards. For example, ITU fading profiles defined for WiMAX, or EPA, EVA and ETU fading profiles defined for 3GPP LTE are supported, including the correlation between the MIMO fading channels.

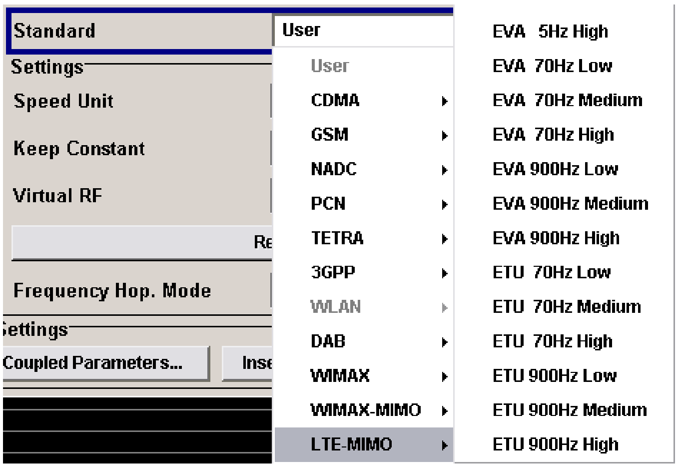

Fig. 25: Predefined fading profiles for digital standards.

A predefined fader setting for MIMO test cases is enabled by choosing e.g. “WiMAX-MIMO” or “LTE-MIMO” in the Fader menu. All fader settings including the correlation matrixes for the different fading paths are automatically configured in accordance with the selected test scenario.

4.1.4 Triggering

As already described in section 4.1.2, baseband A and baseband B have to be triggered simultaneously. There is more than one way of doing this.

- For example, baseband A is triggered manually and baseband B is triggered by baseband A.
- Or, baseband A and baseband B are both triggered externally.

The corresponding trigger settings are described in section 4.1.2.

The fader can either run in Auto mode ("non-stop" mode), or a restart can be triggered in the following ways:

- The fader can be triggered by baseband A (or B).
- Or, the fader can be triggered manually, i.e. independently of the basebands.

In the first case, the Restart Event is set to "Internal Trigger 1" in the Fading menu (Fig. 16); in the second case, the Restart Event is set to "Manual". It is advisable to trigger the fader via baseband A, since this will assure repeatable test conditions for measurements on devices under test.

4.1.5 AWGN

The signal generator allows noise to be superimposed on the faded MIMO signals. An additive white Gaussian noise (AWGN) signal with selectable system bandwidth can be added to the baseband signals after fading. For example, the AWGN signal can be used for simulating a certain signal-to-noise ratio at the receiver to test the receiver sensitivity.

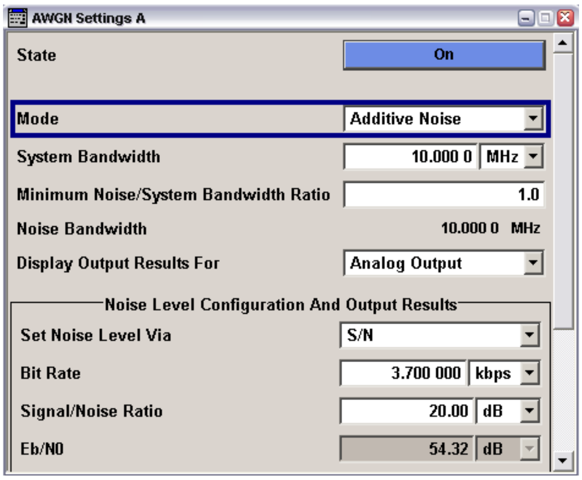

Fig. 26: AWGN Settings menu.

4.1.6 Leveling

The SMU actually combines two signal generators and four fading simulators all in one single instrument, which makes leveling of the output power straightforward.

The fading of the different channels is performed according to the specified correlation matrixes. As a consequence, the channel powers are coupled and so are the levels of the Rx signals. To maintain the correct power relationship of the Rx signals, the RF levels of both instrument paths A and B have to be set to the same value. For example, if the desired Rx level is –10 dBm, then the levels of RF A and RF B must both be set to –10 dBm in the header of the GUI display.

Fig. 27: Detail of the instrument GUI.

Of course, if fading is activated, the instantaneous power of the RF signal fluctuates in time. The set RF level denotes the average power of the faded signal. For example, if the level for RF A is set to –10 dBm, then the signal level of RF A will be –10 dBm when averaged over a longer period of time.

4.1.6.1 Steering Matrix

By default, the diagonal elements of the correlation matrixes are set to Ratio = 1.00, i.e. the simulated power levels of the individual fading paths are equal. However, some applications require the simulation of antennas with different power levels or the simulation of power offsets between individual fading channels, which is done by adjusting the diagonal elements of the correlation matrixes. Reducing the power of one transmit antenna, e.g. Tx1, relative to the other antenna influences the average power in channels AA and AB to the same degree. The average levels of the output signals RF A and RF B will thus be equal. In this case, the RF output levels equal the levels displayed in the header of the instrument GUI. This condition changes when power offsets between the fading channels are introduced via the correlation matrix. For example, reducing the average power of channel AB relative to the other channels will result in a lower average output level for RF B compared to RF A.

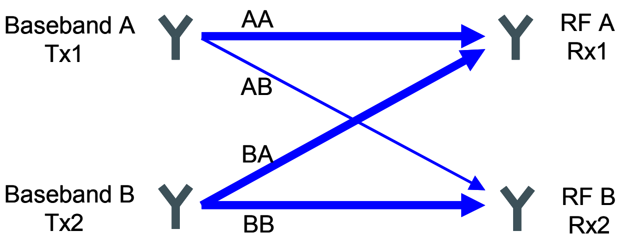

Fig. 28: Schematic of 2x2 MIMO with reduced channel power for fading channel AB.

In this case, one of the two displayed RF levels does not agree with the actual output level, in this example the displayed level for RF B. But the actual output level can be easily determined by means of a correction value that is automatically calculated. This power correction value can be looked up by clicking on the AWGN/IMP function block and selecting “Info” from the list.

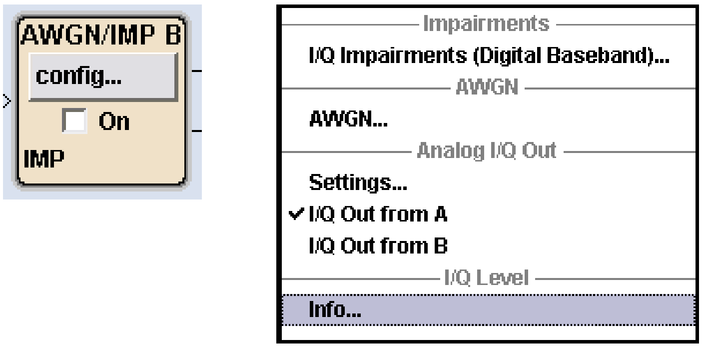

Fig. 29: I/Q Level Info option.

A submenu opens that displays the correction value for the selected instrument path A or B.

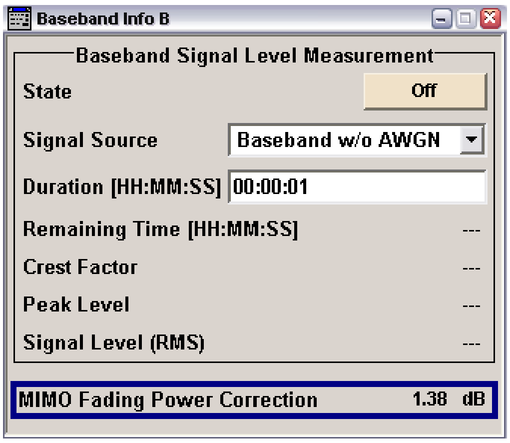

Fig. 30: I/Q Level Info menu.

The power correction value represents the power offset between the two output signals RF A and RF B. The actual output level of the RF signal is given by the RF level displayed in the header of the instrument minus the correction value. In our example, the displayed levels are –10 dBm for both signals RF A and RF B (note that it is essential to set the RF levels of both instrument paths A and B to the same value). The actual output level of RF A is –10 dBm. This corresponds to a correction value of 0.00 dBm. For signal RF B, the correction value is e.g. 1.38 dB due to the reduced average power of channel AB. Thus, the actual output level of RF B is –10 dBm – 1.38 dB = –11.38 dBm.

4.1.6.2 AWGN

The RF level displayed in the header of the GUI denotes the average level of the faded signal *without* AWGN. In case the noise generator is activated, the actual RF output level will be the sum of the set RF level and the specified noise level, i.e. the noise level adds to the nominal RF level.

4.1.6.3 RF Power Measurement

Due to the fading process and the resulting fluctuations in the RF signals, a power measurement can only give an approximation of the average RF level. However, in some cases it may be useful to measure the output power, e.g. to crosscheck if the instruments settings are made correctly and if the expected level is really output. The output power needs to be averaged over a certain period of time to obtain the average RF level. The necessary period of time strongly depends on the fading speed, i.e. the speed at which the fading processes are taking place. If the fading speed is very low, the output level will fluctuate very slowly. With a measurement duration of e.g. 1 min, only a momentary level can be detected. If the fading speed is very high, the output level will fluctuate very fast. Thus, it is possible to capture the full span of level variations within the same measurement duration. As a consequence, to keep the measurement time short the fading speed should be set to a high value during the level measurement. The fading speed can be set in the Path Table (Fig. 17) by configuring the row “Speed”. With a high fading speed, e.g. 1000 km/h, the necessary measurement time (minimum) is in the order of 1 min (empirical observation). In general, there is always a trade-off between measurement duration and accuracy of the measurement result.

Power Sensor
One way to measure the RF output level is to use an R&S®NRP-Z power senor, e.g. an R&S®NRP-Z51 (thermal sensor) or R&S®NRP-Z21 / NRP-Z21 (diode sensors). Due to signal fading, the measured level has to be averaged over a longer period of time to obtain the average RF power. The sensor uses a filter to average over the fluctuations in the measured signal. For the measurement, the filter length of this averaging filter has to be set to a sufficiently large value. As a result, the measurement time increases. The measurement time is given by two times the filter length multiplied by the sensor’s time window. For the mentioned sensors, this time window is 20 ms. To obtain a measurement time of more than 1 min, the filter length has to be set to 2048 or higher.

Test measurement:
The test signal is a single CW carrier. The RF level of path A is set to –10 dBm and an R&S®NRP-Z51 is directly connected to the RF A output connector. The length of the averaging filter is set to 2048 (Fig. 31). It takes 82 seconds for the measurement to complete ($2 \cdot 2048 \cdot 20$ ms = 82 s). After this period the displayed measurement result has roughly settled and the measurement reads –10 dBm, which is the approximate average power of the MIMO faded signal at the receiver (Rx1).

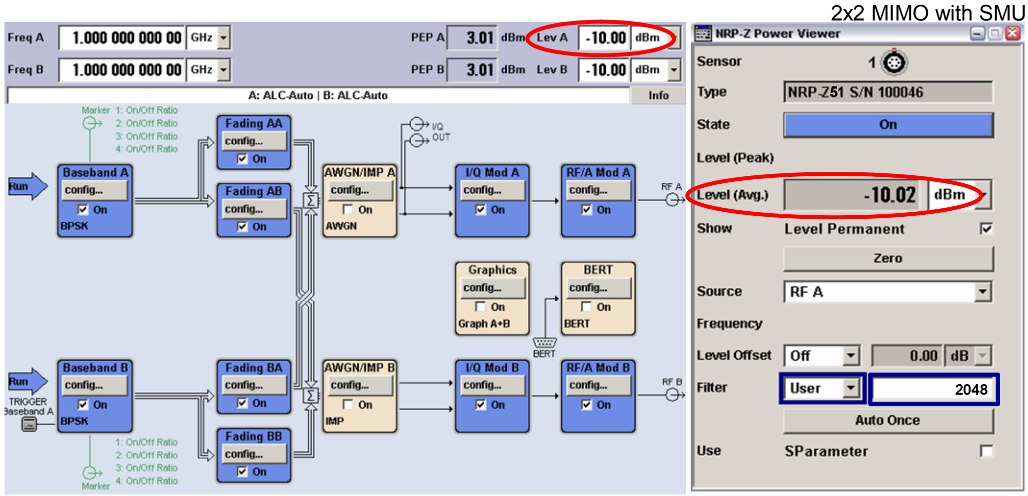

Fig. 31: Measurement of the average RF level of a faded test signal using an R&S®NRP-Z51 sensor.

Test measurement:
Instead of using the R&S®NRP-Z Power Viewer of the signal generator, the sensor can also be controlled and monitored using the external PC software Power Viewer Plus [2]. The test signal is a modulated signal at 5 Msymbol/s. The RF level of path A is set to –10 dBm and an R&S®NRP-Z21 is directly connected to the RF A output connector. The Power Viewer Plus software is used to set the length of the averaging filter to 1024 and to monitor the averaged sensor measurements (upper display in Fig. 32). In addition to the averaging performed by the sensor, the software can provide an averaged value deduced from the signal statistics. This means that the sensor measurements are recorded and a measurement statistic is evaluated (lower display in Fig. 32). Here, the number of samples that are used for evaluation is set to 5000. Due to signal fading, the sensor readings are spread over a level range with a certain distribution. The average reads –10.15 dBm in this example.

Fig. 32: Measurement of the average RF level of a faded test signal using the Power Viewer Plus software.

Note that a power sensor is not measuring frequency-selectively but detects all incoming power within its frequency measurement range.

Spectrum Analyzer

Another way to measure the RF output level is to use an spectrum analyzer from Rohde & Schwarz. Either a time domain power measurement (zero span) or a channel power measurement (frequency domain) can be performed. For both measurement types the following settings need to be made: The rms detector is chosen as trace detector and the sweep time is set to a sufficiently large value for averaging over a longer period of time. For the time domain power measurement, the resolution bandwidth (RBW) is set equal to or greater than the signal bandwidth to capture the full signal, while for the channel power measurement the Tx channel bandwidth is set equal to or greater than the signal bandwidth.

Test measurement:

The RF level of path A is set to –10 dBm and an R&S®FSQ is connected to the RF A output connector via a cable. The test signal has a bandwidth of 5 MHz. The RBW is set to 10 MHz to capture the full signal in a time domain power measurement. The sweep time is set to 10 s. The measured rms power is –10.5 dBm (Fig. 33).

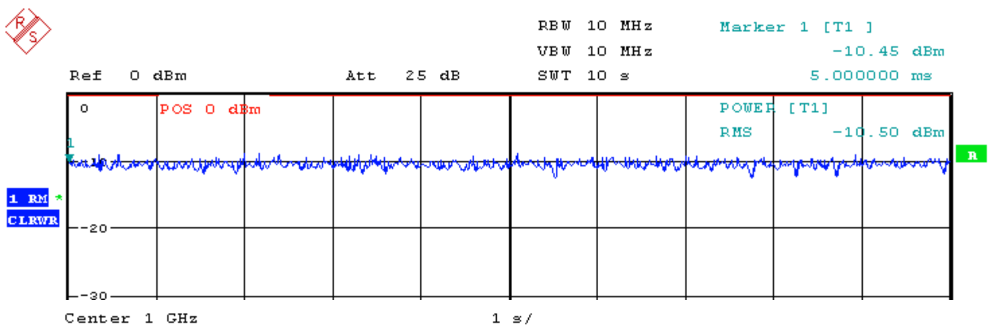

Fig. 33: Time domain power measurement of a faded test signal.

Test measurement:

The same setup and test signal as above are also used for a channel power measurement. The sweep time is again set to 10 s and the Tx channel bandwidth is set to 5 MHz. The measured channel power is –10.1 dBm (Fig. 34).

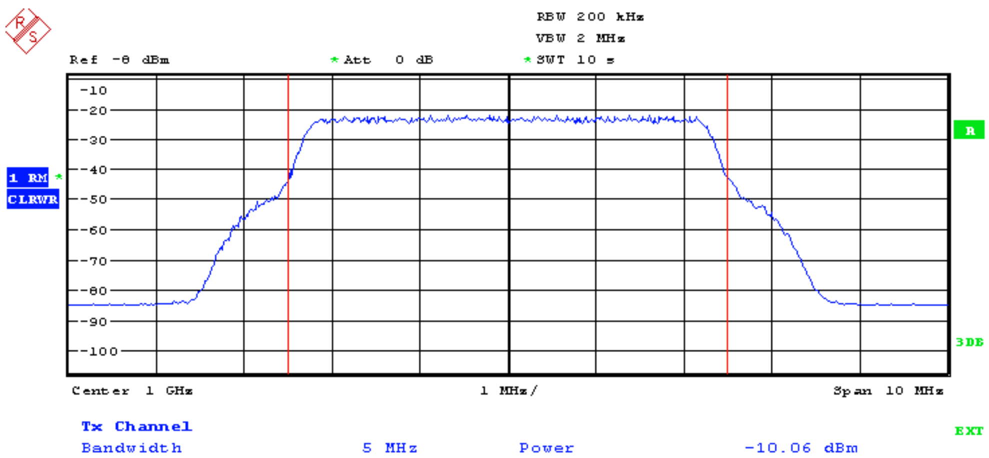

Fig. 34: Channel power measurement of a faded test signal.

A comparison of the results shows that the time domain power measurement differs slightly from the channel power measurement. However, both spectrum analyzer measurements give an indication of the average level of the MIMO faded signal at the receiver (Rx1).

4.1.7 Excursus: Measurement of the Baseband Signal Level

The SMU is able to measure the digital I/Q baseband signal internally. Information on the crest factor, the peak level, and rms level of the baseband signal can be obtained. The associated menu (Fig. 35) is opened by clicking on the AWGN/IMP function block and selecting “Info” from the list. The measured signal is the baseband signal *after fading* (with or without AWGN). Thus, the measurement duration needs to be chosen large enough to average over the faded signal amplitude.

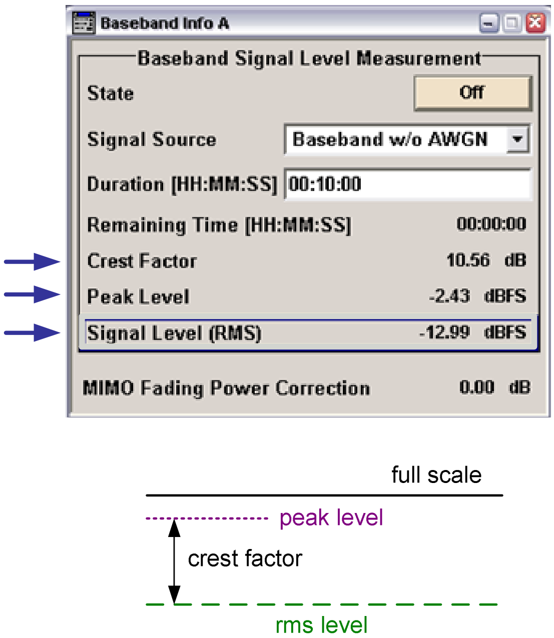

Fig. 35: I/Q Level Info menu together with an illustration of the displayed parameters.

The measured peak level and the rms level of the faded baseband signal are given relative to full scale (0.5 V). The crest factor of the signal is calculated from the two measured level parameters as follows:

Crest Factor [dB] = Peak Level [dBFs] – Signal Level (RMS) [dBFs].

4.2 2x2 MIMO with AMU & SMATE

The SMU is a stand-alone solution comprising internal baseband signal generation, realtime 2x2 MIMO fading and up-conversion to the RF for frequencies up to 3 GHz. An alternative solution is the AMU baseband signal generator and fading simulator in combination with the SMATE vector signal generator. For the following applications, the AMU is the instrument of choice:

- Pure baseband signals
  For applications where no RF is required, the AMU is a one-box solution offering I/Q outputs for both instrument paths A and B.

- RF up to 6 GHz
  For applications requiring RF frequencies up to 6 GHz such as for WLAN 802.11n or WiMAX, a combination of the AMU and SMATE is used. The AMU generates the baseband signal and provides MIMO fading (option AMU-K74). The SMATE merely serves as an up-converter to radio frequencies (option SMATE-B106 and SMATE-B206). Instead of one SMATE, two R&S®SMBV vector signal generators can be used for up-conversion. Please see section 8 for details.

- External I/Q signals
  In contrast to the SMU, the AMU allows external analog or digital I/Q signals to be fed in for *both* instrument paths A and B (2x option AMU-B17). A SMATE can be used for up-conversion of the signals.

Required options for the R&S®AMU200A and the R&S®SMATE200A (minimum instrument configuration):

- 1x R&S®AMU200A — Baseband signal generator
- 2x R&S®AMU-B11 — Baseband generator (16 Msamples)
- 2x R&S®AMU-B13 — Baseband main module
- 1x R&S®AMU-B14 — Fading simulator
- 1x R&S®AMU-B15 — Fading simulator extension
- 1x R&S®AMU-K74 — MIMO fading

- 1x R&S®SMATE200A — Vector signal generator
- 1x R&S®SMATE-B106 — Frequency range 100 kHz to 6 GHz, 1st path
- 1x R&S®SMATE-B206 — Frequency range 100 kHz to 6 GHz, 2nd path

4.2.1 Signal Routing (AMU)

Like the SMU, the AMU is automatically configured for 2x2 MIMO by selecting "2x2 MIMO" in the Fader function block. The signal routing is analogous to the SMU and represents the four fading channels (highlighted in colors for the sake of clarity):

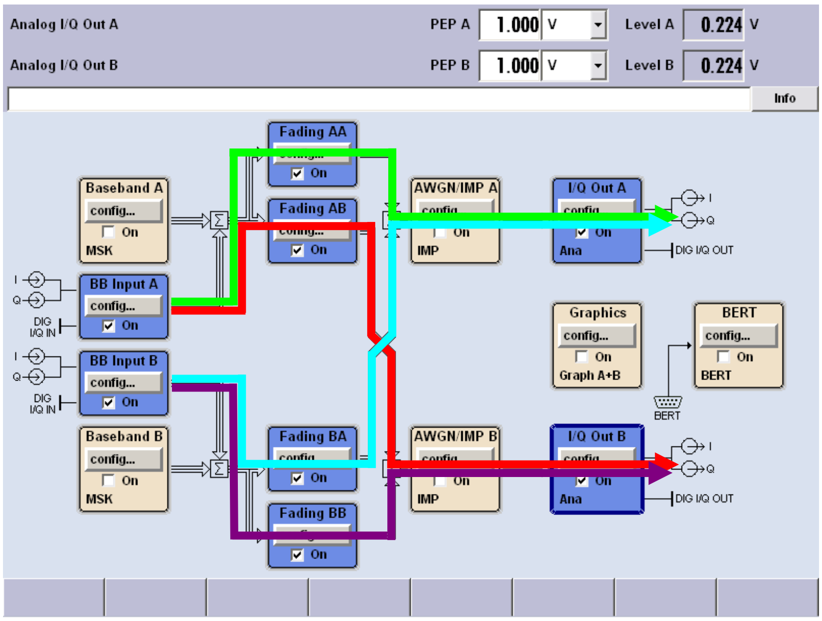

Fig. 36a: Signal routing of the AMU for 2x2 MIMO.

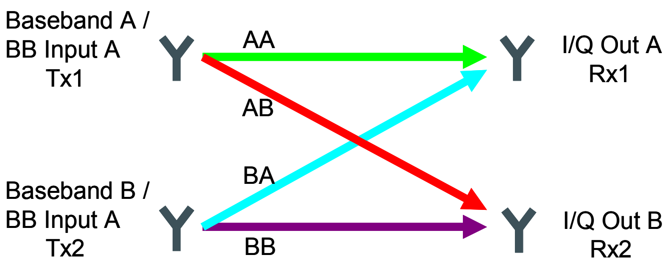

Fig. 36b: Schematic of the signal routing of the AMU for 2x2 MIMO.

4.2.2 Signal Up-Conversion (AMU & SMATE)

With the SMATE, the MIMO faded I/Q output signals of the AMU can be up-converted to radio frequencies of up to 6 GHz. For this setup the analog I and Q outputs of the AMU are connected to the analog I and Q inputs of the SMATE for instrument paths A and B, respectively (Fig. 37).

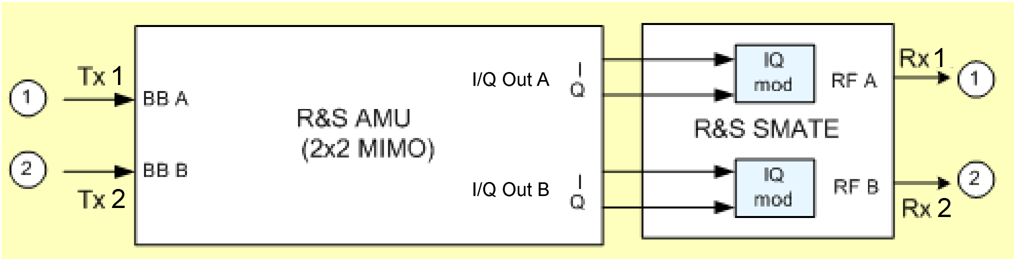

Fig. 37: Instrument setup for 2x2 MIMO with the AMU and SMATE.

For connecting the two instruments, four cables are needed. The cables should have the same length and type.

4.2.3 Baseband Signal (AMU)

Baseband signals are generated via the Baseband function blocks in precisely the same way as described for the SMU.

An alternative to internal signal generation is to apply external baseband signals. For 2x2 MIMO, two pairs of I and Q signals (analog or digital) have to be supplied. In this case, the two BB Input function blocks represent the two transmit antennas. Essential for MIMO is to start both external baseband sources simultaneously.

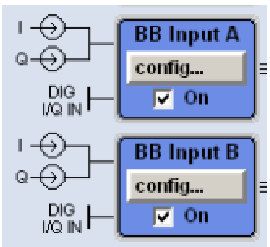

Fig. 38: Input option for external baseband signals.

4.2.4 Fading Settings and AWGN (AMU)

The fading settings for the AMU are made completely analogous to those for the SMU, as the fader functionality is identical for both instruments.

The same applies to the AWGN option, which is nearly identical for the AMU and SMU.

4.2.5 Leveling (AMU and SMATE)

To obtain correct signal leveling at the RF outputs of the SMATE, the instrument settings of the two generators have to be coordinated. The SMATE expects a peak voltage of 0.5 V at the analog I and Q inputs. The correct settings for the analog I/Q outputs of the AMU are shown in the table below and in Fig. 39.

AMU	
Analog I/Q Output Settings	
I/Q Output Type	Single Ended
Load Type	50 Ohm
Set Level Via	PEP
Pep Vp	0.500 V

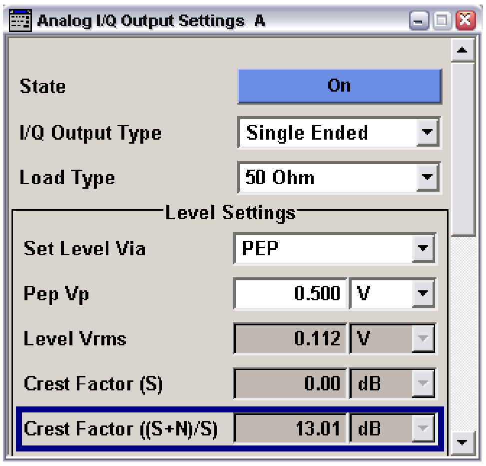

Fig. 39: Analog I/Q Output Settings menu of the AMU.

Due to the fading process, the crest factor of the baseband signal increases. The Analog I/Q Output Settings menu (Fig. 39) shows the inherent crest factor of the baseband signal (Crest Factor (S)) as well as the crest factor of the signal after fading including noise (Crest Factor ((S+N)/S)). The crest factor "Crest Factor ((S+N)/S)" displayed on the AMU needs to be entered into the input field "Crest Factor" of the I/Q Settings menu of the SMATE. The correct settings for the SMATE are shown in the table below and in Fig. 40.

SMATE	
I/Q Settings	
Source	Analog Wideband I/Q Input
Crest Factor	Crest Factor ((S+N)/S) of the input signal

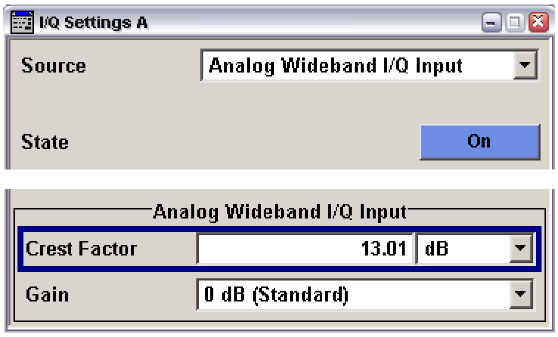

Fig. 40: I/Q Settings menu of the SMATE.

With these instrument settings for the AMU and the SMATE, the average power level at the RF outputs of the SMATE will agree with the level displayed in the header of the SMATE's instrument GUI. Of course, these settings have to be made for both instrument paths of each instrument.

In the AMU, the fading of the different channels is performed according to the specified correlation matrixes. As a consequence, the channel powers are coupled and so are the levels of the up-converted signals Rx1 and Rx2. To maintain the correct power relationship of the Rx signals, the RF levels of both instrument paths A and B (SMATE) have to be set to the same value, i.e. the level of RF A and RF B are both set to e.g. –10 dBm.

4.2.5.1 Steering Matrix

When using a steering matrix, a power correction value has to be taken into account for determining the actual power levels of the Rx signals. The actual RF levels are calculated in precisely the same way as described for the SMU in section 4.1.6.1.

4.2.5.2 AWGN

The RF level displayed in the header of the SMATE's instrument GUI denotes the average level of the faded signal *without* AWGN. If the noise generator of the AMU is activated, the specified noise level will add to the set RF level. Note that the crest factor indicated in the Analog I/Q Output Settings menu (Fig. 39) changes when AWGN is activated. Thus, the crest factor entry in the I/Q Settings menu of the SMATE (Fig. 40) needs to be adjusted accordingly.

4.2.5.3 External Baseband Input

For correct internal signal processing, the crest factor and the peak power of the external baseband signal have to be known. The values can be entered via the Baseband Input Settings menu (Fig. 41) called from the BB Input function block by clicking "Baseband Input Settings".

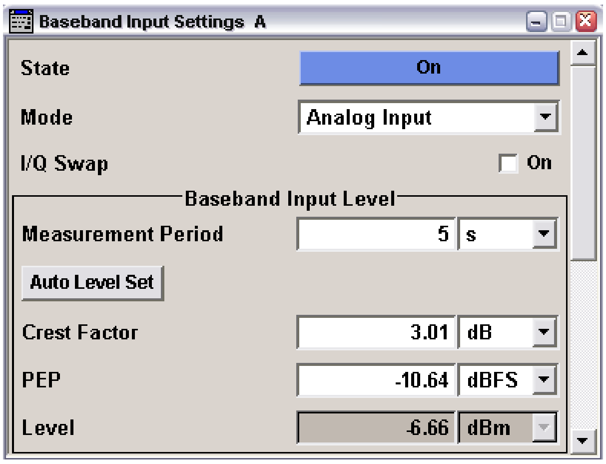

Fig. 41: Baseband Input Settings menu.

The crest factor and the peak power of the external baseband signal can also be determined automatically by an internal measurement. The measurement is started by clicking the “Auto Level Set” button. The measurement estimates the crest factor, the peak power (PEP) and RMS power (Level) of the input signal. The measured values are automatically entered into the corresponding input fields. Using these estimated values, the internal gain control adjusts the input signal gain to achieve an optimal dynamic range. In summary, achieving correct signal leveling with external baseband signals requires only one measurement for each baseband source (A, B) with an appropriate measurement time. In other words, the “Auto Level Set” button must be clicked once per baseband source (A, B).

4.2.6 Excursus: Measurement of the Baseband Signal Level

The AMU is able to measure the digital I/Q baseband signal internally. Information on the crest factor, the peak level, and RMS level of the baseband signal can be obtained. The associated menu (left-hand side of Fig. 42) is opened by clicking on the AWGN/IMP function block and selecting “Info” from the list. The measured signal is the baseband signal *after fading* (with or without AWGN). Thus, the measurement duration needs to be chosen large enough to average over the faded signal amplitude.

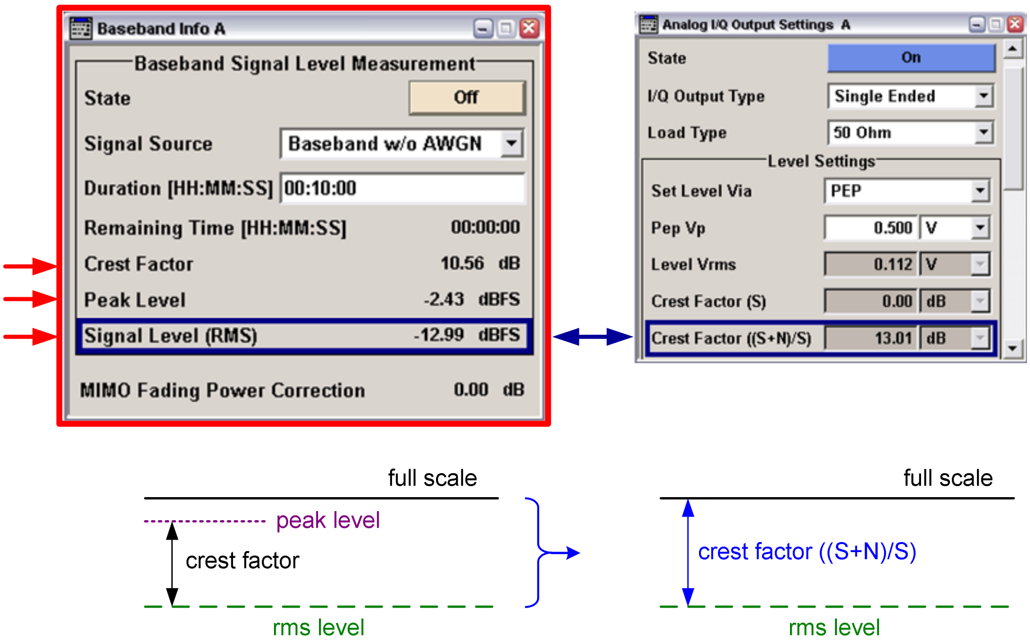

Fig. 42: I/Q Level Info menu (left) and Analog I/Q Output Settings menu (right) together with an illustration of the displayed parameters.

The measured peak level and the RMS level of the faded baseband signal are given relative to full scale (0.5 V). The crest factor of the signal is calculated from the two measured level parameters as follows:

Crest Factor [dB] = Peak Level [dBFs] – Signal Level (RMS) [dBFs].

In contrast, the parameter “Crest Factor ((S+N)/S)” given in the Analog I/Q Output Settings menu (right-hand side of Fig. 42) directly relates to full scale. It gives the level difference in units of dB between the full scale level and the RMS level of the faded baseband signal.

Crest Factor ((S+N)/S) [dB] = 0 dBFs – RMS signal level [dBFs].

5 4x2 MIMO

A 4x2 MIMO system consists of four transmit and two receive antennas. This antenna configuration involves eight fading channels.

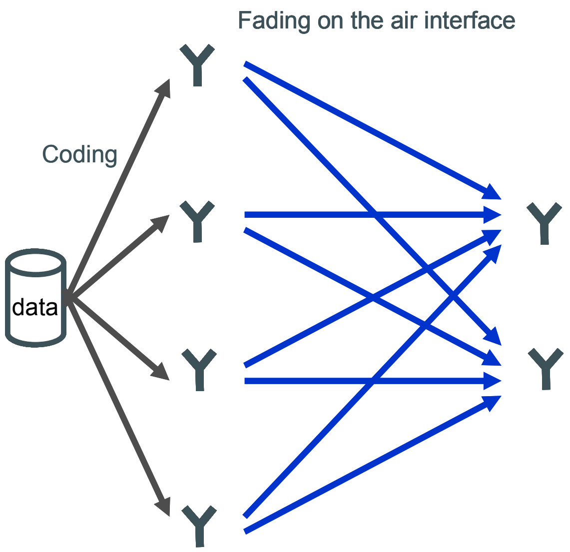

Fig. 43: Schematic of 4x2 MIMO.

This MIMO system can be implemented with either of the two following instrument setups:

- Two SMU signal generators for MIMO signals up to 3 GHz (section 5.1)
- Two AMU signal generators and one SMATE signal generator for MIMO signals up to 6 GHz (section 5.2)

5.1 4x2 MIMO with Two SMUs

The SMU has already been introduced as a stand-alone test solution for 2x2 MIMO. For testing 4x2 MIMO systems up to 3 GHz, a combination of two SMUs is used, offering realtime fading on all eight propagation channels.

5.1.1 Setup and Signal Routing

The two SMUs are configured for 4x2 MIMO by selecting “4x2 MIMO” in the Fader function block of both instruments. For one SMU MIMO Subset 1 is selected, while for the second SMU MIMO Subset 2 is selected (Fig. 44). The MIMO subset defines which fading channels are simulated by the instrument.

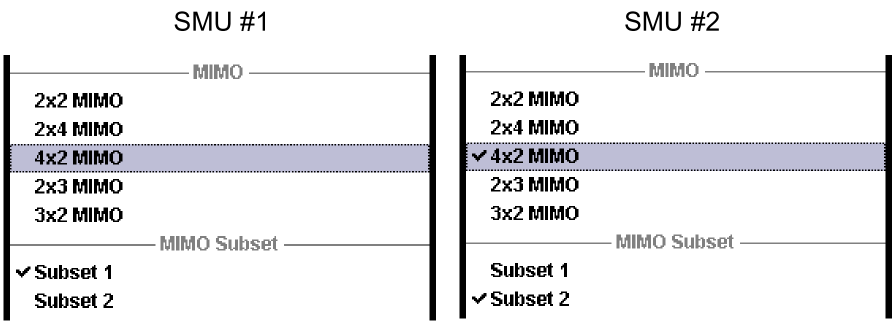

Fig. 44: 4x2 MIMO with different subsets for SMU #1 and #2.

The signal routing of the two instruments is shown in Fig. 45. The eight different fading channels are highlighted in colors for the sake of clarity. The RF A outputs of both instruments have to be connected to an external RF combiner. In the same way, the RF B outputs of both SMUs are connected to a second external RF combiner. The output signals of the two combiners correspond to Rx1 and Rx2, respectively.

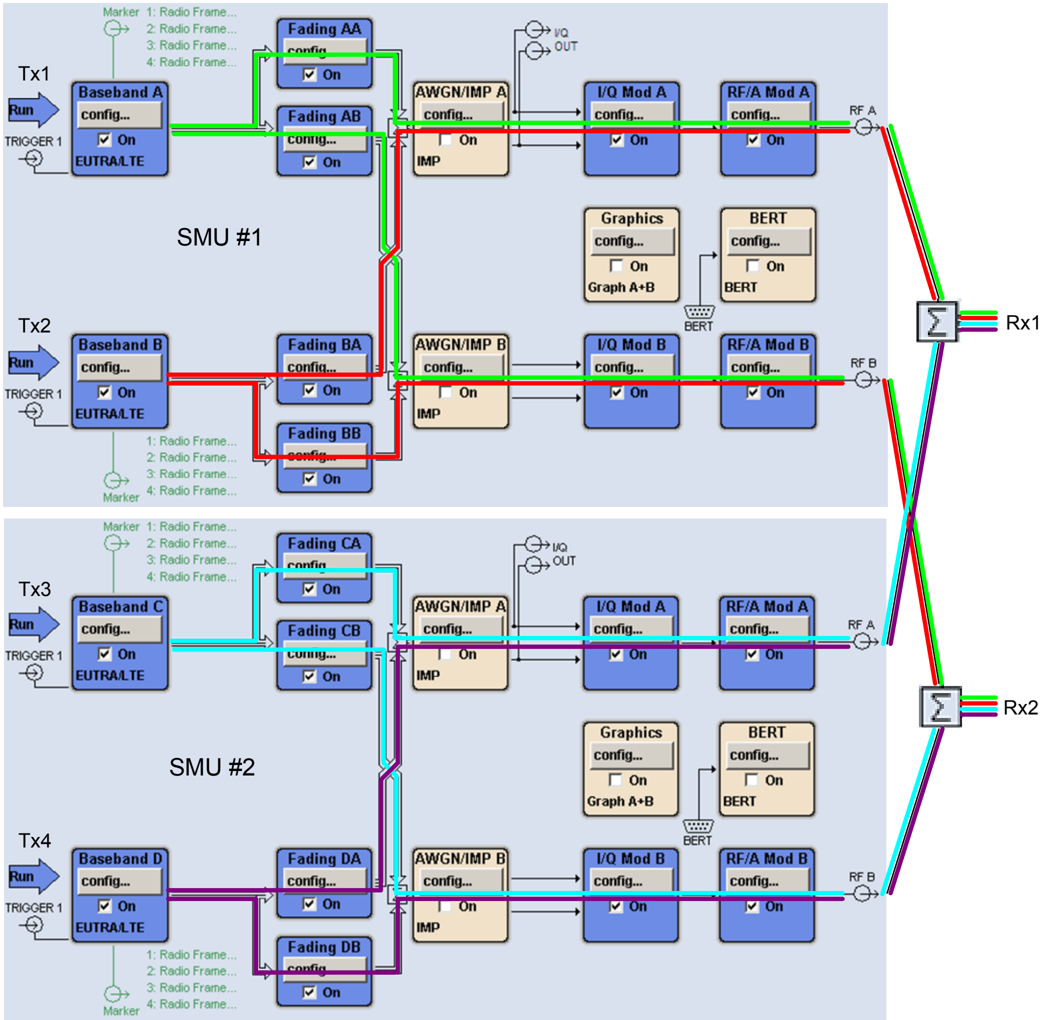

Fig. 45a: Signal routing of the two SMUs for 4x2 MIMO.

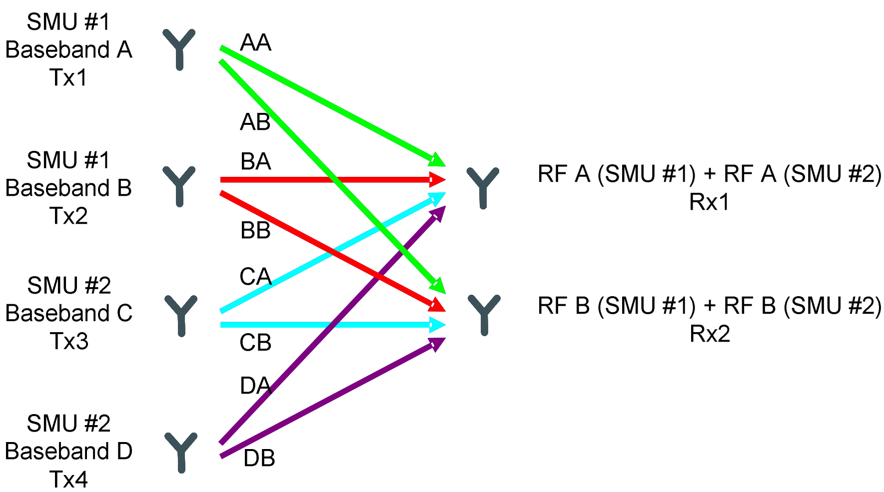

Fig. 45b: Schematic of the signal routing of the two SMUs for 4x2 MIMO.

In MIMO mode 4x2, each generator calculates the fading processes for all eight channels. Although only four fading channels are simulated per SMU, this is necessary in order to determine the correlations. A common 10 MHz reference signal is crucial to ensure the synchronization of the generators. Another requirement is a common external trigger, which defines a common starting point for baseband signal generation and for the calculation of the fading processes (see section 5.1.1.2 for details).

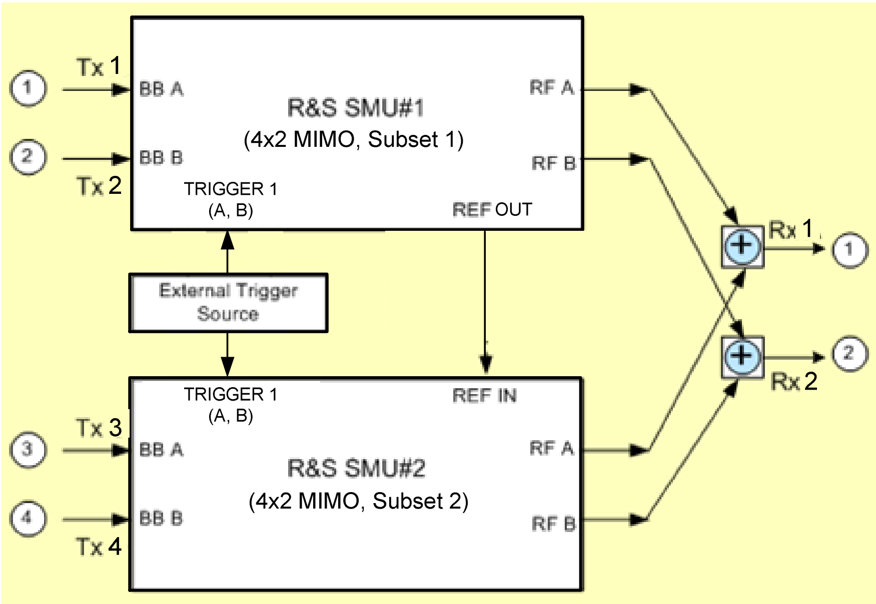

Fig. 46: Instrument setup for 4x2 MIMO with two SMUs.

The following table summarizes the equipment needed for simulating 4x2 MIMO systems up to 3 GHz.

4x2 MIMO up to 3 GHz	
Required equipment	
Instruments	**Additional equipment**
2x SMU*	2x standard RF combiner
	external trigger source
	connecting cables

* each instrument with options as listed in section 4.1

The cables should have the same length and type concerning the trigger connections, the 10 MHz reference connections, and the connections between the RF outputs and the combiners. Unnecessary cable lengths and branching points should be avoided.

5.1.1.1 Common Reference Signal

To synchronize the two generators, a common reference oscillator is crucial. A common 10 MHz reference signal is provided by connecting the output REF OUT of the first instrument (i.e. SMU #1) to the input REF IN of the second instrument (i.e. SMU #2). The Reference Oscillator settings of the instruments need to be configured in the following way: For SMU #1 select the internal source, and for SMU #2 select an external source (10 MHz and wide synchronization bandwidth).

SMU #1 SMU #2

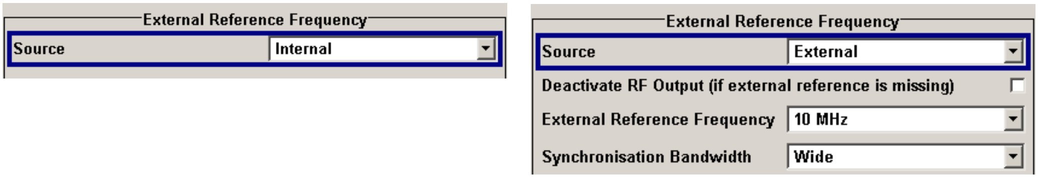

Fig. 47: Reference Oscillator settings for SMU #1 and #2.

Optionally, an external reference source can be used to provide the reference signal for both instruments. In this case, the inputs REF IN of both instruments are connected to the external reference source. Both instruments have the same Reference Oscillator settings: For SMU #1 and SMU #2 an external source is selected, and the External Reference Frequency and the Synchronization Bandwidth are configured accordingly.

5.1.1.2 Common Trigger

A common external trigger is required to provide a common starting point for generating the baseband signals and calculating the fading processes. Therefore, the TRIGGER 1 inputs of both instruments are connected to an external trigger source. All four baseband generators (Tx1 to Tx4) must be triggered simultaneously by this external source (Fig. 48). In the Trigger/Marker/Clock menu of each baseband, the Trigger In Source is set to “External (TRIGGER 1)”.

Baseband

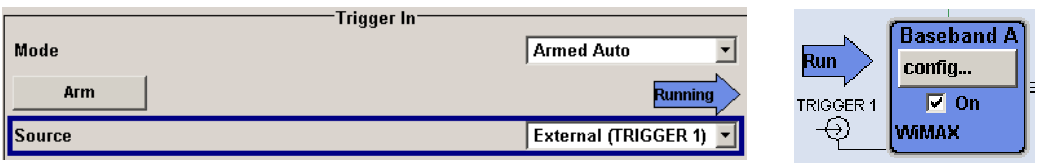

Fig. 48: Trigger settings for the basebands.

It is essential that the faders of the two instruments are also synchronized. A common starting point is provided by selecting the Restart Event to be “Internal Trigger1” in the Fader menu of both instruments (Fig. 49). This means that a restart is triggered by baseband A (of each SMU) and, as a result, the calculation of the fading processes starts synchronously in both instruments (Fig. 50).

Fig. 49: Fader setting for synchronization of the two instruments.

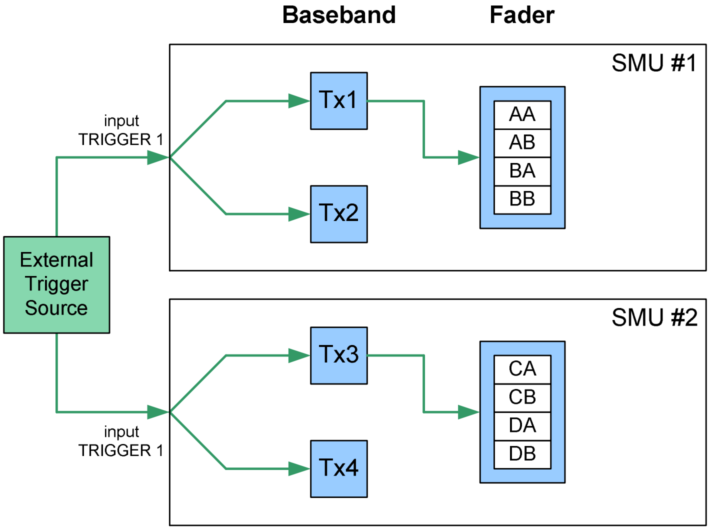

Fig. 50: External trigger for synchronous start of the basebands and the faders of both instruments.

5.1.2 Baseband Signal

4x2 MIMO is implemented by setting up four Tx signals, which differ in only a few parameters (see following subsections). Here, it may be useful to use the Save/Recall functionality of the baseband section to save the settings made for one baseband and recall them for the other basebands. The settings file is transferred from one instrument to the second instrument via a USB stick, an external USB HDD, or a LAN connection. For 4x2 MIMO with data precoding, each of the four baseband generators needs to be assigned to one of the four different transmit antennas for generating the signal of one dedicated antenna (see following subsections). All four baseband generators have to be started simultaneously using an external trigger signal. Thus, for all basebands the Trigger/Marker menu of the selected digital standard needs to be configured accordingly (Fig. 48).

5.1.2.1 LTE

An LTE signal for 4x2 MIMO is generated by setting the Global MIMO Configuration to “4 TxAntennas” in the General DL Settings menus of both instruments. For SMU #1 the Simulated Antenna Path A is “Antenna 1” and the Simulated Antenna Path B is “Antenna 2”. This activates path coupling, and the appropriate configurations of the coupled baseband are set automatically. For SMU #2 the Simulated Antenna Path A is “Antenna 3” and the Simulated Antenna Path B is “Antenna 4”.

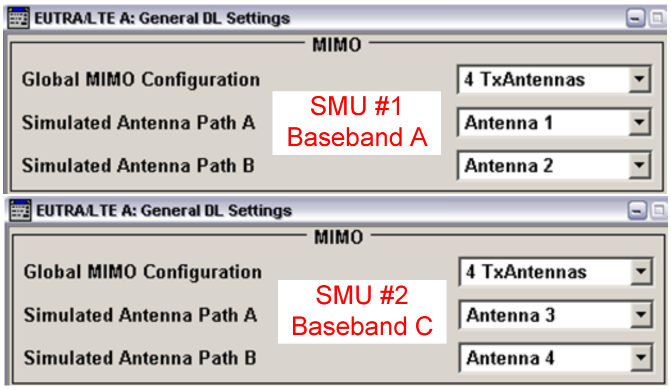

Fig. 51: LTE – MIMO settings for baseband A and baseband C.

The precoding settings are configured in the following way: In the DL Frame Configuration menus of both instruments, click on “Config…” in the Allocation Table to open the Enhanced Settings menu for the selected allocation. Set the Precoding Scheme to “Spatial Multiplexing”. (More details on how to configure a LTE baseband signal can be found in the application note “LTE Downlink MIMO (2x2) with R&S®SMU200A and R&S®FSQ” (1MA143).)

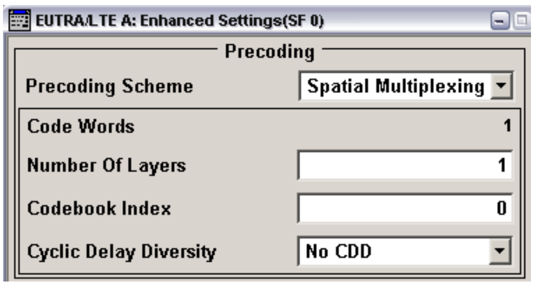

Fig. 52: LTE – Precoding setting for a single allocation.

5.1.2.2 WiMAX

4x2 MIMO for a WiMAX OFDMA signal is implemented by setting the Space-Time Coding Mode of both instruments to “4 Antennas, Matrix B” (coding algorithm for spatial multiplexing). For baseband A, the Space-Time Coding Antenna is “Antenna 0” and for baseband C, it is “Antenna 2” (Fig. 53). The submenus for making these settings are called from the WiMAX menus by clicking the “Frame Configuration” button and then clicking on “Config…” in the Zone Tables. Basebands B and D are configured via basebands A and C, respectively, by checking “Configure Baseband B from Baseband A” in the WiMAX menus (Fig. 54). This automatically sets the appropriate configurations for basebands B and D. Baseband B will automatically be assigned to “Antenna 1” and baseband D to “Antenna 3”. In the WiMAX menus of both instruments, the setting for the Level Reference has to be changed from “Preamble” (default) to “Subframe RMS Power w/o Preamble” (Fig. 54). This is necessary to ensure that the RF output levels of the two instruments match.

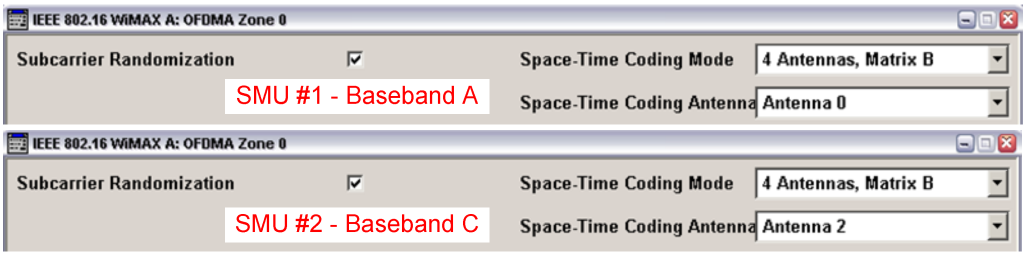

Fig. 53: WiMAX – MIMO settings for baseband A and baseband C.

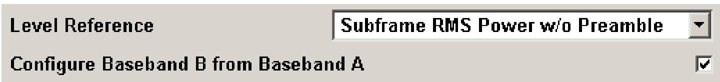

Fig. 54: WiMAX – Level Reference setting for both SMUs (basebands A and C) with automatic configuration of basebands B and D.

5.1.3 Fading Settings

For the 4x2 MIMO setup, it is essential to have the same fader settings in both instruments. Hence, the MIMO fading settings, e.g. the correlation matrixes, have to be configured identically in both SMUs. Here, it may be useful to use the Save/Recall functionality of the fader to save the fader settings of one instrument and load them into the other instrument. The settings file can be transferred either via a USB stick, an external USB HDD, or a LAN connection. The faders of both instruments have to start synchronously. Thus, for both instruments the Fading menu needs to be configured accordingly (Fig. 49, section 5.1.1.2).

Each SMU calculates the fading processes for all eight channels according to the specified correlation matrixes. For 4x2 MIMO mode these correlation matrixes are 8x8 matrixes specifying the correlations between all eight fading channels per fading path (Fig. 55). (A general introduction on how to configure the correlation matrix is given in section 4.1.3.)

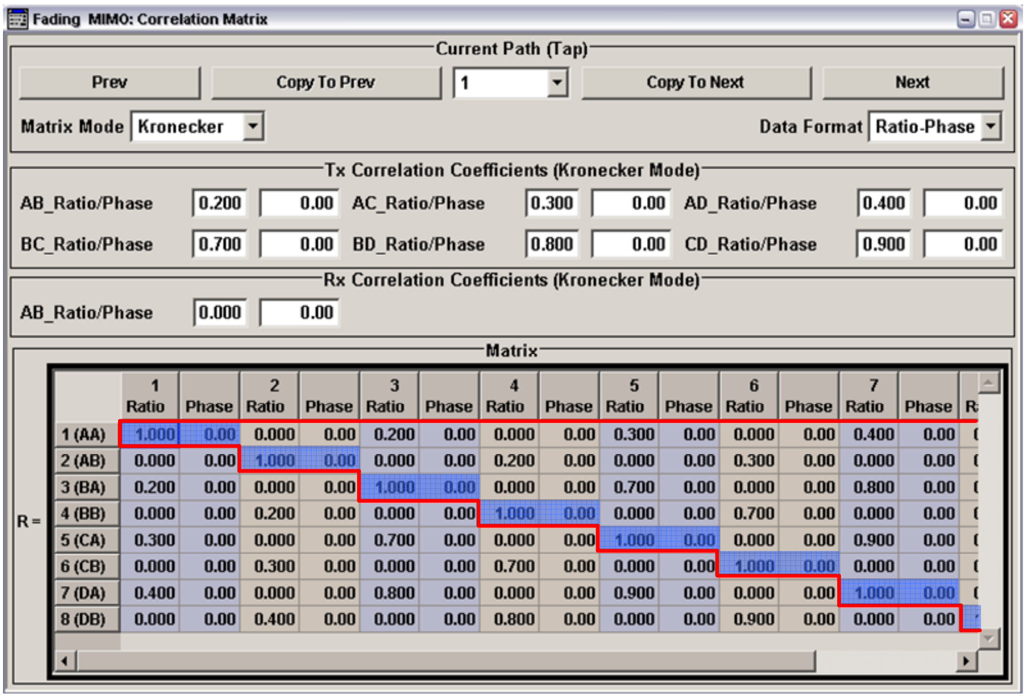

Fig. 55: Correlation matrix for 4x2 MIMO in Kronecker mode.

In Kronecker mode there are six Tx and one Rx correlation coefficients that can be specified. In this way, a correlation between the transmit antennas and a correlation between the receive antennas can be simulated. For every combination of two transmit antennas the correlation can be specified individually. For example, setting a Tx correlation AB correlates the fading of the transmitter signals Tx1 and Tx2. Setting a Tx correlation BD means that the signals Tx2 and Tx4 are faded in a correlated way. Accordingly, setting an Rx correlation correlates the fading of the two receiver signals Rx1 and Rx2. All matrix elements are automatically calculated based on the entered values for Tx and Rx correlation.

5.1.4 Triggering

Although already described in section 5.1.1.2, it should be pointed out once more that the two SMUs need to be synchronized. The question is: What needs to be started simultaneously in both instruments? The answer is easy:

- All four basebands (A, B, C and D) have to be started simultaneously using an external trigger signal. The corresponding trigger settings are described in section 5.1.1.2.
- The faders of both SMUs have to be started simultaneously. This is achieved by internal triggering via the basebands (see Fig. 50). The corresponding fader setting is described in section 5.1.1.2.

As a result, if a restart of the fading processes is desired, the basebands must be restarted with a trigger event from the external source.

5.1.5 Leveling

The fading of the different channels is performed according to the specified correlation matrixes. As a consequence, the channel powers are coupled and so are the levels of the Rx signals. To maintain the correct power relationship of the Rx signals, the RF levels of all four RF paths have to be set to the same value. Note that the actual signal level that is output at each RF output connector is intentionally 3 dB lower than the level displayed on the instruments (see Fig. 56 for clarification). This level reduction is done automatically by the SMUs (in 4x2 MIMO mode only) to account for the subsequent RF combiner in the signal path, which is assumed to be lossless. Leveling of the output power is hence straightforward. For example, if the desired level of the Rx signal is –10 dBm, then the level in the header of the GUI display is set to –10 dBm.

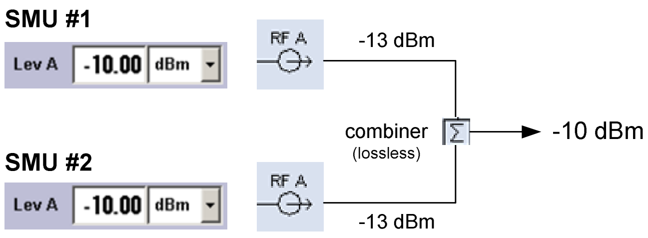

Fig. 56: Level display (GUI) and corresponding RF levels for 4x2 MIMO.

If the RF combiner is not lossless but has an insertion loss of e.g. 3.15 dB (related to power; corresponding to 6.30 dB when related to voltage), then the level of the Rx signal would be –10 dBm – 3.15 dB = –13.15 dB.

Of course, with activated fading, the instantaneous power of the RF signal fluctuates in time. The set RF level denotes the average power of the faded signal.

5.1.5.1 Steering Matrix

When using a steering matrix, the power correction values (see section 4.1.6.1 for details) have to be taken into account for determining the actual power levels of the Rx signals. For 4x2 MIMO mode the power correction value is identical for the RF paths A of both instruments and for the RF paths B of both instruments, respectively. The calculation of the actual Rx signal levels is illustrated by the following example: The correlation matrix is set to simulate reduced average power of channel AA and BA relative to the remaining channels. The RF level is set to –10 dBm for all four RF outputs. (Note that it is essential to set the RF levels of all four RF paths to the same value.) For signal paths RF B the correction factor is e.g. 0.00 dB. For signal paths RF A the correction factor is e.g. 2.81 dB due to the reduced average power of channels AA and BA. The actual level of the receiver signal Rx1 is hence –10 dBm – 2.81 dB = –12.81 dBm, while the level of signal Rx2 is –10 dBm, in this example.

5.2 4x2 MIMO with Two AMUs & SMATE

For testing 4x2 MIMO systems up to 6 GHz a combination of two AMUs and one SMATE is used. This offers realtime fading on all eight propagation channels.

5.2.1 Setup and Signal Routing

The two AMUs are configured for 4x2 MIMO by selecting “4x2 MIMO” in the Fader function block of both instruments. For one AMU MIMO Subset 1 is selected, while for the second AMU MIMO Subset 2 is selected. The MIMO subset defines which fading channels are simulated by the instrument. The signal routing of the two instruments is shown in Fig. 57. The eight different fading channels are highlighted in colors for the sake of clarity. The I/Q outputs of both instruments have to be connected to an external I/Q combiner (R&S®AMU-Z7). The I/Q output signals of this analog I/Q combiner correspond to Rx1 and Rx2, respectively.

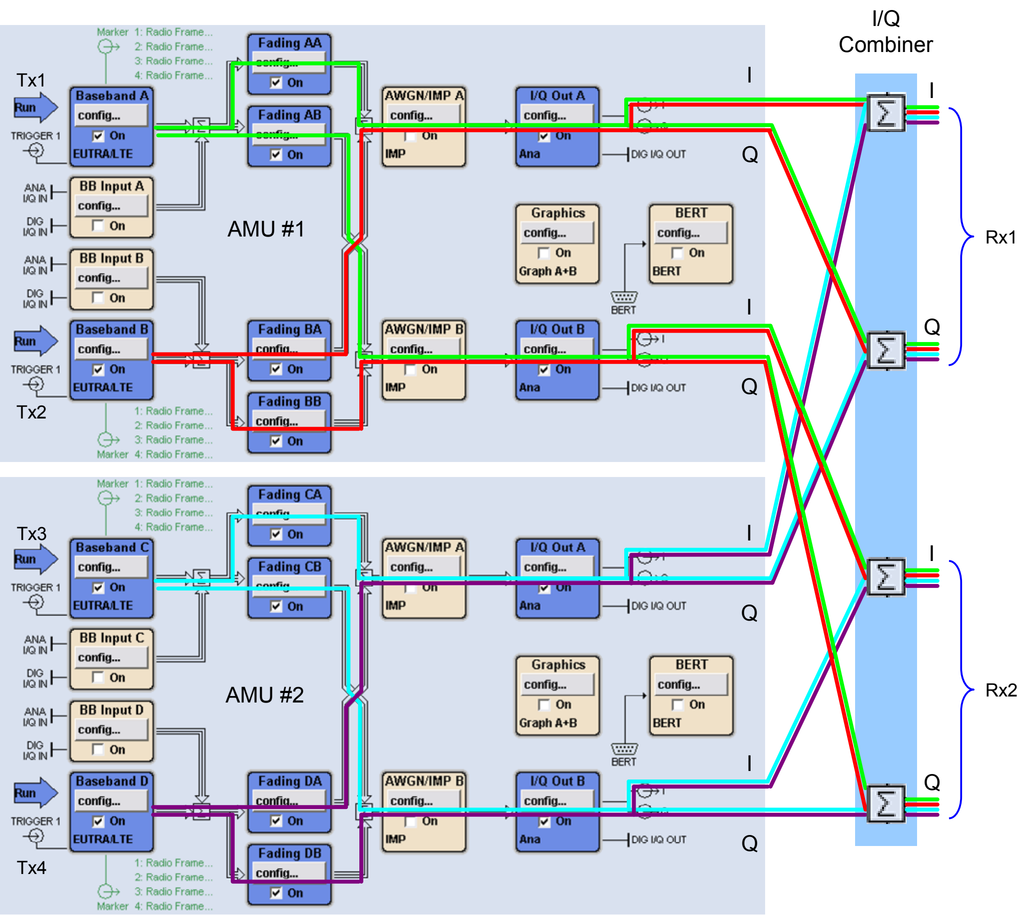

Fig. 57a: Signal routing of the two AMUs for 4x2 MIMO.

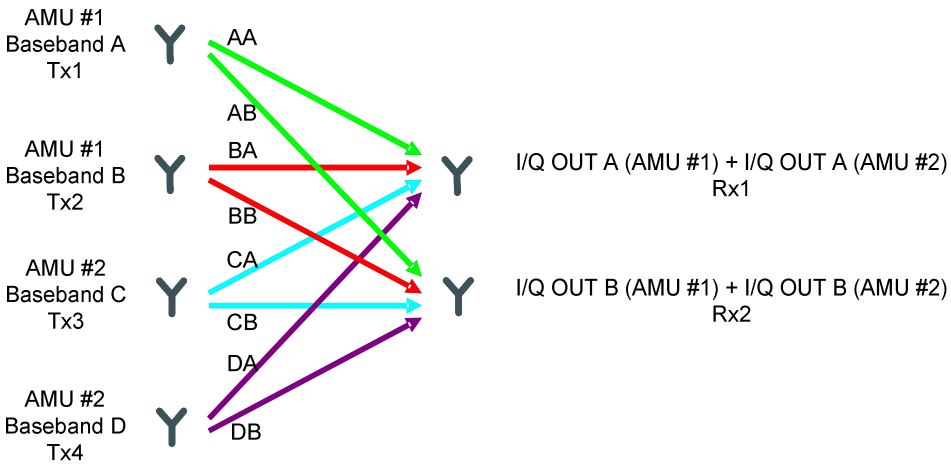

Fig. 57b: Schematic of the signal routing of the two AMUs for 4x2 MIMO.

Fig. 58: Photographs of the AMU-Z7 analog I/Q combiner.

For signal up-conversion, the I/Q outputs of the I/Q combiner are connected to the I/Q inputs of the SMATE for instrument paths A and B, respectively (Fig. 59). In MIMO mode 4x2, each AMU calculates the fading processes for all eight channels. Although only four fading channels are simulated per AMU, this is necessary in order to determine the correlations. A common 10 MHz reference signal is crucial to ensure the synchronization of the generators. Another requirement is a common external trigger, which defines a common starting point for baseband signal generation and for the calculation of the fading processes. Please refer to sections 5.1.1.1 and 5.1.1.2 for details about synchronization and triggering.

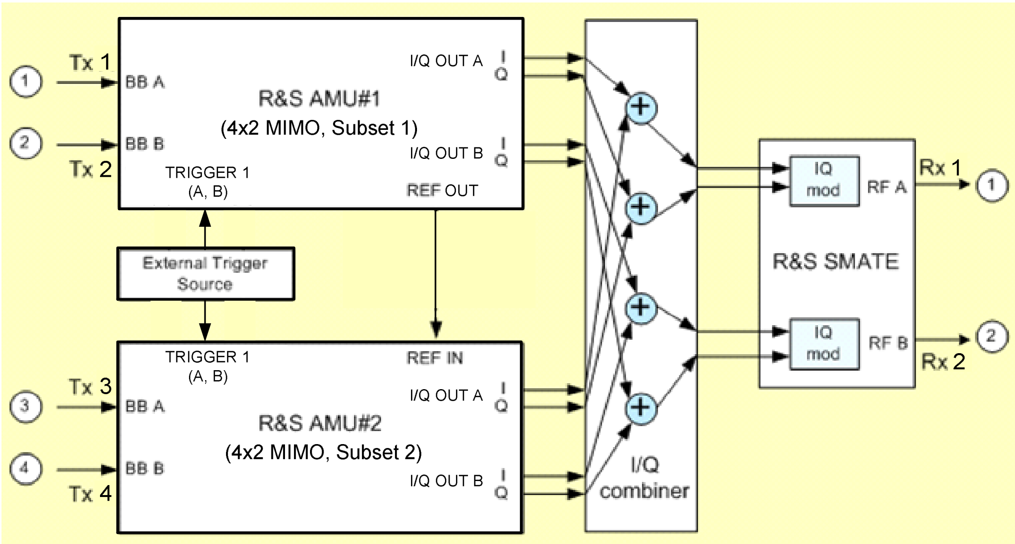

Fig. 59: Instrument setup for 4x2 MIMO with two AMUs, I/Q combiner and one SMATE.

The following table summarizes the equipment needed for simulating 4x2 MIMO systems up to 6 GHz.

4x2 MIMO up to 6 GHz	
Required equipment	
Instruments	**Additional equipment**
2x AMU*	AMU-Z7 analog I/Q combiner
SMATE*	external trigger source
	connecting cables

* each instrument with options as listed in section 4.2

The cables should have the same length and type concerning the trigger connections, the 10 MHz reference connections, the connections between the I/Q outputs (AMU) and the I/Q combiner, and the connections between the I/Q combiner and the SMATE. Unnecessary cable lengths and branching points should be avoided.

5.2.2 Baseband Signal

Baseband signals are generated via the Baseband function blocks in precisely the same way as described for the SMU (section 5.1.2).

An alternative to internal signal generation is to apply external baseband signals. In this case, the AMU is used as pure baseband fader. For 4x2 MIMO four pairs of I and Q signals (analog or digital) have to be supplied. In this case, the four BB Input function blocks represent the four transmit antennas. Essential for MIMO is to start all four external baseband sources simultaneously.

5.2.3 Fading Settings

The fading settings for the AMU are made completely analogous to the SMU (section 5.1.3), as the fader functionality is identical for both instruments.

5.2.4 Triggering

It is essential that the basebands and the faders of the two AMUs are synchronized. Please refer to section 5.1.4 for details.

5.2.5 Leveling

To obtain correct signal leveling at the RF outputs of the SMATE, the instrument settings of the AMU and the SMATE have to be coordinated. The I/Q output signals of the two AMUs must all have equal PEP values (0.5 V nominal). The AMU-Z7 analog I/Q combiner between the AMU and the SMATE adds these I/Q signals, which naturally involves an increase in signal level. The AMU-Z7 accounts for this increase by applying internally an appropriate division such that the level of an output I/Q signal (e.g. Rx1) equals the level of an input I/Q signal (e.g. I/Q Out A). This means that the instrument settings for the AMU are the same as for the standard setup (i.e. direct combination of AMU and SMATE as described in section 4.2.5 for 2x2 MIMO). The SMATE expects a peak voltage of 0.5 V at the analog I and Q inputs. The correct settings for the analog I/Q outputs of the AMU are shown in the table below and in Fig. 39.

AMU	
Analog I/Q Output Settings	
I/Q Output Type	Single Ended
Load Type	50 Ohm
Set Level Via	PEP
Pep Vp	0.500 V

Due to the fading process, the crest factor of the baseband signal increases. The Analog I/Q Output Settings menu (AMU, Fig. 39) shows the inherent crest factor of the baseband signal (Crest Factor (S)) as well as the crest factor of the signal after fading including noise (Crest Factor ((S+N)/S)). Since there are four baseband signals in total (i.e. I/Q Out A, I/Q Out B of AMU #1 and I/Q Out A, I/Q Out B of AMU #2), there are also four corresponding crest factors “Crest Factor ((S+N)/S)”. The four baseband signals are then combined by means of the AMU-Z7 to yield the two signals Rx1 and Rx2 (see Fig. 57a). The question is now: What are the crest factors of these two signals? The resulting crest factors of Rx1 and Rx2 have to be calculated (see section 5.2.5.1). Then, the crest factor of the Rx signal needs to be entered into the input field “Crest Factor” of the I/Q Settings menu of the SMATE. The correct settings for the SMATE are shown in the table below and in Fig. 40.

SMATE	
I/Q Settings	
Source	Analog Wideband I/Q Input
Crest Factor	Crest Factor of the Rx signal

With these instrument settings for the AMU and SMATE, the average power level at the RF outputs of the SMATE will agree with the level displayed in the header of the SMATE's instrument GUI. Of course, these settings have to be made for both instrument paths of each instrument.

In the AMUs, the fading of the different channels is performed according to the specified correlation matrixes. As a consequence, the channel powers are coupled and so are the levels of the up-converted signals Rx1and Rx2. To maintain the correct power relationship of the Rx signals, both RF output levels (SMATE) have to be set to the same value, i.e. the level of RF A and RF B are both set to e.g. –10 dBm.

5.2.5.1 Calculation of the Crest Factor

To simplify matters, I/Q Out A of AMU #1 is designated as Out A, I/Q Out B of AMU #1 as Out B, I/Q Out A of AMU #2 as OUT C, and I/Q Out B of AMU #2 as OUT D.
The PEP value of the four baseband signals (i.e. Out A, Out B, Out C, and OUT D) must be set to 0.5 V each. The AMU-Z7 thus adds up 0.5 V + 0.5 V = 1.0 V [3] and it then divides by a factor of 2. This yields a PEP value of 0.5 V for the signals Rx1 and Rx2.
In the general case of different crest factors "Crest Factor ((S+N)/S)" for all four basebands signals, the corresponding average levels will differ. The table below shows an example calculation with arbitrarily chosen crest factors for the baseband signals. A PEP value of 0.5 V corresponds to 7 dBm in a 50 Ω system. The average signal level is given by the PEP value in units of dBm minus the crest factor minus 3 dB.

Average Level [dBm] = PEP [dBm] – Crest Factor [dB] – 3 dB.

The factor 3 dB comes from the automatic level reduction (in 4x2 MIMO mode only, see also section 5.1.5) to account for the external combiner, which is assumed to be lossless.
Provided that the signals OUT A and OUT C as well as OUT B and OUT D are statistically independent, and provided that the I and Q signals themselves (e.g. $I_{OUT\ A}$ and $Q_{OUT\ A}$) are statistically independent, the RMS level of the Rx signals can be calculated as follows [3]:

$$\text{RMS Level Rx1 [mV]} = 0.5 \cdot \sqrt{(\text{RMS Level OUT A [mV]})^2 + (\text{RMS Level OUT C [mV]})^2}$$

$$\text{RMS Level Rx2 [mV]} = 0.5 \cdot \sqrt{(\text{RMS Level OUT B [mV]})^2 + (\text{RMS Level OUT D [mV]})^2}$$

The factor 0.5 is due to the internal divider of the AMU-Z7. The statistical independence of the signals is assured by prior fading. The fading decorrelates the I and Q signals itself as well as the I/Q OUT signals of the AMU. Even if a high degree of correlation is simulated by means of the correlation matrix, the signals are still statistically independent, since the initial baseband signals (Tx1 – Tx4) differ sufficiently. Therefore, the given relation is valid provided fading is applied.
The crest factor of the Rx signals can be calculated as follows:

Crest Factor Rx [dB] = PEP [dBm] – Average Level Rx [dBm].

In the following example calculation orange fields denote values which need to be calculated using the formulas given above. Light gray fields denote a unit conversion from dBm to millivolt values and vice versa.

Example Calculation				
Baseband Signals				
	OUT A	**OUT C**	**OUT B**	**OUT D**
PEP in Volts	0.5	0.5	0.5	0.5
PEP in dBm	7.0	7.0	7.0	7.0
Crest Factor in dB *	5.0	10.0	2.0	7.0
Average Level in dBm	–1.0	–6.0	2.0	–3.0
RMS Level in Millivolts	199.3	112.1	281.5	158.3
Combined Baseband Signals				
	Rx1		**Rx2**	
PEP in Volts	0.5		0.5	
PEP in dBm	7.0		7.0	
RMS Level in Millivolts	114.33		161.48	
Average Level in dBm	–5.83		–2.83	
Crest Factor in dB	**12.83**		**9.83**	

* corresponds to the parameter “Crest Factor ((S+N)/S)” displayed in the Analog I/Q Output Settings menu (AMU, Fig. 39).

5.2.5.2 Steering Matrix

When using a steering matrix, a power correction value (see section 4.1.6.1 for details) has to be taken into account for determining the actual power levels of the Rx signals. For 4x2 MIMO mode the power correction value is identical for the I/Q outputs OUT A and OUT C as well as for OUT B and OUT D. The calculation of the actual Rx signal levels is illustrated by the following example: The correlation matrix is set to simulate reduced average power of channel AA and BA relative to the remaining channels. The RF level on the SMATE is set to –10 dBm for both RF outputs. (Note that it is essential to set the RF levels of both RF paths to the same value.) For the I/Q outputs OUT B and OUT D the correction factor is e.g. 0.00 dB. For the I/Q outputs OUT A and OUT C the correction factor is e.g. 2.81 dB due to the reduced average power of channels AA and BA. The actual level of the receiver signal Rx1 is hence –10 dBm – 2.81 dB = –12.81 dBm, while the level of signal Rx2 is –10 dBm in this example.

5.2.5.3 External Baseband Input

For a correct internal signal processing, the crest factor and the peak power of the external baseband signal have to be known. Please refer to section 4.2.5.3.

6 2x4 MIMO

A 2x4 MIMO system consists of two transmit and four receive antennas. This antenna configuration involves eight fading channels.

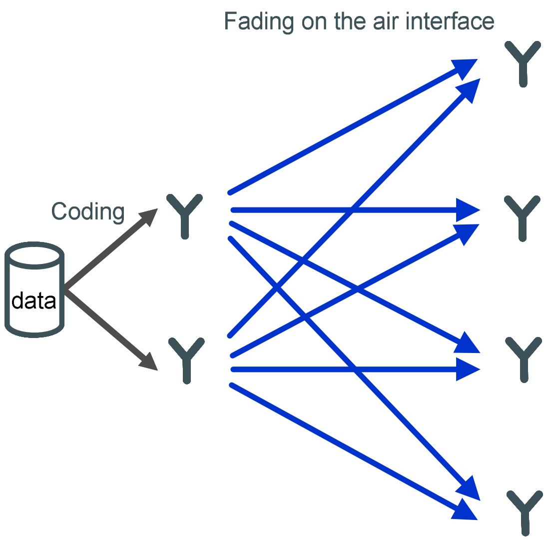

Fig. 60: Schematic of 2x4 MIMO.

This MIMO system can be implemented with either of the two following instrument setups:

- Two SMU signal generators for MIMO signals up to 3 GHz (section 6.1)
- Two AMU signal generators and two SMATE signal generators for MIMO signals up to 6 GHz (section 6.2)

6.1 2x4 MIMO with Two SMUs

The SMU has already been introduced as a stand-alone test solution for 2x2 MIMO. For testing 2x4 MIMO systems up to 3 GHz a combination of two SMUs is used. This offers realtime fading on all eight propagation channels.

6.1.1 Setup and Signal Routing

The two SMUs are configured for 2x4 MIMO by selecting “2x4 MIMO” in the Fader function block of both instruments. For one SMU MIMO Subset 1 is selected, while for the second SMU MIMO Subset 2 is selected. The MIMO subset defines which fading channels are simulated by the instrument. The first transmit antenna (Tx1) is simulated in each generator by baseband A, i.e. baseband A of SMU #1 generates exactly the same signal as baseband A of SMU #2. The second transmit antenna (Tx2) is simulated in each generator by baseband B, i.e. baseband B of SMU #1 generates exactly the same signal as baseband B of SMU #2. The signal routing of the two instruments is shown in Fig. 61. The eight different fading channels are highlighted in colors for the sake of clarity. The four RF outputs correspond to the four receive antennas (Rx1, Rx2, Rx3, and Rx4).

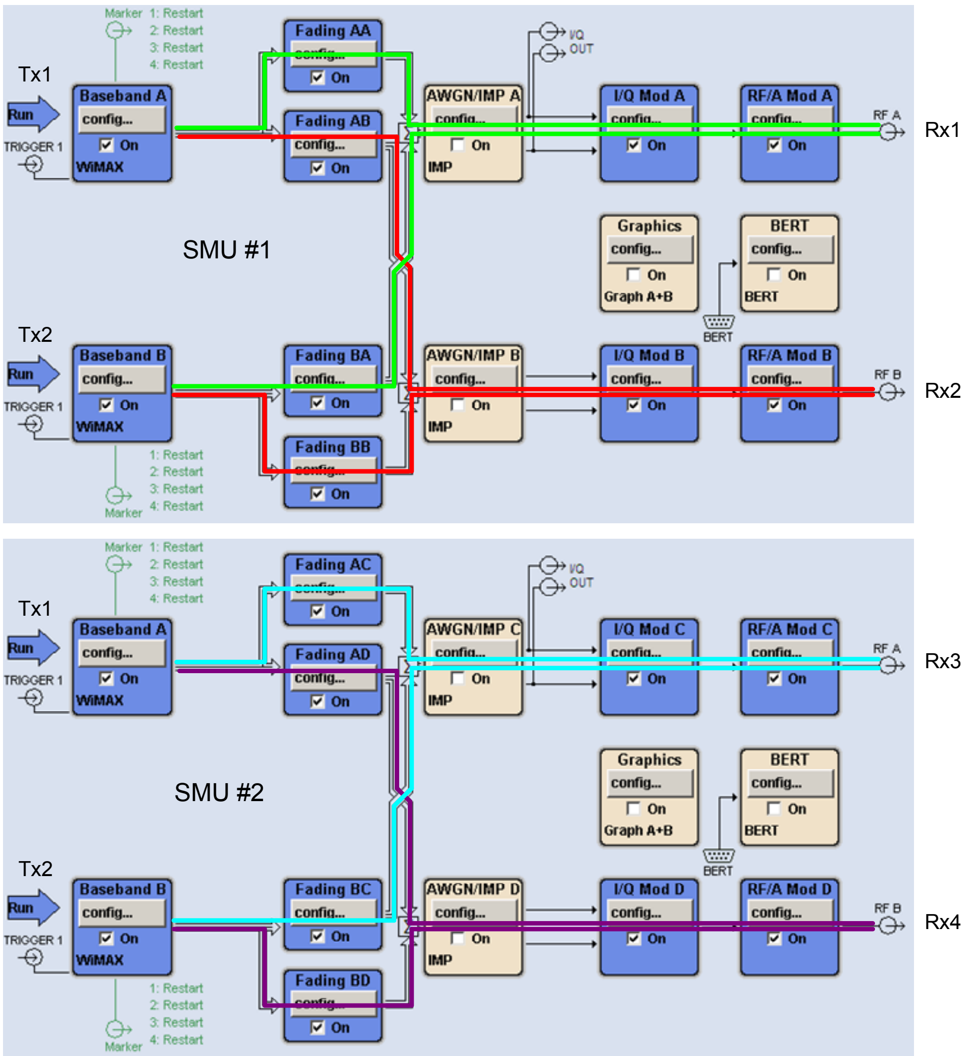

Fig. 61a: Signal routing of the two SMUs for 2x4 MIMO.

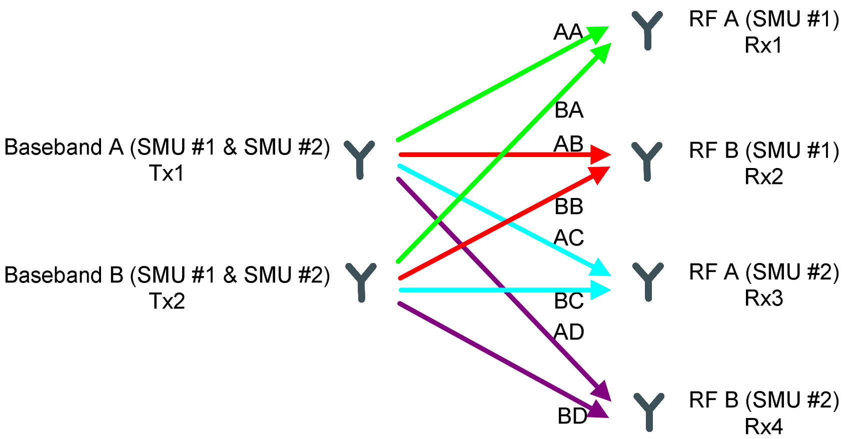

Fig. 61b: Schematic of the signal routing of the two SMUs for 2x4 MIMO.

In MIMO mode 2x4, each SMU calculates the fading processes for all eight channels. Although only four fading channels are simulated per SMU, this is necessary in order to determine the correlations. A common 10 MHz reference signal is crucial to ensure the synchronization of the generators. Another requirement is a common external trigger, which defines a common starting point for baseband signal generation and for the calculation of the fading processes. Please refer to sections 5.1.1.1 and 5.1.1.2 for details about synchronization and triggering. The following table summarizes the equipment needed for simulating 2x4 MIMO systems up to 3 GHz.

2x4 MIMO up to 3 GHz	
Required equipment	
Instruments	**Additional equipment**
2x SMU*	external trigger source
	connecting cables

* each instrument with options as listed in section 4.1

The cables should have the same length and type concerning the trigger connections and the 10 MHz reference connections.

6.1.2 Baseband Signal

2x4 MIMO is implemented by making the exact same baseband settings in both SMUs. This means that exactly the same signal is set up in baseband A of SMU #1 and SMU #2. This signal corresponds to Tx1. The signal Tx2 differs in only a few parameters from Tx1 (see following subsections) and is set up in baseband B of SMU #1 and SMU #2. Here, it may be useful to use the Save/Recall functionality of the baseband section to save the settings made for one baseband and recall them for the other basebands. The settings file is transferred from one instrument to the second instrument either via a USB stick, an external USB HDD, or a LAN connection. For 2x4 MIMO with data precoding, each of the two basebands of one SMU needs to be assigned to one of the two transmit antennas (see following subsections). All four baseband generators have to be started simultaneously using an external trigger signal. Thus, for all basebands the Trigger/Marker menu of the selected digital standard needs to be configured accordingly (Fig. 48). Please refer to section 5.1.1.2 for details.

6.1.2.1 LTE

An LTE signal for 2x4 MIMO is generated by setting the Global MIMO Configuration to “2 TxAntennas” in the General DL Settings menu. The Simulated Antenna Path A is “Antenna 1” and the Simulated Antenna Path B is “Antenna 2”. With these settings, path coupling is activated and the appropriate configurations for baseband B are set automatically. The precoding settings are configured in the following way: In the DL Frame Configuration menu, click on “Config…” in the Allocation Table to open the Enhanced Settings menu for the selected allocation. Set the Precoding Scheme to “Spatial Multiplexing”. (More details on how to configure a LTE baseband signal can be found in the R&S application note “LTE Downlink MIMO (2x2) with R&S®SMU200A and R&S®FSQ” (1MA143).) Note that the baseband settings are absolutely identical for SMU #1 and SMU #2.

6.1.2.2 WiMAX

2x4 MIMO for a WiMAX OFDMA signal is implemented by setting the Space-Time Coding Mode to “4 Antennas, Matrix B” (coding algorithm for spatial multiplexing). For baseband A the Space-Time Coding Antenna is “Antenna 0”. The submenus for making these settings are called from the WiMAX menu by clicking the “Frame Configuration” button and then clicking on “Config…” in the Zone Table. Baseband B is configured via baseband A by checking “Configure Baseband B from Baseband A” in the WiMAX menu. This automatically sets the appropriate configurations for baseband B. Baseband B will automatically be assigned to “Antenna 1”. Note that the baseband settings are absolutely identical for SMU #1 and SMU #2.

6.1.3 Fading Settings

For the 2x4 MIMO setup, it is essential to have the same fader settings in both instruments. Hence, the MIMO fading settings, e.g. the correlation matrixes, have to be configured identically in both SMUs. Here, it may be useful to use the Save/Recall functionality of the fader to save the fader settings of one instrument and load them into the other instrument. The settings file can be transferred either via a USB stick, an external USB HDD, or a LAN connection. The faders of both instruments have to be started synchronously using a common trigger signal. Thus, for both instruments the Fading menu needs to be configured accordingly (Fig. 49 and Fig. 16). Please refer to section 5.1.1.2 for details.

Each SMU calculates the fading processes for all eight channels according to the specified correlation matrixes. For 2x4 MIMO mode these correlation matrixes are 8x8 matrixes specifying the correlations between all eight fading channels per fading path (Fig. 62). (A general introduction on how to configure the correlation matrix is given in section 4.1.3.)

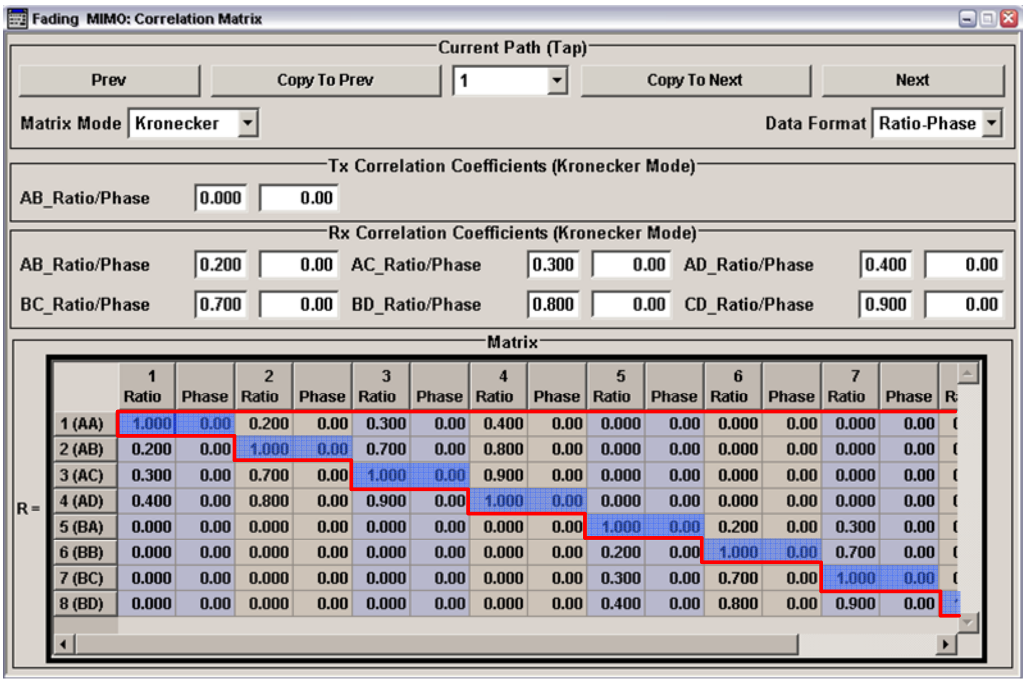

Fig. 62: Correlation matrix for 2x2 MIMO in Kronecker mode.

In Kronecker mode there are six Rx and one Tx correlation coefficients that can be specified. In this way, a correlation between the transmit antennas and a correlation between the receive antennas can be simulated. Setting a Tx correlation correlates the fading of the two transmitter signals Tx1 and Tx2. Accordingly, for every combination of two receive antennas the correlation can be specified individually. For example, setting an Rx correlation AB correlates the fading of the receiver signals Rx1 and Rx2. Setting an Rx correlation BD means that the signals Rx2 and Rx4 are faded in a correlated way. All matrix elements are automatically calculated based on the entered values for Tx and Rx correlation.

6.1.4 Triggering

It is essential that the two SMUs are synchronized. The question is: What needs to be started simultaneously in both instruments? The answer is easy:

- All four basebands (i.e. baseband A of SMU #1 and SMU #2 and baseband B of SMU #1 and SMU #2) have to be started simultaneously using an external trigger signal. The corresponding trigger settings are described in section 5.1.1.2.
- The faders of both SMUs have to be started simultaneously. This is achieved by internal triggering via the basebands (see Fig. 50). The corresponding fader setting is described in section 5.1.1.2.

As a result, if a restart of the fading processes is desired, the basebands must be restarted with a trigger event from the external source.

6.1.5 Leveling

The fading of the different channels is performed according to the specified correlation matrixes. As a consequence, the channel powers are coupled and so are the levels of the four Rx signals. To maintain the correct power relationship of the Rx signals, the levels of all four RF outputs have to be set to the same value, i.e. the levels of RF A, RF B, RF C and RF D are all set to e.g. –10 dBm. Leveling of the output power is hence straightforward. Of course, with activated fading, the instantaneous power of the RF signal fluctuates in time. The set RF level denotes the average power of the faded signal.

6.1.5.1 Steering Matrix

When using a steering matrix, the power correction values (see section 4.1.6.1 for details) have to be taken into account for determining the actual power levels of the Rx signals. For 2x4 MIMO mode, the power correction value is different for each of the four RF paths. The calculation of the actual Rx signal levels is illustrated by the following example: The correlation matrix is set to simulate reduced average power of channels AA and AC relative to the remaining channels. The RF level is set to –10 dBm for all four RF outputs. (Note that it is essential to set the RF levels of all four RF paths to the same value.) For signal paths RF B and RF D the correction factor is 0.00 dB. For signal path RF A the correction factor is e.g. 2.81 dB due to the reduced average power of channel AA. For signal path RF C the correction factor is e.g. 1.42 dB due to the reduced average power of channel AC. The actual level of the receiver signal Rx1 is hence –10 dBm – 2.81 dB = –12.81 dBm, while the level of signal Rx3 is –10 dBm – 1.42 dB = –11.42 dBm. The level of signals Rx2 and Rx4 is –10 dBm in this example.

6.2 2x4 MIMO with Two AMUs and Two SMATEs

For testing 2x4 MIMO systems up to 6 GHz a combination of two AMUs and two SMATEs is used. This offers realtime fading on all eight propagation channels.

6.2.1 Setup and Signal Routing

The two AMUs are configured for 2x4 MIMO by selecting “2x4 MIMO” in the Fader function block of both instruments. For one AMU MIMO Subset 1 is selected, while for the second AMU MIMO Subset 2 is selected. The MIMO subset defines which fading channels are simulated by the instrument. The signal routing of the two instruments is shown in Fig. 63. The eight different fading channels are highlighted in colors for the sake of clarity. The I/Q output signals of the two AMUs correspond to Rx1, Rx2, Rx3, and Rx4.

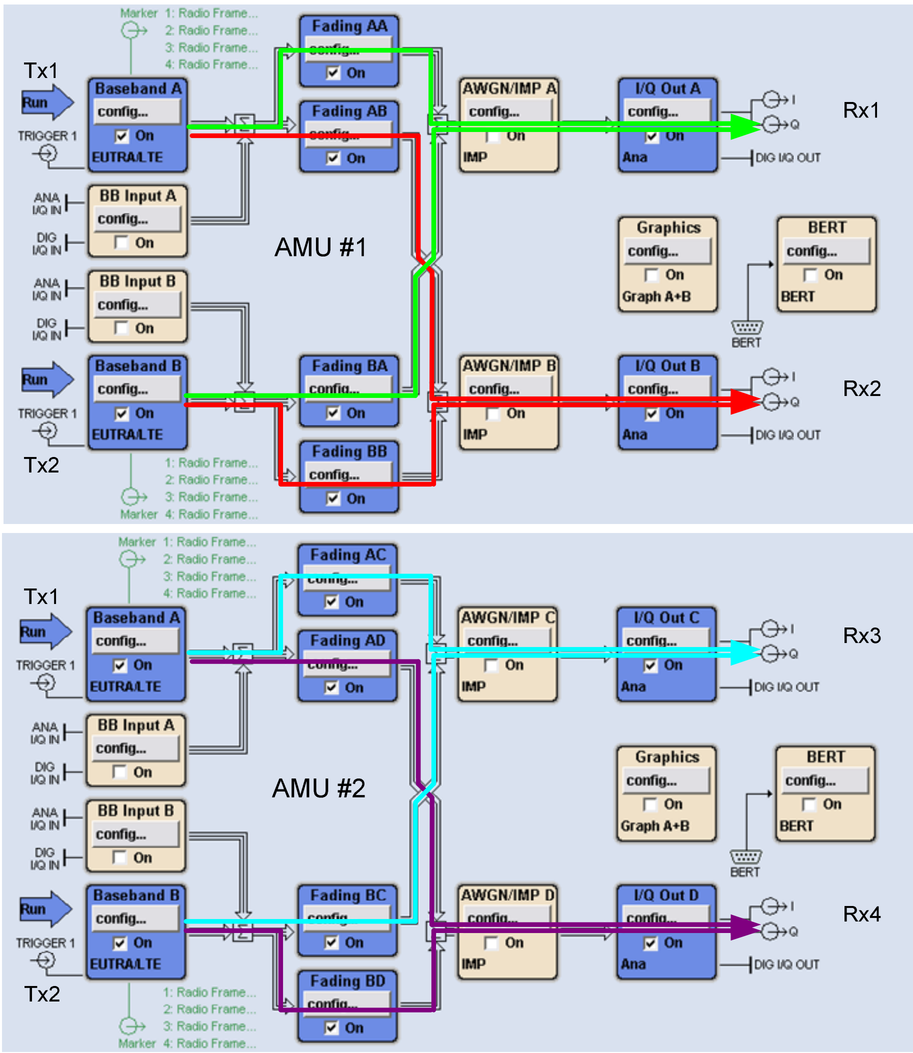

Fig. 63a: Signal routing of the two AMUs for 2x4 MIMO

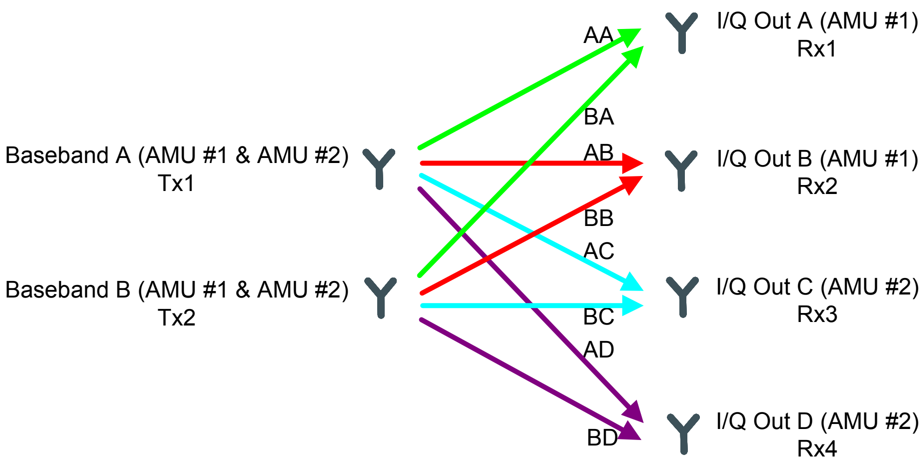

Fig. 63b: Schematic of the signal routing of the two AMUs for 2x4 MIMO.

For signal up-conversion, the I/Q outputs of an AMU are connected to the I/Q inputs of a SMATE for instrument paths A and B, respectively (Fig. 64). In MIMO mode 2x4, each AMU calculates the fading processes for all eight channels. Although only four fading channels are simulated per AMU, this is necessary in order to determine the correlations. A common 10 MHz reference signal is crucial to ensure the synchronization of the generators. Another requirement is a common external trigger, which defines a common starting point for baseband signal generation and for the calculation of the fading processes. Please refer to sections 5.1.1.1 and 5.1.1.2 for details about synchronization and triggering.

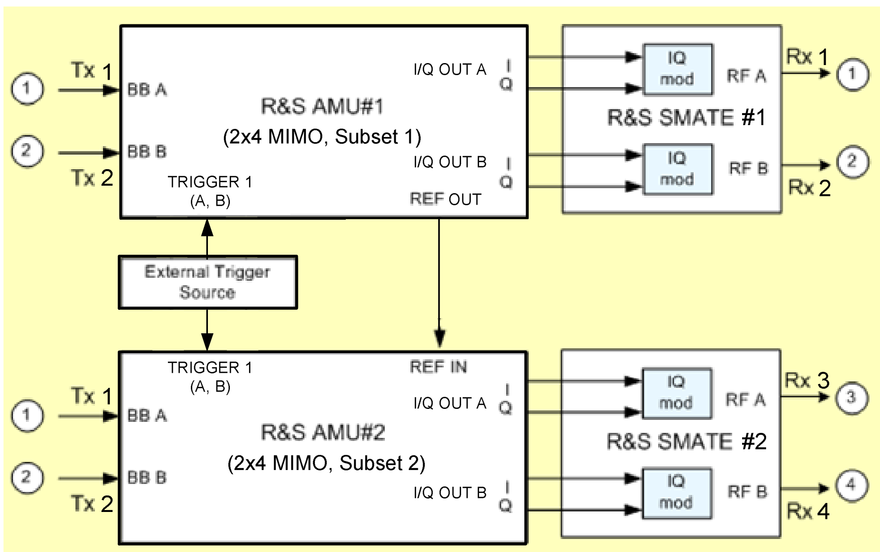

Fig. 64: Instrument setup for 2x4 MIMO with two AMUs and two SMATEs.

The following table summarizes the equipment needed for simulating 2x4 MIMO systems up to 6 GHz.

2x4 MIMO up to 6 GHz	
Required equipment	
Instruments	**Additional equipment**
2x AMU*	external trigger source
2x SMATE*	connecting cables

* each instrument with options as listed in section 4.2

The cables should have the same length and type concerning the trigger connections, the 10 MHz reference connections, and the connections between the I/Q outputs of the AMU and the I/Q inputs of the SMATE, respectively.

6.2.2 Baseband Signal

Baseband signals are generated via the Baseband function blocks in precisely the same way as described for the SMU (section 6.1.2).

An alternative to internal signal generation is to apply external baseband signals. In this case, the AMU is used as pure baseband fader. For 2x4 MIMO four pairs of I and Q signals (analog or digital) have to be supplied. In this case, the BB Input A function block of each AMU represents the first transmit antenna. The second transmit antenna is represented by the BB Input B function block of each AMU. Essential for MIMO is to start the external baseband sources simultaneously.

6.2.3 Fading Settings

The fading settings for the AMU are made completely analogous to the SMU (section 6.1.3), as the fader functionality is identical for both instruments.

6.2.4 Triggering

It is essential that the basebands and the faders of the two AMUs are synchronized. Please refer to section 6.1.4 for details.

6.2.5 Leveling

To obtain correct signal leveling at the RF outputs of the SMATE, the instrument settings of the AMU and the SMATE have to be coordinated. The SMATE expects a peak voltage of 0.5 V at the analog I and Q inputs. The correct settings for the analog I/Q outputs of the AMU are shown in the table below and in Fig. 39.

AMU	
Analog I/Q Output Settings	
I/Q Output Type	Single Ended
Load Type	50 Ohm
Set Level Via	PEP
Pep Vp	0.500 V

Due to the fading process, the crest factor of the baseband signal increases. The Analog I/Q Output Settings menu (AMU, Fig. 39) shows the inherent crest factor of the baseband signal (Crest Factor (S)) as well as the crest factor of the signal after fading including noise (Crest Factor ((S+N)/S)). The crest factor “Crest Factor ((S+N)/S)” displayed on the AMU needs to be entered into the input field “Crest Factor” of the I/Q Settings menu of the SMATE. The correct settings for the SMATE are shown in the table below and in Fig. 40.

SMATE	
I/Q Settings	
Source	Analog Wideband I/Q Input
Crest Factor	Crest Factor ((S+N)/S) of the input signal

With these instrument settings for AMU and SMATE, the average power level at the RF outputs of a SMATE will agree with the level displayed in the header of the SMATE’s instrument GUI. Of course, these settings have to be made for both instrument paths of each instrument.

In the AMUs, the fading of the different channels is performed according to the specified correlation matrixes. As a consequence, the channel powers are coupled and so are the levels of the up-converted signals Rx1, Rx2, Rx3 and Rx4. To maintain the correct power relationship of the Rx signals, all RF output levels (SMATE) have to be set to the same value, i.e. the level of RF A, RF B, RF C and RF D are all set to e.g. –10 dBm.

6.2.5.1 Steering Matrix

When using a steering matrix, a power correction value has to be taken into account for determining the actual power levels of the Rx signals. The actual RF levels are calculated in precisely the same way as described for the SMU setup in section 6.1.5.1.

6.2.5.2 External Baseband Input

For a correct internal signal processing the crest factor and the peak power of the external baseband signal have to be known. Please refer to section 4.2.5.3.

7 Other MIMO Configurations

Besides the MIMO configurations 2x2, 4x2 and 2x4 (described in detail in sections 4, 5 and 6, respectively), also other MIMO modes including SIMO and MISO can be implemented. These configurations are set up in a similar way as the presented MIMO modes 2x2, 4x2 and 2x4. The following table gives an overview of the individual MIMO setups.

MIMO setups			
MIMO mode	**Fader setting**	**Setup similar to…**	**Remarks**
2x1	2x2	2x2	Rx2 (RF B) not used
1x2	2x2	2x2	Tx2 (baseband B) not used
3x2	3x2	4x2	Tx4 (baseband D) not used
4x1	4x2	4x2	Rx2 (RF B of both instruments) not used
3x1	3x2	4x2	Tx4 (baseband D) and Rx2 (RF B of both instruments) not used
2x3	2x3	2x4	Rx4 (RF D) not used
1x4	2x4	2x4	Tx2 (baseband B of both instruments) not used
1x3	2x3	2x4	Tx2 (baseband B of both instruments) and Rx4 (RF D) not used

8 SMBV – An Alternative for the SMATE

In the presented MIMO setups, the SMATE merely serves as a frequency up-converter. An alternative to the two-path SMATE is to use two R&S®SMBV100A vector signal generators. Of course, these one-path generators also merely serve as up-converters for the baseband signals provided by the AMU. In the MIMO setups, one SMATE can be replaced by two SMBVs. The required instrument settings for the SMBV are identical to the settings for the SMATE described in the previous sections.

Required options for the R&S®SMBV100A (minimum instrument configuration):

- 1x R&S®SMBV100A Vector Signal Generator
- 1x R&S®SMBV-B106 Frequency Range 100 kHz to 6 GHz

The SMBV is a mid-range instrument offered at a very attractive price. The SMATE is a high-end instrument with superior RF performance.

8.1 Setup

8.1.1 2x2 MIMO

For testing 2x2 MIMO systems up to 6 GHz, a combination of one AMU and two SMBVs can be used.

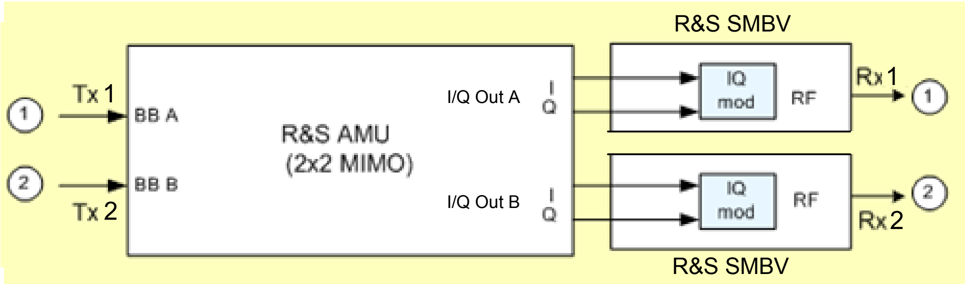

Fig. 65: Instrument setup for 2x2 MIMO with AMU and two SMBV.

8.1.2 4x2 MIMO

For testing 4x2 MIMO systems up to 6 GHz, a combination of two AMUs and two SMBVs can be used.

8.1.3 2x4 MIMO

For testing 2x4 MIMO systems up to 6 GHz, a combination of two AMUs and four SMBVs can be used.

8.2 Leveling

To obtain correct signal leveling at the RF output of the SMBV, the instrument settings of the AMU and the SMBV have to be coordinated. This is done in precisely the same way as described in sections 4.2.5 (2x2 MIMO), 5.2.5 (4x2 MIMO), and 6.2.5 (2x4 MIMO).

9 Summary

The SMU is a powerful one-box solution for testing 2x2 MIMO systems up to 3 GHz. An SMU equipped with two baseband generators and two RF paths offers realtime fading on all four propagation channels including simulation of channel correlations. It is hence a compact stand-alone test solution for 2x2 MIMO offering data precoding for digital standards. For testing more complex MIMO systems such as 4x2 or 2x4 MIMO, a combination of two SMUs is used. This combination integrates eight logical fading simulators and four baseband generators offering realtime fading on all eight propagation channels. This versatile all-in-one solution requires only a minimum of space. For MIMO signal generation up to 6 GHz, combinations of AMU and SMATE are used. While the AMU offers realtime fading on four propagation channels per instrument, the SMATE serves as signal up-converter. These instrument combinations also achieve complex MIMO simulation and make it possible to use external baseband sources. This application note explained in detail how to set up the signal generators for 2x2, 4x2 and 2x4 MIMO testing with a focus on signal routing, synchronization of the generators, and leveling.

10 Abbreviations

AWGN	Additive White Gaussian Noise
BB	Baseband
CW	Continuous Wave
GUI	Graphical User Interface
MIMO	Multiple Input Multiple Output
RF	Radio Frequency
RMS	Root Mean Square

11 References

[1] Rohde & Schwarz, Fading Simulation options for R&S Signal Generators Software Manual

[2] Rohde & Schwarz, R&S Power Viewer Plus Software Manual

[3] Application Note Rohde & Schwarz, “dB or not dB?” (1MA98)

12 Ordering Information

R&S® SMU200A	**Vector Signal Generator**	1141.2005.02
R&S® SMU-B102	Frequency option 2.2 GHz, 1st RF path	1141.8503.02
R&S® SMU-B103	Frequency option 3 GHz, 1st RF path	1141.8603.02
R&S® SMU-B104	Frequency option 4 GHz, 1st RF path	1141.8603.02
R&S® SMU-B106	Frequency option 6 GHz, 1st RF path	1141.8803.02
R&S® SMU-B202	Frequency option 2.2 GHz, 2nd RF path	1141.9400.02
R&S® SMU-B203	Frequency option 3 GHz, 2nd RF path	1141.9500.02
R&S® SMU-B90	Phase Coherence	1409.8604.02
R&S® SMU-B13	Baseband Main Module	1141.8003.04
R&S® SMU-B9	Baseband Generator with ARB (128 Msamples)	1161.0866.02
R&S® SMU-B10	Baseband Generator with ARB (64 Msamples)	1141.7007.02
R&S® SMU-B11	Baseband Generator with ARB (16 Msamples)	1159.8411.02
R&S® SMU-B14	Fading Simulator	1160.1800.02
R&S® SMU-B15	Fading Simulator Extension	1160.2288.02
R&S® SMU-K71	Dynamic Fading and Enhanced Resolution	1160.9201.02
R&S® SMU-K72	Extended Statistic Functions	1408.7062.02
R&S® SMU-K74	MIMO Fading	1408.7762.02
R&S® SMU-K62	Additive White Gaussian Noise (AWGN)	1159.8511.02

R&S® AMU200A	**Baseband Signal Generator and Fading Simulator**	1402.4090.02
R&S® AMU-B13	Baseband Main Module	1402.5500.02
R&S® AMU-B9	Baseband Generator with ARB (128 Msamples)	1402.8809.02
R&S® AMU-B10	Baseband Generator with ARB (64 Msamples)	1402.5300.02
R&S® AMU-B11	Baseband Generator with ARB (16 Msamples)	1402.5400.02
R&S® AMU-B16	Differential I/Q Output	1402.5800.02
R&S® AMU-B17	Baseband I/Q Input (digital/analog)	1402.5900.02
R&S® AMU-B18	Baseband Digital I/Q Output	1402.6006.02
R&S® AMU-B14	Fading Simulator	1402.5600.02
R&S® AMU-B15	Fading Simulator Extension	1402.5700.02
R&S® AMU-K71	Dynamic Fading and Enhanced Resolution	1402.7302.02
R&S® AMU-K72	Enhanced Fading Profiles	1402.9605.02
R&S® AMU-K74	MIMO Fading	1402.9857.02
R&S® AMU-K62	Additive White Gaussian Noise (AWGN)	1402.7202.02
R&S® AMU-Z7	Analog I/Q Combiner	1415.7006.02

R&S® SMATE200A	**Vector Signal Generator**	1400.7005.02
R&S® SMATE-B103	Frequency option 3 GHz, 1st RF path	1401.1000.02
R&S® SMATE-B106	Frequency option 6 GHz, 1st RF path	1401.1200.02
R&S® SMATE-B203	Frequency option 3 GHz, 2nd RF path	1401.1400.02
R&S® SMATE-B206	Frequency option 6 GHz, 2nd RF path	1401.1600.02
R&S® SMATE-B13	Baseband Main Module	1401.2907.02
R&S® SMATE-B9	Baseband Generator with ARB (128 Msamples)	1404.7500.02
R&S® SMATE-B10	Baseband Generator with ARB (64 Msamples)	1401.2707.02
R&S® SMATE-B11	Baseband Generator with ARB (16 Msamples)	1401.2807.02

R&S® SMBV100A	**Vector Signal Generator**	1407.6004.02
R&S® SMBV-B103	Frequency option 3 GHz	1407.9603.02
R&S® SMBV-B106	Frequency option 6 GHz	1407.9703.02
R&S® SMBV-B1	Reference Oscillator OCXO	1407.8407.02
R&S® SMBV-B90	Phase Coherence	1407.9303.02
R&S® SMBV-B10	Baseband Generator with Digital Modulation (realtime) and ARB (32 Msamples), 120 MHz RF bandwidth	1407.8607.02
R&S® SMBV-B50	Baseband Generator with ARB (32 Msamples), 120 MHz RF bandwidth	1407.8907.02
R&S® SMBV-B51	Baseband Generator with ARB (32 Msamples), 60 MHz RF bandwidth	1407.9003.02
R&S® SMBV-B55	Memory Extension for ARB to 256 Msamples	1407.9203.02
R&S® SMBV-B92	Hard Disc (removable)	1407.9403.02

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