LTE Beamforming Measurements
Application Note

Products:

R&S®SMW200A	R&S®FSL
R&S®SMU200A	R&S®FSG
R&S®SMU-K55	R&S®FSQ
R&S®SMBV100A	R&S®FSV
R&S®SMJ100A	R&S®FSW
R&S®SMATE200A	R&S®FS-Z10
R&S®EX-IQ-Box	R&S®ZVA/B
R&S®OSP	R&S®WinIQSIM2™

Multiple input multiple output (MIMO) technology is an integral part of 3GPP E-UTRA long term evolution (LTE). As part of MIMO, beamforming is also used in LTE.
This application note provides a brief summary of the transmission modes (TM) in LTE and describes the beamforming measurements for base stations (BS) and user equipment (UE). The T&M options using various Rohde & Schwarz instruments are also presented.

Application Note

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ROHDE&SCHWARZ

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Rohde & Schwarz test equipment is abbreviated as follows in this application note:

• The R&S®SMW200A,R&S®SMU200A, R&S®SMATE200A, R&S®SMBV100A and R&S®SMJ100A vector signal generators are referred to as the SMU, SMATE, SMBV and SMJ, respectively, or collectively as the SMx
• The R&S®FSL, R&S®FSG and R&S®FSQ signal analyzers are referred to as the FSL, FSG and FSQ, respectively
• The R&S®FSV spectrum analyzer is referred to as the FSV
• The R&S®FSW spectrum analyzer is referred to as the FSW
• The R&S®FSL, R&S®FSG, R&S®FSQ, R&S®FSV and R&S®FSW are referred to collectively as the FSx
• The R&S®FS-Z10 coherence unit is referred to as the FS-Z10
• The R&S®ZVA and R&S®ZVB network analyzers are referred to as the ZVA and ZVB, respectively, or collectively as the ZVx
• The R&S®OSP open switch and control platform is referred to as the OSP
• The R&S®EX-IQ-Box signal analyzer is referred to as the EX-IQ-Box
• The R&S®WinIQSIM2™ simulation software is referred to as WinIQSIM2™

1 Introduction: Beamforming in LTE

1.1 Introduction

Modern communications networks use MIMO technology to achieve high data rates. MIMO also permits targeted illumination of specific areas using beamforming, making it possible to improve transmission to users at the far reaches of cell coverage. Like other communications standards such as WLAN and WiMAX™, UMTS LTE also defines beamforming. Beamforming is particularly important for the time division duplex (TDD) mode in LTE.

Chapter 1 provides a brief overview of the base station's components to be tested, as well as a summary of the transmission modes in LTE. Chapter 2 describes the test setups for beamforming measurements on components. This chapter discusses tests for base stations as a whole and for remote radio heads, and also provides guidelines for a variety of measurements using vector signal generators, signal analyzers and network analyzers. Finally, user equipment (UE) measurements are described. The wide variety of test instruments that support beamforming and phase measurements provide users with flexible options for setting up tests and for expanding existing test systems.

Beamforming in LTE is carried out at the base station. Beamforming can be implemented and tested in both the transmit and receive directions (determining the angle of arrival [AoA] and interferer suppression). Put in simplified terms, a base station consists of the baseband, the RF module and the antenna (or an antenna array) (Fig. 1).

The baseband and the RF module do not have to be in geographic proximity, and in fact more advanced base stations tend to separate the baseband from the RF module (the remote radio head, or RRH). This means that the baseband could even be placed within the network, for example. In this case, the baseband signals are transmitted to the RRH digitally (e.g. via a CPRI interface; see [5]), and only then are they modulated to the RF and amplified.

Another important trend is the use of active base station antennas that consist of multiple transmit and receive elements (transceivers). This configuration is particularly well suited for implementing beamforming. Some suggestions for future base station architectures move the baseband into the antenna.

The test procedures described in this application note can be used in all architectures.

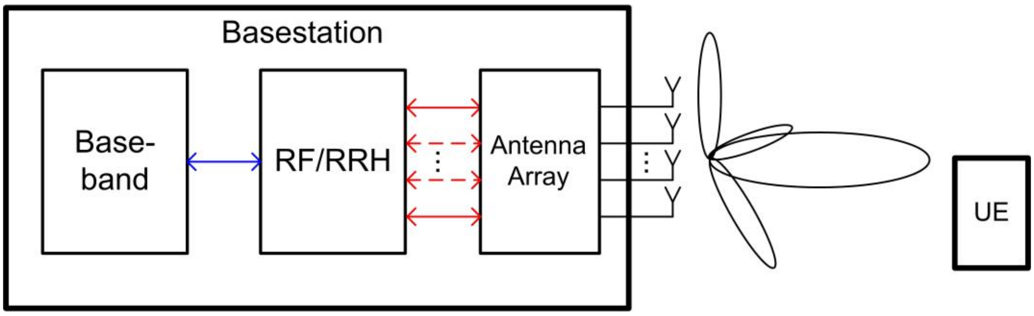

Fig. 1: Block diagram: Mobile radio transmission from base station to UE.

Fig. 2 shows possible setups for a base station. Increasingly, a digital link between the baseband and the RF module is used.

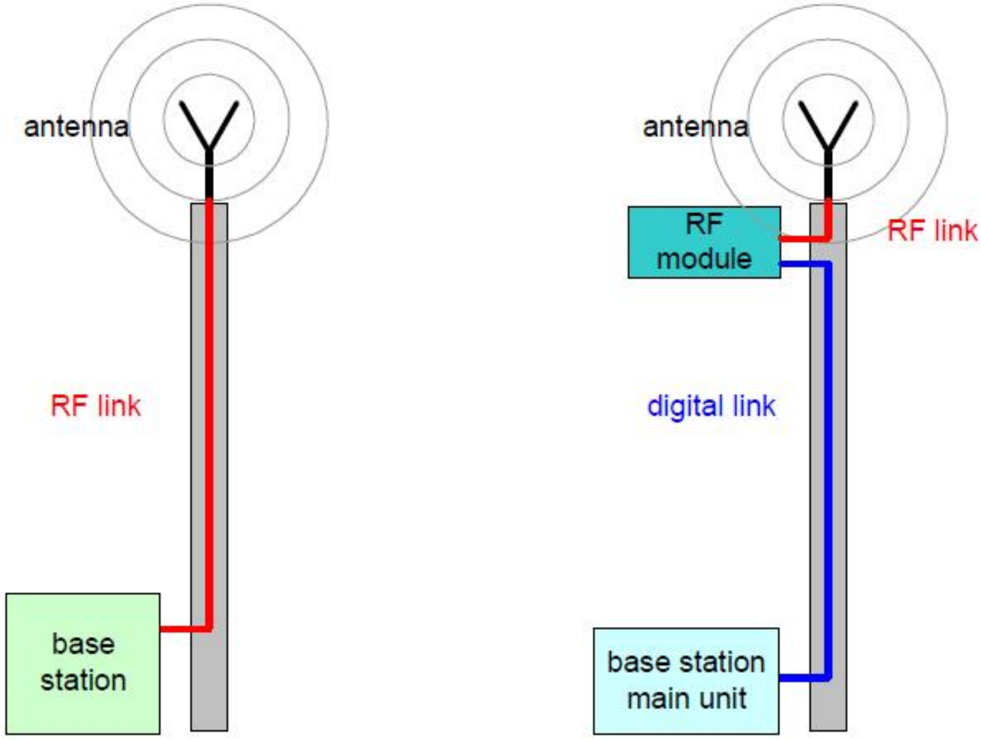

Fig. 2: Base station setup. In state-of-the-art setups, the baseband is separate from the RF module. A digital link between the baseband and the RF module is used (blue). The baseband can be located at the bottom of the mast, co-located directly on the antenna with the RF module, or placed in a completely separate location in the network.

Rohde & Schwarz offers a variety of instruments that support digital communications standards (such as WLAN, WiMAX™ and 3GPP LTE) to allow testing of the individual functional components in the mobile radio connection. This application note covers the various T&M options for beamforming in LTE, which are easily implemented using Rohde & Schwarz test equipment.

1.2 Transmission Modes (TM) in LTE

Only the most important factors for beamforming in LTE are discussed here. Refer to the white paper "Beamforming in LTE" [4] for more detailed information.

The 3GPP Release 9 specification [6] defines eight different transmission modes (TMs).

Transmission modes in LTE Release 9		
Transmission modes	**Designation**	**Comment**
TM 1	Single transmit antenna	Single antenna port; port 0
TM 2	Transmit diversity	2 or 4 antennas
TM 3	Open-loop spatial multiplexing with cyclic delay diversity (CDD)	2 or 4 antennas
TM 4	Closed-loop spatial multiplexing	2 or 4 antennas
TM 5	Multi-user MIMO	2 or 4 antennas
TM 6	Closed-loop spatial multiplexing using a single transmission layer	1 layer (rank 1), 2 or 4 antennas
TM 7	Beamforming	Single antenna port, port 5 (virtual antenna port, actual antenna configuration depends on implementation)
TM 8	Dual-layer beamforming	Dual-layer transmission, antenna port 7 and/or 8

Table 1: Overview of the eight LTE transmission modes according to Release 9 [6].

TMs 7 and 8 use an antenna array for beamforming, although the UE sees only one (TM 7) or two (TM 8) antennas. The base station transmits UE-specific reference signals in both modes.

TMs 6, 7 and 8 are described in more detail below.

TM 6 – Closed-loop spatial multiplexing using a single transmission layer

This mode uses spatial multiplexing with only one layer. The weighting applied to the antennas based on a defined codebook results in beamforming as a side effect. Because the precoding from this codebook is used for the UE receiver test (see section 2.3) in TM 7, this application note mentions TM 6 briefly.

To permit channel estimation at the receiver, the base station transmits cell-specific reference signals (RS), distributed over various resource elements (RE) and over various timeslots. The UE estimates the channel and reports the index of the most suitable precoding matrix back to the base station. The base station transmits the precoded signal via all antenna ports. The codebooks from Table 2 are used, but only the 1-layer variants (yellow background).

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

Table 2: Codebook indices for spatial multiplexing with two antennas, green background for two layers; yellow background for one layer or TM 6 [1].

The varied weighting (precoding) of the signals to the different antennas results in a beamforming as a side effect(see Fig. 3 for two antennas). When four transmit antennas are used, there are 16 different beamforming diagrams.

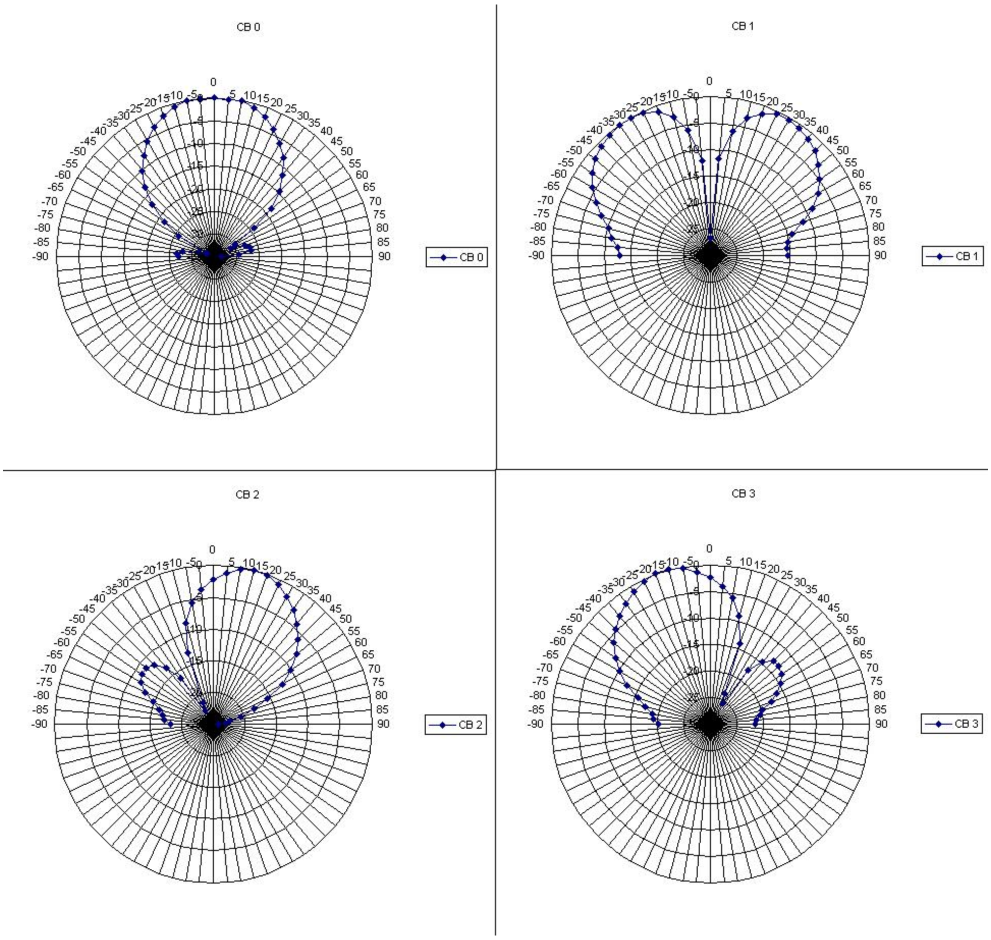

Fig. 3: Schematic representation of TM 6t for two antennas at a distance of λ/2, codebook index 0 to 3.

TM 7 – Beamforming (antenna port 5)

This mode uses UE-specific reference signals (DM-RS). Both the data and the UE-specific RS are transmitted using the same antenna weightings. Because the UE requires only the UE-specific RS for demodulation, the data transmission for the UE appears to have been received from only one transmit antenna, and the UE does not see the actual number of transmit antennas. Therefore, this transmission mode is also called "single antenna port; port 5". The transmission appears to be transmitted from a single "virtual" antenna port 5.

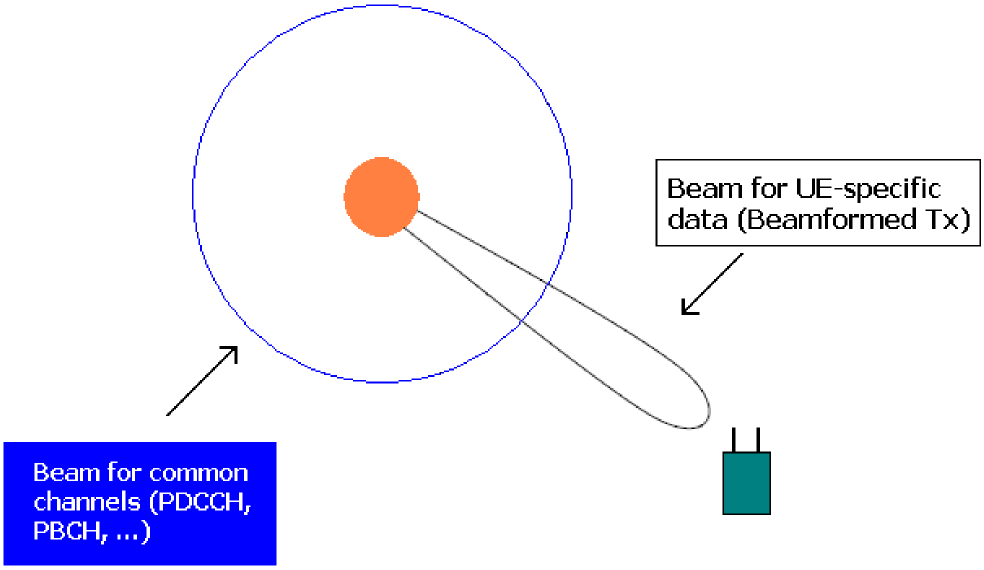

Fig. 4: Beamforming in TM 7; use of UE-specific RS; the common channels use transmit diversity.

There are different algorithms for calculating the optimum beamforming weightings. For example, it is possible to determine the direction of the received uplink signal (direction of arrival [DoA] or angle of arrival [AoA]), and from that to calculate the beamforming weightings. This requires an antenna array in which the individual antenna elements are spaced at a distance of $\mathbf{d \leq \lambda/2}$. It can be difficult to determine the DoA if the angular spread is not small or if there is no dominant direction in the DoA.

Alternatively, it is possible to determine the optimum beamforming weighting from the channel estimation. Because the uplink and downlink take place on the same frequency in a TD-LTE system, the uplink sounding reference signals can be used directly to estimate the channel, which can then be used to derive the weighting for the downlink beamforming. In this case, the beamforming vector is determined by channel estimation, and not from the DoA calculation.

The beamforming calculation is based on the uplink measurement, making calibration of the antenna array and of the RF frontend a major factor in the accuracy of the beamforming.

LTE does not specify any methods for determining the beamforming parameters. Other methods, such as beamswitching, are also available.

TM 8 – Dual-layer beamforming (antenna ports 7 and 8)

While Release 8 of the LTE specification defines beamforming with one layer (as described above), Release 9 specifies dual-layer beamforming. This will permit the base station to weight two layers individually at the antennas so that beamforming can be combined with spatial multiplexing for one or more UEs.

As in TM 7, UE-specific reference signals (DM-RS) are also used here. Since the same resource elements are used for the reference signals in the two antennas, the reference signals must be coded differently so that the UE can distinguish among them. Because two layers are used, both layers can be assigned to one UE (single-user MIMO), or the two layers can be assigned to two separate UEs (multi-user MIMO).

A look ahead to LTE Advanced (Release 10)

Release 10 of LTE (LTE Advanced) brings fundamental changes. In the downlink, the number of antennas is expanded to eight, thus defining transmissions on eight layers. This means that beamforming is also possible on up to eight layers. The new transmission mode 9 expands existing TM 8 to eight antenna ports (AP 7 to 14). It also adds MIMO to the uplink.

1.3 Warning

Very high power occurs on base stations! Be sure to use suitable attenuators in order to prevent damage to the test equipment.

2 LTE Beamforming Measurements

The implementation of beamforming on the base station side makes several special measurements necessary. This includes verifying that the transmission modes are implemented correctly in accordance with 3GPP and that the implemented algorithms perform optimally. These tests require special attention to the phase and amplitude accuracy of the antenna signals in the array. Because the uplink signal is estimated from the downlink antenna weightings, for example, any inaccuracies will directly affect the performance of the beamforming in the downlink. Measurements that ascertain the phase accuracy between the antenna signals are of particular interest.

The base station can perform beamforming in both the transmit and the receive direction; therefore, both directions must be tested.

There are new test requirements from the implementation of TMs 7 and 8 on the UE side, as well. It can be tested how well the UE detects and demodulates a beamformed signal.

2.1 Base Station Transmitter Measurements

Three different solutions are available for base station transmitter measurements; these are described in more detail here. Fig. 5 shows the test point in a block diagram. In addition to the LTE-specific measurements (section 2.1.1), such as the check to ensure that the reference signals were sent correctly in TM 7, it is also possible to measure phase and level independently of any standard (section 2.1.2 and 2.1.3). In this solution, the phase relationships between signals are determined. This makes it possible to check the different signal weightings. This measurement can be performed using either signal analyzers or network analyzers depending on the application or even on the availability of test instruments. Although the test methods described in this application note apply universally, only the LTE-specific settings, such as sampling rates, are discussed here.

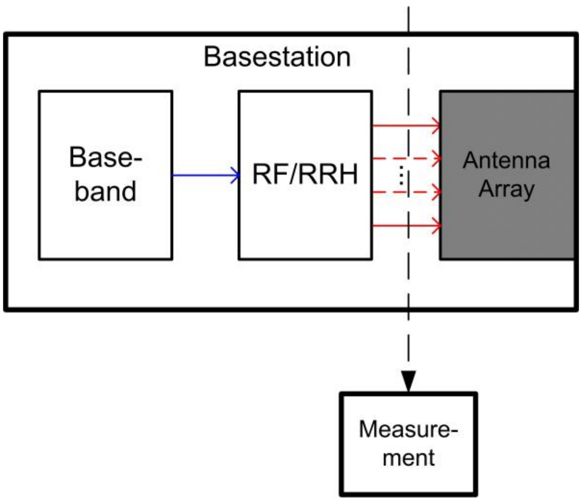

Fig. 5: Block diagram for base station transmitter tests: Measurements are taken in the downlink on the RF module.

2.1.1 Testing Beamforming Using the LTE Analysis Software for Spectrum Analyzers

The LTE analysis software for the R&S FSx signal and spectrum analyzers can be used for the familiar LTE measurements, including power, EVM and spectrum, and also to verify that the beamforming transmission modes are implemented correctly.

In beamforming modes TM 7 and TM 8, both the UE-specific reference signals and the data in the PDSCH are beamformed. All other channels remain unweighted; i.e. they are transmitted with no phase difference (0°).

This means that for the PDSCH and DM-RS, the constellations are rotated based on weighting. Fig. 6 shows an example of two QPSK-modulated signals with the same amplitude that are transmitted with a phase offset over two antennas. Signal 1 on antenna 1 transmits the point at the bottom left (black), and signal 2 on antenna 2 transmits the point at the bottom right (red) with a 90° phase offset. On the receiver, this produces the summation signal shown in the middle (blue).

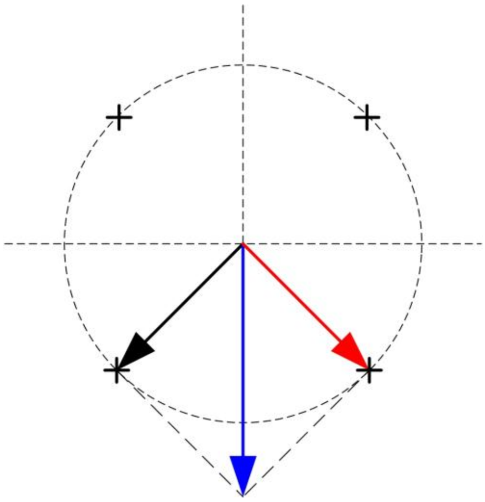

Fig. 6: Example of the weighting of two signals (here with a phase difference of 90°).

As a result, in this example the RS and PDSCH are rotated by 45° for a QPSK signal (Fig. 7).

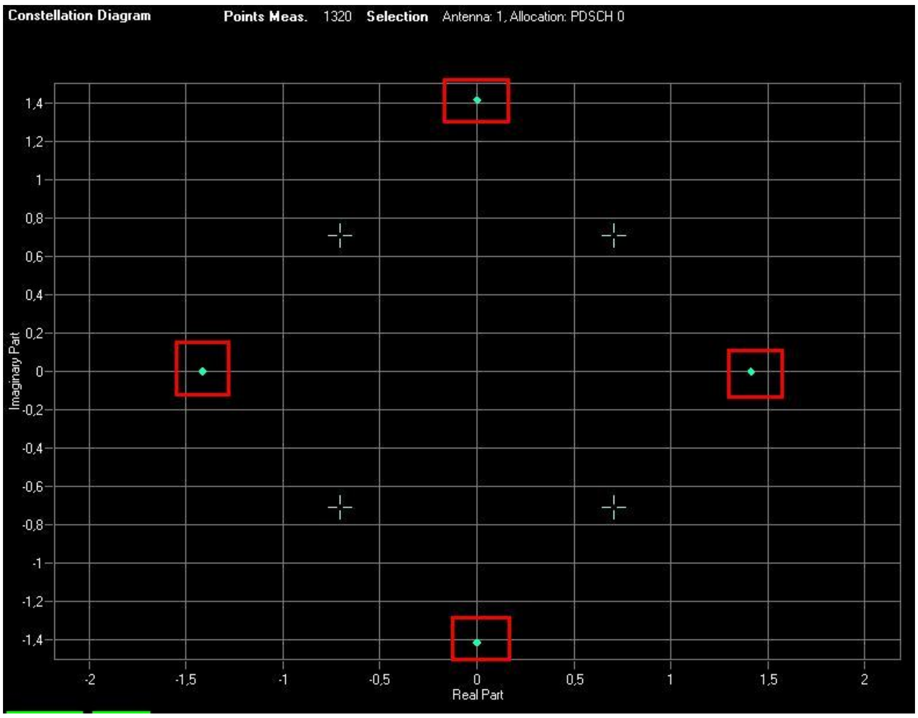

Fig. 7: Resulting 45° phase rotation of a PDSCH allocation at a weighting of 90°.

Testing the individual antennas

Fig. 8 shows the fundamental test setup. The antennas are switched one after the other to the input of an FSx.

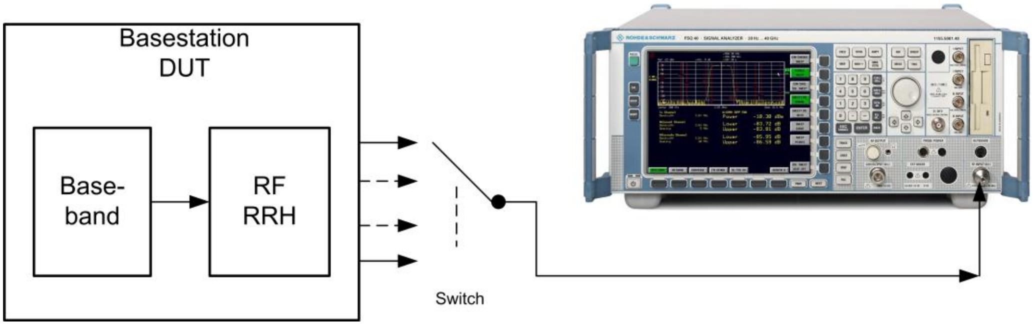

Fig. 8: Test setup for the base station transmitter test with LTE analysis software.

In the **LTE Analysis Software**, open the *Demodulation Settings* dialog box and set the number of antennas (two in this example) in the *MIMO Configuration* section (Fig. 9). If you set transmission mode 7 in the *Enhanced Settings* for an allocation (Fig. 10), the software will calculate the phase offset and rotate the constellation diagrams back to the original points. This makes it possible to demodulate the PDSCH allocations with reference to the DM-RS (Fig. 11). It also allows multiple different beamformed allocations to be analyzed. All standard measurements can be performed.

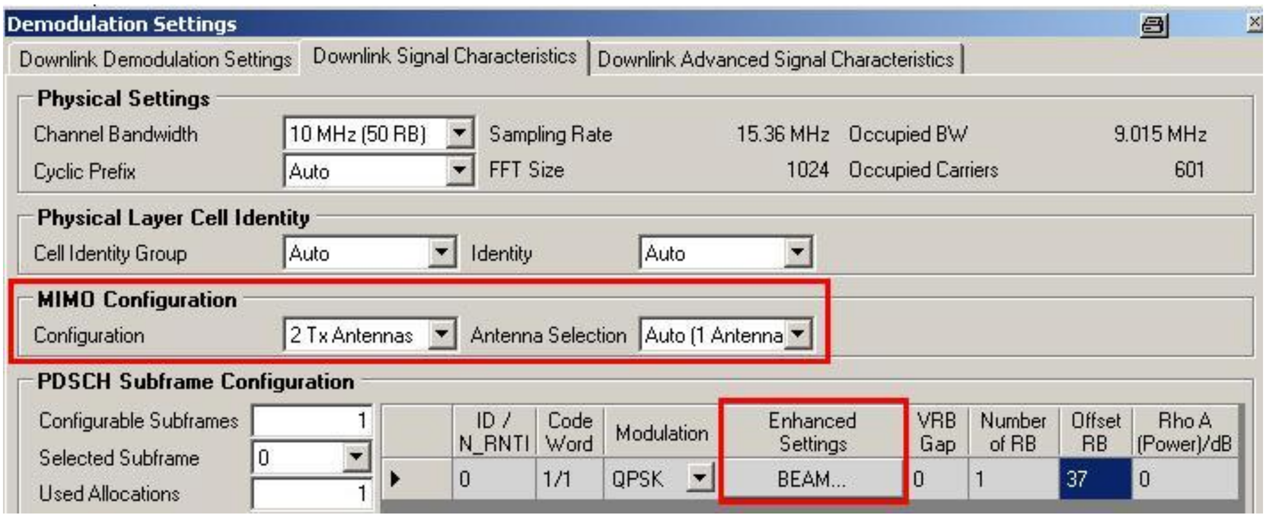

Fig. 9: Beamforming settings in the LTE analysis software for the FSx; TM 7 in this example.

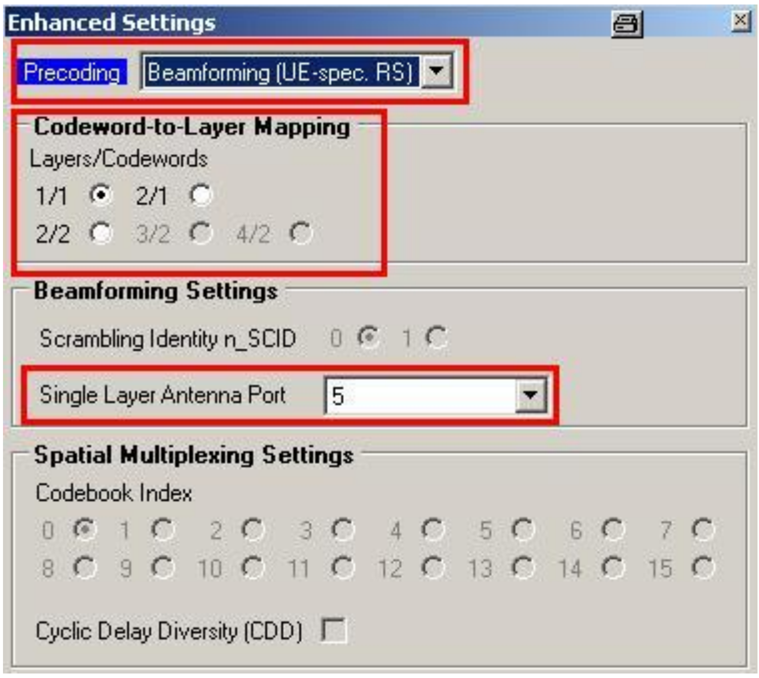

Fig. 10: Additional settings. The precoding is set to beamforming (UE-specific RS). In TM 7, a codeword is mapped to a layer at antenna port 5.

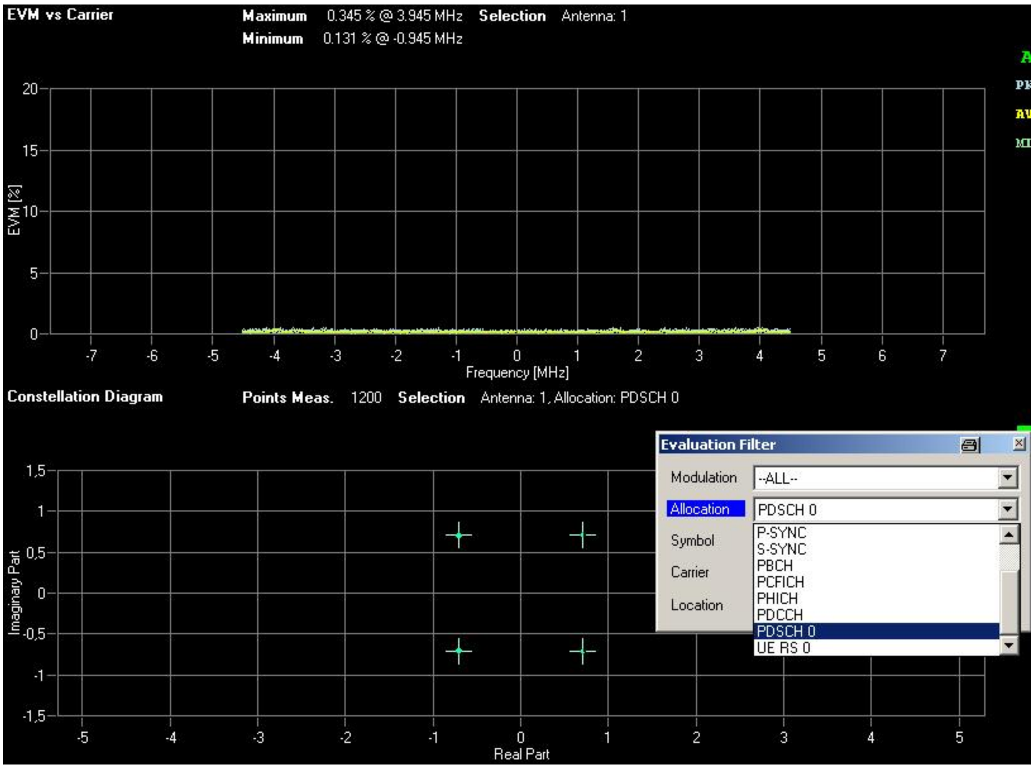

Fig. 11: EVM measurement on antenna 1 and constellation diagram of a beamformed QPSK-modulated data allocation (PDSCH) in summary.

Power measurement on all antennas for beamforming test

The beamforming can be checked based on level by interconnecting all antennas together at the FSx input (Fig. 12).

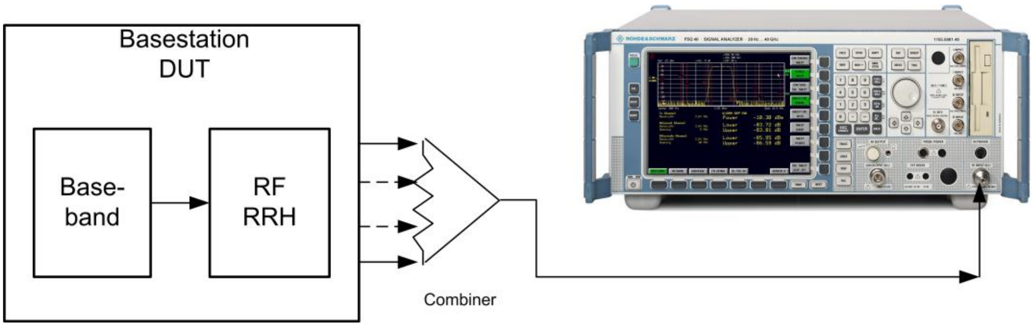

Fig. 12: Test setup for measuring the beamforming level. All antennas are brought together using a combiner.

The levels of the individual channels are displayed in the Allocation Summary. However, the EVM is not meaningful in this situation because, with the exception of the beamformed signals, the antenna signals are overlaid. If these antenna signals have a phase difference of 0°, the FSx receives all signals as if it were located directly in front of the antenna array.

In the example, the PDSCH and RS are weighted with 90°, which means that the beam from the PDSCH and RS does not point toward 0°. The RS are orthogonal so that the level stays constant (e.g. -58.5 dBm in the screenshot). The SYNC channels are transmitted with a phase difference of 0°, that means double the power (6 dB more than the RS: -52.4 dBm). The PDSCH (in example 90°) is in summary 3 dB higher than the RS (-55.4 dBm) (Fig. 13). (Note that the control channels PBCH, PCFICH and PDCCH are coded with TX diversity and therefore cannot be correctly analyzed in this test setup.) Changes to the beamforming settings (i.e. the weightings for PDSCH and RS) will directly affect the level of the PDSCHs.

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Allocation Summary   Selection Antenna: 1

Sub-frame	Allocation ID	Number of RB	Rel. Power/dB	Modulation	Power per RE/dBm	EVM/%
0	RS Ant1		0,000	QPSK	-58,503	0,302
	RS Ant2		0,000	QPSK	-58,501	100,019
	P-SYNC		0,000	CAZAC	-52,434	100,126
	S-SYNC		0,000	RBPSK	-52,433	100,148
	PBCH		0,000	QPSK	-55,448	99,928
	PCFICH		0,000	QPSK	-55,523	99,869
	PDCCH		0,000	QPSK	-55,491	86,782
	PDSCH 0	1	0,000	QPSK	-55,410	0,246
	UE RS 0		0,000	QPSK	-55,405	0,111
	ALL	1				81.396

Fig. 13: Channel summary. The level of the beamformed channels PDSCH and RS is therefore lower than the sync channels in this example.

TM 8

In TM 8, the individual antennas can also be measured as described above. To do this, set two layers/codewords in the Enhanced Settings. The two code words are automatically prefilled in the Demodulation Settings (Fig. 14 and Fig. 15). Fig. 16 shows an EVM measurement and a constellation diagram.

Note: Version 2.7 of the LTE analysis software does not allow compensation of layers with mixed weightings (Compensate Crosstalk). As a result, EVM and constellation diagrams for the PDSCH cannot be evaluated.

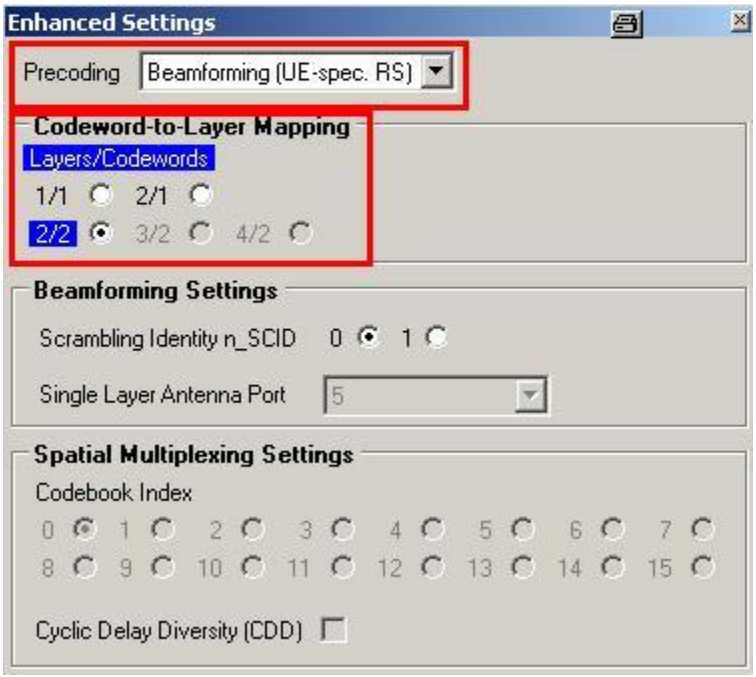


Fig. 14: Additional settings. The precoding is set to beamforming (UE-specific RS). In TM 8, two codewords are used in two layers and mapped to antenna ports 7 and 8.

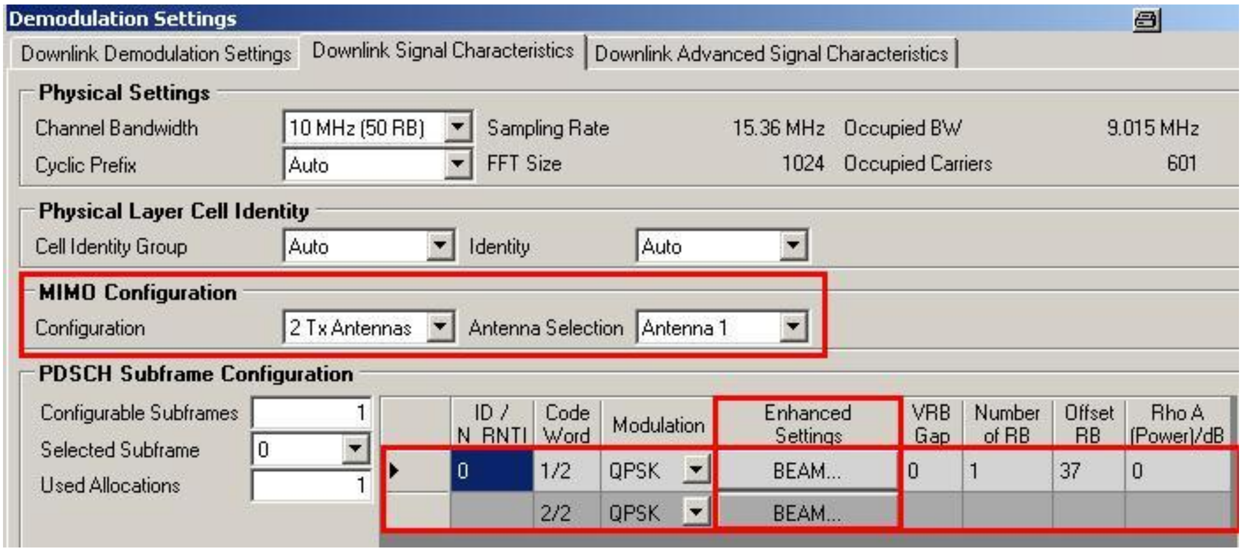


Fig. 15: Beamforming settings in the LTE analysis software for the FSx; TM 8 in this example. In dual-layer beamforming, two layers (codewords) are used.

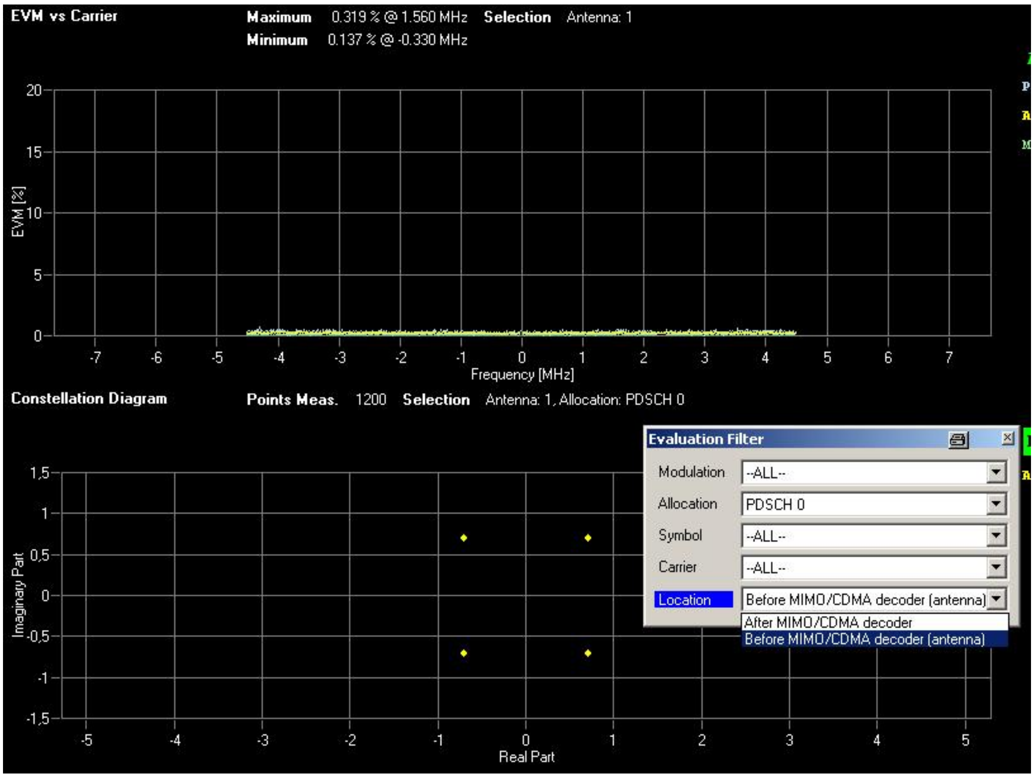


Fig. 16: Summary EVM measurement on antenna 1 and constellation diagram of a beamformed QPSK-modulated data allocation (PDSCH) in TM 8.

2.1.2 Phase Measurements Using Vector Signal Analyzers

The FS-Z10 coherence unit can be combined with two FSx to measure phase, timing and gain for two RF signals without reference to any communications standard. The settings for LTE signals are described here. Refer to **Coherence Measurement between two Signals regarding Timing, Phase and Gain** [2] for a more detailed description. The FS-Z10 returns a value that describes the phase difference between two signals, averaged over the bandwidth. Please note that **no** continuous wave (CW) signals can be measured.

Fig. 17 shows the fundamental configuration.

The following are required:

- Signal analyzer: FSQ, FSG, or FSV as the first analyzer
- Signal analyzer: FSQ, FSG, FSV, or FSL as the second analyzer
- Signal generator: SMU or SMBV as the reference signal generator
- FS-Z10 coherence unit
- **R&S FS-Z10 coherence unit software** for convenient control of the test setup
- LAN cable and hub
- BNC cable

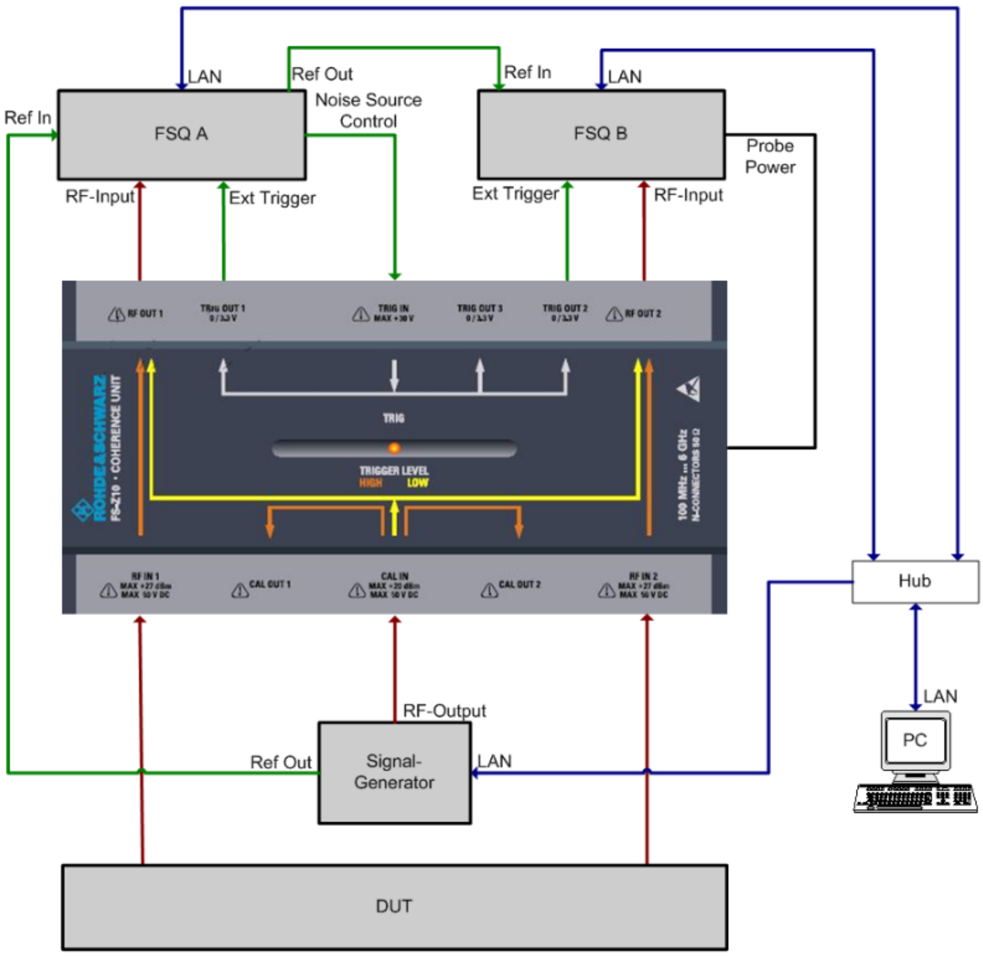


Fig. 17: Test setup for phase determination between two signals using the FS-Z10.

If more than two signals are to be measured, the instrument must switch between the signals so that the measurements are carried out consecutively. Rohde & Schwarz offers the OSP open switch and control platform for this purpose (see section 2.1.4).

Cable calibration

A calibration is then performed with the cables in use. High-accuracy data is available for every FS-Z10 on the R&S website (see [2] for more information).

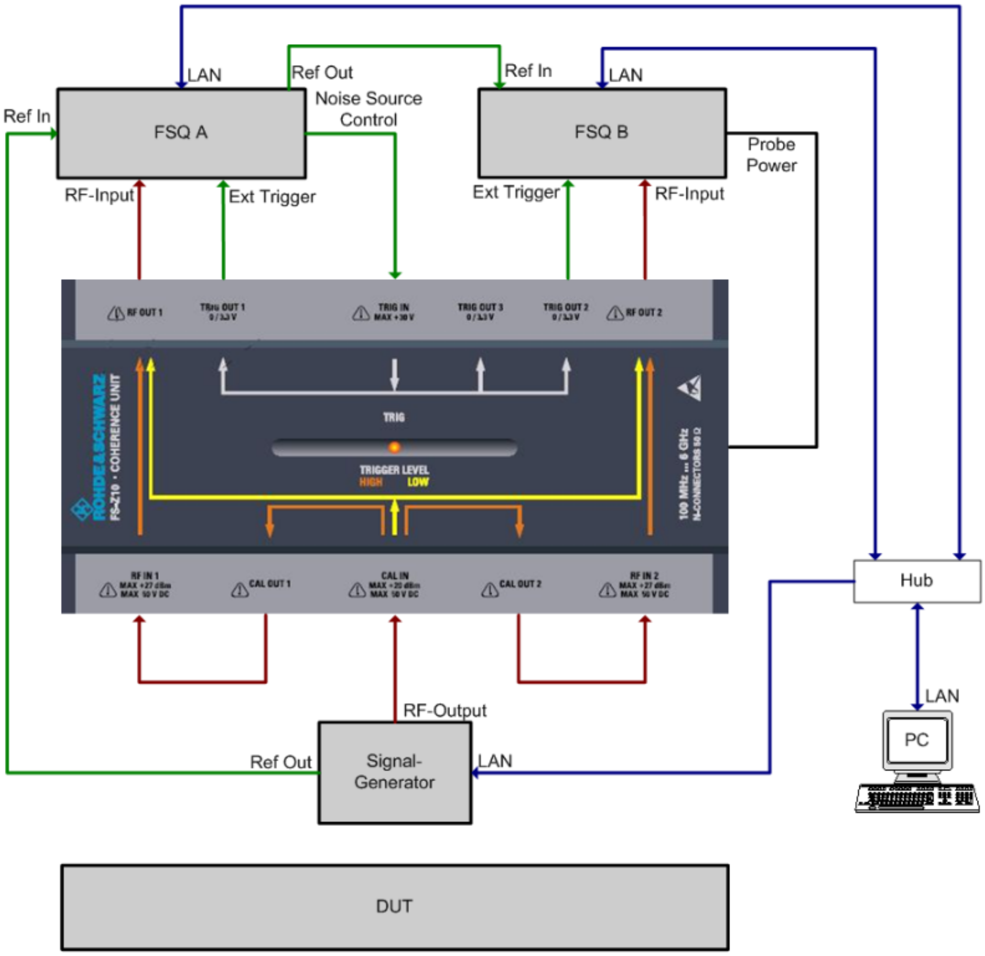


Fig. 18: Test setup for cable calibration with the FS-Z10.

After being launched, the FS-Z10 coherence control software application is displayed as shown in Fig. 19. Take a look at the Calibration Status field. The red UNCAL indicates that cable calibration is required. To do this, first click the Settings button to set the frequency and the sampling rate (Fig. 20).

Fig. 19: Main screen for the FS-Z10 software.

For LTE, the sampling rate should be set based on the bandwidths.

Sampling rates for LTE	
Bandwidth in MHz	**Sampling rate in MHz**
1.4	1.92
3	3.84
5	7.68
10	15.36
15	30.72
20	30.72

Table 3: Sampling rates for LTE.

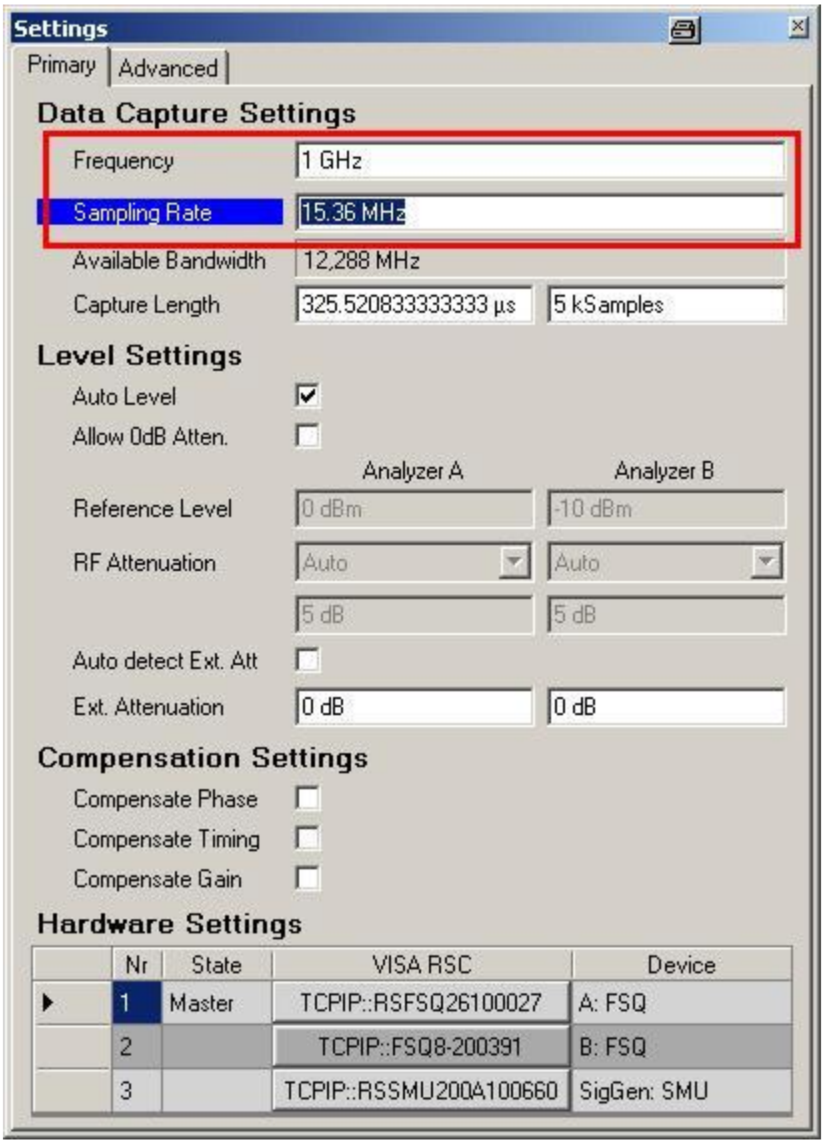


Fig. 20: Setting the frequency and sampling rate. The sampling rate should correspond to the LTE sampling frequencies (see Table 3).

Click Calibrate to set a reference signal on the generator and to start the calibration. The time of the last calibration should now be displayed in green in the Calibration Status field.

After reconfiguring the setup from calibration to test (Fig. 17), click RUN SGL to start the measurement. Fig. 21 shows the result screen.

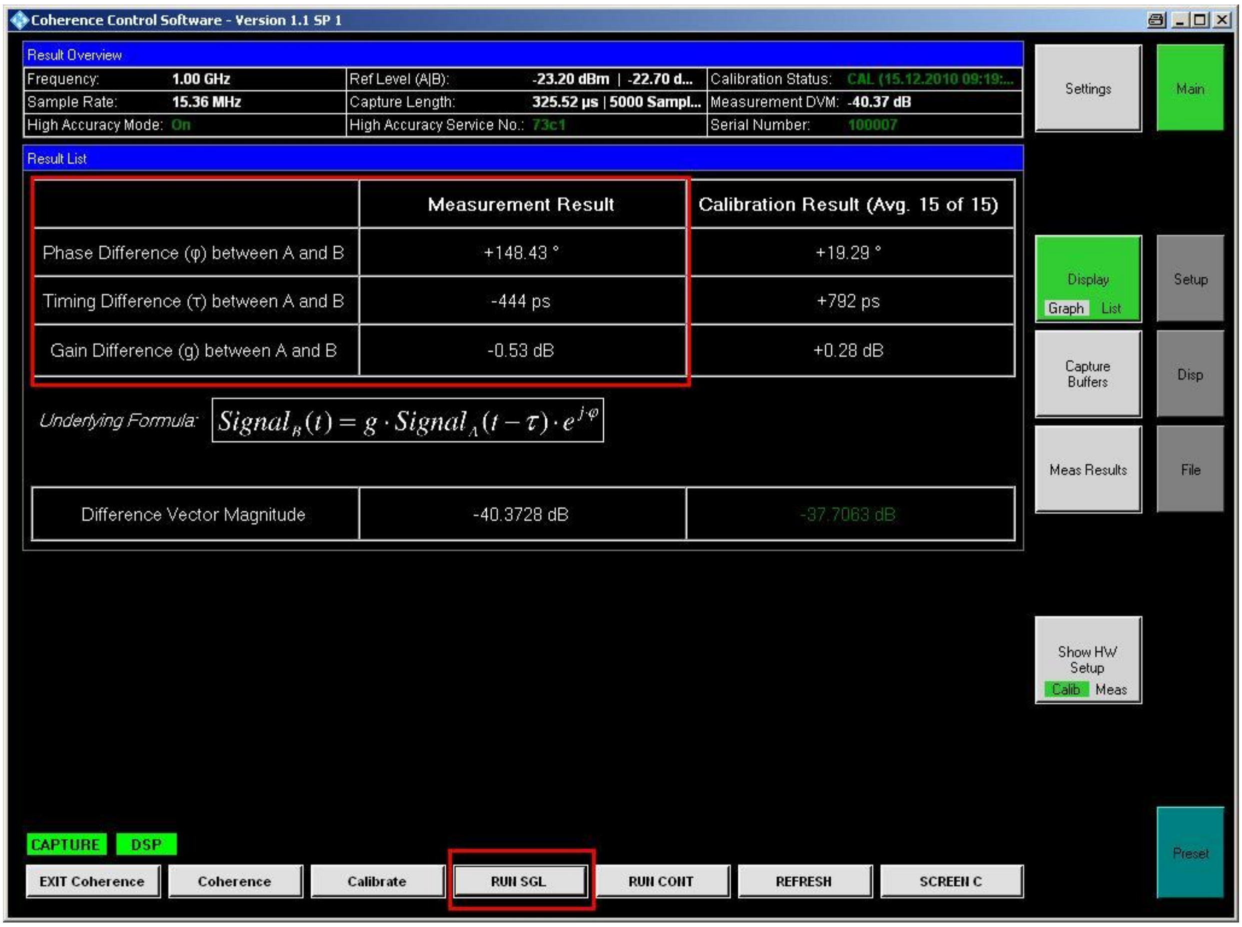


Fig. 21: Measurement using the FS-Z10: Click RUN SGL to start the measurement. The phase, timing and gain differences are displayed.

The software also allows the measured differences to be compensated and the results stored as I/Q data.

2.1.3 Phase Measurements Using the Vector Network Analyzer

A vector network analyzer (VNA) such as the ZVx offers more extensive test options, while still providing the same functionality for measuring the phase difference as the solution described in section 2.1.2. It also allows signals to be measured independently of any standard. Because the relationship among multiple LTE signals is being measured, the internal ZVx generators remain switched off. The ZVx also calculates the phase trace over the entire bandwidth of the signal.

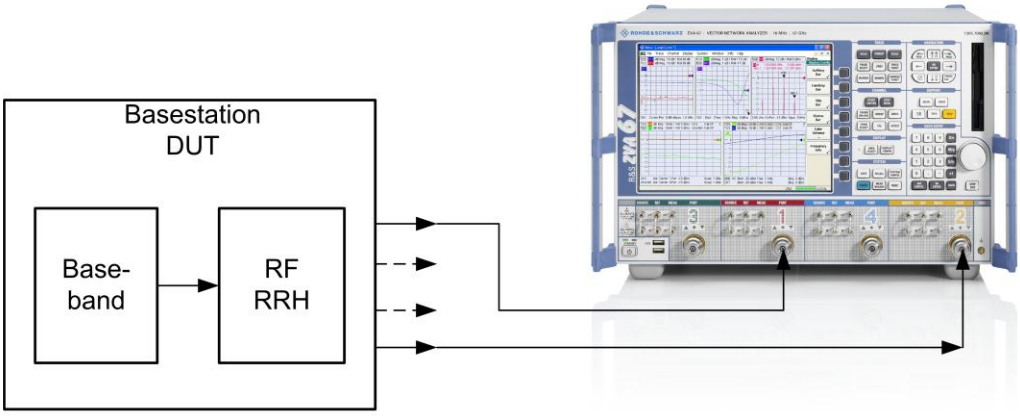


Fig. 22: Transmitter test setup with the ZVx network analyzer. Depending on the model, up to eight RF paths can be measured simultaneously.

The user has several ways to operate the instrument (using the software menu, hard keys, or soft keys).
These detailed instructions and comments describe how to measure two signals:

- Set a ratio measurement of the phases for ports 1 and 2:
1. TRACE|MEASURE|RATIOS| b1/b2 Src Port1
2. TRACE|FORMAT|PHASE

- Set the frequency and bandwidth. The LTE occupied BW can be used as the bandwidth (e.g. BW 10 MHz downlink -> occupied BW 9.015 MHz)
3. CHANNEL|STIMULUS|CENTER <Frequency>
4. CHANNEL|STIMULUS|SPAN <Bandwidth (Occupied BW)>

- Switch off the internal ZVx generators and then select the measurement bandwidth (10 kHz) and an averaging factor (e.g. 20)
5. CHANNEL|POWER BANDWIDTH AVERAGE|RF OFF (ALL CHANS)
6. CHANNEL|POWER BANDWIDTH AVERAGE|MEAS BANDWIDTH|10 KHz
7. CHANNEL|POWER BANDWIDTH AVERAGE|AVERAGE ON
8. CHANNEL|POWER BANDWIDTH AVERAGE|AVERAGE FACTOR <20>

- Set the test point offset to 15 kHz (corresponds to offset from carrier in LTE)
9. CHANNEL|SWEEP|FREQUENCY STEP SIZE <15 KHZ>

- An external trigger must be used for TDD mode
10. CHANNEL|SWEEP|TRIGGER EXTERNAL

The phase trace over the entire bandwidth is now displayed on the ZVx screen, but it is not yet calibrated for physical influences such as varying cable lengths.

Calibrate any errors (e.g. influences from cables) by storing a reference and applying the measurement to it.
11. TRACE|TRACE FUNCT|DATA->MEM
12. TRACE|TRACE FUNCT|MATH=DATA/MEM

You now see a calibrated phase trace.

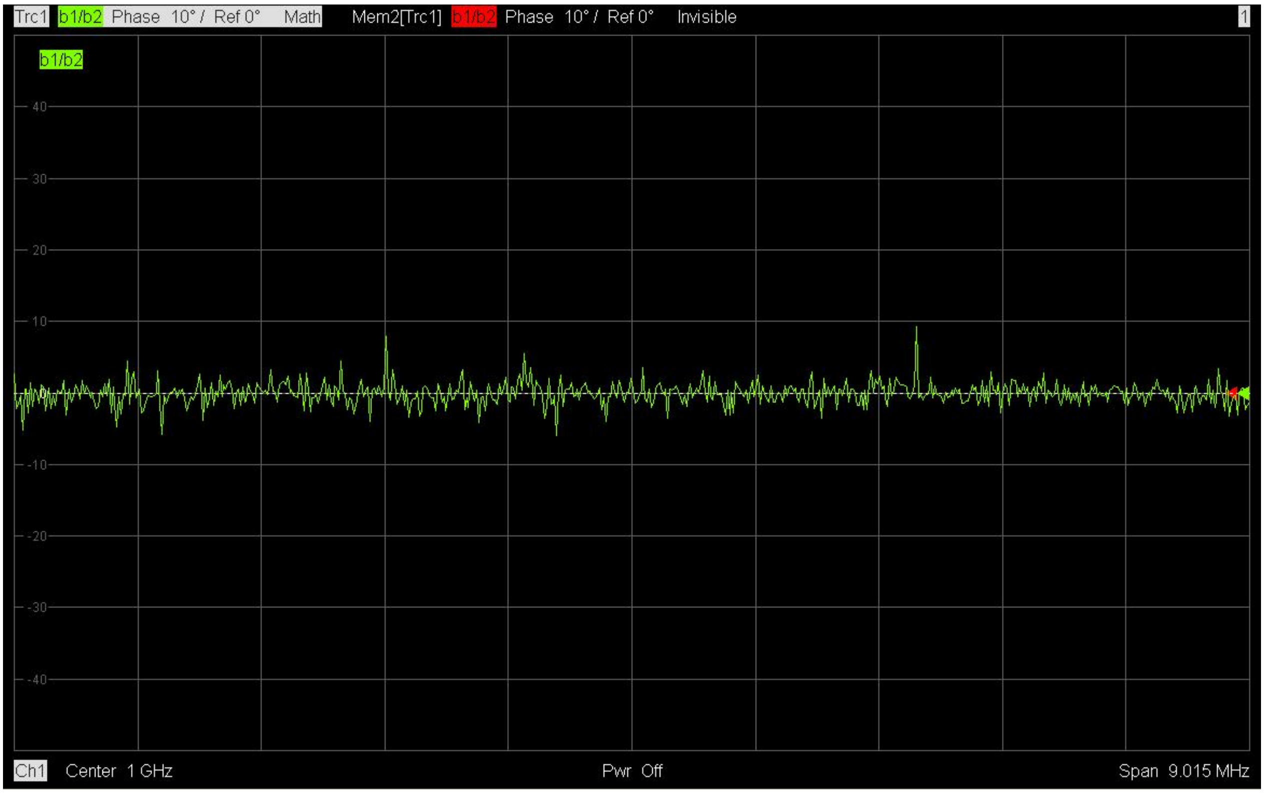


Fig. 23: Calibrated phase trace in ZVx. The display shows the phase ratio for two LTE signals over the complete occupied bandwidth of a 10 MHz signal (50 RBs). In the example, the phase difference between the two signals is 0°.

You can now set various phases on the DUT. Rescale the display area as needed using one of the following:

13. TRACE|SCALE AUTO SCALE or
14. TRACE|SCALE|SCALE/DIV <value>

2.1.4 OSP Open Switch and Control Platform

If the phase relationships for more than two signals are to be considered using the FS-Z10 option for the FSx, for example, the measurements must be carried out one after the other using an RF switch. Rohde & Schwarz offers the OSP open switch and control platform for this purpose. The OSP can switch up to six signals of up to 40 GHz on modules having different RF switch configurations. Fig. 24 shows an example with eight antennas and the FS-Z10. Model OSP130 also allows signal paths to be set manually.

You can find more information on the OSP webpage.

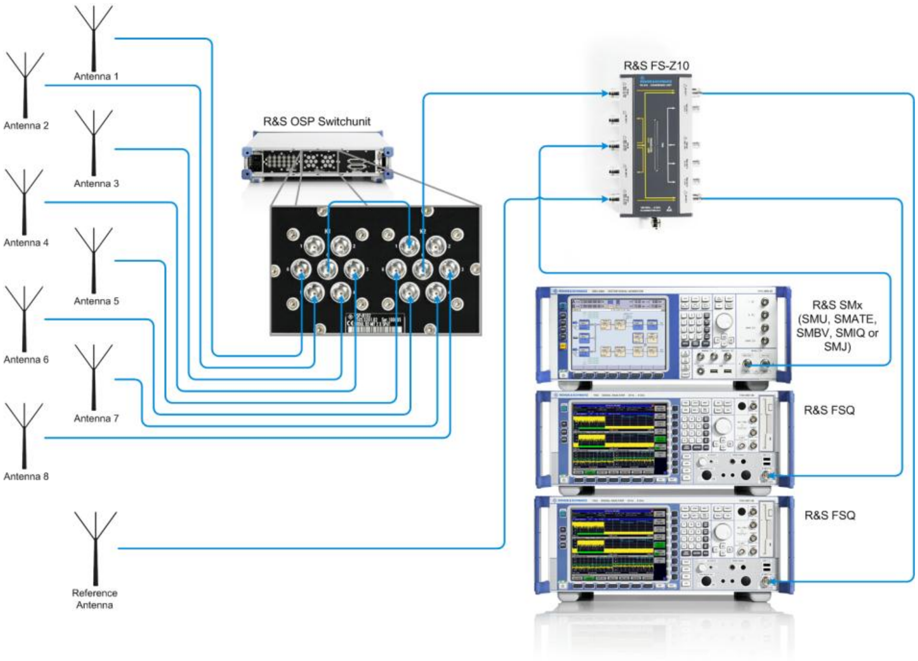


Fig. 24: Example of a test setup with the OSP.

2.2 Base Station Receiver Test: Provision of Uplink Signals

The generation of RF signals with a defined and stable phase relationship is of particular importance for the verification of beamforming algorithms because these signals can be used to achieve reproducible test conditions. To test the base station receiver or the algorithms (e.g. AoA) in the receiver, use an SMU signal generator to generate two LTE uplink signals with adjustable phase relationships. Multiple generators can be linked together to generate more than two RF signals.

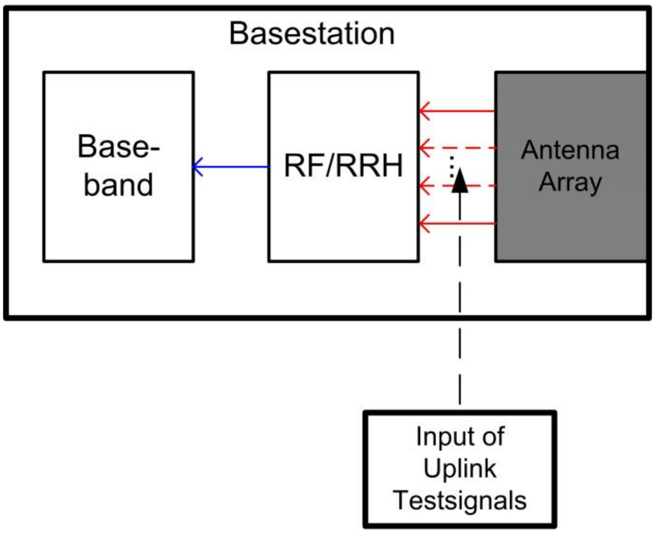


Fig. 25: Block diagram for base station receiver tests: Generation of the uplink signals on the RF module.

The following conditions must be adhered to:

- When there are multiple generators, there must be a common reference frequency for all generators
- Identical LTE uplink signals must be present in the basebands
- All basebands must be synchronized
- Phase coherence must be maintained between all RF outputs (this is ensured by the SMx-B90 **phase coherence** option)

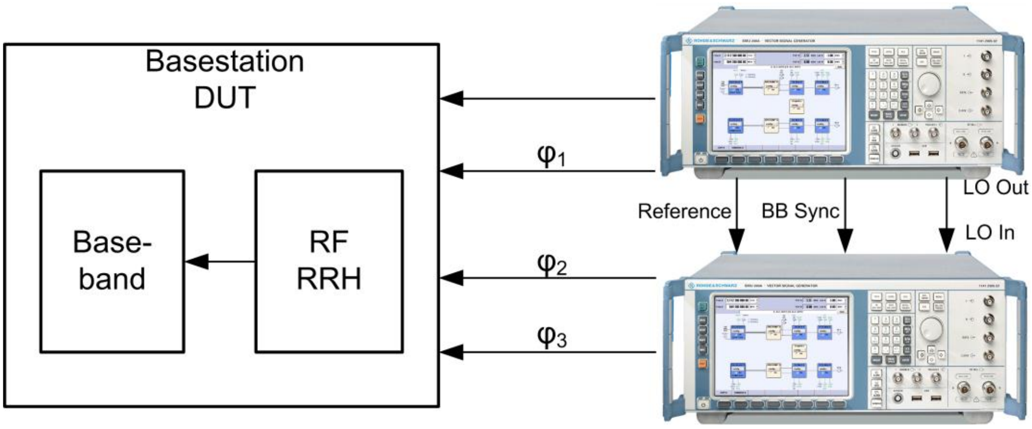


Fig. 26: Example of base station receiver test setup for four RF paths with a phase offset φ generated by two SMUs.

Fig. 26 shows the basic test setup for a base station receiver test for four RF paths generated by two SMUs. Alternatively, signal generators with only one RF path may be used, such as the SMJ or the SMBV (four each in this example).

The generated LTE uplink signals must be identical and can be provided with a phase offset in the baseband.

First, set the desired LTE uplink signal exactly the same in all basebands.

The baseband blocks must also be synchronized in the SMU if the signals are to be transmitted simultaneously. In this case, all basebands (basebands 2 to 4 in this example) are triggered at the start of the first baseband (BB1). To do this, enable BB1 last.
Set the trigger mode for basebands 2 to 4 to **Armed Auto** (Fig. 28). Define the trigger source in the Source field:

- When synchronizing within one SMU, select **Internal** (Baseband A) (Fig. 28).
- When synchronizing across instruments, select Source **External (Trigger 1)** (Fig. 28). The selected trigger is the baseband A restart (Fig. 27), which is fed via a BNC cable from the Marker 1 output of the first instrument to the Trigger 1 input of the second instrument.

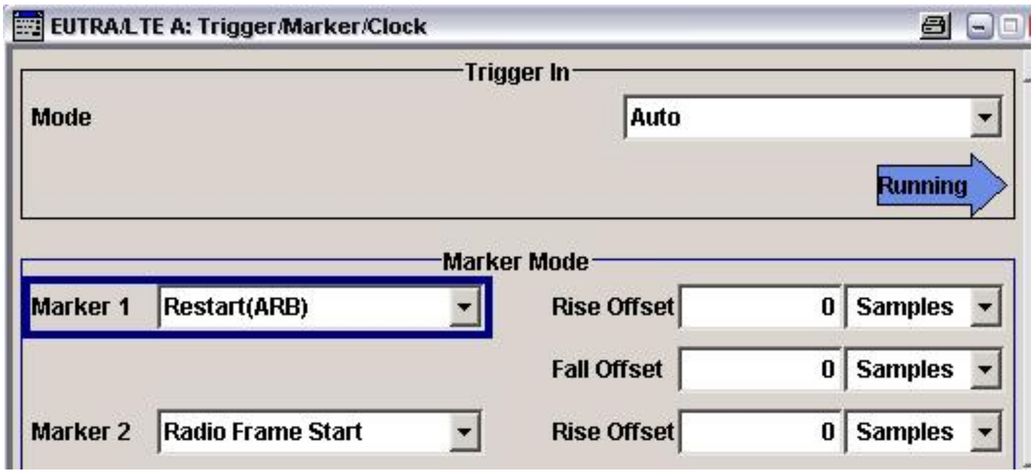


Fig. 27: BB1 marker for synchronizing the remaining basebands.

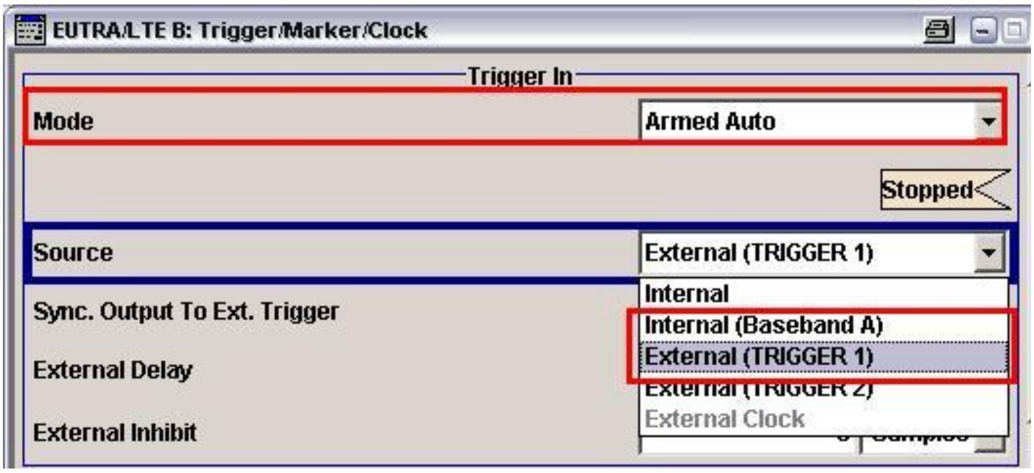


Fig. 28: Synchronizing baseband B to baseband A. Armed Auto is selected as the trigger mode, and the SMU-internal baseband A is used as the source. Enable BB A to start both BBs synchronously.

Phase-coherent generation

The SMx signal generators use the SMx-B90 option to support phase-coherent generation of multiple signals. The signal paths within one instrument can be coupled together, as can multiple instruments. The SMx-B90 option includes hardware that can be used to couple the local oscillators (LO). The LOs are coupled internally via a two-channel instrument (SMU, SMATE). Multiple instruments (SMU, SMATE, SMJ, SMBV) can be coupled via the appropriate LO IN/OUT jacks (located at the back of the instruments) (Fig. 29).

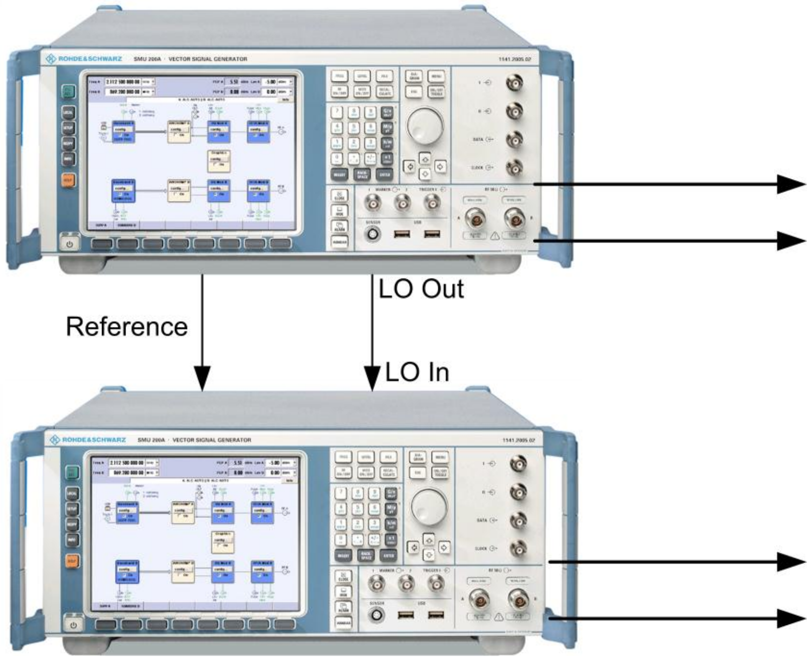


Fig. 29: Linking multiple instruments for phase coherence.

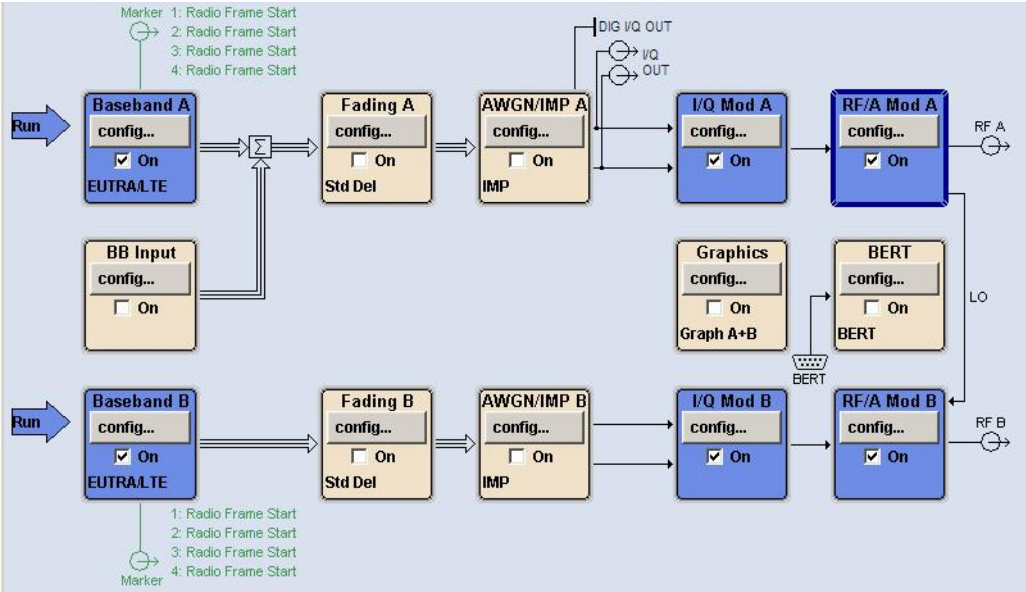


Fig. 30: SMU overview with active SMx-B90 phase coherence option. The LO line between the two RF blocks represents the coupling.

Fig. 31 shows how to enable phase coherence. In the second RF block, select **LO Coupling**. Set the coupling based on instrument configuration in the *Mode* field:

- Within an SMU: *Coupled A->B*
- For a single-channel instrument such as the SMBV or SMJ: *External*
- For a two-channel SMU: *External Coupled A->B*.

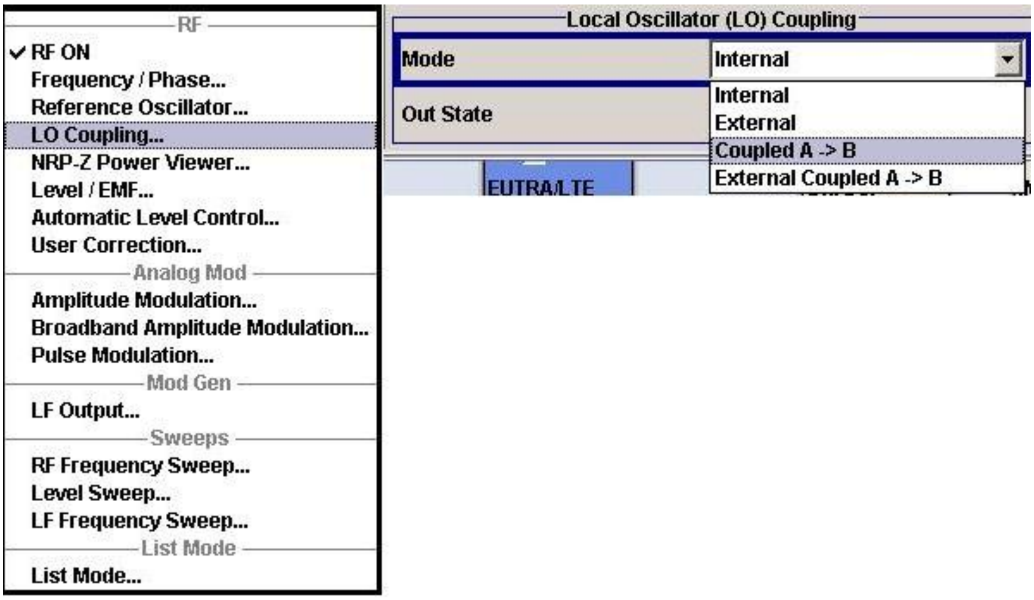


Fig. 31: Enabling phase coherence in the second RF block.

Important note:
In this case, phase coherence means that the phase difference between two signals is fixed, but not 0°. This fixed, base phase difference (measurable using the FS-Z10 or ZVx, for example) has to be taken in account either when defining the settings on the generator or during the measurement itself.

For more information on the SMx-B90 phase coherence option, refer to **Phase Adjustment of Two MIMO Signal Sources with Option B90** [1].

The desired phase offsets can now be set in the individual basebands (Fig. 32).

Fig. 32: Setting a phase offset in baseband B. Both RF paths are coupled via the SMx-B90. Therefore, the phase difference results from the baseband also defined in the RF.

2.3 UE Receiver Test: Provision of Downlink Signals

Although beamforming is a base station function, the UE receiver must also be able to understand a beamformed signal. The SMx provides predefined test signals that meet and exceed the tests defined in specification TS36.521-1, Chapter 8.3 [6]. In addition to the required precoding, the SMU can also perform realtime fading (predefined profiles based on the specification), fading for MIMO setups (e.g. 2x2 and 4x2) and AWGN simulation.

One SMU can be used to simulate two antennas, and two interconnected SMUs can simulate up to four antennas. Please note that LTE Release 9 and therefore beamforming mode TM 8 require an additional software option in the SMx:

- Option SMx-K55: Digital standard LTE/EUTRA (Release 8): TM 7
- Option SMx-K84: Digital standard LTE/EUTRA (Release 9): TM 8

Fig. 33 shows the test setup with one SMU. Configurations with four TX antennas require two connected SMUs.

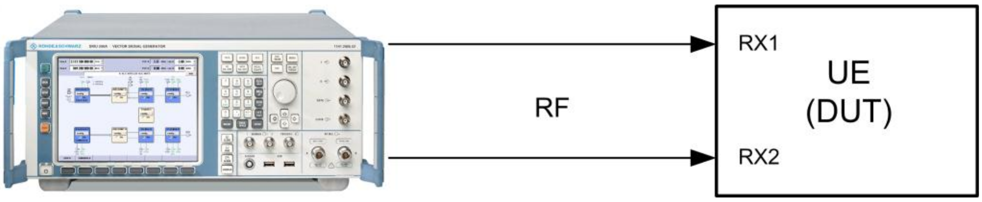


Fig. 33: Block diagram for the UE receiver test; this example shows two antennas.

Virtual antenna ports (AP) – physical antennas

The specification covers virtual antennas (called antenna ports) based on the cell configuration:

- Port 0 to 3: Cell-specific reference signals (CS-RS)
- Port 4: MBSFN-RS
- Port 5: UE-specific reference signals (DM-RS): single-layer (TM 7)
- Port 6: Positioning reference signals (PRS)
- Port 7 and 8: UE-specific reference signals (DM-RS): up to two layers (TM 8)

The number of physical antennas in a base station is not defined. However, a minimum number can be specified. The number of physical antennas must match or exceed the number of layers to be transmitted. Therefore, a transmission with four layers needs at least four physical antennas.

Up to Release 9, the SMU can simulate up to four antennas (two SMUs are needed for four physical antennas). This requires that the antenna ports on the SMU be mapped to the physical RF ports (antennas). For beamforming modes TM 7 and TM 8, AP 5 or AP 7/8 must therefore be mapped to the physical RF ports on the SMU.

In the **General DL Settings** section, set the *PDSCH Scheduling* field to *Auto/DCI* (downlink control indicator). This allows the beamforming settings to be adjusted easily (in a more detailed screen), and the associated PDSCH settings are defined automatically. These settings are transmitted live in the PDCCH. You should also set the number of antennas to be simulated in the *Global MIMO Configuration* field. Up to four antennas are available. The individual basebands of the one or two SMUs then generate the signals for the individual antennas.

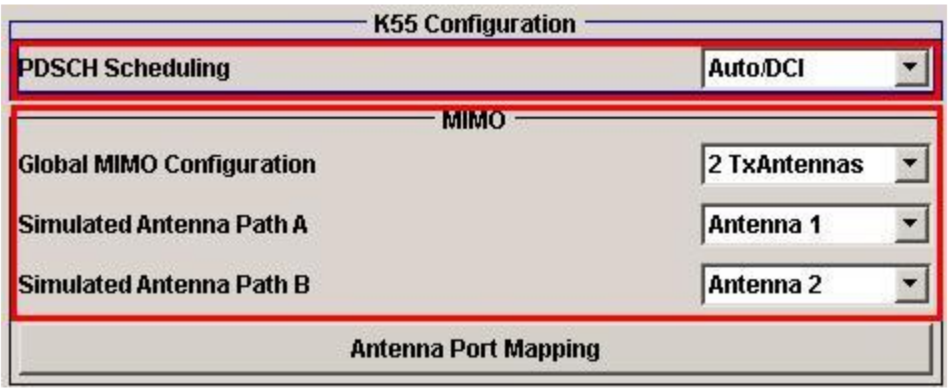


Fig. 34: Number of antennas and assignment to the individual basebands in the SMU.

In the **Frame Configuration** screen (Fig. 35), click *Configure User*. You can now make additional settings related to beamforming. Set the desired transmission mode (TM 7 or 8).

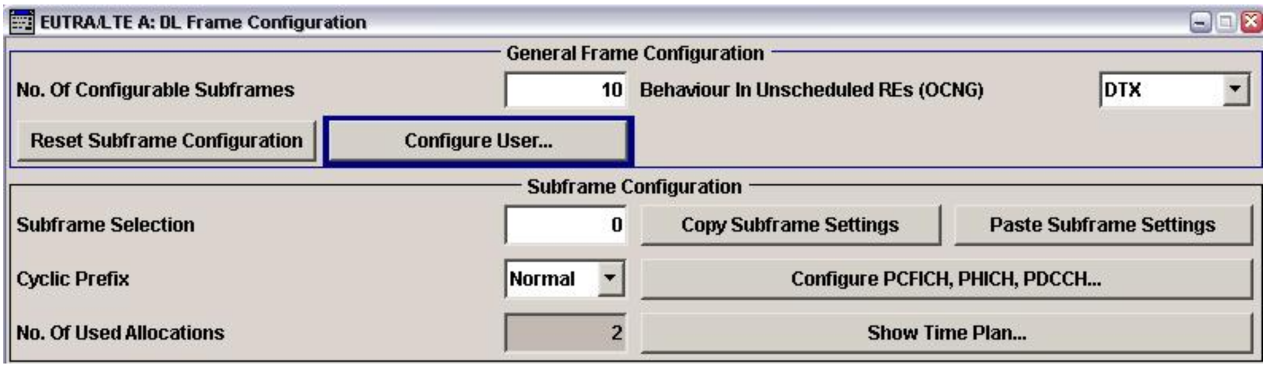


Fig. 35: Frame Configuration screen in the SMU.

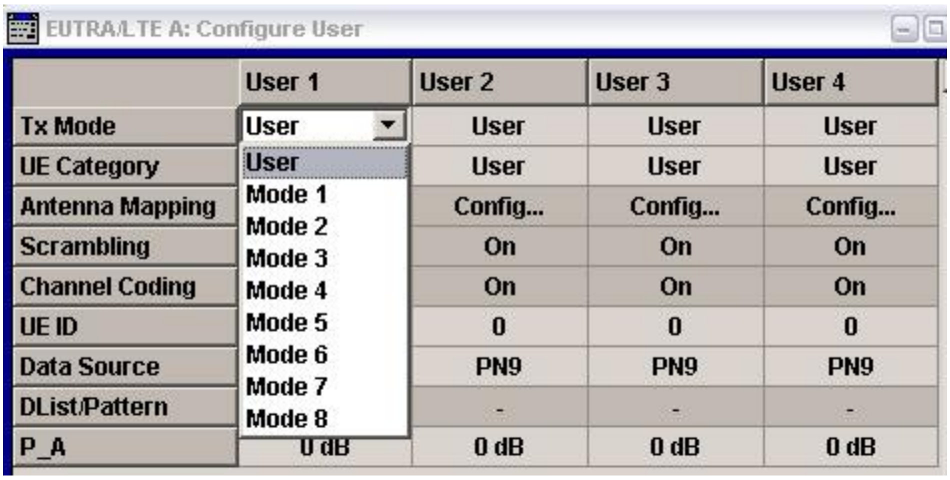


Fig. 36: Set the transmission mode in the Configure User screen. TM 7 and TM 8 apply to beamforming.

Although TM 7 and TM 8 operate fundamentally the same, they are discussed separately below.

2.3.1 Transmission Mode 7

In TM 7, the SMU performs beamforming with the corresponding reference signals (DM-RS) by dividing one layer (codeword) over two or four antennas. Virtual antenna port (AP) 5 is mapped based on the physical antennas.

To use Auto/DCI mode, additional settings must first be made in the PDCCH control channel. Click *Configure PCFICH, PHICH, PDCCH* to make these settings.
The lower section of the screen lists the settings for the PDCCH (Fig. 37). TM 7 defines DCI formats 1A and 1 in accordance with [Table 7.1-5 from 8]. Signal AP 5 with DCI format 1 is used here.

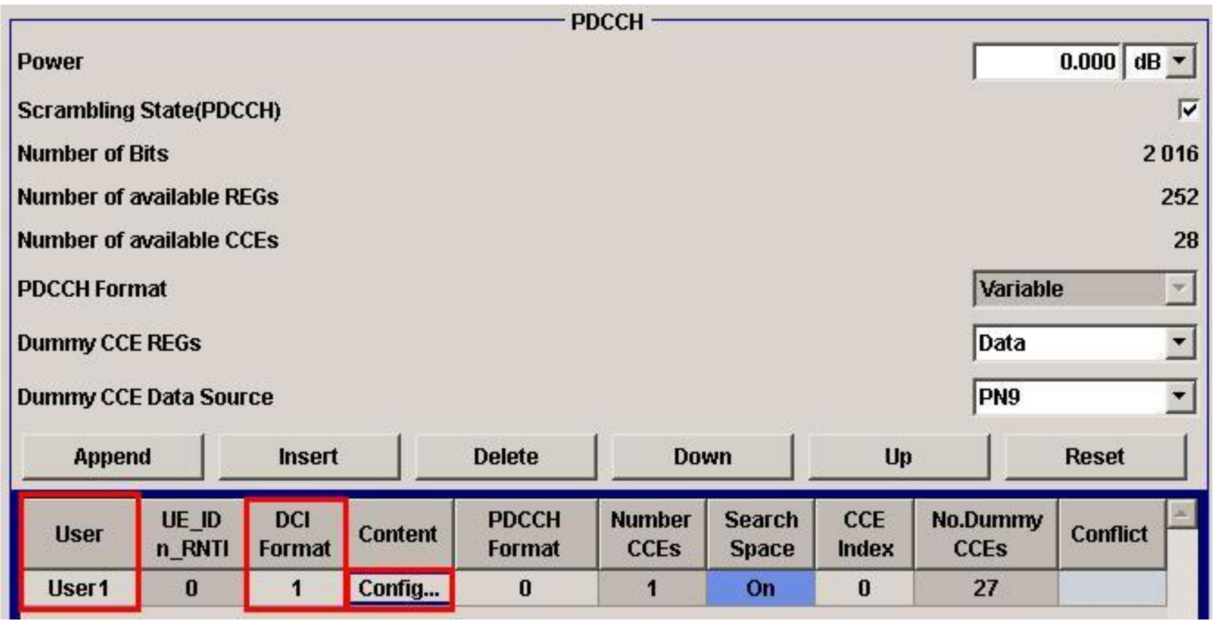


Fig. 37: Setting the DCI format in the PDCCH for TM 7: DCI format 1.

The data to be transmitted in the selected DCI format, and thus also the PDSCH settings, can be further configured by clicking *Config Content*. The transmitted bit pattern for the defined settings can be read in the bottom *Data* section (Fig. 38). The number and position of the resource blocks (RBs) can be set via *Resource Block Assignment*, while the modulation is set via *Modulation and Coding Scheme* [9].

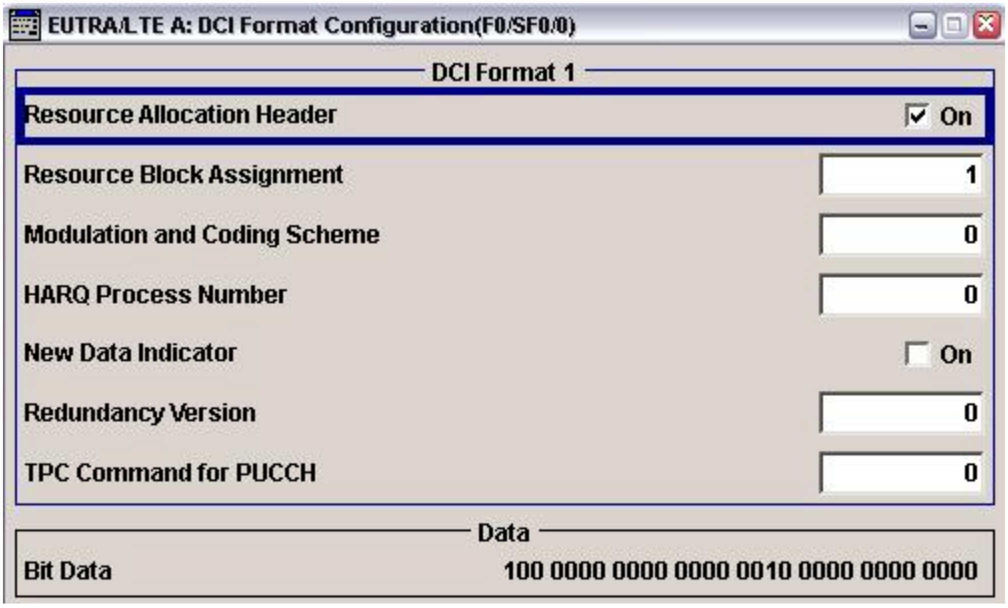
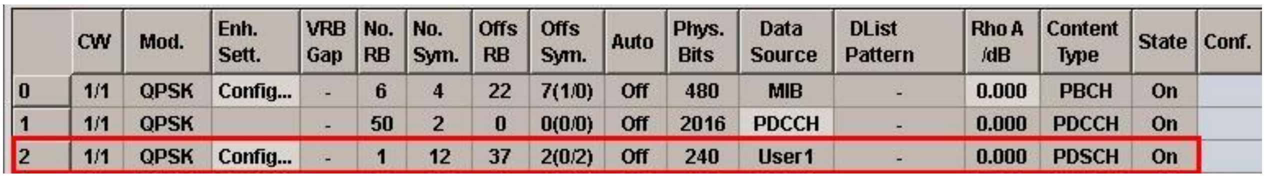


Fig. 38: Example configuration of DCI format 1 for TM 7.

In Auto/DCI mode, the PDSCH settings are prefilled automatically based on the parameters defined here (Fig. 39). The desired settings are also displayed in the timeplan (Fig. 40).



	CW	Mod.	Enh. Sett.	VRB Gap	No. RB	No. Sym.	Offs RB	Offs Sym.	Auto	Phys. Bits	Data Source	DList Pattern	Rho A /dB	Content Type	State	Conf.
0	1/1	QPSK	Config...	-	6	4	22	7(1/0)	Off	480	MIB	-	0.000	PBCH	On	
1	1/1	QPSK		-	50	2	0	0(0/0)	Off	2016	PDCCH	-	0.000	PDCCH	On	
2	1/1	QPSK	Config...	-	1	12	37	2(0/2)	Off	240	User1	-	0.000	PDSCH	On	

Fig. 39: Example of an automatically defined PDSCH allocation in Auto/DCI mode (data source of the defined PDSCH allocation is set to User 1; in this example using Resource Block Assignment 1 and Modulation and Coding Scheme 0 (MCS 0), one RB is allocated with an offset of 37 RBs and QPSK modulation).

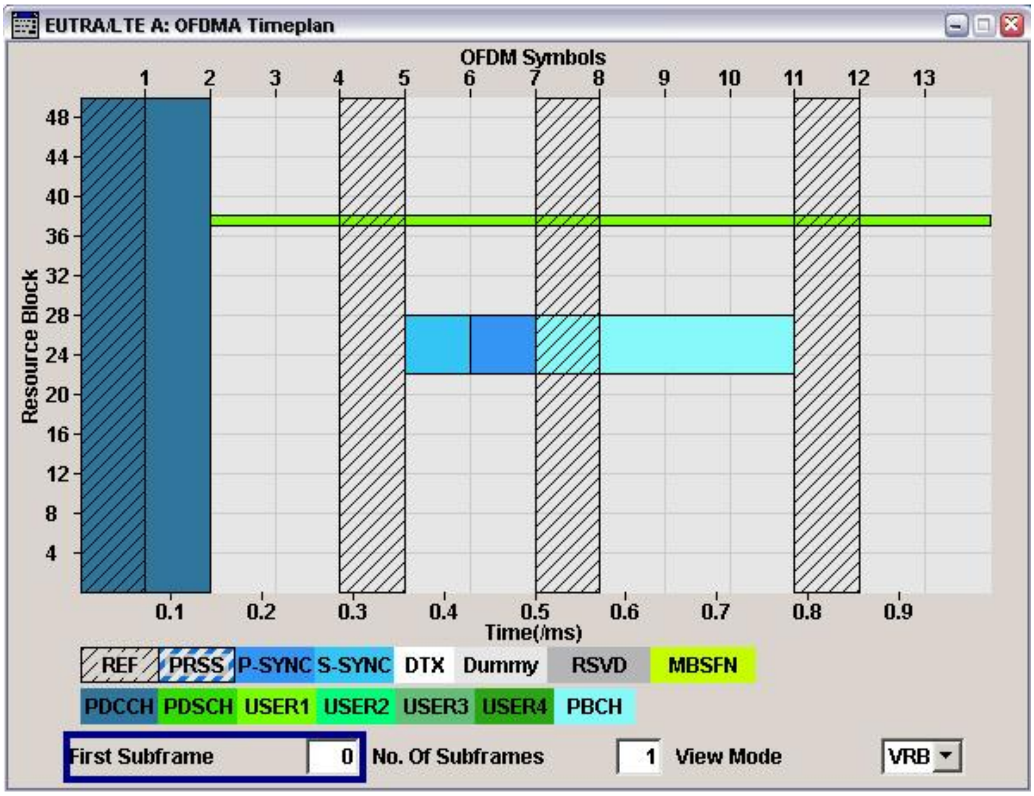
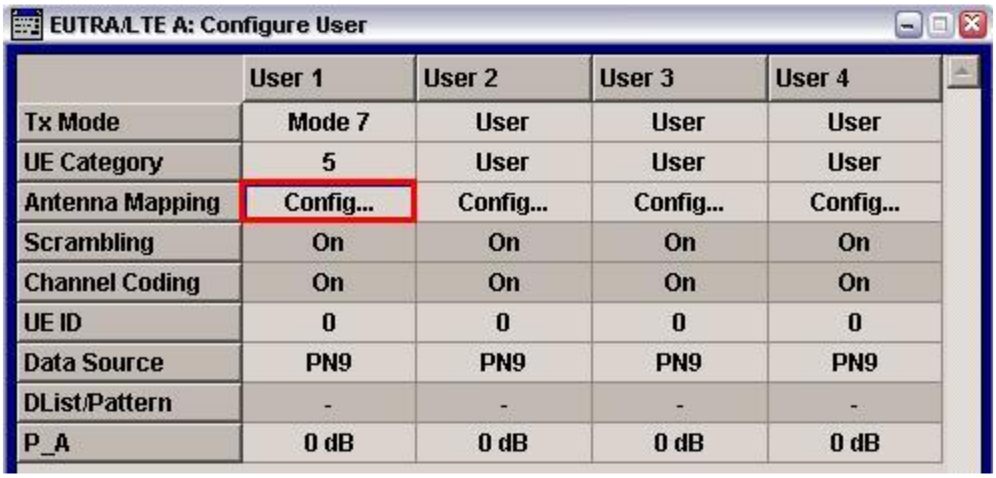


Fig. 40: Display of the OFDMA timeplan parameters that are set automatically in AUTO/DCI mode.

The actual distribution (weighting) to the individual antennas is again carried out in the user settings under Antenna Mapping.


EUTRA/LTE A: Configure User

	User 1	User 2	User 3	User 4
Tx Mode	Mode 7	User	User	User
UE Category	5	User	User	User
Antenna Mapping	Config...	Config...	Config...	Config...
Scrambling	On	On	On	On
Channel Coding	On	On	On	On
UE ID	0	0	0	0
Data Source	PN9	PN9	PN9	PN9
DList/Pattern	-	-	-	-
P_A	0 dB	0 dB	0 dB	0 dB

Fig. 41: Opening the antenna mapping settings.

Click Config in the *Antenna Mapping* field for the individual user to select three different test modes. The available options in the Mapping Coordinates table vary depending on the number of antennas set under **General DL Settings** (see Fig. 34).

► **Codebook**:

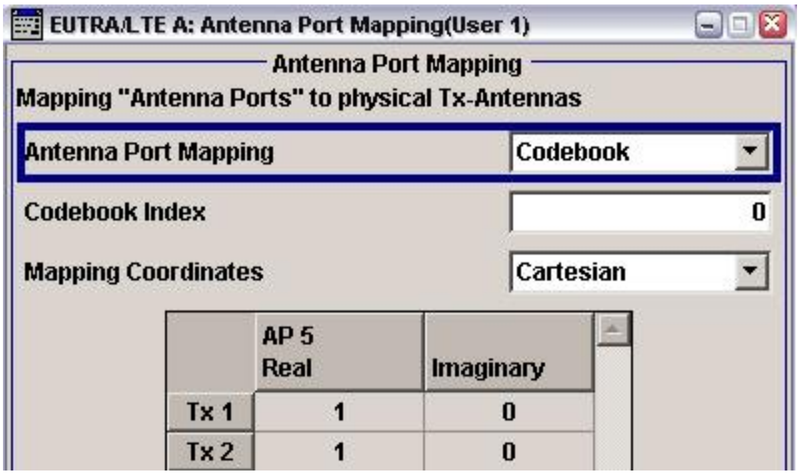


Fig. 42: Antenna mapping codebook.

This is where the precoding weights are chosen based on the index that is selected from the tables in specification 36.211 [6]. For TM 7, they are indices 0 to 3 for two antennas:

Precoding weights for 2 antennas		
Codebook index	Number of layers υ	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Table 4: Allowed precoding weights for TM 7 (with one layer) for two antennas.

Similarly, indices 0 to 15 are used for four antennas (table in [6]; a different view of the precoding matrices is available in the attachment, section 3.2):

Mapping Coordinates displays the defined weights, either in Cartesian or cylindrical coordinates.

► **Random codebook**

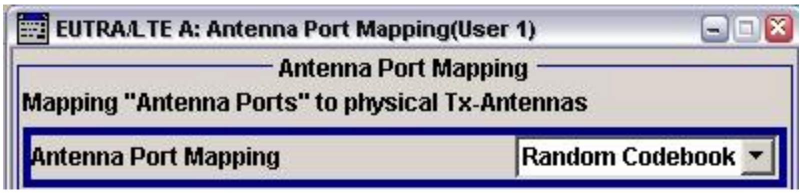


Fig. 43: Random codebooks for tests in accordance with TS36.521, section 8.3.

In this case, the codebooks are randomly selected from the tables. This mode corresponds to test specification TS36.521, section 8.3.
Because the weight settings change continually, *Mapping Coordinates* is not visible.

► **Fixed weight**

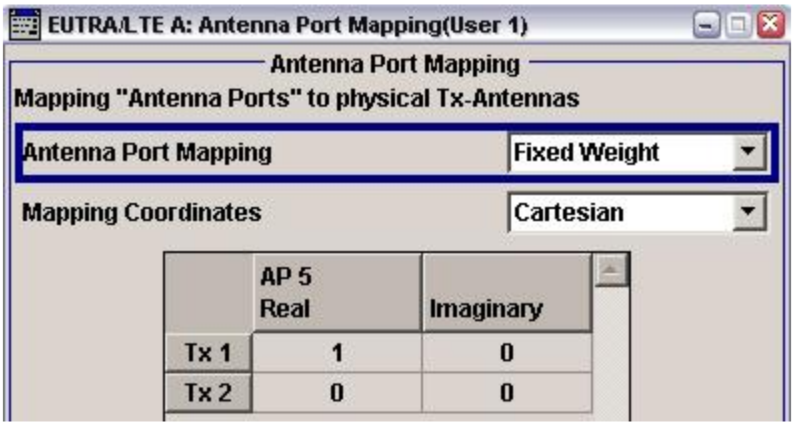


Fig. 44: Fixed weight for TM 7 with two antennas.

The weights can be set in *Mapping Coordinates*. They apply to all user allocations over the entire frame.

Additionally the settings are displayed again in the *Enhanced Settings* for the allocation (Fig. 45).

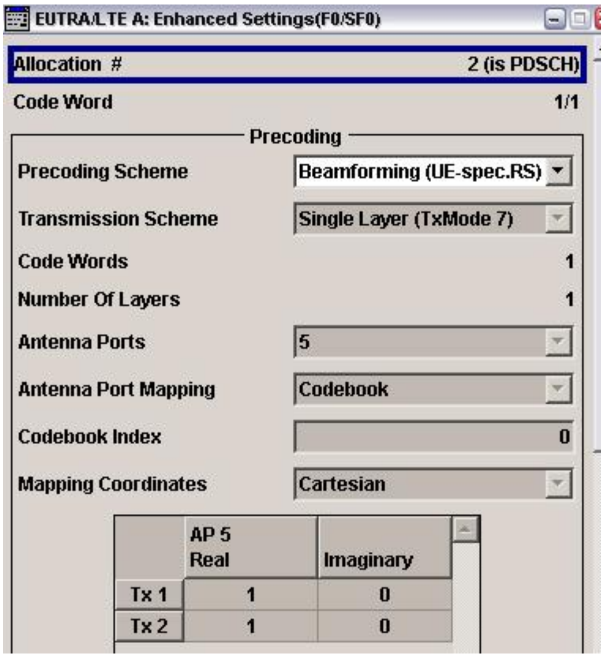


Fig. 45: Display of the beamforming settings in the allocation; this example shows TM 7 on AP 5 with codebook 0.

2.3.2 Transmission Mode 8

In TM 8, the SMU performs beamforming with the corresponding reference signals (DM-RS) by dividing two layers (codewords) over two or four antennas. The virtual antenna ports (AP) 7 and 8 are mapped to the physical antennas accordingly. The layers can be used for either one UE (single-layer MU beamforming) or two UEs (dual-layer beamforming).

To use Auto/DCI mode, additional settings must first be made in the PDCCH control channel. Click *Configure PCFICH, PHICH, PDCCH* to make these settings.
The lower section of the screen lists the settings for the PDCCH (Fig. 37). TM 8 defines DCI formats 1A and 2B in accordance with [Table 7.1-5 from 8]. APs 7 and 8 with DCI format 2B are used here.

Dual-layer beamforming for single user

In this situation, both layers are beamformed for a single UE (user).

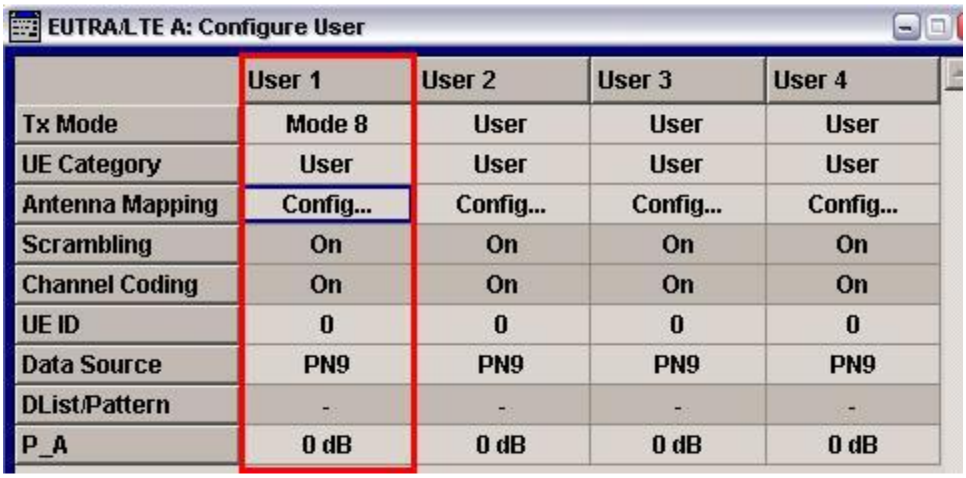


Fig. 46: Setting the user in dual-layer mode for one UE.

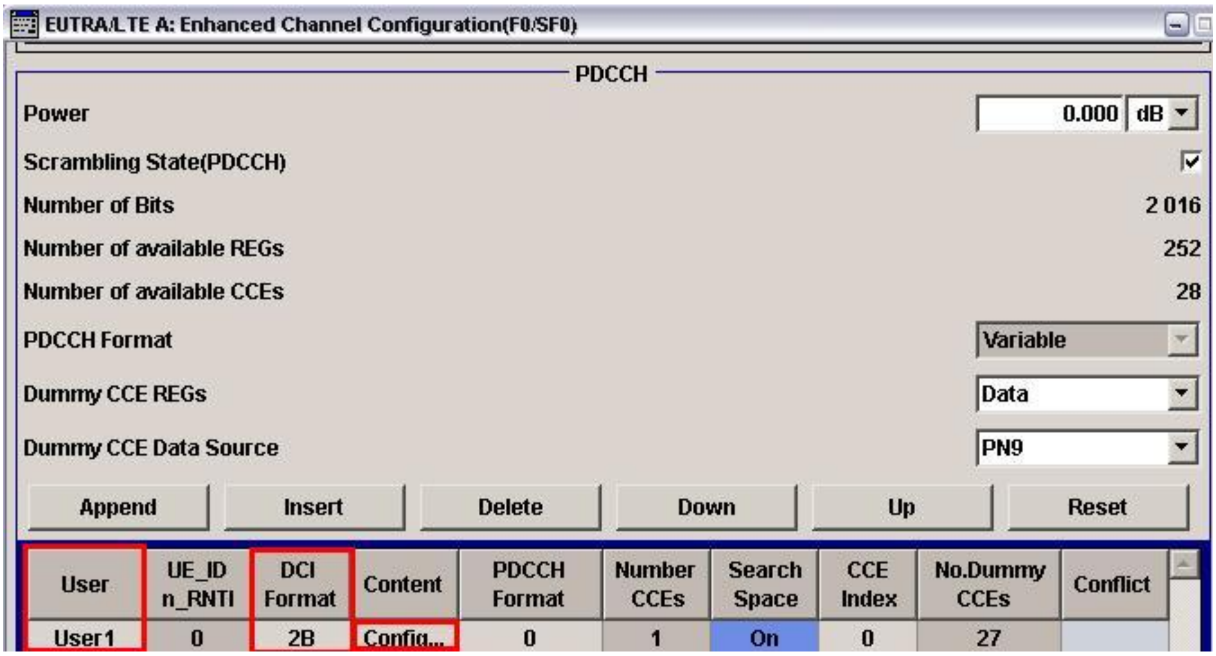


Fig. 47: Setting the DCI format in the PDCCH for TM 8 with one UE: DCI format 2B.

The data to be transmitted in the selected DCI format, and thus also the PDSCH settings, can be further configured by clicking *Config Content*. The transmitted bit pattern of the defined settings can be read in the bottom *Data* section (Fig. 48). The number and position of the resource blocks (RBs) can be set via *Resource Block Assignment*, while the modulation is set via *Modulation and Coding Scheme* [9].The two layers / codewords can be set differently (transport block 1 applies to layer 1, and transport block 2 applies to layer 2).

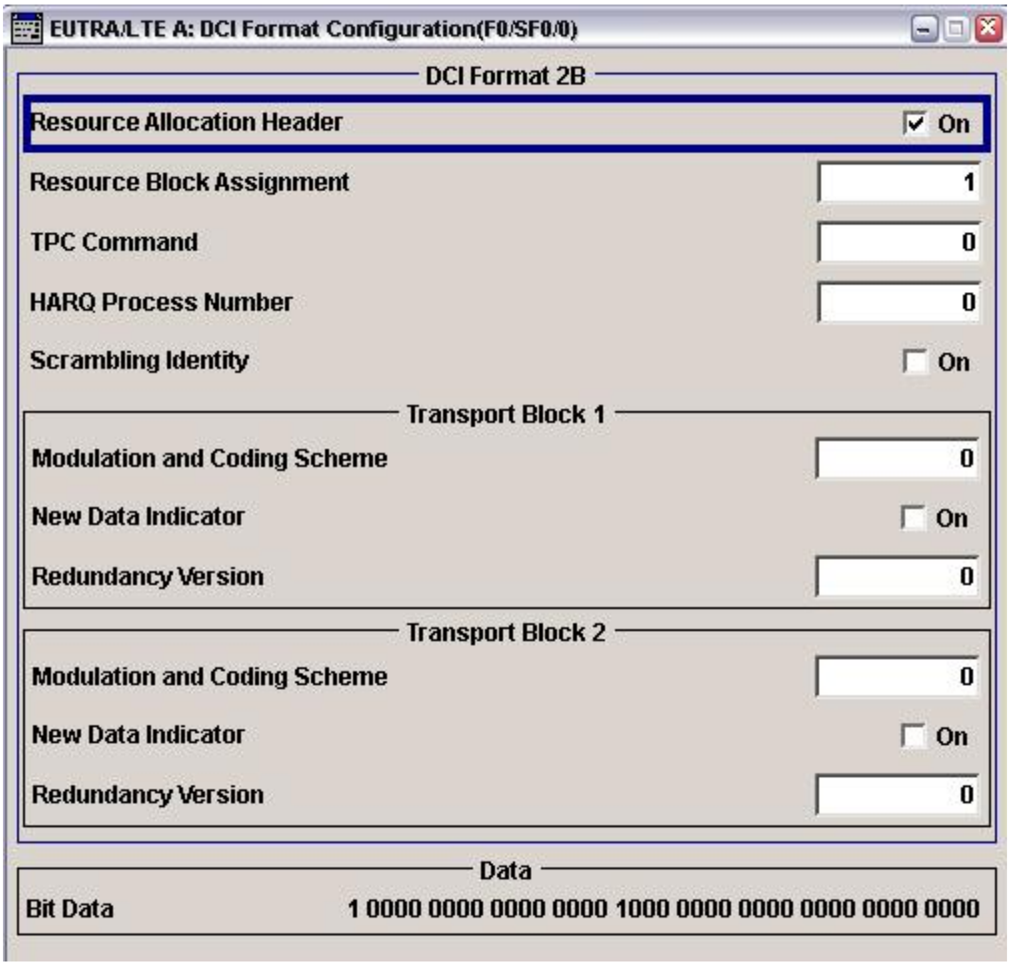


Fig. 48: Example configuration of DCI format 2B for TM 8.

In Auto/DCI mode, the PDSCH settings are prefilled automatically based on the parameters defined here (Fig. 49). The desired settings are also displayed in the timeplan. Two layers were allocated here (allocations 2.1 and 2.2 in Fig. 49) because dual-layer beamforming mode is set.

	CW	Mod.	Enh. Sett.	VRB Gap	No. RB	No. Sym.	Offs RB	Offs Sym.	Auto	Phys. Bits	Data Source	DList Pattern	Rho A /dB	Content Type	State	Conf.
0	1/1	QPSK	Config...	-	6	4	22	7(1/0)	Off	480	MIB	-	0.000	PBCH	On	
1	1/1	QPSK		-	50	2	0	0(0/0)	Off	2016	PDCCH	-	0.000	PDCCH	On	
2.1	1/2	QPSK	Config...	-	1	12	37	2(0/2)	Off	240	User1	-	0.000	PDSCH	On	
2.2	2/2	QPSK	Config...	-	1	12	37	2(0/2)	Off	240		-			On	

Fig. 49: Example of an automatically defined PDSCH allocation in Auto/DCI mode (data source of the defined PDSCH allocation is set to User 1; in this example using Resource Block Assignment 1 and Modulation and Coding Scheme 0 (MCS 0), one RB is allocated with an offset of 37 RBs and QPSK modulation). Two layers/codewords are used automatically.

The actual distribution (weighting) to the individual antennas is again carried out in the user settings under Antenna Mapping.

Click Config in the *Antenna Mapping* field for the individual user to select three different test modes. The available options in the Mapping Coordinates table vary depending on the number of antennas set under **General DL Settings** (see Fig. 34).

► **Codebook**:

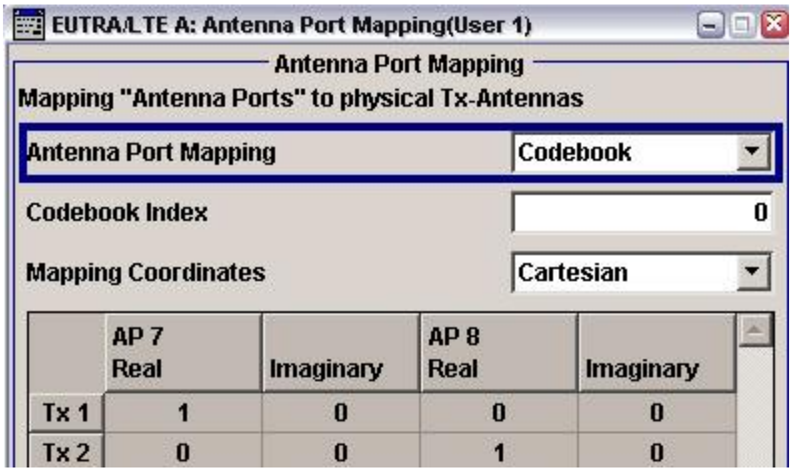


Fig. 50: Antenna mapping codebook.

This is where the precoding weights are chosen based on the index that is selected from the tables in specification 36.211 [8]. For TM 8, they are indices 0 to 2 for two antennas:

Precoding weights for 2 antennas		
Codebook index	Number of layers υ	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Table 5: Allowed precoding weights for TM 8 (with two layers) for two antennas.

Similarly, indices 0 to 15 are used for four antennas (table in [6]; a different view of the precoding matrices is available in the attachment, section 3.2):

Mapping Coordinates displays the defined weights, either in Cartesian or cylindrical coordinates.

► **Random codebook**

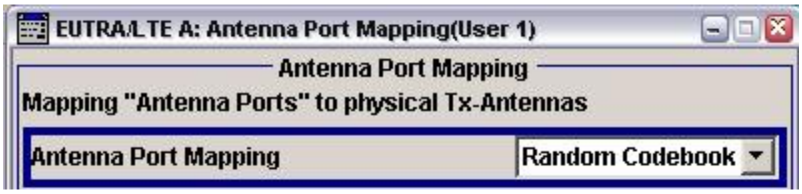


Fig. 51: Random codebooks for tests in accordance with TS36.521, section 8.3.

In this case, the codebooks are randomly selected from the tables. This mode corresponds to test specification TS36.521, section 8.3.
Because the weight settings change continually, *Mapping Coordinates* is not visible.

► **Fixed weight**

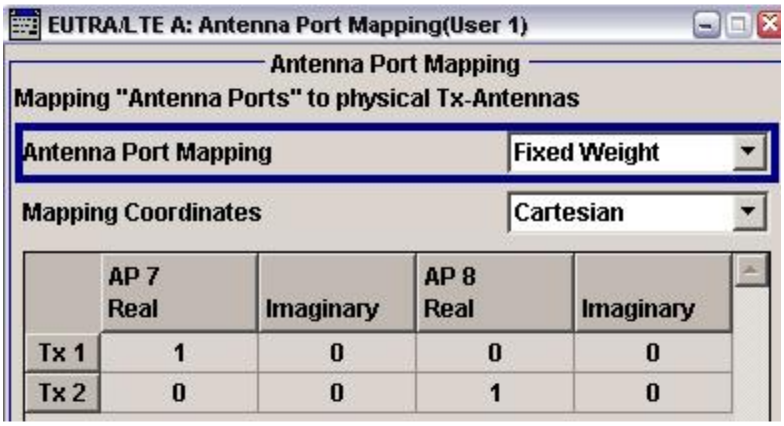


Fig. 52: Fixed weight for TM 8 with two antennas.

The weights can be set in *Mapping Coordinates*. They apply to all user allocations over the entire frame.

Additionally the settings are displayed again in the *Enhanced Settings* for the allocation (Fig. 53).

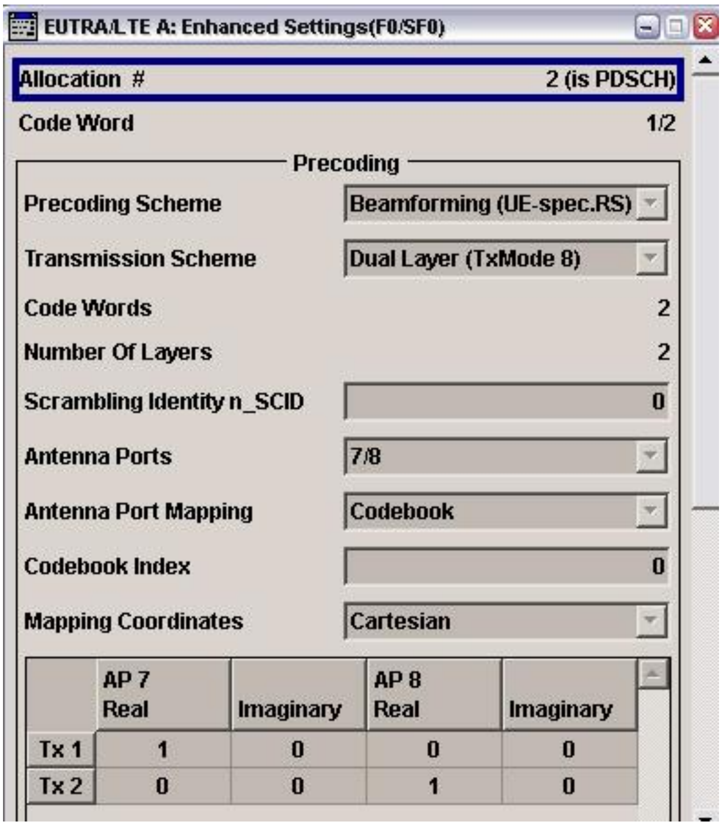


Fig. 53: Display of the beamforming settings in the allocation; this example shows TM 8 on APs 7/8 with codebook 0.

Dual-layer beamforming for multiple users

The individual layers are provided to various UEs (users) in the same way as in multi-user MIMO.
To do this, two users are first created with different UE IDs in the *Configure User* screen.

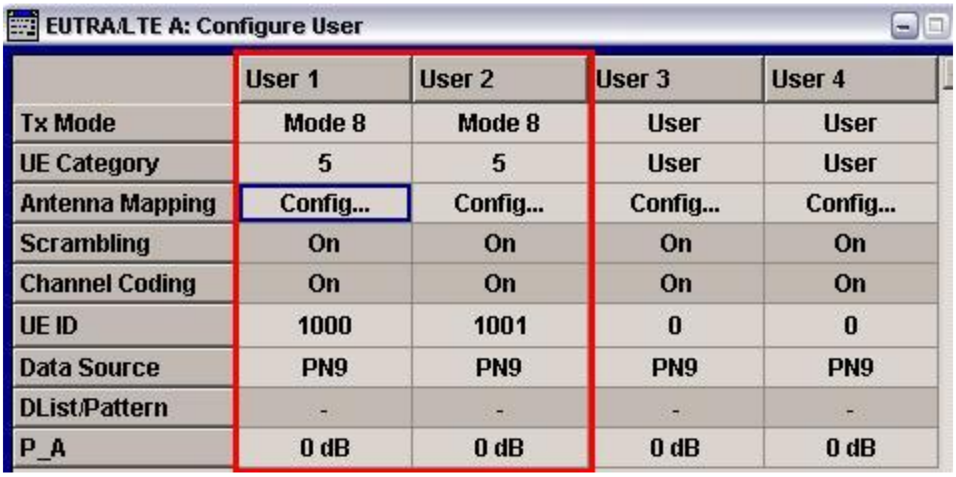


Fig. 54: Setting the users in dual-layer mode for two UEs. Note the different UE IDs.

Two users are also created in the PDCCH settings. Again, dual-layer mode with DCI format 2B is selected.

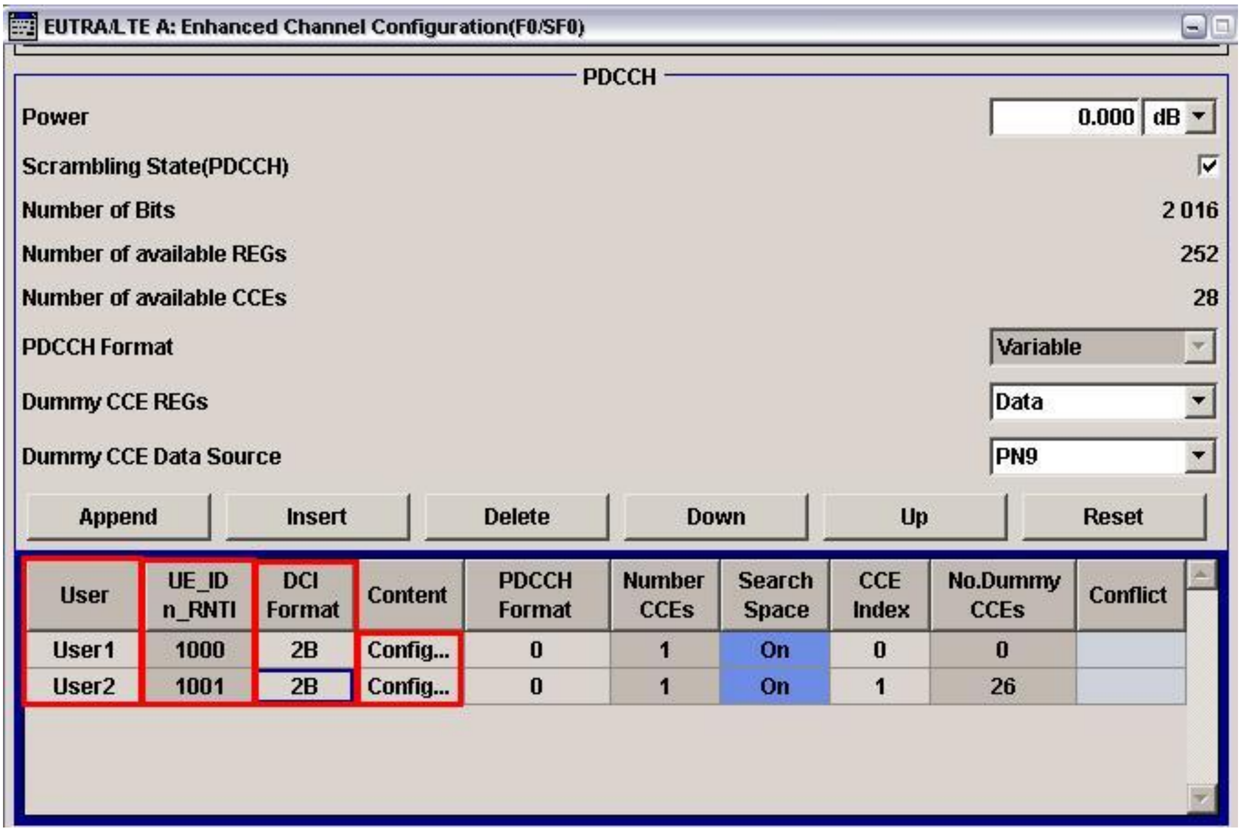


Fig. 55: Setting the DCI format in the PDCCH for TM 8 with two UEs: DCI format 2B.

The data to be transmitted in the selected DCI format, and thus also the PDSCH settings, can be further configured by clicking *Config Content*. The transmitted bit pattern of the defined settings can be read in the bottom Data section. The number and position of the resource blocks (RBs) can be set via *Resource Block Assignment*, while the modulation is set via *Modulation and Coding Scheme* [9]. Because multi-user mode is now used, the second codeword is now disabled for **both** users by setting *Redundancy Version* to 1 (see Fig. 56). AP7 and AP8 are distinguished by the different setting of the *New Data Indicator (see* Fig. 57*)*.

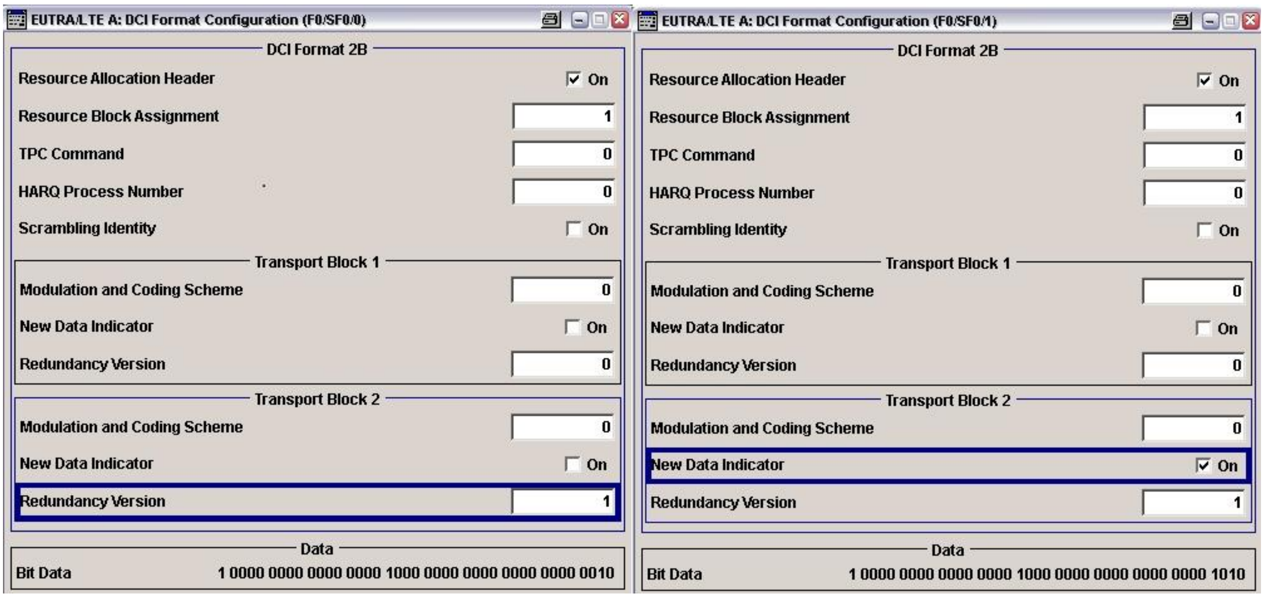


Fig. 56: Example configuration of DCI format 2B for TM 8 in multi-user mode. The second codeword (CW) is disabled by setting Redundancy Version 1. Enabling the New Data Indicator in allocation 3 sets AP8.

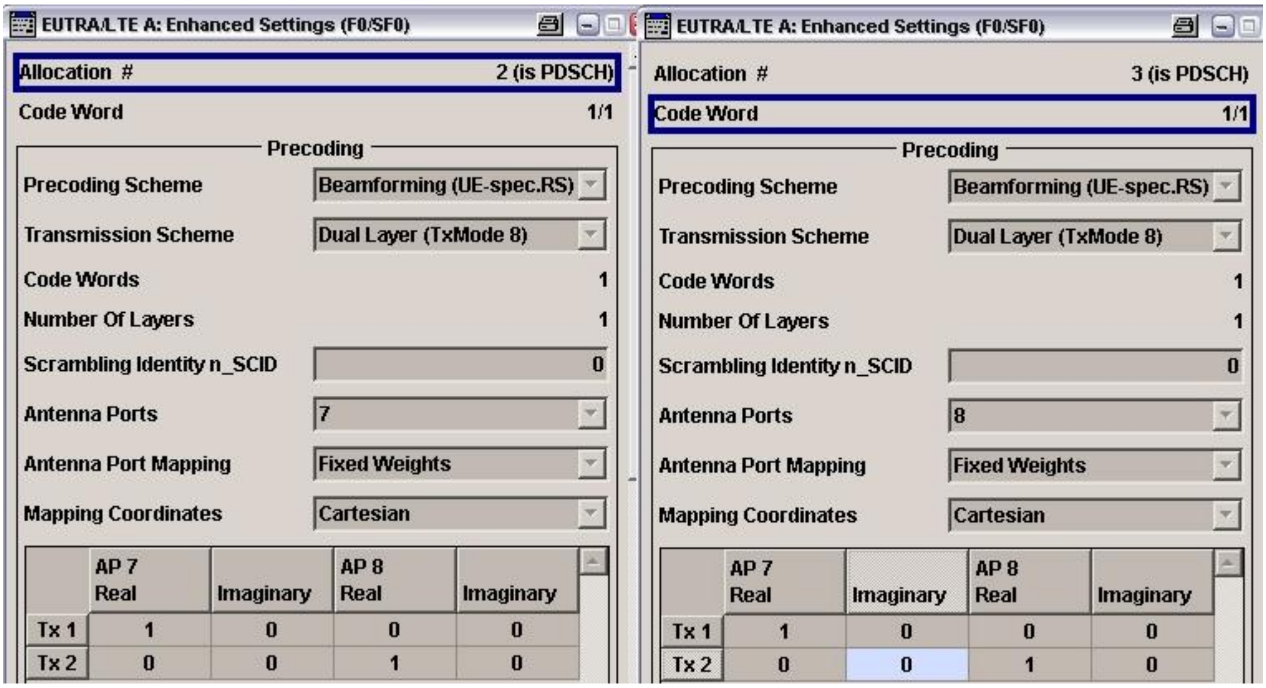


Fig. 57: Different antenna port (AP) settings in Dual Layer Beamforming for Multi User

	CW	Mod.	Enh. Sett.	VRB Gap	No. RB	No. Sym.	Offs RB	Offs Sym.	Auto	Phys. Bits	Data Source	DList Pattern	Rho A /dB	Content Type	State	Conf.
0	1/1	QPSK	Config...	-	6	4	22	7(1/0)	Off	480	MIB	-	0.000	PBCH	On	
1	1/1	QPSK		-	50	2	0	0(0/0)	Off	2016	PDCCH	-	0.000	PDCCH	On	
2	1/1	QPSK	Config...	-	1	12	37	2(0/2)	Off	240	User1	-	0.000	PDSCH	On	
3	1/1	QPSK	Config...	-	1	12	37	2(0/2)	Off	240	User2	-	0.000	PDSCH	On	

Fig. 58: Example of an automatically defined PDSCH allocation in Auto/DCI mode for MU beamforming (data source of the defined PDSCH allocation is set to User 1 and 2; in this example using Resource Block Assignment 1 and Modulation and Coding Scheme 0 (MCS 0), one RB is allocated with an offset of 37 RBs and QPSK modulation). Two independent layers, each with one codeword (CW), are automatically allocated for the various users.

The settings for the weightings correspond to those described in single-user mode.

2.3.3 SISO + Beamforming

In addition to the beamforming modes described here, the SMU also allows beamforming to be generated for SISO. Please note that while generating signal in this mode, the antennas simulated by path A and Path B are not MIMO antennas. The signal at the output of both paths is the same SISO signal with the same cell-specific reference signals. Only the PDSCH is transmitted with a user-defined phase offset. SISO+BF is needed for tests according to Chapter 8.3.2.1.1 of TS 36.521-1 [7].

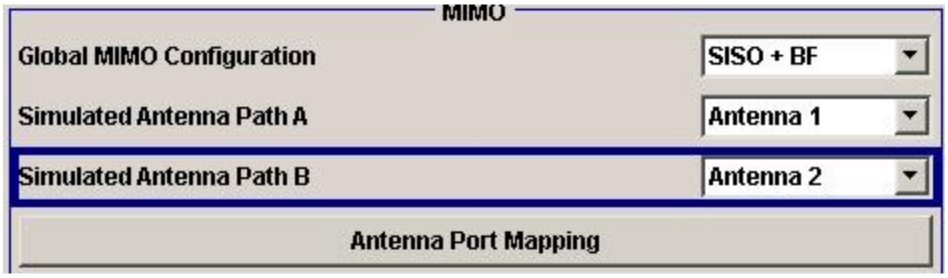


Fig. 59: Settings for SISO beamforming. Cell-specific reference signals are generated for one antenna in this case. Only the PDSCH receives differing phases.

2.3.4 Phase-Coherent Generation

The SMx signal generators use the SMx-B90 option to support phase-coherent generation of multiple signals. The signal paths within an instrument can be coupled, as can multiple instruments. Option SMx-B90 includes hardware that can be used to couple the local oscillators (LO). The LOs are coupled internally via a two-channel instrument (SMU, SMATE). Multiple instruments (SMU, SMATE, SMJ, SMBV) can be coupled via the appropriate LO IN/OUT jacks (located at the back of the instruments).

Refer to the paragraph discussing phase-coherent generation in section 2.2.

Important note:
In this case, phase coherence means that the phase difference between two signals is fixed, but not 0°. This fixed, base phase difference (measurable using the FS-Z10 or ZVx, for example) has to be taken in account either when defining the settings on the generator or during the measurement itself.

For more information on the SMx-B90 phase coherence option, refer to **Phase Adjustment of Two MIMO Signal Sources with Option B90** [1].

2.4 Testing Remote Radio Heads (RRH)

Tests can target the entire base station or be focused on just the remote radio head (RRH). Normally, the coupling between the baseband and the RRH is made via the digital **Common Public Radio Interface** (CPRI™). Rohde & Schwarz supports this with its EX-IQ-Box digital signal interface module. The EX-IQ-Box allows existing instruments such as the SMx and the FSx to take measurements via the CPRI interface, and the Ex-IQ-Box can also be used as a standalone solution for flexible data recording and playback.

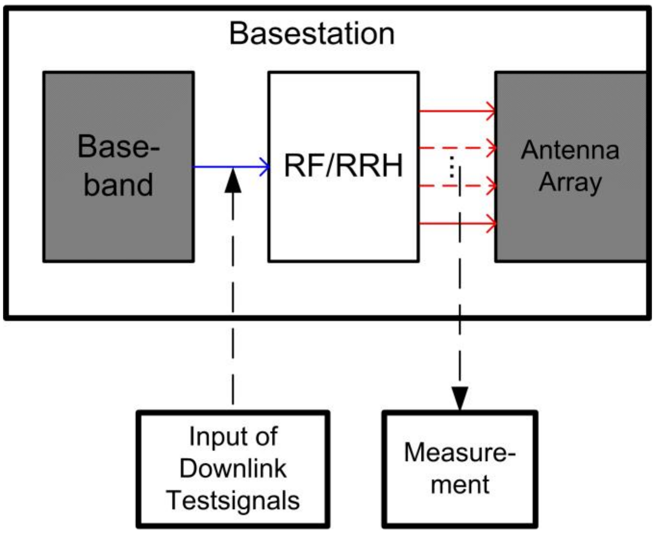


Fig. 60: Block diagram for RRH tests in the downlink.

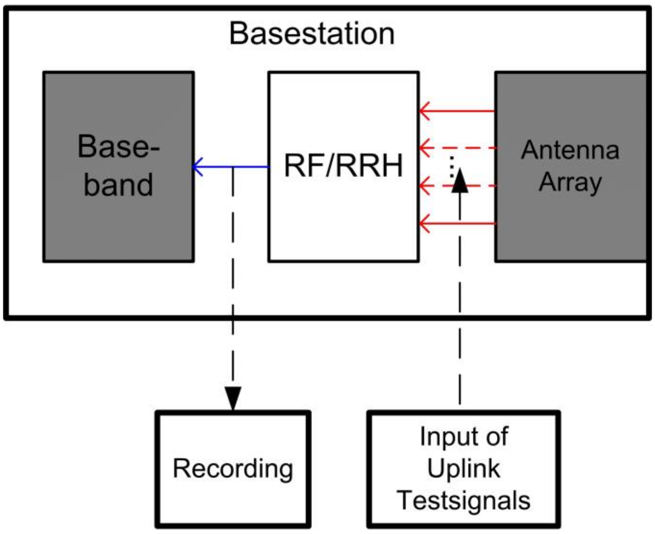


Fig. 61: Block diagram for RRH tests in the uplink.

Please refer to the more detailed application note CPRI RE Testing [5].

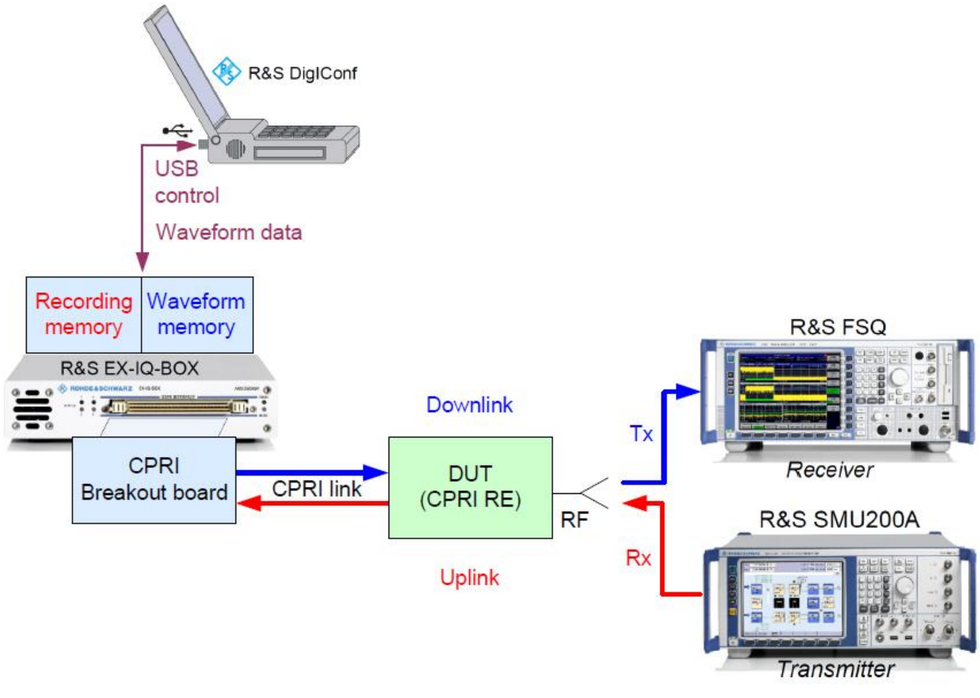


Fig. 62: RRH test setup: Bidirectional CPRI operation with standalone EX-IQ-Box.

The EX-IQ-Box simulates the baseband for the tests. The RF signals are measured and generated in the same way as for the base station test (transmitter [section 2.1] and receiver [section 2.2]). The downlink simulation uses ARB files (created using the WinIQSIM2™ simulation software, for example). Up to four of these files can be played in parallel on the EX-IQ-Box. Up to four baseband signals can be transmitted to the RRH for this purpose.

The uplink signal can be recorded using the EX-IQ-Box.

3 Appendix

3.1 Over-the-Air (OTA) Test System R&S®TS8991

The R&S®TS8991 (OTA) Performance Test System measures the spatial transmission and the reception characteristics of communication devices according to cellular technologies as for example: “GSM, CDMA, W-CDMA up to MIMO LTE.” Devices designed for noncellular technologies as WIMAX, WLAN, Bluetooth, AGPS and GNSS are covered as well as the measurement of gain and phase of passive antennas.

The R&S®TS8991 OTA Performance System is the integration of R&S instruments, signal conditioning and automation devices and a high precision conical cut antenna positioning device with two independent measurement antennas to perform LTE MIMO measurements it's controlled by the antenna measurement software R&S®AMS32. Instruments, software, 3D positioning device and the measurement environment from desktop size DST200 (Diagnostic Anechoic Chamber) for R&D up to CATL certified anechoic chambers, allows to scale the system according to the individual customer requirements.

The R&S®TS8991 OTA-Performance Testsystem has received the certification according to CTIA Testplan 3.1 which is required by PTCRB and GCF. The OTA performance measurements for WLAN are requested by WiFi Alliance Testplan 1.3

3.2 RF Conformance Test System R&S®TS8980

The R&S®TS8980 family of test systems offers the most complete coverage in the industry for applications in WCDMA and LTE test. It includes performance tests for TDD beamforming according to TS36.521-1, Chapter 8.3 [6] with fully compliant signalling amd realtime fading. TS8980 is used by all leading test houses, first-rate chipset and UE manufacturers, and major network operators for accredited certification of mobile devices.

UTRA and E-UTRA Conformance test in line with GCF and PTCRB are complemented by a very broad range of acceptance test packages as defined by many of the leading LTE network operators.

The R&S®CONTEST graphical user interface gives control over test case execution, automation of DUT, Climatic chamber, DC supply and other external devices. The GUI also comes with a brace of functions for DUT management and result reporting as well as internal and external data base control for result handling and storage.

Test case parameters are accessible in very convenient fashion, most important parameters may be reached with a single mouseclick.

Margin search routines and Perfomance evaluation modes allow to evaluate the headroom a DUT has vs certification-level PASS criteria or vs user-specified minimum values.

For even more R&D related work, specific Layer-1 verification packages are available.

Modular, upgradeable hardware and software configurations starting from benchtop setups of a few R&D instruments and extending into fully rack-integrated conformance test systems are available. RF test for LTE and WCDMA may be combined with RRM conformance for LTE/WCDMA, Performance Analysis for LTE/WCDMA. Location-based services test plans complete the range of applications for the R&S®TS8980 test system.

3.3 Precoding Weights for Four Antennas

Precoding weights for four antennas – part 1				
Codebook index	**Number of layers**			
	1	**2**	**3**	**4**
0	$\frac{1}{2}\begin{pmatrix}1\\1\\1\\1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&1\\1&-1\\1&-1\\1&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&1&1\\1&1&-1\\1&-1&1\\1&-1&-1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&1&1&1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}$
1	$\frac{1}{2}\begin{pmatrix}1\\j\\-1\\-j\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-j\\j&1\\-1&-j\\-j&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&-j&j\\j&1&1\\-1&-j&j\\-j&1&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-j&-1&j\\j&1&j&1\\-1&-j&1&j\\-j&1&-j&1\end{pmatrix}$
2	$\frac{1}{2}\begin{pmatrix}1\\-1\\1\\-1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-1\\-1&1\\1&1\\-1&-1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&-1&1\\-1&1&1\\1&1&1\\-1&-1&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-1&1&-1\\1&1&-1&-1\\1&1&1&1\\1&-1&-1&1\end{pmatrix}$
3	$\frac{1}{2}\begin{pmatrix}1\\-j\\-1\\j\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&j\\-j&1\\-1&j\\j&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&j&-1\\-j&1&-j\\-1&j&1\\j&1&j\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}-1&j&1&-j\\-j&1&-j&1\\1&j&-1&-j\\j&1&j&1\end{pmatrix}$
4	$\frac{1}{2}\begin{pmatrix}1\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\j\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&j\\j&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1&j\\j&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&-j&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-j&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&j\\j&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&1&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&-j&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&1\end{pmatrix}$
5	$\frac{1}{2}\begin{pmatrix}1\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\-j\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&-j\\-j&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1&-j\\-j&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&j&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&j&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&-j\\-j&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&1&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&j&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&1\end{pmatrix}$
6	$\frac{1}{2}\begin{pmatrix}1\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\j\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-j\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\j&1\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&-j&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&j\\j&1&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-j&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&1&j\\j&1&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&-j&1\end{pmatrix}$
7	$\frac{1}{2}\begin{pmatrix}1\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\-j\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&j\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\-j&1\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&j&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-j\\-j&1&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&j&\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}\\\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&1&-j\\-j&1&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}\\-\frac{1}{\sqrt{2}}-j\frac{1}{\sqrt{2}}&-\frac{1}{\sqrt{2}}+j\frac{1}{\sqrt{2}}&j&1\end{pmatrix}$

Precoding weights for four antennas – part 2				
Codebook index	**Number of layers**			
	1	**2**	**3**	**4**
8	$\frac{1}{2}\begin{pmatrix}1\\1\\-1\\-1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&1\\1&1\\-1&1\\-1&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&1&-1\\1&1&1\\-1&1&-1\\-1&1&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&1&-1&-1\\1&1&1&1\\-1&1&1&-1\\-1&1&-1&1\end{pmatrix}$
9	$\frac{1}{2}\begin{pmatrix}1\\j\\1\\j\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-j\\j&-1\\1&j\\j&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&1&-j\\j&-j&-1\\1&1&j\\j&-j&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-j&1&-j\\j&1&-j&-1\\1&j&1&j\\j&-1&-j&1\end{pmatrix}$
10	$\frac{1}{2}\begin{pmatrix}1\\-1\\-1\\1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-1\\-1&-1\\-1&1\\1&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&-1&-1\\-1&1&-1\\-1&-1&1\\1&1&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-1&-1&1\\-1&-1&1&1\\-1&1&-1&1\\1&1&1&1\end{pmatrix}$
11	$\frac{1}{2}\begin{pmatrix}1\\-j\\1\\-j\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&1\\-j&j\\1&1\\-j&j\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&1&j\\-j&j&-1\\1&1&-j\\-j&j&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&1&j&j\\-j&j&1&-1\\1&1&-j&-j\\-j&j&-1&1\end{pmatrix}$
12	$\frac{1}{2}\begin{pmatrix}1\\1\\1\\-1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&1\\1&1\\1&-1\\-1&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&1&1\\1&1&-1\\1&-1&1\\-1&1&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&1&1&-1\\1&1&-1&1\\1&-1&1&1\\-1&1&1&1\end{pmatrix}$
13	$\frac{1}{2}\begin{pmatrix}1\\1\\-1\\1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-1\\1&1\\-1&1\\1&1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&1&-1\\1&1&1\\-1&1&1\\1&-1&1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-1&1&1\\1&1&1&-1\\-1&1&1&1\\1&1&-1&1\end{pmatrix}$
14	$\frac{1}{2}\begin{pmatrix}1\\-1\\1\\1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&1\\-1&1\\1&1\\1&-1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&-1&1\\-1&1&1\\1&1&1\\1&1&-1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-1&1&1\\1&1&-1&1\\1&1&1&-1\\-1&1&1&1\end{pmatrix}$
15	$\frac{1}{2}\begin{pmatrix}1\\-1\\-1\\-1\end{pmatrix}$	$\frac{1}{2\sqrt{2}}\begin{pmatrix}1&-1\\-1&1\\-1&-1\\-1&-1\end{pmatrix}$	$\frac{1}{2\sqrt{3}}\begin{pmatrix}1&-1&-1\\-1&1&-1\\-1&-1&1\\-1&-1&-1\end{pmatrix}$	$\frac{1}{4}\begin{pmatrix}1&-1&-1&-1\\-1&1&-1&-1\\-1&-1&1&-1\\-1&-1&-1&1\end{pmatrix}$

3.4 References

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[2] Rohde & Schwarz: **Coherence Measurement between Two Signals regarding Timing, Phase and Gain**, Application Note 1EF70, November 2009

[3] Vollmann, U: **Measurement Procedures for Beamforming in LTE**, Master's Thesis TU München, September 2010

[4] Rohde & Schwarz: **Beamforming in LTE**, White Paper 1MA186, July 2011

[5] Rohde & Schwarz: **CPRI RE Testing**, Application Note 1GP78, October 2010

[6] Technical Specification Group Radio Access Network; **Physical Channels and Modulation**, Release 9; **3GPP TS 36.211 V 9.1.0**, March 2010

[7] Technical Specification Group Radio Access Network; **UE Conformance Specification; Radio Transmission and Reception; Part 1 Conformance Testing**, Release 8; **3GPP TS 36.521-1 V 8.6.0**, June 2010

[8] Technical Specification Group Radio Access Network; **Physical Layer Procedures**, Release 9; **3GPP TS 36.213 V 9.3.0**, September 2010

[9] Technical Specification Group Radio Access Network; **Multiplexing and Channel Coding**, Release 9; **3GPP TS 36.212 V 9.3.0**, September 2010

[10] Rohde & Schwarz: **Two-Channel Method for OTA Performance Measurements of MIMO-Enabled Devices**, White Paper 1SP12, September 2011

3.5 Additional Information

Please send your comments and suggestions regarding this application note to

TM-Applications@rohde-schwarz.com

3.6 Ordering Information

Ordering information		
Vector signal generator		
SMW200A		**1412.0000.02**
SMW-B13	Baseband Main Module, one I/Q path to RF	**1413.2807.02**
SMW-B13T	Baseband Main Module, two I/Q paths to RF	**1413.3003.02**
SMW-B10	Baseband Generator with ARB (64 Msample) and Digital Modulation (realtime), 120 MHz RF bandwidth	**1413.1200.02**
SMW-B10x	1st RF Path	
SMW-B20x	2nd RF Path	
SMW-K511	ARB Memory Extension to 512 Msample	1413.6860.02
SMW-K512	ARB Memory Extension to 1 Gsample	1413.6919.02
SMW-K522	Baseband Extension to 160 MHz RF bandwidth	1413.6960.02
SMW-K55	Digital Standard LTE/EUTRA	1413.4180.02
SMW-K84	Digital Standard LTE/EUTRA, LTE Rel.9	1413.5435.02
SMW-B90	Phase Coherence	1413.5841.02
SMU200A		**1141.2005.02**
SMU-B9	Baseband Generator, 128 Msample	1161.0766.02
SMU-B10	Baseband Generator, 64 Msample	1141.7007.02
SMU-B11	Baseband Generator, 16 Msample	1159.8411.02
SMU-B13	Baseband Main Module	1141.8003.04
SMU-B10x	1st RF Path	
SMU-B20x	2nd RF Path	
SMU-K55	Digital Standard LTE/EUTRA	1408.7310.02
SMU-K84	Digital Standard LTE/EUTRA, LTE Rel.9	1408.8475.02
SMU-B90	Phase Coherence	1409.8604.02
Network analyzers		
ZVA	Vector Network Analyzer	1167.0000.02
ZVB	Vector Network Analyzer	1104.0002.60

Signal analyzers, spectrum analyzers		
FSW	**Up to 3 GHz, 8 GHz, 13.6 GHz or 26.5 GHz**	**1312.8000Kxx**
FSQ	**Up to 3 GHz, 8 GHz, 26 GHz, 31 GHz or 40 GHz**	**1155.5001.xx**
FSG	**Up to 8 GHz or 13 GHz**	**1309.0002.xx**
FSV	**Up to 3 GHz or 7 GHz**	**1307.9002.0x**
FSx-K100	EUTRA/LTE Downlink	1308.9006.02
FSx-K102	EUTRA/LTE Downlink, MIMO	1309.9000.02
FSx-K104	EUTRA/LTE Downlink, TDD	1309.9422.02
FSx-K100PC	EUTRA/LTE Downlink	1309.9916.02
FSx-K102PC	EUTRA/LTE Downlink, MIMO	1309.9939.02
FSx-K104PC	EUTRA/LTE Downlink, TDD	1309.9951.02
FS-Z10	**Coherence Unit**	**1171.6509.02**

xx stands for the different frequency ranges (e.g. 1155.5001.26 MHz to 26 GHz

Note: Available options are not listed in detail. The SMATE and the SMBV vector generators can also be used.
Please contact your local Rohde & Schwarz sales office for further assistance.

About Rohde & Schwarz
Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

Environmental commitment

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

Certified Quality System
ISO 9001

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