# LTE System Specifications and their Impact on RF & Base Band Circuits

Application Note

**Products:**

- R&S®FSW
- R&S®SMU
- R&S®SFU
- R&S®FSV
- R&S®SMJ
- R&S®FSUP


RF physical layer specifications (such as 3GPP TS36.104) describe a variety of requirements that the end equipment needs to meet.

This application note provides insight into some of these specifications and how test & measurement equipment can simplify the task of deriving requirements for RF sub-systems.


ROHDE&SCHWARZ

Application Note


Dr. Oliver Werther/Roland Minihold



04.2013 – 1MA221_1E

# Table of Contents


1 Introduction ........ 4

2 Review of Technical Specifications ........ 5

2.1 Dynamic Range ........ 5

2.1.1 Example: Dynamic Range Test Case for a 5 MHz LTE Signal ........ 9

2.1.2 Dynamic Range: Summary ........ 9

2.1.3 Dynamic Range Test Using the SMU/SMJ ........ 10

2.2 Receiver Blocking Characteristics ........ 11

2.2.1 Example of a Blocking Specification: Adjacent Channel Selectivity (ACS) ........ 11

2.2.2 Summary of Blocking Requirements ........ 13

2.3 Example: Receiver Blocking Test Using the SMU and the FSW ........ 14

2.3.1 ACS and In-Band Blocking ........ 15

2.3.2 Using the Multi Carrier Filter of the R&S FSW and FSV for ACS and Receiver Blocking Measurements ........ 16

3 Impact of Phase Noise on EVM ........ 18

3.1 Transmit EVM ........ 18

3.2 Specification of Phase Noise ........ 19

3.3 Phase Noise Profiles of RF Signal Sources ........ 19

3.4 Introduction of Phase Noise Impairments using the SFU ........ 20

3.4.1 SFU Phase Noise Profiles ........ 20

3.4.2 Phase Noise Profile Creator Software ........ 22

3.5 Impact of Phase Noise on TX-EVM of a LTE signal ........ 23

4 Summary ........ 28

5 Literature ........ 29

6 Additional Information ........ 30

7 Appendix ........ 31

7.1 Downloads ........ 31

7.1.1 SFU Phase Noise Creator Software ........ 31

7.1.2 Application Note “LTE Base Station Tests according to TS 36.141” ........ 31

7.2 Overview of Blocking Requirements ........ 32

7.2.1 Narrow-Band Blocking ........ 32

7.2.2 In-Channel Selectivity (ICS) ........ 33

7.2.3 In-Band Blocking....................................................................................................33
7.2.4 Out-of-Band Blocking.............................................................................................34
7.2.5 Co-Location With Other Base Stations..........................................................35

**8 Ordering Information.............................................................. 36**

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

The R&S FSW spectrum analyzer is referred to as the FSW.
The R&S FSV spectrum analyzer is referred to as the FSV.
The R&S SMU200A vector signal generator is referred to as the SMU.
The R&S SMJ100A vector signal generator is referred to as the SMJ.
The R&S SFU broadcast test system is referred to as the SFU.
The R&S FSUP signal source analyzer is referred to as the FSUP.

# 1 Introduction

Technical specifications that describe RF characteristics and minimum performance requirements of, for example E-UTRA, base stations (TS36.104 [1]) contain many complex test cases. While some of the specifications can be directly translated into requirements of an RF transceiver, other specifications require a detailed review.

This application note will review a few important specifications described in TS36.104.

The Dynamic Range specification in [1] is analyzed and it will be shown that the “Dynamic Range” specification is imposing very stringent requirements onto the baseband demodulator instead of the RF receiver.

Blocking specifications will be reviewed in detail and test scenarios using the SMU vector signal generator and FSW vector signal analyzer will show how complex LTE specific test cases can be easily set up using a built-in test case wizard of the SMU, which provides test cases according to TS36.104.

The impact of phase noise of an RF PLL on the EVM of a LTE signal will be demonstrated. It will be shown how phase noise impairments, created by the SFU, can be used to quickly evaluate the impact of different RF PLL phase noise profiles on the EVM performance of an LTE signal.

# 2 Review of Technical Specifications

The following section provides an overview of a few important specifications that need to be considered for the RF section of, for example, a base-station.
It should be noted that the specifications discussed in section 2 represent only a small part of the requirements that need to be considered for the design of an RF subsystem of a base station. Unless mentioned otherwise, the specifications described in this section are based on the 3GPP specification TS36.104 version 11.2.0 (2012-11) [1].
The Rohde & Schwarz Application Note 1MA154_1e [9] provides an overview of how to perform transmitter and receiver tests of complete base stations. This section provides additional information beyond the scope of a 3GPP specification that enables the user to gain insight on how certain specifications may affect the RF section or the base-band section of a base-station.

## 2.1 Dynamic Range

The term "Dynamic Range" as defined by 3GPP [1] requires additional clarification.

"Dynamic Range" of a receiver is usually defined as the input signal power range at the antenna input port over which the data error rate does not exceed a specific value [2]. The lower end of the dynamic range is close to the receiver sensitivity power level, while the maximum input power level at which the error data rate remains below the target specification determines the upper end of the dynamic range.

The specification "Dynamic Range" as introduced in the document TS 36.104 [1] (section 7.3) describes a completely different test case that will be described below.

According to [1] "The dynamic range is specified as a measure of the capability of the receiver to receive a wanted signal in the presence of an interfering signal inside the received channel bandwidth. In this condition a throughput requirement shall be met for a specified reference measurement channel. The interfering signal for the dynamic range requirement is an Average White Gaussian Noise (AWGN) signal."

The target throughput is specified to be >= 95% for the following conditions:

| Dynamic Range Specification | | | | |
|---|---|---|---|---|
| Wide Area Base Station according to TS 36.104 [1] | | | | |
| E-UTRA Channel BW [MHz] | Ref. Channel (16 QAM, CR=2/3) | Wanted Signal Power [dBm] | Interfering power [dBm] | Type of Interf. Signal |
| 1.4 | A2-1, RB=6 | -76.3 | -88.7 | AWGN |
| 3 | A2-2, RB=15 | -72.4 | -84.7 | AWGN |
| 5 | A2-3, RB=25 | -70.2 | -82.5 | AWGN |
| 10 | A2-3, RB=25 | -70.2 | -79.5 | AWGN |
| 15 | A2-3, RB=25 | -70.2 | -77.7 | AWGN |
| 20 | A2-3, RB=25 | -70.2 | -76.4 | AWGN |

**Table 2-1: Dynamic range specification for Wide Area BS**

In order to gain further insight into above specification the reference sensitivity specification needs to be reviewed. The reference sensitivity specification is listed in [1] in section 7.2 as shown in Table 2-2.

| Reference Sensitivity Specification | | |
|---|---|---|
| **Wide Area Base Station according to TS36.104 [1]** | | |
| **E-UTRA channel BW [MHz]** | **Reference Measurement Channel (QPSK, CR=1/3)** | **Reference sensitivity power level [dBm]** |
| 1.4 | A1-1, RB=6 | -106.8 |
| 3 | A1-2, RB=15 | -103.0 |
| 5 | A1-3, RB=25 | -101.5 |
| 10 | A1-3, RB=25 | -101.5 |
| 15 | A1-3, RB=25 | -101.5 |
| 20 | A1-3, RB=25 | -101.5 |

**Table 2-2: Reference sensitivity specification for Wide Area BS**

A throughput of >= 95% needs to be maintained for all cases listed in Table 2-2. The detailed description of the reference measurement channels A1-1 to A1-3 is described in Annex A of [1].

Comparing the reference sensitivity level listed in Table 2-2 with the wanted signal power listed in Table 2-1 reveals that the wanted signal level for all bandwidths (1.4MHz to 20MHz) has been raised by approximately 30dB above the reference signal sensitivity power level. This translates into a 30dB higher input signal-to-noise ratio (SNR). The type of interference signal that is injected into the input of the receiver is AWGN (refer to Table 2-1:). The average mean power of the interference signal that will be added to the input of the receiver (refer to Table 2-1) is effectively reducing the signal-to-noise ratio of the input signal. The added noise power of the interfering signal is masking the thermal noise at the input of the receiver and, more importantly, all noise contributions of the individual RF circuits of the receiver.

The following block diagram shall illustrate above test case. Figure 2-1 shows a simplified block diagram of a receiver. A duplexer precedes the receiver. Two signal sources represent the desired LTE and the interfering AWGN signal.

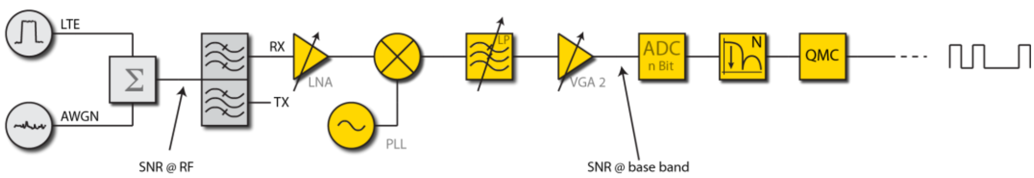


**Figure 2-1: Dynamic Range test configuration according to TS 36.104 [1]**

The level diagram in Figure 2-2 visualizes that the AWGN interference signal ("Noise Interference") masks all noise contributions of the individual RF stages of the receivers.

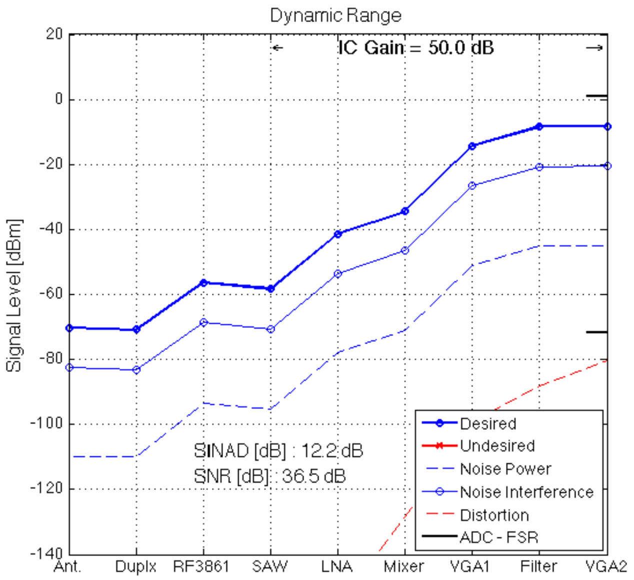


**Figure 2-2: Level diagram of a receiver in the presence of AWGN as an interference signal**

The input and output SNR of the receiver are identical (12.2dB in the example shown in Figure 2-2). Thus, raising the desired signal power and adding in-channel AWGN as an interference signal as specified in Table 2-1: creates a "virtually noise free" RF receiver (NF = 0dB).

In order to understand why the interference levels were specified as described in Table 2-1:, the minimum required SNR at the input of the base band LTE demodulator has to be considered.

The required base band SNR versus coding rate requirements for different modulation schemes are listed in the following table:

| Required Base Band SNR | | |
|---|---|---|
| **SNR Requirements Versus Coding Rate and Modulation Scheme** | | |
| **Modulation** | **Code Rate** | **SNR [dB]** |
| QPSK | 1/8 | -5.1 |
| | 1/5 | -2.9 |
| | 1/4 | -1.7 |
| | 1/3 | -1.0 |
| | 1/2 | 2.0 |
| | 2/3 | 4.3 |
| | 3/4 | 5.5 |
| | 4/5 | 6.2 |
| **16 QAM** | 1/2 | 7.9 |
| | **2/3** | **11.3** |
| | 3/4 | 12.2 |
| | 4/5 | 12.8 |
| 64 QAM | 2/3 | 15.3 |
| | 3/4 | 17.5 |
| | 4/5 | 18.6 |

**Table 2-3: Theoretical minimum SNR at base band demodulator input**

The reference channel that is specified for the dynamic range test ([1], Annex 2, A2-1 to A2-3), requires the following modulation parameters:

- Modulation: QAM 16
- Code Rate: 2/3

According to Table 2-3: a minimum base band SNR of 11.3dB is required to demodulate this LTE signal.

### 2.1.1 Example: Dynamic Range Test Case for a 5 MHz LTE Signal

The following example describes a dynamic range test case for a 5 MHz LTE signal.

According to [1] the desired LTE signal will be raised to -70.2dBm. An in-channel interference AWGN signal will be introduced at a power level of -82.5dBm. The input SNR at the RF input of the receiver is therefore -70.2dBm - -82.5dBm = 12.3dB. The interference noise power that is added at the RF input of the receiver is significantly higher than the thermal noise power of the system (Table 2-1) and masks all noise contributions of the RF receiver, creating a “virtual noise free receiver” with a NF of 0dB. The SNR at the output of the RF receiver is therefore equal to the SNR at the input of the receiver, in this case 12.3dB. The minimum required SNR for the base band demodulator is 11.3dB (Table 2-3), which provides only 1dB of margin for the base band demodulator IC.

### 2.1.2 Dynamic Range: Summary

The so called “Dynamic Range” test case masks all noise contributions of the RF receiver and establishes a well defined test condition for the LTE base band demodulator with about 1dB of SNR margin for the demodulator for all signal bandwidths between 1.4MHz and 20MHz. This margin is often called “base band implementation loss” and accounts for imperfections related to implementing various digital algorithms as well as analog-to-digital converter imperfections.

The following table summarizes the desired, un-desired power levels and the respective SNR margins versus the bandwidth of the desired LTE signal:

| Dynamic Range Test Case Summary | | | | | | |
|---|---|---|---|---|---|---|
| Wide Area Base Station Test Case | | | | | | |
| E-UTRA Channel BW [MHz] | Ref. Channel (16 QAM, CR=2/3) | Wanted Signal Power [dBm] | AWGN Interfering power [dBm] | UnDesired / Desired Power [dB] | Theoretical base band SNR [dB] | SNR Margin (IL) [dB] |
| 1.4 | A2-1, RB=6 | -76.3 | -88.7 | 12.4 | 11.3 | 1.1 |
| 3 | A2-2, RB=15 | -72.4 | -84.7 | 12.3 | 11.3 | 1.0 |
| 5 | A2-3, RB=25 | -70.2 | -82.5 | 12.3 | 11.3 | 1.0 |
| 10 | A2-3, RB=25 | -70.2 | -79.5 | 9.3 | 8.3 | 1.0 |
| 15 | A2-3, RB=25 | -70.2 | -77.7 | 7.5 | 6.5 | 1.0 |
| 20 | A2-3, RB=25 | -70.2 | -76.4 | 6.2 | 5.3 | 0.9 |

**Table 2-4: Dynamic Range test summary**

### 2.1.3 Dynamic Range Test Using the SMU/SMJ

The dynamic range tests can be performed by using the built-in LTE test case wizards of the Rohde & Schwarz SMU and SMJ vector signal generators.

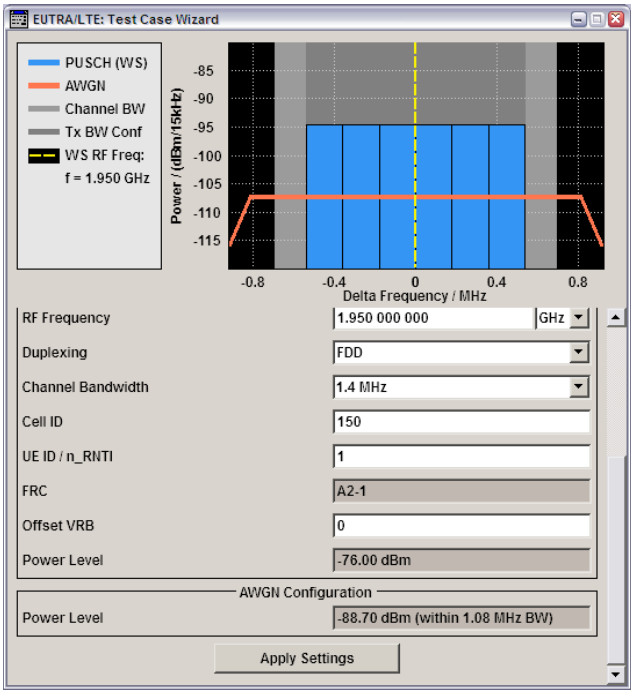


**Figure 2-3: SMU LTE test case wizard for dynamic range testing according to [1]**

The test case wizard will configure all parameters of the desired LTE signal as well as the undesired AWGN noise power according to the TS 36.104 LTE specification for fast and accurate measurements. The R&S application note 1MA154_1e [9] (section 3.2.3, page 29) describes test procedures for automated dynamic range measurements with R&S software (which is available free of charge).

## 2.2 Receiver Blocking Characteristics

The blocking characteristics are a measure of the receiver's ability to receive a wanted signal at its assigned channel in the presence of an interfering signal. TS36.104 [1] specifies several test cases with different types of interference signals (CW versus LTE signal) and frequency offsets between the desired and undesired signals.

In the following sections the undesired to desired power ratios (U/D) will be calculated for each blocking case to indicate the severity of the interference test case.

### 2.2.1 Example of a Blocking Specification: Adjacent Channel Selectivity (ACS)

The adjacent channel selectivity specification describes the test case for N=+/-1 adjacent channels as shown in Figure 2-4.

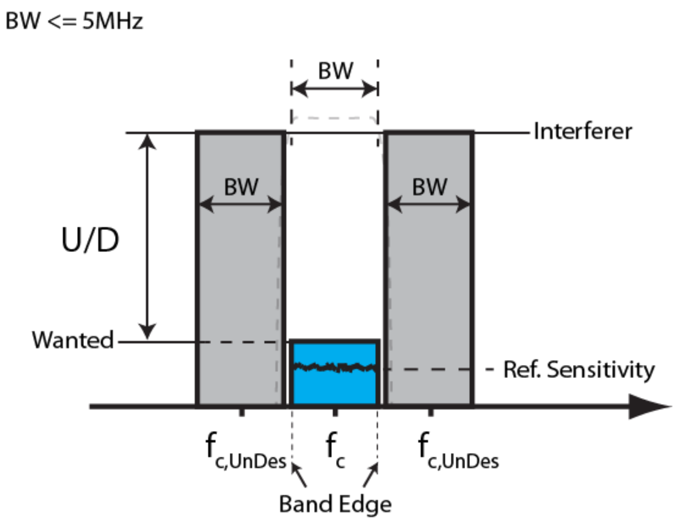


**Figure 2-4: Adjacent channel selectivity test case for bandwidths smaller than 5MHz**

It should be noted that the frequency offset between the undesired and desired signal is not equal to half of the channel bandwidth. An additional offset of either 2.5, 7.5 or 12.5 kHz was specified as shown in
Table 2-5.

| Adjacent Channel Selectivity Specification | | | | | | |
|---|---|---|---|---|---|---|
| **Wide Area Base Station Test Case** | | | | | | |
| **E-UTRA Channel BW [MHz]** | **Wanted Signal Mean Power [dBm]** | | **Interfering signal power [dBm]** | **Type of Interfering Signal** | **UnDes $f_c$ to Des Band Edge [MHz]** | **UnDesired / Desired Power Ratio [dB]** |
| 1.4 | $P_{REFSENS}$ + 11dB | -95.8 | -52 | 1.4 MHz LTE | 0.7025 | 43.8 |
| 3 | $P_{REFSENS}$ + 8dB | -95.0 | -52 | 3 MHz LTE | 1.5075 | 43.0 |
| 5 | $P_{REFSENS}$ + 6dB | -95.5 | -52 | 5 MHz LTE | 2.5025 | 43.5 |
| 10 | $P_{REFSENS}$ + 6dB | -95.5 | -52 | 5 MHz LTE | 2.5075 | 43.5 |
| 15 | $P_{REFSENS}$ + 6dB | -95.5 | -52 | 5 MHz LTE | 2.5125 | 43.5 |
| 20 | $P_{REFSENS}$ + 6dB | -95.5 | -52 | 5 MHz LTE | 2.5025 | 43.5 |

**Table 2-5: Summary of adjacent channel selectivity specifications**

The undesired to desired power levels and ratios for in-channel selectivity (ICS), narrow-band blocking, in-band blocking, out-of-band blocking and co-location blocking requirements are summarized in the appendix in section 7. The application note 1MA154_1e [9] provides guidelines for automated compliance testing for each of these blocking scenarios using R&S software, signal generators and signal analyzers.

### 2.2.2 Summary of Blocking Requirements

This section provides a summary of blocking scenarios. The U/D power ratio for each scenario is used as an indication of the severity of the blocking test case.

| Summary of Blocking Test Cases | | | | | |
|---|---|---|---|---|---|
| **Wide Area Base Station** | | | | | |
| **Blocking Test Case** | **Des. Signal BW [MHz]** | **Wanted Signal Power [dBm]** | **Interfering Power [dBm]** | **Type of Interfering Signal** | **Undesired / Desired Power Ratio [dB]** |
| Co-location | 1.4 | -100.8 | +16 | CW Signal | 116.8 |
| Co-location | 5 | -95.5 | +16 | CW Signal | 95.5 |
| Out-of-band | 1.4 | -100.8 | -15 | 1.4 MHz LTE | 85.8 |
| Out-of-band | 5 | -95.5 | -15 | 1.4 MHz LTE | 80.5 |
| In-band | 1.4 | -100.8 | -43 | 1.4 MHz LTE | 57.8 |
| In-band | 20 | -95.5 | -43 | 5 MHz LTE | 52.5 |
| Narrow-band | 1.4 | -100.8 | -49 | 1.4 MHz LTE (1 RB) | 51.8 |
| Narrow-band | 5 | -95.5 | -49 | 5 MHz LTE (1 RB) | 46.0 |
| ACS | 1.4 | -95.8 | -52 | 1.4 MHz LTE | 43.8 |
| ICS | 10 | -98.5 | -77 | 5 MHz LTE (25 RB) | 21.5 |

**Table 2-6: Summary of base station blocking specifications ordered by difficulty**

Figure 2-5 is a graphical representation of the blocking scenarios described in Table 2-6.

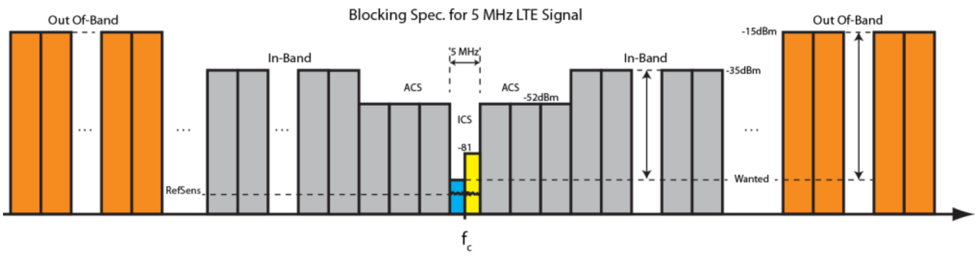


**Figure 2-5: Visual representation of ICS, ACS, In-band and out-of-band blocking specifications for a 5MHz LTE signal**

## 2.3 Example: Receiver Blocking Test Using the SMU and the FSW

The SMU and the FSW can be used to verify the blocking performance of RF receivers in the absence of an LTE demodulator. Figure 2-6 shows a test setup in which the SMU generates the desired and the undesired test signals for the blocking test.

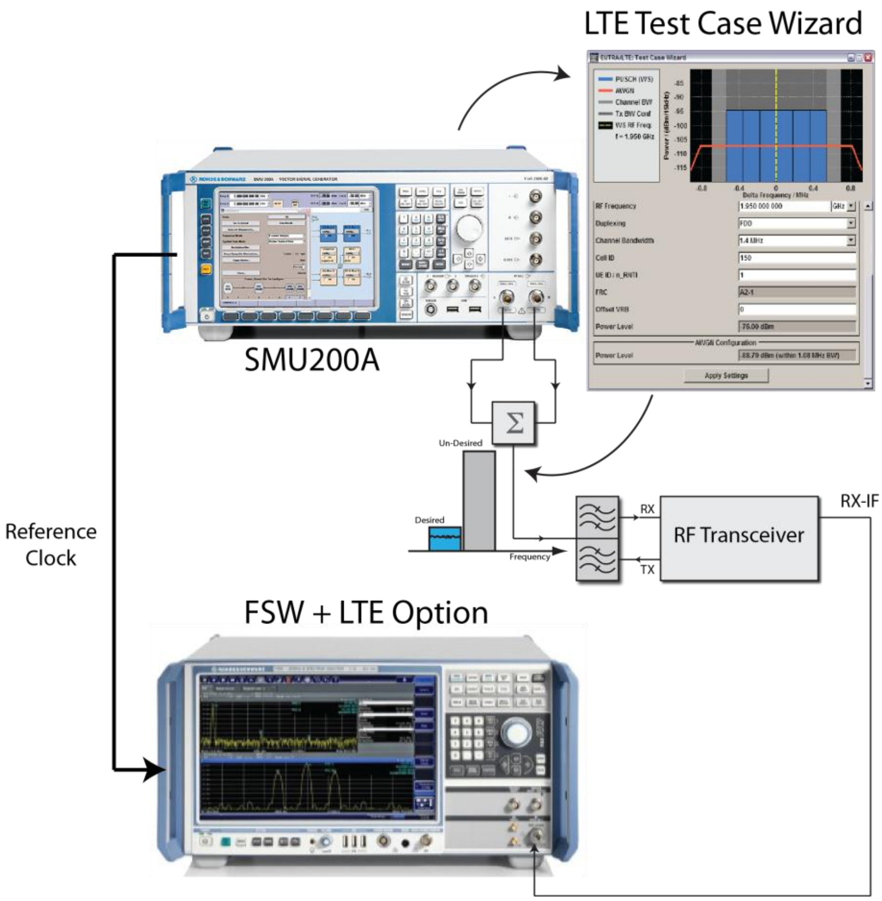


**Figure 2-6: Test setup for LTE blocking measurements of an RF transceiver using the SMU and FSW**

The SMU, with two RF sources in a single unit, simplifies the generation of desired and undesired standard compliant LTE test signals within a single RF signal generator. The vector signal generator can be configured for all test cases discussed in sections 2.2 and 2.3 using the built-in LTE test case wizard.

## 2.3.1 ACS and In-Band Blocking

The blocking test specifications described in section 2.3 are all very similar in their basic setup:

The desired signal power level is raised above the receiver sensitivity threshold by a certain amount (6 to 11 dB, depending on the blocker test case and the bandwidth of the signal).
An interference signal is added at a certain power level and frequency offset.
The increased RF signal level at the receiver input provides some SNR margin that enables the RF transceiver to apply a limited amount of RF AGC to both the desired and undesired signals.

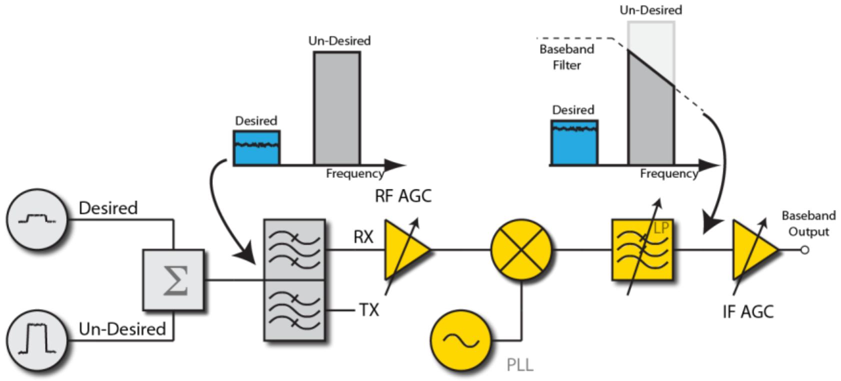


**Figure 2-7: Simplified block diagram describing an RF receiver blocker test scenario**

The RF receiver must maintain the SNR of the signal and suppress the interferer sufficiently to avoid saturation of the ADC.

A possible base-band signal at the input of an ADC is shown in Figure 2-8.

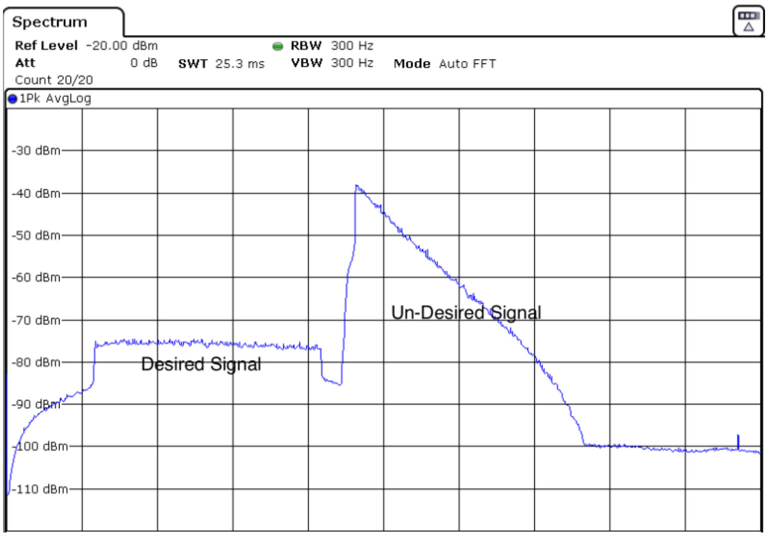


**Figure 2-8: Desired and undesired signal at the output of the RF receiver**

The desired signal shown in Figure 2-8 is slightly above the noise floor while a significant amount of adjacent channel power is still present at the base band output of the receiver. A digital filter following the ADC on a digital demodulator IC is typically used to filter out adjacent channel power to enable proper demodulation of the desired signal at such low SNR values.

### 2.3.2 Using the Multi Carrier Filter of the R&S FSW and FSV for ACS and Receiver Blocking Measurements

The FSW vector signal analyzer can be used as an LTE demodulator [8] to evaluate the signal quality of the desired signal at base band frequencies. The low signal-to-noise ratio of the desired signal (refer to Figure 2-8) in conjunction with a strong adjacent interference signal means the demodulator cannot demodulate the signal without additional filtering (refer to Figure 2-9).

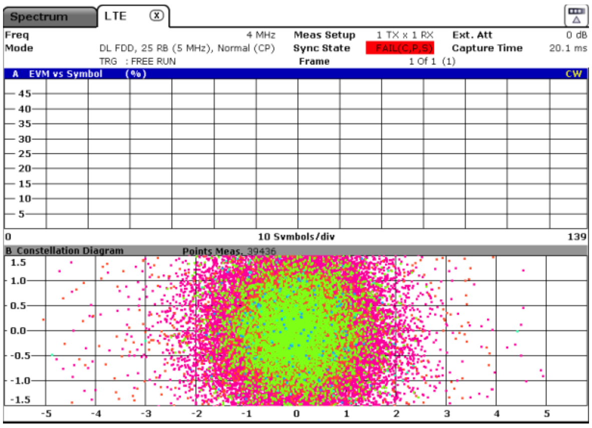


**Figure 2-9: Attempt to demodulate a low SNR LTE signal in the presence of strong adjacent interference signal**

The Rohde & Schwarz FSW and FSV signal analyzers provide the ability to add a digital multi-carrier filter [5] after the ADC thus enabling the demodulation of low SNR signals in the presence of interference signals as shown in Figure 2-8

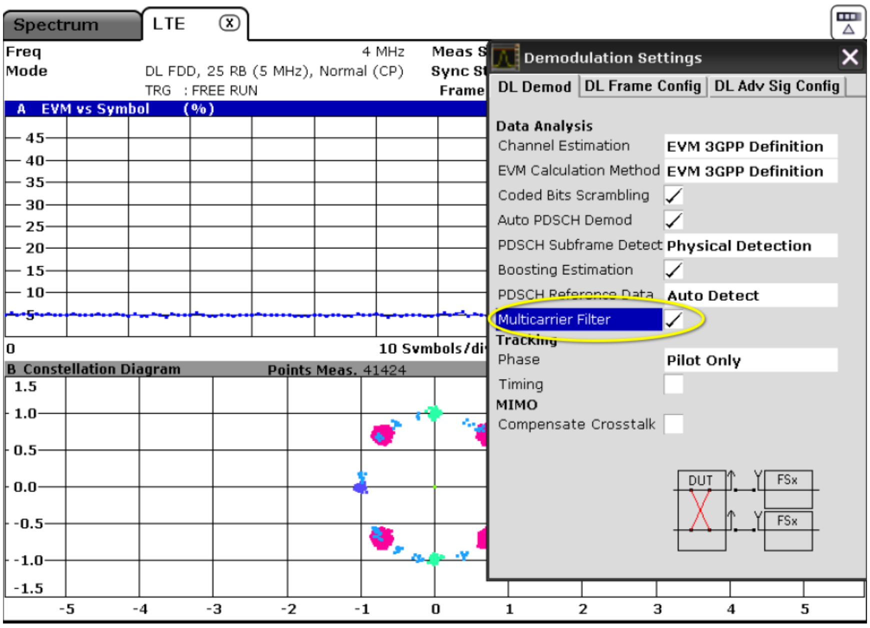


**Figure 2-10: Successful demodulation of a low SNR LTE signal in the presence of strong unwanted interference signal using the built in digital multi-carrier-filter of the FSW, FSV.**

The adjacent channel interference scenario described a test case in which the interference signal is of the same type as the desired signal (e.g. 10 MHz LTE signal).

It is often necessary to receive a wanted signal of one standard (e.g. LTE) in the presence of an unwanted signal of a different wireless standard like GSM. In this case, the Multi Standard Radio Analyzer (MSRA) feature of the FSW can be used to analyze different signals simultaneously within a frequency band of up to 160MHz. The MSRA feature maintains a time correlation between different signals, which significantly eases the debugging of a system, and increases the likelihood of capturing rare events.

Further details on measurement techniques using the MSRA of the FSW can be found in the R&S application note 1EF83_E2 [10], "Using R&S FSW for Efficient Measurements on Multi-Standard Radio Base Stations".

# 3 Impact of Phase Noise on EVM

Phase noise is a critical parameter for the performance of an RF transceiver. Nevertheless, phase noise requirements are not explicitly stated in most wireless standards.
The TS36.104 is no exception and does not provide any guideline regarding the required phase noise performance of an RF transceiver. OFDM based wireless systems like LTE, are orders of magnitude more sensitive to phase noise than single carrier systems [4].
The theoretical and numerical estimation of the impact of an RF PLL on the performance of the EVM of a transmitter requires extensive and complicated modeling of a variety of parameters. In order to develop an accurate model that predicts the effects of phase noise on an OFDM signal using a simulator such as MatLab, many weeks of software development time are needed. This chapter will show how using the capabilities of the SFU, SMU and FSW can significantly shorten the development time.

## 3.1 Transmit EVM

According to [1] "the error vector magnitude is a measure of the difference between the ideal symbols and the measured symbols after the equalization. The difference is called the error vector. The EVM result is defined as the square root of the ratio of the mean error vector power to the mean reference power expressed in percent."

| Transmit EVM Specification | |
|---|---|
| Wide Area Base Station according to TS36.104 [1] | |
| **Modulation Scheme** | **Required EVM [%]** |
| QPSK | 17.5 % |
| 16 QAM | 12.5 % |
| 64 QAM | 8.0 % |

**Table 3-1: Error vector magnitude specification for Wide Area BS**

The minimum EVM requirements listed in Table 3-1 represent the *combined* EVM of the entire transmit chain that includes the base band modulator, the digital-to-analog converter (DAC), the RF transmitter and the power amplifier (PA). The system designer needs to create an EVM budget, which defines the maximum allowed EVM for each section of the transmitter.
The most stringent EVM, according to Table 3-1, is 8% for a 64QAM modulation scheme. The majority of the budget is often allocated to the PA and the signal chain of the RF transceiver, while the EVM degradation of the modulator and the DACs can be typically limited to less than 1%. It is common to limit the EVM degradation due to the synthesizers to less than 2%. The following sections will show how the SFU and SMU vector signal generators enable the system engineer to correlate phase noise of a PLL to the EVM of a transmitter.

## 3.2 Specification of Phase Noise

The phase noise of an oscillator or PLL is typically specified in the frequency domain. Random phase fluctuations of an ideal sine wave signal in the time domain translate into a spectral component $f_0$ with noise side bands in the frequency domain.

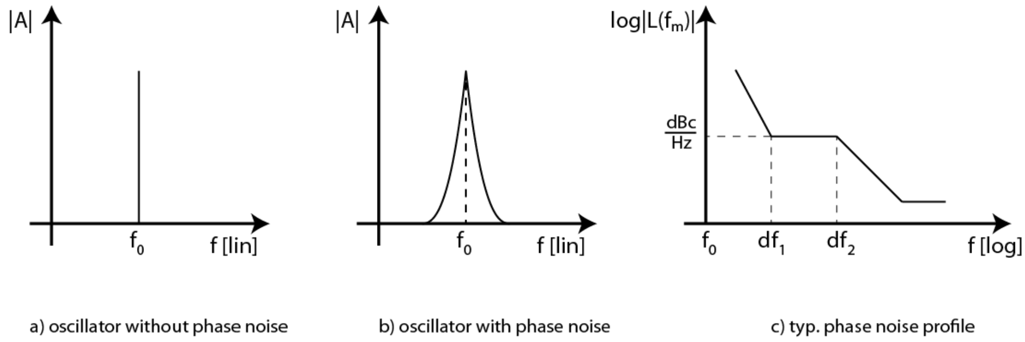


**Figure 3-1: Phase Noise profile of an ideal and real oscillator**

Figure 3-1a represents the frequency response of an ideal sinusoidal signal at frequency $f_0$ without any phase noise impairments. The noise sidebands of a real oscillator are shown in Figure 3-1b.
In order to compare the phase noise of RF signal sources at different frequencies it is common practice to specify the phase noise of an RF source at an offset frequency df from the carrier $f_0$ (Figure 3-1c). The phase noise at the carrier offset is measured in a measurement bandwidth of 1Hz and is referred to the power of the RF carrier. The resulting phase noise $L(f_m)$ is called “Single Sideband Phase Noise” (SSB phase noise) and is specified in a unit of ‘dBc/Hz’. Unless mentioned otherwise, the phase noise definition used in this application note is always the SSB phase noise.

## 3.3 Phase Noise Profiles of RF Signal Sources

Every RF source has a very unique phase noise profile. For example, the phase noise profile of a PLL (as shown in Figure 3-2) is dependent on several components of the PLL.

- The VCO dominates the out-of-band phase noise
- The PLL loop parameter determine the PLL bandwidth
- Amplifiers and dividers may limit the out-of-band noise floor as well as the in-band noise floor (especially for high divider ratios)

The measured phase noise profile of an RF signal source is shown Figure 3-2.

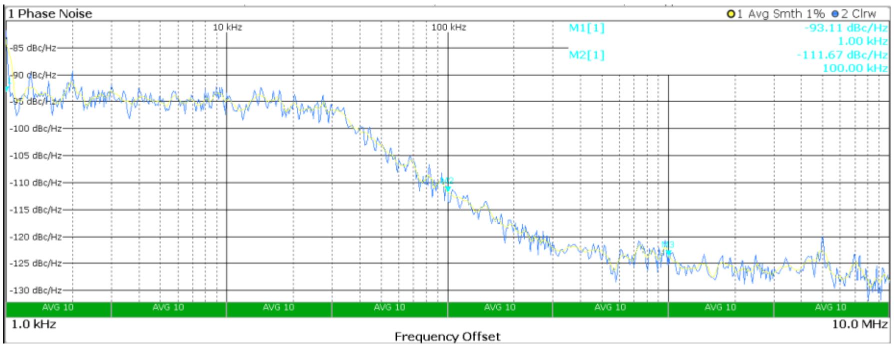


**Figure 3-2: Measured phase noise profile of a Phase Locked Loop of an RF signal source**

In order to evaluate the impact of a specific phase noise profile within a wireless system, the phase noise profile needs to be adjusted. An efficient and flexible method how to do this is presented in the following chapter.

## 3.4 Introduction of Phase Noise Impairments using the SFU

The Rohde & Schwarz SFU signal generator [7] offers the ability to generate many different phase noise profiles using the SFU-K41 phase noise option. The option K41 can be used to define different profiles (e.g. PLL versus a VCO) or to add impairments to an existing profile.

### 3.4.1 SFU Phase Noise Profiles

The SFU provides a graphical user interface to select different phase noise profiles as shown in Figure 3-3.

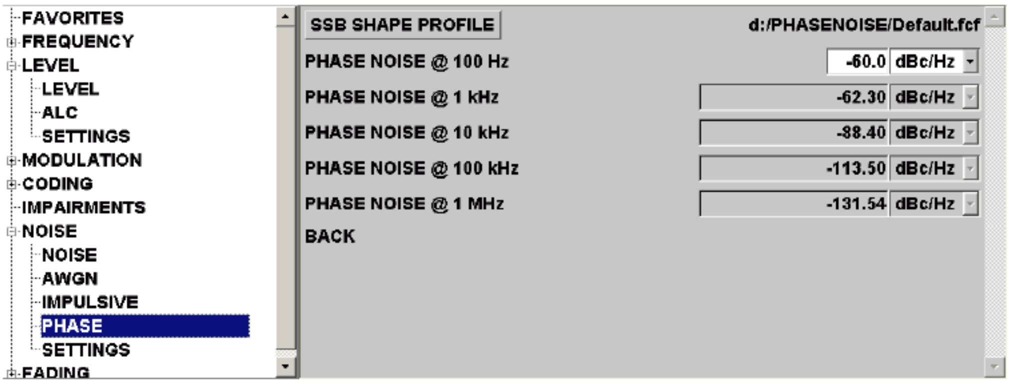


**Figure 3-3: Graphical SFU user interface to select different phase noise profiles**

Figure 3-4 compares two profiles that were created with SFU-K41 option.

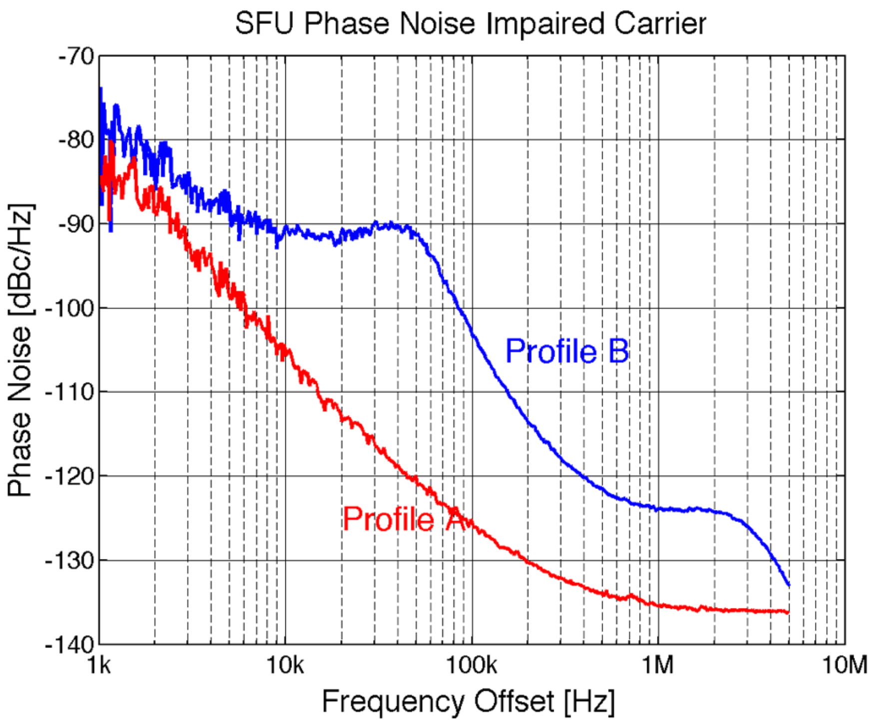


**Figure 3-4: Measured phase noise profiles using the SFU-K41 option**

It is also possible to shift (degrade) a profile by changing the absolute phase noise value at the lowest offset frequency from the carrier as shown in Figure 3-5.

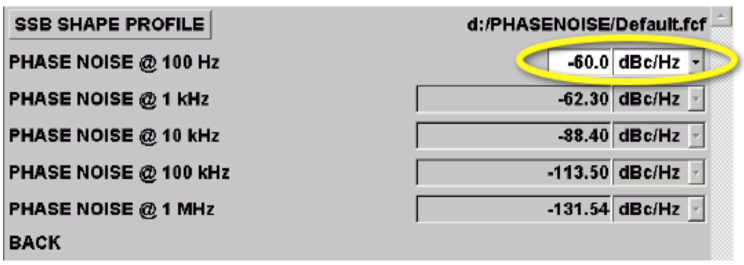


**Figure 3-5: User interface to introduce an offset that shifts the entire phase noise profile**

Figure 3-6 shows an example of a profile created with the SFU-K41 option for various phase noise offset values.

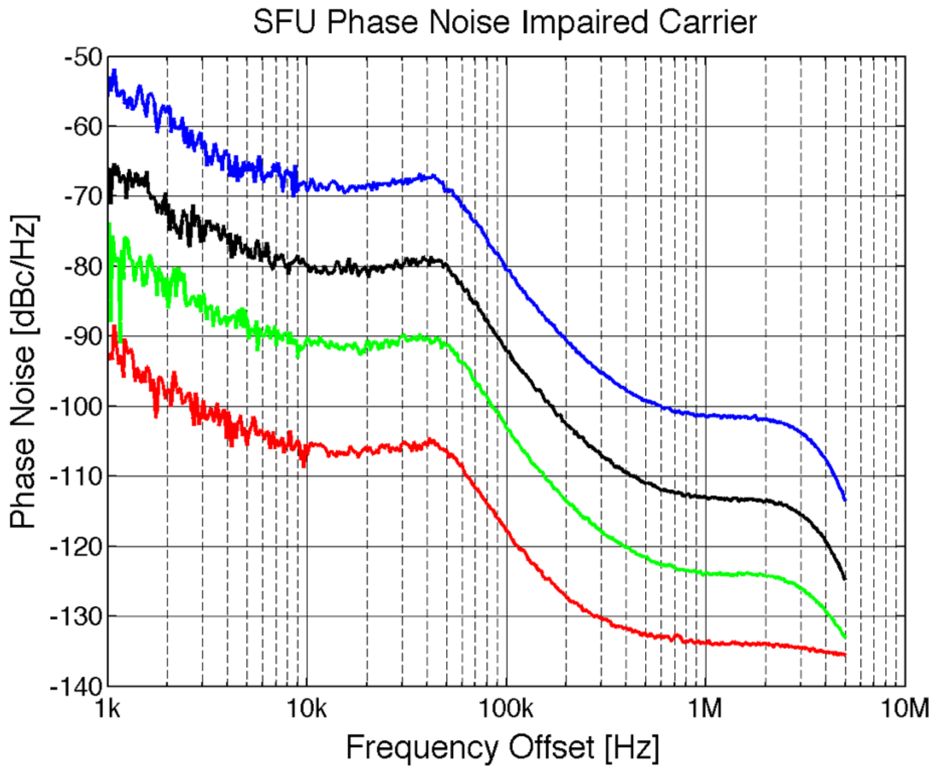


**Figure 3-6: Phase noise profile created with SFU-K41 using different noise offset values**

### 3.4.2 Phase Noise Profile Creator Software

Rohde & Schwarz offers a ”Phase Noise Profile Creator” software free of charge that enables the user to create a custom phase noise profile. Application note 7BM63_2E.pdf explains the steps necessary to create a custom phase noise profile.

The software enables the user to specify various absolute phase noise values at several offset frequencies to create a custom profile. In order to add phase noise impairments to an RF carrier, the baseband IQ data are first converted from a real/imaginary format to a magnitude/phase format. The phase information is then modulated with noise that is passed through a digital filter.
The software on the PC is using an optimization algorithm to minimize the remaining error (difference between predicted and specified phase noise profile) by varying the filter coefficients of the digital filter that filters the noise. The final IQ data will then be converted back from magnitude/phase to a real/imaginary format. Filter coefficients of a phase noise profile will be saved in a file that can be copied onto the SFU. Upon successful transfer of the profile to the SFU, the new custom profile can be selected via a graphical user interface (refer to Figure 3-5).

The phase noise profile generated by the SFU-K41 can be verified with the FSUP phase noise analyzer as shown in Figure 3-7.

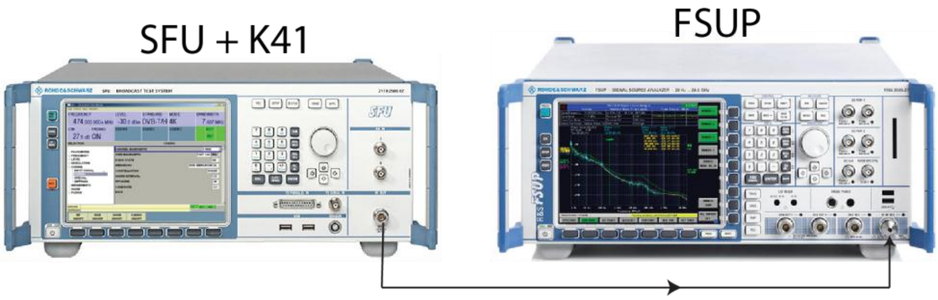


**Figure 3-7: Measurement setup to verify custom phase noise profile using an FSUP**

## 3.5 Impact of Phase Noise on TX-EVM of a LTE signal

LTE uses conventional OFDM in the downlink. The available bandwidth of an LTE signal is divided into subcarriers with equal spacing that can be independently modulated with data symbols. An RF transmitter has to convert a baseband (OFDM) signal to the desired RF frequency. This is accomplished by mixing the baseband signal with a local oscillator (LO). The LO will have a unique phase noise profile that will manifest itself onto each OFDM sub-carrier when up-converted to an RF frequency as shown in Figure 3-8.

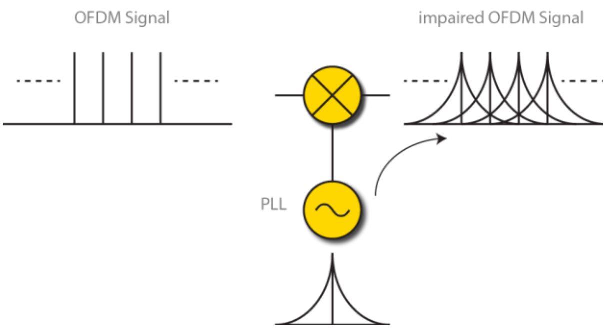


**Figure 3-8: Phase noise profile of a PLL that mixes onto each sub-carrier of the OFDM signal**

The SFU signal generator can now be used to create specific phase noise profiles to study the effect of phase on the transmit EVM of an LTE transmitter. Figure 3-9 shows the test setup using a SMU as an LTE baseband signal source. The IQ baseband data of the SMU are fed into the external IQ modulator of the SFU. The SFU adds the phase noise profile onto the RF carrier and modulates the LTE IQ baseband signal onto the noise impaired RF carrier. The LTE RF signal is connected to an FSW to demodulate the phase noise impaired LTE signal.

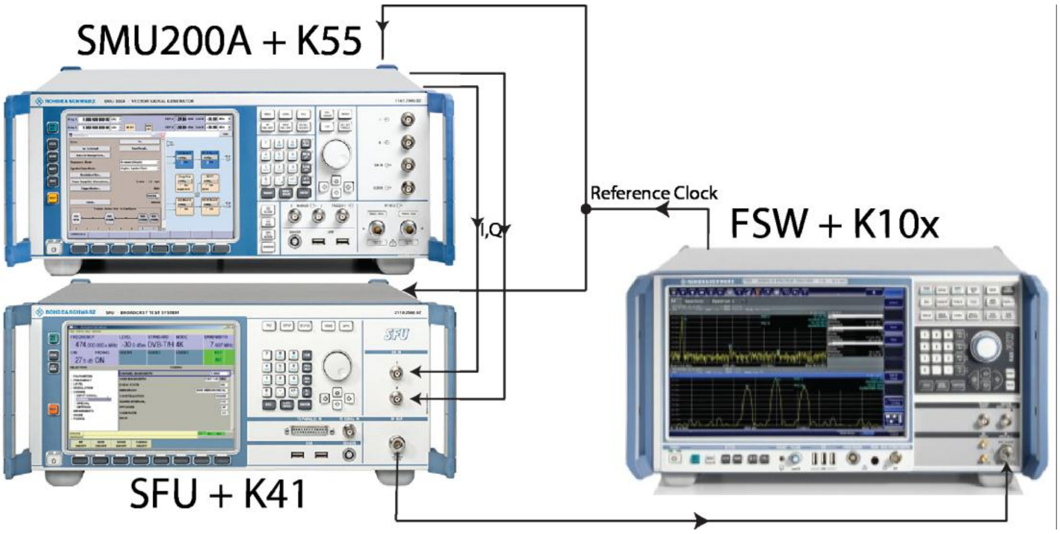


**Figure 3-9: Test setup to evaluate impact of PLL phase noise on TX-EVM**

Two different phase noise profiles shown in Figure 3-10a are used to modulate the RF carrier. These phase noise profiles could represent a PLL with a very narrow loop bandwidth BW (profile A) and a typical PLL phase noise profile (profile B).

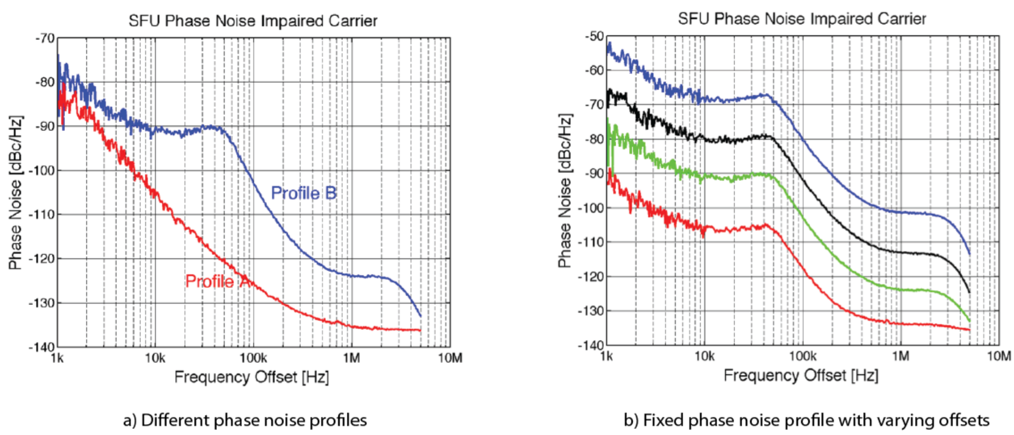


**Figure 3-10: Phase noise profiles used for LTE TX-EVM experiments**

The phase noise offset for each profile is varied, to degrade the absolute phase noise while maintaining the shape of the profile. The LTE demodulator is used the measure the EVM as the phase noise impairments are adjusted. Figure 3-11 shows the measured EVM as a function of the absolute phase noise at a 10kHz offset for two phase noise profiles.

A downlink 10 MHz LTE using 64 QAM modulation was used in this example. The results clearly indicate that for phase noise values larger than -95dBc/Hz the EVM cannot be accurately predicted by specifying the absolute phase noise at a single carrier offset.

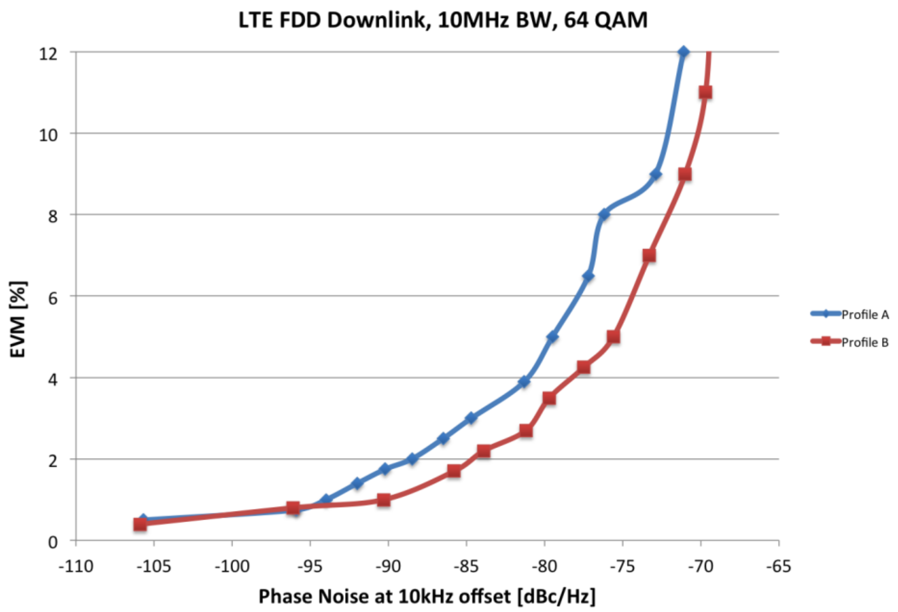


**Figure 3-11: Measured EVM versus absolute phase noise of a PLL at a 10kHz carrier offset for two different noise profiles**

The measurements show, that different noise profiles lead to different EVMs for a given carrier offset. It is therefore necessary to consider a wide range of offset frequencies in order to accurately predict the EVM. Figure 3-11 visualizes that a phase noise impaired carrier of an OFDM signal effects more than the adjacent carriers of the signal. The phase noise associated with each carrier will affect all sub-carriers. An alternative method to specifying the noise at an absolute frequency offset is to integrate all noise contributors over a range of offset frequencies. Therefore the question arises as to how to choose the integration

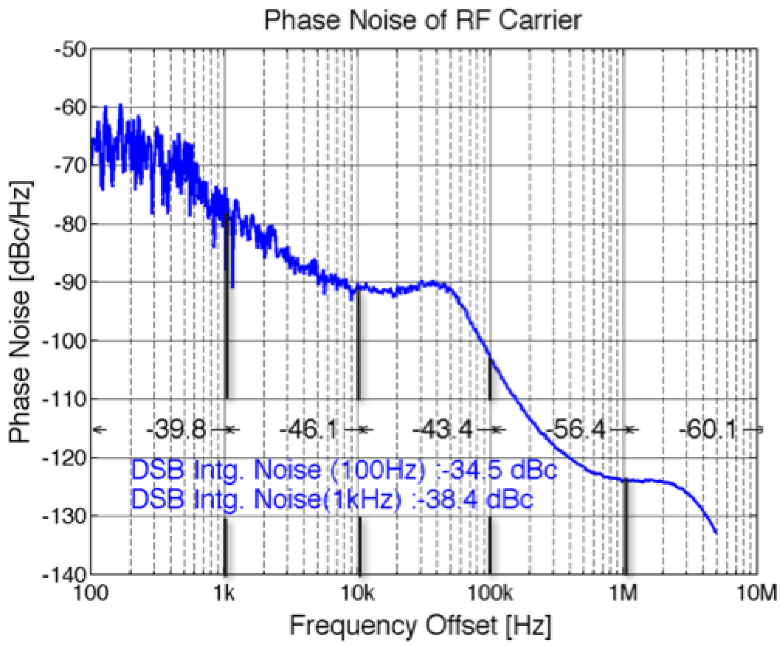


**Figure 3-12: Integrated phase noise of a phase noise profile of a PLL. SSB integrated noise of individual sections are shown.**

limits $f_{low}$ and $f_{high}$. The upper integration limit $f_{high}$ is equal to half of the bandwidth of the desired signal (in this example $f_{high}$ = BW/2 = 5MHz). The choice of the lower integration limit $f_{low}$ is dependent on the implementation of the LTE demodulator. For example, the carrier frequency offset (CFO) algorithm implemented in the demodulator will reduce the effect of phase noise very close to the carrier, as the CFO algorithm has to compensate for frequency carrier offsets. The frequency $f_{low}$ needs to be carefully selected in order to avoid un-necessary stringent phase noise specifications for the RF PLL. The DSB integrated phase noise for individual carrier offset frequencies of a phase noise profile is shown in Figure 3-12.

Figure 3-13 shows the measured EVM as a function integrated phase noise for both noise profiles A and B.

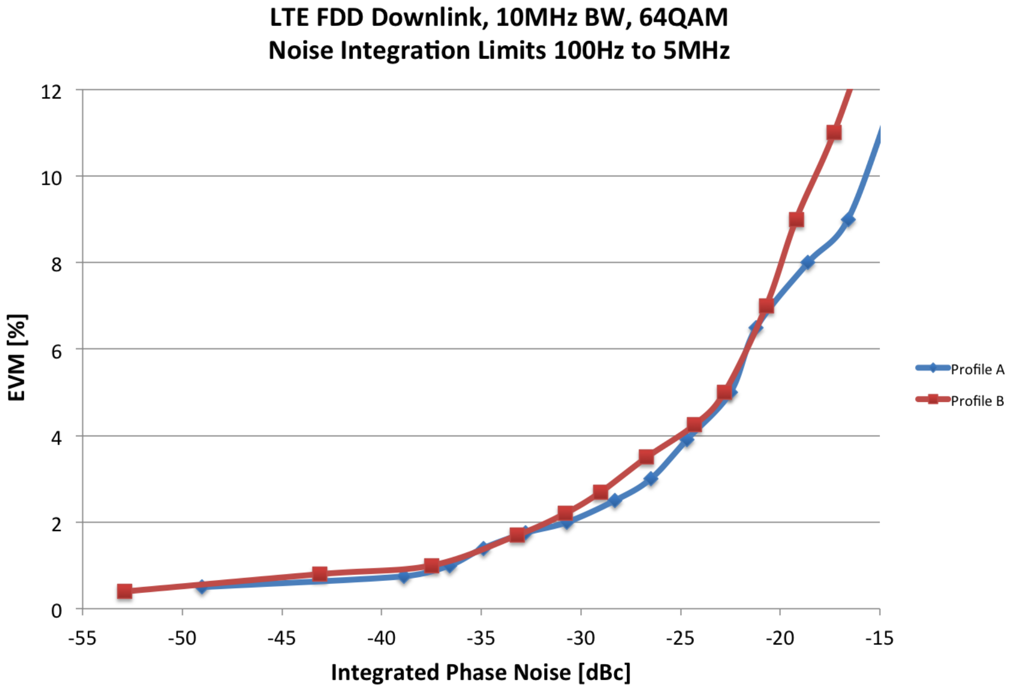


**Figure 3-13: Measured EVM versus integrated phase noise for two different noise profiles**

The measurement results for a 10MHz LTE signal using 64 QAM modulation clearly indicate, that the EVM is independent of the two phase noises profiles A and B. The results show, that the EVM can be predicted with much more accuracy if the integrated phase noise of a phase noise profile of PLL is considered.

The test setup shown in Figure 3-9, enables the design engineer to gain valuable insight into a complicated topic within only a few hours that otherwise may take many weeks of development time using simulators such as MatLab.

# 4 Summary

Technical specifications that describe RF characteristics and minimum performance requirements of for example E-UTRA base stations (TS36.104 [1]) contain many complex test cases.

This application note reviewed a few of the important RF specifications like dynamic range, phase noise and receiver blocking requirements. In the case of the dynamic range specification it was shown, that this specification enforces a stringent requirement (implementation loss) onto the LTE base band demodulator rather than the RF front end of the eNodeB.

The LTE specific setup of blocking test for an RF receiver cases was discussed, and it was shown how complex LTE test cases can be easily setup with built-in test wizards of the SMU vector signal generator.

The multi carrier filter option of the FSW and FSV signal analyzer enables accurate receiver EVM measurements of low SNR LTE signals in the presence of strong undesired interference signals.

The impact of the RF PLL phase noise on the EVM of RF transmitter was discussed. It was shown how the SFU signal generator could be used to add phase noise impairments to an LTE signal generated by the SMU. Transmit EVM measurements of a 10MHz LTE signals, performed with the FSW vector signal analyzer, revealed that the integrated phase noise of an RF PLL is the key indicator for EVM performance of a transmitter impaired by phase noise.

# 5 Literature

[1] Technical Specification Group Radio Access Network; Base Station (BS) radio transmission and reception, Release 11.2; 3GPP TS 36.104 V11.2 (2012-11)

[2] RF System Design of Transceivers for Wireless Communication, Qizheng Gu, Springer, ISBN 0-387-24161-2

[3] LTE: From RF PHY Specifications to RF Circuits, O. Werther, Rohde & Schwarz LTE Forum, April 2012

[4] BER Sensitivity of OFDM Systems to Carrier Frequency Offset and Wiener Phase Noise, T. Pollet, IEEE Transactions on Communications Vol. 43, 2/3/4 Feb/Mar/Apr 1995

[5] Rohde & Schwarz, “FSW Operating Manual”

[6] Rohde & Schwarz, Application Note 7MB63_2E, Phase Noise Creator Software for R&S SFU Version 1.2

[7] Rohde & Schwarz, “SFU Operating Manual”

[8] Rohde & Schwarz, “FSW-K10x (LTE Downlink) LTE Downlink Measurement Application User Manual”

[9] Rohde & Schwarz, Application Note 1MA154_1e, LTE Base Station Tests according to TS 36.141

[10] Rohde & Schwarz, Application Note 1EF83_E2, Using R&S FSW for Efficient Measurements on Multi-Standard Radio Base Stations

# 6 Additional Information

Please send your comments and suggestions regarding this application to

mailto:TM-Applications@rohde-schwarz.com?subject=Application Note

# 7 Appendix

## 7.1 Downloads

### 7.1.1 SFU Phase Noise Creator Software

Instructions on how to access the “Phase Noise Profile Creator for the R&S SFU” software can be found at

7BM63_2E.pdf

### 7.1.2 Application Note “LTE Base Station Tests according to TS 36.141”

The application note 1MA154_1e can be downloaded at

1MA154_1e.pdf

# 7.2 Overview of Blocking Requirements

## 7.2.1 Narrow-Band Blocking

| Narrow Band Blocking Specification | | | | | | |
|---|---|---|---|---|---|---|
| **Wide Area Base Station Test Case** | | | | | | |
| **E-UTRA Channel BW [MHz]** | **Wanted Signal Mean Power [dBm]** | | **Interfering signal power [dBm]** | **Type of Interfering Signal** | **UnDes $f_c$ to Des Band Edge [MHz]** | **UnDesired / Desired Power Ratio [dB]** |
| 1.4 | $P_{REFSENS}$ + 6dB | -100.8 | -49 | 1.4 MHz LTE | +/- (252.5+m*180) m=0,1,2,3,4,5 | 51.8 |
| 3 | $P_{REFSENS}$ + 6dB | -97.0 | -49 | 3 MHz LTE | +/- (247.5+m*180) m=0,1,2,3,4,7,10, 13 | 48.0 |
| 5 | $P_{REFSENS}$ + 6dB | -95.5 | -49 | 5 MHz LTE | +/- (342.5+m*180) m=0,1,2,3,4,9,14, 19,24 | 46.0 |
| 10 | $P_{REFSENS}$ + 6dB | 95.5 | -49 | 5 MHz LTE | +/- (347.5+m*180) m=0,1,2,3,4,9,14, 19,24 | 46.0 |
| 15 | $P_{REFSENS}$ + 6dB | -95.5 | -49 | 5 MHz LTE | +/- (352.5+m*180) m=0,1,2,3,4,9,14, 19,24 | 46.0 |
| 20 | $P_{REFSENS}$ + 6dB | -95.5 | -49 | 5 MHz LTE | +/- (342.5+m*180) m=0,1,2,3,4,9,14, 19,24 | 46.0 |

*Table 7-1: Summary of narrow-band blocking specifications*

### 7.2.2 In-Channel Selectivity (ICS)

| In Channel Selectivity Specification | | | | | |
|---|---|---|---|---|---|
| Wide Area Base Station Test Case | | | | | |
| E-UTRA Channel BW [MHz] | Ref. Channel (QPSK, CR=1/3) | Wanted Signal Power [dBm] | Interfering Power [dBm] | Type of Interfering Signal | UnDesired / Desired Power [dB] |
| 1.4 | A1-4, RB=3 | -106.9 | -87 | 1.4 MHz LTE RB = 3 | 19.9 |
| 3 | A1-5, RB=9 | -102.9 | -84 | 3 MHz LTE RB = 6 | 18.1 |
| 5 | A1-2, RB=12 | -100.0 | -81 | 5 MHz LTE RB = 3 | 19 |
| 10 | A1-3, RB=25 | -98.5 | -77 | 10 MHz LTE RB = 25 | 21.5 |
| 15 | A1-3, RB=25 | -98.5 | -77 | 15 MHz LTE RB = 25 | 21.5 |
| 20 | A1-3, RB=25 | -98.5 | -77 | 20 MHz LTE RB = 25 | 21.5 |

*Table 7-2: Summary of in-channel selectivity specifications*

### 7.2.3 In-Band Blocking

The term “in-band” indicates that the interference signal is located within the RF bandwidth of the operating frequency band (refer to [1], table 7.6.1.1). The in-band blocking specifications are summarized below.

| In-Band Blocking Specification | | | | | | |
|---|---|---|---|---|---|---|
| Wide Area Base Station Test Case | | | | | | |
| E-UTRA Channel BW [MHz] | Wanted Signal Mean Power [dBm] | | Interfering signal power [dBm] | Type of Interfering Signal | UnDes $f_c$ to Des Band Edge [MHz] | UnDesired / Desired Power Ratio [dB] |
| 1.4 | $P_{REFSENS}$ + 6dB | -100.8 | -43 | 1.4 MHz LTE | +/- 2.1 | 57.8 |
| 3 | $P_{REFSENS}$ + 6dB | -97.0 | -43 | 3 MHz LTE | +/- 4.5 | 54.0 |
| 5 | $P_{REFSENS}$ + 6dB | -95.5 | -43 | 5 MHz LTE | +/- 7.5 | 52.5 |
| 10 | $P_{REFSENS}$ + 6dB | -95.5 | -43 | 5 MHz LTE | +/- 7.5 | 52.5 |
| 15 | $P_{REFSENS}$ + 6dB | -95.5 | -43 | 5 MHz LTE | +/- 7.5 | 52.5 |
| 20 | $P_{REFSENS}$ + 6dB | -95.5 | -43 | 5 MHz LTE | +/- 7.5 | 52.5 |

*Table 7-3: Summary of in-band blocking specifications*

### 7.2.4 Out-of-Band Blocking

The out-of-band blocking specifications describe test conditions in which the interference signal is outside the RF band of operation. Interference signals with a center frequency

between 1 MHz and the lower band edge of the operating band, or
between the upper operating band edge and lower than 12.750 GHz

are considered out-of-band interference signals. Typically, fixed frequency RF band definition filters, like SAW or cavity filters, are used to mitigate the impact of out-of-band interference signals. Table 10 summarizes the out-of-band specifications.

| Out-of-Band Blocking Specification | | | | | | |
|---|---|---|---|---|---|---|
| **Wide Area Base Station Test Case** | | | | | | |
| **E-UTRA Channel BW [MHz]** | **Wanted Signal Mean Power [dBm]** | | **Interfering signal power [dBm]** | **Type of Interfering Signal** | **UnDes $f_c$ to Des Band Edge [MHz]** | **UnDesired / Desired Power Ratio [dB]** |
| 1.4 | $P_{REFSENS}$ + 6dB | -100.8 | -15 | CW | +/- 2.1 | 85.8 |
| 3 | $P_{REFSENS}$ + 6dB | -97.0 | -15 | CW | +/- 4.5 | 82.0 |
| 5 | $P_{REFSENS}$ + 6dB | -95.5 | -15 | CW | +/- 7.5 | 80.5 |
| 10 | $P_{REFSENS}$ + 6dB | -95.5 | -15 | CW | +/- 7.5 | 80.5 |
| 15 | $P_{REFSENS}$ + 6dB | -95.5 | -15 | CW | +/- 7.5 | 80.5 |
| 20 | $P_{REFSENS}$ + 6dB | -95.5 | -15 | CW | +/- 7.5 | 80.5 |

*Table 7-4: Summary of out-of-band blocking specifications*

### 7.2.5 Co-Location With Other Base Stations

The co-location requirement is an additional requirement that may be applied for the protection of base station receivers when a GSM, CDMA, UTRA or E-UTRA base station operating in a different frequency band is co-located with an E-UTRA base station. This scenario is the most stringent interference test case and the test conditions are summarized in table 11.

| Co-Location Specifications | | | | | | |
|---|---|---|---|---|---|---|
| **Wide Area Base Station Test Case** | | | | | | |
| **E-UTRA Channel BW [MHz]** | **Wanted Signal Mean Power [dBm]** | | **Interfering signal power [dBm]** | **Type of Interfering Signal** | **UnDes $f_c$ to Des Band Edge [MHz]** | **UnDesired / Desired Power Ratio [dB]** |
| 1.4 | $P_{REFSENS}$ + 6dB | -100.8 | +16 | CW | CW in other freq. band | 116.8 |
| 3 | $P_{REFSENS}$ + 6dB | -97.0 | +16 | CW | CW in other freq. band | 113.0 |
| 5 | $P_{REFSENS}$ + 6dB | -95.5 | +16 | CW | CW in other freq. band | 111.5 |
| 10 | $P_{REFSENS}$ + 6dB | -95.5 | +16 | CW | CW in other freq. band | 111.5 |
| 15 | $P_{REFSENS}$ + 6dB | -95.5 | +16 | CW | CW in other freq. band | 111.5 |
| 20 | $P_{REFSENS}$ + 6dB | -95.5 | +16 | CW | CW in other freq. band | 111.5 |

*Table 7-5: Summary of base station co-location specifications*

# 8 Ordering Information

| Ordering Information | | |
|---|---|---|
| **Vector Signal Generator** | | |
| **SMU200A** | **Vector Signal Generator** | **1141.2005.02** |
| SMU-B103 | RF Path A 100 kHz to 3 GHz | 1141.8603.02 |
| SMU-B203 | RF Path B 100 kHz to 3 GHz | 1141.9500.02 |
| SMU-B10 | Baseband Generator | 1141.7007.02 |
| SMU-B14 | Fading Simulator | 1160.1800.02 |
| SMU-B16 | Differential IQ Output | 1161.0066.02 |
| SMU-B17 | Analog Baseband Input | 1142.2880.02 |
| SMU-B31 | High Power Output | 1159.8011.04 |
| SMU-K55 | EUTRA/LTE | 1408.7310.02 |
| SMU-K61 | Multi Carrier CW Generation | 1160.8505.02 |
| SMU-K62 | Additive White Gaussian Noise | 1159.8511.02 |
| SMU-K80 | BER Measurement | 1159.8770.02 |
| SMU-K81 | LTE Logfile Generation | 1408.8169.02 |
| SMU-K84 | LTE Release 9+ Enhanced | 1408.8498.02 |

| Ordering Information | | |
|---|---|---|
| **Vector Signal Analyzer** | | |
| **FSW** | **Vector Signal Analyzer** | **1312.8000.08** |
| FSW-B24 | RF Pre-Amplifier | 1313.0832.13 |
| FSW-B25 | Electronic Attenuator, 1dB steps | 1313.0990.02 |
| FSW-B40 | Extension to 40MHz Demodulation Bandwidth | 1313.0861.02 |
| FSW-K30 | Noise Figure Measurement | 1313.1380.02 |
| FSW-K40 | Phase Noise Measurement | 1313.1397.02 |
| FSW-K100 | LTE Downlink, FDD | 1313.1545.02 |
| FSW-K104 | LTE Downlink, TDD | 1313.1574.02 |

| Ordering Information | | |
|---|---|---|
| **TV Generator** | | |
| **SFU** | **Broadcast Test System** | **2110.2500.02** |
| SFU-B30 | Fading Emulator | 2110.7530.02 |
| SFU-B90 | High Output Power | 2110.8008.03 |
| SFU-K40 | AWGN | 2110.7653.02 |
| SFU-K41 | Phase Noise Impairments | 2110.7660.02 |
| SFU-K42 | Impulsive Noise | 2110.7676.02 |
| SFU-K43 | Multi Noise Use | 2110.7682.02 |

**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, radio monitoring 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

**Regional contact**
Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1-888-TEST-RSA (1-888-837-8772)
customer.support@rsa.rohde-schwarz.com

Latin America
+1-410-910-7988
customersupport.la@rohde-schwarz.com

Asia/Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86-800-810-8228 /+86-400-650-5896
customersupport.china@rohde-schwarz.com



**Rohde & Schwarz GmbH & Co. KG**
Mühldorfstraße 15 | D - 81671 München
Phone + 49 89 4129 - 0 | Fax + 49 89 4129 – 13777

www.rohde-schwarz.com