WiMAX

Generating and analyzing 802.16-2004 and 802.16e-2005 signals

Application Note

This Application Note gives an introduction on measurements of WiMAX signals (802.16-2004 & 802.16e).

Subject to change – M. Weiss 07.2006 - 1MA97_0E

Contents

1 Overview

The new WiMAX radio technology – worldwide interoperability for microwave access – is based on wireless transmission methods defined by the IEEE 802.16 standard. WiMAX has been developed to replace broadband cable networks such as DSL and to enable mobile broadband wireless access.

Rohde & Schwarz offers a complete test solution for WiMAX applications by combining its R&S SMU200A, R&S SMJ100A or R&S SMATE200A Signal Generator with the R&S FSQ Signal Analyzer plus the appropriate options.

This Application Note is one of three papers dealing with the WiMAX standard, providing a guide for measurement of WiMAX signals. It describes all measurements from power and spectrum measurements down to bit pattern analysis and demodulation measurements.

Chapter 2 shows all measurements as required in the different standard documents, giving an overview of the complete range of measurements.

Chapter 3 gives an overview of the complete range of test & measurement equipment from Rohde & Schwarz for performing WiMAX measurements, starting with signal generators and ending with signal and spectrum analyzers.

Chapter 4 covers the topic of signal generation with all relevant aspects such as the generation of multiple signals, fading, etc.

Chapter 5 explains how to perform fundamental measurements on WiMAX signals – power measurement, crest factor and CCDF measurement, and spectrum, spectrum mask and ACP measurements.

Chapter 6 describes how to get a more detailed view of the signal using the demodulation capabilities of the signal analyzers or measuring signal FFT spectrum in gated mode.

The Application Note 1MA96

WiMAX – General information about the standard 802.16

[A] gives a detailed introduction to the WiMAX standards 802.16-2004 and 802.16e, explaining also details about OFDM and other general digital modulation aspects.

The Application Note1EF57

WiMAX: 802.16-2004, 802.16e, WiBRO – Introduction to WiMAX Measurements

[C] gives an overview of both standard and measurement, and also provides a short video sequence that shows the operation of Rohde & Schwarz instruments for WiMAX measurement.

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

- The R&S® SMU, SMATE and SMJ Vector Signal Generators are referred to as the SMU, SMATE and SMJ.
- The R&S® NRP Power Meter is referred to as the NRP.
- The R&S® NRP-Z11, NRP-Z21, NRP-Z51 and NRP-Z55 Sensors are referred to as the NRP-Z11, NRP-Z21, NRP-Z51 and NRP-Z55.
- The R&S® FSL, FSP and FSU Spectrum Analyzers are referred to as the FSL, FSP and FSU.
- The R&S® FSQ Signal Analyzer is referred to as the FSQ.
- The R&S® AFQ I/Q Modulation Generator is referred to as the AFQ.
- The R&S® FSH Handheld Spectrum Analyzer is referred to as the FSH.

2 Test & Measurement Requirements

The following table lists all measurement requirements and the corresponding paragraph in the standard.

How to read the table:
TX, ***EVM*** measurement for ***OFDM*** can be found in Chapter **8.3.**10.1.2.

	Standard	SC (8.1…)	SCa (8.2…)	OFDM (8.3…)	RCT OFDM Requirement		OFDMA (8.4…)
					SS (8.2…)	BS (8.3…)	
CQ	RSSI mean and standard deviation	.9.2	.2.2	.9.2	.6	---	.11.2
	CINR mean and standard deviation	.9.3	.2.3	.9.3	.7	---	.11.3
TX	Transmit power level control	Table 166	.3.5	.10.1	.16		.12.1
	Transmitter spectral flatness	---	---	.10.1.1	.17	.15	.12.2
	Transmitter constellation error (EVM)	.8.2.3 / Table 166	.3.4	.10.1.2	.18	.16	.12.3
	Transmitter channel bandwidth and RF carrier frequencies	Table 165 / 166	.3.1	.10.2			---
	Output power	.8.2.1	---	---			---
	Emission mask and adjacent channel performance	.8.2.2	.3.7 .3.8	---			---
	Maximum Ramp Up / Down Time	Table 165 / 166	.3.6	---			---
	RTG / TTG Performance	---	---	---	.21 .22	---	---
	Frequency and timing requirements	Table 165 / 166	.3.3	.12		.18	.14.1
	Transmit spectral mask	Chapter 8.5.2	Chapter 8.5.2	HUMAN 8.5.2	.20	.17	Chapter 8.5.2
RX	Receiver sensitivity		.3.9	.11.1	.2	.2	.13.1
	Receiver adjacent and alternate channel rejection	Table 165 / 166	.3.11	.11.2	.8 / .9	.7 / .8	.13.2
	Receiver maximum input level	---	.3.10	.11.3	.10	.9	.13.3
	Receiver maximum tolerable signal	---	---	.11.4	.1	.1	.13.4
	Receiver image rejection	---	---	.11.5	.11	.10	---

3 R&S WiMAX Test Equipment Product Portfolio

Signal Generators and Modulation Sources

Rohde & Schwarz provides a wide range of signal generators capable of generating WiMAX 802.16-2004 and 802.16e signals for R&D and production testing of WiMAX modules or WiMAX receivers:

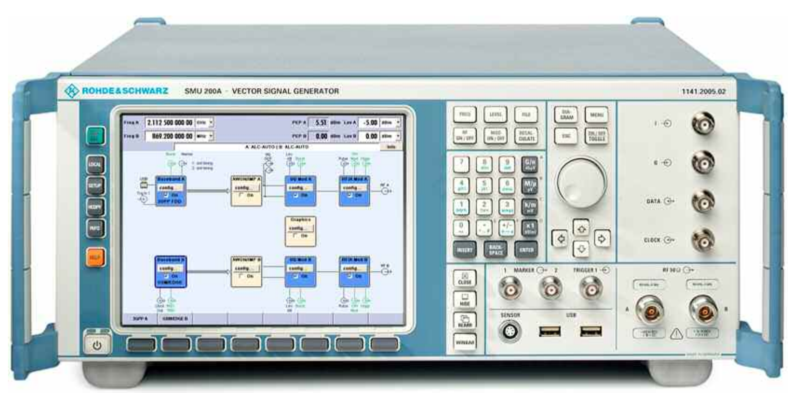
- As top-class, the **SMU200A** *Vector Signal Generator* can combine two complete RF and baseband paths at a frequency up to 6 GHz in the first path and 3 GHz in the second path. Together with the built-in **SMU-B13** *Baseband Main Module* and the **SMU-B10** (64 Msamples) **/** **SMU-B11** (16 Msamples) *Baseband Generators* and the **SMU-K49** *Digital Standard 802.16-2004* option, it is the ideal instrument for generating two independent 802.16-2004 signals to perform all the necessary receiver tests including alternate channel tests − with only a single instrument.

  With up to 64 OFDMA bursts in one frame, up to 511 frames, multiple-zone OFDMA signal creation and individual configuration of any parts of the signal (preamble, MAC layer, burst levels, etc), this instrument covers all needs for generating a WiMAX signal. Furthermore, with the SMU's two path option and straightforward interface it is very easy to create an interfering signal such as a CW, another WiMAX signal or another digitally modulated interferer in combination with the desired WiMAX signal to set up receiver tests such as adjacent channel rejection. An I/Q modulator with 200 MHz RF bandwidth and up to 64 Msamples I/Q memory depth make the SMU future-proof.

  The SMU also offers an internal **SMU-B14 / SMU-B15** *Fading Simulator* option to create realistic fading profiles. This ability is critical for testing device performance in a mobile environment. The SMU fading option comes preconfigured with fading profiles specified in many of the wireless standards, but user-defined fading profiles can easily be set up and stored.

  Outstanding signal performance, a very intuitive graphical user interface (GUI) based on a block diagram signal flow user interface, 1-step signal creation, and very fast remote control of GPIB and LAN are only some of the key features of this instrument.

  Due to a standard IEEE and LAN remote control interface and their very high speed, all Rohde & Schwarz signal generators provide the ideal solution for fast, high-performance automated tests in lab and production environments.



- The **SMJ** *Vector Signal Generator* offers the same outstanding features and digital standard options as the SMU. The SMJ differs from the SMU, however, because only one path is possible and no fading options are offered. The unit is available as a 3 GHz or 6 GHz model.

- The **AFQ100A** *I/Q Modulation Generator* with 300 MHz sampling rate and up to 1 Gsample I/Q memory can generate in combination with the **AFQ-K249** *Digital Standard 802.16-2004* option any kind of WiMAX signal. Together with the built-in differential analog I/Q outputs and the **AFQ-B18** *Digital I/Q Outputs* option, it makes an ideal instrument for any kind of R&D tests including module and component tests on analog or digital level.

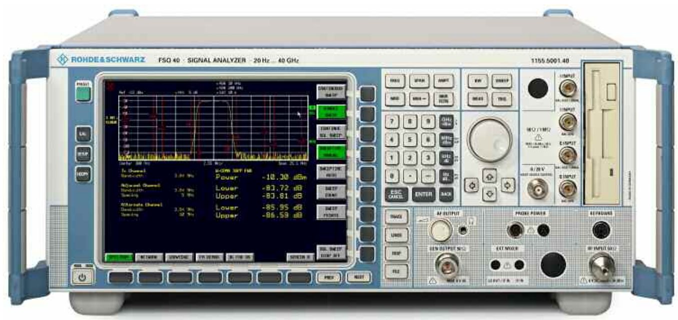
Signal Analyzers, Spectrum Analyzers

Rohde & Schwarz offers a wide range of signal and spectrum analyzers for WiMAX measurements.

- The **FSQ** *Signal Analyzer* combines an RF spectrum analyzer with a signal analyzer and baseband analyzer in one box. As a spectrum analyzer, the FSQ offers excellent phase noise, adjacent channel performance and a low noise floor, just to name a few of its outstanding features. As a signal analyzer, the FSQ offers the highest accuracy and, with the FSQ-K92 option, the analysis of 802.16 fixed OFDM signals. In addition to the required transmitter measurements such as EVM and spectrum flatness, in combination with the **FSQ-K92** *Application Firmware WIMAX (802.16-2004)* software option, it is possible to analyze WiMAX standard signals (802.16-2004) to maximum accuracy. All important signal parameters (EVM, constellation diagram, frequency and phase errors, bit stream, etc) are available in graphical or numerical and list form. Due to a standard IEEE and LAN remote control interface and the signal analyzer's very high analysis speed, this option is the ideal solution for fast, high-performance automated tests in lab and production environments. **FSQ-K93** *Application Firmware for WiMAX IEEE 802.16e and WiBRO* offers an easy-to-use, high-performance and flexible analysis of

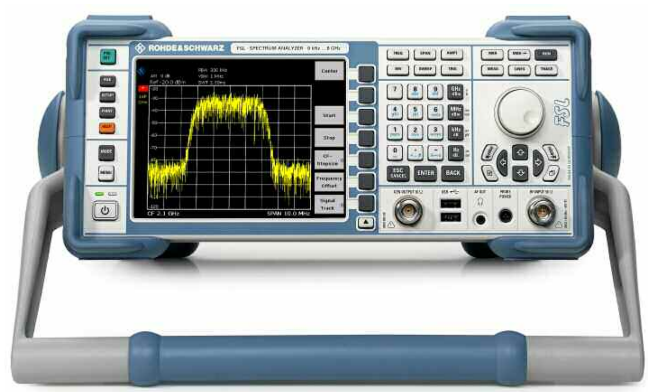
802.16e and WiBRO signals. The operation is very easy, and features such as automatic configuration exchange with the SMU/SMJ and remote control via a LAN interface result in fast and reliable analysis for WiMAX 802.16e and WiBRO signals.
Together with the **FSQ-B71** *Baseband Inputs* hardware option, analog I/Q signals can also be analyzed with high performance.
This is all offered as a single-box solution with IEEE/IEC and LAN bus interface[1)], ready for production or R&D usage.

[1)] FSQ-K93 offered as external software solution.



- The **FSU** *Spectrum Analyzer* is the ideal choice for measurement tasks where a vector analysis of the WiMAX signal is not needed.
  Except for WiMAX modulation analysis, it provides high performance in RF and measurement speed.

- The **FSL** *Spectrum Analyzer* is an extremely lightweight and compact analyzer with a wide range of applications in development, service and production. It offers functions that up to now have only been provided by high-end spectrum analyzers and therefore has an excellent price/performance ratio. With a tracking generator up to 6 GHz and a demodulation bandwidth of 20 MHz as well as a graphical user interface similar to that of the FSU and the FSP, it is the best choice for RF and modulation measurement at everyone's desk or in production.



- The **FSP** *Spectrum Analyzer* is an instrument ideal for production use due to the fast IEEE and LAN operation, high RF performance, very high measurement speed - vital for production line use - plus many more features.

- The **FSH3/6** *Handheld Spectrum Analyzer* is a handy, robust and portable spectrum analyzer for rapid and cost-effective signal tests. It is ideal for fast tests in field use, providing features such as channel power measurement or direct connection to an FSH-Zx power measurement sensor. It can also be operated via RS232 or USB interface with the **FSH-K1** *Remote Control* option.

Power Meters, Additional Equipment

- The versatility of the novel **NRP** *Power Meter* family is due to the newly developed sensors. These sensors are intelligent standalone instruments that communicate with the base unit or a PC via a digital interface. The SMART SENSOR TECHNOLOGY^{TM} sets new standards in terms of universality and accuracy. A wide range of different sensor types are available.

Certification Test System

WiMAX products need to pass a threefold certification test process: Radio conformance testing (RCT), protocol conformance testing (PCT) and interoperability testing (IOT). Rohde & Schwarz is one of two RCT system vendors to be selected by the WiMAX forum (www.wimaxforum.org). The **R&S TS8970** *Test System* offers all required radio conformance tests and is based on the WiMAX application firmware of the SMU and FSQ in particular. It is controlled by RS-PASS (parametric system software), the well known software from the **R&S TS8950** *RF Conformance Test System* and its derivatives.

4 WiMAX Receiver Measurements

In order to test a WiMAX amplifier or other passive components or to perform WiMAX receiver tests, WiMAX test signals must be generated.

The built-in SMU-K49 software option for the SMU, SMJ and SMATE Signal Generators makes it possible to generate a WiMAX test signal, including fully configurable frame content, MAC header, channel coding, etc. With all these possibilities, any kind of standard-compliant and even non-standard-compliant signals can be generated.

Setting up a WiMAX Test Signal

The SMU-K49 option offers a very easy-to-use graphical user interface (GUI) within the SMU, providing all settings necessary to set up a WiMAX signal (OFDM and OFDMA).

The images below show the GUI for setting up a WiMAX OFDM and OFDMA signal.

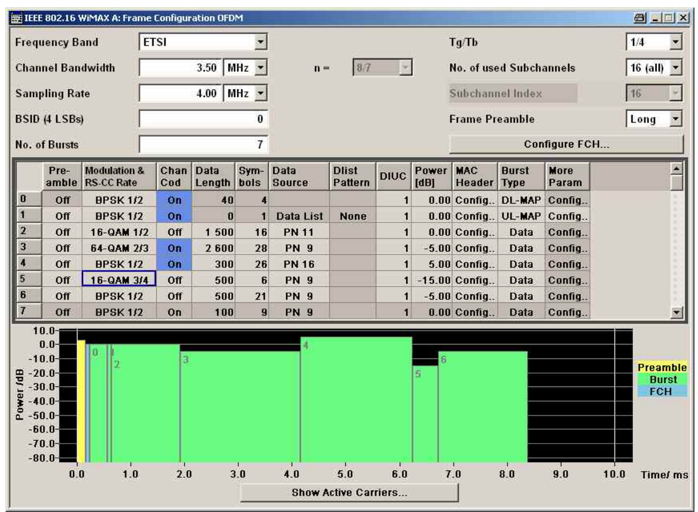


Image 1 – SMU-K49 user interface – OFDM

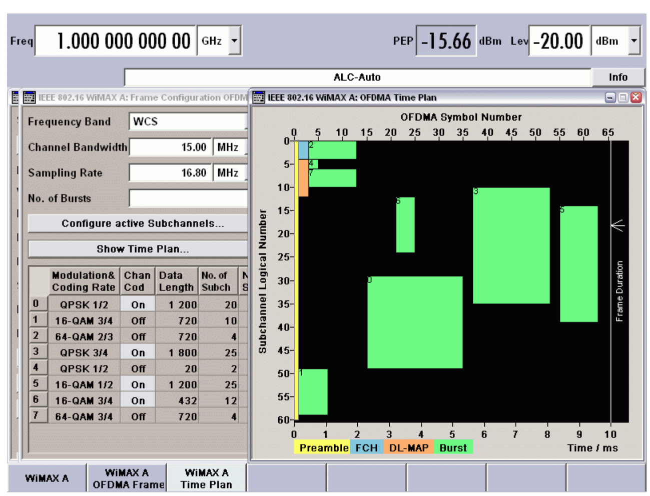


Image 2 – SMU-K49 user interface – OFDM

Setting the Signal Level

For WiMAX signals, setting the level differs from the normal level setup.

The level (**LEV** display) that is set in the user interface can be either

- the level of the preamble

or

- the level of the FCH/burst.

The level of the complete burst (preamble, FCH and burst) cannot be set directly on the SMU.

The figure below shows the graphical user interface (GUI) of the SMU and the corresponding areas within the burst where the level is adjusted. Each modification within the tables can be immediately seen in the graphical display, and any setting conflicts will be indicated immediately during the data entry phase. Also, color coding and frame limit lines help a lot during the "design phase" of the signal.

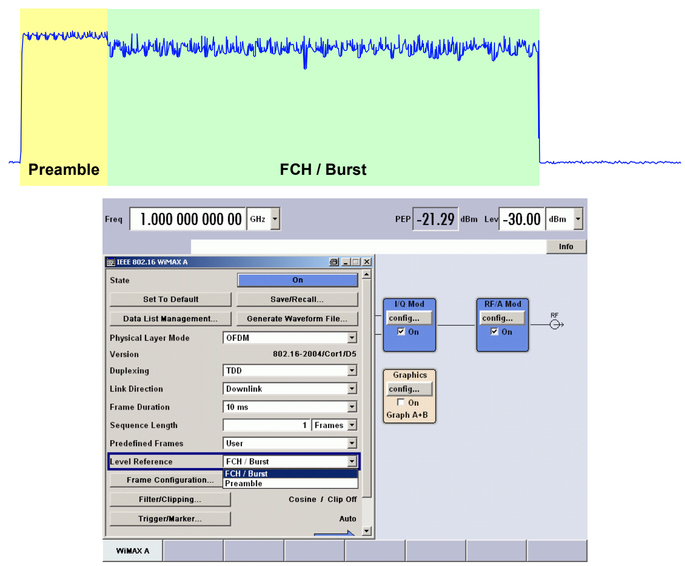


Figure 1 – SMU level setup

	The following setups and measured values correspond:	
	SMU	**FSQ**
	Lev when Level Reference = ***Preamble***	- RSSI - Result Summary values
	Lev when Level Reference = ***FCH / Burst***	- Burst Power - Result Summary values

!	As the Lev is not the RMS level of the complete signal (or the complete burst), the difference between PEP and Lev is not the crest factor of the signal as e.g. for a normal IQ data file. The crest factor of the complete signal can only be calculated directly from the displayed values on the SMU if only bursts with BPSK and 0 dB level are active.

Predefined Frame Setups

There are no special test signals defined in the 802.16 standard (as you may know from e.g. 3GPP standards).

The standard 802.16-2004 only defines some **Test Messages** for measuring receiver sensitivity (see [1], 8.3.11.1).

Three different lengths of test messages are defined (**Short** with 288 data bytes, **Mid** with 864 data bytes and **Long** with 1536 data bytes), and all test messages can be recalled for every modulation type and coding rate very easily inside the SMU.

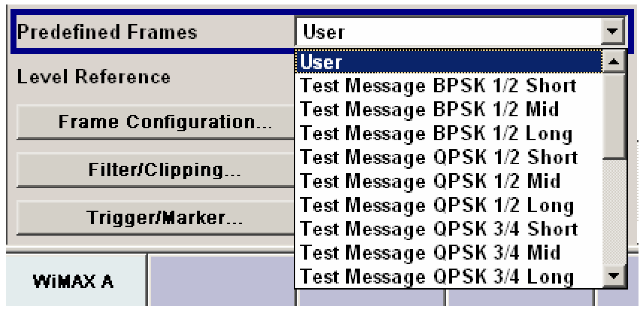


Image 3 – Predefined test message frames

Creating Downlink and Uplink Simultaneously

For some applications such as repeater tests, it may be important to generate a downlink (DL) and an uplink (UL) signal at the same time.

Therefore, the SMU provides the possibility to generate two baseband signals at the same time when using two baseband signal generators inside one physical box. Both generators can be triggered simultaneously for providing an exact timing relation between the two signals.

The following table shows the important settings on both baseband (BB) generators for simultaneous DL and UL signal generation.

Parameter	BB A (DL)	BB B (UL)
Frame Duration	x ms	x ms (= BB path 1)
Downlink Subframe Duration	---	required UL offset
Trigger Mode	any	Armed retrigger
Trigger Source	---	Internal (baseband A)

The following figure shows the relations described in the above table.

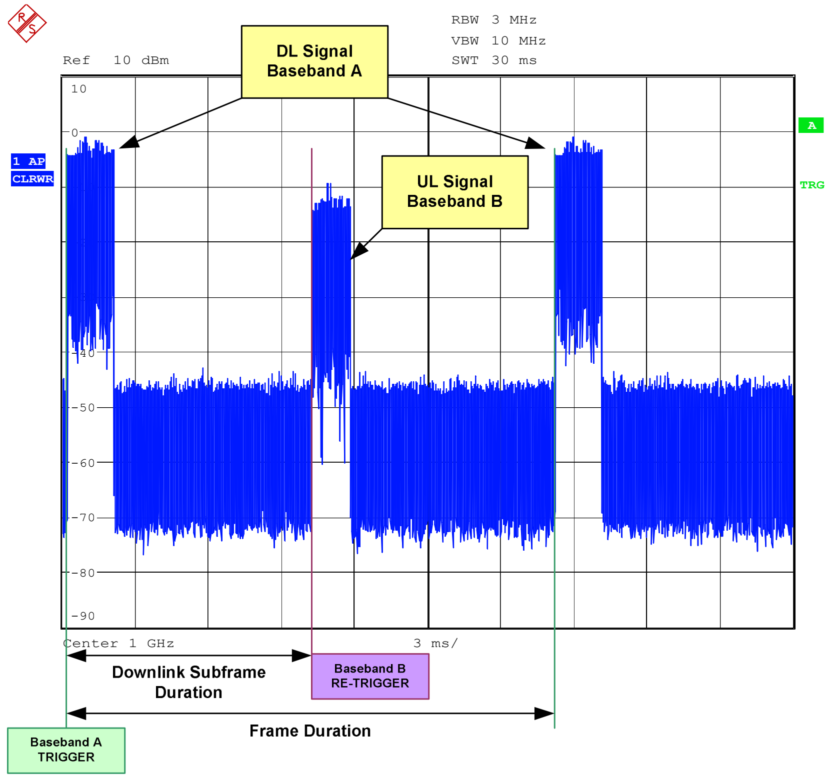


Figure 2 – Simultaneous DL and UL generation

!	If baseband B is triggered by baseband A and the settings from baseband B are changed, baseband B will stop. In order to restart baseband B, stop and restart baseband A.

TDD Mode

For TDD mode (DL and UL at the same frequency), the easiest way is to use two baseband generators inside the SMU and combine them digitally.

The image below shows the setup of the SMU.

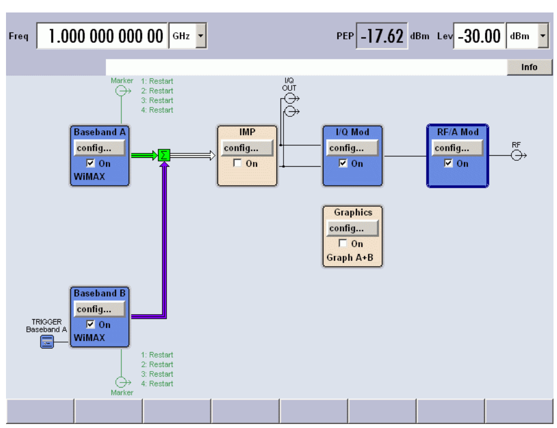


Image 4 – DL and UL – TDD

FDD Mode

For FDD mode (DL and UL at different frequencies), there are two possible settings on the SMU:

1. Combine both baseband signals, using a digital frequency offset in baseband A and / or B (**"narrow" mode**).
2. Use two different RF paths **("wide mode")**.

UL and DL signal with same RF generator ("narrow" mode)

If you combine both signals in the baseband, you can specify the frequency offset for the signal from Baseband B.

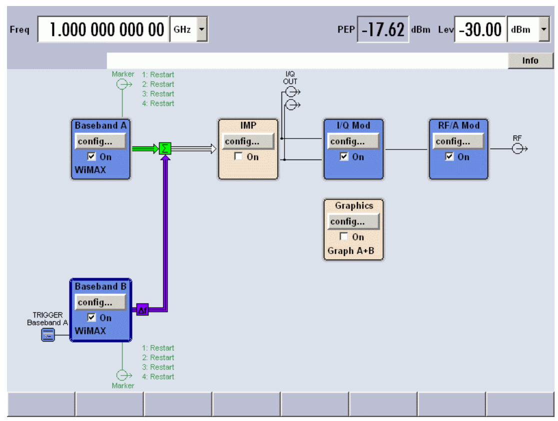


Image 5 – DL and UL - FDD "narrow"

If you set the offset frequency, the following rule must match:

> The maximum offset value f_{offset} for the baseband offset frequency is ± 40 MHz, reduced by half of the used signal or RF bandwidth f_{used} (which can be determined by the ARB clock rate):
>
> $$-40\text{ MHz} + (f_{used} / 2) \leq f_{offset} \leq +40\text{ MHz} - (f_{used} / 2)$$
>
> If both signals have the same used bandwidth f_{used}, the maximum possible center frequency spacing $f_{spacing}$ of both signals is
>
> $$f_{spacing,\,max} = 80\text{ MHz} - f_{used}$$

The following figure illustrates the above formula. A frequency offset can also be set for both channels in order to shift baseband A down and baseband B up in frequency.

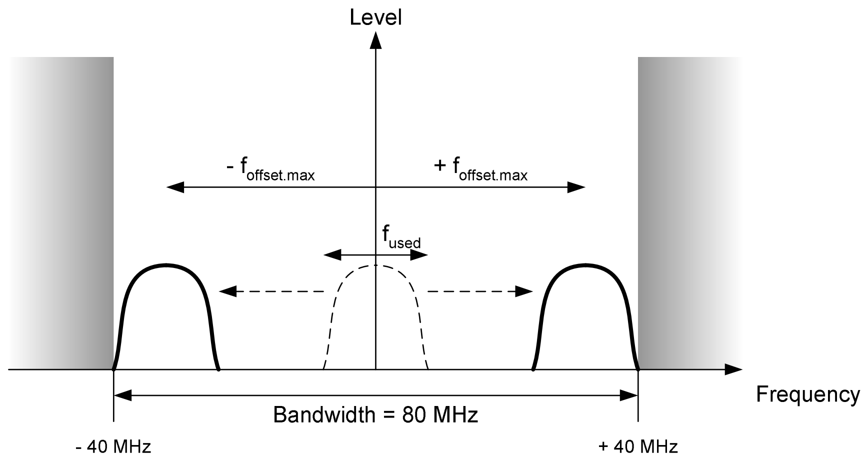


Figure 3 – Maximum baseband offset frequency for SMU setup

UL and DL signal with different RF generator ("wide" mode)

If the spacing for both downlink and uplink signals exceeds the maximum possible spacing, it is necessary to use two different analog I/Q modulators and RF generators and combine the signal with an external RF signal combiner.

With this combination, the only limit for the carrier spacing is the maximum RF frequency of the signal generator.

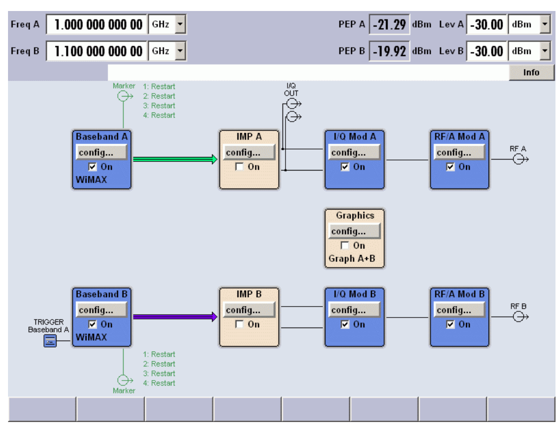


Image 6 – DL and UL - FDD "wide"

Applying Fading to the WiMAX Test Signal

In order to check the performance of a WiMAX receiver − especially for the mobile standard 802.16e − it is necessary to check the performance under conditions of fading.

Fading occurs not only when the route between the transmitter and the receiver (also called channel) is a direct, undisturbed path (the "line of sight" (LOS) path), but also when signal levels are obtained over additional paths (reflections on walls, etc). In addition, the distance between transmitter and receiver may vary (as e.g. the receiver is moving), which may result in a Doppler shift of frequency.

The SMU Signal Generator's built-in hardware options **SMU-B14** (Fading Simulator) and **SMU-B15** (Fading Simulator Extension) enables the instrument to apply fading with up to 40 paths to a WiMAX signal generated by the digital baseband section of the signal generator or provided by an external I/Q signal generator.

Currently (04/2006), no standard fading profile is defined for WiMAX. Up to now, the **Stanford University Interim (SUI)** model defines six different scenarios (SUI-1 to SUI-6), but 3GPP fading models can also be used for testing. The technical working group of the WiMAX forum is currently discussing channel models for mobile WiMAX (16e). Some possible profiles may be based on the 3GPP fading models or on the SUI model.

The image below shows a typical fading configuration for a multipath environment as it is commonly used for WLAN testing.

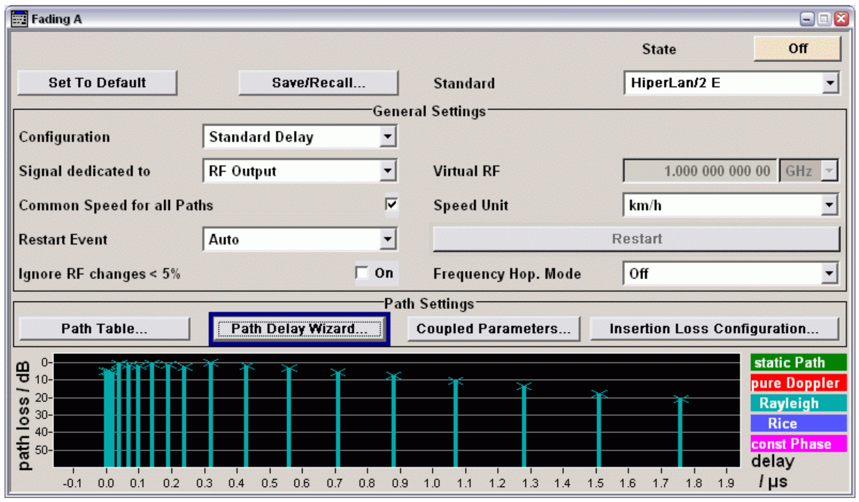


Image 7 – Typical fading setup

5 Analyzing WiMAX Signals − Power & Spectrum Measurement

For all the measurements described in this chapter, the following signal parameters are assumed.

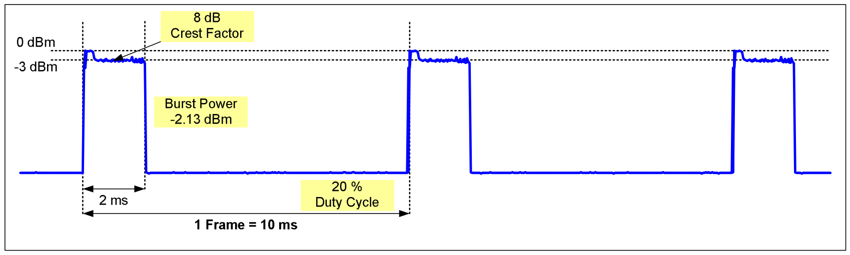


Figure 4 – Power profile of WiMAX signal

The signal contains a burst with a duration of 2 ms and a gap with a length of 8 ms (where no signal is present). The total frame length is exactly 10 ms.

- Frame Duration: 10 ms
- Burst Length: approx. 2 ms
- Idle Time: 10 ms − Burst Length; approx. 8 ms

Power Measurements Using NRP Sensors

The easiest way to measure some basic parameters such as the power of a WiMAX signal is to use a power measurement sensor.

For power measurements, different sensor types are available. They are suitable for certain measurement tasks.

- ***Thermoelectrical sensors*** such as the ***NRP-Z51*** Thermal Power Sensor are the most precise power sensors but cannot show fast signal changes over time. As their measurement principle is based on the heating of a thermoelectric cell, the RMS measurement value is taken with a frequency of around 1 kHz.
  Therefore a thermoelectrical sensor is the best choice for
  - maximum-precision power measurements of non-pulsed signals
  - pulsed signals with a known duty cycle.
- ***Diode sensors*** can acquire fast signal changes (the sampling frequency is around 100 kHz or even higher), but may have problems with signals having high crest factors, which are caused by the non-quadratic behavior outside the diode operation range. With the three-stage diode design of the ***NRP-Z11*** or ***NRP-Z21*** Average Power Sensors, this problem is solved, since three diodes for three different power ranges are automatically combined. Furthermore, a diode sensor is much more sensitive than a thermoelectric sensor, which results in better measurement performance at low signal levels.
  For this reason diode sensors are the best choice for
  - having a look at the power-vs.-time behavior of the signal
  - measuring the power in certain areas of the signal
  - measuring the burst power of signals with unknown duty cycle
  - measuring the total power of the signal.

There are two ways of performing measurements with the NRP-Zxx power sensors:

- Using them together with the ***NRP*** Power Meter and ***control unit***.
- Connecting the sensors with an ***USB adapter to the PC*** and using e.g. NRPView [11] for the measurements.

Measuring the power of a WiMAX signal with a power sensor involves two tasks:

1. Measure the ***total (burst) power*** (only one numerical value).
2. Measure the ***power-vs.-time graph*** (values over time).

Total Power, Burst Power, Duty Cycle

A typical WiMAX signal is not continuous, but has a ***bursted structure***. This leads to certain areas over time where no signal level is present. As a ***thermal power sensor*** takes the average power over a certain time that is longer than the frame length of the signal, areas with no signal present are also included in the RMS power calculation.

To overcome this problem, which leads to wrong power measurement results, the ***duty cycle*** must be included in the RMS power calculation. The duty cycle indicates how much percent of the signal over time is occupied with the signal. In the example above, the 10 ms frame contains a 2 ms burst, which leads to a duty cycle of 20 %. This value can be entered e.g. in the NRP base unit, and the measured power will then be adjusted by this correction factor.

▶ For a signal with a duty cycle of D (0 to 1), the correction factor R can be calculated with $R = 10 \cdot \log_{10}(D)$

The following image shows a burst power measurement with an NRP-Z51 thermoelectric measurement sensor (in ContAV measurement mode), measuring the total signal power (left) and the (correct) burst power (right) by setting the correct signal duty cycle. The correction factor calculates to $10 \cdot \log_{10}(^{20}/_{100}) = 7$ dB.

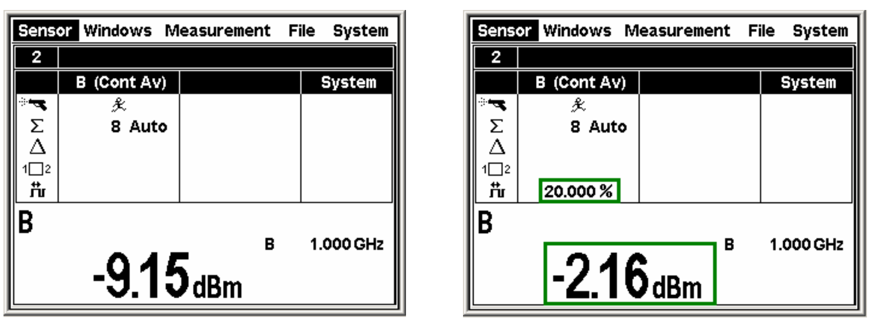


Image 8 – Power measurement using the NRP-Z51

The problem with this type of measurement is that without an exact knowledge of the duty cycle, a precise power measurement of the burst is not possible as the correction factor for the pulse/pause ratio (the duty cycle) is unknown.

Therefore, for measurements of the burst power on signals with unknown or changing duty cycles, a diode sensor such as the NRP-Z11 is the better choice.

Power Over Time

Another method for measuring power is the power-vs.-time measurement, which is called ***Scope Mode*** inside the NRP base unit. In this operating mode, you can easily determine the burst structure of the signal and make measurement over certain areas of the signal.

The figure below shows a measurement with the NRP-Z11 diode sensor, measuring the power of the complete frame and the power of the burst. It is very easy to move the two markers (marked green in the figure below) and determine the exact power within the two limit lines.

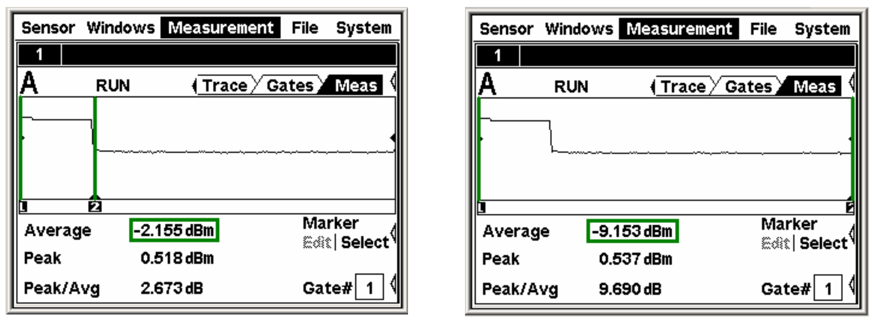


Image 9 – Scope Mode measurement using the NRP-Z11

The problem with this measurement is that you have to set the limits for the burst power measurement manually. This is not possible if e.g. the duty cycle changes.

For a precise automatic burst power measurement without knowing the exact duty cycle, the Burst Mode is available inside the diode sensors.

Burst Mode

By using the Burst Mode (available with diode sensors), the sensor automatically detects the burst, so entering the burst duration or using an external trigger is not required.

The image below shows how to activate the burst measurement function and the resulting power level, which is equal to the burst power.

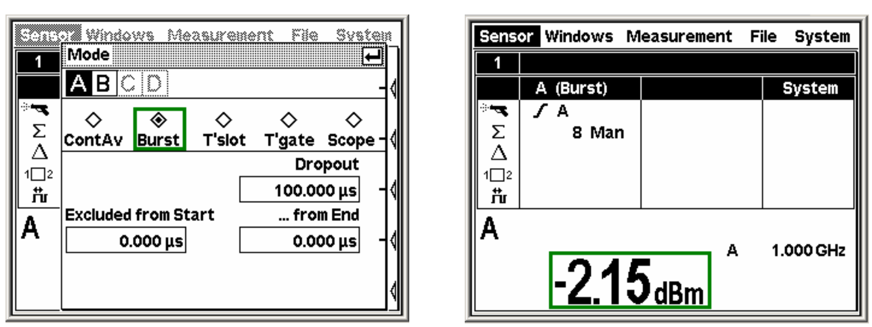


Image 10 – Burst Mode measurement using the NRP-Z11

Power Measurements Using a Spectrum Analyzer

As a typical WiMAX signal is bursted, the best way to measure the power of a WiMAX signal is in time domain.

Correct RBW Setup

As the WiMAX signal in time domain is detected at the full resolution bandwidth (RBW), you have to set the RBW to a value at which the complete RF spectrum fits into this bandwidth.
Take also into account that the RBW at the analyzer is the ***3dB bandwidth***, meaning that the filter attenuation goes down to 3dB of the peak value at the filter edges.

The following figure shows a WiMAX signal with 2 MHz bandwidth (blue) and the shape of a 2 MHz standard filter (black) and a 2 MHz channel filter (green).

As the edge of the standard 2 MHz filter decreases by roughly 3 dB at the edges of the WiMAX signal spectrum, the time domain power is not measured correctly anymore − even if the signal bandwidth is less than 2 MHz as used in this example (misreading: 0.5 dB in this example). As you can see, the 2 MHz channel filter shows a much lower loss over the complete filter bandwidth, which leads to a correct power reading.

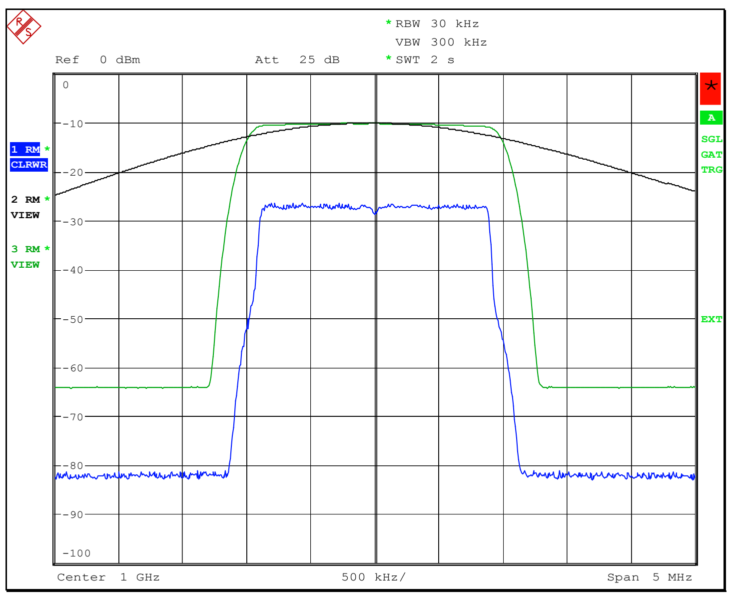


Figure 5 – Different RBW filter types for time domain power measurement

!

Please make sure that the measurement bandwidth is high enough to measure the complete bandwidth of the signal.

To make a correct time power measurement, choose a normal filter with a RBW of ≈ 5 x BW_{signal} or a channel filter with RBW ≥ BW_{signal}.

Time Domain Power Measurement

The time domain power function can be easily used to measure the power in different areas of the burst (e.g. in the preamble and the data part).

You can very easily evaluate the power in certain ranges of the burst.

[PRESET]	set instrument to default state
[FREQ] [*CENTER*] {value}	set signal frequency
[SPAN] [*ZERO SPAN*]	switch to time domain
[TRIG] [*EXTERN*]	use an external trigger cable for optimum measurement setup
[AMPT] [*REF LEVEL*] {value}	set level to maximum expected RF level
[SWEEP] [*SWEEP TIME*]	set the sweep time to display one or more bursts and gaps
[MEAS] [*TIME DOMAIN*]	switch on time domain measurement
[TRACE] [*DETECTOR*] [*DETECTOR RMS*]	switch on the RMS detector for optimum measurement
[*START LIMIT*] / [*STOP LIMIT*]	use the limit lines to evaluate power in certain areas

The following figure shows a typical time domain measurement on a WiMAX OFDM signal with a power measurement of the preamble:

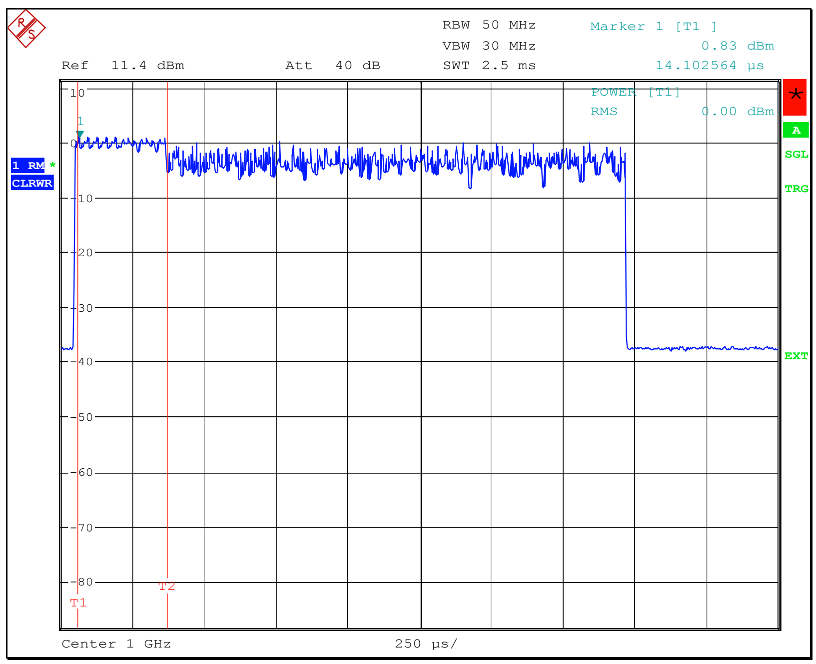


Figure 6 – Typical time domain measurement - Preamble Power

Spectrum Measurements

Correct RBW Setup

In contrast to the time domain power measurement, the resolution bandwidth for frequency domain measurement must be set to a value where the signal shape to be measured is not influenced by the RBW filter of the spectrum analyzer. As you can see in e.g. [1], 8.5.2, the RBW for measuring the transmit spectral mask must be set to 100 kHz.

To express the "steepness" of a signal, the ***shape factor*** (SF) was introduced. The SF is the relation between the 60 dB bandwidth and the 3 dB bandwidth of a filter shape curve (also other values for both BW can be defined, but $SF_{60/3} = B_{60dB} / B_{3dB}$ is the most popular factor). The lower the factor, the steeper the filter (an ideal rectangular filter has the same value for 60 dB and 3 dB BW, so the shape factor would calculate to 1).

> ▶ For measuring the spectral shape of a signal, set the RBW to a maximum of 10 % of the occupied bandwidth and consider that the RBW filter's shape factor must be low enough so that it does not influence the shape of the signal, which may result in a lower RBW to be set.

The following image shows the measurement of a WiMAX signal (2 MHz bandwidth) using a 200 kHz RBW filter (blue curve) and a 10 kHz RBW filter (black curve). As can clearly be seen, the blue curve does not show the correct spectral shape of the signal, as the shape factor of the WiMAX signal is much lower than the shape factor of the RBW filter.

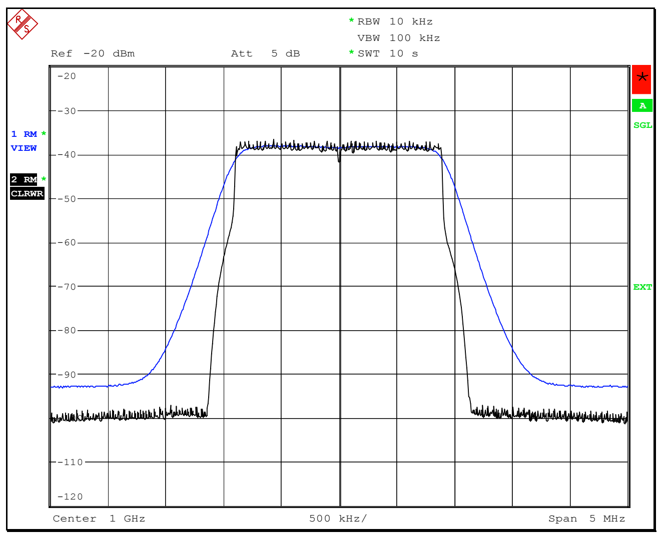


Figure 7 – RBW influence on signal shape

Measuring the shape factors results in:

- **WiMAX**
  $B_{3\,dB}$ = 1.798 MHz, $B_{60\,dB}$ = 2.246 MHz → $SF_{60/3}$ = 1.25
- **RBW filter 10 kHz**
  $B_{3\,dB}$ = 9.91 kHz, $B_{60\,dB}$ = 53.45 kHz → $SF_{60/3}$ = 5.39
- **RBW filter 200 kHz**
  $B_{3\,dB}$ = 196.5 kHz, $B_{60\,dB}$ = 1.898 MHz → $SF_{60/3}$ = 9.66

Measuring the Signal Spectral Shape

First, you need to have a look at the spectral shape of the signal, which means you have to measure the bandwidth, see the filter influence or determine the spectrum emission mask criteria of the signal.

To measure the spectral shape of a bursted signal, one basic calculation must be performed in order to set up the analyzer correctly.

With a normally swept spectrum analyzer (as are all Rohde & Schwarz analyzers), the spectral shape versus frequency is measured by setting the mixing frequency to a certain frequency, detecting the signal (maximum peak, minimum peak, RMS, etc), and then moving forward to the next frequency point. Typically, an FSQ uses 625 points for one complete sweep (can be determined and set via **[SWEEP]** [*SWEEP COUNT*]) and performs this complete measurement in the time set via the sweep time (**[SWEEP]** [*SWEEPTIME MANUAL*]).

To measure the total power of a bursted signal in spectrum domain, the sweep time must be set to

- a minimum of T_{Sweep} for max. or min. peak detection
- an integer multiple of T_{Sweep} for RMS detection

where

$$T_{Sweep} = N_{Sweep\ points} \cdot T_{Signal\ Cycle}$$

- $T_{Sweep,Minimum}$ is the minimum sweep time to be set for a correct signal measurement
- $N_{Sweep\ points}$ is the number of sweep points (default 625 for the FSQ)
- $T_{Signal\ Cycle}$ is the time for one complete signal repetition (typically identical to the frame duration).

For the example above ($N_{Sweep\ points}$ = 625 and $T_{Signal\ Cycle}$ = 10 ms), we get $T_{Sweep,Minimum}$ = 625 · 0.01 s = 6.25 s.

- If the selected sweep time is too short, the global maximum and minimum peak power may not be detected, as the measurement may only take place within the burst (where the min. peak is detected incorrectly) or within the pause (where the max peak is detected incorrectly). Also, the RMS detection may fail.
- If the selected sweep time is too long, max. peak is detected correctly, but the RMS value of the signal may be detected incorrectly, since e.g. two bursts occur but only one pause is detected.
- Min. peaks cannot be detected, since − for a correct sweep time setup − always min. values within the signal gaps are detected.

The figure below shows too short a setting of the sweep time and the resulting errors in detection (detector: max. peak).

An example of too long a measurement time is given in the section entitled

Crest Factor Measurement with FSQ-K92.

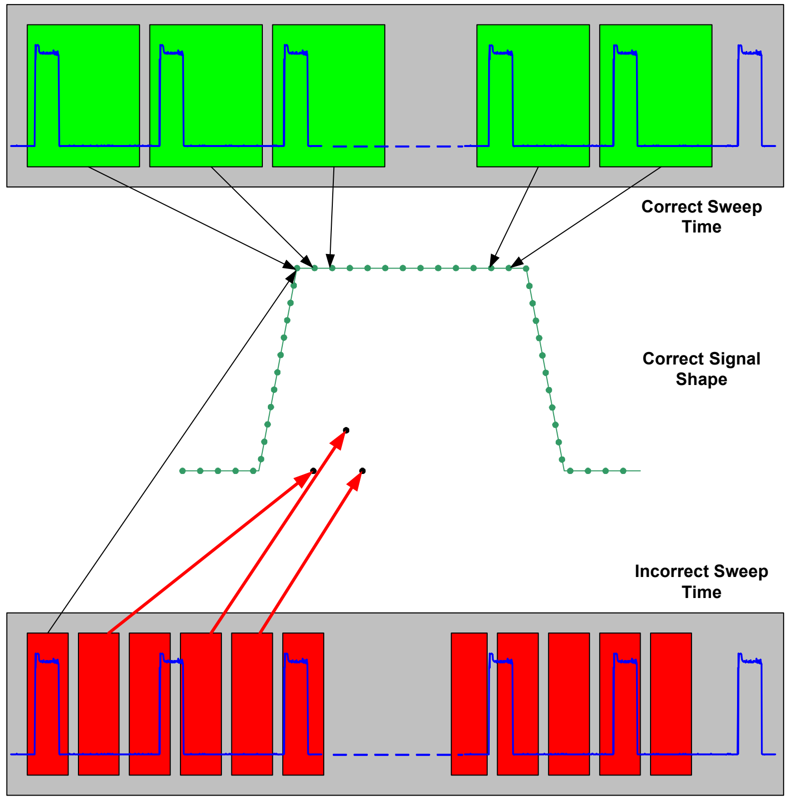


Figure 8 – Effects of correct and incorrect sweep time setup

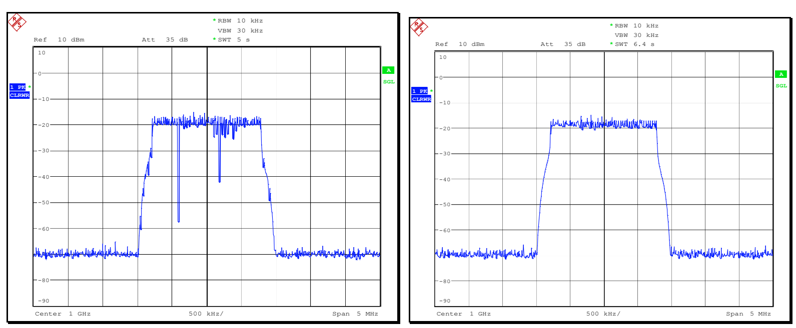


Image 11 – Results of incorrect (left) and correct (right) sweep time setup

The disadvantage of this method is that the gaps are also included in the power calculation, which leads to a lower power within the spectrum when using RMS detection (as both burst and gap are included in the RMS calculation). The next section will describe how to overcome this problem.

Gating

To overcome the problems described above, it is possible to analyze only that ***part of the signal*** (in time domain) that contains the spectral power. This is done by using the ***gating mode*** of the spectrum analyzer. The following table shows how to set up the instrument for gated measurement.

[PRESET]	set instrument to default stats
[FREQ] [*CENTER*] {value}	set signal frequency
[SPAN] {value}	select a span for viewing the complete signal
[TRACE] [*DETECTOR*] [*DETECTOR RMS*]	switch on RMS detection
[AMPT] [*REF LEVEL*] {value}	set level to maximum expected RF level
[BW] [*RES BW MANUAL*] {value}	set the bandwidth you want to use for the measurement
[TRIG] [*EXTERN*] or [*IF POWER*]	switch to trigger at burst start
[TRIG] [*GATE SETTINGS*]	switch to gate configuration
[*SWEEPTIME*]	set the sweep time to see the gated signal in detail
[*GATE DELAY*]	set the gate start to the start of the signal
[*GATE LENGTH*]	move the gate length to cover the complete signal to be analyzed
[*GATE TRIGGER*]	switch on gated trigger mode
[SWEEP] [*SWEEP TIME MANUAL*] {value}	set the sweep time (see formula below)

The following image shows how to set the gate and the resulting spectral shape curve.

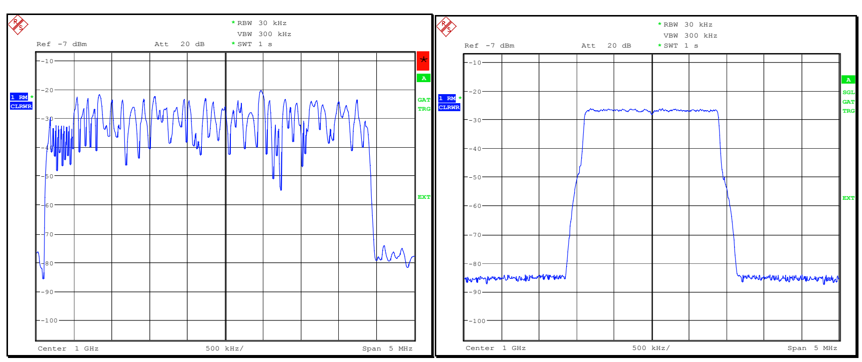


Image 12 – Gate in time domain and resulting spectrum

As with gating, the spectrum analyzer only has to perform the measurement when the signal is on, which results in a ***shorter measurement time***. For the standard example used in this application note (burst time 2 ms, gap length 8 ms), it can be shown by calculation that the measurement can be performed five times faster when using gating.

To measure the total power of a bursted signal in spectrum domain using gating, the sweep time must be set to a minimum

$$T_{Sweep} = N_{Sweep\ points} \cdot T_{Burst}$$

- $T_{Sweep,Minimum}$ is the minimum sweep time to be set for a correct signal measurement
- $N_{Sweep\ points}$ is the number of sweep points (default 625 for the FSQ)
- T_{Burst} is the length of the burst (or the part of the burst you want to analyze)

Measuring the Occupied Bandwidth (OBW)

An important characteristic of a modulated signal is its occupied bandwidth. In a radio communications system for instance, the occupied bandwidth must be limited to enable distortion-free transmission in adjacent channels. The occupied bandwidth is defined as the bandwidth containing a defined percentage of the total transmitted power. A percentage between 10 % and 99.9 % can be set on the FSQ ([**MEAS**] [*OCCUPIED BANDWIDTH*] [*% POWER BANDWIDTH*].

The figure below shows the measurement of the OBW (99 %).

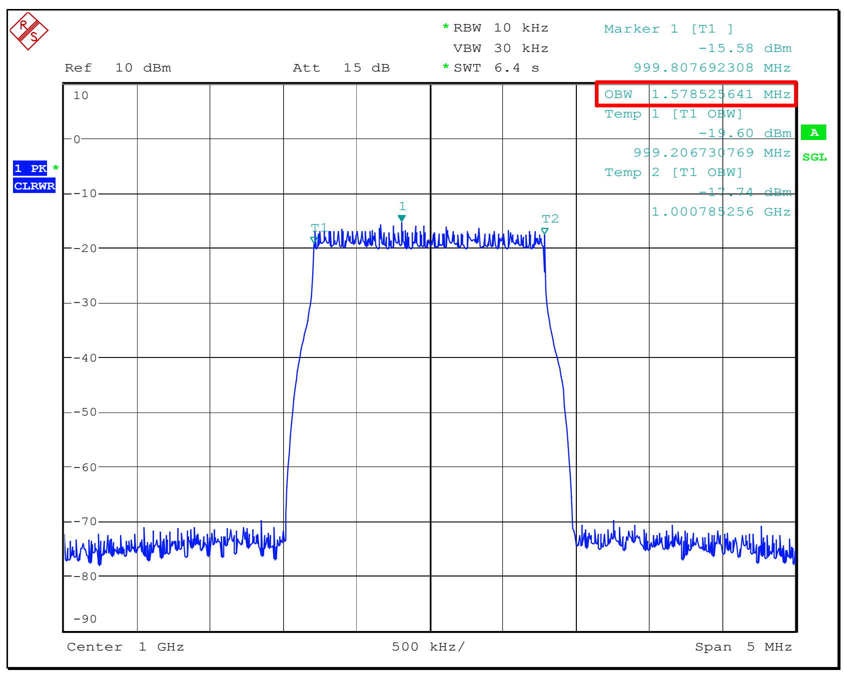


Image 13 – Measurement of the OBW

!

Please make sure that the measurement time for determining the OBW is set in accordance with the aforementioned instructions.

Spectrum Emission Mask

The 802.16-2004 standard defines a transmit spectral mask for unlicensed bands (see [1], 8.5.2). This mask is defined for 10 MHz and 20 MHz channel bandwidth.

As there are a couple of other channel bandwidth settings defined (see [A]), the spectrum mask can be "stretched" to fit the other bandwidth settings (but these stretched masks are not real standard masks). The complete spectrum emission mask test can be performed automatically by the FSQ-K92 measurement firmware ([**MEAS**] [*SPECTRUM*] [*SPECTRUM IEEE*]).

Additionally, the ***ETSI*** standard [5] defines ***masks*** for all available and defined channel bandwidth settings. These masks can also be selected inside the firmware and are adjusted automatically to the correct values ([**MEAS**] [*SPECTRUM*] [*SPECTRUM ETSI*]).

Beside this, the normal spectrum analyzer offers the flexible limit line concept for advanced evaluation of user-specific limit line setups.

The image below shows a typical spectrum emission mask measurement performed by the FSQ-K92 firmware.

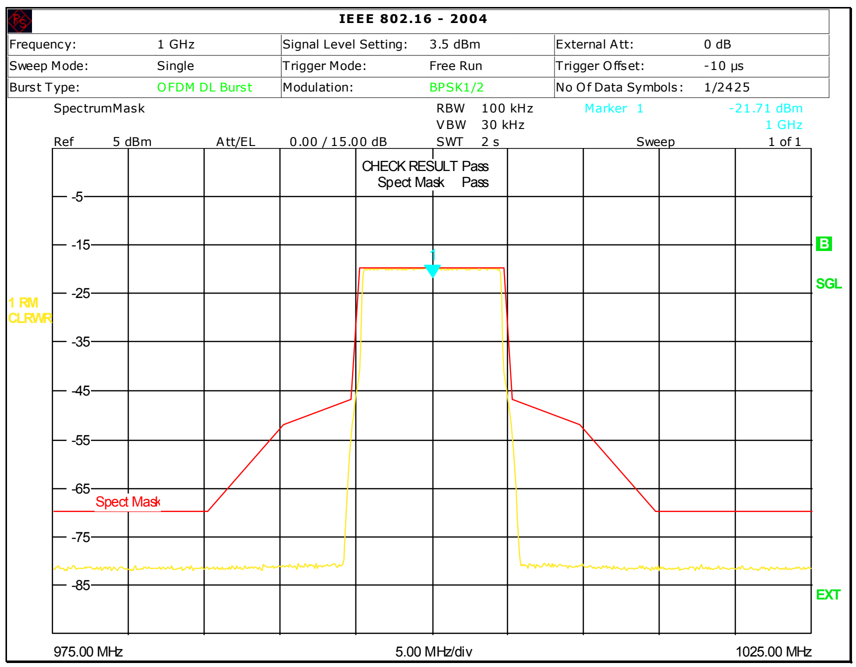


Image 14 – Spectrum emission mask - 10 MHz channel BW

Adjacent Channel Power (ACP)

Adjacent channel power is the ratio between the power in the main transmitter channel and the channels adjacent to this channel. The value is normally given in dB.

802.16 does not specify any measurement for ACP, but with the FSQ and FSQ-K92 option, it is possible to make a flexible ACP measurement in accordance with the custom-specific setup.

The image below shows a typical ACP measurement.

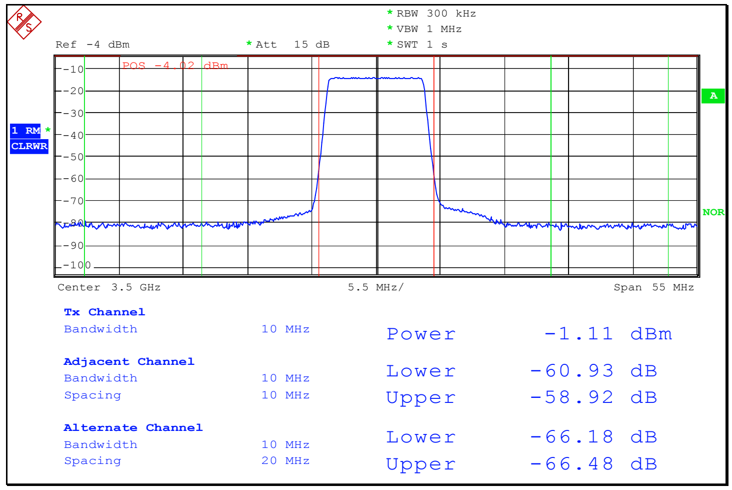


Image 15 – ACP measurement

Crest Factor Measurement

The crest factor is defined as the ratio between the peak level and the RMS level of a signal.

Crest Factor of Pulsed Signals

For a bursted signal, there are two different crest factors:

- The crest factor of the ***burst itself*** ("burst crest factor")
- The crest factor of the ***complete signal*** ("total crest factor").

The figure below shows again the signal used for the power measurement considerations. The crest factor of the burst is 8 dB.

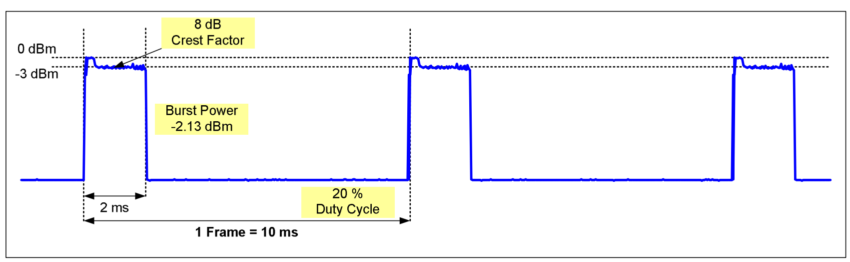


Figure 9 – Crest factor measurement of bursted signals

It can be seen by observing the complete signal that the peak value of the signal does not change (as the peak occurs in the burst), but the RMS value does change.

> The relation between the burst crest factor R_{Burst} [dB] and the total crest factor R_{Total} [dB] of a bursted signal with a duty cycle of D ($0 < N_{Duty} < 1$) is defined as
>
> $$R_{Total} = R_{Burst} + 10^{1-D}$$

For the signal above, the total crest factor can be calculated as follows:

$R_{Total} = 8\ \text{dB} + 10^{1-0,2} = 8\ \text{dB} + 6.3\ \text{dB} = 14.3\ \text{dB}$

There are basically three ways to determine the crest factor:

- Make a measurement using two traces, one trace with the max. hold detector and one trace with the RMS detector
- Use the FSQ's built-in measurement function (**[MEAS]** [*SIGNAL STATISTICS*] [*CCDF*])

Use the FSQ-K92 option's built-in measurement function ([*DISPLAY LIST*]).

Crest Factor Measurement with Two Traces

One possible solution for measuring the crest factor is to evaluate the ***peak value*** and the ***RMS value*** of the signal using two traces within the spectrum analyzer.

The measurement is set up in the same way as for Power Over Time. After setting up the measurement, a 2nd trace with max. hold is added, and the difference between the RMS value of the 1st trace and the peak value of the 2nd trace can be calculated.

The following image shows the measurement results in split-screen mode. The upper screen is used to measure the crest factor of the complete signal. From the RMS power over the complete burst (-29.82 dBm, blue box and trace) and the peak power (-20.64 dBm, black box and trace), a crest factor of 9.18 dB can be calculated.

With this method, it is also very easy to obtain the crest factor of different areas of the burst simply by changing the search limits within which the RMS value is calculated and the peak value is searched for. This is shown in the lower screen. From the RMS (-27.43 dBm) and the peak (-23.89 dBm), a crest factor of 3.54 dB can be calculated.

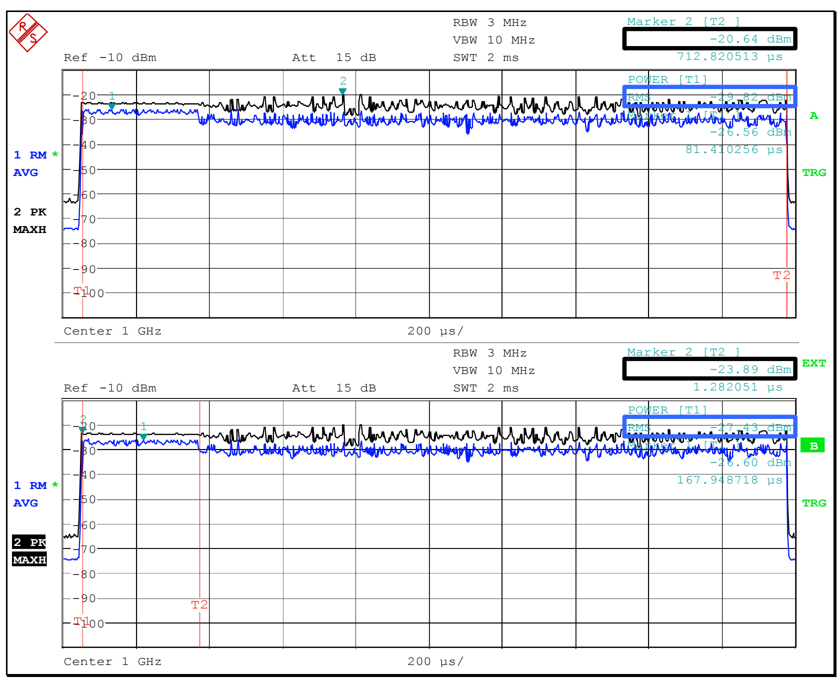


Image 16 – Crest factor measurement using two traces - total & preamble

Crest Factor Measurement with FSQ-K92

The evaluation of the crest factor depends on two values: the signal's RMS value and the signal's peak value. This evaluation causes some problems which can be solved by taking a closer look at how signal sampling works together with the crest factor calculation.

RMS level measurement

The signal's ***RMS value*** is calculated over a large number of sample values of the signal, and some sort of mean value is derived from all samples. If a bursted signal is to be measured, the RMS value is determined by the RMS level of the burst and the duty cycle of the signal. If the FSQ is running in free trigger mode, make sure that you do not measure only parts of the burst. The relations are the same as those described in the previous section. But if the measurement time is too long, you will not obtain the correct RMS reading.

The following image illustrates the problem. The area marked in yellow is the length of the signal detection window. In the first detection, one burst is included in the detection area, but the second detection area contains two bursts. A simple calculation shows that the RMS level of the second detection area is 3 dB higher than that of the first detection area.

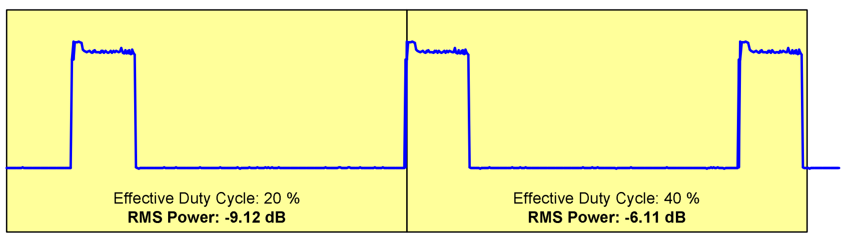


Figure 10 – "Wrong" RMS detection of pulsed signals

► For a correct RMS reading of the total signal power (burst & gap) for a bursted signal, the measurement length should be an integer multiple of the frame length.

Peak level measurement

The ***peak value*** is calculated by taking the maximum level within the signal. As every digital signal processing uses sampling of the signal, values are only available at certain times (depending on the sampling frequency). The figure below shows the problem that may occur in this context. The signal (a sine wave in this example) is sampled with a certain frequency, and the peak is found (red points). Unfortunately, the signal is sampled around this real peak value, so the real peak is not detected. This error can have a value of up to several dB.

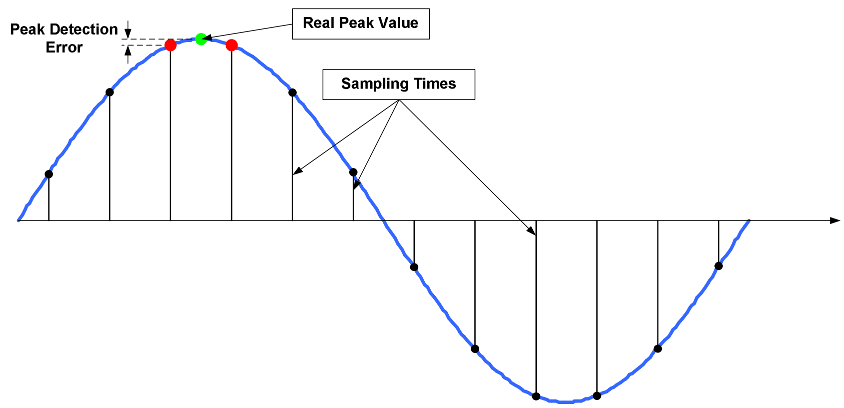


Figure 11 – Peak detection and crest factor calculation

There are two ways to overcome this problem:

- Increase the sampling frequency and thus reduce the probability of sampling just the "wrong" peaks
- Take several uncorrelated measurements (with free-run trigger) and find the "global" peak over all measurements.

> **!**
>
> To get a correct crest factor reading from FSQ-K92, set up the "Overall Burst Count" to e.g. 10, select "Free Run" trigger and read out the ***Maximum*** crest factor as the real crest factor of the signal.
>
> The displayed crest factor from FSQ-K92 is the crest factor of the evaluated parts of the burst (which are marked in green).

The following image shows the result of a measurement considering only two bursts for the peak evaluation (upper image), and a measurement considering 100 bursts (lower image). As can clearly be seen, the measured maximum crest factor is higher and closer to the real crest factor of the signal (9.61 dB).

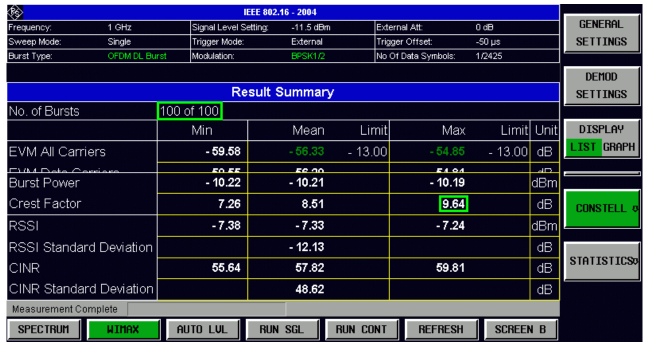


Image 17 – Crest factor measurement with FSQ-K92

Complementary Cumulative Distribution Function (CCDF)

The CCDF is a statistic evaluation functionality. It is a cumulative histogram function and evaluates the probability that the signal amplitude will have a certain level above the RMS level of the signal.

As a result, the maximum level of the CCDF function (marked with a blue and red square in the following image) is the crest factor of the signal, as the probability of a signal level above the peak level is 0 %.

There are two ways to measure the CCDF within a Rohde & Schwarz signal analyzer:

- Use the normal CCDF measurement function within the basic instrument firmware (**[MEAS]** [*SIGNAL STATISTICS*] [*CCDF*]).
- Use the CCDF measurement function within the FSQ-K92 WiMAX application firmware ([*WIMAX*] [*STATISTICS*] [*CCDF*]).

> ▶ Due to the different measurement concepts, the CCDF measurement function within the normal analyzer mode can only evaluate the CCDF of the complete trace, whereas the CCDF measurement function within FSQ-K92 can also evaluate the CCDF of certain areas within the burst ("gating").

The following image shows the CCDF (normal spectrum analyzer mode) evaluation of a WiMAX signal with only preamble and FCH (black) and with preamble, FCH and one burst (blue) in a non-bursted mode. From the blue curve (trace 1), you can see that the crest factor is 9.00 dB (this value can also be read from the table or evaluated via a marker function); the black curve shows a much lower crest factor of 5.40 dB.

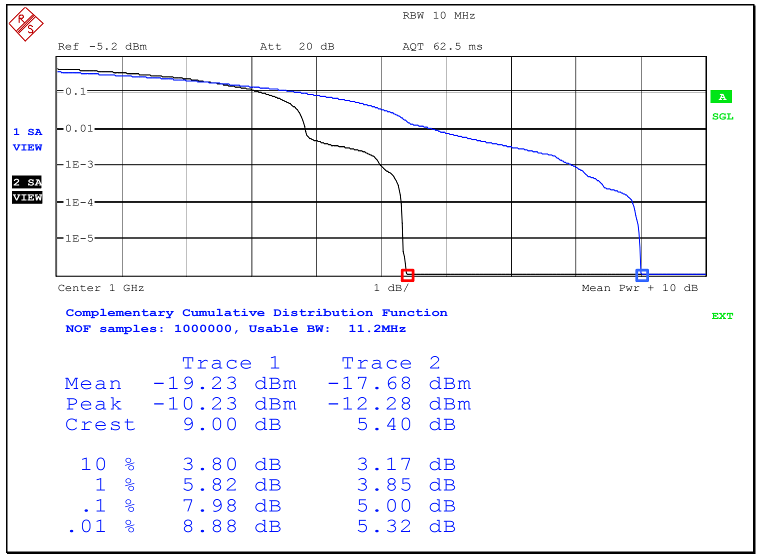


Image 18 – CCDF - complete signal/preamble and FCH

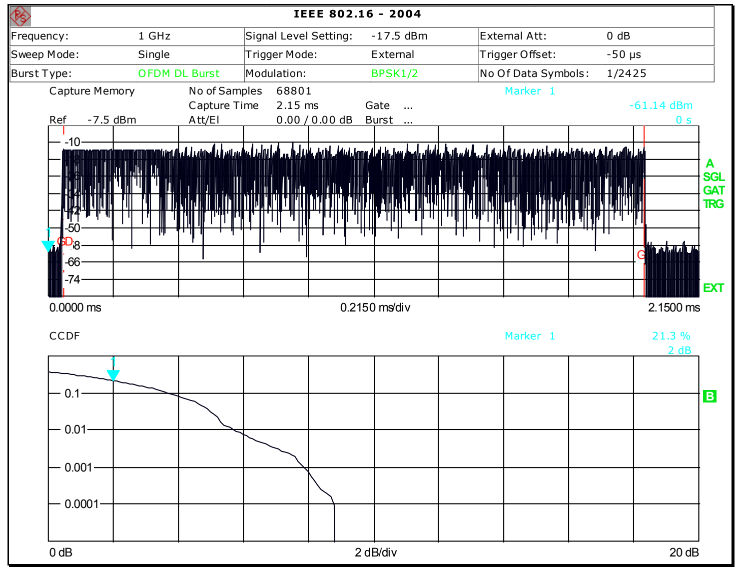
The evaluation of the CCDF of certain areas within the burst may also be important to obtain detailed information about e.g. the CCDF of the payload in combination with different compression methods in an amplifier system.

The FSQ-K92 application firmware can run a gated CCDF measurement on the signal even if the demodulation fails, so this is the best way to determine the modulation and properties of the signal. The signal evaluation is executed on the complete capture buffer (all captured I/Q samples) and can be limited by the gate to certain areas of the signal. As a demodulation is not required for this measurement, you can increase the number of samples (and thus the precision of the measurement) used for evaluation by increasing the sampling rate.

In order to switch on a gated measurement, run the following sequence:

[PRESET]	set instrument to default state
[FREQ] [*CENTER*] {value}	set signal frequency
([*MORE*]) [*WIMAX*]	switch to FSQ-K92
[*RUN CONT*]	switch on sweeping
[*GENERAL SETTINGS*] [Sampling Rate] {value}	set the rate at which the A/D converter will sample the signal
[SWEEP] {value}	select the sweep time
[TRIGGER] {trigger mode}	switch on the desired trigger mode
[*STATISTICS*] [*CCDF*]	switch on CCDF measurement
[NEXT] [*GATING **ON***]	switch on gating
[*GATE SETTINGS*]	adjust the gate for the measurement

The following image shows two measurements with gated CCDF, which display the CCDF of the preamble and the CCDF of the payload.



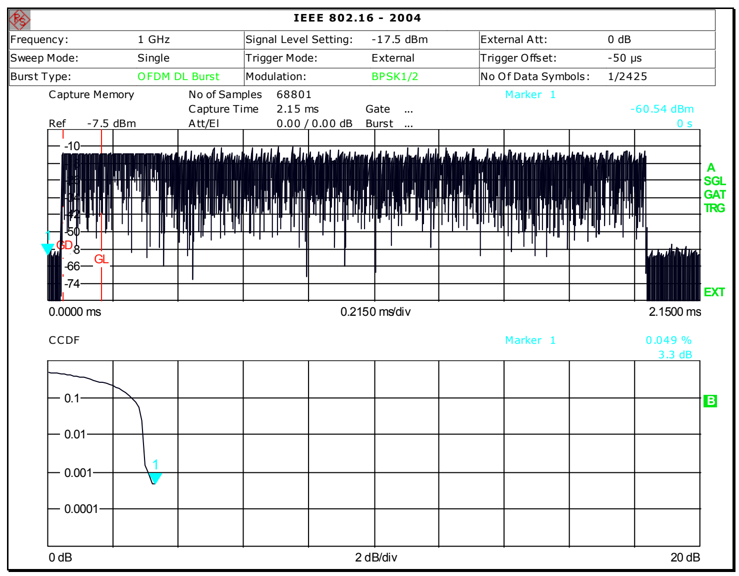


Image 19 – Gated CCDF with FSQ-K92: all / preamble only

6 Analyzing WiMAX Signals − Modulation Measurement

General Aspects and Error Scenarios

A WiMAX signal (OFDM and OFDMA) can show a lot of different errors which, in turn, lead to different errors and misbehaviors of the signal.

The list below shows the basic systems of a WiMAX transmitter and the typical error sources.

System & error	Result in modulation analysis	
Digital "binary" baseband		
errors in randomizer	none (bits change, but not compared to any reference)	
errors in forward error correction	none (bits change, but not compared to any reference)	
errors in interleaver	none (bits change, but not compared to any reference)	
Modulation generation		
wrong bits → symbol mapping	none (symbols change, but no reference available)	
wrong logical → physical carrier mapping	none (carrier symbols change, but no reference available)	
wrong pilot → physical carrier mapping	bad EVM	
wrong modulation type − OFDM	depends on modulation detection mode	
	None	high EVM (use "EVM vs Symbol" for analysis)
	User	NAP (only burst of selected type analyzed)
	Auto	none (use "Burst Summary" for detailed analysis)
wrong modulation type − OFDMA	high EVM (wrong burst displayed in Burst Summary List)	
wrong FFT size	NAP (NBF)	
wrong bandwidth	NAP (NBF)	
wrong guard interval setup	bad EVM & wrong modulation and burst detection	
wrong preamble	NAP (NBF)	
wrong pilot sequence	NAP (pilots: default) / none (pilots: detected)	
wrong burst levels − OFDM	bad EVM when "Track Level" is switched off	
wrong burst levels − OFDMA	bad EVM	
D/A conversion		
I/Q swapped	bad EVM & wrong modulation and burst detection	
I/Q offset (I/Q origin shift)	high "I/Q Offset" reading, high "off" level in burst gaps	
Gain Imbalance (Gain$_I$ <> Gain$_Q$)	bad EVM & high "Gain Imbalance" reading	
Quadrature Imbalance (I-Q phase <> 90°)	bad EVM & high "Quadrature Imbalance" reading	
Clock Rate error (static)	bad EVM and high "Clock Error"	
Clock Rate error (jitter)	bad EVM and high "Clock Error"	
wrong filter type / parameters	bad EVM / bad ACP / failed spectrum mask	
Clipping (I/Q scalar)	bad EVM (no "classical" clipping visible in I/Q display)	
Clipping (I/Q vector)	bad EVM (no "classical" clipping visible in I/Q display)	
Noise	bad EVM	
I/Q → RF conversion		
wrong RF frequency	high "Center Frequency Error" reading	
Noise	bad EVM	

Abbreviations:

- **NAP** No analysis possible
- **NBF** No burst found (FSQ-K92 warning)
- **NDB** No burst of desired type to analyze (FSQ-K92 warning)

Measuring OFDM Symbols Spectrum

If the signal transmitted was checked by having a look at the output power and spectrum but fails to be analyzed with the vector demodulation application firmware, you may first have to look at the output spectrum of the OFDM signal to determine if the signal is modulated.

The easiest way to check if the signal has an OFDM modulation is to use a gated sweep and measure the FFT spectrum of the signal.

The FSQ-K92 application firmware can run a gated FFT measurement on the signal even if the demodulation fails, so this is the best way to determine the modulation of the signal.

Run the following setups to execute the gated sweep:

[PRESET]	set instrument to default state
[FREQ] [*CENTER*] {value}	set signal frequency
([*MORE*]) [*WIMAX*]	switch to FSQ-K92
[*RUN CONT*]	switch on sweeping
[*GENERAL SETTINGS*] [Sampling Rate] {value}	set the rate the A/D converter will sample the signal
[SWEEP] {value}	select the sweep time
[TRIGGER] {trigger mode}	switch on the desired trigger mode
[*SPECTRUM*] [*SPECTRUM FFT*]	switch on FFT spectrum mode
[NEXT] [*GATING* ***ON***]	switch on gating
[*GATE SETTINGS*]	adjust the gate for the measurement

For the gated spectrum measurement, the gate length must be equal to the Useful Symbol Time T_b which can be calculated with

$$T_b = N / F_s$$

and the distance between two valid symbols T_s is

$$T_s = T_b \cdot (1 + G)$$

where

- N is the FFT size
- F_s is the sampling frequency of the signal
- G is the guard period ratio.

For an 802.16-2004 signal, N = 256, G can have the values $^1/_4$, $^1/_8$, $^1/_{16}$ or $^1/_{32}$ and F_s can have discrete values between 1.72 and 32 MHz, depending on the channel bandwidth and the sampling factor (for details, see [A]).

The measurements below were taken with a 2 MHz signal and G = $^1/_4$ (T_b = 256 / 2 MHz = 128 µs and T_s = 128 µs · (1 + $^1/_4$) = 160 µs), showing the long preamble, 1st and 2nd symbol and a data symbol. As can clearly be seen, the instrument cannot demodulate the signal (due to a wrong analysis setup), but the gated FFT spectrum mode is still available and working. For the measurement, a trigger delay of 50 µs was set. The 1st symbol shows 50 preamble carriers, the 2nd symbol shows 100 preamble carriers, and the 3rd symbol shows the first data symbol, which uses only 4 subchannels.

Image 20 – Gated measurement - long preamble - 1st symbol

Image 21 – Gated measurement - long preamble - 2nd symbol

Image 22 – Gated measurement - 1st data symbol

Signal Analysis – Overview

The figure below shows the principal design of the WiMAX OFDM analysis within the FSQ-K92 measurement software. More details on the signal processing can also be found in the FSQ-K92 manual ([8]).

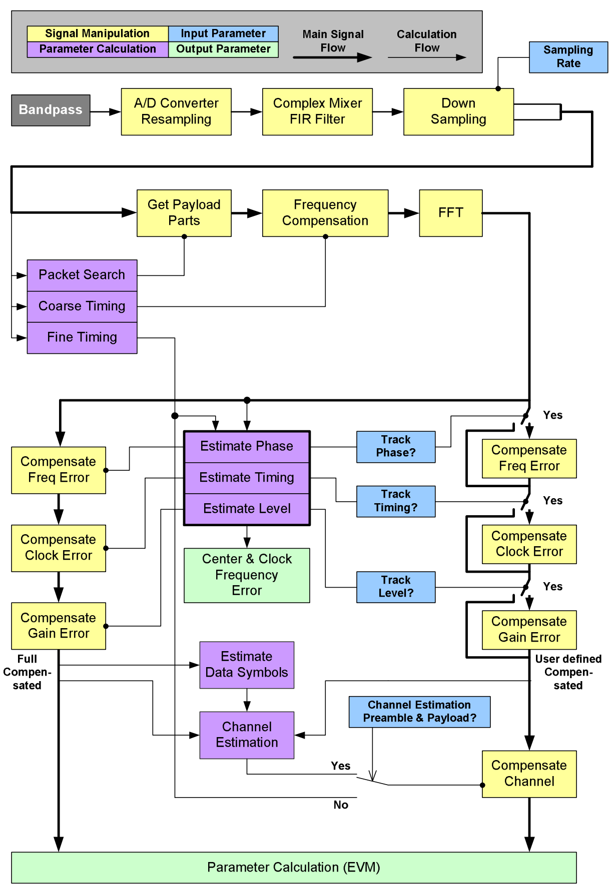


Figure 12 – FSQ-K92 signal processing

Making Modulation Measurements − OFDM

Making a vector measurement on a WiMAX signal is very easy with FSQ-K92.

After the following steps have been executed, the analyzer should be able to analyze the signal.

[PRESET]	set instrument to default state
[FREQ] [*CENTER*] {value}	set signal frequency
([*MORE*]) [*WIMAX*]	switch to FSQ-K92
[*RUN CONT*]	switch on sweeping
[*GENERAL SETTINGS*] [Channel Bandwidth] {value}	set the bandwidth of the signal
[SWEEP] {value}	select the sweep time
[TRIGGER] {trigger mode}	switch on the desired trigger mode

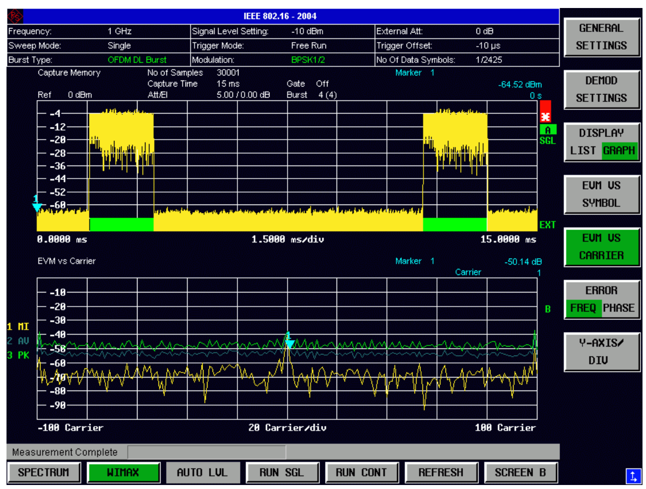
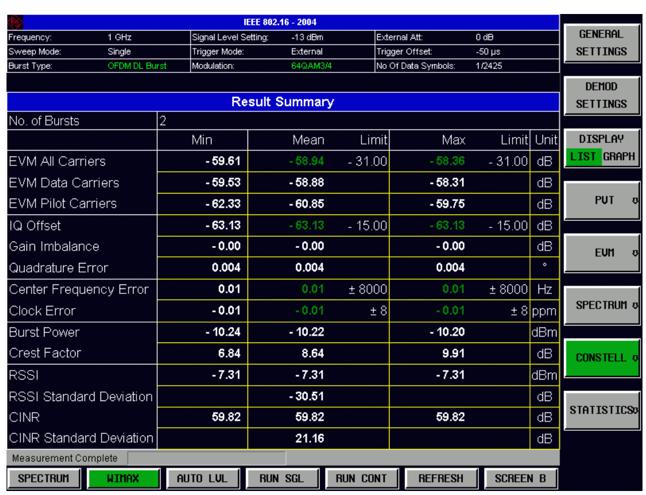


Image 23 – Typical 802.16-2004 OFDM measurement



	Min	Mean	Limit	Max	Limit	Unit
EVM All Carriers	-59.61	-58.94	-31.00	-58.36	-31.00	dB
EVM Data Carriers	-59.53	-58.88		-58.31		dB
EVM Pilot Carriers	-62.33	-60.85		-59.75		dB
IQ Offset	-63.13	-63.13	-15.00	-63.13	-15.00	dB
Gain Imbalance	-0.00	-0.00		-0.00		dB
Quadrature Error	0.004	0.004		0.004		°
Center Frequency Error	0.01	0.01	± 8000	0.01	± 8000	Hz
Clock Error	-0.01	-0.01	± 8	-0.01	± 8	ppm
Burst Power	-10.24	-10.22		-10.20		dBm
Crest Factor	6.84	8.64		9.91		dB
RSSI	-7.31	-7.31		-7.31		dBm
RSSI Standard Deviation		-30.51				dB
CINR	59.82	59.82		59.82		dB
CINR Standard Deviation		21.16				dB

Image 24 – OFDM measurement results

In Image 20 you can see that the FSQ shows all demodulated signal parts with a green bar. This is very helpful for detecting parts of the signal which could not be analyzed or have different types of modulation.

It is also possible to force the analyzer to measure all bursts or only bursts with a dedicated modulation. This can be set up in the [*DEMOD SETTINGS*] menu ("Modulation Detection Mode" All or User).

Editing the Table Limits

The limits used for evaluation of PASSED or FAILED within the List Display are automatically set to values in accordance with the standard.

If you want to change the limits, you can edit them very easily.

Switch to the List Mode and press the **[LINES]** hardkey. You can then select the limit with the cursor keys and change them.

If you want to set them back to the default values, use the [*DEFAULT CURRENT*] or [*DEFAULT ALL*] button.

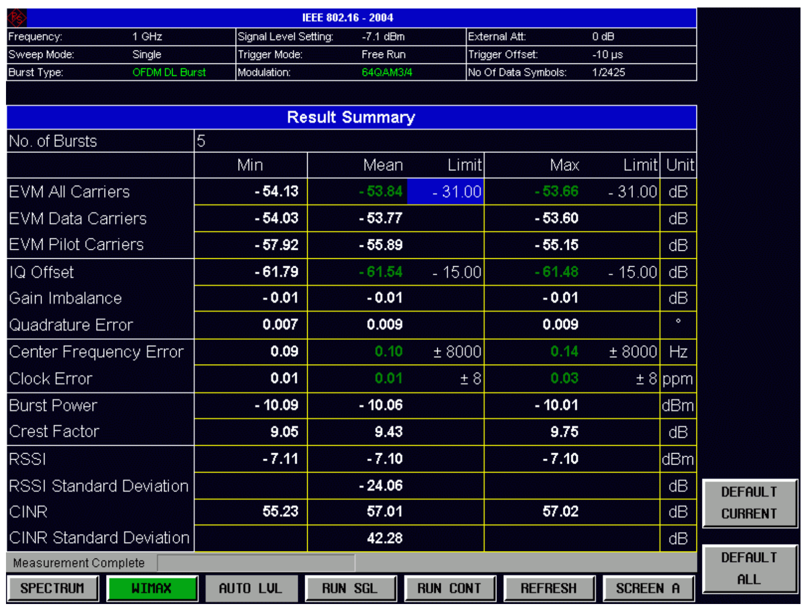
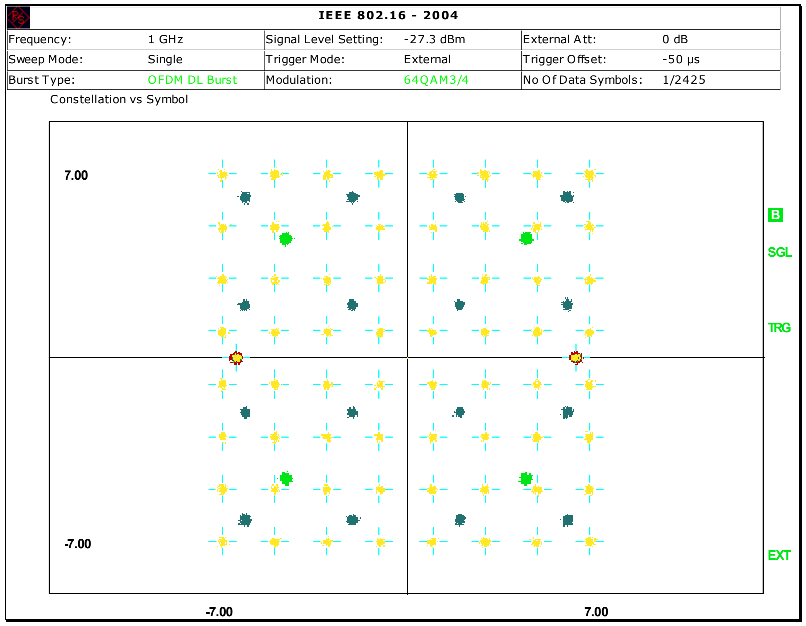
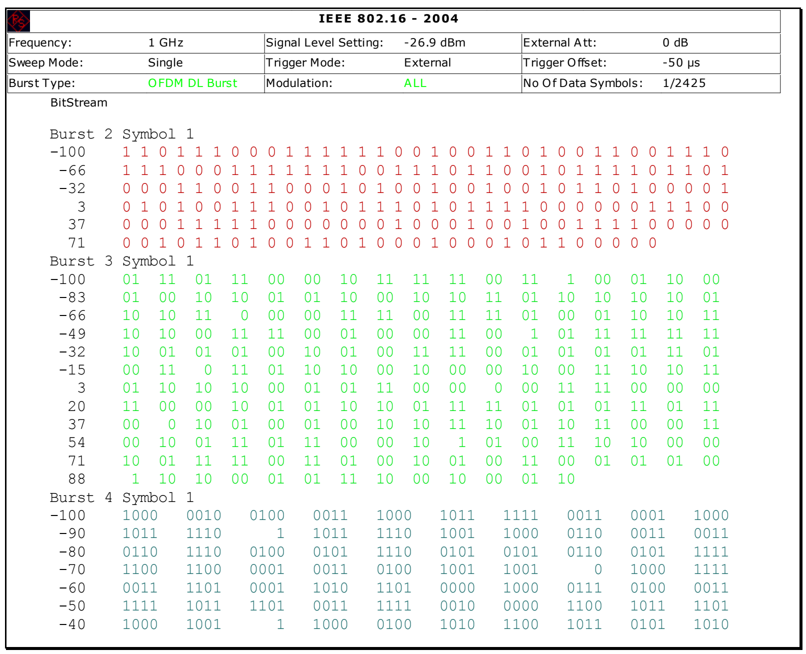


Image 25 – Editing the EVM All Mean Limit

Typical Measurements

For a detailed analysis, FSQ-K92 offers a lot of helpful features. One of them is the color coding of the demodulated constellation diagram and bit stream according to the modulation (BPSK, QPSK, etc). The following images show the constellation and bit stream for a frame with different modulations.





Frequency:	1 GHz	Signal Level Setting:	-26.9 dBm	External Att:	0 dB
Sweep Mode:	Single	Trigger Mode:	External	Trigger Offset:	-50 µs
Burst Type:	OFDM DL Burst	Modulation:	ALL	No Of Data Symbols:	1/2425

BitStream

```
Burst 2 Symbol 1
-100   1 1 0 1 1 1 0 0 0 1 1 1 1 1 1 0 0 1 0 0 1 1 0 1 0 0 1 1 0 0 1 1 1 0
 -66   1 1 1 0 0 0 1 1 1 1 1 1 1 0 0 1 1 1 0 1 1 0 0 1 0 1 1 1 1 0 1 1 0 1
 -32   0 0 0 1 1 0 0 1 1 0 0 0 1 0 1 0 0 1 0 0 1 0 0 1 0 1 1 0 1 0 0 0 0 1
   3   0 1 0 1 0 0 1 1 1 0 0 1 0 1 1 1 0 1 0 1 1 1 1 0 0 0 0 0 0 1 1 1 0 0
  37   0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 1 1 1 1 0 0 0 0 0
  71   0 0 1 0 1 1 0 1 0 0 1 1 0 1 0 0 0 1 0 0 0 1 0 1 1 0 0 0 0 0
Burst 3 Symbol 1
-100   01  11  01  11  00  00  10  11  11  11  00  11   1  00  01  10  00
 -83   01  00  10  10  01  01  10  00  10  10  11  01  10  10  10  10  01
 -66   10  10  11   0  00  00  11  11  00  11  11  01  00  01  10  10  11
 -49   10  10  00  11  11  00  01  00  00  11  00   1  01  11  11  11  11
 -32   10  01  01  01  00  10  01  00  11  11  00  01  01  01  01  11  01
 -15   00  11   0  11  01  10  10  00  10  00  00  10  00  11  10  10  11
   3   01  10  10  10  00  01  01  11  00  00   0  00  11  11  00  00  00
  20   11  00  00  10  01  01  10  10  01  11  11  01  01  01  11  01  11
  37   00   0  10  01  00  01  00  10  10  11  10  01  10  11  00  00  11
  54   00  10  01  11  01  11  00  00  10   1  01  00  11  10  10  00  00
  71   10  01  11  11  00  11  01  00  10  01  00  11  00  01  01  01  00
  88    1  10  10  00  01  01  11  10  00  10  00  01  10
Burst 4 Symbol 1
-100   1000  0010  0100  0011  1000  1011  1111  0011  0001  1000
 -90   1011  1110     1  1011  1110  1001  1000  0110  0011  0011
 -80   0110  1110  0100  0101  1110  0101  0101  0110  0101  1111
 -70   1100  1100  0001  0011  0100  1001  1001     0  1000  1111
 -60   0011  1101  0001  1010  1101  0000  1000  0111  0100  0011
 -50   1111  1011  1101  0011  1111  0010  0000  1100  1011  1101
 -40   1000  1001     1  1000  0100  1010  1100  1011  0101  1010
```

Image 26 – Constellation and bit stream display

The Burst Summary List is also a very helpful feature; it provides detailed information such as power, EVM, symbol length and modulation of each burst

IEEE 802.16 - 2004					
Frequency:	1 GHz	Signal Level Setting:	-12 dBm	External Att:	0 dB
Sweep Mode:	Single	Trigger Mode:	External	Trigger Offset:	-50 µs
Burst Type:	OFDM DL Burst	Modulation:	ALL	No Of Data Symbols:	1/2425

Burst Summary

Downlink Burst Summary List

Burst	Area	Modulation	Length[sym]	Power[dBm]	EVM[dB]
FCH	Preamble	BPSK	2	-7.11	-59.26
	Data	BPSK	1	-10.05	-58.03
Burst 2	Data	BPSK	15	-10.05	-58.20
Burst 3	Data	QPSK	15	-10.07	-58.51
Burst 4	Data	16QAM	15	-10.05	-54.13
Burst 5	Data	64QAM	14	-10.05	-56.31
FCH	Preamble	BPSK	2	-7.21	-58.23
	Data	BPSK	1	-10.06	-57.51
Burst 7	Data	BPSK	15	-10.05	-58.15
Burst 8	Data	QPSK	15	-10.07	-57.90
Burst 9	Data	16QAM	15	-10.05	-54.16
Burst 10	Data	64QAM	14	-10.06	-56.40
FCH	Preamble	BPSK	2	-7.23	-57.95
	Data	BPSK	1	-10.06	-58.20
Burst 12	Data	BPSK	15	-10.06	-58.26
Burst 13	Data	QPSK	15	-10.08	-58.20
Burst 14	Data	16QAM	15	-10.05	-54.15
Burst 15	Data	64QAM	14	-10.06	-56.47
FCH	Preamble	BPSK	2	-7.25	-58.67
	Data	BPSK	1	-10.06	-59.17
Burst 17	Data	BPSK	15	-10.06	-58.42
Overall			204	-9.35	-57.13

Image 27 – Burst Summary List

Making Modulation Measurements − OFDMA

For 802.16-2004 OFDMA / 802.16e measurements, FSQ-K93 has to be used.

Operating the FSQ-K93 option is basically the same as operating the FSQ-K92 option, except that the burst layout within a zone is more complex, as bursts can be placed in time and frequency domain and may also have offsets in frequency and time domain leading to gaps in the time and frequency plan.

Entering the Zone Setup and Global Settings

The zone setup is basically entered in the same way in the SMU and the FSQ. The following two images show a typical zone layout entered with the FSQ user interface.

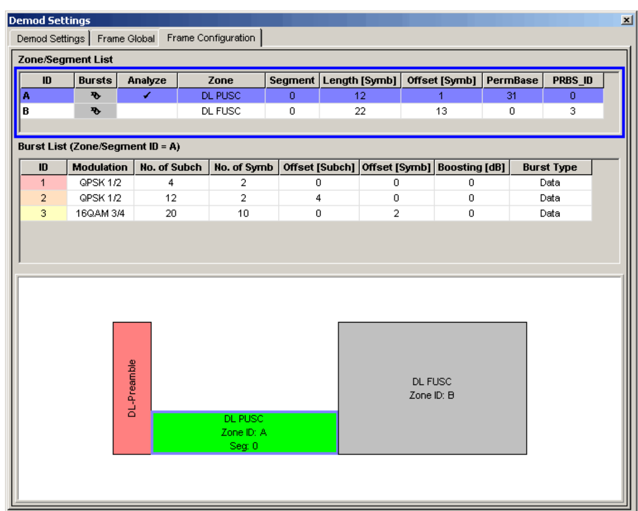


Image 28 – FSQ-K93 - Zone setup

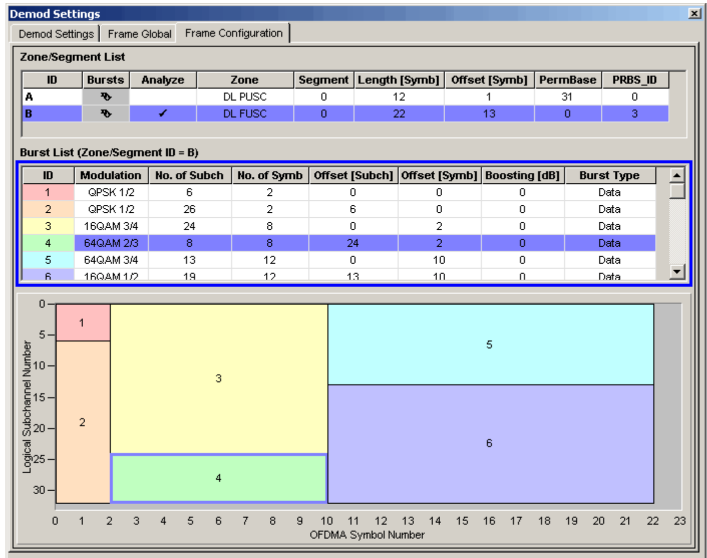
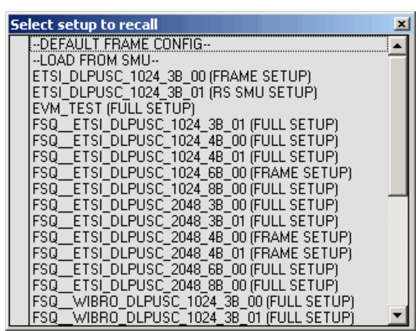


Image 29 – FSQ-K93 - Burst Setup

As the setup for zones and bursts has to be performed on both the SMU and the FSQ and involves setting a lot of different numbers and parameters, FSQ-K93 is able to read different setup file types from stored settings or from the SMU's (and also from the SMJ's or the SMATE's) setup files. This can be done by using a file or directly connecting the SMU via an IEEE or LAN interface and reading the setups directly from the instrument.

The figure below shows the recall dialog from the FSQ-K93 software and the different file types and their description.



Default frame configuration

"preset" the zone & frame setup

Load from SMU

connect to the SMU and load setup

Frame Setup

zone & frame setup stored within FSQ-K93

Full Setup

zone, frame and global setup stored within FSQ-K93

RS SMU Setup

zone & frame setup stored within the SMU (*.wimax)

Typical Error Scenarios

In the following, typical error conditions and their measurement results are described.

The basic error scenarios are basically the same for OFDM and OFDMA, so both modes are discussed here. They will only be discussed separately if there are significant differences between the two modes.

Wrong Burst Power

If one or more bursts show a wrong burst power, you can see this by using the constellation display.

> **!** You have to ***switch off level tracking*** in order to see the wrong constellation points in the results.
> When level tracking is switched on, the level will be corrected and the constellation points will be displayed in the corrected positions.

The image below shows the constellation plot for a frame. It contains a number of bursts with different modulations. Color coding and the indication of the correct constellation location help to identify the wrong power levels of the bursts.

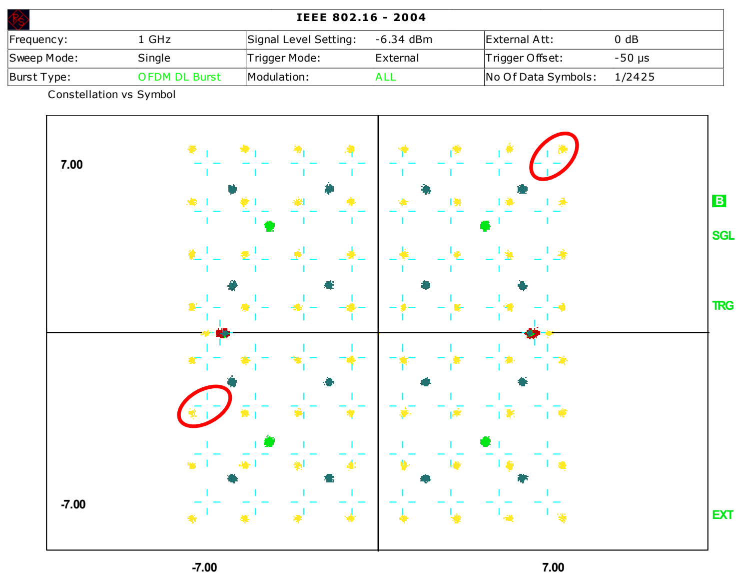


Image 30 – Wrong burst power 64QAM

In-Band Spurious

Within the transmitter or receiver, there may be spurious signals generated by the mixer or other components. These signals lead to a peak in the EVM vs. Carrier display, as you can see in the following image.

The following image shows the OFDM signal in normal time domain (OFDM signal in yellow and spurious signal in blue) and the demodulated signal in Power vs. Time (upper) and EMV vs. Carrier (lower) display. You can clearly see the peak in the EVM vs. Carrier trace at the spurious position.

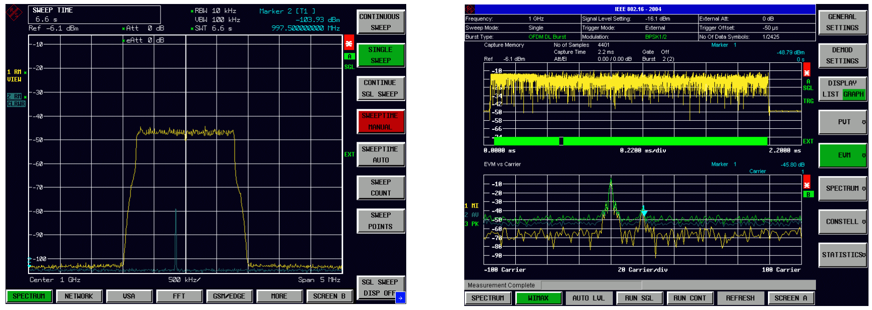


Image 31 – In-band spurious in frequency and vector domain

I/Q Offset

An I/Q offset can easily be measured in the vector domain. It results in increased center carrier amplitude in the EVM vs. Carrier display and an increased level of the Tx-Rx gap. The image below shows a measurement with the corresponding areas marked.

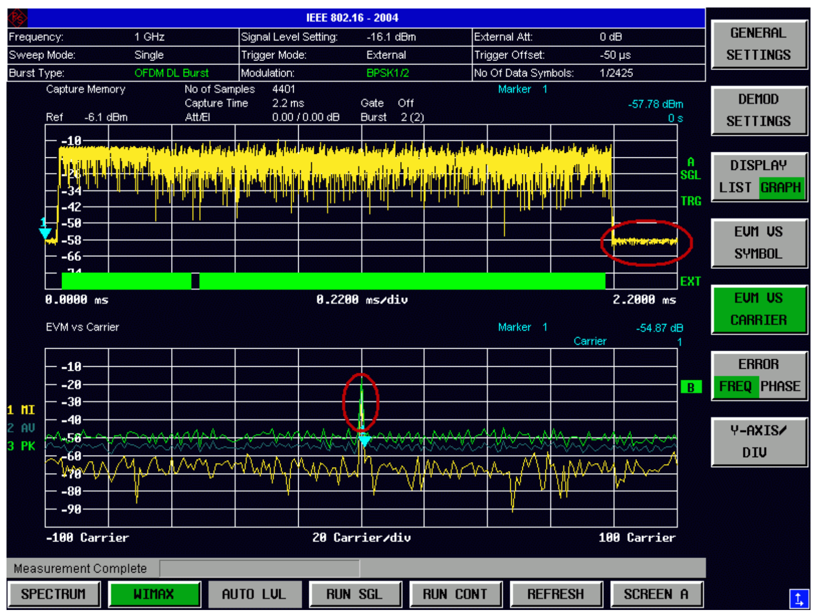


Image 32 – Result of I/Q offset in measurement results

I/Q offset can also be measured within the preamble by using the gated FFT spectrum mode of the instrument.

For this measurement, the amplitude of the center carrier (measured with the marker) can be compared with the total power of the part of the burst used for channel estimation (preamble power, which is displayed as RSSI reading in the List Display, or total power, which is displayed as Burst Power in the List Display). The following image shows how to run this measurement using FFT mode.

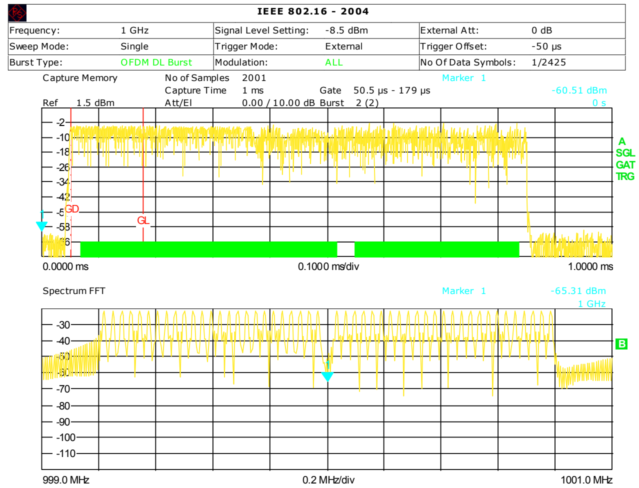


Image 33 – I/Q offset measurement in preamble

!

A frequenty made mistake is to calculate the I/Q offset by comparing the DC carrier amplitude with the amplitude of the 1st active carrier in the FFT spectrum. This measurement is wrong, as I/Q offset is defined relative to the preamble power/burst power.

As measuring the DC carrier amplitude in FFT mode using the preamble is also very sensitive to the correct gate start, the I/Q offset reading from the List Display should be used.

Gain Imbalance & Quadrature Error

A gain imbalance (i.e. the gain of the I path is different from the Q path gain) or a quadrature error (phase between I and Q path is not 90°) leads to a constant, reduced EVM performance in the EVM vs. Carrier display. The image below shows the effect (gain imbalance 0.5 dB).

Image 34 – Result of gain imbalance in measurement results

Setting Correct Tracking & Channel Estimation

The tracking function inside FSQ-K92 and FSQ-K93 is used to compensate errors in phase, timing and level over the complete frame.

In accordance with the standard [1], 8.3.10.1.2 "Transmitter constellation error and test method", only frequency offsets (= phase errors) are allowed to be compensated (c) and d)), whereas timing and level errors are not compensated.

Thus, the default setup for tracking is Phase ON and Timing and Level OFF.

The following table shows EVM for different tracking and error scenarios.

Test signal (802.16-2004 OFDM):

- 1 GHz + 500 Hz Center Frequency
- 2 MHz - 5 ppm Clock Rate Error
- Two 64QAM bursts, 28 symbols each, 2nd burst 1 dB level error
- Generator and analyzer (10 MHz reference oscillator) coupled

Tracking			Error			EVM
Phase	Timing	Level	Freq	Clock	Level	
OFF	OFF	OFF	YES	YES	YES	-22.1 dB
ON	OFF	OFF	YES	YES	YES	-22.3 dB
ON	ON	OFF	YES	YES	YES	-24.9 dB
ON	ON	ON	YES	YES	YES	-54.7 dB
OFF	OFF	OFF	YES	YES	NO	-25.3 dB
ON	OFF	OFF	YES	YES	NO	-25.7 dB
ON	ON	OFF	YES	YES	NO	-55.0 dB
OFF	OFF	OFF	YES	NO	NO	-33.4 dB
ON	OFF	OFF	YES	NO	NO	-55.5 dB
OFF	OFF	OFF	NO	NO	NO	-35.5 dB
ON	OFF	OFF	NO	NO	NO	-55.5 dB

!

For the best EVM reading on the instrument, switch on tracking for phase, timing and level.

If the measurement is to be performed in accordance with the standard, you should only switch on tracking for phase.

The following images show the signal with the noted errors and tracking switched OFF (upper image) and ON (lower image).

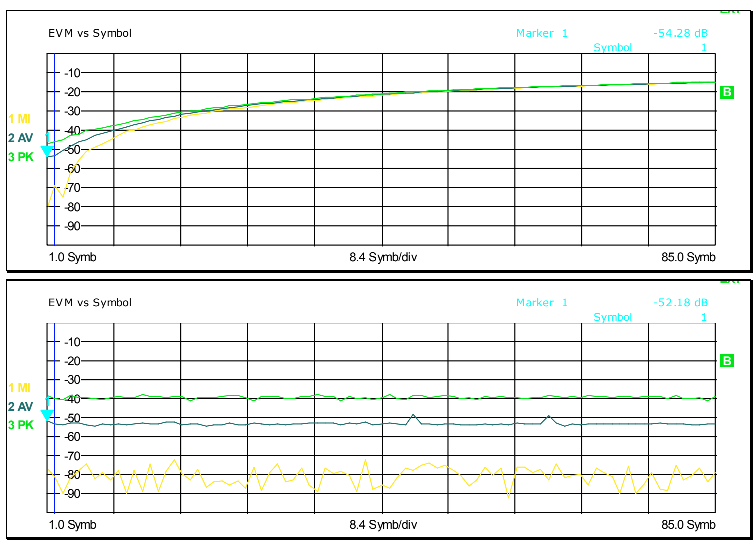


Image 35 – Signal with frequency error and phase tracking OFF / ON

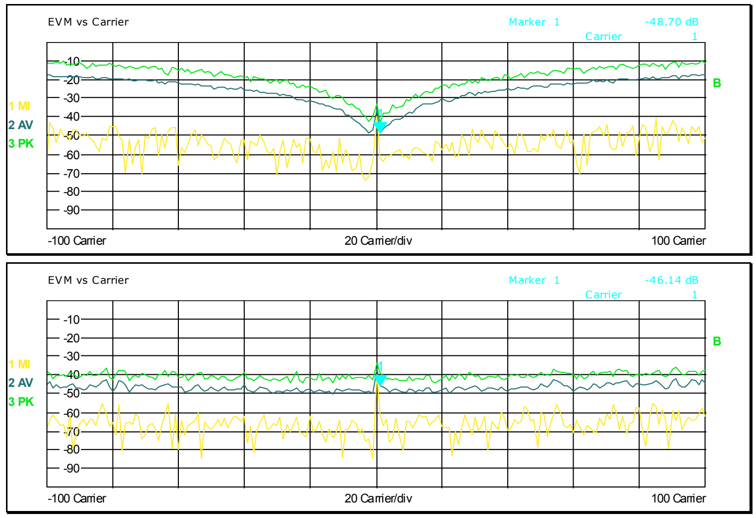


Image 36 – Signal with clock error and timing tracking OFF / ON

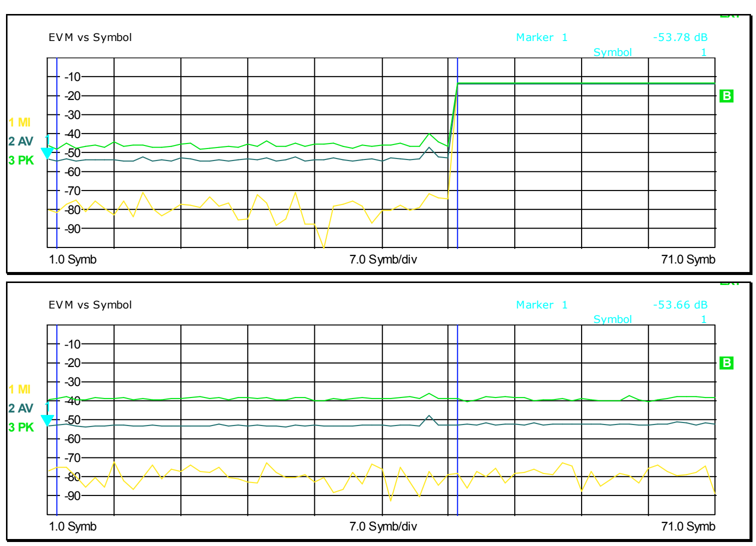


Image 37 – Signal with two burst levels and level tracking OFF / ON

Increasing the Remote Control Measurement Speed

In order to increase the measurement speed − especially when operating the instrument via remote control in a production environment − use the following methods to reduce the measurement time:

- Switch off the display using the remote control command "**SYST:DISP:UPD OFF**" (when running the instrument via remote).
- Switch off auto leveling.
- Use an external trigger (if available from the signal source).
- Switch the modulation detection mode to "None" or "User".
- Switch off all tracking not required ("Phase" must normally be on).
- Switch "CH Estimation in Preamble & Payload" off.

7 Definitions and Abbreviations

AAS	***A**daptive **A**ntenna **S**ystem*
AMC	***A**dvanced **M**odulation and **C**oding*
BS	***B**ase **S**tation* The unit that communicates with one or more subscriber stations.
BSID	***B**ase **S**tation **I**dentifier* Number identifying the base station; used e.g. to initialize the randomizer in OFDM.
CQ	***C**hannel **Q**uality*
DIUC	**D**ownlink **I**nterval **U**sage **C**ode Value for initializing the scrambler for 802.16-2004 (OFDM).
DL	***D**own**l**ink* Link direction from the base station to the user.
FCH	***F**rame **C**ontrol **H**eader* Header within a WiMAX frame containing information such as frame lengths.
FFT	***F**ast **F**ourier **T**ransformation* A fast method to convert a signal from time to frequency domain and back again.
FUSC	***F**ull **U**sage of **S**ub**c**hannels* A zone mode within 802.16-2004 OFDMA.
MIMO	***M**ultiple **I**nput **M**ultiple **O**utput* A method for using multiple antennas for Tx and Rx to increase the performance.
NLOS	***N**on **L**ine **o**f **S**ight* No direct "shortest length" connection between e.g. BS and SS.
OFDMA	***O**rthogonal **F**requency **D**ivision **M**ultiple **A**ccess* An OFDM mode that combines users in both time and frequency domain.
O-FUSC	***O**ptional **FUSC*** A zone mode within 802.16-2004 OFDMA.
PUSC	***P**artial **U**sage of **S**ub**c**hannels* A zone mode within 802.16-2004 OFDMA.
RCT	***R**adio **C**onformance **T**est* Document describing how to test a WiMAX SS / BS.
RTG	***R**eceive **T**ransition **G**ap* The gap between UL and subsequent DL burst.
Rx	***R**eceive / **R**eceiver*
SC	***S**ingle **C**arrier* Modulation mode.
Slot	Minimum possible data allocation unit for OFDMA PHY Has a certain number of OFDMA symbols and a certain number of subchannels.
SS	***S**ubscriber **S**tation* Equivalent to a mobile for GSM end user equipment.
SUI	***S**tanford **U**niversity **I**nterim* Fading model used to describe WiMAX fading profiles.
TTG	***T**ransmit **T**ransition **G**ap* The gap between DL and subsequent UL burst.
Tx	***T**ransmit / **T**ransmitter*

UIUC	**U**plink **I**nterval **U**sage **C**ode Value for initializing the scrambler for 802.16-2004 (OFDM).
UL	***U***p***l***ink Link direction from the user to the base station.
WiMAX	***W***orldwide ***I***nteroperability for ***M***icrowave ***A***ccess
WirelessMAN	***Wireless M***etropolitan ***A***rea ***N***etwork
WLAN	***W***ireless ***L***ocal ***A***rea ***N***etwork

For additional information on definitions and abbreviations, also see [1], Chapters 3 and 4.

8 Literature

Besides the literature listed below, you can visit the official web pages of the following institutes for detailed information about 802.16:

- Official IEEE 802.16 homepage:
  http://www.ieee802.org/16/
- Official ETSI homepage:
  http://www.etsi.org

[A] **WiMAX – General information about the standard 802.16**
Rohde & Schwarz, Application Note 1MA96
Available for free download:
http://www.rohde-schwarz.com/appnote/1MA96

[C] **WiMAX: 802.16-2004, 802.16e, WiBRO – Introduction to WiMAX Measurements**
Rohde & Schwarz, Application Note 1EF57
http://www.rohde-schwarz.com/appnote/1EF57

[1] **IEEE 802.16-2004**
IEEE Standard for Local and metropolitan area networks
Part 16: Air Interface for Fixed Broadband Wireless Access Systems
Available for free download:
http://standards.ieee.org/getieee802/download/802.16-2004.pdf

[1n] **IEEE 802.16e-2005**
IEEE Standard for Local and metropolitan area networks
Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems
Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands
and
Corrigendum 1

[2] **Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN**
Intel Technology Journal, Volume 08, Issue 03, pp. 201 - 212
Available for free download:
http://www.intel.com/technology/itj/2004/volume08issue03

[3] **IEEE C802.16-02/05**
IEEE Standard 802.16: A Technical Overview of the WirelessMAN™ Air Interface for Broadband Wireless Access
Available for free download:
http://www.ieee802.org/16/docs/02/C80216-02_05.pdf

[4] **IEEE P802.16e/D12**
Draft IEEE Standard for Local and metropolitan area networks
Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems
Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands

[5] **ETSI EN 301 021**
Fixed Radio Systems; Point-to-multipoint equipment; Time Division Multiple Access (TDMA); Point-to-multipoint digital radio systems in frequency bands in the range 3 GHz to 11 GHz
Available for free download:
http://pda.etsi.org/pda/queryform.asp

[6] **Vector Signal Generator R&S® SMU200A - Manual**
Rohde & Schwarz, 1007.9845.32
Available for free download:
http://www.rohde-schwarz.com/product/SMU (→Downloads)

[7] **Signal Analyzer R&S® FSQ3/8/26/31/40 - Operating Manual**
Rohde & Schwarz, 1155.5047.12
Available for free download:
http://www.rohde-schwarz.com/product/FSQ (→Downloads)

[8] **WiMAX IEEE 802.16-2004 TX Tests - Application Firmware R&S® FSQ-K92 - Software Manual**
Rohde & Schwarz, 1300.7462.42
Available for free download:
http://www.rohde-schwarz.com/product/FSQ-K92 (→Downloads)

[9] **PC Software for IEEE 802.16e OFDMA Signal Analysis - Manual**
Rohde & Schwarz
Available for free download:
http://www.rohde-schwarz.com/product/FSQ-K93 (→Download)

[10] **Fundamentals of Spectrum Analysis**
Rohde & Schwarz, 0002.6635.00
Published by the Rohde & Schwarz in-house publisher; available from Rohde & Schwarz sales offices.

[11] **R&S NRPView - PC Software for R&S NRP-Zxx Sensors**
Rohde & Schwarz Application Note 1MA77
Available for free download:
http://www.rohde-schwarz.com/appnote/1MA77

9 Additional Information

This Application Note is updated from time to time. Please visit the website **1MA97** in order to download new versions.

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

10 Ordering Information

RF Signal Generator and Options

SMU200A	Vector Signal Generator	1141.2005.02
SMU-B102	Frequency range 100 kHz to 2.2 GHz for 1st RF path 1)	1141.8503.02
SMU-B103	Frequency range 100 kHz to 3 GHz for 1st RF path 1)	1141.8603.02
SMU-B104	Frequency range 100 kHz to 4 GHz for 1st RF path 1)	1141.8703.02
SMU-B106	Frequency range 100 kHz to 6 GHz for 1st RF path 1)	1141.8803.02
SMU-B202	Frequency range 100 kHz to 2.2 GHz for 2nd RF path 1)	1141.9400.02
SMU-B203	Frequency range 100 kHz to 3 GHz for 2nd RF path 1)	1141.9500.02
SMU-B13	Baseband Main Module 1)	1141.8003.04
SMU-B10	Baseband Generator with ARB (64 Msamples) 2)	1141.7007.02
SMU-B11	Baseband Generator with ARB (16 Msamples) 2)	1159.8411.02
SMU-B14	Fading Simulator 2)	1160.1800.02
SMU-B15	Fading Simulator Extension 2)	1160.2288.02
SMU-K49	Digital Standard IEEE 802.16-2004 3)	1161.0366.02

IQ Modulation Generator and Options

AFQ100A	I/Q Modulation Generator, 100 MHz I/Q Bandwidth	1401.3003.02
AFQ-B10	Waveform Memory 256 Msamples 4)	1401.5106.02
AFQ-B11	Waveform Memory 1 Gsample 4)	1401.5206.02
AFQ-K249	Digital Standard IEEE 802.16 5)	1401.6654.02

Power Meters

NRP	Power Meter (display and control unit)	1143.8500.02
NRP-Z11	Average Power Sensor 10 MHz to 8 GHz, 200 pW to 200 mW	1138.3004.04
NRP-Z21	Average Power Sensor 10 MHz to 18 GHz, 200 pW to 200 mW	1137.6000.02
NRP-Z51	Thermal Power Sensor 0 GHz to 18 GHz, 1 µW to 100 mW	1138.0005.02

RF Signal Analyzer and Options

FSQ3	Signal Analyzer 20 Hz to 3.6 GHz, I/Q BW 28 MHz 6)	1155.5001.03
FSQ8	Signal Analyzer 20 Hz to 8 GHz, I/Q BW 28 MHz 6)	1155.5001.08
FSQ-B71	Analog Baseband Inputs, 50/1M Ohm, I/Q BW 36 MHz 6)	1157.0113.03
FSQ-B72	I/Q Demodulator Bandwidth Extension, I/Q BW 120/60 MHz 6,7)	1157.0336.02
FSQ-K92	WiMAX (802.16-2004) Tx Measurements 8)	1300.7410.02
FSQ-K93	WiMAX (802.16e) Tx Measurements 8)	1300.8600.02

1) **requires SMU200A**
2) **requires SMU-B13**
3) **requires SMU-B10 or SMU-B11**
4) **requires AFQ100A**
5) **requires AFQ-B10 or AFQ-B11**
6) **I/Q BW = I/Q demodulation bandwidth**
7) **120 MHz if RF > 3.6 GHz, otherwise 60 MHz**
8) **requires FSQ**

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