Preliminary

Products: SMIQ, FSP, FSU, FSQ, NRP, ZVR

Testing Power Amplifiers
for 3G Base Stations

Application Note

This application note describes essential tests, test setups and test procedures for 3GPP power amplifiers especially for production lines.

ROHDE & SCHWARZ

Subject to change – Roland Minihold 09/2002 – 1MA40_2E

Contents

1 Introduction

Testing 3G base station power amplifiers and especially multi-carrier amplifiers is a challenge for the measuring equipment used. The signal generator used to stimulate the power amplifier must not only have ideal modulation capability to produce an undistorted in-band signal, but also superior signal to noise ratio and intermodulation performance to avoid generating signal components outside the wanted signal. The analyzer used to measure the output signal characteristic of the power amplifier must also have the best available dynamic range to meet the stringent test requirements for 3GPP base station power amplifiers. The R&S SMIQ03HD signal generator offers the ideal solution for stimulating the power amplifier, while the R&S spectrum analyzers FSU or especially FSQ have the accuracy, dynamic range, and bandwidth to meet current and future requirements in 3GPP power amplifier testing. The R&S NRP power meter is ideally suited for highly accurate power measurements at the highest available dynamic range. The extreme flexible configurations supported by the network analyzers of the R&S ZVR family provide precise measurements of complex S-parameters, phase and group delay, as well as measurement of nonlinear parameters.

2 Overview

Section 3 describes typical test setups. Section 4 describes the different tests necessary for 3G power amplifiers and gives instructions for instrument settings. Block diagrams for a universal power amplifier test system are presented in section 5.

3 Suggested Test Setups

The test setup shown in figure 1 is appropriate for most of the following measurements. A SMIQ03HD serves as a signal source. A bi-directional coupler is used to couple out the forward and reflected signals at the power amplifier's (DUT) input. The power meter attached to sensor 3 ensures that the power amplifier's output power can be measured with the maximum achievable accuracy . Although the absolute power measurement accuracy of an FSU or FSQ is excellent for a spectrum analyzer (0.3 dB absolute accuracy) the accuracy of a power meter, especially that of the NRP power meter, will always be better.

Optionally the power meter can be used with an additional sensor (sensor 1) to measure the input level of the power amplifier and further increase the accuracy for gain measurement. Optionally sensor 2 measures the amplifier's reflected input power in order to measure the input VSWR (Voltage Standing Wave Ratio) of the amplifier.

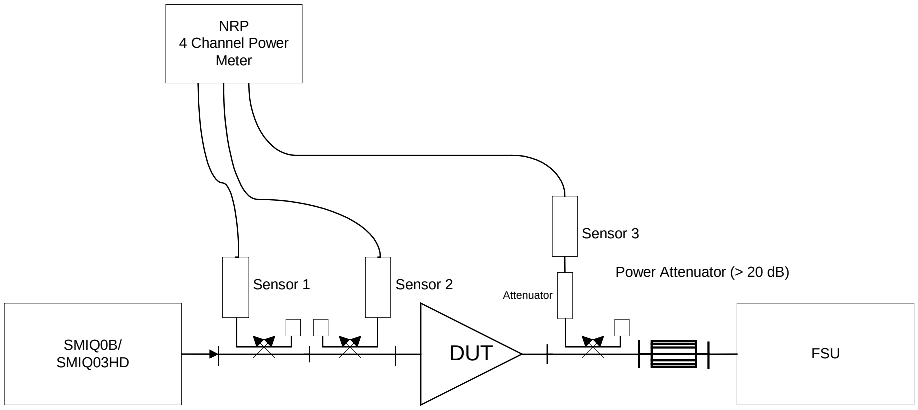


Fig. 1 Typical test setup for a 3GPP base station power amplifier (1 input)

There are also 3G power amplifiers which use 2 separate inputs to combine two 3G-transmitter signals without the need for an external combiner. A modified setup is thus necessary. An adittional generator is necessary to deliver an appropriate second input signal. Additional couplers, sensors and a second power meter are also necessary to measure gain and input VSWR (see figure 2).

By using NRP-Z11 sensors the power meters can be omitted since these sensors can be used as standalone measuring instruments and be connected directly via NRP-Z4 USB-Adapters to a controller.

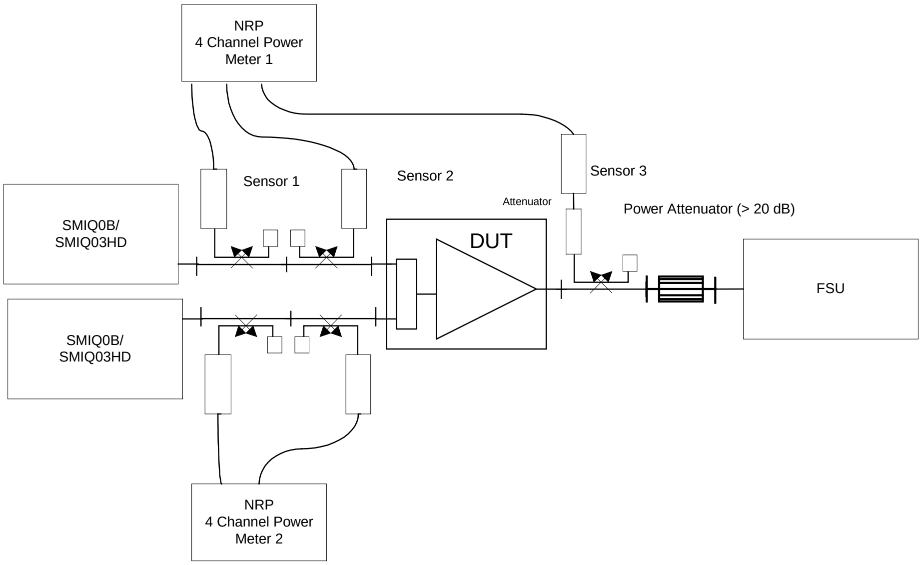


Figure 2: Test setup for a 2-input power amplifier

A vector network analyzer is the appropriate instrument to measure complex S-parameters S11, S21, phase or group delay on a power amplifier. The power level can be handled with a test setup shown in figure 3. The R&S ZVR is ideally suited to carry out these measurements, see [10] for details.

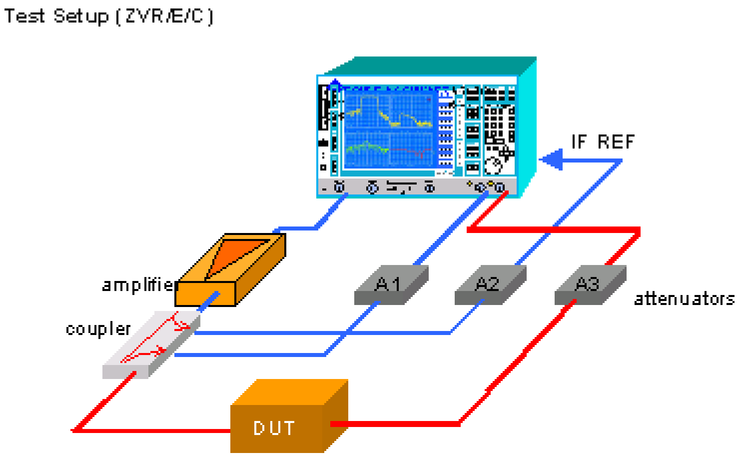


Figure 3: Test setup for measuring S11 and S21 for a power amplifier with a vector network analyzer

4 Test Procedures

Power and Gain

Accurate power measurement at the output of the amplifier is most important. It must be guaranteed that the amplifier delivers the nominal power and in addition meets the specifications at exactly that power, for example ACLR. Although state of the art spectrum R&S analyzers like FSP, FSU or FSQ show extraordinary good absolute power measurement accuracy (0.3 dB) a power meter will always be the first choice for best accuracy. Ideally suited especially for the measurement on 3GPP signals is the NRP with sensor NRP-Z11. Up to 4 sensors can be connected to the power meter. The NRP-Z11(-Z21) sensors show a very high dynamic range of 90 dB. Modulation-dependent errors can be ignored.

Gain must be measured as well at nominal output power (nominal gain) for amplifying one or more 3GPP signals. Measurements with a network analyzer using low level sine signals may deliver misleading results. Best accuracy is achieved by using high performance directional couplers in combination with a power meter (see figure 1 or 2).

The gain is calculated with following formula (valid for test setup 1):

$$\text{Gain/dB} = \text{Power Indication}_{\text{Sensor 3}}\text{/dBm} - \text{Power Indication}_{\text{Sensor 1}}\text{/dBm}$$

<u>*Note:*</u> This is just the basic formula. Variable coupling losses, insertion losses of couplers, and the attenuator in front of sensor 3 have to be taken into account additionally. The easiest way to calibrate the test setup is to connect the couplers without the DUT at a sufficient high SMIQ level, for example 10 dBm in CW mode.

Besides the nominal gain, the gain variation within transmit band and out of band gain must also be measured. Both can also be measured with test setup on figure 1 or 2.

Input Return Loss / Input VSWR

The magnitude of the input return loss can be measured either with a power meter with 2 sensors and a bi-directional coupler (see test setup 1, sensor 1 and 2) or with a network analyzer (see test setup in figure 3). A vector network analyzer can measure magnitude and phase while ensuring the highest possible measurement accuracy.

Especially in production it may be sufficient to check the magnitude only, and the more economic solution without a vector network analyzer will be preferred. A bi-directional coupler with high directivity (e.g. NARDA Model 3022) in combination with the R&S high-dynamic power sensors NRP-Z11/Z21 ensures sufficiently low measurement uncertainties.

<u>*Example:*</u>
Assuming a coupler-directivity of 30 dB and a specified return loss value of the amplifier of 18 dB a measurement uncertainty of –1.95 dB and + 2.51 dB can be derived. To be able to guarantee the 18 dB return loss for the amplifier, a value of 18 dB + 1,95 dB = 19,95 dB has to be measured.

(Other small error contributions like measurement errors of power sensors are neglected).

The return loss is calculated with following formula (valid for test setup 1):

$$\text{Return Loss}_{\text{input}}/\text{dB} = \text{Power Indication}_{\text{Sensor 2}}/\text{dBm} - \text{Power Indication}_{\text{Sensor 1}}/\text{dBm}$$

Output Return Loss/Output VSWR

Output return loss measurement normally requires a vector network analyzer. Especially for power amplifiers there may be a significant difference in the behaviour between output impedance measured at small signal levels (the vector network analyzer) or measured at the nominal power ("hot S22 measurement"). However, 3GPP base station power amplifiers typically use an isolator circuit in front of the output connector circuit. When measuring S22 only the isolator's passive load resistor can be measured, with an impedance which is the same at small signals or nominal power. In production lines the measurement of output return loss is often skipped.

Phase, Group Delay (of S21)

Phase and or Group Delay measurement is a task that requires a vector network analyzer like the ZVR of R&S. (see test setup at figure 3). More information regarding the measurement with the Vector Network Analyzer ZVR can be found in [10]

Adjacent Channel Leakage Ratio (ACLR)

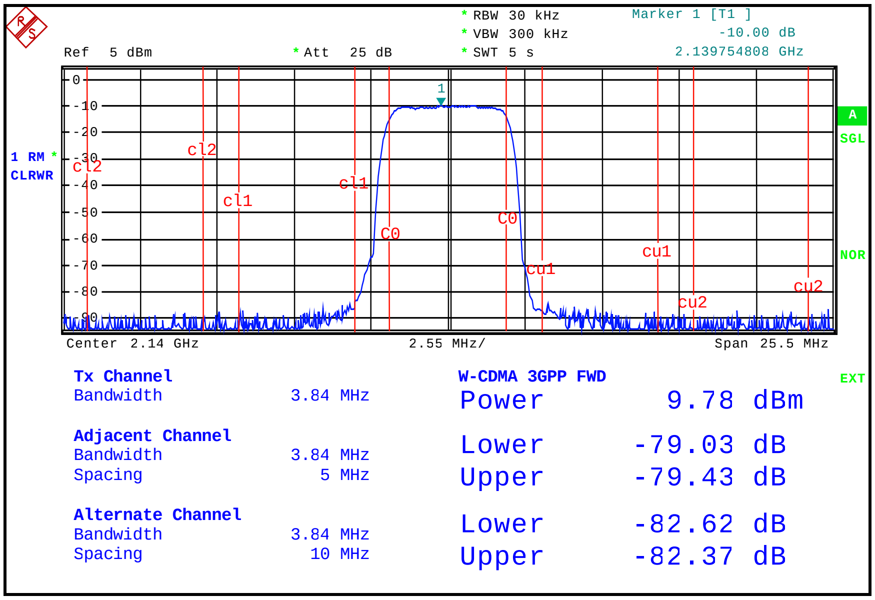
For WCDMA base stations, the 3G specifications demand an ACLR performance of 45 dB in the adjacent channel and 48 dB in the alternate channel. The manufacturers of base stations add some headroom so that their products typically have an ACLR of around 50 dB. The power amplifier needs to have an even better ACLR, to fulfill the overall specifications. That means the ACLR of the amplifier must be in the range of 60 dB to 70 dB. If the combined ACLR of the signal generator and spectrum analyzer were in the same range (0 dB margin), the additional error of the ACLR measurement would be about 3 dB (see curve below).

Fig. 4 ACLR measurement error as a function of margin

In order to decrease the additional error to less than 1 dB, the margin must be greater than 6 dB. For errors of less than 0.5 dB the margin must be at least 9 dB. This is why the ACLR of both signal generator and spectrum analyzer have to be one order of magnitude higher than that of the components be tested (e.g. the power amplifier).

The best available ACLR performance for measuring power amplifiers is achieved by using a SMIQ03HD with option SMIQ-B57 High ACLR as a signal generator and FSU or FSQ as a spectrum analyzer.

SMIQ-B57 enhances the spectral quality of a single WCDMA carrier (3GPP test model 1, 64) measured by FSU or FSQ significantly to an ACLR value of typically 79 dB (71 dB without option B57) in the adjacent channel and typically 82 dB (74 dB without option B57) ACLR in the alternate channel, as shown in Fig. 5.

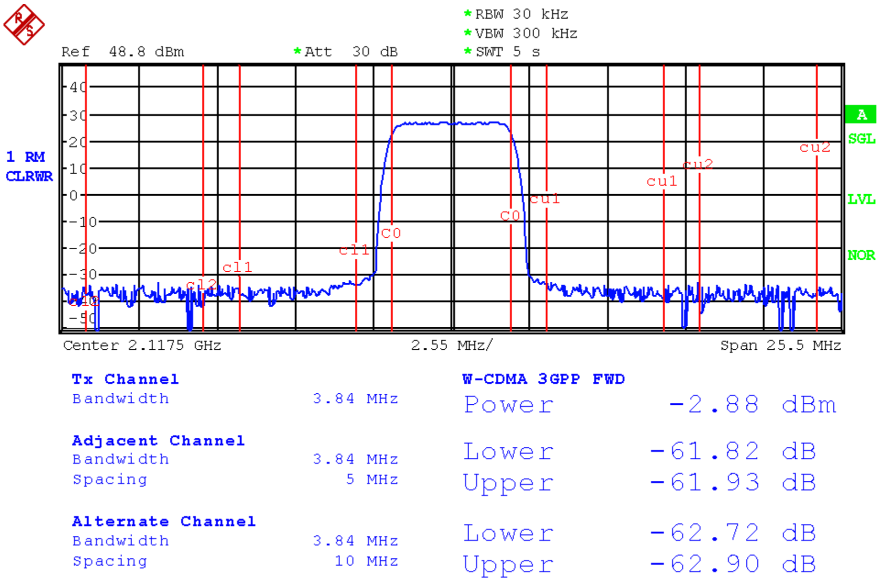


```
                                  * RBW  30 kHz      Marker 1 [T1 ]
                                  * VBW  300 kHz              -10.00 dB
Ref   5 dBm            * Att   25 dB   * SWT  5 s         2.139754808 GHz

Center  2.14 GHz                  2.55 MHz/              Span  25.5 MHz

Tx Channel                                W-CDMA 3GPP FWD
Bandwidth               3.84 MHz          Power          9.78 dBm

Adjacent Channel
Bandwidth               3.84 MHz          Lower        -79.03 dB
Spacing                    5 MHz          Upper        -79.43 dB

Alternate Channel
Bandwidth               3.84 MHz          Lower        -82.62 dB
Spacing                   10 MHz          Upper        -82.37 dB
```

Fig. 5 If the SMIQ03HD is fitted with the High ACLR option SMIQ-B57 the ACLR performance improves significantly.

Note that the FSU's or FSQ's unique noise compensation function is used to measure that performance.

If cost plays the key role e.g. as is often the case in a production test system, an FSP7 in combination with an SMIQ03HD might be sufficient. The typical ACLR performance in the adjacent and alternate channel for this combination is about 61/62 dB compared to 79/82 dB of the upper combination SMIQ03HD with high ACLR option and FSU3/7, see figure 6 below.



*RBW 30 kHz
*VBW 300 kHz
*SWT 5 s
Ref 48.8 dBm
*Att 30 dB
Center 2.1175 GHz
2.55 MHz/
Span 25.5 MHz

Tx Channel		**W-CDMA 3GPP FWD**	
Bandwidth	3.84 MHz	Power	-2.88 dBm
Adjacent Channel			
Bandwidth	3.84 MHz	Lower	-61.82 dB
Spacing	5 MHz	Upper	-61.93 dB
Alternate Channel			
Bandwidth	3.84 MHz	Lower	-62.72 dB
Spacing	10 MHz	Upper	-62.90 dB

Fig. 6 Typical achievable dynamic range with a combination of SMIQ03B + FSP (Noise Corr ON)

ACLR Measurement On Multi-Carrier Base Station PA

Two setups are possible depending on the accuracy required, either a single generator plus ARB (Arbitrary Waveform Generator) or several generators.

Single Signal Generator SMIQ03HD and SMIQ-B60

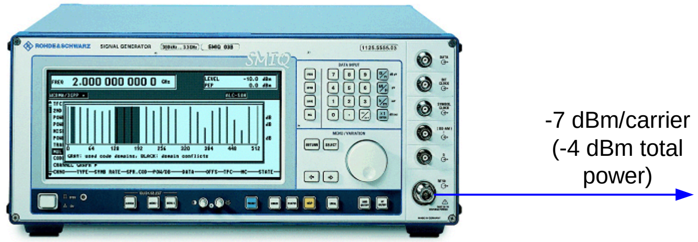
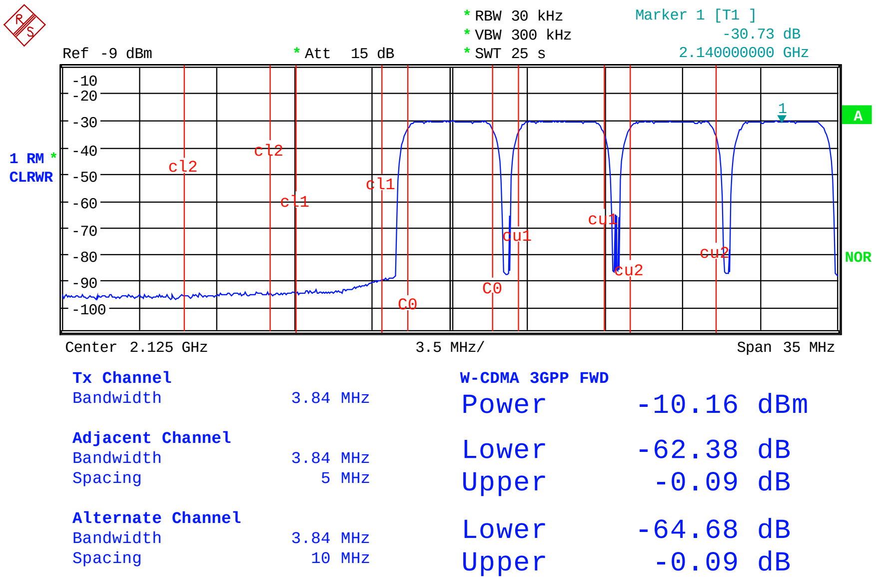


Fig. 7 Generating a 4-carrier 3GPP signal with a single SMIQ

The simplest way to obtain a 3GPP test signal with four modulated physical carriers is to use a single SMIQ03HD with ARB. The baseband signal is generated in the ARB Option SMIQ-B60 and used to modulate the RF output of the Signal Generator SMIQ.

A multi-carrier waveform (4 x 3GPP Test Model 1, 64 with 64 DPCH logical carriers with 5 MHz spacing, as supplied with this application note in the file: *4x3GPPMulticarrier_OS1_SCV.wv*) is downloaded into the Signal Generator SMIQ. The carriers are de-correlated using different scrambling codes (0, 1, 2 and 3). Each carrier is given an offset of 1/5 of a WCDMA/3GPP slot. The crest factor of the 4-carrier signal is calculated with the R&S simulation software WinIQSIM^{TM} as 11.32 dB. The SMIQ sets the correct PEP (Peak Envelope Power) according to the calculation automatically. The 10 MHz IQ filter is switched on within the Vector Mode menu to suppress baseband noise outside the wanted spectrum. Further the SMIQ should be set to LOW-NOISE within the Level menu. This function suppresses further existing broadband noise in the generator. The overall peak power of the SMIQ should not exceed +8 dBm to avoid excessive generation of adjacent channel power due to intermodulation in the SMIQ signal path. This limits the available overall power to about –4 dBm and the channel power per channel to about –10 dBm.

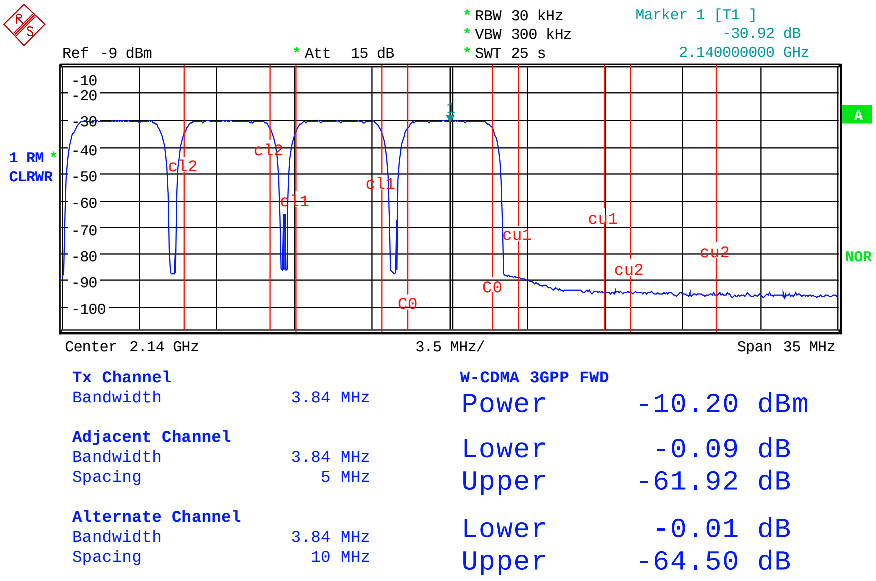
Note: The warning in the SMIQ display that occurs when switching on the 10 MHz IQ filter can be ignored. The 4 carrier spectrum fits well in the filter bandwidth.



*RBW 30 kHz
*VBW 300 kHz
*SWT 25 s
Marker 1 [T1]
-30.73 dB
2.140000000 GHz
Ref -9 dBm
*Att 15 dB
Center 2.125 GHz
3.5 MHz/
Span 35 MHz

Tx Channel		**W-CDMA 3GPP FWD**	
Bandwidth	3.84 MHz	Power	-10.16 dBm
Adjacent Channel			
Bandwidth	3.84 MHz	Lower	-62.38 dB
Spacing	5 MHz	Upper	-0.09 dB
Alternate Channel			
Bandwidth	3.84 MHz	Lower	-64.68 dB
Spacing	10 MHz	Upper	-0.09 dB

Fig. 8 ACLR measurement results, lower adjacent and 1st alternate channel



Tx Channel
Bandwidth 3.84 MHz

W-CDMA 3GPP FWD
Power -10.20 dBm

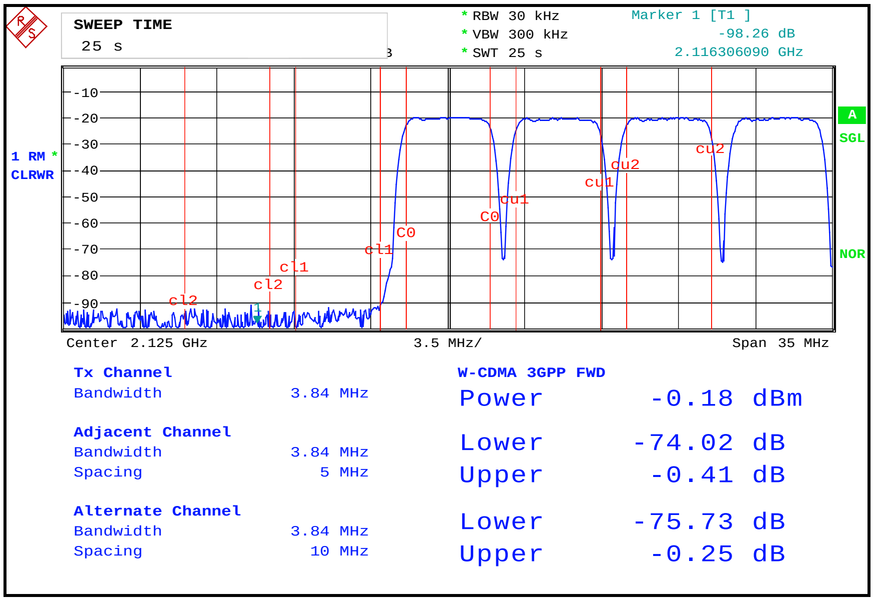
Adjacent Channel
Bandwidth 3.84 MHz
Spacing 5 MHz
Lower -0.09 dB
Upper -61.92 dB

Alternate Channel
Bandwidth 3.84 MHz
Spacing 10 MHz
Lower -0.01 dB
Upper -64.50 dB

Fig. 9 ACLR measurement results, upper adjacent and 1st alternate channel

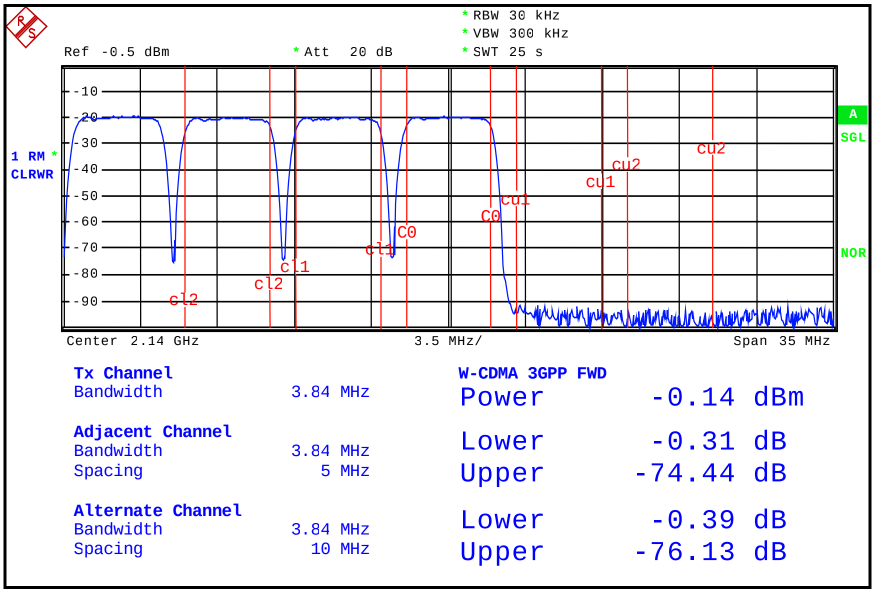
Maximum ACLR Dynamic with SMIQ03HD and SMIQ-B57

Using High-ACLR option SMIQ-B57 only one 3GPP Signal can be produced with one SMIQ03HD (The reason is the limited bandwidth of the IF filter used with Option SMIQ-B57). The solution to generate multi-carrier signals with the highest possible performance is therefore to combine several SMIQ03HDs each with the SMIQ-B57 option using an external combining circuit. The exact number of SMIQ03HD's will depend on the number of 3GPP carriers needed. A dramatical increase in performance can be achieved, e.g. instead of –62 dBc with the 1-generator solution, –74 dBc is the typical performance with the 4 generator solution. Another advantage is the higher possible output level using the SMIQ-B57 which provides up to + 30 dBm Peak Envelope Power (PEP). This means about +12 dBm output power/Channel or +18 dBm total power using test model 1, 64 within each SMIQ, assuming a 7 dB loss within the external combiner.



```
SWEEP TIME                                    * RBW  30 kHz        Marker 1 [T1 ]
 25 s                                         * VBW  300 kHz             -98.26 dB
                                              * SWT  25 s           2.116306090 GHz
1 RM *
CLRWR
Center  2.125 GHz                  3.5 MHz/                          Span  35 MHz

Tx Channel                                W-CDMA 3GPP FWD
Bandwidth            3.84 MHz             Power          -0.18 dBm

Adjacent Channel
Bandwidth            3.84 MHz             Lower         -74.02 dB
Spacing                 5 MHz             Upper          -0.41 dB

Alternate Channel
Bandwidth            3.84 MHz             Lower         -75.73 dB
Spacing                10 MHz             Upper          -0.25 dB
```

Fig 10 The lower adjacent channel and the lower alternate channel ACLR performance of 4 SMIQ03HD each generating a separate WCDMA/3GPP signal with option SMIQB57.



```
                                              * RBW  30 kHz
                                              * VBW  300 kHz
Ref  -0.5 dBm               * Att   20 dB     * SWT  25 s
1 RM *
CLRWR
Center  2.14 GHz                   3.5 MHz/                          Span  35 MHz

Tx Channel                                W-CDMA 3GPP FWD
Bandwidth            3.84 MHz             Power          -0.14 dBm

Adjacent Channel
Bandwidth            3.84 MHz             Lower          -0.31 dB
Spacing                 5 MHz             Upper         -74.44 dB

Alternate Channel
Bandwidth            3.84 MHz             Lower          -0.39 dB
Spacing                10 MHz             Upper         -76.13 dB
```

Fig. 11 The upper adjacent channel and the upper alternate channel ACLR performance of 4 SMIQ03HD each generating a separate WCDMA/3GPP signal with option SMIQB57.

Meas. high ACLR on 3G multicarrier signals with FSU/FSQ

Several parameters of the spectrum analyzer influence its inherent dynamic range:

- the load capability of the signal path without distorting the WCDMA signal
- the thermal noise floor of the spectrum analyzer
- the phase noise of the internal local oscillators.

As these requirements go to the limit of the dynamic capabilities of a spectrum analyzer, it has to be set up very carefully in order to attain optimum dynamic range.

The firmware function Noise Correction (*NOISE CORR ON*) compensates for the thermal noise floor by switching off the input signal and making a sweep to calculate the inherent power. This information used later in signal processing stages for noise compensation. A remarkable increase in dynamic range of about 7 dB is achieved.

The reference level of the analyzer and the attenuator should be set independently for best matching (select the function RF ATTEN MANUAL).

Setting Reference Level

To minimize the effects of IF noise, the reference level should be set as low as possible (i.e. the gain in the IF stage of the analyzer should be as high as possible) while taking care to avoid overloading.

To achieve this, reduce the reference level in 1-dB steps until the overload limit is reached (observe the IFOVL warning at the left-hand side of the screen). Then increase the reference level until the overload warning switches off.

Automatic Configuration Routine for Maximum Dynamic Range

The FSU/FSQ and FSP all provide an automatic setting routine which achieves optimum dynamic range. In most cases the automatic setting routine is the right choice.

Switch ON Noise Correction

To achieve the maximum dynamic range with the FSU (FSQ or FSP) switch on the noise correction function (*NOISE CORR ON*) after setting of the attenuation and the reference level. Note that the best results with noise compensation are achieved with a lower mixer level signal as compared to the normal ACLR measurement. This is because the compensation works only for the input noise and not for the inherent intermodulation products generated by the FSU. The change to the mixer level is done automatically through a 5 dB increase in the input attenuation, when the noise compensation is switched on.

Frequency Setting

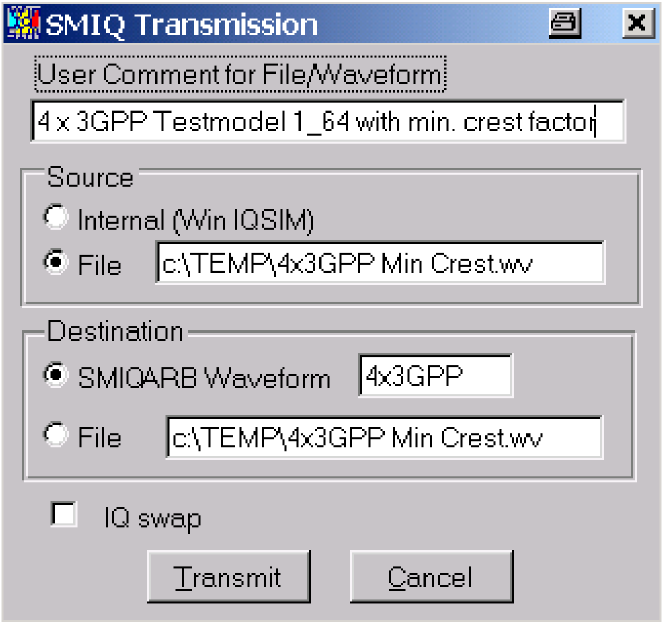
The center frequency of the FSU(FSQ) has to be set either to the lowest carrier for measuring lower adjacent and alternate channels, or to the highest carrier for measuring the upper channels.

Example: ALCR Measurement on 4-carrier 3GPP Base Station Signal

Level x dBm, with carrier frequencies 2125, 2130, 2135, 2140 MHz, generated by one SMIQ03HD with SMIQ-B60 ARB option.

WinIQSIM^{TM} settings/waveform transm. to SMIQ03HD

Start WinIQSIM^{TM} and download the supplied waveform file *4x3GPPMulticarrier_OS1_SCV.wv* to SMIQ03HD using SMIQ Transmission (see fig. 12).



SMIQ Transmission

User Comment for File/Waveform: 4 x 3GPP Testmodel 1_64 with min. crest factor

Source

○ Internal (Win IQSIM)

● File: c:\TEMP\4x3GPP Min Crest.wv

Destination

● SMIQARB Waveform: 4x3GPP

○ File: c:\TEMP\4x3GPP Min Crest.wv

☐ IQ swap

Fig. 12 WinIQSIM^{TM} menu for transmitting waveform files to the SMIQ (e.g. 4x3GPPMulticarrier_OS1_SCV.wv).

SMIQ03HD Setting

[**PRESET**] Switch on preset settings.

[**FREQUENCY**: 2132.5 MHz] Set frequency to 2132.5 MHz (center frequency of output spectrum).

[RETURN]

[ARB:SELECT WAVEFORM:WAVEFORM 4x3GPP]

[RETURN:ARB ON]

[Level]: x dB Set overall SMIQ level to the required value (Note: keep below – 4 dBm to keep below +8 dBm peak power)

Output Mode: Low Noise] Set Low Noise mode in level menu

[RETURN:RETURN:RETURN]

[VECTOR MOD: IQ Filter 10 MHz] Switch on 10 MHz IQ filter. Note: The warning in the SMIQ display that occurs when switching on the 10 MHz IQ filter can be ignored.

FSQ/FSU/FSP Settings (same as FSP)

[**PRESET**] Switch on preset settings.

[**FREQ**: *CENTE*R: 2110 MHz] Set center frequency to 2110 MHz (center frequency of lowest carrier.

[**AMPT**: x+10 dBm] Set reference level 10 dB above the level of an x dBm average power signal.

[**MEAS:**CHAN PWR ACP:CP/ACP STANDARD W-CDMA 3GPP FWD] Switch on ACP measurement to 3GPP Standard

[**SPAN** 35 MHz] Increase span suitable for a 4 carrier signal with 5 MHz spacing

[**MEAS:**CHAN PWR ACP:ADJUST REF LEVEL] The analyzer's level setting is automatically adjusted for optimum dynamic performance

[SWEEP: SWEEPTIME MANUAL 25s] Increase the sweep time to get stable readings (depending on your needs a shorter sweeptime may be suffiecient)

[MEAS: CHAN PWR ACP: NOISE CORR ON] Switch on the noise compensation function.

Spectrum Emission Mask

The spectrum emission mask covers unwanted emissions from 2.515 MHz beside the carrier(s) up to either 12.5 MHz above or below the carrier or to the edge of the transmit band whichever is greater.

Close to the carrier a 30 kHz measurement bandwidth is used whereas far off the carrier a 1 MHz bandwidth is used. Test model 1 is specified in TS25.141 for the measurement. Figure 13 shows the limits and the associated measurement bandwidths dependent on the frequency offset from the transmit channel:

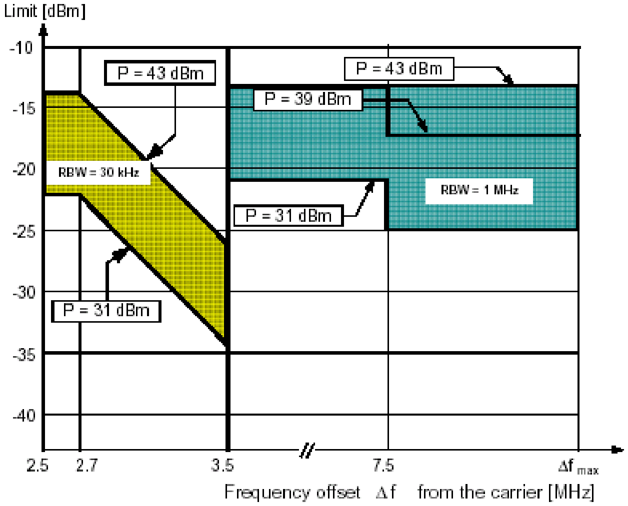


Figure 13: Limits for spectrum emission mask measurement depending on max. output power

The test limits are dependent on the output power of the base station. With most spectrum analyzers, using 4- or 5-pole Resolution Bandwidth (RBW) filters the selectivity of the 1-MHz RBW filter causes leakage of the transmit signal close to the carrier at 3.5 MHz offset. Using a 1-MHz resolution bandwidth, leakage power due to the filter characteristic is measured rather than leakage power due to the signal itself. The standard TS25.141 allows simulation of the 1-MHz measurement bandwidth using a narrow resolution bandwidth and integration over 1 MHz. This so-called Integrated Bandwidth method (IBW) gives true results for the average power in the 1 MHz bandwidth. The peak power due to transients can however not be measured correctly. The tester also has the option to define which power class limits to test against, or even to define the limits.

Spectrum Emission Mask Measurement

Configure SMIQ03HD at Frequency 2117.5 MHz

[**PRESET**] Switch on preset settings.

[**FREQUENCY**: 2117.5 MHz] Set frequency to 2117.5 MHz (center frequency of output spectrum).

[Digital Standard:WCDMA/3GPP:Test Model 1_64]

[...:State ON

[Vector Modulation: IQ Filter 2.5 MHz] Switch On 2.5 MHz IQ Lowpass

[**Level]**: x dB Set overall SMIQ level to achieve wanted power amplifier output level

Configure FSU/FSQ at Frequency 2117.5 MHz

[**PRESET**] Switch on preset settings.

[**FREQ**: *CENTE*R: 2117.5 MHz] Set center frequency to 2117.5 MHz (center frequency of output spectrum).

[**AMPT**: x + 5 dBm] Set reference level 5 dB above to average power x of input signal.

[3GPP FDD BS] Switch on 3 GPP BTS Measurement personality

[**MEAS:** SPECTRUM EM MASK] Switch on spectrum emission mask measurement

[ADJUST REF LEVEL] Adjust attenuator and level setting for max. dynamic range

[**SWEEP**: SWEEPTIME 500 ms]

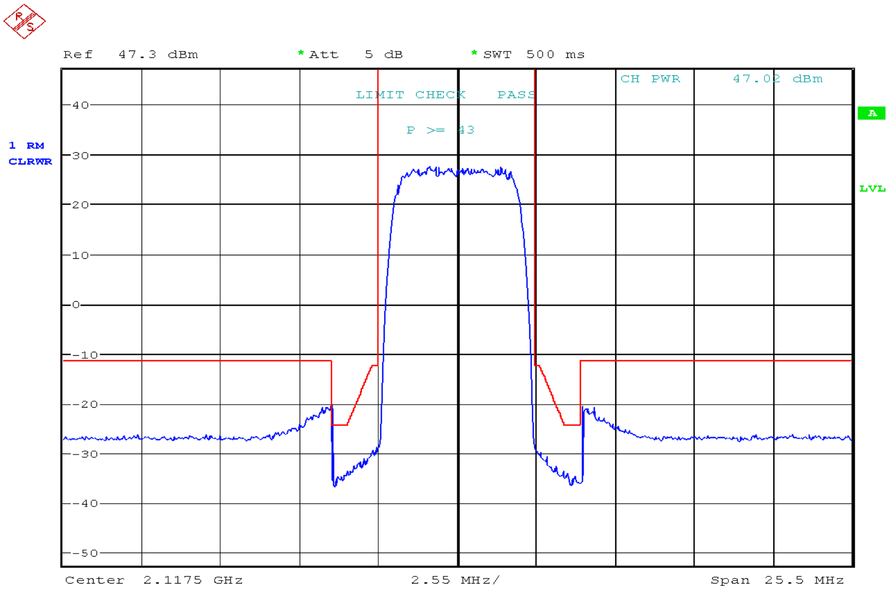


Fig. 14 Dynamic range of spectrum emission mask measurement with SMIQ03HD and FSU/FSQ

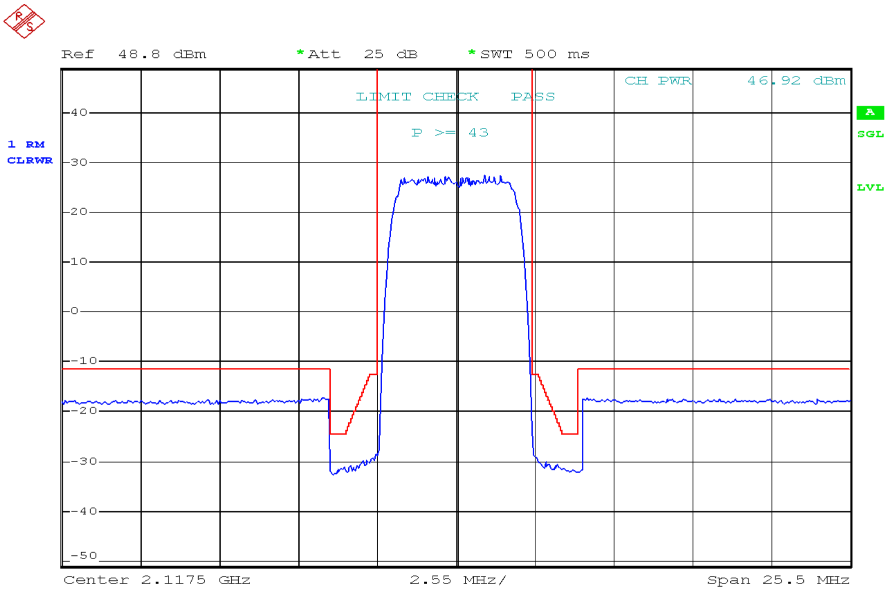
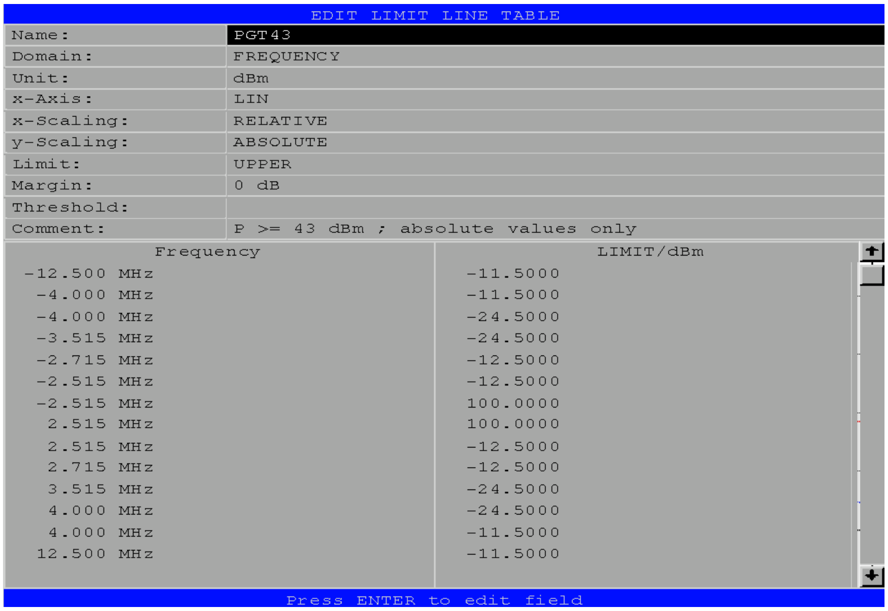


Fig. 15 Dynamic range of spectrum emission mask measurement with SMIQ03HD and FSP7

Creating a User Defined Spectrum Emission Mask

A custom spectrum emission mask limit line can be defined. The simplest way to achieve this is to modify a standard emission mask limit line and to save it under a different name. Limit lines are accessable via the LINES button of FSU/FSQ or FSP.



EDIT LIMIT LINE TABLE

Name:	PGT43
Domain:	FREQUENCY
Unit:	dBm
x-Axis:	LIN
x-Scaling:	RELATIVE
y-Scaling:	ABSOLUTE
Limit:	UPPER
Margin:	0 dB
Threshold:	
Comment:	P >= 43 dBm ; absolute values only

Frequency	LIMIT/dBm
-12.500 MHz	-11.5000
-4.000 MHz	-11.5000
-4.000 MHz	-24.5000
-3.515 MHz	-24.5000
-2.715 MHz	-12.5000
-2.515 MHz	-12.5000
-2.515 MHz	100.0000
2.515 MHz	100.0000
2.515 MHz	-12.5000
2.715 MHz	-12.5000
3.515 MHz	-24.5000
4.000 MHz	-24.5000
4.000 MHz	-11.5000
12.500 MHz	-11.5000

Press ENTER to edit field

Fig. 16 Emission Mask Limit Line for base station power > 43 dBm

Spurious Emissions

Spurious emissions at the output of a power amplifier used in a 3G base station are caused by harmonic emissions and especially in the case of a Multi-carrier power amplifier by intermodulation products. Depending on the concept of the power amplifier additional spurious emissions may be caused by digital signals and internal oscillators used, for example in some feed forward concepts. In addition excessive noise produced by the power amplifier outside the transmit band may lead to violations of the spurious emission limits. Spurious emission is defined as transmission outside the frequency band 12.5 MHz below the first carrier and 12.5 MHz above the last carrier transmitted by a base station or in this case emitted at the output of the power amplifier.

The frequency range for spurious emission measurement is specified from 9 kHz to 12.75 GHz. TS25.141 states two categories of limits to be fulfilled by the base station. Category A applies in general and specifies relaxed limits compared to category B, which applies only for Europe. All limits are specified as absolute values in dBm. This results in requirements harder to meet with high power base station. The power of any spurious emission shall not exceed the values shown in the following graphics:

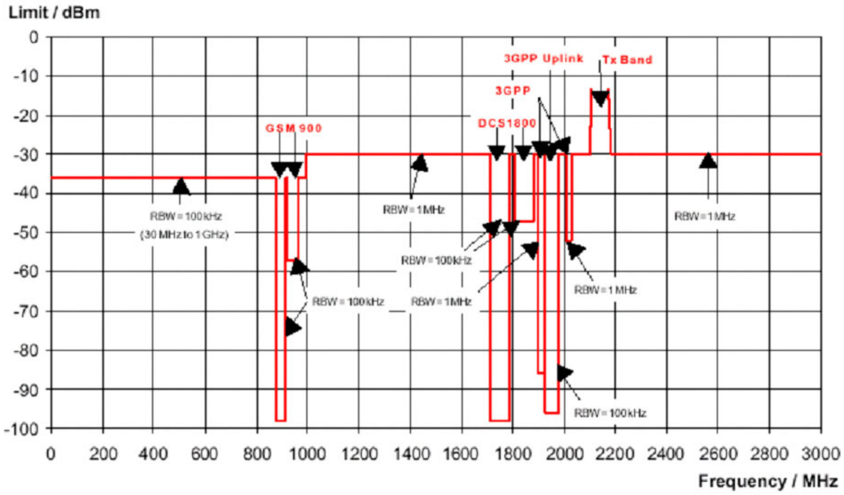
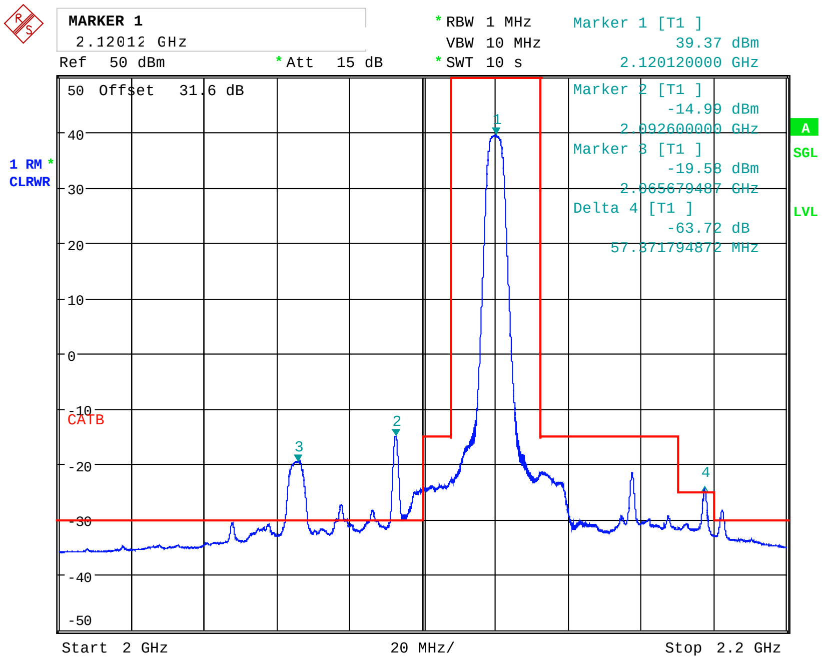


Fig. 17 Limits for spurious emission up to 3 GHz

In a base station there is always a passive high frequency selective network called a diplexer after the power amplifier. It separates the transmit from the receive band and cuts off frequencies outside the transmit band. The requirements necessary for the power amplifier generally are therefore **much less critical** than the requirements for the whole base station, to be measured at the antenna connector. Above all, the spurious emissions near the transmit band, where the frequency selection has less suppression may be critical and have to be tested. These near transmit band limits may be even more stringent than the limits for the whole base station as stated in TS25.141.

For the spurious emission measurements test model 1, 64 shall be used. Use any of the test setups suggested in section 3 for spurious testing.



MARKER 1
2.12012 GHz
Ref 50 dBm
*Att 15 dB
*RBW 1 MHz
VBW 10 MHz
*SWT 10 s
Offset 31.6 dB

Marker 1 [T1]
39.37 dBm
2.120120000 GHz

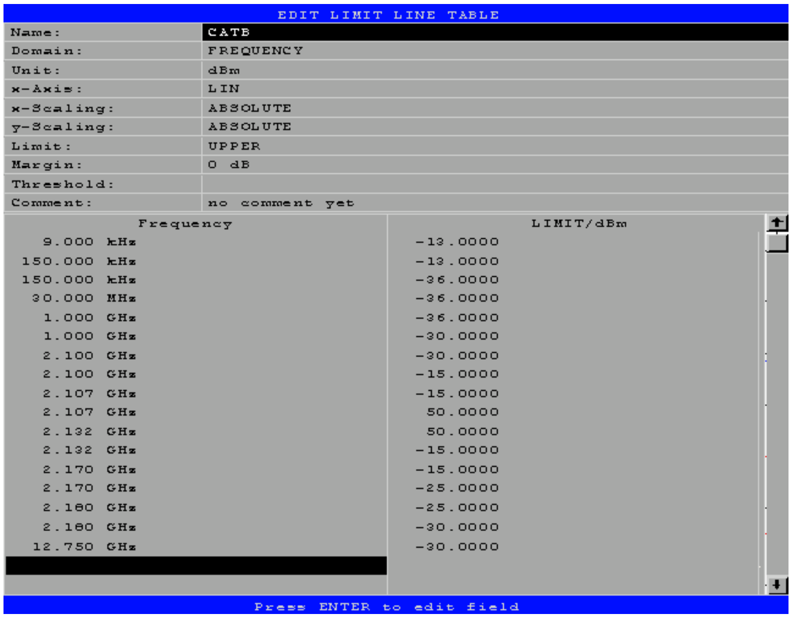
Marker 2 [T1]
-14.99 dBm
2.092600000 GHz

Marker 3 [T1]
-19.58 dBm
2.065679487 GHz

Delta 4 [T1]
-63.72 dB
57.371794872 MHz

Start 2 GHz
20 MHz/
Stop 2.2 GHz

Fig. 18 Spurious measurement from 2 to 2.2 GHz on a prototype 3G power amplifier at transmit frequency 2120 MHz with limit line CAT B (according to BS mandatory spurious emission limits)



EDIT LIMIT LINE TABLE

Name:	CATB
Domain:	FREQUENCY
Unit:	dBm
x-Axis:	LIN
x-Scaling:	ABSOLUTE
y-Scaling:	ABSOLUTE
Limit:	UPPER
Margin:	0 dB
Threshold:	
Comment:	no comment yet

Frequency	LIMIT/dBm
9.000 kHz	-13.0000
150.000 kHz	-13.0000
150.000 kHz	-36.0000
30.000 MHz	-36.0000
1.000 GHz	-36.0000
1.000 GHz	-30.0000
2.100 GHz	-30.0000
2.100 GHz	-15.0000
2.107 GHz	-15.0000
2.107 GHz	50.0000
2.132 GHz	50.0000
2.132 GHz	-15.0000
2.170 GHz	-15.0000
2.170 GHz	-25.0000
2.180 GHz	-25.0000
2.180 GHz	-30.0000
12.750 GHz	-30.0000

Press ENTER to edit field

Fig. 19 Example for a limit line for spurious emissions category B at 2120 MHz center frequency

Harmonics

Harmonics created by the power amplifier fall into the spurious frequency region and must therefore meet the –36 dBm limit measured with 1 MHz RBW at the base station output. The amplifier itself must only meet a much less stringent limit (depending on the actual suppression of the diplexer) because the diplexer connected after the power amplifier's output suppresses frequencies outside the transmit band,. The SMIQ03HD used to stimulate the amplifier has a specification of < - 30 dBc harmonic content and a typical performance of about –40 dBc (with active option HIGH ACLR < - 40 dBc and a typical performance of about –50 dBc). A lowpass filter must be placed after the signal generator, if this does not give enough margin. It should have small ripple and good VSWR not to adulterate other power amplifier measurements like VSWR, gain variation within transmission band etc. Otherwise it should be used only for the harmonics/spurious measurement and removed for all other tests.

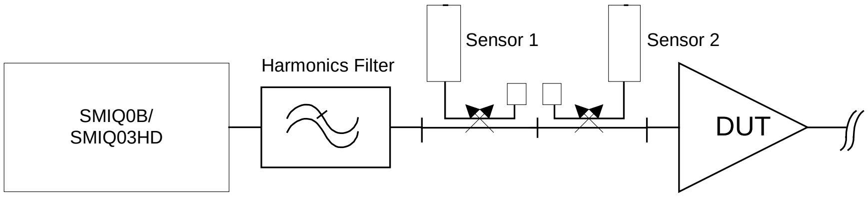


Fig. 20 Lowpass filter placed after the signal generator to suppress it's own harmonics

Transmit Intermodulation

Transmit intermodulation can be caused by the presence of the wanted signal and an interfering signal reaching the amplifier's output via the antenna output. It is measured by introducing a WCDMA modulated interference signal into the amplifier's output with a level –30 dB below the wanted signal at signal offsets 5, 10 and 15 MHz from the carrier. For multi-carrier signals, the offsets must be applied below the lowest and above the highest carrier.

The basic test setup is shown in figure 21. The interfering signal is produced by an additional SMIQ03B. To deliver sufficient level an amplifier may be necessary (depending on the DUT max. power) for example a Mini Circuits ZHL-42.

A circulator (e.g. Narda SCC-01A-2023) is used to feed the interference signal to the DUT's output and to decouple the amplifier output from DUT's power. Depending on the circulator's isolation, an additional isolator (e.g. Narda SIH-01A-2023) may be necessary to prevent the creation of intermodulation products at the amplifier's output.

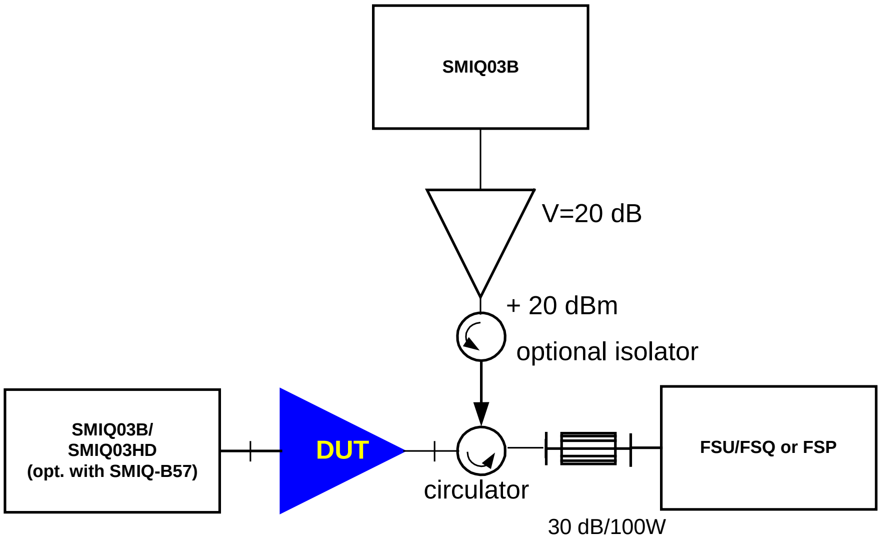


Fig. 21 Test setup for transmit intermodulation measurement

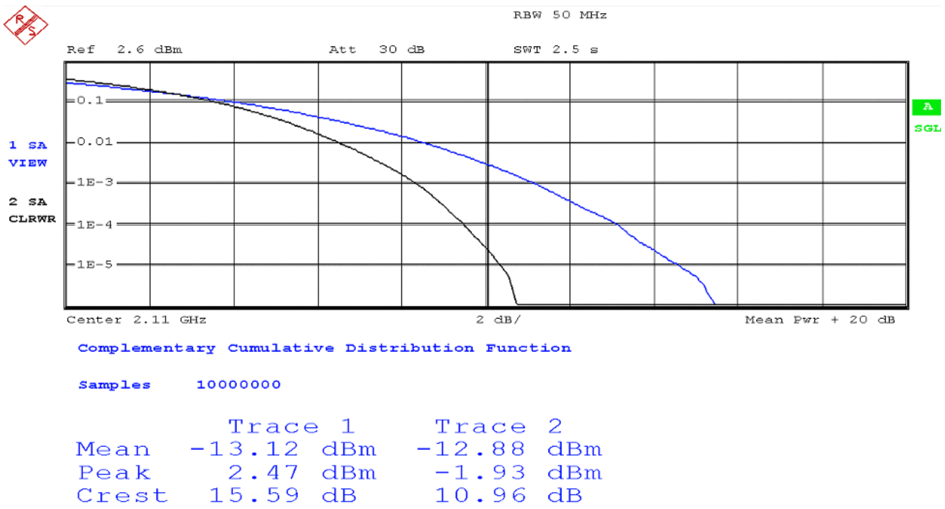
Crest Factor / CCDF

Digitally modulated signals like 3GPP signals appear similar to white noise within the transmit channel, but are actually different in their amplitude distribution. In order to transmit the modulated signal without distortion all amplitudes of the signal have to be transmitted linearly from the output power amplifier whereby the peak amplitude values are the most critical. Degradation in transmit quality caused by a power amplifier is dependent on the amplitude of the peak values as well as on their probability.

The Complementary Cumulative Distribution Function (CCDF Function) of the FSU/FSQ is an important measurement function for 3GPP signals and shows the probability of an amplitude exceeding a specific value, the x-axis is scaled relative to the MEAN POWER measured. It also delivers the Crest factor of the signal which is ratio of peak power to average power of the signal. CCDF and Crest factor measurements are useful for both, to check the input signal and the output signal of the power amplifier under test to look for its influence on the signal.

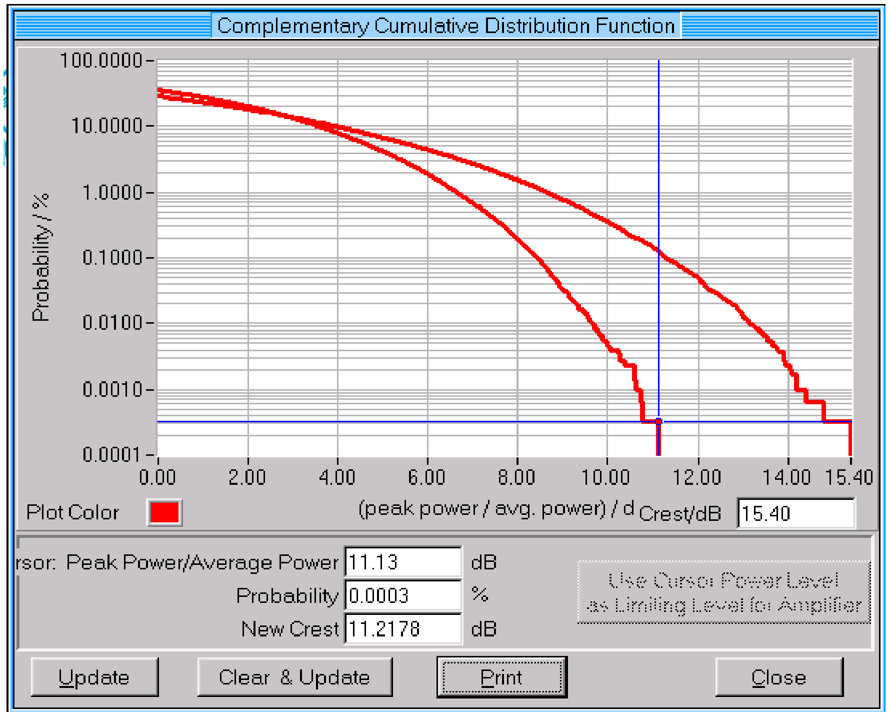
While the CCDF function of the FSU with its maximum video bandwidth of about 7 MHz is well suited for a single 3GPP carrier, the wider video bandwidth of the FSQ (about 30 MHz) provides precise measurement of CCDF and Crest factor for 3GPP multi-carrier signals with 4 and more carriers with 5 MHz spacing.

Figure 22 records measurements on 2 different 4-Carrier 3GPP signals (each modulated with test model 1, 64) The first one has a theoretical Crest factor of 11.13 dB and the second one of 15.4 dB, see figure 23 for the calculation results of WinIQSIM^{TM}. The difference arises because the 4 3GPP carriers have zero timing offset at signal No. 2 , whereas signal No. 1 has timing offsets of 1/5 slot.



```
Complementary Cumulative Distribution Function

Samples     10000000

             Trace 1      Trace 2
Mean     -13.12 dBm   -12.88 dBm
Peak       2.47 dBm    -1.93 dBm
Crest     15.59 dB     10.96 dB
```

Fig. 22 CCDF and Crest factor of 2 different 4-carrier 3GPP signals measured by an FSQ. The measured crest factors of 10.96 dB and 15.59 dB match well with the calculated values of 11.13 dB and 15.5 dB.



Crest/dB 15.40

rsor: Peak Power/Average Power 11.13 dB

Probability 0.0003 %

New Crest 11.2178 dB

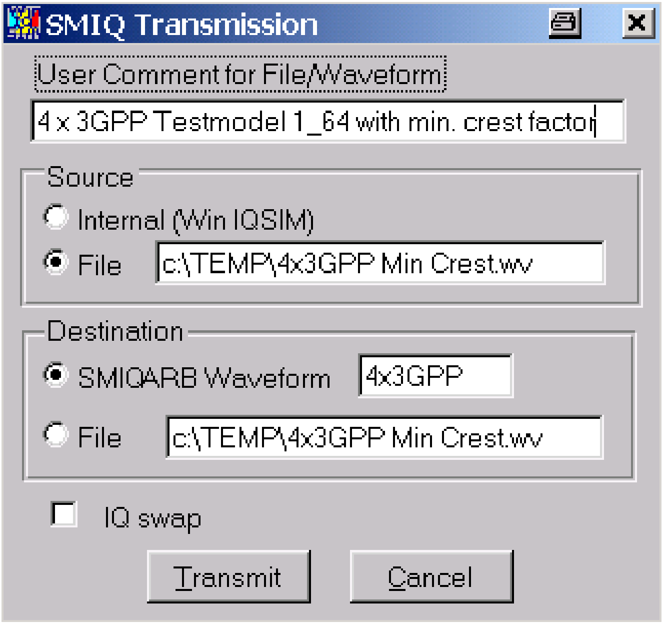
Fig. 23 Calculated CCDF/Crest factor of 2 different 4-carrier 3GPP signals with WinIQSIM^{TM}

Example: CCDF measurement on 4 Carrier 3GPP Base Station signal

Level x dBm, carrier frequencies 2110, 2115, 2120, 2125 MHz

WinIQSIM^{TM} settings / waveform transmission to SMIQ03HD

Start WinIQSIM^{TM} Software on controller and download the supplied waveform file *4x3GPPMulticarrier_OS1_SCV.wv* to SMIQ03HD (using SMIQ Transmission, see Figure 24)



SMIQ Transmission

User Comment for File/Waveform: 4 x 3GPP Testmodel 1_64 with min. crest factor

Source

○ Internal (Win IQSIM)

● File: c:\TEMP\4x3GPP Min Crest.wv

Destination

● SMIQARB Waveform: 4x3GPP

○ File: c:\TEMP\4x3GPP Min Crest.wv

☐ IQ swap

Fig. 24 WinIQSIM^{TM} menu for Transmitting waveform files to the SMIQ (e.g. 4x3GPPMulticarrier_OS1_SCV.wv).

SMIQ03HD Setting

[**PRESET**] Switch on preset settings.

[**FREQUENCY**: 2117.5 MHz] Set frequency to 2117.5 MHz (center frequency of output spectrum).

[RETURN]

[ARB:SELECT WAVEFORM:WAVEFORM 4x3GPP] Select 4x3GPP wave form previously transmitted

[RETURN:ARB ON] Switch on ARB function of SMIQ

[Level]: x dB Set overall SMIQ level to wanted value (Note: keep below – 4 dBm to keep below +8 dBm peak power)

FSQ Settings

[**PRESET**] Switch on preset settings.

[**FREQ**: *CENTE*R: 2117.5 MHz] Set center frequency to 2117.5 MHz (center frequency of output spectrum).

[**AMPT**: x+18 dBm] Set reference level 18 db above the level of an x dBm average power signal.

[**BW**: 50 MHz] Set resolution bandwidth to 50 MHz (resolution bandwidth shall be wider than signal bandwidth 25 MHz to have the complete signal within the resolution bandwidth).

[**MEA**S] Call the menu for measurement functions.

[*SIGNAL STATISTI*C] Call the menu for signal statistics measurement.

[*CCDF ON /OF*F] Switch on measurement of the complementary cumulative distribution function. The FSQ switches to zero span mode. The power of the signal and the CCDF is calculated for the number of samples selected. With the CCDF function sample detector and video bandwidth are set automatically.

[NO OF SAMPLES: 100 000 000] Set the number of measurement samples to 100 000 000 to give reproducible numbers.

[SINGLE MEAS] Start the measurement sequence. At the end the resulting trace will display the CCDF for the measured 100 000 000 samples as shown in figure 22.

Modulation Quality

The Error Vector Magnitude (EVM) is defined as the difference between themeasured waveform and the theoretical modulated waveform. An error vector is calculated from the difference of both waveforms for each chip of the modulation. From the error vectors the Mean Error Vector Power (MEVP) is calculated for a complete timeslot. The MEVP is related to the Mean Reference Signal Power (MRSP) within the same slot. From these two power values the EVM is calculated as follows:

$$\text{EVM/\%} = \sqrt{\frac{MEVP}{MRSP}}$$

Test model 4 using the Paging Indication Channel (PICH) and theSynchronization Channels (SCH), only is applied. While the measurement interval is specified to be one timeslot, the EVM result is one numbered value per timeslot. The specification of the EVM is valid over the total ower dynamic range.

A power amplifier may significantly distort the waveform signal and therefore worsen the EVM performance, mostly due to compression effects but also to excessive in-band noise as well.

Figure 25 shows the typical EVM performance of about 1.5% for an SMIQ signal generator and FSU spectrum analyzer connected directly to each other. Figure 26 show the influence of a prototype 3G power amplifier. The measured EVM increases by about 4%.

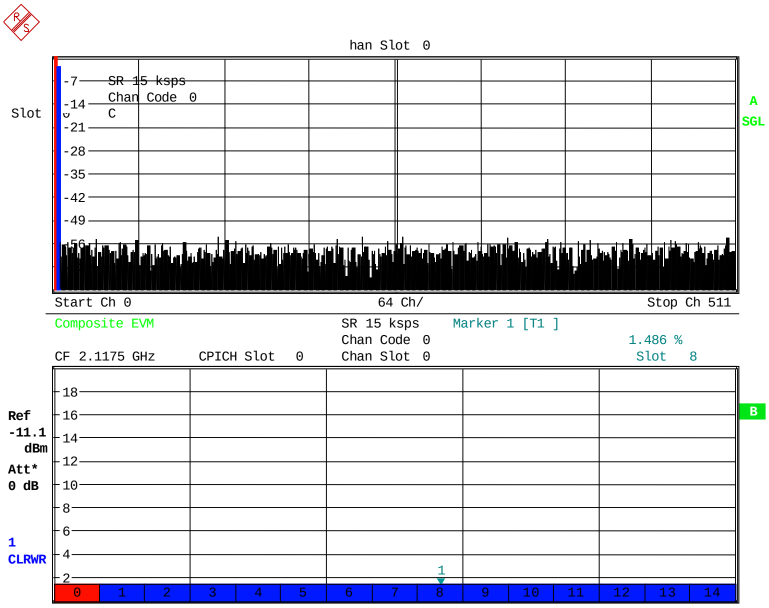


Fig. 25 EVM measurement with SMIQ03HD and FSU directly connected: typical EVM value of 1.5%

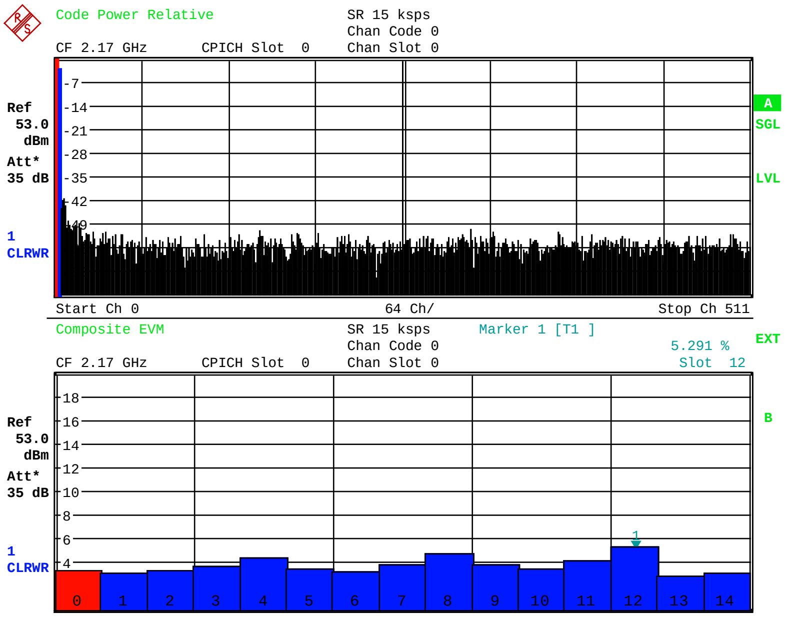


Fig. 26 Influence of prototype 3G BS power amplifier. The measured EVM worsens to about 5.3%

EVM Measurements

Configure SMIQ03HD at Frequency 2117.5 MHz

[**PRESET**] Switch on preset settings.

[**FREQUENCY**: 2117.5 MHz] Set frequency to 2117.5 MHz (center frequency of output spectrum).

[Digital Standard:WCDMA/3GPP:Test Model 4]

[..:State ON]

[**Level]**: x dB Set overall SMIQ level to achieve the desired amplifier output level

Configure FSU/FSQ at Frequency 2117.5 MHz

[**PRESET**] Switch on preset settings.

[**FREQ**: *CENTE*R: 2117.5 MHz] Set center frequency to 2117.5 MHz (center frequency of output spectrum).

[**AMPT**: x + 11 dBm] Set reference level 11 dB above the average power x of input signal.

[3GPP FDD BS] Switch on 3 GPP BS Measurement personality

[CHAN CONF: CODE CHAN PREDEFINED 3GB_4]

[SCREEN B]

[RESULTS: COMPOSITE EVM] Switch on Composite EVM measurement at screen B

[MKR-->: Peak] Set marker to time slot with maximum EVM (read marker 1 value)

Peak Code Domain Error

The peak code domain error is computed by projecting the error vector power onto the code domain at the spreading factor 256.

The error vector for each power code is defined as the ratio to the mean power of the reference waveform expressed in dB. The peak code domain error is defined as the maximum value for the code domain error. The measurement interval is one power control group (timeslot) in duration.

Test model 3_16 must be used for Peak Code Domain Error measurements.

Influence of a prototype 3G power amplifier on the peak code domain error: While the direct measurement with SMIQ03HD and FSU without an amplifier shows a typical peak code domain error of – 54 dB, the insertion of the power amplifier increases the error to – 44 dB.

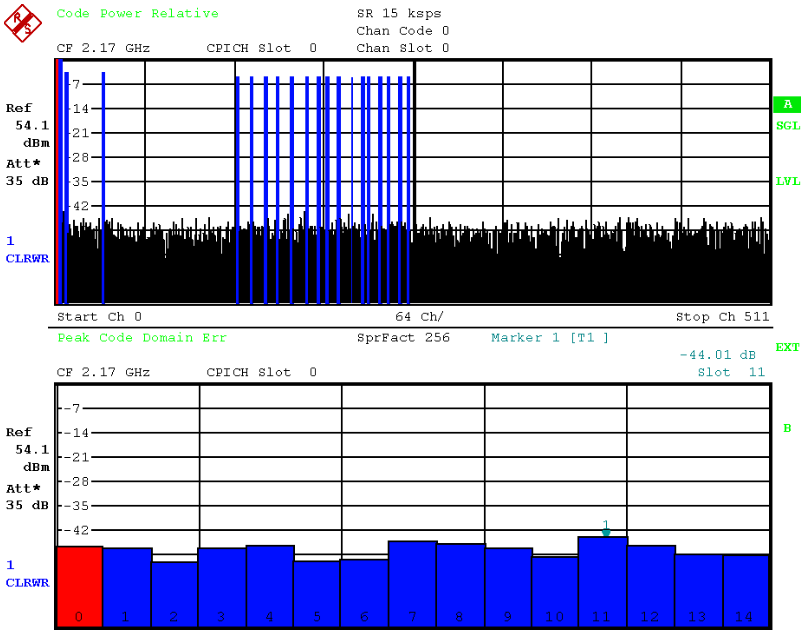


Fig. 27 Peak code domain error measurement at the output of a sample 3G base station amplifier at its nominal output power of +44 dBm (See marker 1 indication of screen B –44.01 dB)

Peak Code Domain Error Measurements

Configure SMIQ03HD at Frequency 2117.5 MHz

[**PRESET**] Switch on preset settings.

[**FREQUENCY**: 2117.5 MHz] Set frequency to 2117.5 MHz (center frequency of output spectrum).

[Digital Standard:WCDMA/3GPP:Test Model 4]

[..:State ON]

[**Level]**: x dB Set overall SMIQ level to achieve wanted power amplifier output level

Configure FSU/FSQ at Frequency 2117.5 MHz

[**PRESET**] Switch on preset settings.

[**FREQ**: *CENTE*R: 2117.5 MHz] Set center frequency to 2117.5 MHz (center frequency of output spectrum).

[**AMPT**: x + 11 dBm] Set reference level 11 dB above the average power x of input signal.

[3GPP FDD BS] Switch on 3 GPP BS Measurement personality

[CHAN CONF: CODE CHAN PREDEFINED 3GB_3_16]

[SCREEN B]

[RESULTS: Peak Code Domain Err] Switch on Code Domain Error Measurement at screen B

[MKR-->: Peak] Set Marker to time slot with max. Peak Code Domain Error (readout Marker 1 value)

AM-AM, AM-PM Conversion

Determining Pre-Distortion Parameters (Complex IQ data)

State of the art 3G power amplifiers, especially multi-carrier amplifiers often use pre-distortion techniques: The input signal for the power amplifier is distorted in such a way that it's output signal is nearly distortion free. The complex amplitude-to-amplitude and also the amplitude-to-phase transfer function (AM-AM conversion, AM-PM conversion) of the amplifier has to be measured.

AM-AM and AM-PM conversion measurement is a conventional measurement task for a vector network analyzer like the ZVR. The vector network analyzer performs a power sweep at a fixed frequency and measures output-amplitude and –phase over input level.

However, the measurement results obtained by that measurement may differ significantly from the amplifier's behaviour when fed with a real world WCDMA signal.

Another method to determine AM/AM and AM/PM conversion is to feed the power amplifier with a suitable input signal such as a WCDMA signal or a band limited noise signal and measure complex IQ Data at the power amplifier output and do some tricky calculations afterwards. See [5], [6] for more information.

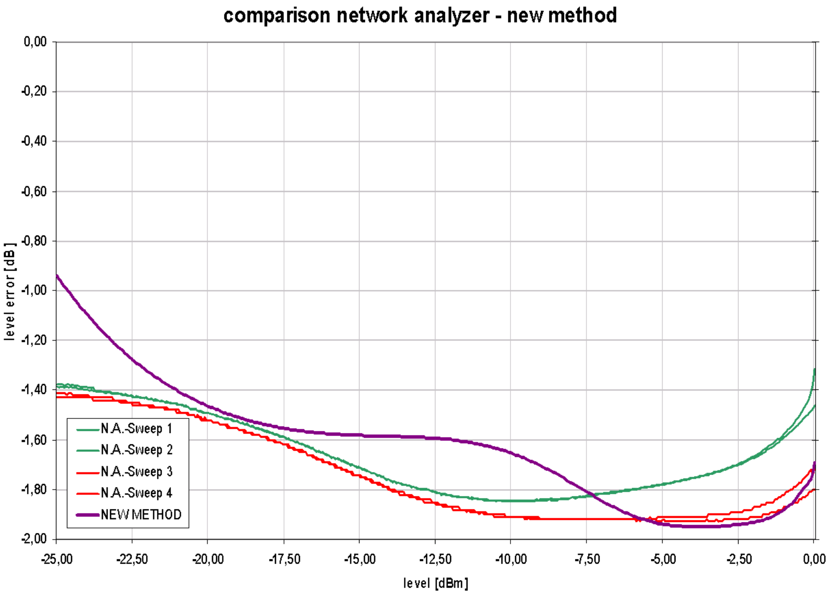
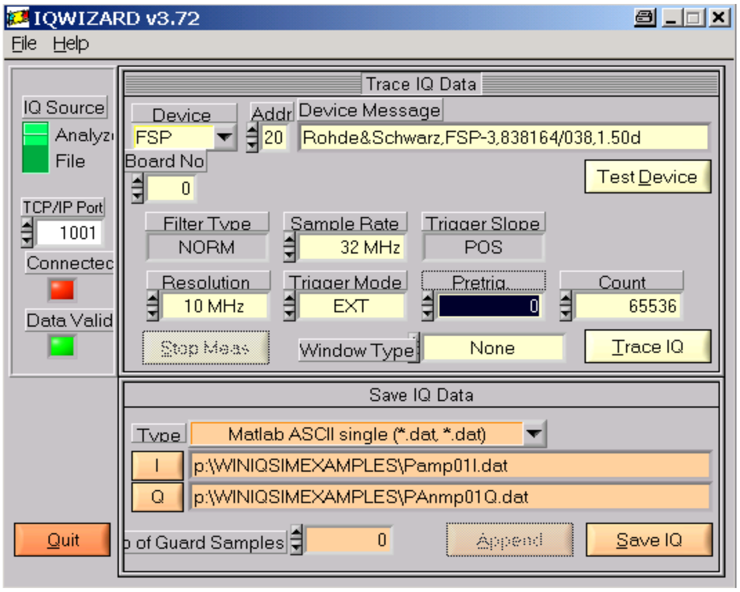


Fig. 28 Red and green traces show varying AM-AM got by a conventional vector network analyzer results depending on the sweep parameters. Magenta trace AM-AM results were obtained by stimulation with a WCDMA signal.

The extreme wide bandwidth of the FSQ (60 MHz) in combination with its very high dynamic range guaranties meaningful measurement results.

As recommended test setup, the standard test setup of figure 1 or 2 may be used. The output power of the power amplifier has to be set carefully to obtain the desired results. The absolute power accuracy is achieved by using a power meter.

The correct tool for getting IQ data out from the FSQ(or FSP/FSU) is IQ-Wizard [10]. IQ-Wizard is an R&S application program which can be downloaded from the R&S Home Page. It transfers IQ data from FSIQ (with B70 option), FSP, FSU or FSQ analyzer The IQ data may be stored in various file formats for further processing with signal analysis, simulation and generation tools such as **MathCAD**, **MatLab** and **ADS**.



Device: FSP
Addr: 20
Device Message: Rohde&Schwarz,FSP-3,838164/038,1.50d
Board No: 0
TCP/IP Port: 1001
Filter Type: NORM
Sample Rate: 32 MHz
Trigger Slope: POS
Resolution: 10 MHz
Trigger Mode: EXT
Pretrig: 0
Count: 65536
Window Type: None
Type: Matlab ASCII single (*.dat, *.dat)
I: p:\WINIQSIMEXAMPLES\Pamp01I.dat
Q: p:\WINIQSIMEXAMPLES\PAnmp01Q.dat
of Guard Samples: 0

Fig. 29 IQWizard (IQ Signal measurement and Conversion) User interface

DC Parameters

An important parameter for 3G base station power-amplifier is the efficiency which is the quotient of available RF power and the DC Power (supply current multiplied by the supply voltage).

5 Block Diagrams for Universal 3G Base Station PA Test Systems

In the following two block diagrams of complete 3G base station testers covering all the measurements discussed in this application note are presented. Figure 30 shows a test setup for a 1-input power amplifier whereas figure 31 shows that for a 2-input amplifier.

The vector network analyzer can be used to measure complex S11 and S21 parameters (including group delay) at nominal power (but with a CW signal). In addition PORT 1 and 2 are connected to the amplifier inputs and output to measure S22 and S12 parameters of the amplifier.

Caution: The power amplifier may easily destroy the analyzer's input.

Depending on the necessary measurements, parts of the setup may be skipped.

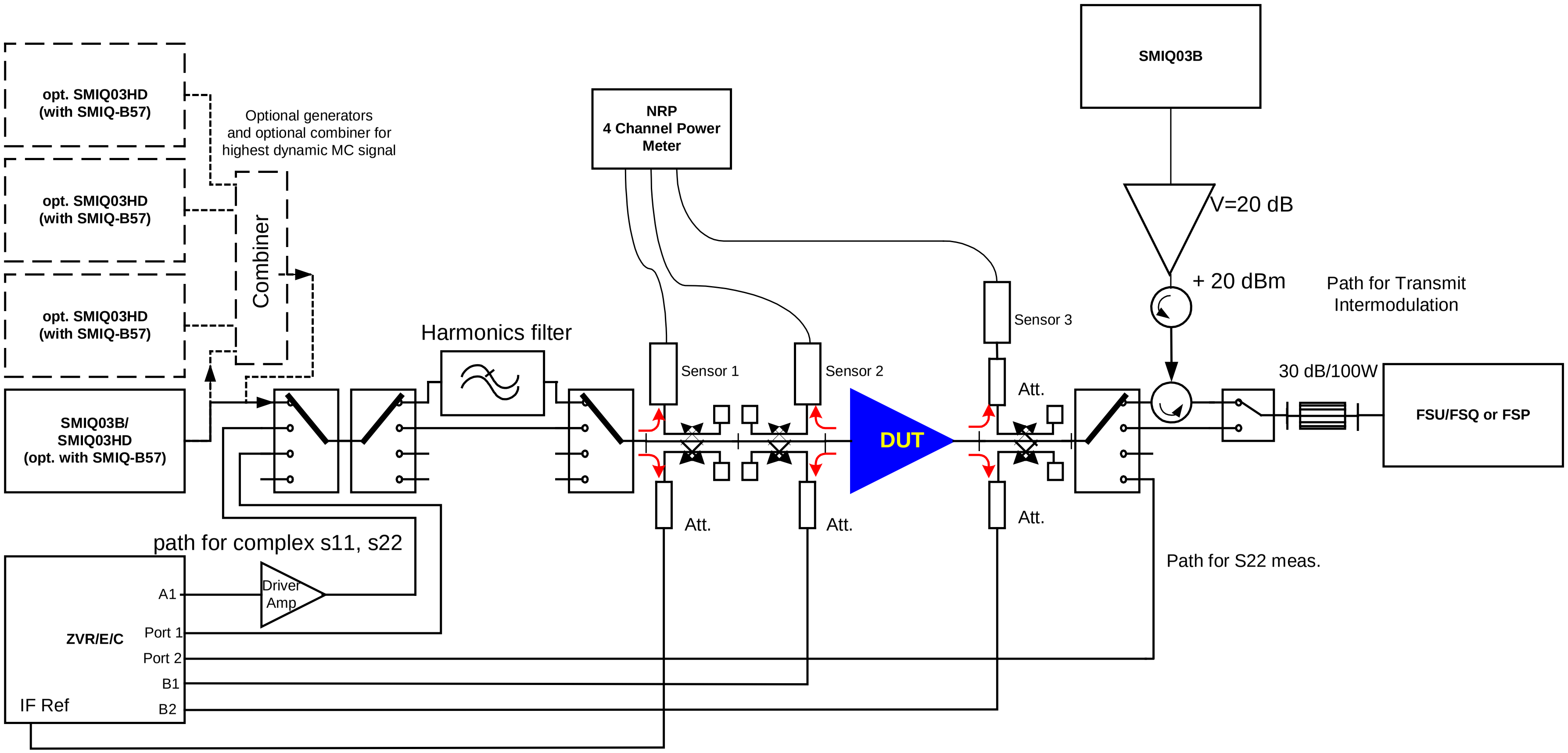


Fig. 30 Block diagram of a universal 3G power amplifier test system

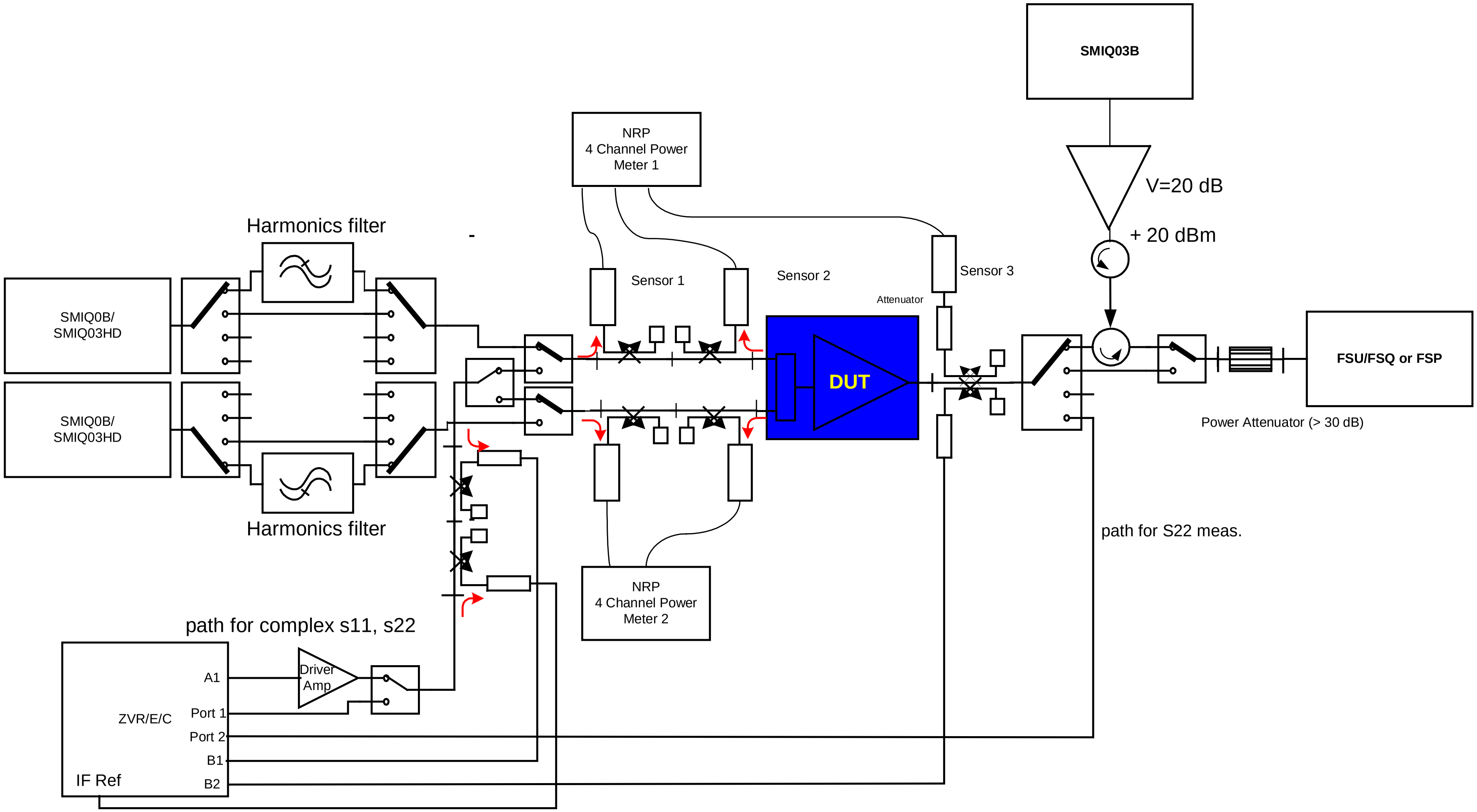


Fig. 31 Block diagram of a universal 3G base station power amplifier tester (2 input amplifier)

6 Literature

(1) Dr. Markus Banerjee / Dr. Rene Desquiotz "Generating Multicarrier Signals for Amplifier Tests with SMIQ03HD and WinIQSIM^{TM}"

(2) D. Picken / R. Minihold "Generating and Analyzing 3GPP Multicarrier Signals with High Dynamic Range", R&S application note 1MA48

(3) Josef Wolf "3GPP Base Station Transmitter Tests" R&S application note 1EF44

(4) Kay Uwe Sander/Josef Wolf/ "Spurious Emission Measurement on 3GPP Base Station Transmitters" R&S application note 1EF45

(5) "Measuring the Dynamic Characteristic of High-Frequency Amplifiers with Real Signals", European Wireless 2000

(6) Martin Weiß "Amp Tune Software for Measuring Amplifier Nonlinearity in Realistic Conditions" R&S application note 1MA27

(7) Detlev Liebl "Tests on 3G-Base Station to TS25.141 with FSIQ and SMIQ" R&S application note 1MA38

(8) Dr. René Desquiotz "WCDMA Signal Generator Solutions" R&S application note 1GP39

(9) Dr. René Desquiotz "3GPP BS Tests with SMIQ" R&S application note 1GP41

(10) Ottmar Gerlach "IQ Wizard - IQ Signal Measurement & Conversion" R&S application note 1MA28

(11) Getting Started with ZVR, Part II, ZVR-CD ROM

(12) Josef Wolf " Measurement of Adjacent Channel Power on Wideband CDMA Signals" R&S application note 1EF40

(13) Josef Wolf "Measurement of Adjacent Channel Leakage Power on 3GPP W-CDMA Signals with the FSP" R&S application note 1EF41

7 Additional Information

Please contact **TM-Applications@rsd.rohde-schwarz.com** for comments and further suggestions.

8 Ordering information

Vector Signal Generator

Name of instrument	range	Ordering number
SMIQ03B	300 kHz to 3.3 GHz	1125.5555.03
SMIQ03HD	300 kHz to 3.3 GHz	1125.5555.33
Options:		
R&S SMIQB11	Data Generator	1085.4502.04
R&S SMIQB20	Modulation Coder	1125.5190.02
R&S SMIQB45	Digital Standard 3GPP	1104.8232.02
R&S SMIQ-B57	High ACLR for WCDMA 3GPP (2110 MHz to 2170 MHz)	1105.1831.02
R&S SMIQ-B60	Arbitrary Waveform Generator incl. WinIQSIM^{TM}	1136.4390.02

Spectrum Analyzer

Name of instrument	range	Ordering number
FSU3	20 Hz to 3.6 GHz	1129.9003.03
FSU8	20 Hz to 8 GHz	1129.9003.08
FSU26	20 Hz to 26 GHz	1129.9003.26
FSQ3	20 Hz to 3.6 GHz	1155.5001.03
FSQ8	20 Hz to 8 GHz	1155.5001.09
FSQ26	20 Hz to 26 GHz	1155.5001.26
Options:		
R&S FS-K72	WCDMA 3GPP Application Firmware BTS Code Domain Power Measurements for FSU	1154.7000.02

Vector Network Analyzer

Name of instrument	range	Ordering number
ZVR	9 kHz to 4 GHz	1127.8551.61

Power Meter

NRP		1143.8500.02
Options		
NRP-B2	2nd sensor input	1146.8801.02
NRP-B5	3rd and 4th sensor input	1146.9608.02
NRP-Z11	Power sensor 10 MHz to 8 GHz	1138.3004.02
NRP-Z4	USB adapter (passive)	1146.8001.02

Recommend accessories

R&S RDL 50	High Power Attenuator 20dB, 50 W, 0 to 6 GHz	1035.1700.52

ROHDE&SCHWARZ

ROHDE & SCHWARZ GmbH & Co. KG · Mühldorfstraße 15 · D-81671 München · P.O.B 80 14 69 · D-81614 München ·
Telephone +49 89 4129 -0 · Fax +49 89 4129 - 13777 · Internet: http://www.rohde-schwarz.com