# Testing LTE MIMO Signals using a R&S®RTO Oscilloscope

**Products:**

- R&S®FS-K102/K103PC

- R&S®RTO1044

- R&S®SMU200A

LTE was designed to utilize MIMO transmissions right from the start. MIMO offers multiple advantages like increased data rate, more robust transmission or using different spatial streams for different users. This application note describes the possibilities to measure LTE MIMO with the LTE-Software R&S®FS-K102/K103PC in combination with an R&S®RTO1044 oscilloscope.

**ROHDE & SCHWARZ**

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# 1 Introduction

LTE (Long Term Evolution) supports multiple input/output (MIMO) antenna schemes. For increasing the throughput or robustness with a MIMO transmission different approaches are possible. The LTE standard makes use of the following MIMO schemes:

- **Transmit Diversity** is a spatial diversity scheme. The benefit is that the transmission is made more robust without the need for more than one antenna at the mobile UE.

- **Spatial Multiplexing** increases the data rate by dividing the data into separate streams which are transmitted in parallel.

- **Beamforming** is a method used to control the radiation pattern of an antenna array. It maximizes the signal strength at the position of a specific mobile UE.

An introduction to MIMO is available with the Rohde & Schwarz application note 1MA142 [1]. A guide to verify LTE downlink MIMO signals can be found in another Rohde & Schwarz application note 1MA143 [2], which introduces measurements on MIMO signals by measuring two antennas in parallel using two spectrum analyzers. This application note presents an approach to measure a MIMO signal transmitted on two or four antennas using the R&S®RTO1044 digital oscilloscope (4 GHz, 4 channels) and the R&S®FS-K102/103PC LTE MIMO downlink/uplink PC software. This approach has multiple advantages:

- Only one measurement instrument is required. This not only reduces the number of test instruments but also simplifies the test setup and cabling; no reference oscillator or trigger cabling and no additional hardware for synchronization is required, as would be the case with the R&S®FS-Z11.

- The measurement time is reduced.

- The input channels of an oscilloscope are very precisely aligned (channel-to-channel skew for a calibrated setup is typically < 5 ps), which allows for highly accurate beamforming measurements.

The intention of this application note is to demonstrate, for three important use cases, how to measure LTE MIMO using an oscilloscope. Firstly it is shown how to verify multi-layer spatial multiplexing and secondly how to measure LTE signals over the air with up to four layers. In the third use case a straightforward method is presented to measure the phase difference between antennas, where beamforming precoding is applied.

Section 2 of this application note shows how to prepare the instruments for MIMO measurements. In Section 3 a spatial multiplexing MIMO precoding is verified for one example configuration. A demonstration of over-the-air analysis is given in Section 4. Section 5 highlights the measurement of phase differences for beamforming antenna signals. Sections 6 and 7 contain references and ordering information respectively.

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

▪ The R&S®RTO1044 digital oscilloscope (4 GHz, 4 channels) is referred to as the RTO.

▪ The R&S®FS-K102/103PC LTE MIMO downlink/uplink PC software is referred to as the LTE-Software.

▪ The R&S®FSW signal and spectrum analyzer is referred to as the FSW.

▪ The R&S®SMU200A vector signal generator is referred to as the SMU.

# 2 Preparations for Measuring LTE MIMO Signals using an RTO Oscilloscope

In this section the hardware configuration including the required cabling and the basic software settings are given.

## 2.1 Hardware Setup

For measuring LTE signals, the RTO needs to be equipped with the options R&S®RTO-B4 and R&S®RTO-K11.

In Figure 2-1 the general hardware setup is illustrated. All transmit antennas (TX) of the device under test (DUT) (in this example an SMU) are connected to the RF inputs of the RTO. Either two or optionally four antennas are connected. The LTE-Software runs on a PC and is connected to the RTO via a local area network (LAN).
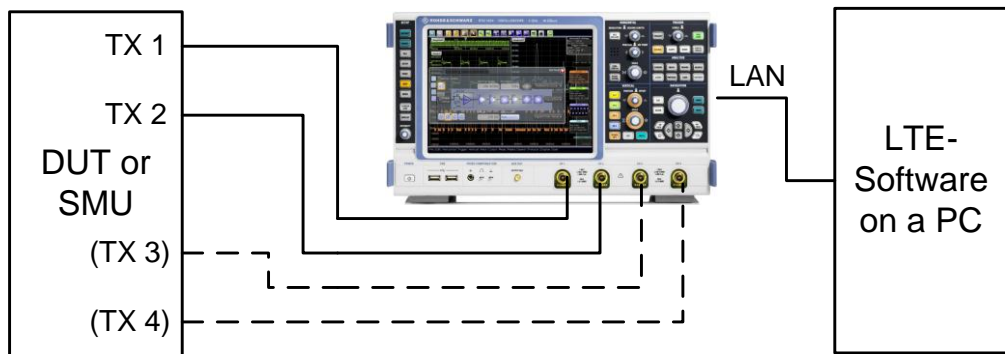


**Figure 2-1: Hardware setup of the device under test (DUT) and the RTO**

When using an RTO for LTE measurements the expected residual EVM is below 1 %. Unwanted emissions measurements (like adjacent channel leakage power ratio) are not supported in the LTE-Software for an RTO.

## 2.2 Basic LTE Settings

Before measuring any LTE signal, some basic settings must first be configured. These include the duplexing mode (frequency division multiplex (FDD) or time division multiplex (TDD)), the link direction (uplink (UL) or downlink (DL)), the RF center frequency and the LTE channel bandwidth (see Figure 2-2 for the LTE-Software and Figure 2-3 for the SMU). For TDD, the UL/DL allocations and the configuration of the special subframe must be provided.
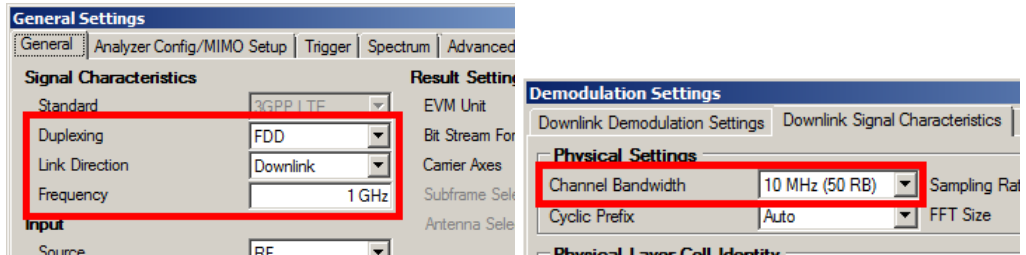


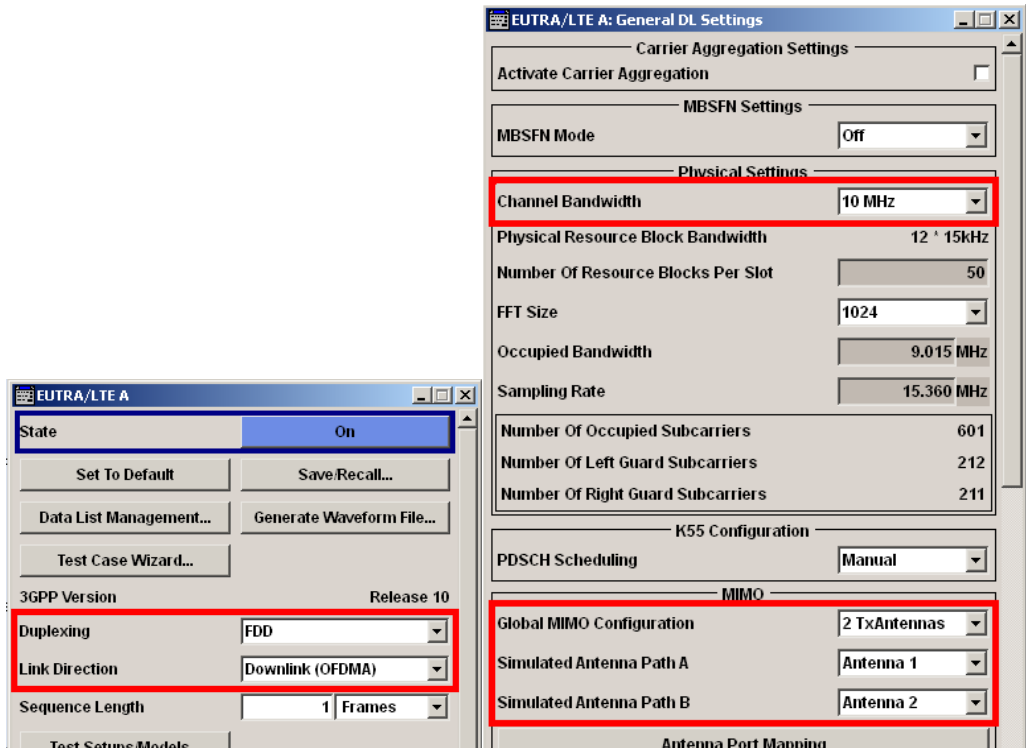**Figure 2-2: Basic signal settings for the LTE-Software**



**Figure 2-3: Basic LTE signal settings for the SMU**

To successfully connect the LTE-Software to the RTO, set the correct network address in the Analyzer Configuration table and set the hardware properties (i.e., the Number of Channels) according to Figure 2-4.

For configuring the number of active RTO inputs, the DUT MIMO Configuration (2 TX Antennas or 4 TX Antennas) and the TX Antenna Selection must be set. The DUT MIMO Configuration describes which antennas are available and the TX Antenna Selection defines how many IQ data streams are captured and how the antennas are assigned to those streams. To measure more than one antenna at a time, TX Antenna Selection must be set to All, Auto (2 Antennas) or Auto (4 Antennas). The setting All means that all available TX antennas are measured and that the antennas are assigned to the streams in ascending order. In Auto mode the antenna assignment is automatically detected, where for Auto (2 Antennas) two streams are captured and for Auto (4 Antennas) four streams are captured.
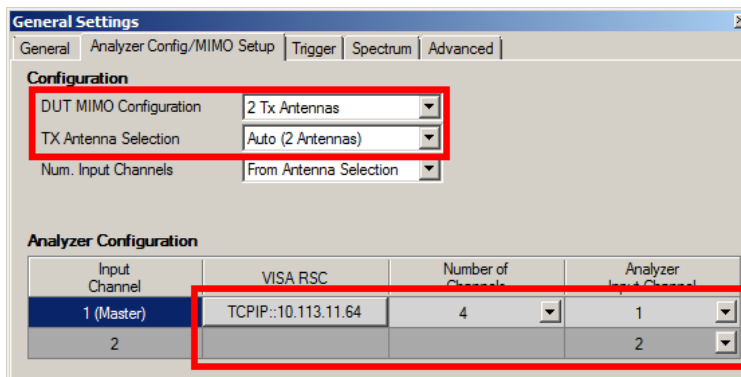


**Figure 2-4: Configuration of the RTO connection and the RTO input channel setup**

The signal level of each RTO input channel is measured and the reference level and attenuation settings are adjusted automatically. If a manual setting is preferred or for speed optimization purposes, the automatic level adjustment can be disabled in the General tab of the General Settings dialog.

# 3 Verification of Spatial Multiplexing MIMO Precoding

In this section a demonstration setup with an SMU as signal generator is used to show how spatial multiplexing with more than one layer can easily be verified. A MIMO codebook in the transmitter is successfully verified if the constellation diagram after the MIMO decoder corresponds to the expected modulation type and the EVM is below a threshold of 20 %. Additionally the decoded bits can be compared to the transmitted ones.

For successful decoding of spatial multiplexing MIMO the minimum number of transmit and receive antennas must be higher than or equal to the number of spatial layers. In the following example an SMU is used to generate a 2 TX MIMO signal with two layers.

In the SMU Frame Configuration window, set the No. Of Configurable Subframes to 1. This way, only one subframe has to be set and the SMU will copy the first subframe configuration into the other subframes. Configure one active data channel (PDSCH) by setting the No. Of Used Allocations to 3. We use 25 resource blocks with two codewords where the first codeword is QPSK modulated and the second codeword is 16-QAM modulated. In the Enhanced Settings window the spatial multiplexing codebook index 1 is chosen to make sure the codeword data is spread over all antenna signals.

The PDSCH settings for the SMU are shown in Figure 3-1 and for the LTE-Software in Figure 3-2.
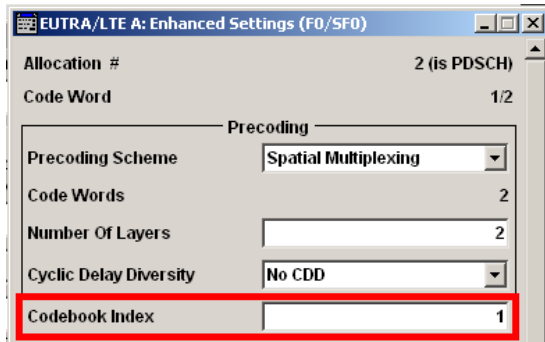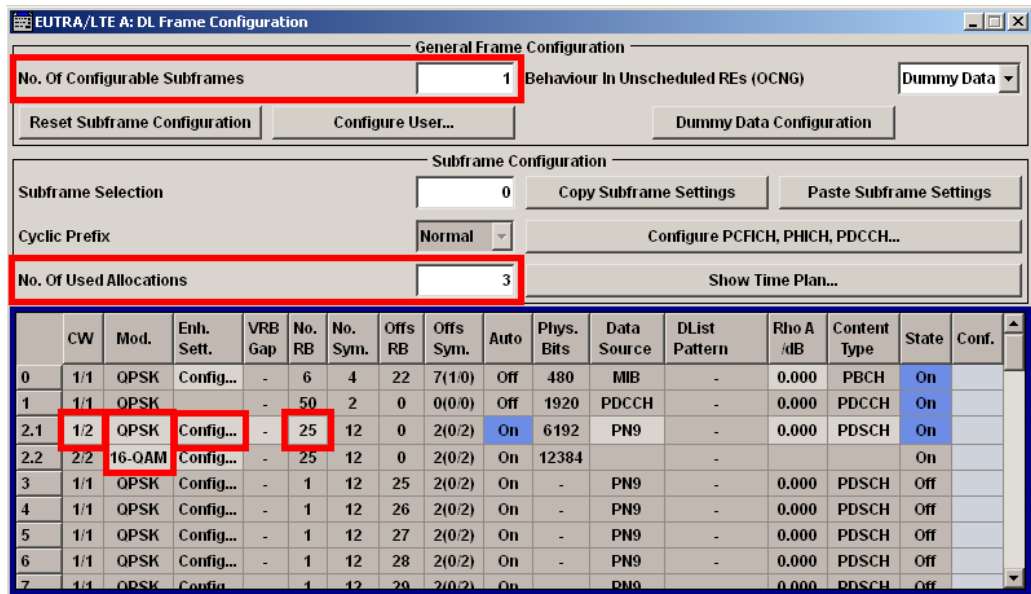
Figure 3-1: Configuration of a two layer spatial multiplexing PDSCH on the SMU
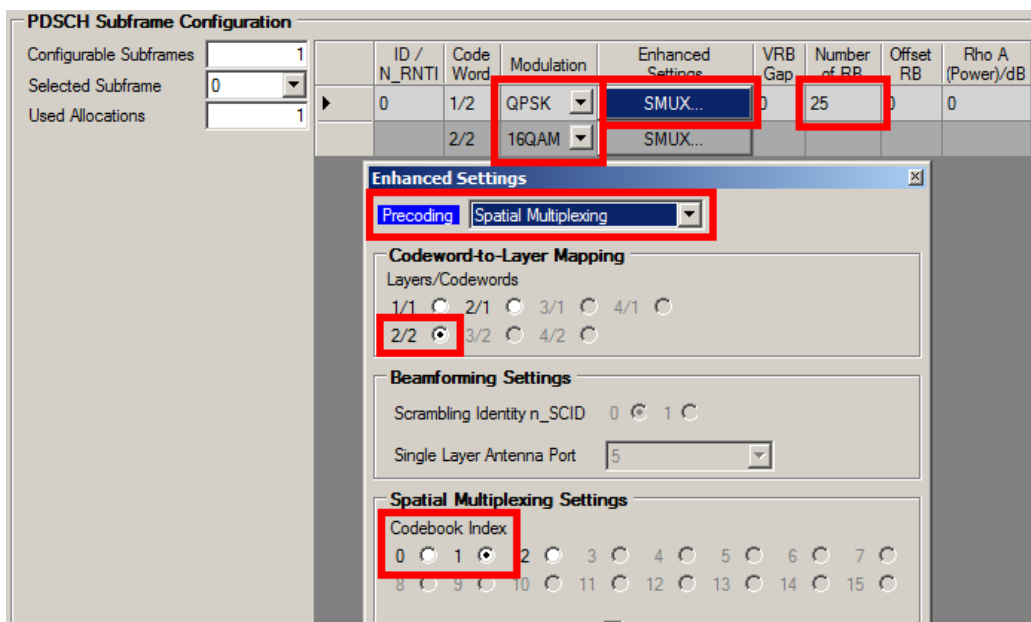


Figure 3-2: Configuration of a two layer spatial multiplexing PDSCH in the LTE-Software

In the analysis results, the constellation diagram calculated "before MIMO decoder" shows a constellation which is a superposition of the QPSK and 16QAM modulated codewords. This is shown in Figure 3-3 for both antennas.
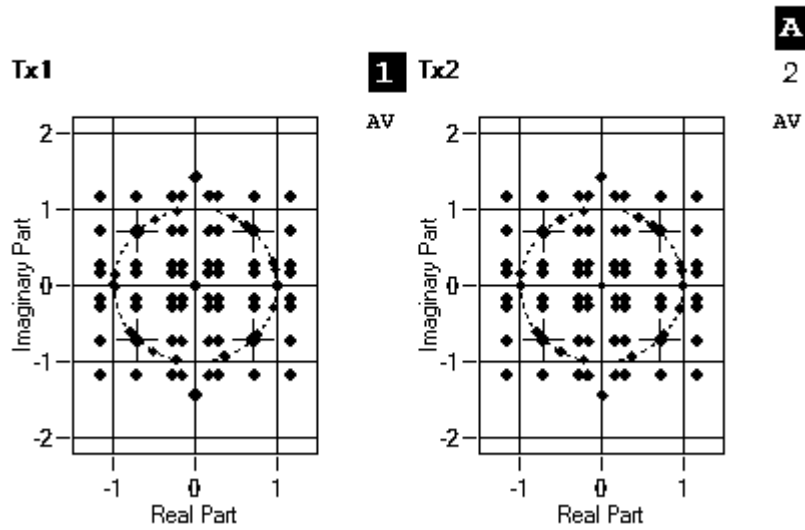


**Figure 3-3: Constellation diagram (before MIMO decoder)**

If the two antenna signals are combined in the MIMO decoder, the original codeword modulations are recovered as can be seen in Figure 3-4. This view is activated in the constellation selection window with Location set to After MIMO/CDMA decoder.
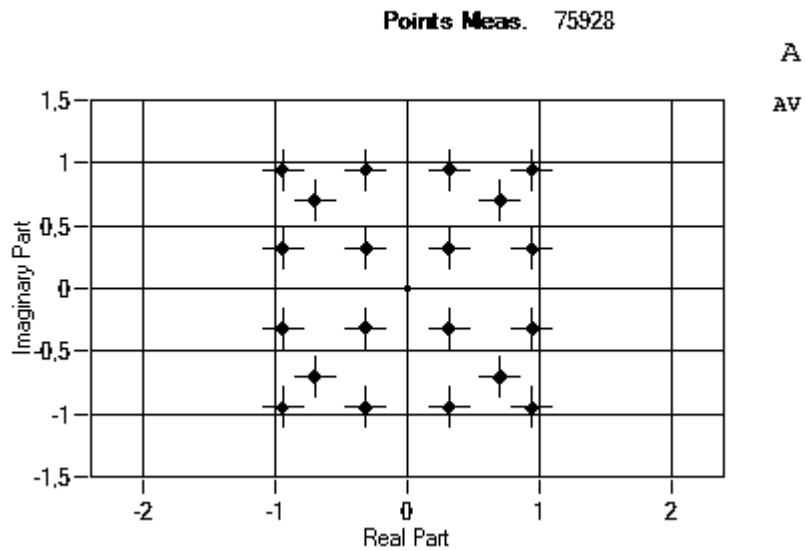


**Figure 3-4: Constellation diagram (after MIMO decoder)**

The MIMO precoding in the transmitter is verified by the display of the expected QPSK and 16-QAM modulation constellation points.

Another means of verification is to evaluate the EVM results. In Figure 3-5 it can be seen that for this example the EVM vs. Carrier measurement results show a low EVM value.
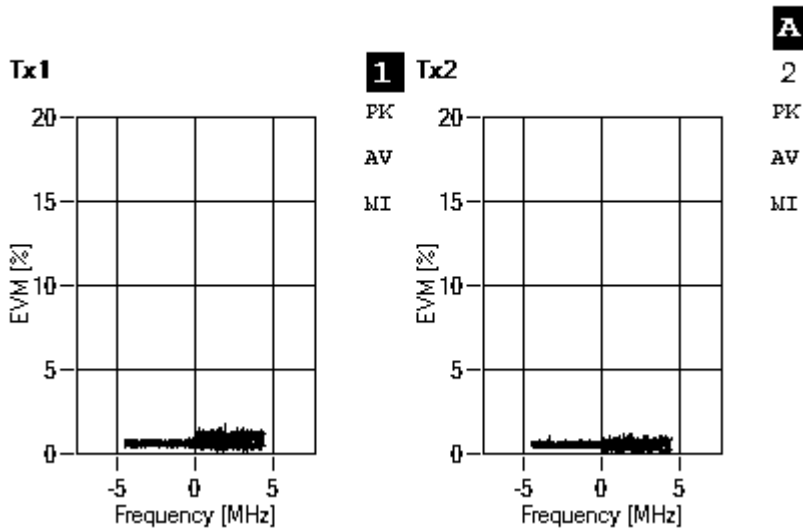


**Figure 3-5: EVM vs. Carrier measurement result**

A third verification method is to compare the transmitted bits to the decoded ones. These decoded bits can be found in the Bit Stream measurement. By changing the state of Scrambling of Coded Bits in the Downlink Demodulation Settings dialog, either the bits with or without the scrambling are given.

# 4 Measuring LTE Base Station Signals Over-the-Air

The RTO can be used to conveniently measure LTE base station signals over-the-air including successful decoding of spatial multiplexing MIMO precodings with more than one spatial layer. First configure the basic settings as in Section 2.2. To set the LTE-Software in the over-the-air mode, adjust the downlink demodulation settings according to Figure 4-1.
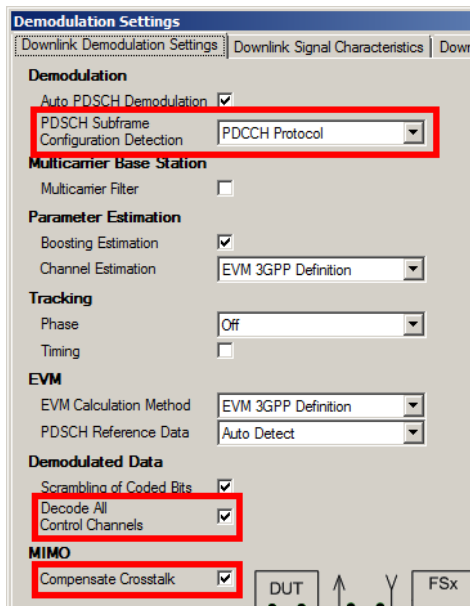


**Figure 4-1: Demodulation settings for over-the-air measurements**

The PDSCH Subframe Configuration Detection based on the PDCCH protocol extracts all the MIMO precoding settings for each detected PDSCH from the control channel (PDCCH) protocol. By enabling the decoding of all channels the PDSCH will also be decoded. For over-the-air measurements the compensation of the channel crosstalk needs to be activated.

The following pictures show measurement results of a real LTE base station captured over-the-air with two RX antennas. Figure 4-2 gives the power distribution of the received signal for all OFDM resource elements for each antenna separately. Red regions indicate high power and yellow regions are unused resource elements.
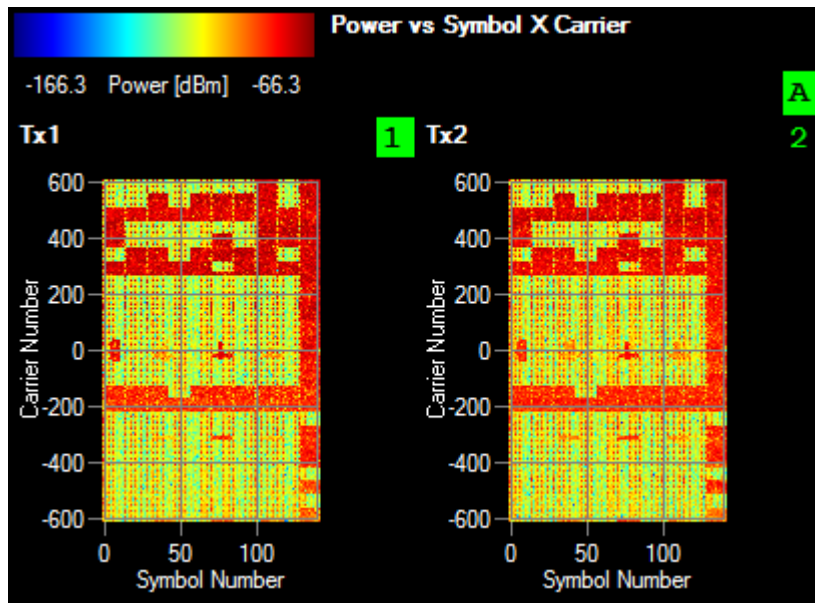
Figure 4-2: Power vs. Symbol X Carrier measurement for an over-the-air measurement

Figure 4-3 shows the detected type of physical signals and channels of each resource element in the Allocation ID vs. Symbol X Carrier measurement. The green color marks the PDSCH, the synchronization signals and broadcast channels are highlighted in blue color.

It can be seen that the LTE-Software has detected the signal correctly as the green blocks in Figure 4-3 match the red blocks in Figure 4-2.
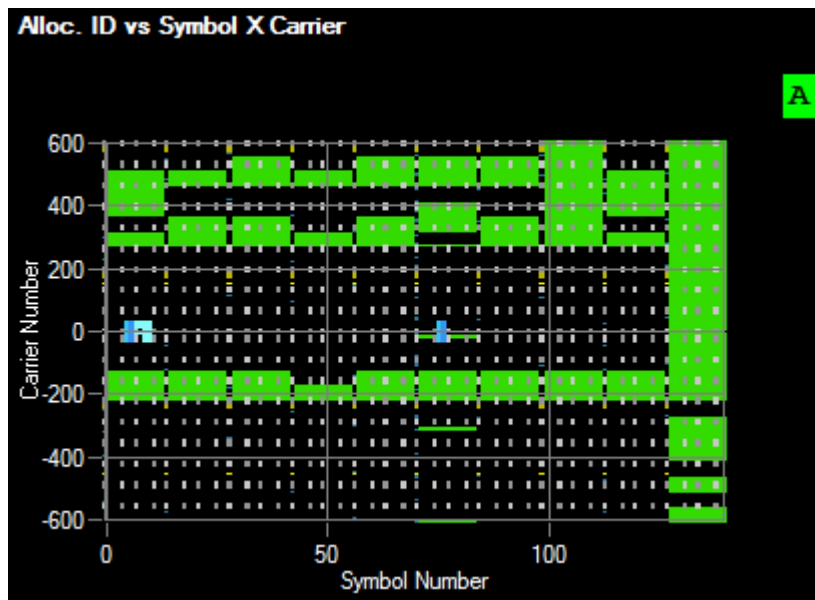


Figure 4-3: Allocation ID vs. Symbol X Carrier measurement for an over-the-air measurement

The LTE-Software is capable of decoding the PDSCH content, i.e. the binary content after channel decoding and cyclic redundancy check (CRC) can be viewed. In the PDSCH section of the Channel Decoder Results measurement, the bits for each of the two codewords which were transmitted over different spatial layers are displayed (see Figure 4-4).

**Channel Decoder Results**

```
Sub-    Allocation                                Data
frame       ID
0       PBCH          2 Tx Ant., Bandwidth 20 MHz, Frame Number 760
                      PHICH normal duration, PHICH resource 1/6
        PCFICH        1 symbol for PDCCH
        PHICH         ACK(1)/NACK(0)                    Rel. Power/dB
                      -1-- 1---         -  | -2,01|   -  |  -  |-24,01|   -  |  -  |   -
                      ---- ----         -  |  -  |   -  |  -  |  -  |   -  |  -  |   -
                      ---- ----         -  |  -  |   -  |  -  |  -  |   -  |  -  |   -
        PDCCH         #  RNTI   DCI Format  PDCCH Format  CCE Offset
                      0  29140  2A            0             9

                      #  Bit Data
                      0  0000 0000 0110 0000 0001 0111 0001 1010 1100 0100 1100 0000
        PDSCH 29140 CW  Bit Index  Bit Data
                      1/2 0          000001011001110111111001010110101001000001100000
                      1/2 48         110110110101001001001000100101101001100001101111
                      1/2 96         110011110111010001000001000000011001011111101
```

…

```
                      1/2 12864      11011011010001110000001000101011111111001100001
                      1/2 12912      001100110011010100010001110110100101000001111110
                      2/2 0          001001011000010100001101000111111001110111111010
                      2/2 48         010100000110000011110011010101111101100011101110111011
                      2/2 96         10011111010011111101110001001011010101001001111
```

**Figure 4-4: Channel Decoder Results measurement showing PDSCH decoding results**

In this figure the start of the bit stream of the second codeword is marked (CW = "2/2") to show that a real multi-layer transmission has been used. Such a decoding is only possible if multiple antenna signals are captured at the same time.

# 5 Beamforming Phase Difference Measurement

In the beamforming MIMO mode it is required that the phase difference between different antennas in the transmitter is small, since phase errors lead to a rotation of the radiation pattern. The LTE-Software supports a phase measurement of the cell-specific reference signal and the beamforming reference signal (UE-specific reference signal) for each TX antenna. The RTO is perfectly suited for these kinds of measurements since it has very good phase coherence between different input channels. To eliminate measurement errors caused by constant phase offsets of the RTO input channels and the cabling, a calibration must be performed prior to the measurement.

As an example we measure the phase difference of a beamforming signal on antenna port 5 generated by an SMU. For this measurement, the SMU must be equipped with the R&S®SMU-B90 Phase Coherence option and a phase calibration must be performed. In this application note we calibrate similarly to what is described in the Rohde & Schwarz application note 1GP67 [3].

Connect the RF outputs of the SMU to a two-way RF resistive power combiner and connect the output of the combiner to a spectrum analyzer (e.g. the FSW) as shown in Figure 5-1. It is important that the same cables which were used for the SMU calibration (herein "SMU Calibration Cables") are also used for the following phase measurement.
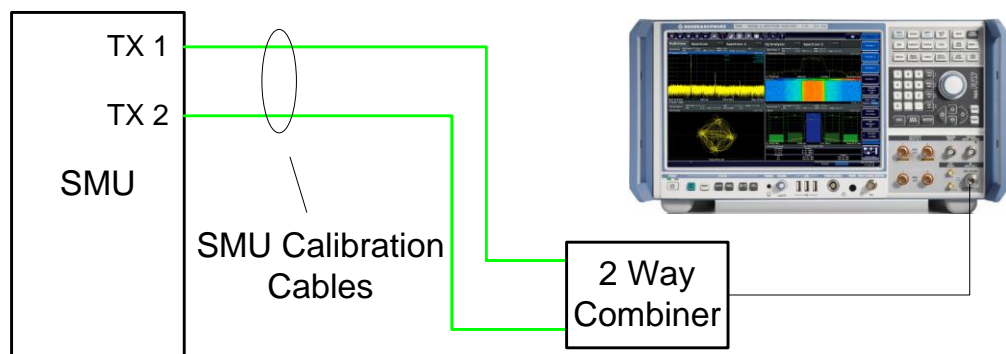


Figure 5-1: Hardware setup of the SMU and the FSW for SMU phase calibration

**SMU calibration procedure:**

● Preset both instruments.

● Open EUTRA/LTE in baseband B in the SMU.

● Open the Trigger/Marker dialog and set the Trigger In Mode to Armed Auto and the Source to Internal (Baseband A) to ensure that both base band paths are synchronized (see Figure 5-2).

● Then activate baseband B.

● Open EUTRA/LTE in baseband A and activate this also.

- Press the config button of the RF A block and select LO Coupling.

- Adjust the local oscillator settings according to Figure 5-3 and activate RF for both paths.

- In the spectrum analyzer set the center frequency to 1 GHz and the span to 40 MHz.

- Change the phase offset of baseband A (see Figure 5-4) until the measured RF level is minimal.
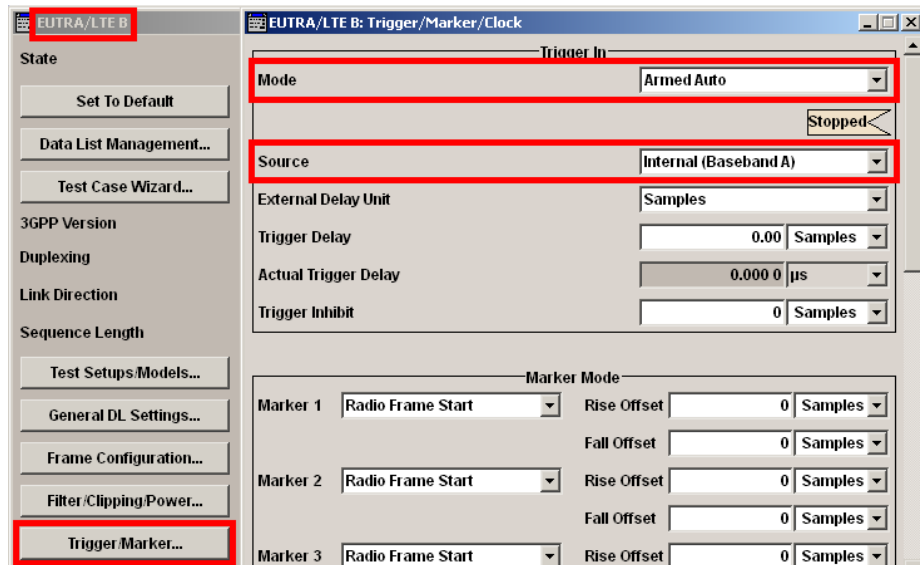


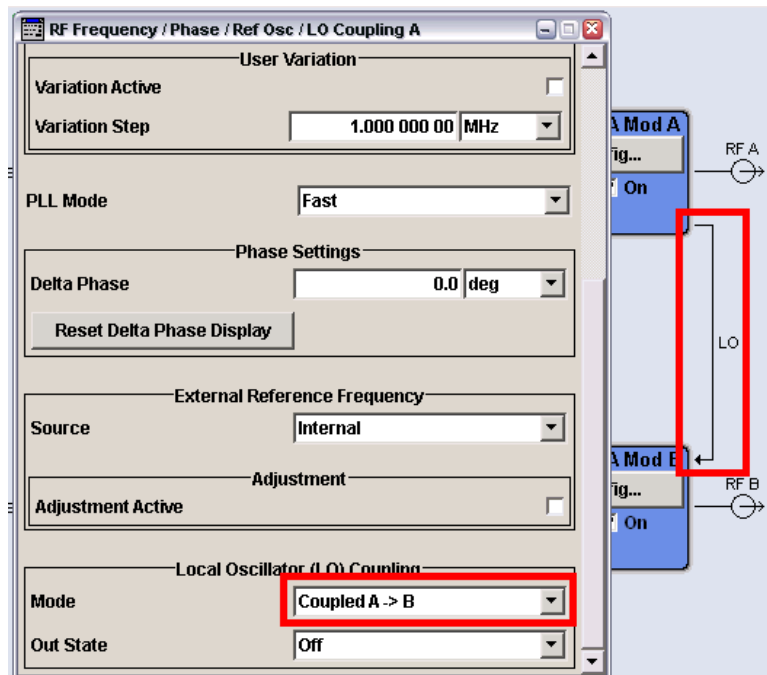**Figure 5-2: Synchronization of the baseband paths for phase calibration on the SMU**



**Figure 5-3: Configuration of the local oscillator coupling for phase calibration on the SMU**
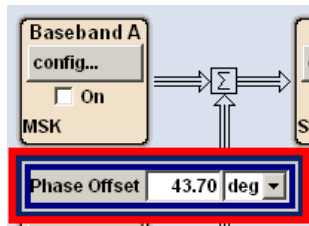
**Figure 5-4: Setting the baseband A Phase Offset**

After calibration open EUTRA/LTE in baseband A and press the Set To Default button. The phase offset of baseband B must now be set to 180° to have a zero phase at the combiner input (see Figure 5-5).
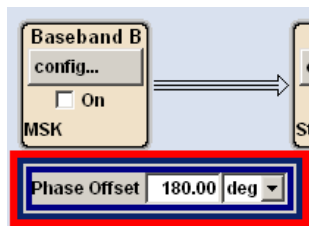


**Figure 5-5: Setting the baseband B Phase Offset to 180°**

Begin with the same SMU and LTE-Software settings as given in Section 2.2 and 3. In the SMU Frame Configuration window change the number of codewords (CW column) to 1/1 and the Precoding Scheme in the Enhanced Settings to Beamforming (UE-spec. RS). The Codebook Index must be set to 0 so that the same phase is used on all antennas (see Figure 5-6).
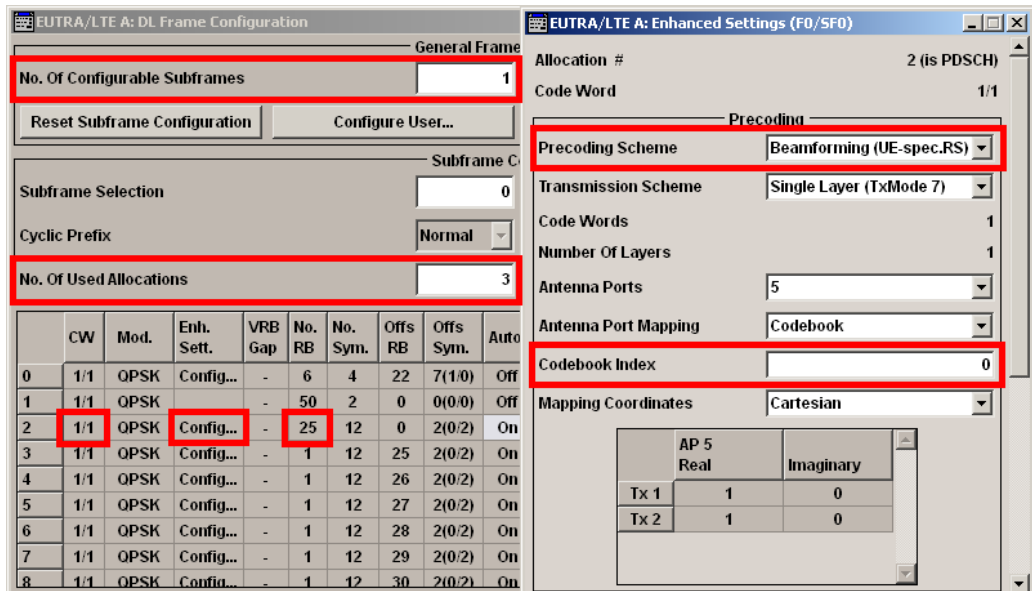


**Figure 5-6: Modifications of the SMU settings to enable beamforming**

In the Demodulation Settings window of the LTE-Software modify the Enhanced Settings to support beamforming as indicated in Figure 5-7.
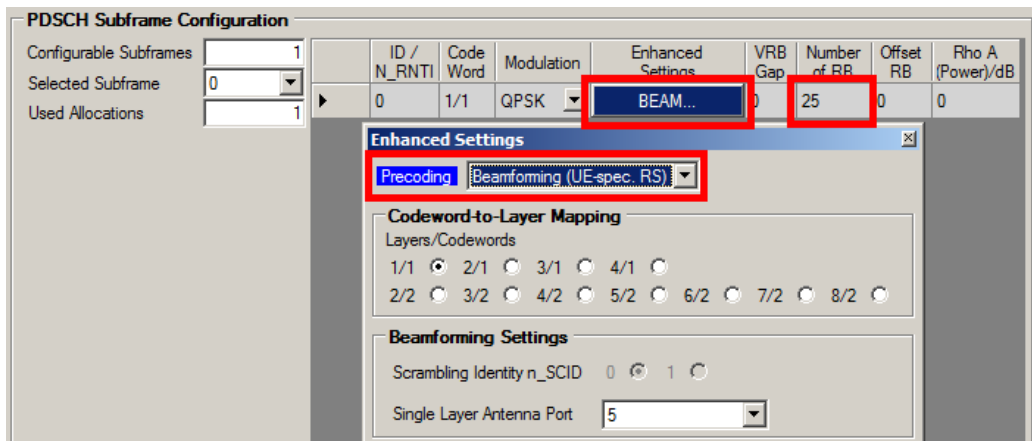


**Figure 5-7: Modifications of the LTE-Software settings to enable beamforming**

For the phase calibration of the RTO, the SMU signal on RF A (first MIMO antenna) can be used. Connect the RF A output of the SMU with a two-way RF resistive power splitter and connect the outputs of the splitter to the first two inputs of the RTO as shown in Figure 5-8.

**It is necessary to use a different set of cables for the RTO calibration as were used for calibrating the SMU since both calibration methods include the cables in the calibration.**
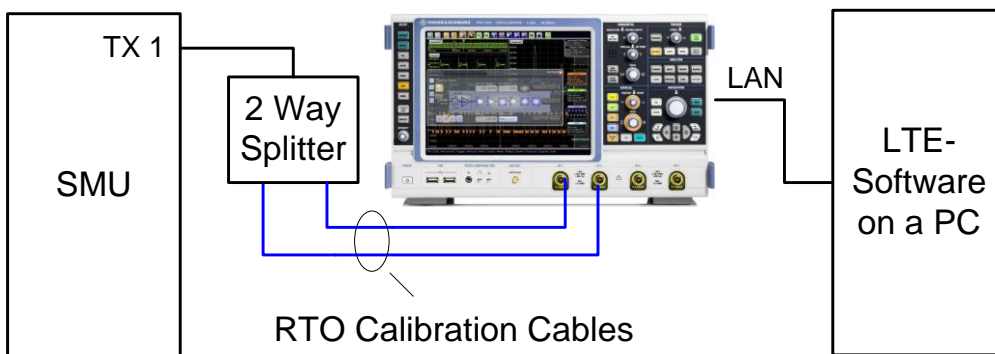


Figure 5-8: Hardware setup of the SMU and the RTO for RTO phase calibration

Now press the SETUP button in the LTE-Software and initiate the calibration run by clicking on the GENERATE CALIBRATION DATA button. The calibration data can optionally be stored in a file for later use. In the header of the LTE-Software a yellow label indicates that the phase difference measurements have been calibrated. After the calibration use the same cables to connect the RTO inputs to the SMU RF cable set according to Figure 5-9, were we have a serial connection of the RF cables from the SMU and RTO calibration. The two adapters to connect the two cable sets must be of the same type to minimize additional phase errors caused by the connections.
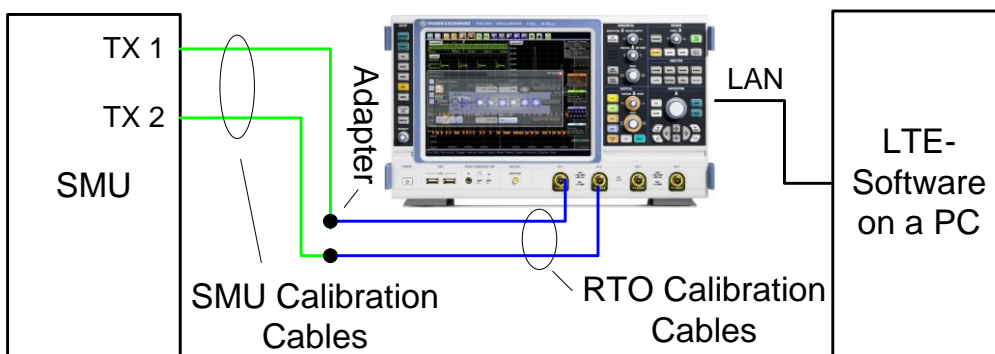


Figure 5-9: Hardware setup of the SMU and the RTO for calibrated phase difference measurements

The LTE-Software measures the phase difference of each UE-specific reference signal weight and each PDSCH allocation for all antennas which are not the reference antenna. The reference antenna is always antenna one.

Start the measurement by pressing RUN SGL. The UE-specific Reference Signal Weights measurements require a specific subframe to be selected. E.g. choose subframe 0 in the Subframe Selection of the Result Settings in the General Settings window.

Select screen B and show the UE-specific RS Weights vs Allocation measurement by clicking on MEAS ⇒ BEAM FORMING ⇒ UE RS WEIGHTS VS ALLOCATION. Select screen D and click twice on UE RS WEIGHTS DIFF to show the UE-specific RS Weights Phase Difference measurement.

The results of the phase difference measurements are given in Figure 5-10. Note that the UE-specific reference signal is only present on subcarriers where the PDSCH is located. Therefore, only the left half of the used subcarriers is available in this example.
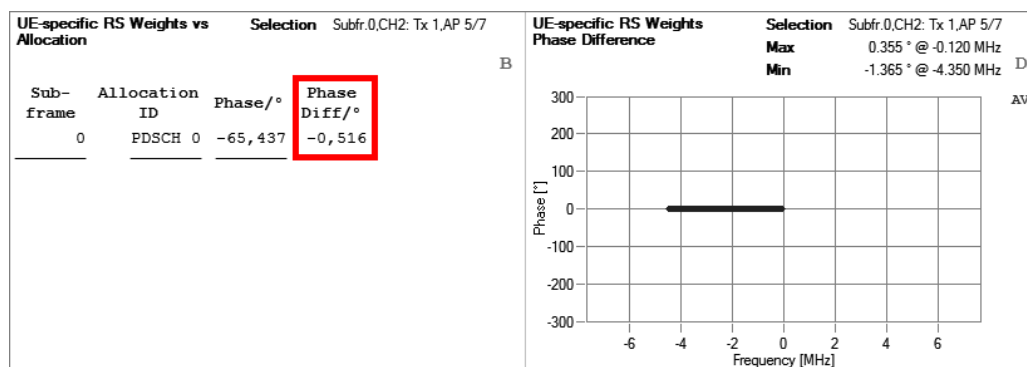


**Figure 5-10: Beamforming phase difference measurements for the UE-specific reference signal**

In our example no beamforming is applied. Therefore, the measured phase difference of all antennas must be close to zero. As expected we measure only a small phase offset between the two antennas.

The measurement results can be exported via remote control for further analysis (e.g. to calculate an average of all results for increased precision).

# 6 Literature

[1] Rohde & Schwarz: Application Note 1MA142 "Introduction to MIMO"

[2] Rohde & Schwarz: Application Note 1MA143 "LTE Downlink MIMO Verification"

[3] Rohde & Schwarz: Application Note 1GP67 "Phase Adjustment of Two MIMO Signal Sources with Option B90 (Phase Coherence)"

# 7 Ordering Information

| Designation | Type | Order No. |
|---|---|---|
| Digital Oscilloscope, 4 GHz, 4 channels | R&S®RTO1044 | 1316.1000.44 |
| I/Q Software Interface | R&S®RTO-K11 | 1317.2975.02 |
| OCXO 10 MHz | R&S®RTO-B4 | 1304.8305.02 |
| EUTRA/LTE FDD Downlink PC Software | R&S®FS-K100PC | 1309.9916.02 |
| EUTRA/LTE Uplink FDD PC Software | R&S®FS-K101PC | 1309.9922.02 |
| EUTRA/LTE Downlink MIMO PC Software (incl. LTE-Advanced) | R&S®FS-K102PC | 1309.9939.02 |
| EUTRA/LTE Uplink MIMO PC Software (incl. LTE-Advanced) | R&S®FS-K103PC | 1309.9945.02 |
| EUTRA/LTE TDD Downlink PC Software | R&S®FS-K104PC | 1309.9951.02 |
| EUTRA/LTE TDD Uplink PC Software | R&S®FS-K105PC | 1309.9968.02 |
| Vector Signal Generator | R&S®SMU200A | 1141.2005.02 |
| Digital Standard EUTRA/LTE | R&S®SMU-K55 | 1408.7310.02 |
| Phase Coherence | R&S®SMU-B90 | 1409.8604.02 |

## 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.

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