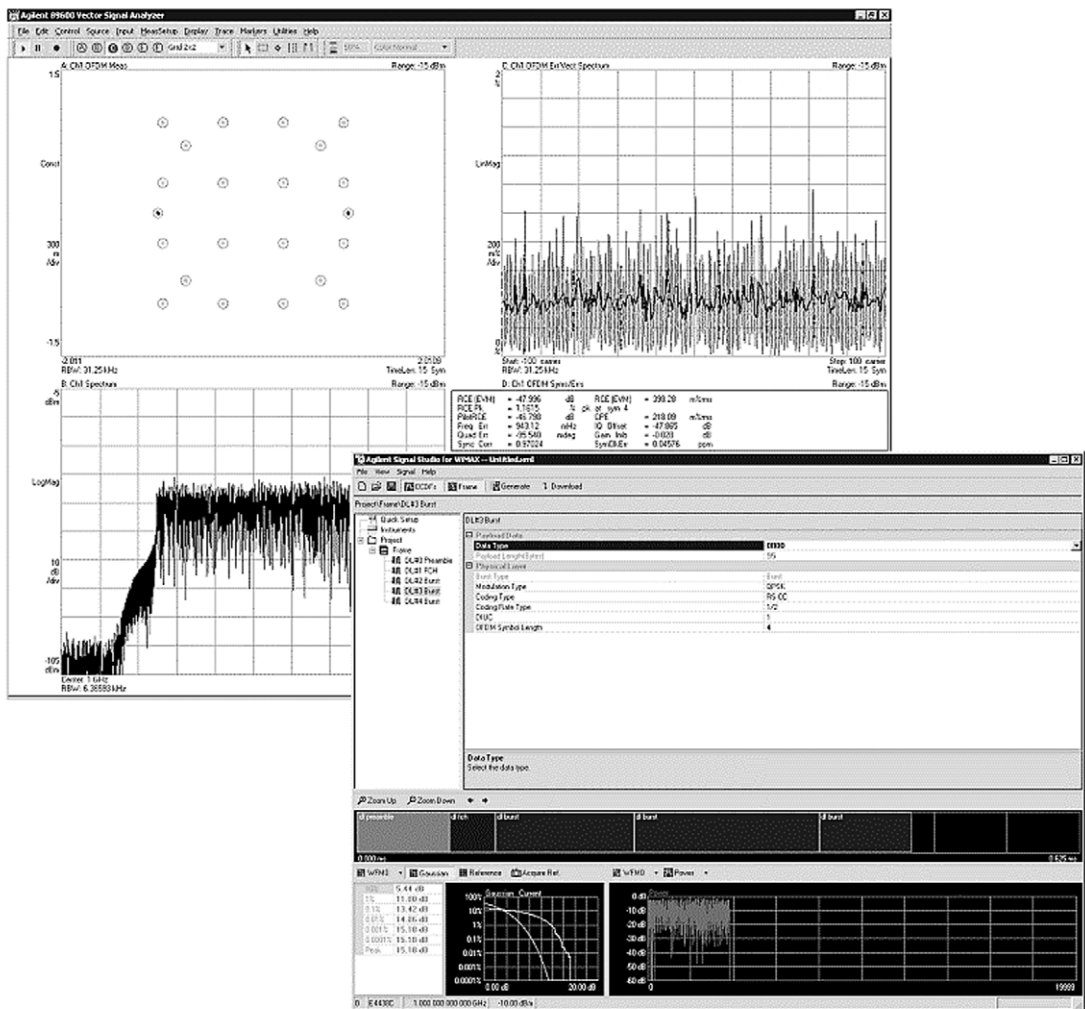


# WiMAX Concepts and RF Measurements

## IEEE 802.16-2004 WiMAX PHY layer operation and measurements

### Application Note



Agilent Technologies

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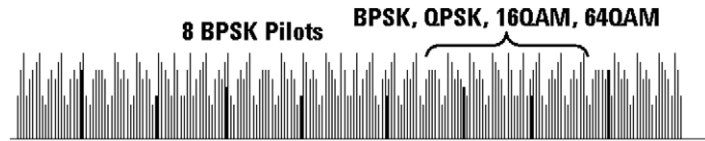
## Introduction

This application note is intended for engineers that need an overall understanding of the basic RF characteristics of the 256 carrier OFDM air interface defined in 802.16-2004 and the specific RF parametric measurement techniques that can be performed with Agilent test solutions.

The 802.16-2004 standard describes four different air interfaces. One of these interfaces is optimized for non-line-of-sight, RF frequencies < 11 GHz, and distances up to 30 km. Although the standard has officially named this PHY layer as WirelessMAN-OFDM, many people refer to this as the WiMAX air interface. The basic characteristics of the air interface are 256 carrier OFDM, bandwidths that range from 1.25 MHz to 20 MHz, and carrier frequencies up to 11 GHz.

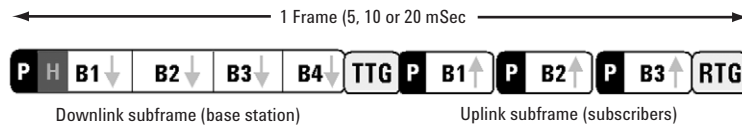
## WiMAX Air Interface

In the WiMAX air interface, the basic OFDM symbols are based on a 256 point FFT. As with other OFDM systems, a portion of these 256 subcarriers are set aside (unused) for guard bands and the center frequency subcarrier is not used because it is easily susceptible to RF carrier feed through. In WiMAX, only 200 subcarriers are actually used. These 200 carriers are allocated as 192 carriers for data and 8 carriers as pilots (see Figure 1). The pilot carriers are always BPSK modulated and the data carriers are BPSK, QPSK, 16 QAM, or 64 QAM.



**Figure 1. OFDM subcarriers**

The system can be configured to use any bandwidth from 1.25 MHz to 20 MHz and regardless of the bandwidth; the symbols always contain 200 carriers. For narrow bandwidth systems, this implies the subcarriers are very closely spaced, which provides a relatively long symbol period (symbol period is defined as  $1 / \text{subcarrier spacing}$ ). These closely spaced subcarriers and long symbols help overcome channel impairments such as multipath. This long symbol period is a key differentiator between WiMAX systems and wireless LAN systems (relatively short symbols), which provides WiMAX with significant advantages for long distances and non-line-of-sight applications.

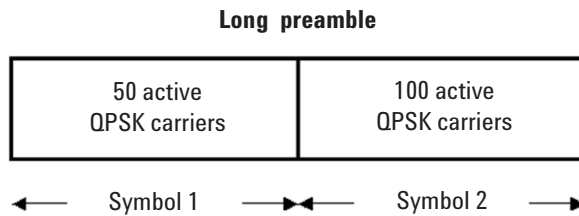


**Figure 2. Downlink and uplink subframes**

WiMAX systems can be deployed as TDD, FDD, or half-duplex FDD. Figure 2 shows a typical frame in a TDD configuration where the basestation and subscriber equipment each transmit on the same RF frequency, separated in time. The basestation transmits a downlink subframe, followed by a short gap called transmit/receive transition gap (TTG), and then individual subscribers transmit the uplink subframes. The subscribers are accurately synchronized such that their transmissions do not overlap each other as they arrive at the basestation. Following all uplink subframes, another short gap called receive/transmit transition gap (RTG) is allocated before the basestation can again start transmitting.

Notice each uplink subframe is preceded by a preamble. This is called a “short preamble” and allows the basestation to synchronize on each individual subscriber.

Looking closer at the downlink, a downlink subframe always begins with a preamble, followed by a header, and one or more downlink bursts of data. These downlink bursts are generally made up of multiple symbols within the burst. Within each burst, the modulation type is constant; however, from burst to burst the modulation type can change. Bursts using robust modulation types such as BPSK and QPSK are required to be transmitted first, followed by less robust modulation types (16 and 64 QAM). Downlink subframes containing all four types of modulation would need to be in this order: BPSK followed by QPSK, 16 QAM, and finally 64 QAM.



**Figure 3. Long preamble**

Every transmission on both the uplink and downlink always begins with a preamble. This preamble allows receivers to synchronize with the transmitter and is used for channel estimation. The downlink transmission begins with a long preamble. The long preamble (Figure 3) is made up of two symbols of QPSK modulation. The first symbol uses 50 of the available 200 carriers (every 4th subcarrier) and the second symbol uses 100 of the 200 carriers (all the even numbered subcarriers). These preamble symbols are transmitted with 3 dB more power than all other symbols in the downlink subframe, making them easier for the receivers to demodulate and decode correctly. A “short preamble” is used at the beginning of each uplink bursts. The short preamble is a single symbol of 100 QPSK carriers (all the even numbered subcarriers). When using extremely long downlink bursts that contain many symbols, it may be desirable to insert a midamble (short preamble) in between the downlink bursts. This short preamble helps receivers resynchronize and perform additional channel estimation.

Following the preamble is a frame control header (FCH). This FCH is implemented as a single symbol of BPSK modulation. This symbol contains 88 bits of overheard data that describes critical system information such as base station ID and the downlink burst profile that receivers need to decode the subframe. The FCH does not contain enough information to fully describe the network or downlink profile, but it does contain enough that receivers can start decoding the downlink bursts.

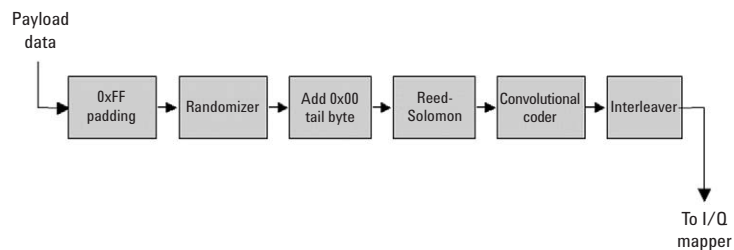
The downlink bursts contain user data as well as control messages. The downlink bursts each contain one or more symbols. Each symbol in the burst contains between 12 and 108 bytes of payload data, depending on the modulation type and coding gain. Table 1 shows the seven different combinations of modulation type and coding gain. For each of these combinations a specific amount of payload data is required for each symbol.

**Table 1. Modulation and coding combinations**

Modulation	RS code	CC code	Overall coding	Uncoded blocks (bytes)	Coded blocks (bytes)
BPSK	(12,12,0)	1/2	1/2	12	24
QPSK	(32,24,4)	2/3	1/2	24	48
QPSK	(40,36,2)	5/6	3/4	36	48
16 QAM	(64,48,8)	2/3	1/2	48	96
16 QAM	(80,72,4)	5/6	3/4	72	96
64 QAM	(108,96,6)	3/4	2/3	96	144
64 QAM	(120,108,6)	5/6	3/4	108	144

The coding process to get from payload data to actual bits sent to the IQ mapper is shown in Table 1. When necessary, padding adds bits so that the payload data is in correct block sizes that will map into an integer number of symbols. The Randomizer XOR's the data with a pseudo random bit sequence to toggle some of the 1's to 0's and some 0's to 1's. This randomizer eliminates long strings of 1's or 0's in the payload data. A single tail byte is added and the bits are ready for Reed-Solomon and convolutional coding. These coding steps provide forward error correction and are very common coding methods used in digital communication systems. This coding adds redundant data that helps identify and fix bits that are missing or corrupted.

The final steps in coding involve interleaving, which is performed in two steps. The first step of interleaving is to rearrange the ordering of the bits to make certain that adjacent bits are not mapped onto adjacent carriers. This helps eliminate errors by reducing the chance that adjacent bits would be lost if a portion of the channel bandwidth is degraded with some type of spurious or band limited noise. The second step of interleaving is to reorder the bits so that the original adjacent bits are alternately mapped into more or less reliable points on the IQ constellation. In complex modulation like 64 QAM, each IQ point represents multiple bits of data, and some of these bits are easier to detect (therefore, more reliable) than other bits. After interleaving, the coded bits are mapped to the IQ constellation, starting with carrier number -100 on up to carrier number +100.

**Figure 4. Channel coding**

To simplify transmitter and receiver designs, all symbols in the FCH and DL data bursts are transmitted with equal power. Because symbols use four different modulation types (BPSK, QPSK, etc.), it is necessary to scale each such that the average symbol power from each symbol is approximately equal. Figure 5 shows an actual measured IQ constellation of a single frame that contains symbols of BPSK, QPSK, 16 QAM, and 64 QAM. This diagram shows each modulation type is scaled differently, and because the individual IQ points do not align, it is possible to see all 86 discrete IQ points (64 QAM + 16 QAM + 4 QPSK + 2 BPSK). Measurements like this help designers quickly identify trouble areas with amplitude scaling or IQ modulation. Recall that the preamble bursts are 3 dB higher than these FCH and downlink burst symbols. The preamble is decoded and used for channel estimation and synchronization, however these symbols are not shown in this display of the IQ constellation.

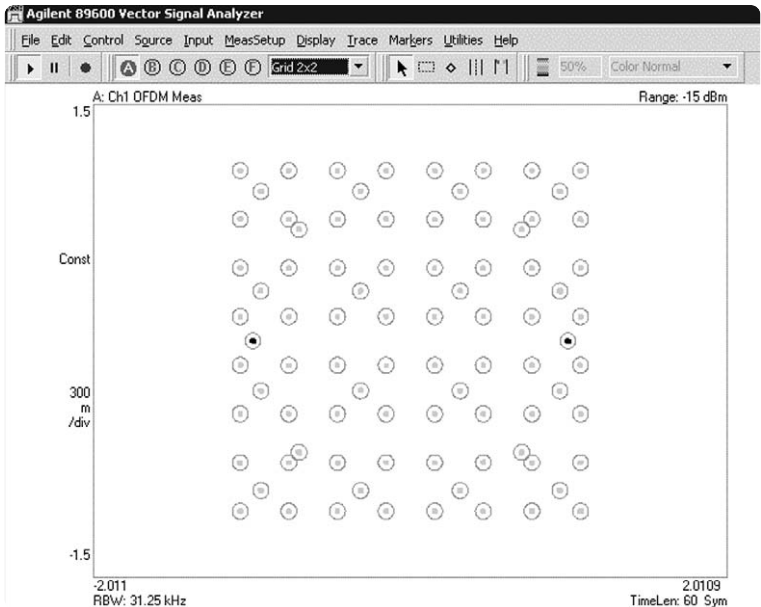


Figure 5. Agilent 89600 IQ measurement of WiMAX downlink frame

## RF Characterization

The overall system performance relies on carefully specified and controlled RF properties. These RF specifications are defined in both the 802.16-2004 as well as “WiMAX certification” documents. Agilent provides a variety of test solutions that can be used to verify various portions of the RF specifications. The remainder of this document describes each RF transmitter and receiver measurement and details Agilent’s recommended test procedure and test solution for each of these measurements. Consider these recommendations as a guideline or starting point that can be tailored to individual needs.

## DUT Control

Although the RF parametric test conditions are defined in 802.16-2004, the standard does not specify how the DUT is controlled. Most device vendors have implemented special DUT control software and DUT test modes that can control transmitter and receiver operation independent of the MAC and protocol control that is used during normal system operation. These special test modes are optimized for repeatable measurements that can be performed quickly without the unnecessary overhead of establishing a link and controlling the air interface through normal MAC/protocol operations.

## Transmitter Tests

Transmitter requirements are defined in IEEE 802.16-2004 section 8.3.10 and 8.5.2. These tests include:

- 8.3.10.1 - **Transmit power level control**
- 8.3.10.1.1 - **Transmitter spectral flatness**
- 8.3.10.1.2 - **Transmitter constellation error**
- 8.5.2 - **Transmit spectral mask (for unlicensed band operation)**
- Additionally, some key transmitter measurements such as **ACPR, maximum output power, spurious and harmonics** are not defined in the 802.16-2004 standard but are left to “local regulations” that are dependent on where the device will be deployed.

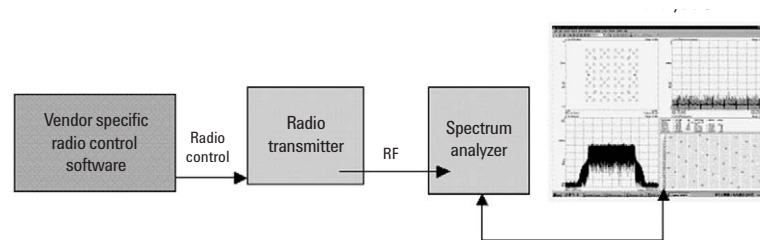


Figure 6. Typical connection diagram for transmitter measurements



## Transmit power level control

Base stations and subscriber stations must be able to adjust their output power over a defined range. Base stations are required to have a minimum adjustment range of 10 dB, where subscriber stations must have a minimum adjustment range of 30 dB for all devices and 50 dB for devices that support subchannelization. Within these ranges step sizes must be a minimum of 1 dB and relative accuracy of all steps less than 30 must be  $\pm 1.5$  dB. Larger steps have  $\pm 3$  dB relative accuracy.

**Table 2. Specifications for transmit power level control**

Step size	Relative accuracy
1 to 30 dB	$\pm 1.5$ dB
> 30 dB	$\pm 3$ dB

### Recommended RF test equipment

- Agilent E4440A PSA Series spectrum analyzer and 89600 Series vector signal analysis (VSA software) with Option B7S WiMAX analysis software

### Agilent measurement setup

For this measurement, the DUT must be set to various output power settings. The RF test equipment is used to accurately measure the relative power of each DUT power setting.

1. The DUT should be set to transmit at valid output power with a frame structure that has a proper preamble and data burst.
2. Measure and record the DUT output power of the data burst with the recommended test equipment.
3. Repeat step 2, looking closely at the power amplifier switch points (power level where a PA is switched in or switched out). Compare the measured data with expected output power from the device.

### Considerations when using the Agilent 89600 VSA with WiMAX analysis software

As shown in the following display, the VSA software provides power measurement results for each burst in the frame. This display shows separate power measurement results for preamble, FCH, and each data burst. To improve accuracy, use bursts that contain many symbols. This provides averaging over a larger number of samples.

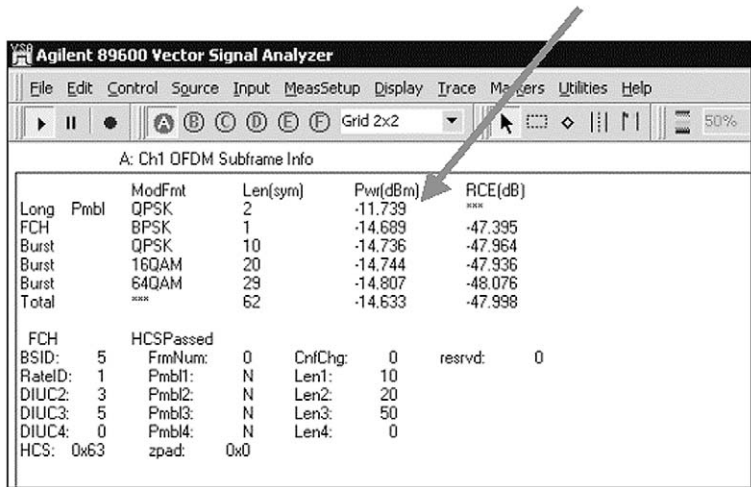


Figure 7. Downlink subframe power measurements

**Test considerations**

The transmitted signal is most likely a preamble followed by bursts of data. The preamble symbols are transmitted at a 3 dB higher power than the data bursts. Because the amplitude varies across the frame, some caution is needed to insure the measurement is performed properly. When making a reference measurement, record the preamble power separate from the power of the data bursts. Then, when the signal output level is changed, compare the new preamble power and data burst power separately to the initial reference measurements. The 802.16-2004 standard does not specifically define which portion of the transmitted signal is used for this measurement, however, because the test is a relative measurement, the test will be valid so long as the reference measurements are performed correctly.

**Transmitter spectral flatness**

During normal system operation, all uplink and downlink transmissions begin with a preamble. The preamble is critical because receivers rely on these preambles to synchronize with the transmitter and perform various channel estimation and equalization processes. The preamble uses QPSK modulation and has no embedded BPSK pilots. Because of this, the preamble is ideally suited to specify spectral flatness across all the subcarriers.

The 802.16-2004 standard states that data shall be taken from the “channel estimation step”, which is the preamble. The specification states, “the absolute difference between adjacent subcarriers shall not exceed 0.1 dB”. In the preamble, because only half or one-fourth of the 200 subcarriers are actually used, adjacent carrier spacing in the preamble is wider than data bursts.

Table 3. Specifications for transmitter spectral flatness

Spectral lines	Spectral flatness
Spectral lines from -50 to -1 and +1 to +50	±2 dB from the measured energy averaged over all active tones
Spectral lines from -100 to -1 and +1 to +100	+2dB /-4 dB from the measured energy averaged over all active tones
Adjacent subcarriers	±0.1 dB

### Recommended RF test equipment

- Agilent PSA Series and VSA software with Option B7S WiMAX analysis software

### Agilent measurement setup

1. The DUT should be set to transmit at valid output power with a frame structure that has a proper preamble.
2. Measure DUT spectral flatness with recommended test equipment. It is necessary to compare relative amplitude of each subcarrier with its adjacent subcarriers.
3. Repeat step 2 at various band edges for RF frequencies and power levels that may have marginal performance.

### Considerations when using the Agilent 89600 VSA with WiMAX analysis software

The VSA analysis software provides a channel equalization function that is ideal for measuring flatness of the preamble. Much like a typical receiver, the analysis software uses the preamble for channel estimation. One of the steps in channel estimation is to determine frequency response (or frequency flatness) of the preamble. This measurement shows the measured spectral flatness of the preamble.

The following display is from the analysis software and shown the equalizer response required to correct the preamble for perfect flatness. The scaling is 0.05 dB / division, so this response is easily within the specification of 0.1 dB flatness from carrier to carrier.

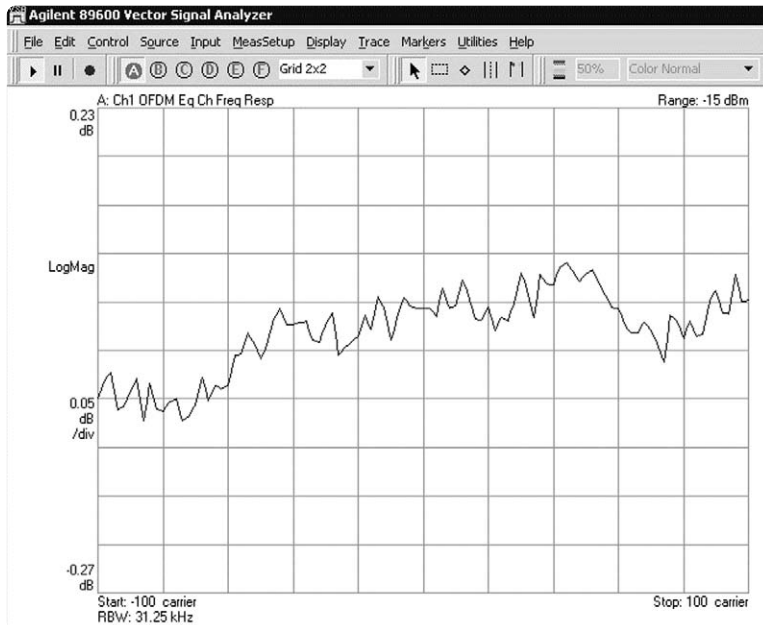


Figure 8. Spectral flatness or channel frequency response with the Agilent 89601A

The preamble used in this measurement contains only even numbered carriers. To estimate the channel response for the odd numbered carriers, the software uses a simple linear interpolation between the two adjacent even numbered carriers. To determine relative flatness from subcarrier to subcarrier, the trace data can be easily downloaded into a spreadsheet for comparison with test limits.

### Test considerations

Although the standard specifies this measurement only for the preamble, because BPSK and QPSK modulated subcarriers all have the same amplitude, it would be possible to characterize a transmitter using data bursts (instead of preambles) that have BPSK or QPSK modulation.

## Transmitter constellation error

This test is a measurement of the transmitter modulation accuracy. Accurate transmitter modulation is necessary to insure the receiver can demodulate the signal with minimal decode errors. This measurement is similar to Error Vector Magnitude (EVM) used in many other digital communication standards. 802.16 introduces a new term - Relative Constellation Error (RCE). A specific algorithm is defined in the standard. This measurement method determines the magnitude error of each constellation point and RMS averages them together across multiple symbols, frames, and packets.

Each of the seven burst profiles (modulation / coding types) has a specification for RCE expressed in dB. The following table shows the allowable RCE for each burst profile.

**Table 4. Specifications for transmitter constellation error**

Burst type	Relative constellation error (dB)
BPSK – 1/2	-13.0
QPSK – 1/2	-16.0
QPSK – 3/4	-18.5
16 QAM – 1/2	-21.5
16 QAM – 3/4	-25.0
64 QAM – 2/3	-28.5
64 QAM – 3/4	-31.0

### Recommended RF test equipment

- Spectrum analyzer (such as E4440A) with WiMAX analysis software (89600 Option B7S)

### Agilent measurement setup

1. DUT should be set to transmit valid subframes (preambles followed by data bursts).
2. Measure DUT Relative Constellation Error with recommended test equipment.
3. Repeat step 2 at various band edges for RF frequencies, modulation types and power levels.

## Considerations when using the Agilent 89600 VSA with WiMAX analysis software

The following display shows the VSA software measurement results for constellation error. The displays shown include a graphical output (to help troubleshooting) as well as a tabular function, which shows numeric results for the RCE calculation. This calculation is the averaged result from all symbols as defined in the configuration for Demod Properties.

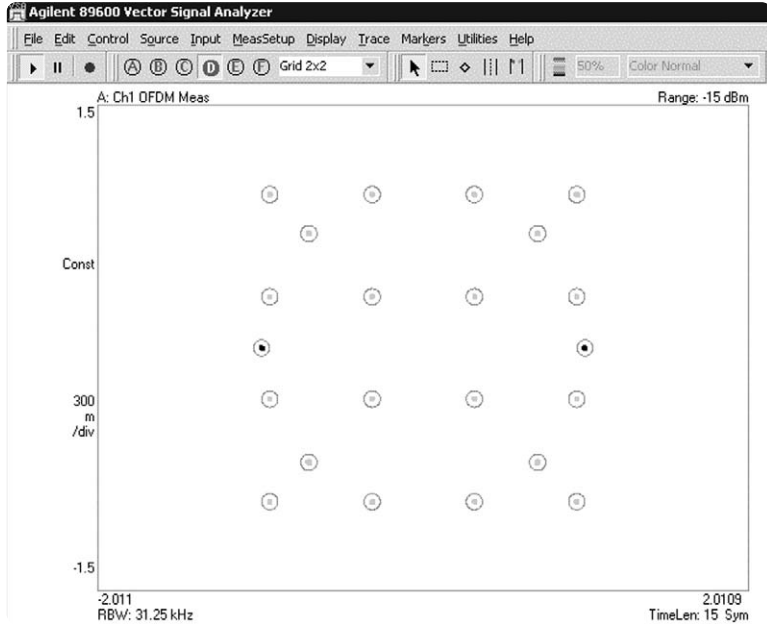


Figure 9. Graphical display of IQ constellation

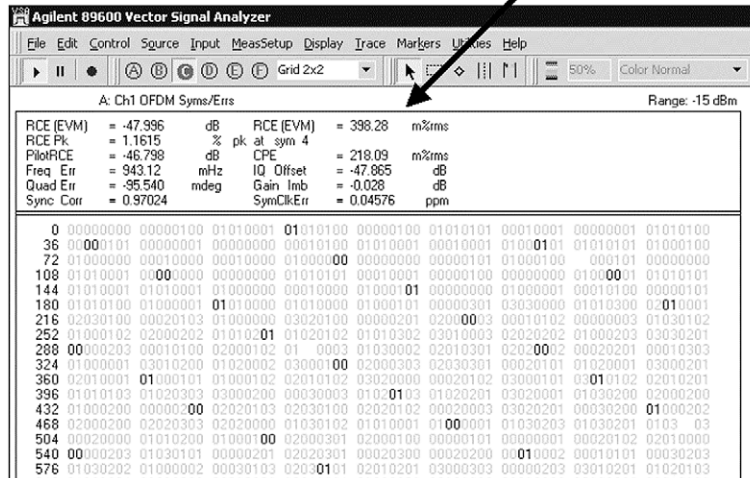


Figure 10. Numeric display of RCE results

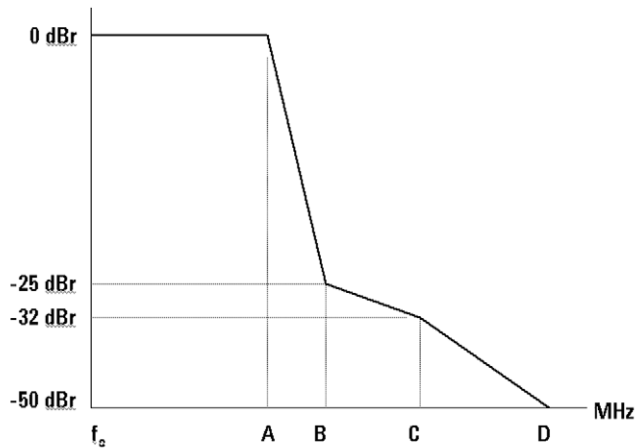
**Test considerations**

In the analysis software under MeasSetup ≥ Demod Properties, it is possible to specify which symbols within the captured RF signal that are to be used to calculate the measurement results. This allows a user to select specific symbols that have specific modulation types. This is necessary because each modulation type has its own specification for RCE. The 802.16-2004 standard specifies that all active carriers in the symbol are to be used for calculation of the constellation error. This is the algorithm implemented in the VSA software.

**Transmitter spectral mask**

This test measures the spectral profile of the transmitter to verify that the device is not transmitting excessive energy outside its assigned channel bandwidth. Most WiMAX deployments will be in frequency bands that are controlled by local regulations and because these regulations vary widely, the 802.16 specification does not attempt to specify spectral mask for any operation other than “unlicensed”. The measurement procedure defined here is the same, however specific limits must be determined by the user and will depend on where the device will be deployed.

The following diagrams show the spectral mask specification for 802.16 “unlicensed” operations.



Channelization (MHz)	A	B	C	D
20	9.5	10.9	19.5	29.5
10	4.75	5.45	9.75	14.75

Figure 11. Spectral mask and limits

**Recommended RF test equipment**

\* Spectrum analyzer (such as E4440A) with WiMAX analysis software (89600 Option B7S)

**Agilent recommended test procedure**

1. DUT should be set to transmit a subframe with valid preamble and data burst.
2. Measure DUT spectral output with recommended test equipment.
3. Repeat step 2 at various band edges for RF frequencies, modulation types, and power levels.

## **Considerations when using the Agilent 89600 VSA with WiMAX analysis software**

The recommended test configuration will measure and display the spectral output with a variety of Resolution BW and Video BW choices. Although the software does not perform “pass/fail” testing, it is possible to define trace lines that provide an easy method to visually see if the spectrum is above or below the recommended spectral mask.

### **Test considerations**

When a transmitter is at very low output power it is often not reasonable and not necessary for a device transmitter to have a mask that is 50 dB below the in-channel power. Spectral mask regulations will generally have some absolute value lower limit (in dBm) to specify the lowest required out-of-channel power for these low level measurements.

## **Non-specified transmitter measurements**

Some key transmitter measurements such as ACPR, maximum output power, spurious and harmonics are not defined in the 802.16-2004 standard but are left to “local regulations”. The test limits will be dependent on where the device will be deployed but the test methods described here are generic enough to be applied in almost all circumstances.

### **ACPR / ACLR**

Adjacent Channel Power Ratio (ACPR) or Adjacent Channel Leakage Ratio (ACLR) is a measure of the transmitter energy that is ‘leaking’ into an adjacent or alternate channel. Ideally, a transmitter could keep all of its transmitted energy in its assigned channel, but realistically some small amount of the transmitter energy will show up in other nearby channels. A spectrum analyzer is ideal to make this measurement.

The first step is to measure the in-channel power. After this, the analyzer is re-tuned to a frequency offset 1 channel away, and the ‘leakage’ power is measured. The difference in these two measurements is the ACP ratio. This will typically range from 30 dB to 80 dB depending on the application. In some cases, the analyzer itself does not have sufficient performance to reject the in-channel signal when measuring the adjacent channel power. In these cases a special notch filter is used to suppress the in-channel power while measuring the small out of channel signal.

### **Maximum output power**

For WiMAX applications, the maximum output power will be specified by local regulations depending on the band of operation. During normal operation, the transmitter will generally only transmit sufficient power for the system to function properly. Higher output power will cause unnecessary interference in the system and for hand held devices; excessive output power causes unnecessary battery drain. Test equipment such as power meters and spectrum analyzers are ideal for performing output power measurements.

### **Spurious and harmonics**

A typical RF output section will have some filtering devices to suppress unwanted “internal” signals from being transmitted. The internal signals are unwanted by-products of the normal signal creation process (such as mixing, modulation, or amplification). These are typically classified as either harmonics or spurious signals. Harmonics are integer multiples of the primary transmitter frequency and therefore the frequency at which they will appear is very predictable. Spurious signals are typically image frequencies caused by internal mixing of an oscillator or clock frequency with the primary transmitter output frequency.

Understanding the block diagram of a device is helpful to understand potential sources of spurious energy, however it is still common to use “spur searches” to scan the entire output spectrum of the device looking for spurious energy. Spectrum analyzers are ideal instruments to be used for both harmonic and spurious measurements. Typically harmonics are measured to at least the 5th harmonic - implying that for a 3.5 GHz signal, a spectrum analyzer of at least 17.5 GHz is required.

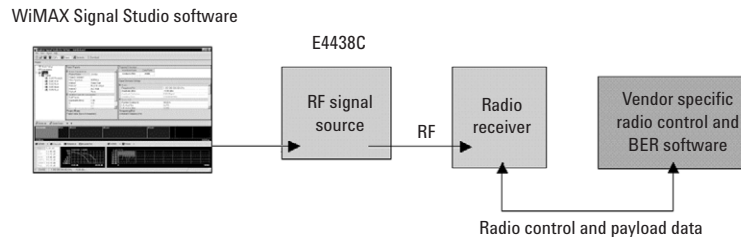


## Receiver Tests

Receiver requirements are defined in IEEE 802.16-2004 section 8.3.11. These tests include:

- 8.3.11.1 - **Receiver sensitivity**
- 8.3.11.2 - **Receiver adjacent and alternate channel rejection**
- 8.3.11.3 - **Receiver maximum input signal**
- 8.3.11.4 - **Receiver maximum tolerable signal**
- 8.3.11.5 - **Receiver image rejection**

These five receiver tests can all be performed as variations of the *Receiver Sensitivity* test described here. The test for *Receiver adjacent and alternate channel rejection* requires an additional RF source to be added as a jamming signal. This jamming source must be a conforming signal with OFDM modulation.



**Figure 12. Typical configuration for receiver test**

## Receiver sensitivity

This test measures a receiver's performance using known signal conditions that include: modulation and coding type, SNR, and input level. Using these specified conditions, receivers must be able to decode data bits with a BER less than  $1 \times 10^{-6}$ . The specific data patterns are specified in IEEE 802.16-2004 section 8.3.11.1. The following table summarizes the test conditions for a variety of bandwidths and modulation types.

**Table 5. Specifications for receiver sensitivity (dBm)**

Bandwidth	Modulation and coding rate						
	BPSK	QPSK		16 QAM		64 QAM	
	1/2	1/2	3/4	1/2	3/4	2/3	3/4
1.75 MHz	-93.7	-90.7	-88.9	-83.7	-81.9	-77.4	-75.7
3.5 MHz	-90.7	-87.7	-85.9	-80.7	-78.9	-74.4	-72.7
7.0 MHz	-87.6	-84.6	-82.8	-77.6	-75.8	-71.3	-69.6
10.0 MHz	-86.1	-83.1	-81.3	-76.1	-74.3	-69.8	-68.1
20.0 MHz	-83.0	-80.0	-78.2	-73.0	-71.2	-66.7	-65.0
Rx SNR (dB)	6.4	9.4	11.2	16.4	18.2	22.7	24.4

### Recommended RF test equipment

- Agilent E4438C ESG vector signal generator with Option 403 (AWGN) and N7613A Signal Studio for WiMAX application software

### Agilent measurement setup

1. Using the application software, set the RF signal generator to generate the test signals defined in the previous table. The RF input level to the DUT is critical. Any cable losses between the RF source output and the DUT input must be compensated by adjusting the RF output level higher than the value specified in the table.
2. Set the DUT to receive and decode a continuous stream of packets that contain the special data patterns defined in the 802.16-2004 standard. The DUT must calculate BER or provide the data bits externally to a BER test set that can calculate BER by comparing the received data bits with the expected values. The BER calculation is performed on fully decoded payload data that does not contain Forward Error Correction.
3. Repeat this test for all valid modulation and coding rates.

### Considerations when using the Agilent ESG signal generator with Signal Studio software

The special data patterns described in 802.16-2004 are available as part of Agilent's Signal Studio for WiMAX application software for the ESG signal generator. The ESG with Option 403 also includes the ability to digitally add AWGN noise and create test signals with highly accurate SNR and output power levels. Because the payload data rate will vary widely depending on the system bandwidth, modulation type and coding rate, the amount of time required to run this test will also vary. High bandwidth systems with QAM modulation should only require one or two seconds of data and lower bandwidth systems with BPSK or QPSK would need to be run for at least several seconds.

The Signal Studio software has a MAC PDU editor that allows users to configure various data choices. The IEEE 802.16-2004 special payload data is included as one of these choices. Figure 13 shows a picture of the MAC PDU editor in the Signal Studio software.

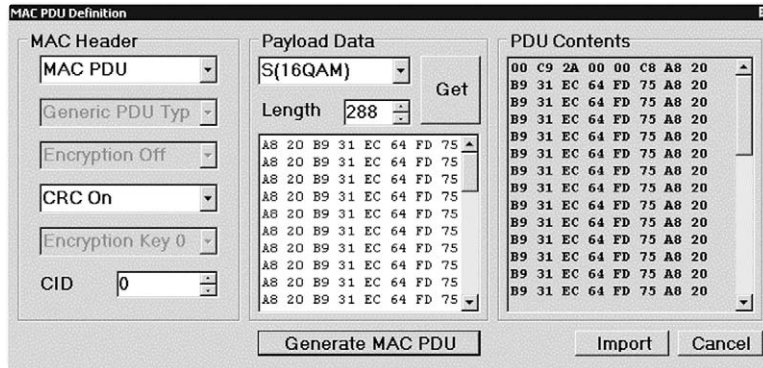


Figure 13. MAC PDU editor

## Related Literature

*89600 Series Vector Signal Analysis Software 89601A/89601AN/89601N12, Data Sheet*, Literature Number 5989-1786EN

*E4438C ESG Vector Signal Generator, Data Sheet*, Literature Number 5988-4039EN

*89600 Vector Signal Analyzers, Data Sheet*, Literature Number 5988-7811EN

*89600 Series Vector Signal Analysis Software WiMAX, Demonstration Guide and Application Note*, Literature Number 5989-2029EN

*Equalization Techniques and OFDM Troubleshooting for Wireless LANs, Application Note 1455*, Literature Number 5988-9440EN

### *References*

*IEEE 802.16-2004 Air Interface for Fixed Broadband Wireless Access Systems*

## Web Resources

For additional information, please visit:  
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