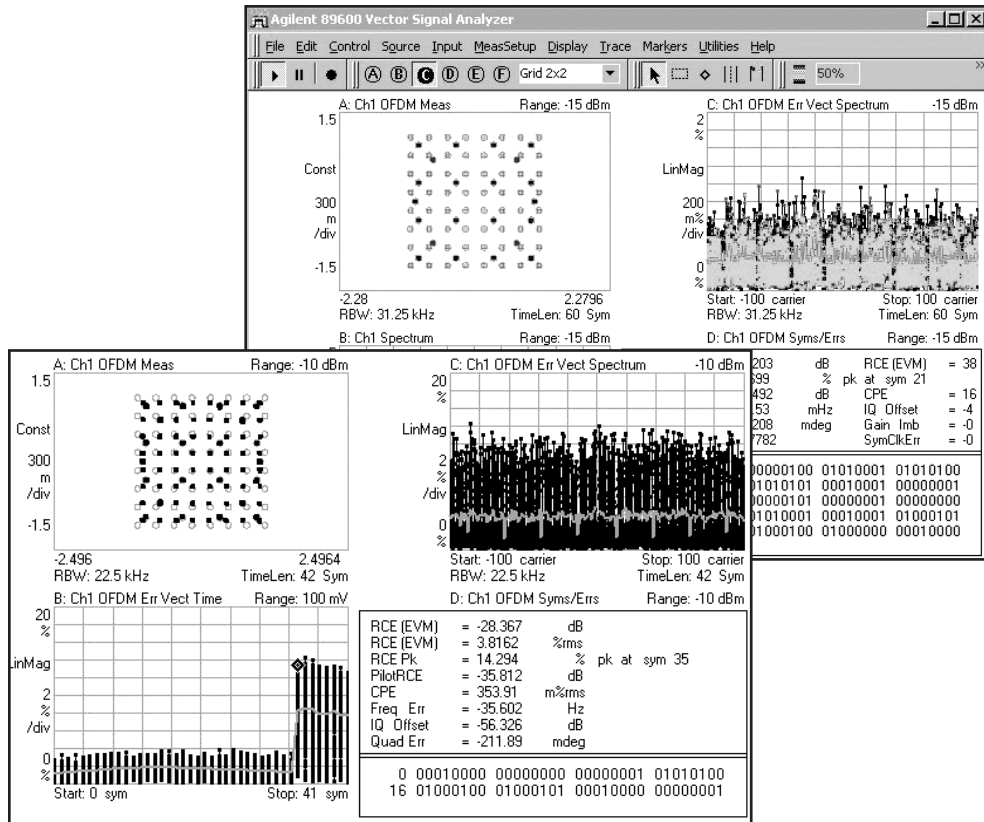


# Agilent 89600 Series Vector Signal Analysis Software WiMAX (IEEE 802.16-2004)

## Demonstration Guide and Application Note

Includes general measurements and digital modulation analysis.



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## Overview

This demonstration guide describes typical procedures for making RF measurements on WiMAX signals. These measurements may be made on complete systems such as base stations or subscriber units, or on subsystems or circuits such as modulators, amplifiers, or RF conversion circuits. Measurements may be made for the purpose of system integration and troubleshooting (finding the source of problems), or for the purpose of testing against published or internal specifications.

Successful evaluation and troubleshooting of signals as complicated as WiMAX signals requires an organized approach. This guide uses the following approach:

### **Step 1: Spectrum and time domain measurements**

These measurements evaluate the basic parameters of the signal, the parameters that must be correct for demodulation to take place. Parameters such as center frequency, bandwidth, burst timing, preamble structure and carrier spacing.

### **Step 2: Basic digital demodulation**

These measurements evaluate the quality of the constellation. Along with a display of the constellation they include static parameters such as: EVM, gain imbalance, quadrature error, I/Q offset, frequency error, and symbol clock error.

### **Step 3: Advanced digital demodulation**

These measurements are used to investigate the causes of errors uncovered in the basic modulation parameters, particularly EVM errors. These include dynamic parameters such as: Error vector frequency, error vector time, and WiMAX specific measurements such as pilot error, frequency response, subframe information, and FCH information.

## Equipment Needed

This demonstration uses the 89600 vector signal analysis (VSA) software and a PC meeting the requirements shown. The measurements shown are made on time capture (recording) files supplied with the 89600 software and are the same as the measurements of "live" signals from signal generators or from actual WiMAX equipment.

## Trial Use of Software

You can get a fully operational copy of the 89600 software from the Agilent web site. Go to the site ([www.agilent.com/find/89600](http://www.agilent.com/find/89600)) and scroll down to "Order free 89600 Demonstration Software".

You can use the 89600 software on a trial basis for free. After installing the software select either the trial license or the demo license:

- The *trial license* provides all 89600 functionality, including measurements with analyzer hardware and all options. The duration of this license is two weeks.
- The *demo license* does not have a time limit but it measures only the signal capture files provided with the Agilent 89600 software. These capture files include the two WiMAX examples used in this demo guide. The demo license must be selected each time the analyzer software is started, and can be used both before and after the trial license is used.

Both the trial and demo licenses provide full access to the 89600 help text and measurement tutorials, including example impaired signals. You do not need to contact Agilent to obtain these licenses.

**Table 1. System requirements**

PC requirement	Desktop	Laptop
CPU	180 MHz Pentium or AMD-K6 (> 300 MHz recommended)	> 300 MHz Pentium or AMD-K6
Empty slots (required only if using measurement hardware)	1 PCI-bus slot (two recommended)	1 CardBus type II slot (two recommended)
RAM	192 MB (256 MB recommended)	192 MB (256 MB recommended)
Video RAM	4 MB (8 MB recommended)	4 MB (8 MB recommended)
Hard disk space	200 MB available	200 MB available
Operating system	Microsoft® Windows 2000 or XP Professional	Microsoft Windows 2000 or XP Professional
Additional drive	CD ROM or 3.5 inch floppy	CD ROM or 3.5 inch floppy
Interface support (required only if using measurement hardware)	IEEE 1394-1995 (FireWire), LAN, or GPIB	IEEE 1394-1995 (FireWire), LAN, or GPIB

**Table 2. Software requirements**

Version	89600 version 5.30, or higher
Options	- 200: Basic vector signal analysis - 300: Hardware connectivity (required only if measurement hardware will be used) - B7S: 802.16 OFDM modulation analysis

## Spectrum and Time Domain Measurements

Even when the primary purpose of a measurement is to evaluate modulation quality, it is usually a good idea to view the signal in the time and frequency domains first, to verify proper center frequency, span, and input range. For pulsed/bursted signals it can also be very helpful to use the analyzer's time-domain displays to properly set trigger parameters and measurement length.

For OFDM signals such as WiMAX, time and frequency domain measurements provide valuable insight into the signal and the channel, as we will see in the demonstrations that follow.

Preset the signal analyzer and recall the first recorded signal as shown in Table 3.

*Note: In the tables the general instructions are shown in italicized text. The text following the colon indicates the toolbar and menu information.*

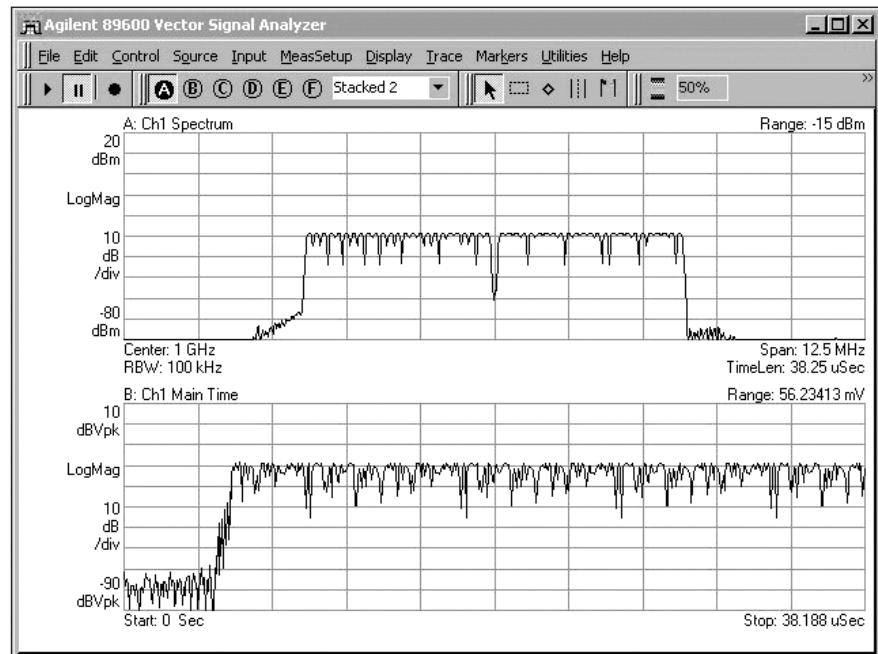
**Table 3. Frequency and time domain setup**

Instructions	Navigation
<i>Preset the analyzer.</i>	Click File > Preset > Preset All.
<i>Recall the simulated WiMAX signal WiMAX_7MHz.sdf.</i>	Click File > Recall > Recall Recording and navigate to the directory which contains the signal C:\Program Files\Agilent\89600VSA\help\signals\WiMAX_7MHz.sdf).
<i>Begin replay of the recording.</i>	Click on ▶ (toolbar, left side).
Notes	
The size of the display window can be changed, as desired. It may be useful to enlarge the display window (click and drag, as with any standard window) to see fine structure in a time domain or frequency domain display.	

Click the Restart button ▶ to start the measurement. The analyzer will playback and measure the signal, starting at the beginning of the recording each time the restart button is pressed. The analyzer defaults to the span used to record the signal, and an overlap (governs the speed of signal playback) of 90%.

Click the pause button II in the toolbar to temporarily halt playback. Click it again to resume playback from the point where it was paused.

If you wish to see what portion of the recording is currently selected for analysis, you can bring up the player window by selecting Control > Player. This window provides both a graphical and numeric indication of the current analysis location in the recording.



**Figure 1. Spectrum (top trace) and RF burst envelope (bottom trace) of a 7 MHz WiMAX signal.**

The analyzer defaults to a stacked 2-trace display where the top trace is a spectrum measurement and the bottom trace is a time domain measurement, as shown in Figure 1. The default for the bottom trace is a vertical axis indicating logarithmic signal magnitude (envelope of the signal). The RF bursts in this signal can be seen as the recording is played back. The recording begins with the RF signal off (between subframes), and the first RF burst (a downlink subframe) begins after a number of display updates.

You can now examine the signal spectrum in the top trace, and RF bursts (burst profiles or envelopes) in the bottom trace. The spectrum measurement in the top trace corresponds to the time record shown in the bottom trace. The spectrum changes as successive measurements are performed on data from the time capture recording.

The signal may be easier to see clearly if you auto-scale the spectrum trace by right-clicking the mouse pointer anywhere in the upper trace and selecting “Y Auto Scale” with either mouse button.

## Changing the playback speed of a recording

Next, slow down the replay of the recording to examine the changes in the signal in more detail. See the instructions in Table 4.

Displays such as this are useful for verifying the proper position of analysis in the time and frequency domains, before demodulation is performed. It is possible to verify the proper center frequency and measurement span, and to select a trigger level on bursted signals, as we will show below.

**Table 4. Changing the replay speed of the recording**

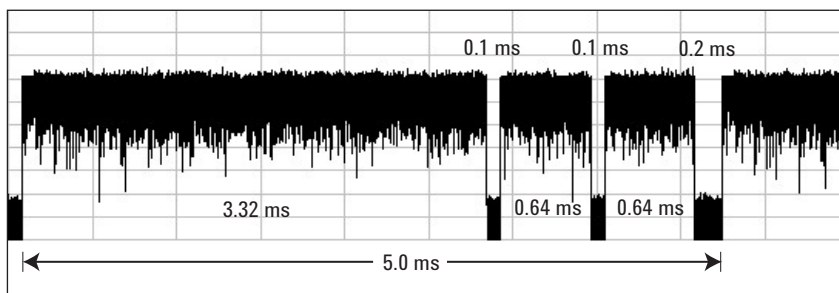
Instructions	Navigation
<i>Change the overlap for non-averaged measurements.</i>	Click MeasSetup > Time >. Click “Max Overlap (Avg Off)” and change the number to 95%. Click ▶ to restart playback/measurement.

### Note

The greater overlap slows the playback and more display updates are required (after a restart) before the downlink subframe begins. This measurement setup offers a better chance to see the spectrum change as the preamble and the data part of the subframe are measured. You may be able to identify some of the OFDM carriers in symbols one and two of the preamble at the beginning of each subframe. Playback can be slowed further by using overlap settings greater than 95%.

## WiMAX example signal

The WiMAX\_7MHz.sdf recording contains five WiMAX frames, center frequency at 3.5 GHz, with a new frame beginning every 5 ms. The downlink subframe is 3.32 ms long and the uplink subframes are both 0.64 ms in length. There are 100 μs gaps after the downlink subframe and the first uplink subframe, with a 200 μs gap between the second uplink subframe and the next downlink subframe.



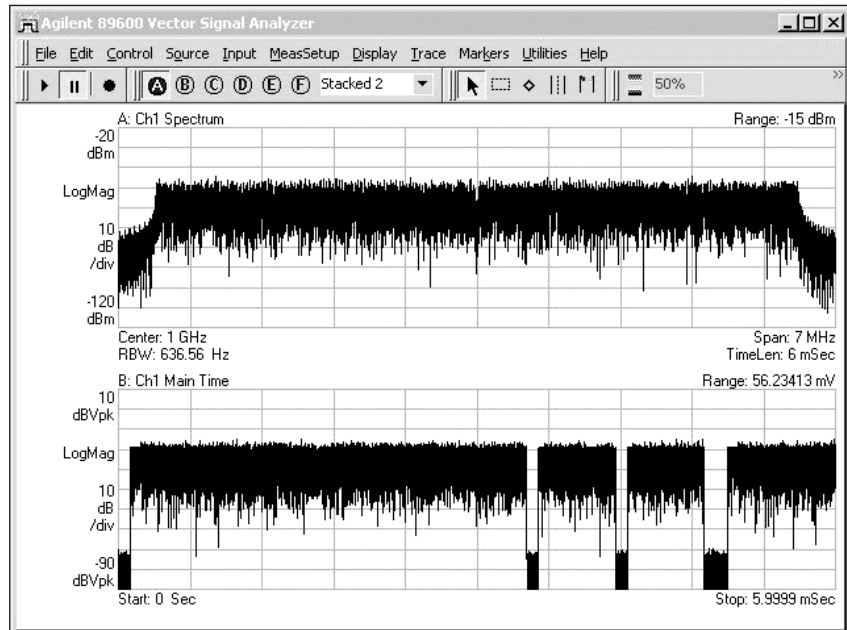
**Figure 2. WiMAX signal example.**

## Examining signal timing parameters

Composite signals such as the one used in this analysis are challenging to measure accurately, due to time-varying characteristics such as unequal-length bursts, unequal-length off-times, and modulation related amplitude variations. Some sort of triggering or synchronization is usually necessary for stable and accurate measurements in time, spectrum, and digital demodulation modes. Fortunately, the 89600 software includes features such as magnitude (RF envelope) triggering, trigger hold off, and pre- or post-trigger delay. These features are available for both live and recorded signals, and can be used to stabilize measurements on any portion of the signal, as we will demonstrate below.

First, the analyzer will be configured to measure the timing parameters of the entire uplink/downlink frame, with a frequency span that more closely matches the bandwidth of this signal. In the 89600, the span (also the center frequency) of the analysis can be changed after a recording is made, and the time record length can be extended as described in Table 5.

An example measurement of the entire downlink/uplink frame (and part of another) is shown in Figure 2. The large number of frequency points selected in Table 5 has allowed a much longer time record and provided much more frequency resolution (much narrower RBW).



**Figure 3. Spectrum (top) and RF burst envelope (bottom) of the 7 MHz WiMAX frame, including downlink subframe and two uplink subframes. The beginning of the second downlink subframe is also shown.**

**Table 5. Changing playback frequency span and time length**

Instructions	Navigation
<i>Reduce frequency span to 7 MHz.</i>	Click MeasSetup > Frequency tab >. Click "Span:" and enter "7 MHz". (You can also double-click on the span annotation in the lower right of the upper display grid (trace A) and enter "7 MHz" in the box.)
<i>Select a larger number of frequency points.</i>	Click MeasSetup > ResBW tab >. Click the "Frequency Points" drop-down arrow and scroll up and select 51201. (Increasing the number of frequency points allows a longer time record while maintaining the 7 MHz frequency span; for more information on time record go to Help > Content > Index and enter "time record length".)
<i>Select a longer time record length.</i>	Click MeasSetup > Time >. Click "Main Time Length:" and enter "6 ms". Click ▶ to restart playback then click    to pause the playback.

### Note

The beginning of the RF burst should be in the first division of the time domain display (see Figure 3) in the lower trace. If playback progresses too far, simply click the ▶ and || buttons again.

## Burst timing measurements

Accurate values for the time parameters of the RF burst (frame and subframe) can now be measured directly using markers, as described in Table 6. The mouse can be used to select marker locations for an offset measurement. The result is shown at the bottom of the display (see Figure 4). The marker can be quickly and precisely placed on the desired portion of the signal by first dragging it to the approximate location and then fine-tuning the selection with the left/right arrow keys on the keyboard. A great deal of resolution is available in a display such as this, due to previous selection of 50,000 frequency points.

Verifying signal timing parameters in this way also provides useful information for setting up triggered measurements.

## Triggering on WiMAX frames

The analyzer can be configured for stable triggering and measurement of WiMAX frames. Triggering on a downlink sub-frame is described in Table 7. The off-time in one of the RF bursts in the frame has a duration of 200  $\mu$ s while the duration of the other two off-times is 100  $\mu$ s. Stable triggering can be achieved by any hold off value greater than 100  $\mu$ s and less than 200  $\mu$ s. This triggering approach works the same with live signals as it does with recorded ones.

**Table 6. Measuring frame and subframe timing**

### Navigation

Click the  $\diamond$  in the marker tools area of the toolbar to activate the marker. The cursor will change to a  $+$ .

Click on the rising edge of the downlink (long) subframe in the lower trace. A  $\diamond$  marker will appear on the trace.

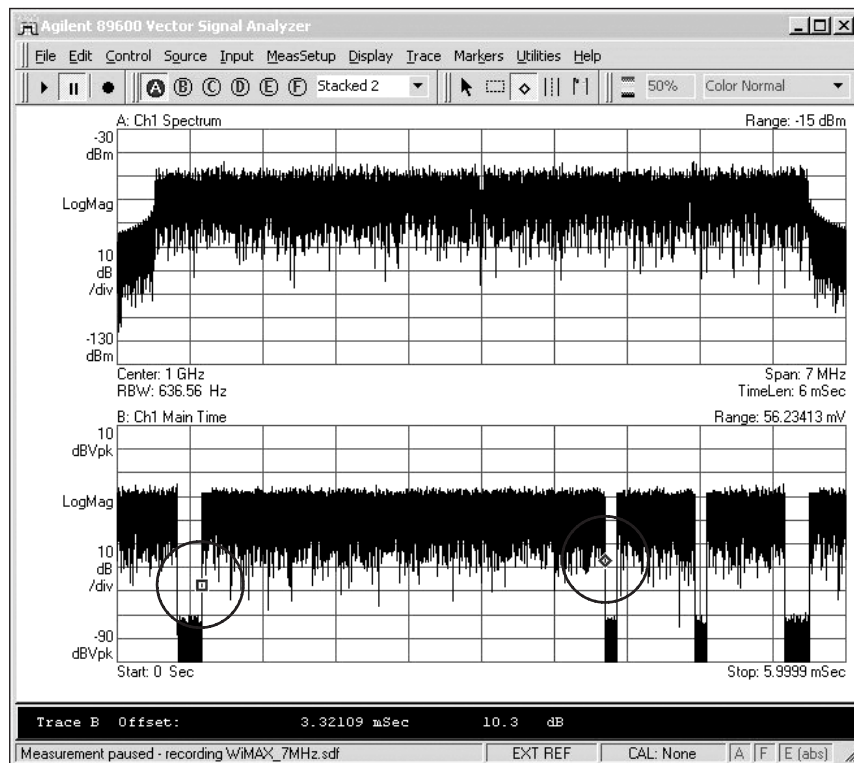
Place the marker precisely on the rising edge by holding down the left/right arrow keys on the keyboard until the desired point on the rising edge is selected.

Right click the mouse with the cursor in the lower trace and select "Move Offset to Mkr"; an offset marker [  $\square$  ] will overlay the  $\diamond$ .

Use the mouse to click and drag the  $\diamond$  to the falling edge of the burst. Use the left/right arrows on the keyboard to adjust the placement of the marker; the difference in time between the two markers is shown at the bottom of the display.

### Note

To turn the markers off right-click in the lower trace and de-select "Show Marker" and "Show Offset".



**Figure 4. Offset marker (bottom trace) measuring WiMAX down link burst.**



Because hold off is used, the precise trigger level is not critical, and values between 0.5 mv and 110 mv will work well. The negative (pre-trigger) delay used in Table 7 allows the rising edge of the RF burst to be more easily viewed and measured. Other delay values, including positive ones, allow other portions of the frame to be selected for measurement. For example, a positive trigger delay of 3.42 ms (3.32 ms for the first subframe and 0.1 ms for the off-time) sets the beginning of the measurement to the beginning of the first uplink subframe.

### Downlink measurements

We may now take a closer look at the spectrum and time views of the initial parts of the downlink subframe. With stable triggering established this is a simple matter of reducing the time record length, adjusting trigger delay if necessary, and performing time-gated analysis using the gate markers as described in Table 8.

The two symbols in the long preamble of this 7 MHz nominal bandwidth WiMAX signal are 40  $\mu$ s long, including a 1/4 guard interval, so a good value for the time record length is 100  $\mu$ s.

The spectrum in the upper trace of Figure 5 represents the entire time record shown in the lower trace, which includes the rising edge of the long preamble, the two 40  $\mu$ s long symbols of the preamble and part of the frame control header (FCH), the first symbol after the downlink preamble.

**Table 7. Setting up trigger parameters for the composite WiMAX signal**

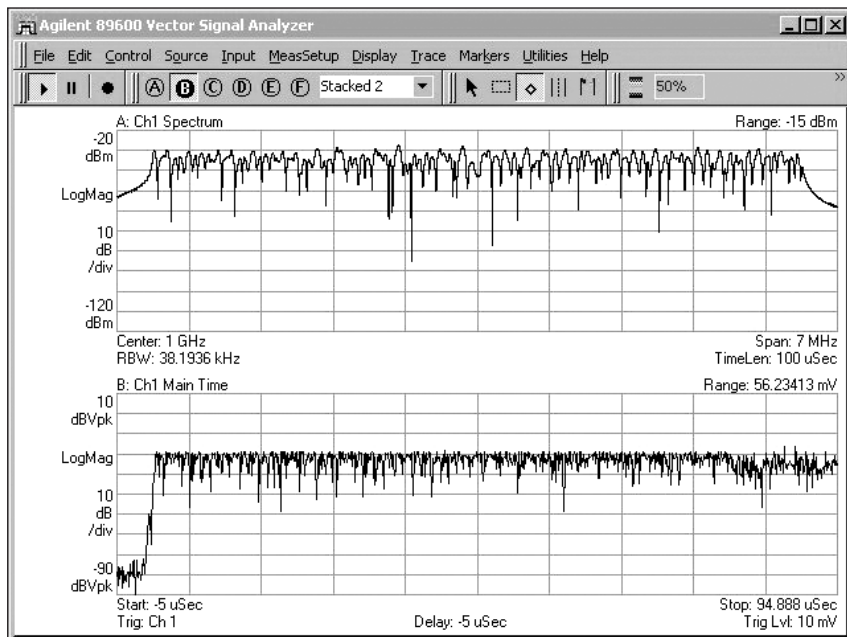
Instructions	Navigation
Select playback triggering with delay and hold off appropriate for this signal.	Click Input > Playback Trigger > . Click the "Type:" drop-down arrow and select "Magnitude". Click "Mag Level:" and enter "10 mv". Click "Hold-off:" and enter a value greater than 100 $\mu$ s and less than 200 $\mu$ s. Click "Delay:" and enter "-5 $\mu$ s" (a negative value representing a pre-trigger delay). Click ▶ to restart playback/measurement.

**Table 8. Time-domain and spectrum analysis of the initial portion of the downlink subframe**

Instructions	Navigation
Select a shorter time record length.	Click MeasSetup > Time > . Click "Main Time Length:" and enter "100 $\mu$ s". Click ▶ to restart playback.

### Note

The subframes in this recording are repeated copies of the same symbols and the analyzer can make new measurements without playing back new data, so the analyzer can respond more quickly to time gate adjustments in the pause mode.



**Figure 5. Detailed spectrum and time domain displays of WiMAX signal. The lower trace shows the turn-on event and amplitude variations due to modulation for the two symbols in the preamble (equalizer training sequence).**

## Time-gated measurements of the preamble

The spectrum and time parameters of the preamble play a key role in successful demodulation of the subframe. The time-gated measurement function is an easy and direct way to analyze these parameters.

The time-gating parameters can be set up numerically or graphically as described in Table 9. The example signal begins with a long preamble containing two WiMAX symbols, each 40  $\mu$ s in length. Your measurement should be similar to the one shown in Figure 7.

The first symbol in the preamble is composed of every 4<sup>th</sup> OFDM carrier (50 out of 200 total) and is used by the receiver for coarse signal acquisition and initial equalizer setup. The current RBW (determined by the selected time gate length) of the analyzer is inadequate to clearly resolve the individual carriers. Fortunately the vector signal analyzer software offers a selection of RBW filter shapes so you can trade some amplitude accuracy for greater frequency resolution. This is accomplished by changing the RBW window type as described in Table 10. Gate length is also changed to exactly 40  $\mu$ s, to match the WiMAX symbol time.

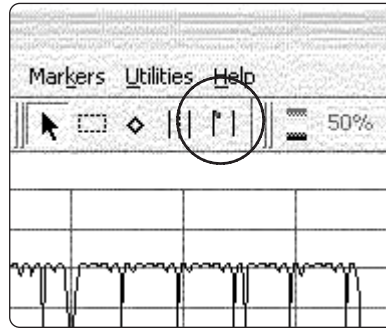


Figure 6. Time gate marker enable.

Table 9. Time gate measurement of the preamble

Instructions	Navigation
Activate the gate marker.	Click Markers > Tools > Time Gate. (Alternately select the time gate marker tool from the marker function toolbar at the top of the display, see Figure 6.)
Set the start location for the time gate by clicking the mouse at the top of the rising edge of the RF burst; the analyzer will switch to time-gated mode (default length approximately 2 $\mu$ s) and display two vertical lines in the time trace as gate markers.	Click on the left vertical marker line and drag it to the desired start location (if needed). Click on the right marker and drag it out to a length of approximately 40 $\mu$ s (4 divisions of the display).

### Note

The display should look like Figure 7. The spectrum in the top trace will now reflect only the time between the gate markers.

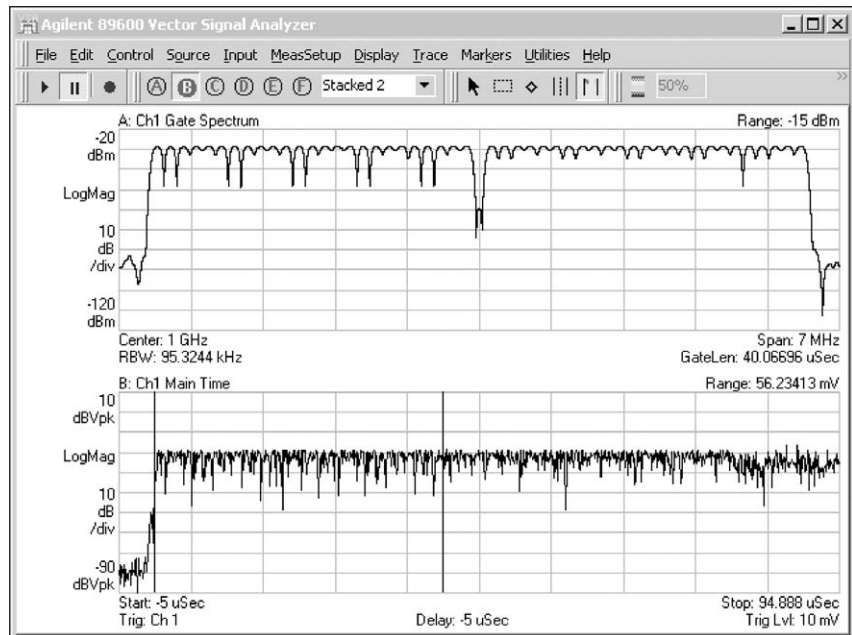
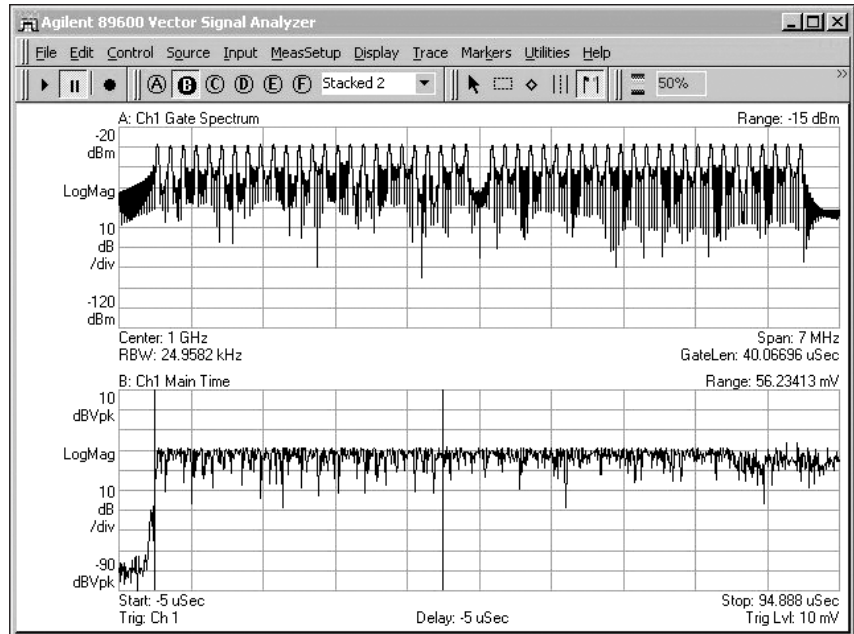


Figure 7. Time-gated spectrum measurement (top trace) of preamble symbol one. The time gate markers are shown by vertical lines in the lower (time envelope) trace.

Now the individual carriers (every 4<sup>th</sup> one) can be resolved, as shown in Figure 8. Note the absence of the center carrier and the relative flatness of the peak amplitudes of the carriers. These carriers are all transmitted at the same amplitude with QPSK modulation, making it easier for the receiver to acquire the signal and estimate the channel frequency response.

**Table 10. Changing RBW shape and time gate length**

Instructions	Navigation
Change RBW (window) shape to Uniform.	Click MeasSetup > ResBW. Click the "Window Type:" drop-down arrow and select "Uniform".
Change gate time length to 40 $\mu$ s.	Click MeasSetup > Time. Click "Gate". Click "Length:" (under "Gate") and enter 40 $\mu$ s. Click "Ch1 Delay" and enter 5 $\mu$ sec (to compensate for trigger hold-off previously set).



**Figure 8. Time-gated spectrum measurement of preamble symbol one, using an RBW shape optimized for frequency resolution. The every-4<sup>th</sup>-carrier structure of this part of the equalizer training sequence is clearly revealed.**

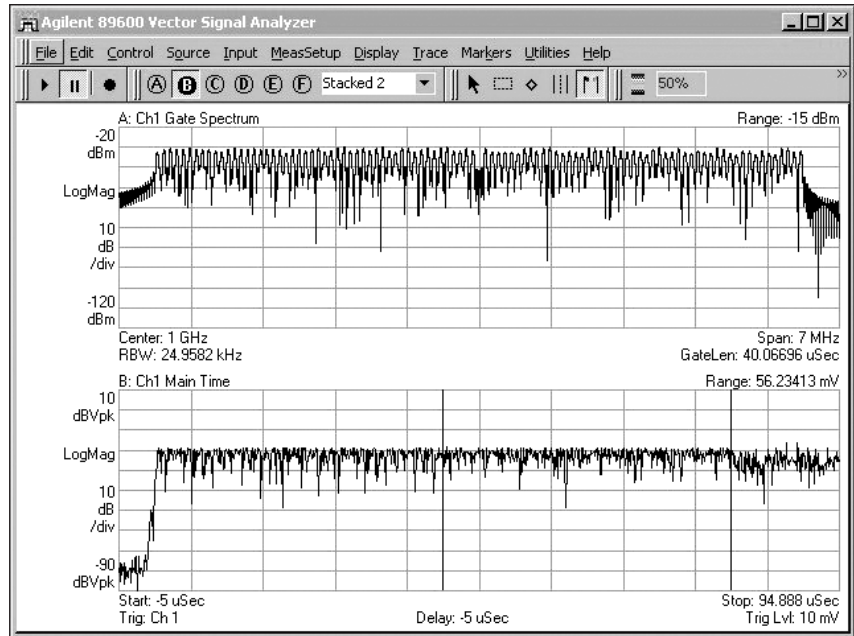
## Measuring preamble symbol 2

While the first symbol in the preamble is useful for coarse signal acquisition, it is not sufficient for detailed channel (frequency response) measurement and correction. Therefore in the downlink subframes, the first symbol is followed by another of the same length, containing every 2nd carrier. This provides a finer estimate of channel frequency response, and is measured as described in Table 11.

Note the change in appearance of the spectrum measurement in the upper trace, Figure 9. The carriers are at the same amplitude, but there are twice as many, providing twice the frequency resolution for channel measurements and associated equalizer corrections. Note also that the increased number of carriers makes the symbol 2 peak/average power different from symbol 1. Note that the signal envelope behavior changes yet again with the beginning of data modulation. The preamble is transmitted at an average power 3 dB greater than the frame control header (FCH) and the data symbols. This step down in power is visible at the end of the second symbol immediately after the right gate marker in the lower trace.

**Table 11. Changing time gate from preamble symbol one to preamble symbol 2**

Instructions	Navigation
Increase time gate delay by 40 $\mu$ s.	MeasSetup > Time. Click "Ch1 Delay:" ("Gate" section) and enter a number 40 $\mu$ s larger than the number already there (for example, change from 5 $\mu$ s to 45 $\mu$ s).
Note	
The display should look like Figure 9.	



**Figure 9. Time-gated spectrum measurement of the channel estimation sequence showing its every-2<sup>nd</sup>-carrier structure. The time gate markers have been moved 40  $\mu$ s to select the 2<sup>nd</sup> preamble symbol. The individual carriers can now be resolved and measured.**

## Uplink measurements

The measurements just made on the downlink subframe can also be made on uplink subframes. As mentioned previously, a positive trigger delay of 3.42 ms (3.32 ms for the first subframe and 0.1 ms for the off-time) will set the beginning of the measurement to the beginning of the first uplink subframe. Refer to Table 12.

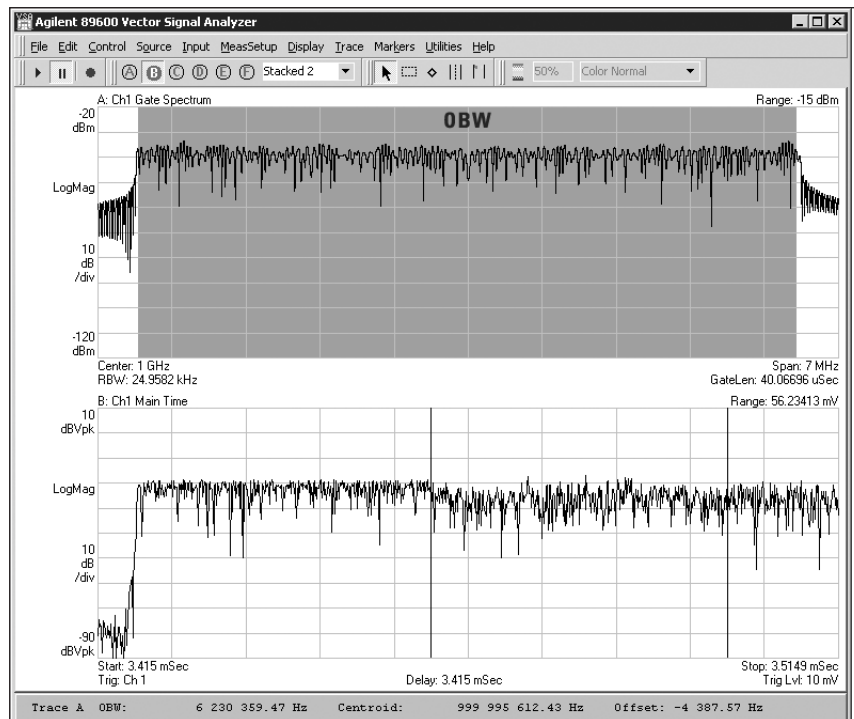
Your display should be similar to Figure 10.

Note that this uplink subframe uses the short preamble, containing a single symbol, which is the equivalent (every other carrier) of the second symbol in the downlink preamble. Because the time gate markers were left in the position set in the prior measurement, the gate now falls on the second symbol of the uplink subframe which is the first data symbol. The difference is apparent in the spectrum measurement in the top trace, where individual OFDM carriers are no longer visible. The 3 dB lower average power and the increased peak/average ratio of the data portion of the subframe are apparent in the time trace.

The occupied bandwidth (OBW) marker calculation includes results for the occupied bandwidth (calculated according to the adjustable power percentage selected under the OBW tab) and the frequency centroid, which is a spectrally weighted calculation of center frequency.

**Table 12. Changing trigger delay to measure the preamble of the first uplink subframe**

Instructions	Navigation
Change from a negative trigger delay to a longer positive value.	Click Input > Playback Trigger. Click "Delay:" and enter 3.415 ms (3.42 ms - 5 $\mu$ s); to see the rising edge of the uplink subframe in this measurement, the trigger delay is reduced by 5 $\mu$ s. Click ▶ to restart playback.
Switch on the occupied bandwidth marker in trace A.	Click in trace A to select it. Click Markers > OBW. Click the "OBW" tab then "OBW". Click    if desired for more convenient adjustment of the gate interval.
<b>Note</b> The display should look like Figure 10.	



**Figure 10. Measurement of the short preamble and the beginning of the data symbols in the first uplink subframe.**

## Additional spectrum and time domain measurements

Time and frequency domain measurements are valuable for determining and verifying many characteristics of the signal, which may not be obvious in digital demodulation measurements. Indeed, in many cases these measurements may reveal why digital demodulation fails.

A variety of additional measurements are possible in this mode, using setups similar to this one.

- Gated CCDF—A CCDF measurement of a time-varying signal such as this one benefits from time gating. Simply select the desired time gate interval and from the main menu: choose Trace > Data > CCDF or double-click on the trace data label and select CCDF.
- Band power—The average power of the signal elements (preamble symbols, FCH, data symbols) can be individually measured with the band power marker feature. Select the band power marker tool from the marker function toolbar at the top of the display, see Figure 11. This tool is shown as two vertical lines with a dashed vertical line between them, and can be selected by clicking on it. The band edges can be entered directly (from the main menu choose Markers > Calculation > and click the Band Power box and enter the desired parameters) or the band can be selected by dragging the vertical markers for the band edges and/or band center (the dashed vertical marker).

- Carrier spacing—A basic check of carrier spacing and signal bandwidth can be performed using the offset markers and measuring the frequency difference between the two outer carriers (carriers -100 and +100). For example, including the missing (not transmitted) center carrier, the 31.25 kHz spacing for this 7 MHz signal should result in an outer carrier frequency difference of  $31,250 \times 200$  or 6.25 MHz.

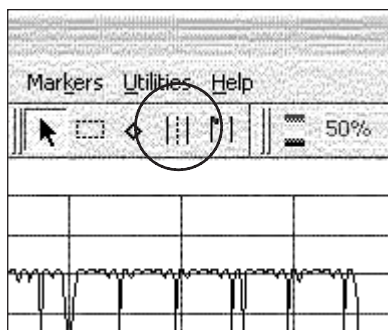


Figure 11. Bandpower Marker enable.

- Occupied bandwidth—Another fast and convenient method for confirming the correct nominal bandwidth of the signal (or time-specific portions of the signal) is to use the occupied bandwidth marker function. Instructions for this frequency spectrum calculation are provided in Table 12 and the result is shown in Figure 10.

## Basic Digital Demodulation

Digital demodulation of WiMAX signals is performed in a way similar to other digitally modulated signals. You will find that WiMAX demodulation uses the same measurement setups and displays as 802.11a OFDM demodulation, except for a few additional parameters that must be manually entered. As with 802.11a demodulation in the Agilent 89600 vector signal analysis software, the WiMAX modulation types (BPSK, QPSK, QAM, etc.) are auto-detected, with a provision for manual override. This auto-detection extends to downlink subframes containing multiple modulation types as well as uplink subframes. Since some WiMAX physical layer signal properties can be changed by the user, they must also be selected as part of demodulation. These properties include:

- Nominal signal bandwidth
- Guard interval

The following WiMAX signal demodulation example uses the same recording as the previous demonstrations. Since the recording contains both downlink and uplink subframes and the goal is to demodulate the more complex downlink subframe, the triggering setup from Table 7 will be used again.

## Setup and initial digital modulation measurements

If necessary (if you have recalled a different recording or changed other settings), preset the analyzer and recall the WiMAX\_7MHz.sdf signal as directed in Table 3. Then follow the instructions in Table 7 to set triggering and pre-trigger delay to measure only the downlink subframe.

If you have not made other changes from the previous demonstrations, simply reset the trigger delay to  $-5 \mu\text{s}$  (Input > Playback Trigger). Be sure to use a negative value for the trigger delay, as a positive value will cause the pulse search algorithm to find the first uplink subframe instead of the downlink subframe. Then switch the analyzer to its demodulation mode and make the appropriate settings for demodulating this recorded signal as described in Table 13.

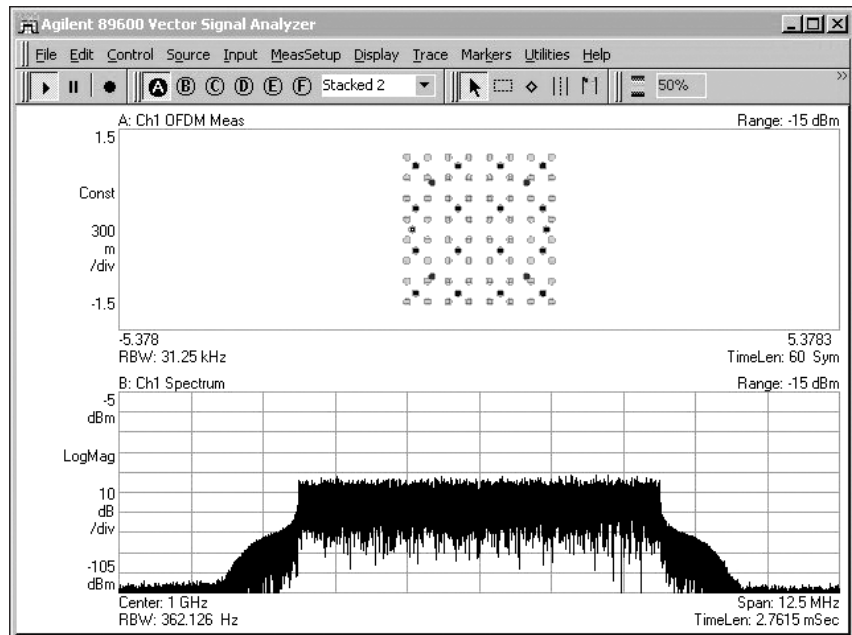
You should now have a display similar to Figure 12, with a clean constellation in the upper display, indicating successful demodulation. Compared to those of traditional digital modulation formats, this constellation display may appear to have an unusual configuration. The constellation is a composite, containing an overlay of BPSK, QPSK, 16QAM, and 64QAM constellations and, accordingly, a total of 86 constellation points. All four types of modulation are present in the selected (by default) 60-symbol result length from the downlink subframes in this recording.

**Table 13. Setup for basic digital demodulation**

Instructions	Navigation
Switch off the OBW marker calculation.	Right click on trace A and uncheck "Show OBW".
Switch on demodulation.	Click MeasSetup > Demodulator > Broadband Wireless Access > 802.16 OFDM.
Reset demodulation parameters that may have been set differently in earlier measurements.	Click MeasSetup > Demod Properties. Click the "Format" tab. Click "Standard:" drop-down arrow and select "IEEE 802.16 2004". Click "Preset to Standard..." and select "7 MHz", the Fs/BW ratio defaults to 8/7; this figure is appropriate for this signal. In the "Guard Interval" section click "1/4". This is a typical value, and is appropriate for this signal. Click the "Time" tab and note the default search length of 120 symbol-times or 4.8 ms; this value is appropriate for this signal, but could be adjusted according to the time parameters verified in previous measurements if necessary (in general, a pulse search length of at least [(2 x on-time) + (1 x off-time)] is adequate to ensure that a valid RF burst will always be contained in the search length). Click the ► button to restart the measurement.

### Note

The display should look like Figure 12.



**Figure 12. Constellation and spectrum measurements of the WiMAX signal. The modulation and resulting constellation is a combination of BPSK, QPSK, 16QAM and 64QAM.**

## Modulation quality parameters and error displays

Numerical measurement of modulation quality and visual evaluation of potential error is easier with the use of multiple simultaneous measurement displays. The 89600 VSA software offers up to 6 simultaneous displays. For an example display combining spectrum and modulation analysis parameters, select 4 grids and auto scale the error vs. frequency display as described in Table 14.

As shown in Figure 13, the four displays now show error vs. frequency (or carrier number) on trace C, and a combination of numerical error parameters and transmitted bits on trace D.

**Table 14. Demodulation and spectrum results with a 4-trace display**

### Instructions

Switch from a stacked 2-trace display to a 2x2 grid.

Auto scale the OFDM error vector spectrum display.

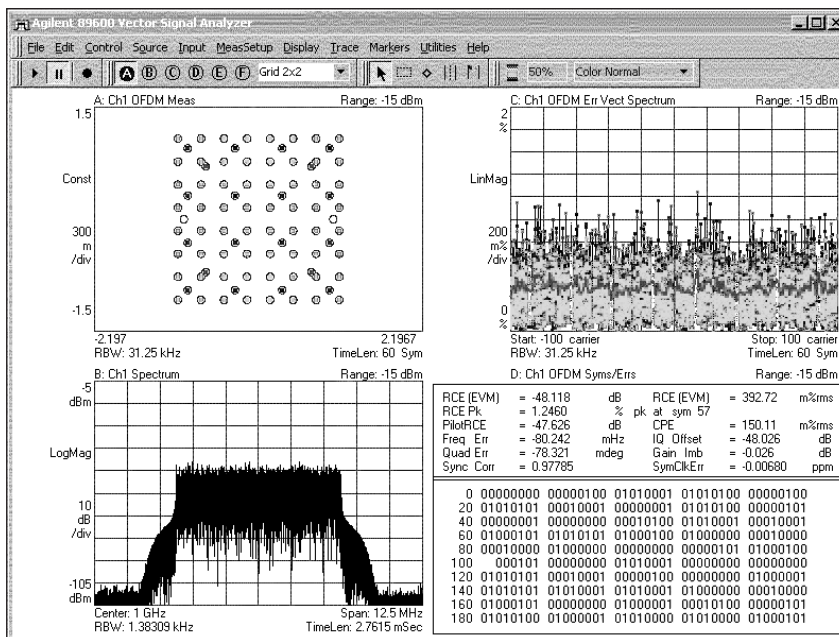
### Note

The display should look like Figure 13.

### Navigation

Click Display > Layout > Grid 2x2 (you may also click on the drop-down arrow in the display toolbar and select "Grid 2x2").

Right click in trace C (upper right display) and select "Y Auto Scale".



**Figure 13. Multi-trace measurement results including constellation, spectrum, error spectrum (error vs. carrier), and a table showing demodulated bits and numerical results (lower right).**



## The symbol/error summary table

In addition to producing graphical measurement results, the 89600 VSA software creates a numeric display that includes a table of numerical measurement results and a table of demodulated results (physical layer) bits.

The most complete version of these tabular results is shown when the symbols/errors trace (currently trace D, CH1 OFDM Syms/Errs) is expanded to full screen. Follow the steps in Table 15. Your display should be similar to Figure 14.

The upper (error summary) table in the display contains basic modulation parameters. It is headed by RCE (relative constellation error), the general figure-of-merit for WiMAX signals. RCE is equivalent to EVM (error vector magnitude), a figure commonly used in other digital communication systems. The RCE is calculated for the entire measurement interval in terms of dB and % rms. Values are also calculated for: peak RCE error and the symbol where it occurs, the RCE for the pilot carriers, common pilot error, frequency error and symbol clock error. Sync correlation is also measured.

**Table 15. Setting a single trace display**

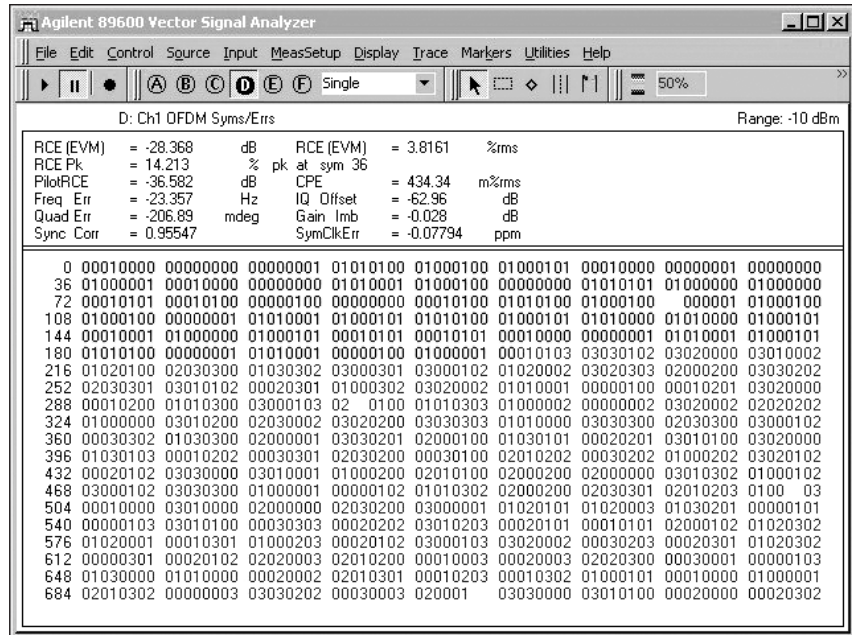
### Navigation

Select trace D (Ch1 OFDM Syms/Errs) by clicking anywhere in the trace.

Click Display > Layout > Single (you may also click on the drop-down arrow in the display toolbar and select "Single").

### Note

Your display should be similar to Figure 14.



**Figure 14. The 89600's combined error summary and symbol table provides an extensive numeric summary of modulation quality and signal errors, along with the demodulated subframe payload data. This display can be set to represent the entire subframe, an individual carrier, or a time interval of one or more symbols (see Advanced Demodulation section).**

I/Q errors are shown in the summary as quadrature error, IQ (origin) offset, and gain imbalance of the I and Q signal components.

The lower (transmitted physical symbols) table of the display contains demodulated bits for the measurement interval including the FCH. This data is color-coded by modulation type and/or function (FCH, pilots, data). The coding scheme coordinated with color coding used in other displays. The demodulated data is raw data and has not been processed to remove scrambling or interleaving.

## Time domain and frequency domain displays of modulation error

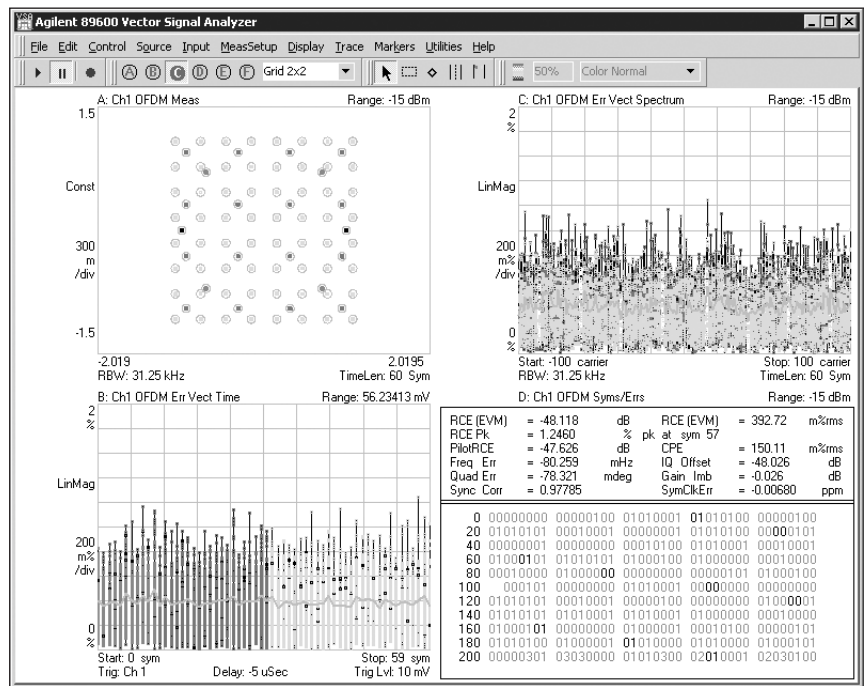
In evaluating system performance and isolating the source of problems it can be very useful to examine modulation quality in both the time and frequency domains. In demodulation mode, the default for trace C (in the upper right) is error vector spectrum, where frequency is shown by carrier number (carrier spacing is 31.25 kHz). All symbols from the measured result are shown for each carrier. The corresponding time domain display is error vector time, where time is represented by symbols (symbol spacing is 40  $\mu$ s), and the error of every carrier is shown at each symbol time. You can select the error vector time display by following the instructions in Table 16.

Your display should be similar to that shown in Figure 15, with the error (relative constellation error or RCE) vector time and spectrum measurements in the lower left and upper right corners of the display, respectively. The display points representing symbols of different modulation types are color coded, and the color-coding is consistent between all four displays or grids. Separate colors are used for the 3 modulation types used for the data, along with one color for the BPSK pilots and another color for the BPSK frame control header (FCH).

**Table 16. Selecting and scaling a display of error vs. symbols or time**

Instructions	Navigation
Return to a 2x2 grid display.	Click Display > Layout > Grid 2x2 (you may also click on the drop-down arrow in the display toolbar and select "Grid 2x2").
Select an error vector time measurement for trace B.	Double-click on the trace B label (Ch1 Spectrum) and select "Error Vector Time" in the scroll box.
Auto scale the error vs. time display.	Right click anywhere in trace B and select "Y Auto Scale".

**Note**  
The display should look like Figure 15.



**Figure 15. Multi-trace display including EVM vs. time or symbol (lower left). The gray lines in the error vector time and error vector spectrum (upper right) displays indicate average error at each symbol time and at each carrier number, respectively.**

If desired, any trace can be used to display any measurement, and up to 6 measurements can be shown at one time. The error vector time and error vector spectrum displays shown here are a useful and natural pair to show together, as they are orthogonal to each other and often complementary. In the

error vector spectrum trace, each of the carriers is viewed separately, with all of the symbols for each carrier shown together. In the error vector time trace, each symbol is shown separately, with all of the carriers shown together.

## Advanced Demodulation

### Analyzing specific portions of the signal in time and frequency

To isolate the source of problems or to measure the modulation quality of a single downlink segment or uplink subscriber, it can be helpful to perform modulation analysis on specific time (symbol) periods or specific frequency (carrier) intervals. With the 89600 series VSA software, these intervals are selected using the Demod Properties dialog box.

These demodulation operations will be demonstrated with a recording of an impaired 5 MHz WiMAX signal. Accordingly, the error of this signal will be considerably higher than the signal used in the earlier recording. This signal contains a downlink subframe only, and therefore playback triggering is no longer necessary. Instead, the pulse search capability in the digital demodulation mode will be used to identify the RF burst timing for demodulation.

First, recall the `WiMAX_5MHz_Impaired.sdf` recording and set up initial digital demodulation according to the instructions in Table 17.

**Table 17. Recalling the 5 MHz WiMAX recording and setting up digital demodulation**

<b>Instructions</b>	<b>Navigation</b>
<i>Recall the 5 MHz WiMAX recording.</i>	Click File > Recall > Recall Recording. Navigate to the directory containing the signal: <code>C:\Program Files\Agilent\89600VSA\help\signals\WiMAX_5MHz_Impaired.sdf</code> .
<i>Switch off playback triggering.</i>	Click Input > Playback Trigger. Click the "Type" drop-down arrow and select "Free Run". If necessary (if the analyzer is not already in 802.16 demodulation mode), switch on demodulation. Click MeasSetup > Demodulator > Broadband Wireless Access > 802.16 OFDM.
<i>Set the demodulation properties to correspond to the recorded signal.</i>	Click MeasSetup > Demod Properties > Format tab > Preset to Standard and select "5 MHz". Click ▶ to restart the measurement.

#### **Note**

The default  $F_s/BW$  ratio for this signal is 144/125, and that is appropriate for this recorded signal.

Note that the Guard Interval is set to 1/4. This is the default value, and is appropriate for this signal.

The recorded signal is centered at 3.5 GHz and is approximately 4.75 MHz wide. The recording contains 7 subframes, and each one is 2.45 ms long, with a 0.05 ms interval between. For this signal the formula described in Table 13 suggests a search length of 5 ms. This search length is set according to the instructions in Table 18.

Your display should be similar to Figure 16. You should see a constellation in trace A. This constellation is a combination (an overlay display) of all WiMAX modulation types present in the subframe from BPSK through 64QAM. You may wish to select the marker tool and place a marker in error vector time trace B (lower left) at the point in the subframe where the error increases significantly.

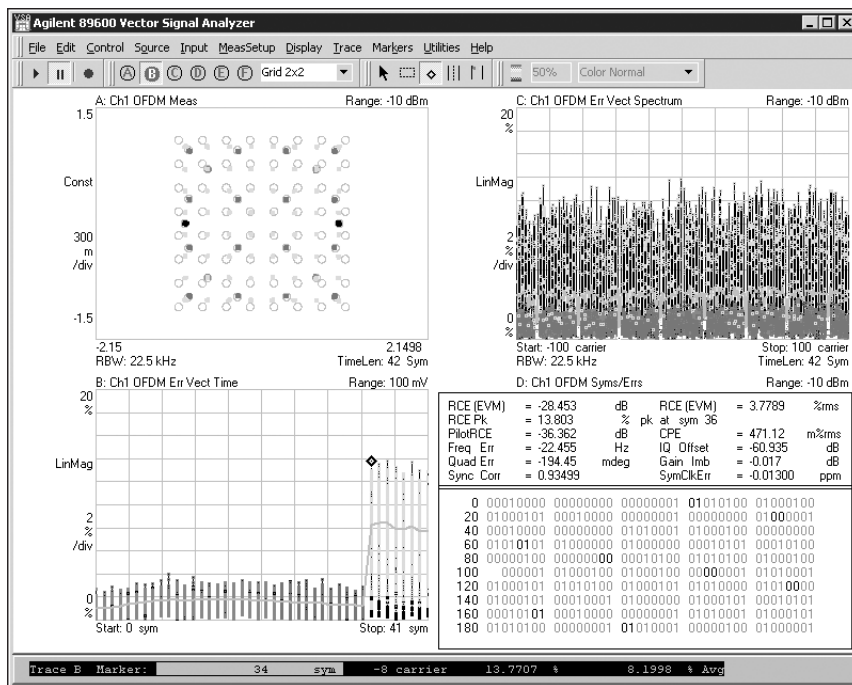
Most displays in the WiMAX digital demodulation mode are color-coded according to modulation type. In addition, the pilots and FCH symbol are displayed in a different color than the other modulation types. The combination of color-coded error vector time and error vector spectrum displays are particularly useful in understanding impairments such as the one in this signal. The color-coding makes it easy to see that the green 64QAM symbols generally have much larger error than the other modulation types. The scaling or average amplitude of the 64QAM modulation is too low, and this can be confirmed by examining the constellation diagram in trace A. You may wish to select trace A and switch to a single-trace display to see this error more clearly. Note that there is amplitude error even in the interior states of the 64QAM constellation diagram, and this indicates that the impairment is due to DSP scaling not amplifier compression (which would primarily affect the outer or corner constellation points).

**Table 18. Setting the search length and playing back the recording**

Instructions	Navigation
Set search length.	Click MeasSetup > Demod Properties. Click the "Time" tab. Click "Search Length:" and enter "5 ms" (90 symbol-times). Click ▶ to restart the playback.
Autoscale trace B (error vector time) and trace C (error vector spectrum).	Right click on each trace and select "Y Auto Scale".

**Note**

The display should look like Figure 16.



**Figure 16. Demodulation results for a WiMAX signal including BPSK through 64QAM modulation types. The marker in the error vector time measurement in the lower left reveals that the RCE increases sharply at symbol 34 when the modulation type switches to 64QAM. (Pilot BPSK = white, FCH BPSK = violet, QPSK = red, 16QAM = blue, 64QAM = green).**

## Examining subframe information

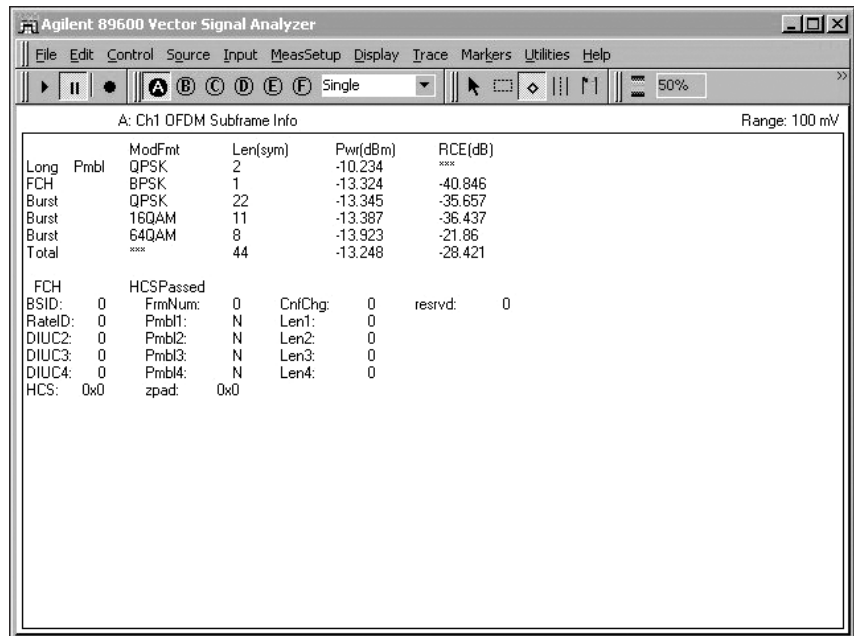
Viewing the structure and measuring the parameters of a subframe is made easier with the 89600's Subframe Info measurement type. Follow the instructions in Table 19 to display the subframe information.

Your display should be similar to Figure 17, with a tabular summary of the subframe and its components. This display combines elements of both demodulation and time mode measurements, including modulation quality for each data burst and associated average RF power for the bursts. The power measurements show the power level for the 64QAM signal is about 0.5 dB less than the other data bursts, confirming the observation made previously on the constellation diagram.

The subframe information measurement display provides a large amount of useful data in a single location. The structure of the burst is summarized, including preamble type (short or long), modulation types used, and their respective power levels and modulation quality. The FCH is decoded and its checksum is tested, and results are shown in the lower portion of the display, along with other information such as the configuration change bit.

**Table 19. Viewing subframe information**

Instructions	Navigation
<p>Select a single-grid display.</p> <p>Select trace A for display.</p>	<p>Click Display &gt; Layout &gt; Single.</p> <p>Click Display &gt; Active Trace &gt; Active A (you may also use the drop-down box in the Active Trace portion of the tool bar and select "Single" then click "A" to the left of this drop-down box).</p>
<p>Select the Subframe Info data type.</p>	<p>Click Trace &gt; Data &gt; Subframe Info (you may also click on the trace label (Ch1 OFDM Meas) at the top of the trace and click "SubFrame" in scroll box).</p>



**Figure 17. Subframe Info summary display. Note that the preamble average power is approximately 3 dB greater than the rest of the subframe, while the average power of the 64QAM burst is approximately 0.5 dB lower.**

## Measurement of specific data bursts

As mentioned previously, modulation analysis can be selectively performed on specific time or frequency intervals. For example, isolating the measurement to a specific data burst (a time interval where symbols represent time) allows for the measurement of specific transmitters with different modulation formats.

As shown in the subframe information section, the subframes in this recording contain several modulation types. These can be selectively demodulated using settings under the Time tab in the Demodulation Properties dialog box. Symbols 1-22 are QPSK. Symbols 23-33 are 16QAM. Symbols 34 and above are 64QAM, with incorrect average amplitude (and consequently larger error). BPSK pilot carriers are transmitted continuously throughout the subframe, and are therefore shown on all constellation diagrams. In Error Vector Time trace the preamble symbols are ignored and symbol 0 is the FCH symbol.

To perform time-selective demodulation of this signal use the instructions in Table 20 to return to a quad (Grid 2x2) display format including a constellation and select a specific demodulation time interval.

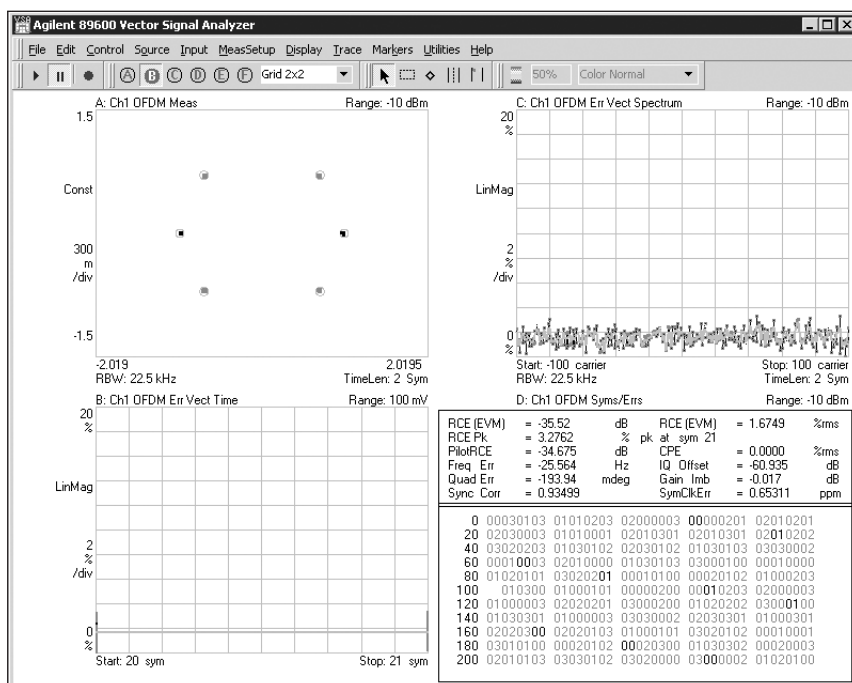
Note the change in constellation types from QPSK to 64 QAM, along with the corresponding color changes in all 4 traces. Your displays should be similar to Figures 18 through 20, consecutively.

**Table 20. Selective demodulation of different modulation types according to symbol**

Instructions	Navigation
<i>Switch back to a quad display, including a constellation measurement.</i>	Click Display > Layout > Grid 2x2 (you may also click on the drop-down arrow in the display toolbar and select “Grid 2x2”). Four data traces should appear.
<i>Change trace A to IQ Meas (Ch1 OFDM Meas) data type.</i>	Double click on the trace A label (top left of trace A) and select “IQ Meas” from the resulting scroll box. The subframe constellation should appear.
<i>Measure symbols 20-21 in the subframe.</i>	Click MeasSetup > Demod Properties... Click the “Time” tab. Click “Measurement Interval:” and enter “2”. Click “Measurement Offset:” and enter “20”. <i>The display should look like Figure 18.</i>
<i>Measure symbols 23-24.</i>	Click “Measurement Offset:” and press the keyboard up-arrow 3 times (you may also directly enter an offset of 23 symbol-times). <i>The display should look like Figure 19.</i> Note the constellation change.
<i>Measure symbols 35-36.</i>	Click “Measurement Offset:” and enter “35”. (You can also press the keyboard up-arrow 12 times.)

### Note

The display should look like Figure 20.



**Figure 18. Time-selective demodulation of WiMAX subframe including results calculated for symbols 20-21 only. The constellation shows QPSK (data) and BPSK (pilots) modulation for these symbols.**

Note that the numerical summary at the top of the Symbols/Errors table in trace C (lower right) changes as different portions of the subframe are selected with the offset and interval values. This data is measured on the symbols in the measurement interval and allows different transmitters and/or modulation types to be isolated and separately measured.

The separate measurement of the 64QAM modulation segment (Figure 20) reveals greater modulation error for this format, with results that are both visually and numerically different from those for the other formats. This error is due to an average power level for this modulation type that is too low, because of improper scaling in the DSP used for the signal generation. Coupled markers could be used to verify this hypothesis, by searching for peak errors and correlating the largest errors to specific constellation points, subframe timing, modulation type, etc.

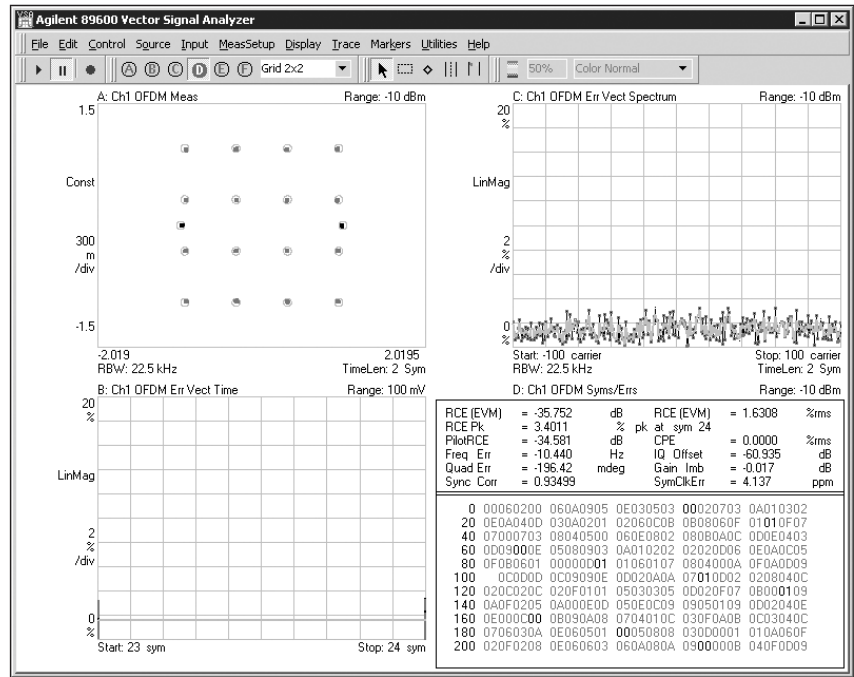


Figure 19. Time-selective demodulation of WiMAX subframe including results calculated for symbols 23-24 only. The constellation shows 16QAM (data) and BPSK (pilots) modulation for these symbols.

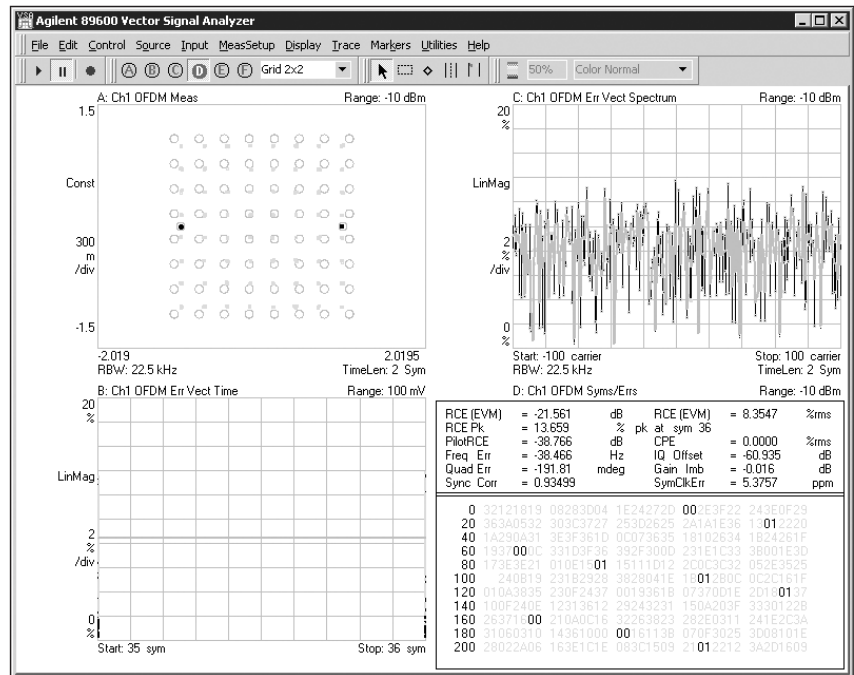


Figure 20. Time-selective demodulation of WiMAX subframe including results calculated for symbols 35-36 only. The constellation shows 64QAM (data) and BPSK (pilots) modulation for these symbols.

## Measurement of a specific frequency/carrier

In addition to demodulating selected symbol (or time) intervals as shown previously, the 89600 VSA software can be used to demodulate specific carriers. This kind of selective demodulation may be useful, for example, in understanding the effect of spurious interference (whether continuous or impulsive) or other frequency-related phenomena such as filter rolloff at band edges.

Continue with measurement of the 5 MHz WiMAX recording, as described above, and demodulate a specific carrier using the steps in Table 21.

Now all four displays reflect only the data, modulation quality measures, and constellation of this specific carrier. This represents measurement of a single carrier over an interval in time, in this case the entire subframe. Your display should be similar to Figure 21.

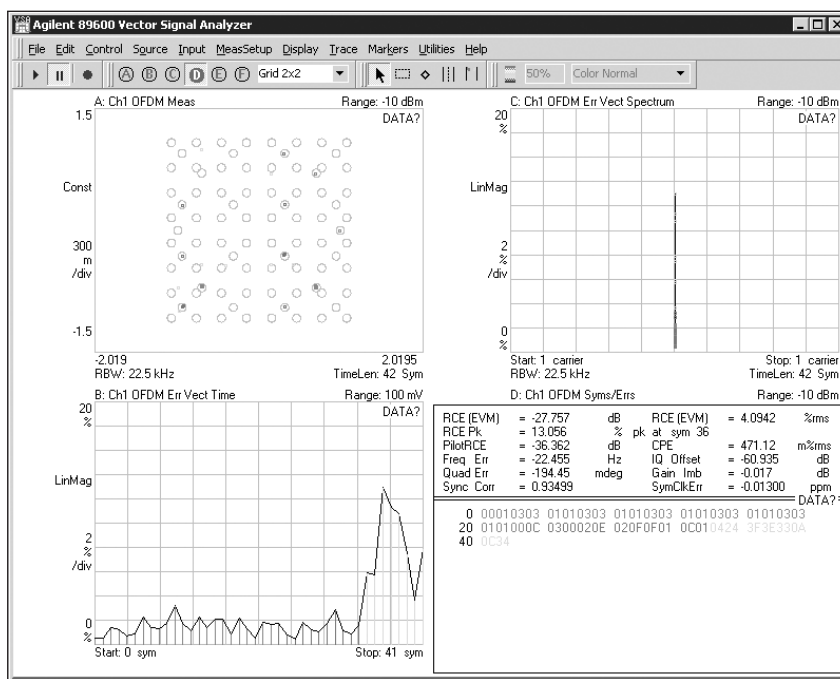
In examining the error vector time trace B, you can see that the error is greater during the later portion of the subframe, where the modulation type changes to 64QAM. If you choose one of the pilot carriers, such as  $\pm 13$ , you will not see this phenomenon because the BPSK pilot carriers do not have the scaling problem that affects the 64QAM modulated data carriers.

**Table 21. Selective demodulation of a single OFDM carrier**

Instructions	Navigation
Return the measurement interval to the default.	Click MeasSetup > Demod Properties... Click the "Time" tab. Click "Measurement Offset" and enter "0". Click "Measurement Interval" and enter the same number of symbol-times as shown for "Max Result Length" (60 symbol-times, top of dialog box).
Select a single carrier to demodulate.	<ul style="list-style-type: none"> <li>You can also use the Preset to Standard button under the "Format" tab of the Demod Properties and once again preset demodulation to the 5 MHz standard settings.</li> </ul>
	Click the "Advanced" tab. In the "Sub-Carrier Select" box select "Single Carrier". Enter the desired carrier (the default is carrier #1), using a number from -100 to 100, excluding carrier 0 (which is not transmitted).

### Note

Your display should be similar to Figure 21 (assuming you selected carrier #1).



**Figure 21. Selective demodulation of a single OFDM carrier, carrier +1. The specific data and modulation quality for this single carrier are shown both graphically and numerically.**



## Pilot tracking

A full discussion of pilot tracking is beyond the scope of this demonstration guide, but a brief example will serve to describe the function and its associated 89600 demodulation controls.

In receivers using pilot tracking demodulation is performed using the eight BPSK modulated pilot carriers as phase and amplitude references. Thus the demodulation is all relative to the pilots and the signal changes common to all pilots will be removed or "tracked out" for every symbol.

In the 89600 pilot tracking can be independently enabled and disabled. The average of the symbol-by-symbol pilot error with respect to an ideal pilot is shown in the Symbol/Error table as Common Pilot Error.

The 5 MHz WiMAX signal we have been measuring contains some amplitude drift in the early data bursts in addition to the impairments previously measured. This drift can be shown by the steps in Table 22. Your display should be similar to Figure 22. Note the difference in amplitude error shown by error vector time in trace B (lower left) when amplitude tracking is switched on and off.

**Table 22. Measuring common pilot error**

<b>Instructions</b>	<b>Navigation</b>
<i>Switch back to measuring all carriers.</i>	Click MeasSetup > Demod Properties. Click the "Advanced" tab. In the "Sub-Carrier Select" box select "All".
<i>Re-scale the error vector time display to show the effects of amplitude drift.</i>	Click in trace B (OFDM Err Vect Time) to select it. Click Trace > Y Scale. Click "Y Per Division:" and enter "0.5%". Click "Close". The drift in the average magnitude error, signified by the arch in the heavy grey line, is more apparent using this Y-axis scaling.
<i>Switch on pilot amplitude tracking.</i>	Click MeasSetup > Demod Properties. Click the "Advanced" tab. In the "Pilot Tracking" section select "Track Amplitude". Note that the amplitude drift shown in trace B is removed.
<i>Start the common pilot error display to see the error correction provided by the pilot amplitude tracking.</i>	Double click on the trace C label (top left of trace) and select "Common Pilot Error" in the resulting scroll box.
<i>Switch trace C to a display the log magnitude of the common pilot error.</i>	Click Trace > Format. Click the "Format" box drop-down arrow, select "Log Mag (dB)" and click "Close". (You can also double-click on the Y-axis label (Wr Phs) and select "Log Mag (dB)" from the choices provided.) Click in trace B (OFDM Err Vect Time) to select it.
<i>Re-scale the error vector time display to better show the effects of amplitude drift.</i>	Click Trace > Y Scale. In the "Y Per Division" box enter "0.5%" and click "Close".
<b>Note</b>	
Your display should be similar to Figure 22.	

Examining trace B (lower left) you can see that the amplitude tracking operation does not correct the amplitude error in the 64QAM signal. That error is due to a scaling error of the 64QAM signal and is therefore not present in the BPSK pilots.

The VSA software provides three types of pilot tracking: amplitude, phase and timing. The phase tracking selection is particularly useful for removing phase errors caused by close-in phase noise in the oscillators of either the transmitter or receiver.

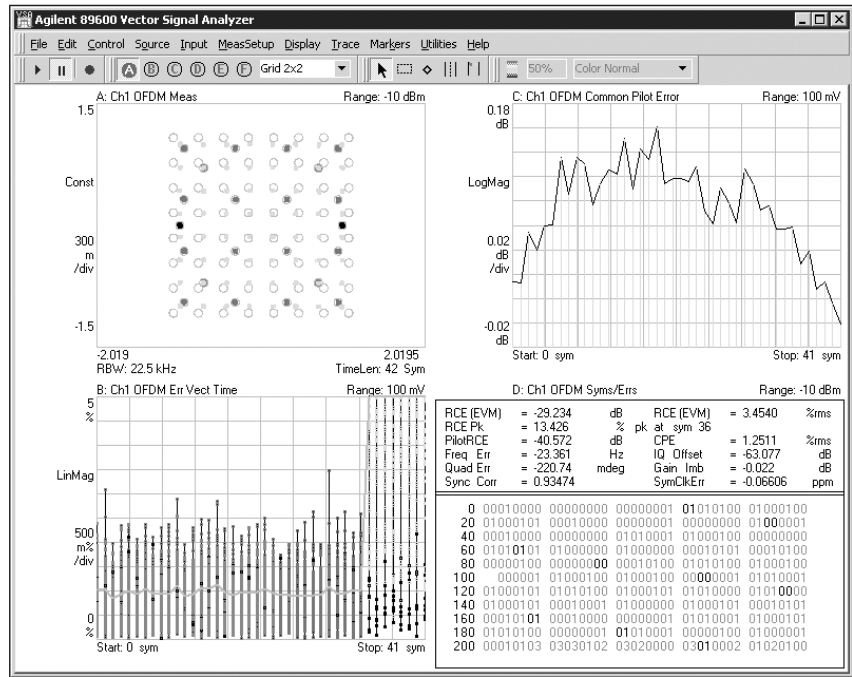


Figure 22. The effects of tracking the amplitude of the OFDM pilots. In trace B (lower left) the amplitude error is now relatively constant across the subframe except for the 64QAM modulation. In trace C (upper right) the amplitude error that has been "tracked out" is shown directly.

## Related Agilent Literature

5989-1679EN	<i>89600 Series Vector Signal Analysis, Technical Overview</i>
5989-1786EN	<i>89600 Series Vector Signal Analysis 89601A/89601AN/89601N12, Data Sheet</i>
5980-1989E	<i>89600S Vector Signal Analyzer, CD</i>

## Web Resources

For additional information, visit:

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