Keysight Technologies
IEEE 802.16e WiMAX™ OFDMA Signal Measurements and Troubleshooting

Application Note

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Introduction

The 89600 VSA software shown in this document has been replaced with the new 89600B software. To find out how you can see through signal complexity with the new 89600B VSA software visit **www.keysight.com/find/89600B**

This application note is a guide to effective measurement and troubleshooting of IEEE 802.16e OFDMA "Mobile WiMAX™" signals, components, and systems. The most distinctive term used to describe this new technology is OFDMA or orthogonal frequency division multiple access, and therefore we will use the term OFDMA in this note as a compact reference to the signal and its associated standard.

This note provides a broad overview of measurement and troubleshooting approaches for OFDMA signals, and is not limited to digital demodulation or modulation quality analysis. Indeed, we will show that some of the most productive types of analysis for OFDMA signals are generally grouped under the heading of time domain and frequency domain or "vector" signal analysis.

Though the measurements and principles discussed here would apply to any OFDMA measurements, they are described with specific reference to the 89600 vector signal analysis (VSA) software and Option B7Y IEEE 802.16 OFDMA modulation analysis. This software can analyze signals from a wide variety of sources including spectrum analyzers, modular VXI hardware, oscilloscopes, logic analyzers (for data already in digitized form), and design/simulation software such as ADS.

The IEEE 802.16e OFDMA standard is a complex and extensive one, with many more specifics than can be covered in a note of this type. This note will focus on a general process for the most effective measurements, with examples of some typical problems you may find, paired with the measurement and troubleshooting techniques and displays to help you most efficiently find and fix these problems.

Since the focus of this note is measurement and troubleshooting techniques, some other topics, such as hardware configurations and step-by-step measurement instructions, will be covered in other documents. Please consult the "Other Resources" summary below and the "References" section at the end of this note.

Other resources

The focus of this application note is on measurement and troubleshooting techniques and examples. For more information on products, configurations, and step-by-step instructions, please consult the following additional resources. The locations and literature numbers for these documents are listed in the "References" section at the end of this note.

Free demo CD

89601A VSA software with option B7Y 802.16 "OFDMA modulation analysis" in free trial license mode. The software includes example OFDMA signals and extensive help text with measurement tutorials. This is available by ordering publication number 5980-1989E.

OFDMA, WiMAX and other OFDM technical references

Tech Online IEEE 802.16e OFDMA webcast (archived – original presentation September 2005) http://seminar2.techonline.com/s/keysight_sep1505 or go to www.keysight.com/find/wimax for an archived version)

Tech Online IEEE 802.16-2004 WiMAX webcast (archived – original presentation January 2005) http://www.keysight.com/find/WiMAXeSeminar

Effects of Physical Layer Impairments on OFDM Systems, Published in RF Design, May 2002

Product Web site

For the most up-to-date and complete application and product information, please visit our product Web site at: www.keysight.com/find/wimax

Related Literature

Publication Title	Publication Type	Publication Number
Step-by-step instructions and measurement examples		
Keysight 89600 Series Vector Signal Analysis Software for IEEE 802.16 OFDMA Evaluation and Troubleshooting	Self-Guided Demonstration	5989-2383EN
Vector signal analyzer product information		
Keysight 89600 Series Vector Signal Analysis Software 89601A/89601AN/89601N12	Technical Overview	5989-1679EN
Keysight 89600 Series Vector Signal Analysis Software 89601A/89601AN/89601N12	Data Sheet	5989-1786EN
Hardware Measurement Platforms for the Keysight 89600 Series Vector Signal Analysis Software	Data Sheet	5989-1753EN
OFDMA, WiMAX and other OFDM technical references		
Keysight WiMAX Signal Analysis; Part 1: Making Frequency and Time Measurements	Application Note	5989-3037EN
Keysight WiMAX Signal Analysis; Part 2: Demodulating and Troubleshooting the Subframe	Application Note	5989-3038EN
Keysight WiMAX Signal Analysis; Part 3: Troubleshooting Symbols and Improving Demodulation	Application Note	5989-3039EN

Measurement and Troubleshooting Sequence

When measuring and troubleshooting digitally modulated systems, it is tempting to go directly to digital demodulation and the measurement tools provided in that operational mode of analyzers such as the 89600 Series VSAs. We have learned from experience that it is usually better to follow a measurement sequence instead: one that begins with basic spectrum measurements and continues with vector (combined frequency and time) measurements, before switching to digital demodulation and modulation analysis as shown in Table 1.
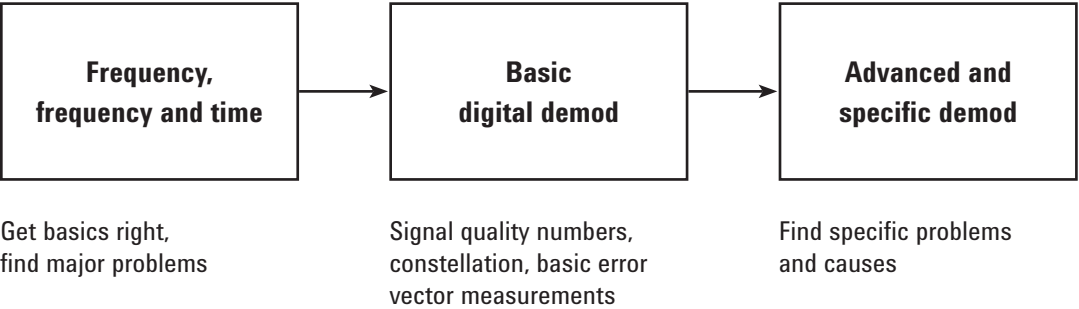
This is the sequence we will use in this application note. The sequence of measurements is especially useful because it improves the chance that you will find important signal problems at the earliest stages of design. In particular, the time and frequency domain measurements at the beginning of the sequence provide for the measurement and verification of many signal parameters (including many associated with the digital modulation itself) without performing digital demodulation. This is an advantage in some development situations where demodulation is not yet available or is in some way questionable. In addition, some important measurements such as spectral occupancy and CCDF are typically not performed in a demodulation mode.

It is certainly useful to make a variety of modulation analysis measurements on a system in question, watching for things that look wrong or questionable. You can find many problems that way. However, some important defects are not apparent in demodulation results, or may manifest themselves differently from one demodulator to another. In situations such as this, you can waste a great deal of time on unproductive measurement approaches or demodulation results that are difficult to interpret. The danger of missing fundamental problems is particularly acute in applications such as IEEE 802.16 OFDMA due to the complexity of the signal and the possibility that demodulation will fail due to relatively subtle problems such as PRBS errors or incorrect definition of data bursts. Therefore, it is important to isolate problems as early as possible in the measurement and troubleshooting process and to eliminate the maximum number of simple signal problems before attempting digital demodulation. This is especially true when working on baseband DSP operations to create signals with correct modulation, pilot configuration, etc.

Table 1. A suggested measurement sequence for troubleshooting and performance verification.

| Frequency, frequency and time | Basic digital demod | Advanced and specific demod |

Get basics right, find major problems

Signal quality numbers, constellation, basic error vector measurements
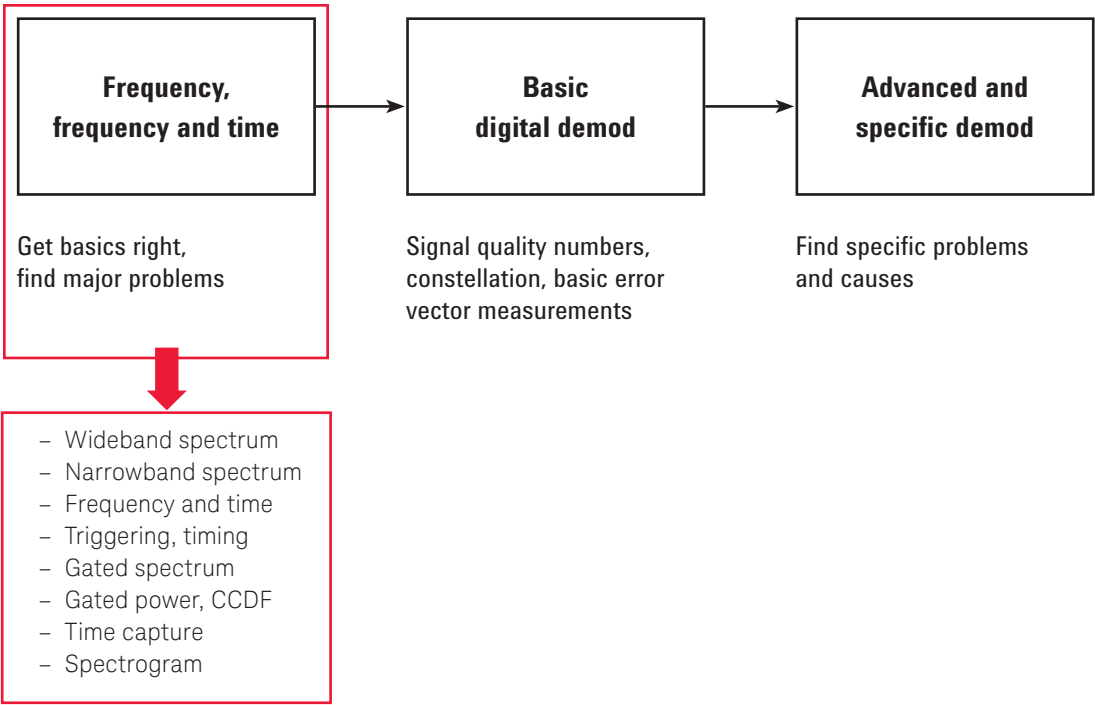
Find specific problems and causes

Time and Frequency Domain (Vector) Measurements

Time and frequency domain analysis can range from basic spectrum and RF envelope measurements to a wide variety of time-gated measurements, composite spectrum measurements such as spectrograms, and statistical measurements such as CCDF (complementary cumulative distribution function), which may also be made in a time-gated mode.

In addition to a wide range of demodulators and modulation analysis tools, the 89600 VSA software offers very powerful and comprehensive vector signal analysis. The combination of vector signal analysis and digital demodulation is the most productive measurement approach for digitally modulated signals.

Table 2. Vector (combined time & frequency domain) measurements are an excellent first step in understanding the performance of a circuit or system.

Frequency, frequency and time	**Basic digital demod**	**Advanced and specific demod**
Get basics right, find major problems	Signal quality numbers, constellation, basic error vector measurements	Find specific problems and causes

– Wideband spectrum
– Narrowband spectrum
– Frequency and time
– Triggering, timing
– Gated spectrum
– Gated power, CCDF
– Time capture
– Spectrogram

Time and Frequency Domain (Vector) Measurements (continued)

Getting basics right and finding major problems

Our approach begins with frequency (basic spectrum) measurements and progresses to vector measurements that combine frequency and time domain analysis. You can learn a great deal about digitally modulated signals before using digital demodulation, and some important signal characteristics not readily visible during digital demodulation.

Some examples of problems with digitally modulated signals which can be found through vector analysis include malformed or truncated training sequences (which can cause compatibility issues even if digital modulation is successful) and improper amplitude or ranging (which may disguise itself as digital modulation problems such as timing errors). Even some problems which arise in the digital modulation process itself may be seen more readily in the vector (and not digital demodulation) mode.

Vector analysis also provides a good opportunity to set triggering and pulse search length to optimum values. This ensures, for example, that a "pulse not found" message during digital demodulation actually indicates a signal problem and not just a setup problem or variations in signal amplitude due to modulation. Attaching clear meanings to errors reported by the analyzer enhances the value of the analyzer's results and makes the analysis itself more comprehensive.

Time-varying signals require good coordination of time domain and frequency domain measurements. Typically you can measure and verify the time domain characteristics, and then use time-related factors such as triggers and gating to make the desired frequency domain measurements.

The situation is particularly demanding for signals such as WiMAX OFDMA because the signal changes characteristics in several significant ways, even during a single RF burst or subframe. For example, the preamble of a downlink subframe may have higher power than the rest of the subframe, and that same preamble will have different spectral characteristics and power statistics from the rest of the subframe. Indeed, different OFDM symbols within the burst are also likely to have different spectral and power characteristics, including power statistics such as peak/average power ratio.

It is easiest to see these characteristics and how they are measured through the use of examples. The following examples will be presented in a sequence which promotes an orderly approach to measurements and troubleshooting, and which enhances the chance that problems will be found at the earliest possible stage.

Time and Frequency Domain (Vector) Measurements (continued)

Setting up basic measurements

The measurements described here will illustrate the general measurement approach and provide specific examples of OFDMA analysis. While detailed step-by-step instructions will not be provided in this application note (instead, see the 896000 VSA help text and Option B7Y demonstration guide described above), many of the menu and dialog choices will be listed.

Demonstration software note: The measurements made here will use the OFDMA example signal recordings provided with rev. 6.20 (or later) of the 89600 vector signal analyzer software. You may obtain this software from Keysight Technologies, Inc., install it in a user PC, and operate it in a demonstration/training license mode without the need to purchase the software or contact Keysight to obtain a permanent license. This demonstration/training license is available each time the software is started, and the demonstration/training license capability does not expire. The demonstration/training license provides full access to the analyzer's detailed help facility, digital modulation tutorials, and demonstration videos.

Using an example recorded signal

An excellent example signal for both vector and modulation analysis is provided with the 89600 VSA software as a recording under the file name i80216e_DL10MHz.sdf (the path to the recordings is usually c:\Program Files\Keysight\89600 VSA\Help\Signals\). This OFDMA downlink recording includes slightly more than 5 RF bursts (downlink subframes) which have a burst length of 2.37 mSec and a repetition interval of 5 mSec.

When playback is first initiated in the 89600 VSA, the analyzer is set to the center frequency and frequency span used when the recording was made (though these can be changed later). The analyzer defaults to a two-trace display of frequency domain (spectrum) and 90% time domain (RF envelope) where the spectrum measurement corresponds to the time record shown in RF envelope form. The analyzer also defaults to a frequency resolution (FFT size) of 801 points and a playback overlap of 90%. The overlap figure sets the analyzer to construct each successive time record in playback by concatenating the last 90% of the previous time record with 10% "new" data from the next segment in the recording file. In this way the effective playback speed of the recording can be adjusted, with 0% overlap yielding a fast playback and 99.99% yielding a very slow playback.

Time and Frequency Domain (Vector) Measurements (continued)

Setting up triggering

Untriggered analysis of framed or bursted signals such as OFDMA is generally clumsy and unproductive. It is usually vital to measure specific portions of the signal, and this generally requires a combination of triggering and positive or negative trigger delay. Where an external frame trigger is not used, the analyzer can construct its own magnitude or IF trigger from the input signal itself. When measuring signals with significant amplitude variation due to modulation (this certainly applies to OFDMA!), the amplitude (RF envelope) variations can cause false triggers during a burst. Therefore trigger holdoff is also an important parameter to set, though the actual holdoff value is not critical for the purpose of avoiding false triggering due to modulation. Any value that is well in excess of the temporary minima caused by modulation will work well; 1 µSec is a good value to begin with.

Trigger holdoff has one other important use for framed signals such as OFDMA. Where a signal is composed of different bursts (such as uplink and downlink) and where the inter-burst timing varies, holdoff can be used with IF triggering to select a trigger point which is unique in an RF burst sequence. For example, there may be one inter-burst interval which is longer than all others, and this may be repeated once in each complete frame. Using a trigger holdoff value which is shorter than the longest inter-burst interval but is longer than the other intervals will yield a single valid trigger at a specific point in each frame. Positive and negative trigger delay can then be used to select any portion of the signal for measurement, referenced to this unique trigger point.

All of these trigger capabilities are available whether the signal is "live" (from input hardware) or from a recording. Triggers based on the recorded signal are grouped under the Playback Trigger tab of the Input menu.

While these trigger capabilities can be used in the digital demodulation mode as well, typical demodulation measurements are made with the "pulse search" functions specific to a demodulation type. These pulse search functions are in some ways more advanced than the triggering described here. The most common exception to this practice occurs when pulse search is unsuccessful or unreliable in demodulation operations, perhaps leading to questions about the validity of the pulses constructed by the system. In cases such as this the normal triggering and holdoff functions can help identify defective bursts.

Time and Frequency Domain (Vector) Measurements (continued)

When making triggered measurements on RF bursts, a good practice is to begin by setting a negative or pre-trigger delay of approximately 10% of the time record. Then choose an appropriate trigger holdoff value and adjust trigger level until a stable measurement is produced in the frequency and time domain. For the following measurements on the i80216e_DL10MHz. sdf recorded signal, a trigger level of 10 mV, a trigger holdoff of 1 μSec, and a pre-trigger delay of –3 μSec works well. See Figure 1.
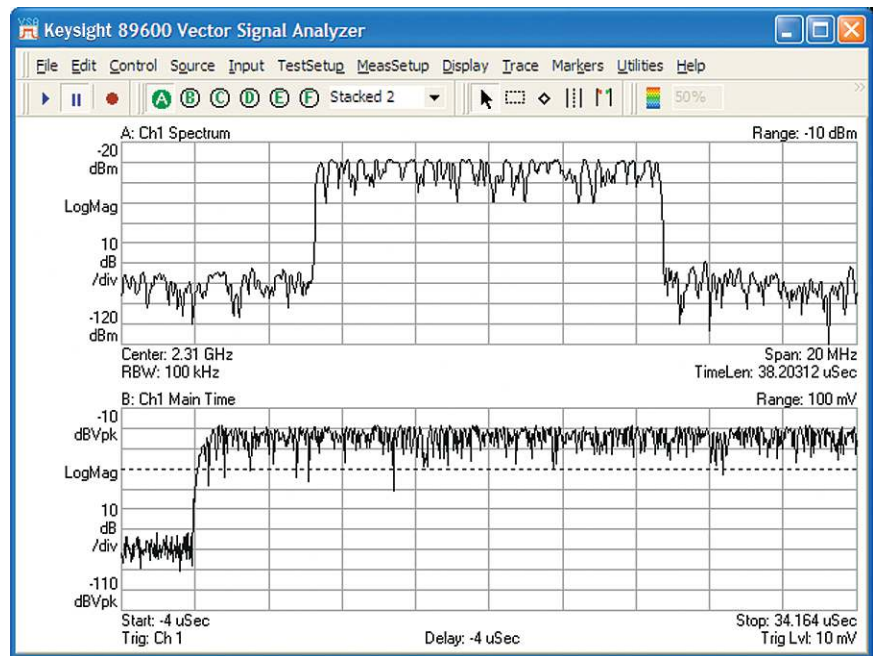

Figure 1. Triggered measurement of spectrum and RF envelope with negative trigger delay, showing leading edge of burst. Horizontal dashed line on RF envelope shows trigger level.

Time and Frequency Domain (Vector) Measurements (continued)

Basic measurements of the preamble

With the measurement stabilized, you can configure the analyzer to determine some basic signal parameters. Measuring the preamble of this down-link signal is a good place to begin, as the characteristics of this portion of the subframe are stable and well-defined. Since the preamble is 1 OFDM symbol time in length and may have a different power level than the rest of the subframe, it makes sense to set a time record length of about 2.5 times the OFDM symbol length, or about 250 µSec.

Given a particular frequency span (and resulting sample rate), FFT size, and RBW/window configuration there is a limit on the maximum length of a time record. For the 20 MHz span and 801 point FFT size of the analyzer's default configuration, this maximum time length is about 40 µSec. Since the desired length for this measurement is 250 µSec and since maximum time length and number of FFT points scale linearly, we need an FFT length approximately 6 times longer than the default 801 points. The ResBW tab of the MeasSetup menu provides a Frequency Points setting, and we should thus select a number of 6401 or greater from the binary sequence in the drop-down list.

Time and Frequency Domain (Vector) Measurements (continued)

Once the number of points is increased, the Main Time Length can be set on the Time tab of the MeasSetup menu to 250 µSec. The resulting time domain display now clearly contains the turn-on event, the preamble, and the first symbol following the preamble, along with the spectrum of this time segment. It is then a straightforward matter to use the band power marker tool and the mouse to measure both the power and time duration of the preamble, as shown in Figure 2. In the same way, we can select the occupied bandwidth marker for an approximate measure of the bandwidth of the signal. The default power percentage

for occupied bandwidth measurements can be changed, though this is not a particularly precise measurement for signals such as OFDM, which have varying sideband levels.

Since the band power marker length was set visually from the appearance of the RF envelope trace, the length setting (shown in the Calculation tab of the Markers menu, after selecting trace A) is a good way to verify approximate preamble (and therefore also OFDM symbol) length. In this way, you can measure and verify many of the basic parameters before attempting operations such as digital demodulation. At

this point it might be useful to use the mouse on the dashed vertical band power center line to drag the band power markers to the first symbol after the preamble. This would provide a good relative or absolute measurement of the relative power level of the OFDM symbols.
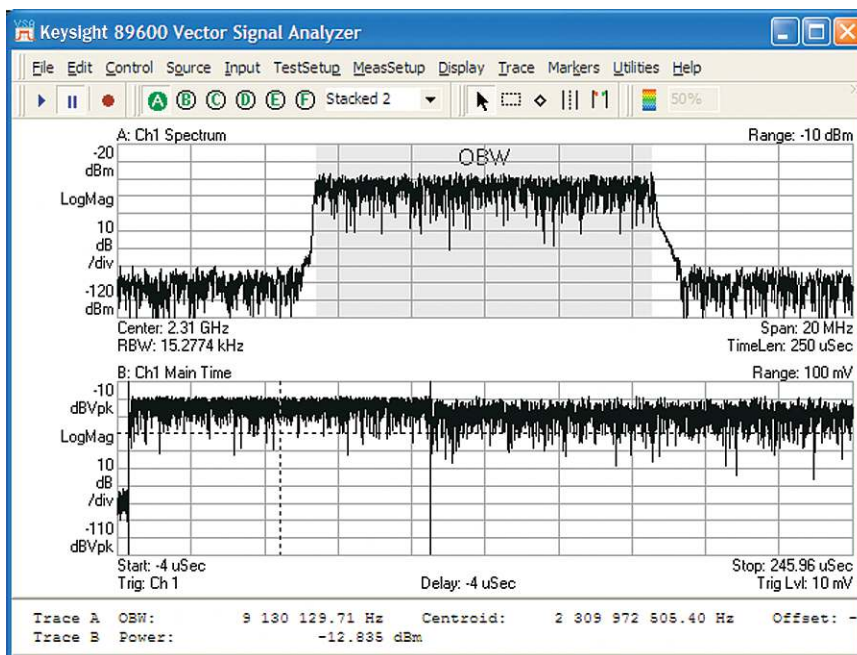

Figure 2. Occupied bandwidth and band power measurements; numeric results are shown at the bottom of the display.

Time and Frequency Domain (Vector) Measurements (continued)

Time-gated spectrum

You can make more precise and more specific measurements of spectrum and signal bandwidth, and of critical parameters such as carrier spacing using time-gated spectrum measurements on a frequency span just adequate to cover the signal. In this case a good choice for frequency span is 10 MHz, and this parameter (along with the center frequency, if desired) can be changed on a recorded or captured signal.

You can set up time-gated measurements visually by using the mouse, or numerically through the menus. In this case it is convenient to set specific parameters such as the gate length using the Time tab on the MeasSetup menu, and then move the gate window visually to align with the preamble. For optimum spectrum resolution, you should set the gate window to match the OFDM symbol time of 102.9 µSec, and set the Window Type (RBW shape) on the ResBW tab of the MeasSetup menu to Uniform. The uniform window is a good choice for self-windowing functions such as OFDM symbols, pro-

viding maximum frequency resolution for a given gate (time record) length. If necessary (as the result of other parameter changes) you should reset the main time length to a value such as 250 µSec, to allow measurement of different portions of the signal. Such a measurement is shown in Figure 3, where the gated spectrum measurement in trace A is the result of the gate window placed in trace B.

The individual carriers are resolved in trace A, and the offset marker function is used to measure their frequency difference. By measuring the outermost carriers and dividing by the number of carriers, an accurate (more accurate than one derived from occupied

bandwidth) measurement of carrier spacing can be made without the need for digital demodulation. This gated measurement is particularly well-suited to the preamble, where only every third OFDM carrier is transmitted and individual carriers are thus easily resolved and examined. The expanded X-axis scaling of trace C (about 10:1) shows both the untransmitted center carrier and the individual subcarriers in the preamble in more detail. If desired, you can move the gate window to the symbol following the preamble by dragging the left gate marker with the mouse or increasing the numerical gate delay (and therefore the start of the gate) by 1 OFDM symbol time.
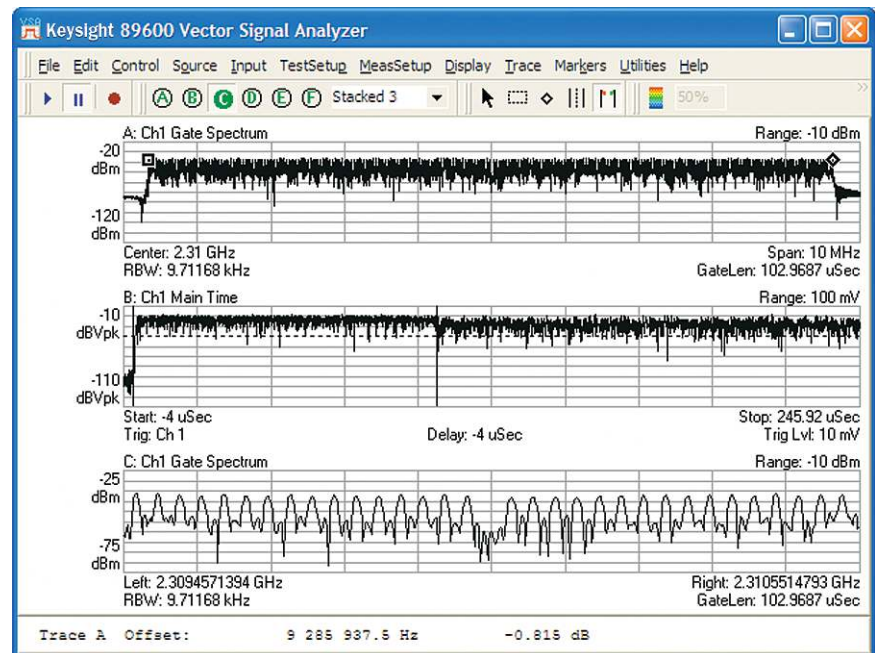

Figure 3. Gated spectrum measurement of only the downlink preamble. The gate windows are shown in trace B and the entire subcarrier set (every 3rd carrier) is shown in trace A. In trace C the X-axis of the middle portion of trace A is expanded to show individual subcarriers and the missing center carrier.

Time and Frequency Domain (Vector) Measurements (continued)

Measuring subframe timing

A three-trace display and X-axis scale expansion is also useful for measuring the actual burst length and turn-on/turn-off behavior of the signal. To obtain a sufficiently long main time (time record) length, the number of frequency points must be expanded again, this time to 25,601. Then a combination of offset markers, X-axis scale expansion, and marker coupling between all three traces produces the measurement shown in Figure 4.

Marker offset references can be selected separately or together for each trace. In this measurement the reference for the offset marker signifies the beginning of the RF burst and is set on trace B. The end of the RF burst can be most easily set by placing a marker on trace C (which places a marker at the same time point on trace B, though it is off-scale to the right), and the RF burst time duration can be read from the offset marker B value at the bottom of the screen.

Marker coupling is particularly useful for measurements such as this, where the measurement data far exceeds what can be shown on a normally-scaled trace. The offset markers could also be used on individual traces to measure the power ramps.

Gated vector measurements are useful for a variety of tests not involving digital demodulation. For component manufacturers, for example, statistical power measurements such as CCDF provide important information for comparing different amplifiers or power settings.
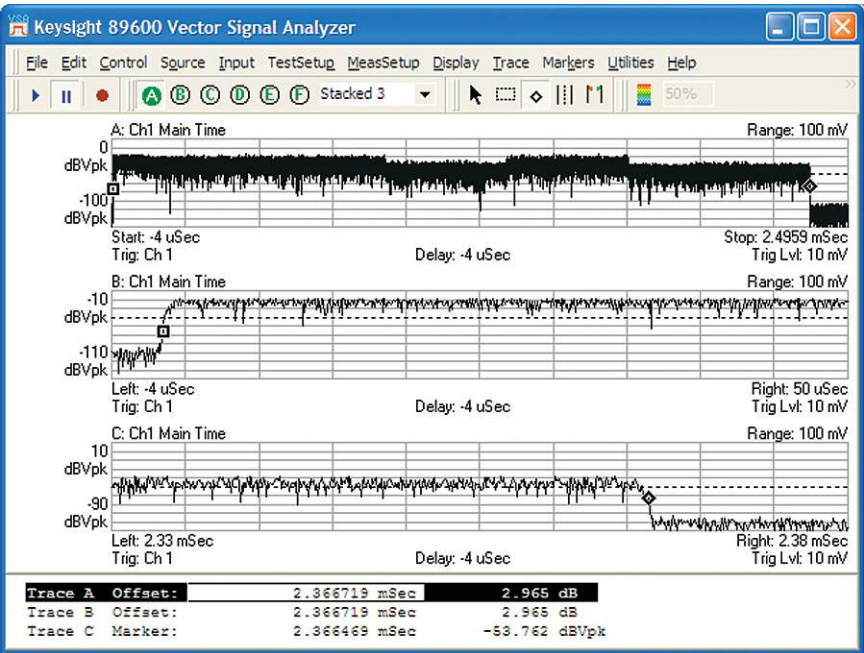

Figure 4. RF envelope of the entire subframe (top trace) along with expanded-scale views of the turn-on and turn-off events (lower traces). Coupled offset markers are used with the expanded scaling to accurately measure the subframe length. Note also the varying power of the RF burst envelope as shown in trace A.

Time and Frequency Domain (Vector) Measurements (continued)

CCDF measurements

As with spectrum measurements, CCDF measurements are most valid and consistent when made in a time-gated mode. In particular, for a signal such as OFDMA, where signal structure and modulation (and therefore power statistics) change during a subframe, it can be very useful to make measurements focused on particular parts of the signal. Alternatively, measurements can be made on the same signal both before and after a particular component (such as an amplifier) or operation (such as filtering or crest factor reduction) to better understand the effects.

The setup for time-gated CCDF is very similar to that used for the gated spectrum measurements of Figure 3. For illustration, the CCDF of the preamble is measured and saved in a data register. It is then overlaid with a measurement of a later portion of the subframe which uses all subcarriers. The result is shown in Figure 5.

As can be seen from the RF envelope trace, the power statistics are quite different for the preamble and later portions of the subframe. At the 1% probability point the peak/average power ratios are almost 3 dB different! Note that while the actual average power levels of the preamble may be different from the rest of the subframe, the CCDF calculations normalize this difference out. In a similar way, the CCDF of different portions of the RF burst (as shown by the power variations in the top trace of Figure 4) could be measured by graphically or numerically placing gate markers.
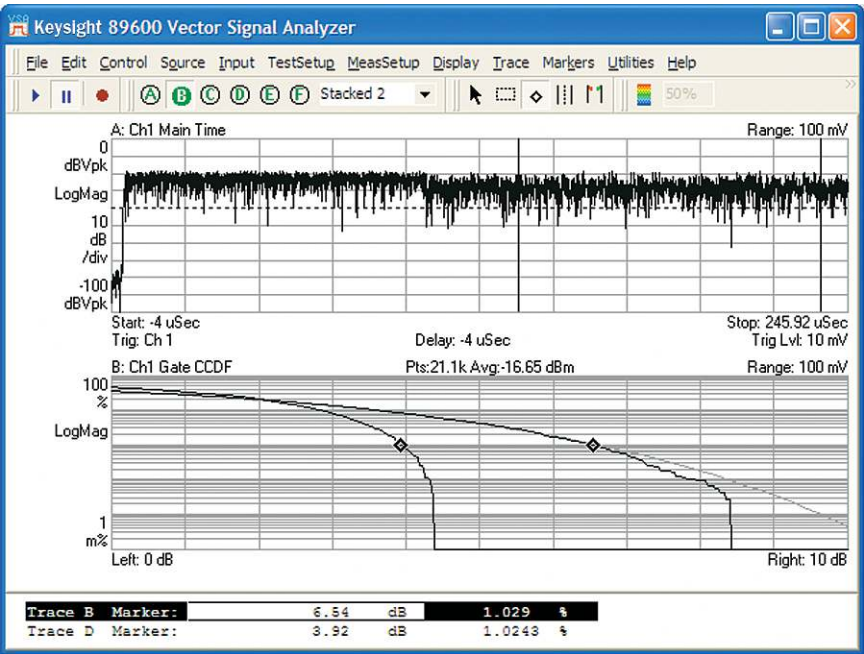

Figure 5. Time-gated CCDF of preamble and data portion of OFDMA downlink subframe overlaid (bottom trace). The gate window is shown in the upper trace and a reference AWGN curve is shown by a gray line in the lower trace. Specific peak/average power figures for the 1% probability point are listed in the marker table for comparison.

Time and Frequency Domain (Vector) Measurements (continued)

Spectrograms

With a comparatively wide bandwidth, long time length, and large number of carriers, an OFDMA subframe typically contains a large amount of data. Most time and frequency domain displays, however, contain a limited amount of information. Spectrograms are an excellent way to present a large amount of spectral information on a single screen by using color as an additional information axis. To do this, each individual spectrum measurement is reduced to one pixel row in height, and amplitude is encoded as a color or brightness value. By stacking successive spectrum measurements, the Y-axis of the display is a time axis. In this way hundreds of spectrum measurements can be presented on a single display, enhancing the visibility of subtle spectral effects.

Spectrograms are particularly useful when made from signal recordings, since the analyzer is in a real-time analysis mode during recording and playback, ensuring that the mea-surement data is contiguous and no signals are missed. In addition, the adjustable overlap parameter available for playback allows you to adjust the time interval represented by successive spectrum measurements (and therefore the vertical time scale of the spectrogram) as needed to optimize the measurement.

Spectrograms covering bandwidths much wider than the OFDMA channel can be useful for detecting interference and understanding band usage. For the purposes of this application note, however, we will discuss the use of a time-gated spectrogram of the downlink subframe previously analyzed. The setup is essentially the same as the gated spectrum measurements in Figure 3, with a 1 symbol gate length and a uniform window shape. Triggering (specifically Playback Triggering) should be switched off for these spectrogram measurements and Max Overlap for this example time capture should be set to 98-99%.

Time and Frequency Domain (Vector) Measurements (continued)

For this measurement, Y-axis scaling should be reduced (to 2 dB/division in this example) to emphasize spectral changes associated with OFDM symbol transitions. You can then increase and adjust the overlap, first to show the initial symbols of the subframe, and later to show the entire subframe and its changing spectral content. As needed, you can adjust the spectrogram enhancement parameter to emphasize the amplitude range of interest. The symbol transitions are most clearly seen in color displays.

For the first measurement, the analyzer's Trace Select spectrogram marker will be used. This allows one spectrum measurement to be selected from the spectrogram and displayed in another display trace, as shown in Figure 6.
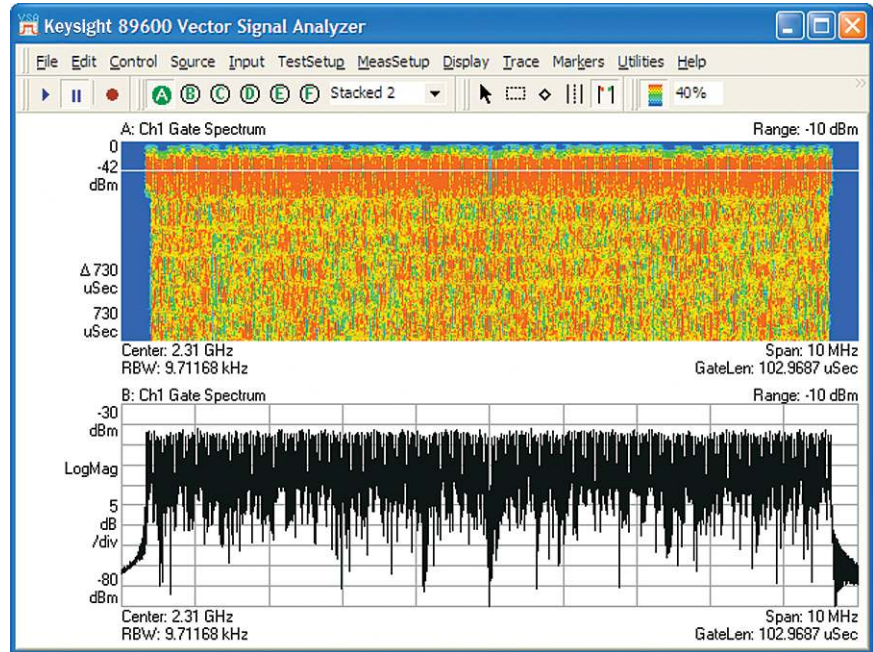

Figure 6. Spectrogram and spectrum measurements of preamble and first symbols of downlink subframe. The Trace Select marker is used in spectrogram to identify individual spectrum measurement for display in bottom trace. Note that the occupied bandwidth of the signal is somewhat wider during the preamble.

Time and Frequency Domain (Vector) Measurements (continued)

Correlating a spectrogram with data bursts

Since this example signal contains several different data bursts in each of two different zones, and each zone contains a combination of data-carrying and unoccupied (pilots-only) symbols, it is possible to match the subframe with the data burst maps used by the analyzer for digital demodulation operations in OFDMA analysis. To perform this visual match, the data burst maps (which use logical subchannels as their Y-axis and OFDM symbol index/time as their X-axis) will be rotated 90 degrees and aligned with the spectrogram to produce the graphic shown in Figure 7. The window (RBW) shape has been returned to the default flat top shape to show the increased sideband energy that marks the symbol transitions on either side of the spectrogram.
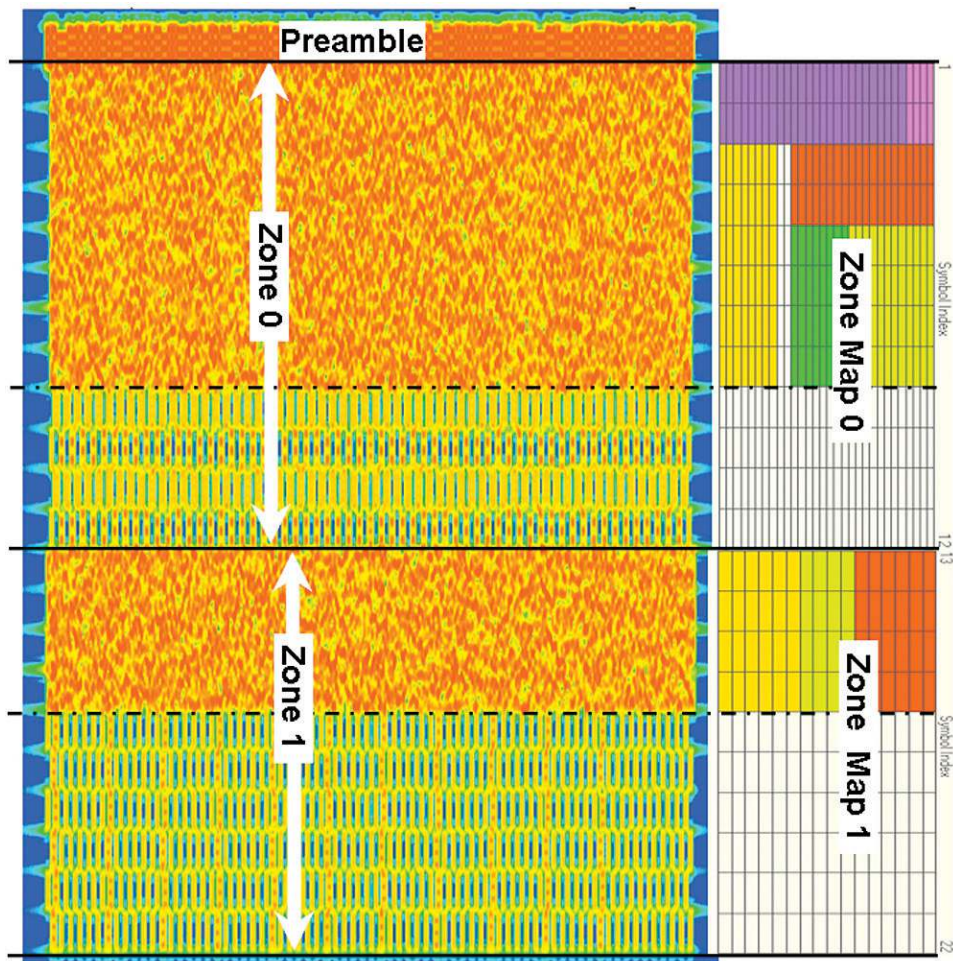

Figure 7. Spectrogram (left) and data burst maps (right) aligned to show the same events in time (Y-axis). The change in OFDMA subcarriers corresponding with data bursts and logical subchannels is clearly shown. Note in particular the different spectral characteristics associated with data-carrying symbols and unoccupied (pilot carriers only) symbols.

Time and Frequency Domain (Vector) Measurements (continued)

By adjusting the spectrogram parameters, the structure of the subframe and its data bursts is revealed. Even the timing of the individual symbol transitions can be seen by the temporary increase in sidelobe energy at the left and right edges of the spectrogram. Especially distinct spectral changes are obvious in the latter part of each zone, where the data bursts have ended and only pilot subcarriers are transmitted. The changing subcarrier numbers of these pilots from symbol to symbol are also shown in the spectrogram. With X-axis scaling and the spectrogram's Trace Select function, you could see details of pilot and subcarrier behavior on a symbol-by-symbol basis. In general, the use of the uniform window (Figure 3 above) provides the best frequency resolution for resolving OFDM subcarriers, and the flat top and Gaussian windows provide the dynamic range to reveal the symbol transitions.

Vector measurements summary

As the examples here show, you can understand, measure, and verify many of the most important characteristics of the OFDMA signal before performing digital modulation analysis. Indeed, the use of vector time and frequency domain analysis to more fully understand the signal and its characteristics will improve digital modulation analysis and may reveal to you problems or impairments which would otherwise remain obscure.

Basic Digital Demodulation

The goal of basic digital demodulation is successful and valid demodulation of the signal (a "locked" demodulation result with correctly detected symbol states, etc.). This demodulation will produce a wide variety of valid modulation quality measurements plus basic error displays primarily in terms of time (or OFDM symbol) and frequency (or OFDM subcarrier).
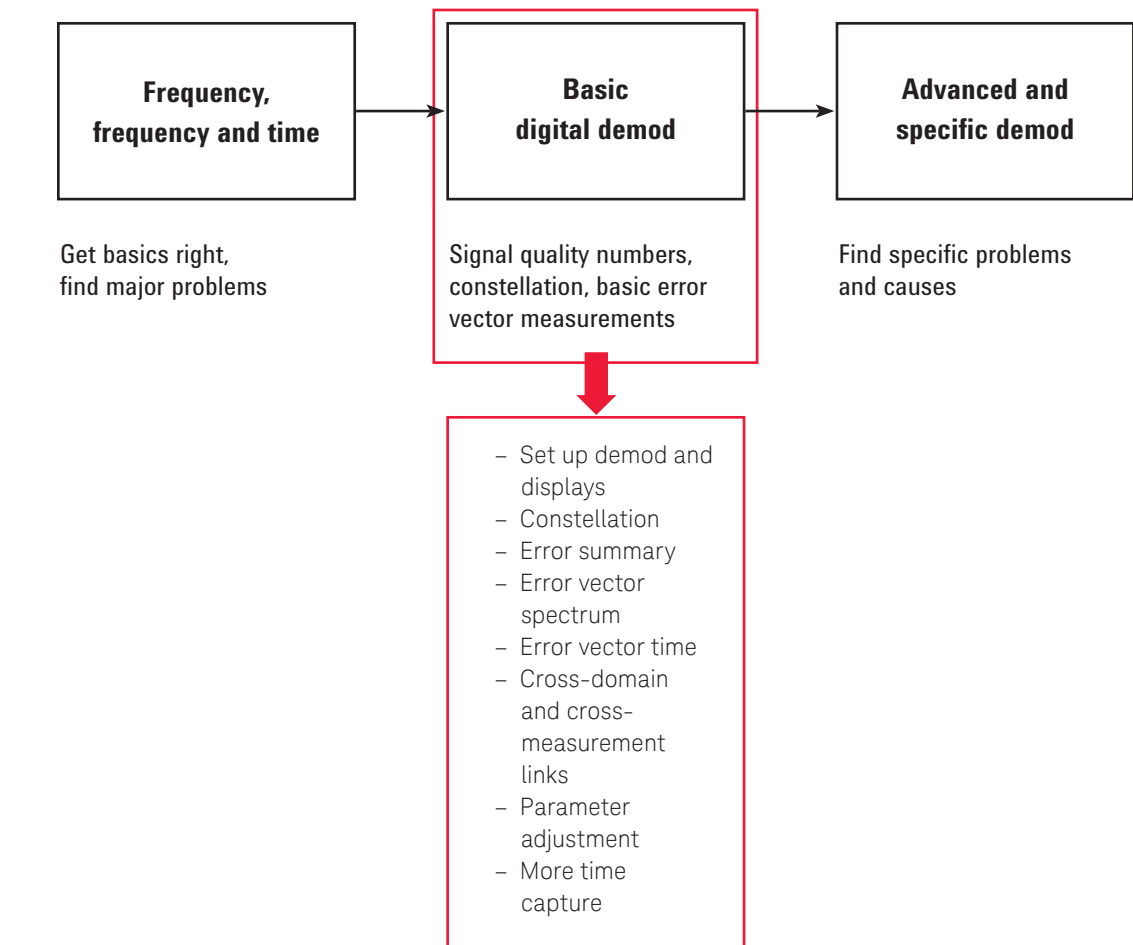
The information gained during initial vector measurements enhances the reliability of digital demodulation measurements and the insight provided by them.

For some measurement tasks, especially design verification, basic digital demodulation will be sufficient. The error summary table provides a complete numeric summary of signal quality and the magnitude of major error types. A large amount of measurement data is available at this stage and you can perform significant troubleshooting as well. Error vector time and frequency measurements, in particular, are an excellent way to begin tracking down potential problem sources.

One powerful technique (often overlooked, and not available in many other product solutions) is to use marker coupling to link error measurements across different domains. Error sources may be invisible in one measurement type and obvious in another. This is particularly true in multicarrier formats such as OFDMA, and we will discuss some examples of the use of marker coupling in this note.

Table 3. Basic digital demodulation measurements verify proper modulation and quantify the main error parameters such as EVM vs. symbol and subcarrier.

Frequency, frequency and time → Basic digital demod → Advanced and specific demod

Get basics right, find major problems

Signal quality numbers, constellation, basic error vector measurements

Find specific problems and causes

- Set up demod and displays
- Constellation
- Error summary
- Error vector spectrum
- Error vector time
- Cross-domain and cross-measurement links
- Parameter adjustment
- More time capture

Basic Digital Demodulation (continued)

Understanding I/Q errors in OFDM

One excellent reference on troubleshooting OFDM signals is an RF Design magazine article by Robert Cutler of Keysight Technologies. A summary table from that article is shown here (with a table error corrected). You can find this reference in the Resources section at the end of this application note.

Note, in particular, that many types of signal impairments do not provide the distinctive error displays in OFDM that they would in single-carrier modulation. Understanding the specific type of error is a primary use of many of the 89600

VSA's digital demodulation measurement displays. Fortunately, impairments and defects (such as flatness/frequency response, symbol timing, phase noise, frequency error, EVM, I/Q defects, etc.) have the same appearance as they do for IEEE 802.16 OFDMA WiMAX. Also, some of the setup parameters can be entered the same way as they are for other modulation types.

Table 4. Using constellation displays to determine OFDM signal impairments is somewhat more complicated than for signals with single-carrier modulation.

Impairment	OFDM	Single carrier modulation (SCM)
IQ gain balance	State spreading (uniform/carrier)	Distortion of constellation
IQ Quadrature skew	State spreading (uniform/carrier)	Distortion of constellation
IQ channel mismatch	State spreading (nonuniform/carrier)	State spreading
Uncompensated frequency error	State spreading	Spinning constellation
Phase noise	State spreading (uniform/carrier)	Constellation phase arcing
Nonlinear distortion	State spreading	State spreading (may be more pronounced on outer states)
Linear distortion	Usually no effect (equalized)	State spreading if not equalized
Carrier leakage	Offset constellation for center carrier	Offset constellation
Frequency error	State spreading	Constellation phase arcing
Amplifier droop	Radial constellation distortion	Radial constellation distortion
Spurious	State spreading or shifting of affected	State spreading, generally circular

Basic Digital Demodulation (continued)

Capturing a signal for analysis

To make accurate demodulation measurements, the analyzer setup must match the signal. This matching process may involve some experimentation with demodulator settings and characteristics, and the use of the 89600 VSA's time capture can be very helpful in this effort. By capturing one or more examples of the signal for repeated playback, you can be assured that any changes in the demodulation result (including both success/failure of demodulation and changes in measured signal quality) are the results of the intended setup changes and not a consequence of changes in the signal itself. This approach reduces the number of variables in signal analysis and troubleshooting and improves the chances for consistent and meaningful results. The use of time capture files has additional benefits, allowing you to archive signals for future comparisons and providing an easy method to distribute signals to different design teams.

In the 89600 VSA, time capture operations primarily require the setting of analyzer center frequency and span, and selection of a capture length. Generally a frequency span of 1.2 to 1.5 times the nominal bandwidth is sufficient. The center frequency need not be exact, as you can change both center frequency and span after signal capture. You can set the length of the time capture in terms of samples (expressed as a number of time records) or time. For signals such as those described here, a capture of one to five frames should be sufficient. The time capture operation can be a triggered event, and it is useful to trigger on the rising edge of the burst, with a negative (pre-trigger) delay of 5 to 50% of the burst length. Trigger holdoff, if necessary, should be set as described previously in the vector measurements section of this note.

Basic Digital Demodulation (continued)

Two types of demodulation measurements

When analyzing OFDMA signals with the 89600 VSA software, there are two types of demodulation measurements to make: "uniform" mode and "data burst" mode. In a uniform mode measurement, the analyzer assumes that the signal will have only one type of modulation and one power level throughout the permutation zone to be analyzed. In "data burst" analysis, the analyzer demodulates the signal according to a subchannel-by-symbol (or "slot") "zone definition" grid that the user creates or provides in the form of a setup file. This grid indicates the type of modulation used for each logical subchannel and each symbol of the subframe, allowing the analyzer to demodulate and display the individual data bursts, either separately or together, and to produce a Data Burst Info summary results table, which will be described later in this note.

One good approach for getting demodulation working and making modulation error measurements with the minimum amount of difficulty is to limit the complexity of the signal. An excellent way to limit the complexity of the signal is to use a "uniform" signal. As used in this note, the uniform signal is limited to a single modulation type and uses all logical subchannels (and therefore all subcarriers) for the entire subframe. The power of the uniform signal remains constant for each symbol in the subframe. In addition, the pilots (relative to which the signal is demodulated) are easy to find.

This simplified signal is not an appropriate one for normal system operation, since one of the limitations on its complexity is its lack of a QPSK-modulated frame control header (FCH).

The uniform signal offers benefits for both signal creation and signal analysis. On the creation end, the uniform signal can be created in the same way that simpler OFDM signals are, reducing the chance for DSP or other errors in signal creation which might be confused with errors in modulation analysis (parameter) setup, demodulation algorithms, etc.

Since the uniform signal is generally representative of other signals in terms of spectrum and power statistics, it is a good test signal for testing part or all of the RF signal chain. The uniform signal is spectrally correct and usually correct for power statistics as well: these statistics should approach the AWGN curve. While downlink signals can change power during a subframe, for a single OFDM symbol, the CCDF power statistics should be similar between uniform and nonuniform signals.

Basic Digital Demodulation (continued)

Downlink modulation quality measurements of a uniform signal

This downlink analysis will use the example downlink recording i80216e_DL-PuscUniformQ64.sdf supplied with the 89600 VSA software. Many important characteristics of this signal can be determined using the techniques described previously in the vector measurements section of this note. For example, the signal is 22 OFDM symbol times long in total, including 20 symbols of 64QAM data plus the preamble. This uniform signal occupies all of the slots in the zone, which means that all of the OFDM subcarriers are active throughout the subframe and are modulated with 64QAM (except for the pilots, which are modulated with BPSK).

As described above, it is generally helpful to make the vector (time envelope and spectrum or gated spectrum) measurements on a signal before setting up to perform digital demodulation. Accordingly, it is assumed here that the signal has no gross uncorrected defects that could be seen in vector mode, and which could be expected to prevent digital demodulation.

Whether entered directly or derived from the vector measurements described previously, it is assumed that the signal analyzer's amplitude parameters (attenuation or input range),

frequency parameters (center, span) and trigger conditions (external/internal and trigger level delay and holdoff, if necessary) have been correctly set. In many cases the VSA's pulse search capability will eliminate the need for triggering and for selecting parameters including holdoff.

Set the center frequency to the most accurate value known or derived from previous measurements. The analyzer will calculate the precise center frequency of the signal during the demodulation process, and the analyzer will also report the error in the error summary table. In general, the demodulation algorithms should operate well on OFDMA signals where the selected center frequency is accurate to within about one half of the OFDM carrier spacing. If you suspect a configuration error larger than this value, you can configure the 89600 VSA software for a larger demodulation carrier lock range by selecting the Extend Frequency Lock Range check box in the Advanced tab of the OFDMA Demodulation Properties dialog box. This expanded lock range is only available for uplink signals, due to their lack of a preamble. Once a more accurate center frequency is derived from a locked demodulation measurement, that frequency should be selected as the analyzer center frequency, and you should clear the Extend Frequency Lock Range box to yield the most stable and accurate demodulation results.

Recall that when using recorded signals with the 89600 VSA, you can change the analyzer's center frequency and span during any stage or mode of analysis – even after the recording is made. This is true so long as the desired analysis span is contained fully within the original recording span.

The default demodulation settings for the 89600 VSA include a pulse search function, so triggering is not usually necessary for pulsed signals such as most OFDMA downlink and uplink signals. However, if the signal under test includes both uplink and downlink signals, and/or if the intent is to measure a specific RF burst among others, you would normally use triggering. This triggering can be internal triggering, where a combination of trigger level, negative/positive trigger delay, and trigger holdoff are used to select the desired RF burst. Alternatively, you can use external triggering when an external trigger signal is available. Both negative and positive trigger delay are available for this trigger type, and they can be used to measure a specific burst even if the trigger is not coincident with the burst. Indeed, you would ordinarily use external triggering to examine the relationship between a supplied trigger signal and RF burst power (vector mode) or between a supplied trigger and data modulation (digital demodulation mode).

Basic Digital Demodulation (continued)

The first step in digital demodulation is to select the demodulation mode. You do this from the analyzer's MeasSetup > Demodulator > Broadband Wireless Access menu sequence, where 802.16 OFDMA is chosen. The next step is to bring up the 802.16 OFDMA Demodulation Properties dialog box (MeasSetup > Demod Properties) and its four tabs, beginning with the Format tab, as shown in Figure 8.

The Format tab contains a drop-down list used to select the applicable standard. This selection should be the first action you take in setting up digital demodulation. Selecting the standard configures certain properties of the demodulator, as described in detail in the analyzer's online Help facility. Next to this box is the Preset to Standard button, and it is generally a good idea to use this button once the standard is selected. There are very many measurement configuration and

demodulation parameters to set when performing OFDMA demodulation, and this button will reset most of them, reducing the chance that parameters specific to a prior measurement will be incompatible with the current one.

The 89600 VSA software supports two standards: the approved IEEE 802.16e OFDMA standard, plus an additional proposed standard (Corrigendum 1, Draft 2), useful for troubleshooting systems developed earlier. There are 3 pre-set profiles to choose from: 5 MHz, 10 MHz, and WiBro. To examine our current signal, i80216e_DLPuscUni-formQ64.sdf, select the 10 MHz profile.

For this measurement we want to use the "uniform zone analysis" mode and not "data burst analysis." Note that the current definition of the standard preset does select the data burst analysis mode. This setting needs to be changed, and you can do this by clearing the Data Burst Analysis box on the Zone Definition tab of the Demod Properties dialog box. On the right side of the Format tab, select the appropriate subframe, either Uplink or Downlink. Note that this section of the application note describes a downlink measurement.
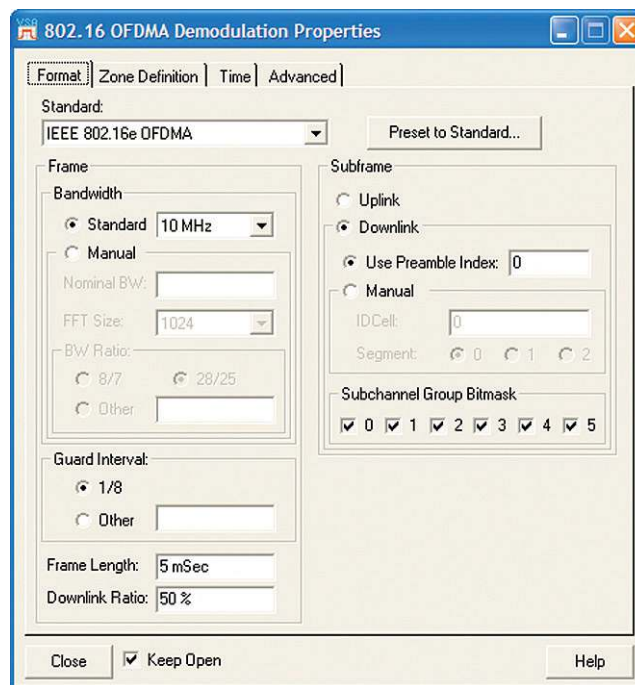

Figure 8. The Format tab of the Demodulation Properties dialog box is where the IEEE 802.16e standard and the main demodulation properties are selected.

Basic Digital Demodulation (continued)

The next step is to confirm or change the parameters on the left side of the Format tab associated with the analyzer's sampling of the signal. Choosing the Preset to Standard > 802.16e: 10 MHz automatically defaulted to the correct values for Bandwidth, BW Ratio, and FFT Size. You may choose values other than the standard values by selecting the Manual box on the Format tab.

The FFT size associated with the 10 MHz nominal bandwidth signal is 1024, yielding 840 active OFDM carriers during the data portion of the burst. Since carrier spacing is held constant in IEEE 802.16 OFDMA, a 20 MHz nominal bandwidth signal would use an FFT size of 2048 and 1640 active carriers, while a 5 MHz nominal bandwidth signal would use an FFT size of 512 and 420 active carriers.

For uniform mode analysis, the modulation format is automatically detected on a symbol-by-symbol basis. With these parameters and default measurement selections for a four-trace display, the analyzer produces a display such as Figure 9 from the supplied example downlink recording i80216e_DLPuscUniformQ64.sdf.
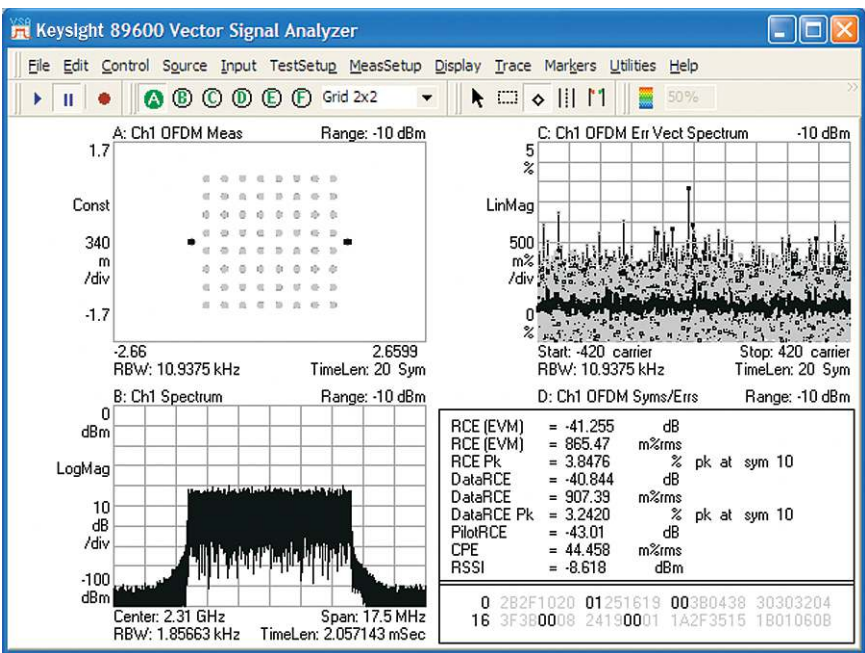

Figure 9. Demodulation results from a uniform downlink signal using only 64QAM modulation. The uniform appearance of the error vector spectrum display in the upper right indicates that all OFDM subcarriers or logical subchannels are occupied.

Basic Digital Demodulation (continued)

One of the most useful symmetries in the display and analysis of OFDMA signals is between the error vector spectrum (error vs. frequency or subcarrier) measurement and the error vector time (error vs. time or symbol) measurement. These measurements are complementary and orthogonal, and can be valuable both for ensuring correct measurement and for signal verification or troubleshooting. Accordingly, it is frequently useful to have both measurements in the same display, and that is easily accomplished by selecting trace B (merely click anywhere on the desired trace), double-clicking the Trace Data label at the upper left of the trace, and selecting Error Vector Time from the (alphabetized) list in the resulting dialog box. The error vector time trace can then be autoscaled by right clicking the trace and selecting Y Auto Scale. Now you can simultaneously evaluate the signal error in the time and frequency domains. Using the mouse and the marker tool (the small diamond) in the toolbar, you can activate and place a marker in any desired trace. You can use markers on all of the traces (and associated domains) and couple markers between them. To do this, select Couple Markers from the Markers

menu and choose the marker location by selecting it in the trace which is currently active. The markers in all other traces will be shifted accordingly. An example result is shown in Figure 10.

As shown in the figure, a symbol, such as one associated with an error peak, can be chosen from a desired domain

(time, frequency, I/Q constellation location, etc.) and examined in multiple domains at once as a way to determine its cause or significance. Errors may be associated with a specific symbol value (as determined from the symbol table), with a specific time (or symbol), or with a specific frequency (or subcarrier).
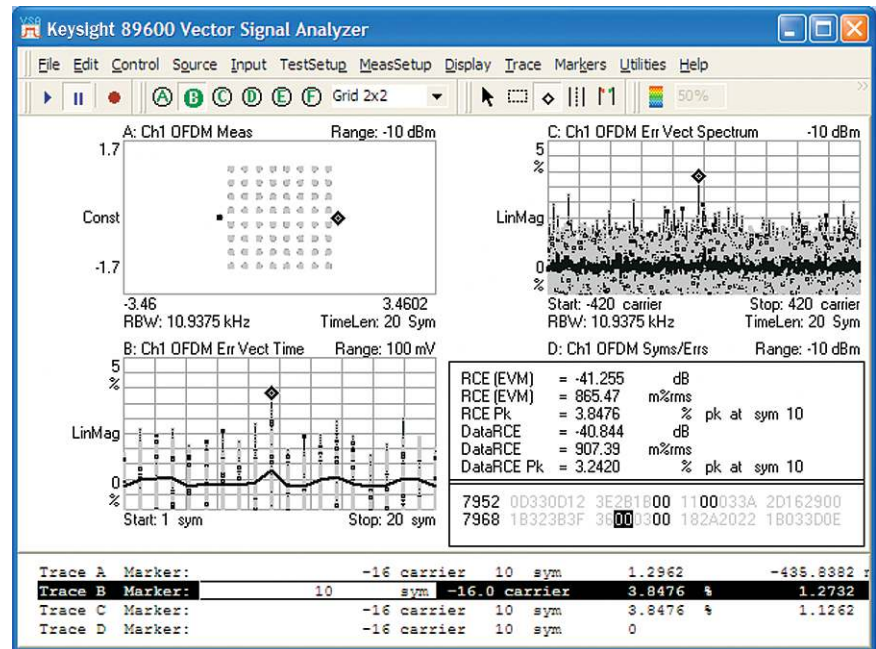

Figure 10. Demodulation results showing error in both the time (lower left) and frequency (upper right) domain. Coupling markers together on all traces lets you "walk" through the signal and investigate anomalies. For instance, in this measurement, the peak in the error vector time trace is associated with one of the BPSK pilots.

Basic Digital Demodulation (continued)

In some troubleshooting applications on complex pulsed or bursted signals such as these, it can be helpful to simultaneously see both demodulated information and spectrum or time domain information. Where there is sufficient display space, you can use the 6 trace display mode of the 89600 VSA by selecting Display > Layout from the menus or by clicking the drop-down list to the right of the trace buttons in the toolbar. 3 x 2 or 2 x 3 configurations can be selected as desired, and the additional two traces can be used to good advantage to show both the spectrum of the signal and RF envelope of the signal bursts

used for the pulse search operation (Ch1 Search Time). An example is shown in Figure 11.

In particular, the use of the search time display is useful for diagnosing consistent or intermittent demodulation failures on pulsed/bursted signals. The search time result should always include at least one full RF burst (subframe) including the rising and falling edges. You can use the search time display with the numeric figures and graphics provided in the Time tab of the Demod Properties dialog box, as will be described in a later section of this note.
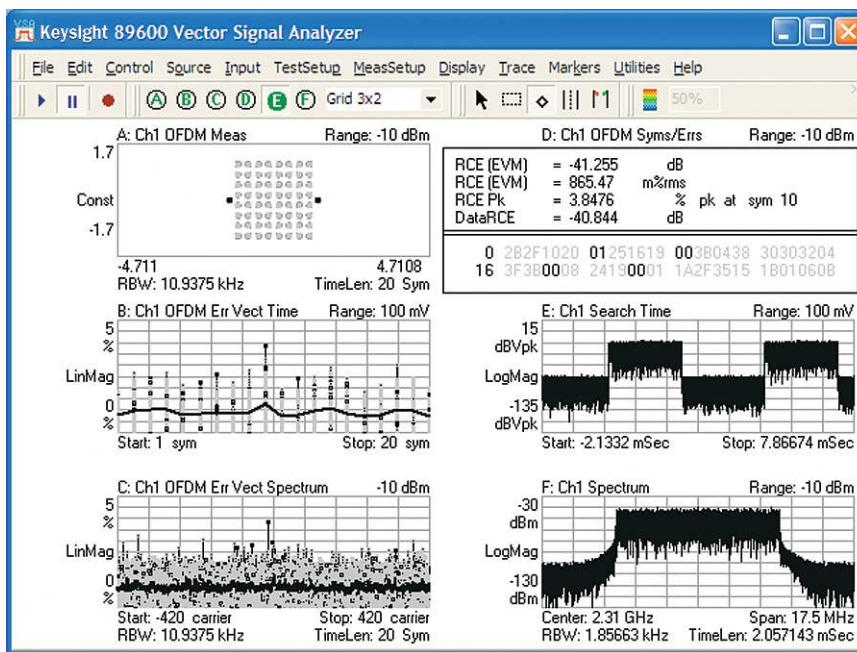

Figure 11. A 6-trace display lets you see even more information, including search time, which is useful when troubleshooting pulsed or bursted signals. Normally, a 6-trace display would be used with a much larger display than in this example and would include additional annotations and marker data.

Basic Digital Demodulation (continued)

If a specific demodulation format is desired in a uniform zone measurement, and you do not want the analyzer's automatic format detection, you can manually set the Data Tone Modulation by switching Data Tone Modulation to Manual on the Advanced tab of Demod Properties, as described in the 89600 Help. As might be expected, selecting the wrong type of modulation (a mismatch to the actual modulation type used in the signal) will cause high errors in the time and frequency domains, though the demodulation will "lock" properly due to the presence of the BPSK pilots. An example result of 64QAM demodulated as QPSK is shown in Figure 12.

The data tone selection operates somewhat differently in data burst analysis mode than it does in the uniform zone analysis mode described here, and those differences will be described during a discussion of data burst analysis later in this note.
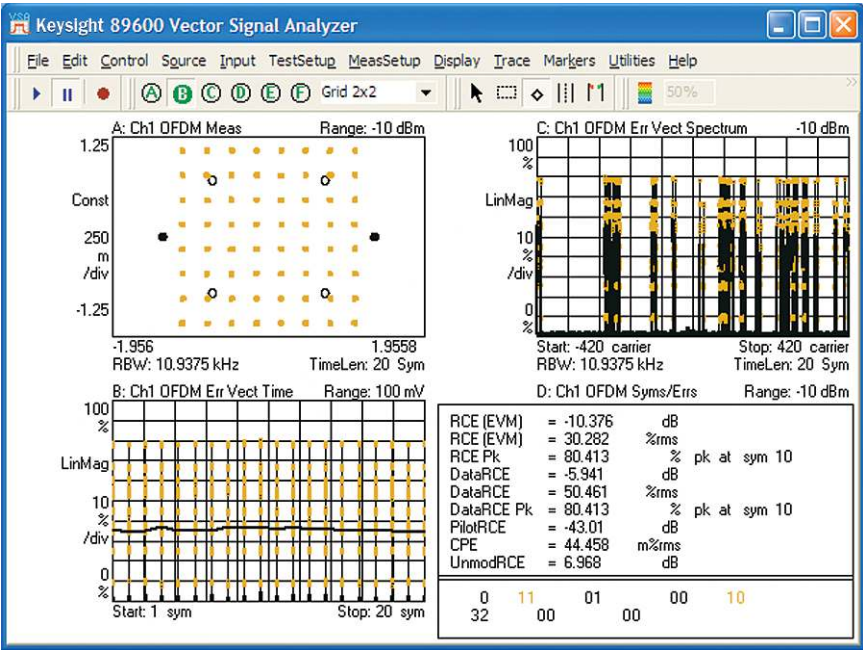

Figure 12. Forcing QPSK demodulation of a 64QAM signal produces a large error (none of the detected symbols is actually within the displayed QPSK targets), though the demodulation locks successfully due to the presence of the BPSK pilots. The Y-axis scaling has been changed from previous measurements.

Basic Digital Demodulation (continued)

Downlink modulation quality measurements of a burst (nonuniform) signal

The next discussion of digital demodu-lation of a downlink signal will use the example downlink recording i80216e_DL10MHz.sdf, supplied with the 89600 VSA software.

Prior to recalling any signal, it is a good idea to use File > Preset > Preset Setup to place the analyzer in a known state.

This new signal contains two zones (i.e., it is not a uniform signal) and is 23 symbol times in length. The first zone is PUSC and has an FCH (frame control header), DL-MAP, UL-MAP, and three data bursts: one each of QPSK, 16QAM, and 64QAM. It occupies 12 symbols, though no data bursts occupy the last 4 symbols. The second zone is FUSC and contains three data bursts: one each of QPSK, 16QAM, and 64QAM. They occupy the first 4

symbols of the 10 symbol FUSC zone, leaving the last 6 symbols unoccupied. Note that you can see any of these unoccupied symbols on the time trace. The total downlink subframe is then 22 symbols plus the preamble.

This discussion will describe data burst analysis, using the Zone Definition Map file supplied with the signal recording as part of the normal 89600 VSA soft-ware installation.

Remember, from our previous discus-sion, that it is generally helpful to make vector (time envelope and spectrum or gated spectrum) measurements on a signal before setting up to perform dig-ital demodulation. Once successfully completed, you can continue with more confidence.

As with the previous measurement, digital demodulation begins with selection of the digital demodulation mode in the 89600 VSA and use of the

Preset to Standard > 802.16e: 10 MHz in the Demod Properties dialog box's Format tab. In this case we want to perform data burst analysis, so we will not change the results of the preset operation in this area.

The selection of the Downlink Sub-frame and the Preset to Standard operation on the Format tab causes the synchronization to fail with this example signal because it uses a nonzero preamble index. Changing the Use Preamble Index to 14 (which can be determined by experimentation with different values) will correct this. Note that the SyncCorr value on the Syms/Errs table changes from 0.04 to 0.98 after correcting this value. After this setup you will be measuring only the FCH (frame control header) data burst. Without using a map file or otherwise defining data bursts, the only burst whose modulation and location is known (by the analyzer, from the stan-dard) is the FCH.

Basic Digital Demodulation (continued)

You can verify this by examining the constellation display, where only QPSK and BPSK modulation are present. Note that in the default color coding configuration for the 89600 VSA, the BPSK pilot symbols are shown in white (the default has been changed here for clarity in monochrome printing), and the QPSK FCH symbols are shown in pink as in Figure 13.
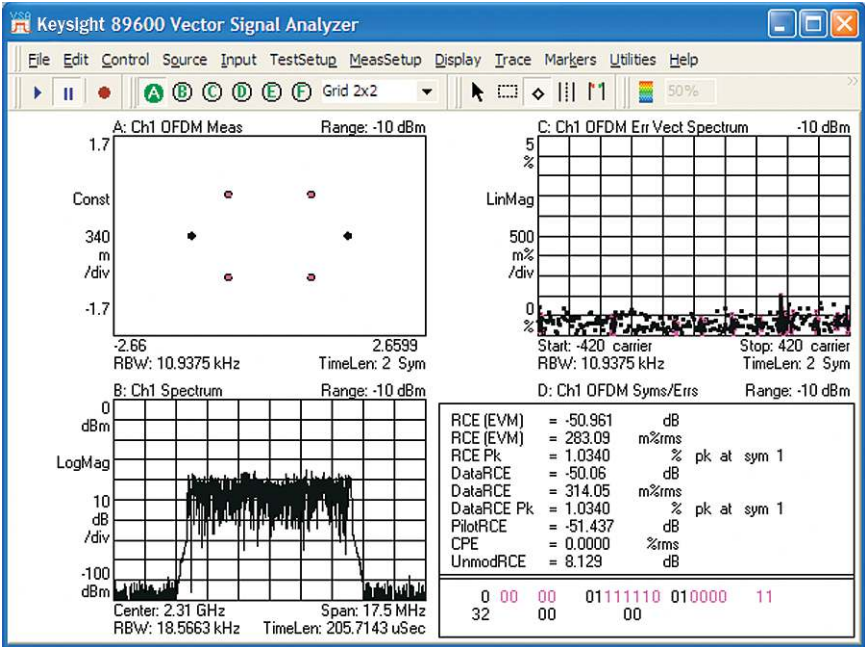

Figure 13. Measurement of a downlink PUSC signal. As indicated by the constellation display and color-coding, this measurement only includes the BPSK pilots and the QPSK FCH. The color coding of the data bursts is consistent across all traces.

Basic Digital Demodulation (continued)

OFDMA Signal Maps

The IEEE 802.16 OFDMA signal structure is very complex. The analyzer setup must match the setup of the transmitted signal. There are three ways to do this in the analyzer.

The first, and easiest, is to recall a Keysight N7615A Signal Studio for 802.16 OFDMA setup file. To do this, simply go to the 89600 VSA tool bar and select File > Recall > Recall Signal Studio Setup. This provides the analyzer with a zone definition map matching the signal created with the N7615A Signal Studio for 802.16 OFDMA. Thus, you only need to create the signal definition once.

The second way is to use the Zone Definition Grid. The Zone Definition Grid is a dynamic graphical user interface used to create uplink and downlink zone definitions. You specify the data burst signal characteristics (name, data tone modulation, symbol length/offset, etc.) and then use the mouse to map the data burst region within the zone area of the Zone Definition Grid. When you have defined all the data bursts for the zone, you can save the completed zone definition to a map file.

The third way is to use a Map File. A Map File contains zone definitions in a file (.omf extension) to simplify making measurements of frequently used signals. You can Create, Edit, Delete, Export, and Import map files. Map files can save very complicated OFDMA frame analysis zone definitions, which make them a time-saving and accurate method to repeat a measurement. Also, map files are ideal for recreating the identical measurement made by other users.

Basic Digital Demodulation (continued)

Next, select the Zone Definition tab of the Demodulation Properties dialog box. The default Zone Definition Grid map is shown at the bottom of this tab; only the FCH data burst has been defined. Other data bursts could be defined manually (this will be discussed in a later section of this note), but for this measurement we will use a zone definition map file that has already been constructed for this recording. This user map file is attached to a setup file provided with the 89600 software in the same location as the recorded signal. To access it, recall the setup file i80216e_10MHz.set. To use this map file it is only necessary to select the Use Map File box. An entry field and drop-down list in this area will show only <none> and i80216e_10MHz (from setup) as map file choices unless others have been defined.

The map file shows logical subchannels on the Y axis and OFDM symbols on the X axis. In addition to the FCH, 3 data bursts are defined and color-coded as shown in Figure 14.
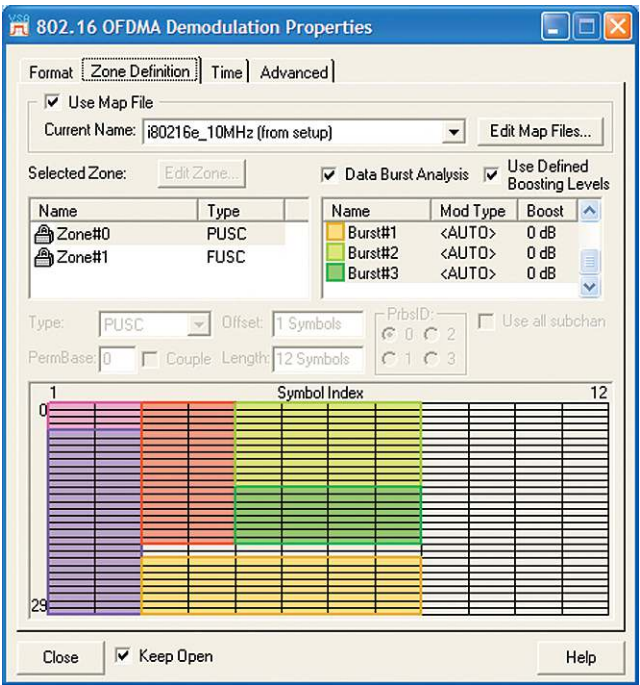

Figure 14. This Zone Definition Grid map was provided by a user map file. The color-coding of the bursts in this map will appear in all the bursts' measurement and error displays.

Basic Digital Demodulation (continued)

After selecting the map file, the default is for display and analysis of all data bursts in the map. This means that all measurement displays and the error statistics summary table reflect the composite of all the data bursts in the map. This can be seen graphically in the constellation trace of Figure 15, where BPSK (pilots), QPSK, 16QAM and 64QAM constellations are overlaid, along with small circles as targets for the symbol states. Note that the color coding for data bursts is consistent between the Zone Definition Grid map and all of the analyzer displays.
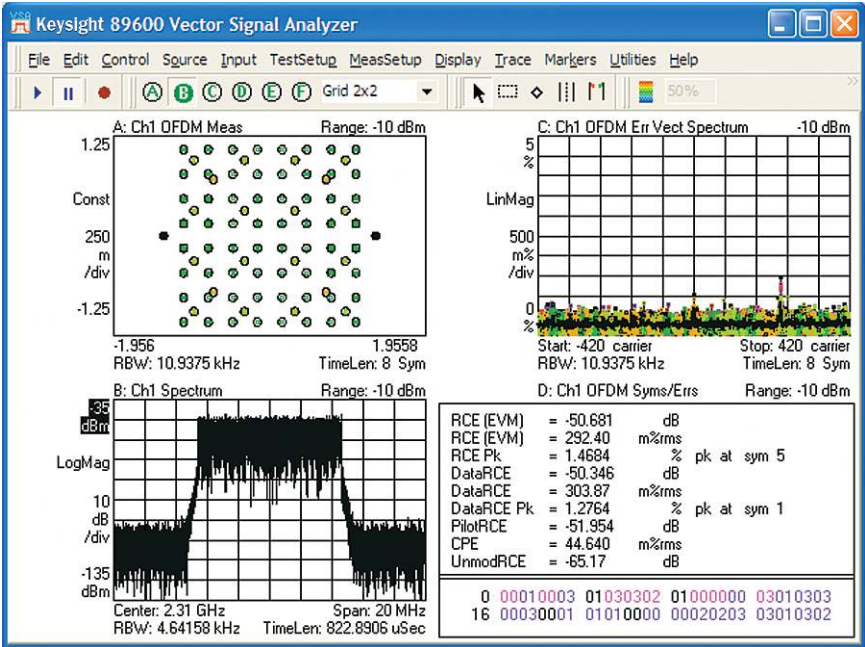

Figure 15. Using the example downlink map file (recalled as part of the setup file provided) causes all data bursts to be measured and displayed. Note the display of multiple simultaneous modulation types in the constellation diagram.

Basic Digital Demodulation (continued)

Data burst analysis can be used to display and analyze single data bursts or selected groups. To select a specific data burst, click the Zone Definition Grid, or click the Burst name in the list box above the map. The list box shows the burst name, modulation type, and boost level. After selecting a data burst for analysis, you will see the analyzer displays change to reflect the measured characteristics and data of the selected burst. The displays will generally be up-dated immediately after you make these changes, and it will not be necessary to acquire new data. For bursts such as these, where the modulation format is different for each one, the easiest way to see the change is to watch the constellation display.

To select and measure multiple data bursts at once, press the Ctrl key while clicking the desired data bursts. To se-lect all data bursts, right-click the Data Burst list box or the Zone Definition Grid, and click Select All.

One diagnostic clue for the proper configuration of a transmitter, or of the Zone Definition Grid map in the analyz-er, is the absence of symbols at the cen-ter or origin of the constellation when measuring downlink signals. Symbols in this location indicate that the analyzer is expecting a modulated subcarrier at a frequency where it is receiving little or no signal energy. This phenomenon indicates that one or more data bursts are configured to expect logical sub-channels or individual subcarriers which are not being transmitted. You can diagnose the specifics by coupling the analyzer's markers, setting the marker on one or more of the center constella-tion symbols, and determining whether the symbols are all associated with subcarriers which can be identified with specific logical subchannels.

Basic Digital Demodulation (continued)

Uplink modulation quality measurements of a uniform signal

This example of uplink analysis will use the example uplink recording i80216e_ULPuscUniform Q64.sdf, supplied with the 89600 VSA software. Again, before recalling this signal, it is a good idea to perform a Preset > Preset Setup. This uniform signal occupies all of the slots in the zone, which means that all of the OFDM subcarriers are active and modulated with same type of modulation (except for the pilots, which are modulated with BPSK). Using the vector measurement techniques described earlier in this note, we can see that the subframe in this recording is 24 OFDM symbol times with approximately constant power, and there is no preamble. In IEEE 802.16 OFDMA, uplink signals do not include preambles.

As with the previous measurement, begin digital demodulation by selecting the OFDMA digital demodulation mode in the 89600 VSA, and choose the appropriate Uplink Subframe type in the Demodulation Properties dialog box's Format tab. Then use the Preset to Standard function, also on the Format tab. The result shown in a typical 4-trace digital demodulation display after auto-scaling, is given in Figure 16. While the constellation is clear, the error vector spectrum and the RCE figure for the unmodulated carriers indicate that the default digital demodulation configuration is not entirely correct.

Fortunately, there are indications of a way to correct the analyzer configuration. First, the constellation shows that carrier lock and symbol lock have
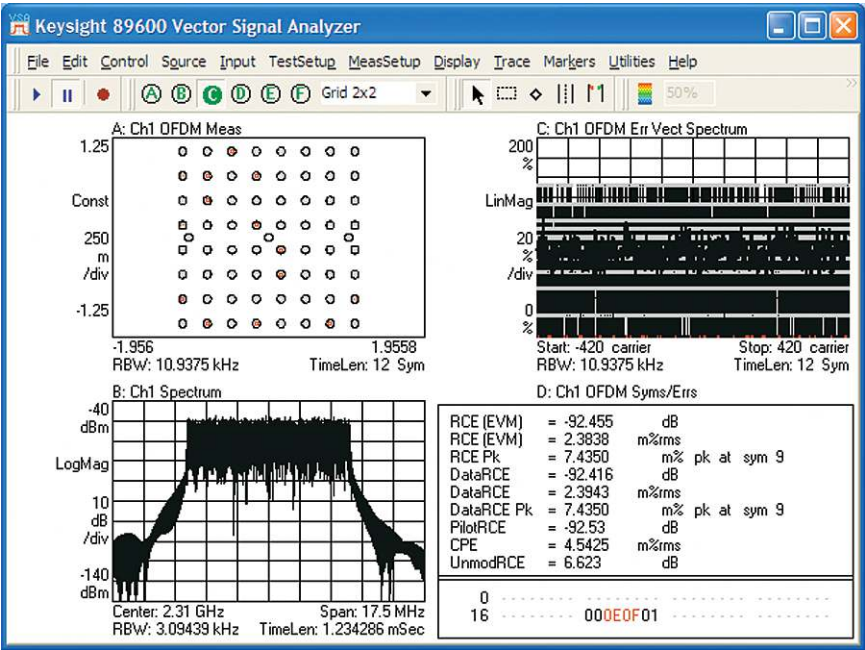

Figure 16. A uniform 64QAM uplink PUSC signal incorrectly demodulated with the default settings, (including the performance of data burst analysis). Note the difference between the RCE (EVM) and UnmodRCE values in the Sym/Errs table.

Basic Digital Demodulation (continued)

been achieved. Second, the use of data burst analysis (the default in the Preset to Standard operation) is not needed when analyzing a uniform signal. However, before we switch off data burst analysis, it is useful to notice several things about the constellation and the Syms/Errs table. The constellation is clearly locked to something, although color-coding indicates a mixing of the pilot and data locations. In addition, the error vector time trace is very high, while the numerical error data (RCE) reported in the Syms/Errs table is quite low – with one exception: the UnmodRCE data (representing the RCE of unmodulated carriers).

The reason for this result can be seen by going to the Advanced tab of Demod Properties. The analyzer's default settings for several parameters are different for UL and DL signals. For UL signals, the default is to include all inactive subchannels in all traces. In the Sym/Errs tabular data, the errors are always broken out by carrier type:

Data RCE, Pilot RCE, and UnMod RCE. By turning off Use Default Settings and Include Inactive Subchannels on the Advanced tab of the Demodulation Properties tab, the trace error displays appear more congruent with the error data values being displayed in the Sym/Errs table.

You can adjust other parameters on this tab as well, including directing the analyzer to auto-detect modulation format, or manually setting the modulation format for uniform signals. For burst signals, you can either let the analyzer automatically detect the modulation format, or force it to use the modulation formats described in the burst definitions. Note that the analyzer will attempt to use these definitions whether they are correct or not.

To correctly view this uniform signal, however, we need to turn off Data Burst Analysis. As before, the Zone Definition tab on the OFDMA Demodulation Properties dialog box is the

Basic Digital Demodulation (continued)

place to deactivate Data Burst Analysis. The analyzer defaults to automatic detection of the 64QAM modulation type. Since the analyzer typically is able to update demodulation results even when recording playback is in the paused mode, the effect of the change should be immediate. Example results are shown in Figure 17, with error vector time and spectrum displays set to 0.1%/division.

This signal is a digital simulation and has virtually no error, and the demodulation results are now correct. This uniform uplink signal is a relatively straightforward signal to analyze, as it uses only one type of modulation for the data carriers for a single data burst, and does not include a preamble or FCH.
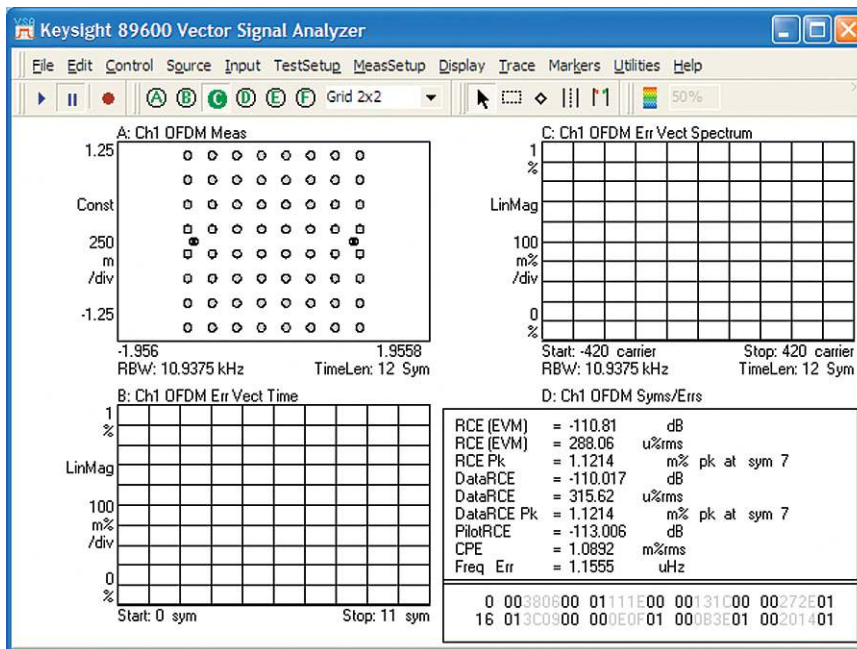

Figure 17. A uniform 64QAM uplink signal, correctly demodulated after Data Burst Analysis is switched off. The analyzer automatically detects the single type of data modulation.

Basic Digital Demodulation (continued)

For the analyzer or a receiver, de-modulating uplink subframes may be a challenge for several reasons. First, the lack of timing, frequency synchro-nization, and equalization information that might be provided by a preamble requires more complicated synchro-nization algorithms, with receivers assuming specific pilot locations and values. Second, settings for the frame number index and the frame type (PUSC, FUSC, etc.) must be correct to provide the receiver with the accurate pilot locations and values that are essential for demodulation.

Incorrect frame numbers will not gen-erally produce recognizable constel-lations, though the constellations may nonetheless exhibit some recognizable digital modulation characteristics.

To help with UL synchronization the 89600 software will demodulate a signal even if its PRBS is incorrect. The recovered PRBS seed result is present-ed on the Sym/Errs table. The user can decompose this 11-bit Status value into a Frame Number and IDCell for the UL in order to confirm that the settings match expectations. A small indica-tor ("*") is provided if the software detects a mismatch between the PRBS sequence and the setup, and yet a fur-ther indicator ("?") is presented if the 89600 software cannot uniquely iden-tify the PRBS seed. This may indicate an incorrect PRBS generator, or insuffi-cient data to deduce the PRBS. Since the PRBS determines the carrier and pilot positions, a correct PRBS is vital to even beginning measurements. This unique 89600 VSA software capability can help you troubleshoot your early development efforts and get a working design as quickly as possible.

Basic Digital Demodulation (continued)

Uplink modulation quality measurements of a burst (nonuniform) signal

The next discussion of digital demodulation of an uplink signal will use the example uplink recording i80216e_UL-10MHz.sdf supplied with the 89600 VSA software. This example will describe data burst analysis, though analysis is simpler on the uplink signals due to the presence of a single data burst in this signal.

We will use the same setup file used earlier for downlink analysis: i80216e_10MHz.set. Again, prior to recalling the signal and its setup file, you should Preset Setup to avoid having previous settings contaminate the new setup. After recalling the i80216e_10MHz.set setup file, choose the appropriate Uplink subframe type

in the OFDMA Demodulation Properties dialog box's Format tab. Changing trace B from spectrum to error vector time produces a display similar to that of Figure 18.

After switching to the uplink subframe type, the analyzer has defaulted to measurement of the first zone of the subframe; a PUSC zone. The analyzer is automatically detecting the modulation type of the single data burst in this zone, as shown by the Zone Definition tab. Also on the Zone Definition tab, you can see the Zone Definition Grid which shows that the data burst is in "wrapped format" covering the first 15 symbols of the subframe and does not use all of the logical subchannels. Therefore, many of the OFDM subcarriers are not used for this burst and could be used for other bursts.

In the constellation display of Figure 18, the signal (or lack of signal) from the unused subcarriers is shown by symbol states and a symbol target at the center of the constellation diagram. Indeed, the ideal location for the symbols associated with unused OFDM subcarriers is the exact center of the constellation diagram, signifying that no power is transmitted on these unused subcarriers and their associated logical subchannels. Power transmitted on these subchannels would tend to interfere with reception of intended transmissions on these frequencies by other mobile stations, especially in unfavorable near/far configurations of transmitters and receivers. In uplink measurements, the 89600 VSA defaults to a measurement of EVM which includes the contribution of unused subchannels. The 89600 VSA automatically reports RCE (EVM) of unmodulated carriers in its Syms/Errs table.
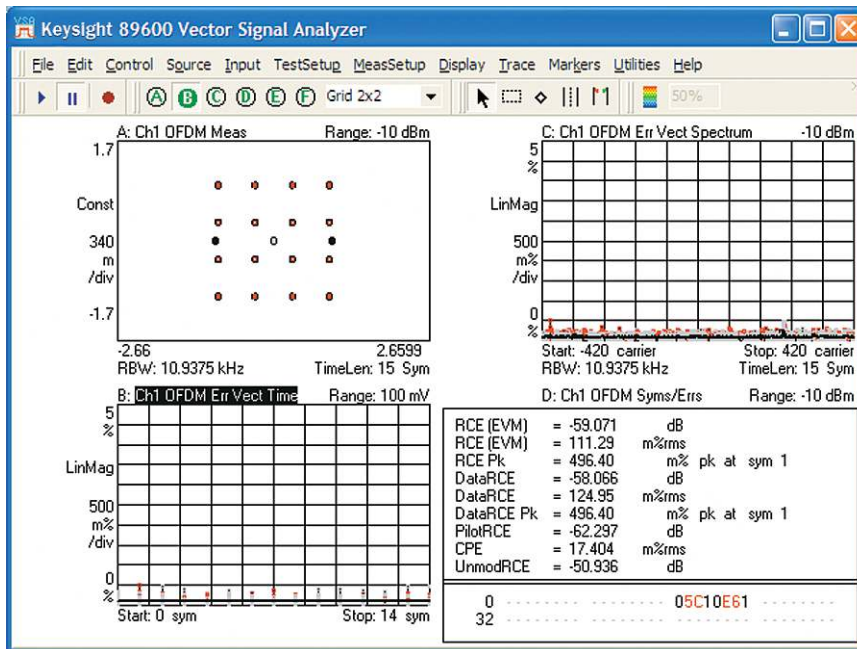

Figure 18. Demodulation of the PUSC zone of a 16QAM uplink signal. The constellation diagram also includes the BPSK pilots and a central symbol target for subcarriers not used by the mobile station.

Basic Digital Demodulation (continued)

This is in some ways similar to a noise power ratio measurement or code domain error. Where it is desirable to view only the active subchannels associated with the selected data burst, the display configuration can be changed by clearing a box on the Advanced tab of the OFDMA Demodulation Properties dialog box labeled Include Inactive Subchannels in EVM.

This signal contains two zones: 15 symbols of PUSC, and 6 symbols of OPUSC. Measuring the OPUSC zone is slightly more complex because the analyzer expects the OPUSC zone to be located at the trigger location chosen by the pulse search algorithm. Instead, the PUSC zone begins at that time. So, to measure the OPUSC zone the analyzer must be set to skip the first 15 symbols of the PUSC zone. To do so, go to the Time tab of OFDMA Demodulation Properties and select Manual Sync Search, with an Offset of

15 symbols. Then switch back to the Zone Definition tab and click Zone#1, the OPUSC zone in the list of selected zones. The analyzer will now use its pulse search algorithms to locate the RF burst, and then delay 15 symbols to begin the analysis of the OPUSC zone, as shown in Figure 19.
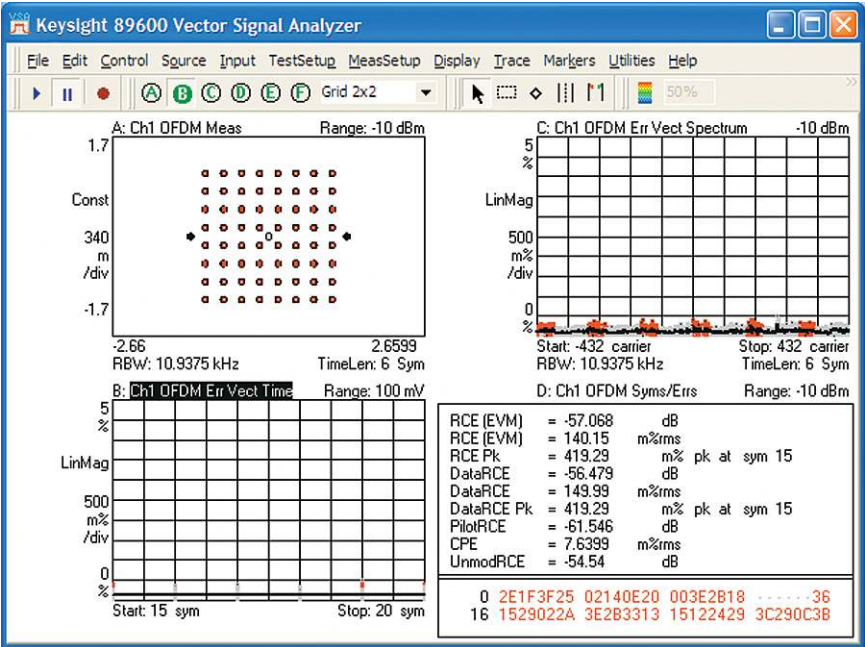

Figure 19. Measurement of the 6 symbols of the second (OPUSC) zone of the same uplink signal as used previously in Figure 18.

Basic Digital Demodulation (continued)

Common problems and troubleshooting approaches for "uniform" measurements

Both the IEEE 802.16 OFDMA standard and the signal itself are quite complex from an RF physical layer standpoint (RF bursting, multiple carriers, moving pilots, multiple modulation types, etc.) and from a baseband digital stand-point (preamble indexes, subchannel bitmasks, permutation functions, etc.). There are, therefore, many possible causes of demodulation failure including uncertainty and confusion over the correct interpretation of the standard itself. As an aid to troubleshooting, the following are some typical demodulation results, along with suggestions as to possible causes.

Low "Sync Corr" (sync correlation; see the table in the Syms/Errs trace data type) value and possible demodulation failure. An incorrect preamble value on downlink signals may be the cause. The preamble index may be incorrect, or may be selected based on a different interpretation of the standard than that of the 89600 VSA.

Circular symbol configuration when phase tracking is turned on (see the Pi-lot Tracking box on the Advanced tab): BPSK symbols not colored as pilots while QPSK/QAM symbols are. This

may be a problem with incorrect pilot locations on a downlink signal, either due to an incorrect offset value (on the Zone Definition tab of the OFDMA Demodulation Properties dialog box), or the pilot location may be based on a different interpretation of the standard than that of the 89600 VSA.

Symbol constellations appear to have a near-random "cloud" pattern. This type of constellation on an uplink signal suggests that the pilot symbols were not detected for synchronization. Causes are similar to the previous phenomenon, including mismatched setup parameters and differing inter-pretations of the standard. Successful demodulation may be possible by experimenting with parameters such as Offset and PermBase in the Zone Definition tab to find a match with the signal.

Noisy constellations with a large symbol clock error (SymClkErr, see the table in the Syms/Errs trace data type), or unlocked measurements. These phe-nomena may be caused by incorrect values of the Bandwidth (or Nominal BW if set manually) value in the Format tab of the OFDMA Demodulation Prop-erties dialog box. The bandwidth value determines OFDM carrier spacing, and it should be set as closely as possible to the actual value. Subcarrier mea-

surements such as those described in the time and frequency (vector) domain section earlier in this application note may be helpful in determining the exact subcarrier spacing and the actual bandwidth of a specific signal.

Pulse search failure. A variety of condi-tions may cause this error enunciator to appear (typically along with demodula-tion failure). You can disable the pulse search function in digital demodulation and configure a trigger as a substitute. The trigger may be internally gener-ated using an IF magnitude value and appropriate holdoff and delay values, or external triggers may also be used if available.

Basic Digital Demodulation (continued)

Common problems and troubleshooting approaches for "data burst" measurements

The suggestions above for uniform measurements are also applicable to data burst measurements. In addition, the following approaches may be helpful.

Unexpected modulation formats (or noise) appear in the constellation where other modulation formats are expected. Incorrect permutation parameters on downlink signals may be causing zone parameters to be mismatched or the parameters may be based on a different interpretation of the standard than that of the 89600 VSA. The PRBS Status on the Syms/ Errs table can provide information on what was actually decoded, including such parameters as the PRBS seed, ID cell, segment, PermBase, PRBS_ID, and much more. In addition, it may be helpful to try the P802.16 OFDMA (Cor1/D2) standard mode, selected from the Format tab in the OFDMA Demodulation Properties dialog box.

Symbol constellations appear to have a near-random "cloud" pattern. This type of constellation on an uplink signal suggests that the pilot symbols were not detected for synchronization. Causes are similar to those for the uniform measurements, including mismatched setup parameters and differing interpretations of the standard. Successful demodulation may be possible by experimenting with parameters such as Offset and PermBase in the Zone Definition tab to find a match with the signal. This situation is essentially similar to the uniform measurement mode measurements performed on uplink signals, as described previously.
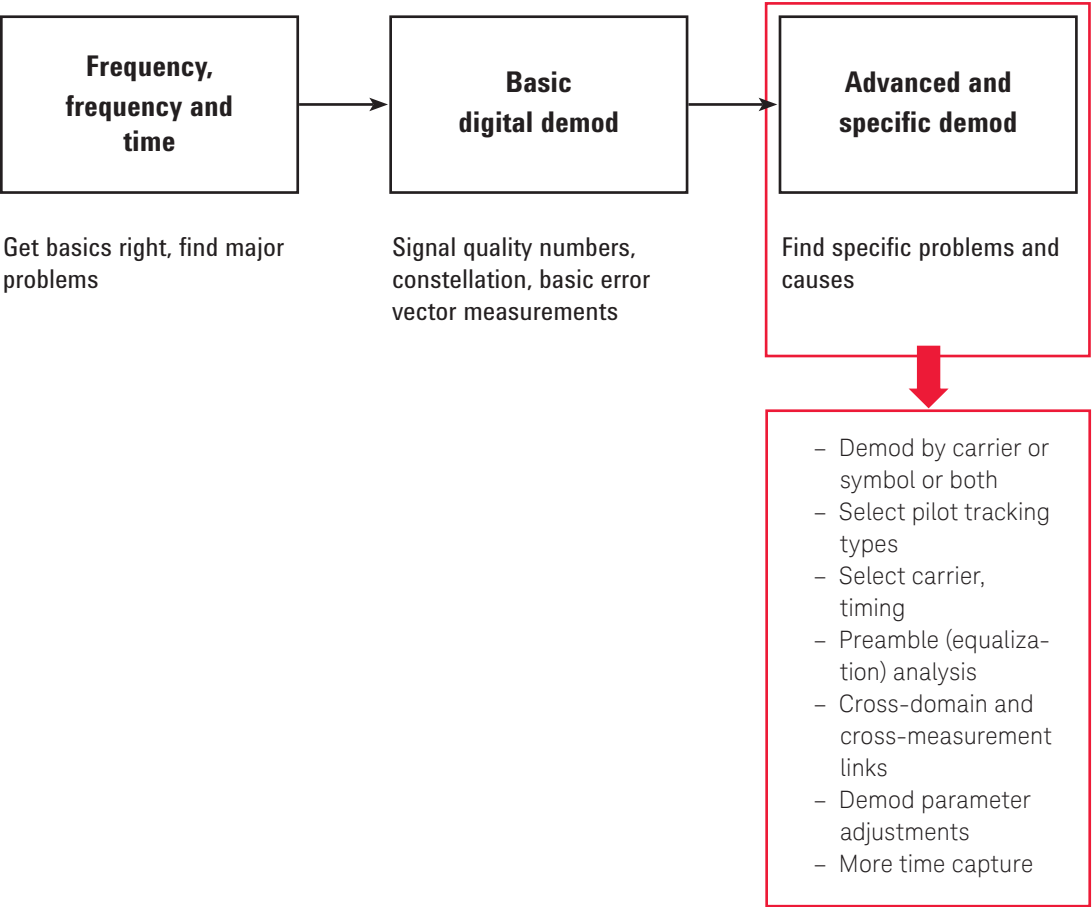
Advanced Digital Demodulation

The last step in our measurement and troubleshooting sequence is the most powerful for finding and measuring problems that are either subtle or are more complex than those discussed so far.

The analyzer provides a variety of specialized demodulation configurations for more advanced analysis, including demodulation of specific portions of the signal and adjustment of many different demodulation parameters.

Some of these analysis techniques take advantage of specific characteristics of the OFDMA signal, including the built-in equalization training sequences and pilot carriers. Some other types of more advanced signal analysis primarily involve display and measurement types particularly relevant to these OFDMA signals, such as the data burst information table and channel frequency response adjacent difference display.

Table 5. Advanced demodulation operations provide more sophisticated and specific measures of signal characteristics and impairments.

Frequency, frequency and time

Get basics right, find major problems

Basic digital demod

Signal quality numbers, constellation, basic error vector measurements

Advanced and specific demod

Find specific problems and causes

– Demod by carrier or symbol or both
– Select pilot tracking types
– Select carrier, timing
– Preamble (equalization) analysis
– Cross-domain and cross-measurement links
– Demod parameter adjustments
– More time capture

Advanced Digital Demodulation (continued)

Advanced displays

Equalization and channel frequency response

As shown previously in both vector and basic digital demodulation measurements, downlink subframes include a preamble with a time length of one OFDM symbol. The preamble is composed of every third OFDM subcarrier, with one each transmitted at equal amplitude. In addition to its use by subscriber unit receivers, this preamble is very useful for diagnostics by the 89600 VSA.

Adaptive equalization is required by the WiMAX standards and is normally used to compensate for linear errors such as amplitude and phase flatness, either in the transmitters or in the transmit channel. When measured directly at the output of a transmitter, typical causes of error include baseband or IF filtering errors, and incorrect sin(x)/x compensation.

These errors may be caused by multipath or by tilt or ripple in the frequency response of a system. In contrast, noise, intermodulation, and the effects of amplifier compression are nonlinear forms of distortion, and are not corrected by adaptive equalization.

Similar to the receiver in a subscriber unit, the 89600 VSA uses the preamble to calculate coefficients for its adaptive equalizer, and these filter coefficients are very useful for troubleshooting. In addition, (in contrast to the typical subscriber unit receiver) the 89600 VSA software allows the adaptive equalizer to be trained on either the preamble or on the entire subframe, including the preamble. Including both the preamble (also called the channel estimation sequence) and the subframe data improves the channel equalization estimate, and is called data-driven equalization. The improved channel equalization estimate has the dual benefits of typically more accurate modulation quality results and a more accurate estimate of the channel frequency response for display and analysis.

Advanced Digital Demodulation (continued)

For the design engineer, a major benefit of equalization is that the results can be viewed, quantified, and then used to find the source of problems. Using the same nonuniform downlink PUSC signal (i80216e_DL10MHz.sdf) as in previous digital demodulation measurements, you can configure the analyzer to show the equalization results in a variety of different ways as shown in Figure 20.

The equalization results are shown in several different forms in this figure. The equalizer channel frequency response in log magnitude form (trace B) is perhaps the most familiar. This is the combined amplitude frequency response of the channel and the transmitter, displayed against the OFDM carrier frequency number. The frequen-

cy response can be displayed in terms of phase as well, as shown in trace C, where phase is selected as the data format. The analyzer can also display the impulse (time domain) response of the filter it created to equalize the channel, and this is shown in trace D, labeled OFDM Eq Impls Resp. This impulse response result may be more useful than frequency response in some DSP design efforts.

As mentioned previously, the analyzer's equalizer can be trained on the preamble (channel estimation sequence) or on the entire subframe including both the preamble and the data, or on the channel estimation plus pilots. Since an uplink signal has no preamble, the analyzer uses either the pilots or a combination of data and pilots,

depending on which Equalizer Training parameter is selected. This training choice is available as check boxes on the Advanced tab of the OFDMA Demodulation Properties dialog box, and may result in significantly different modulation quality results, depending on the specific signal involved. Since the signal recording used as an example here is of high quality and does not have significant multipath, the effect of the change in equalizer training is to change the measured modulation quality (RCE/EVM) from approximately −49 dB to −52 dB depending on which mode is chosen, though all indicate very low levels of error. The effect on the equalizer display traces is correspondingly slight.
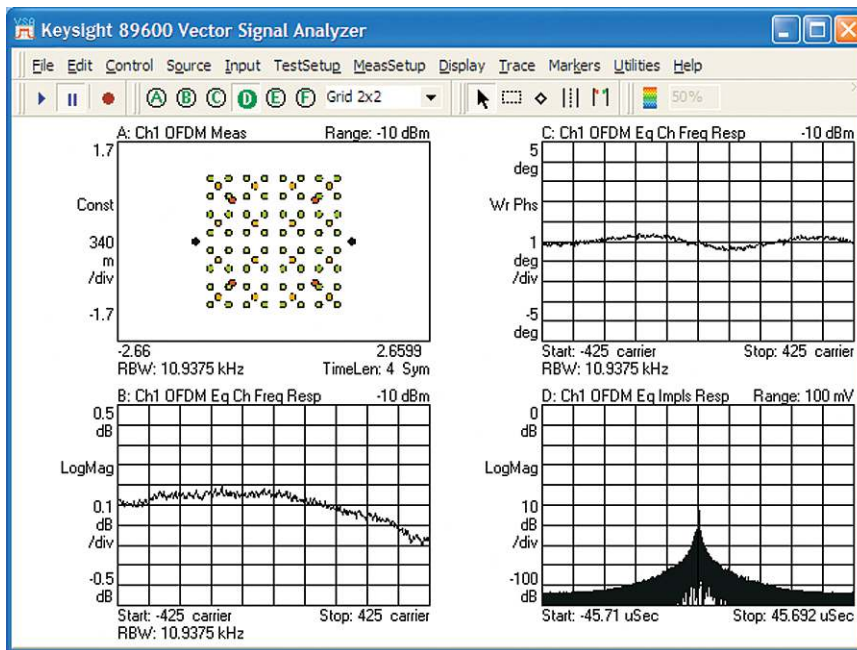

Figure 20. Channel frequency response amplitude (lower left) and phase (upper right) and equalizer impulse response (lower right) derived from adaptive equalizer trained on downlink preamble.

Advanced Digital Demodulation (continued)

Channel frequency response adjacent difference

Analyzer equalization results can be displayed in a variety of ways. Where the specific interest is in the amount of subcarrier-to-subcarrier (or equivalently, FFT bin-to-FFT bin) variation, the ChFreqRespAdj Diff trace will be useful. This trace is derived from the adaptive equalizer's channel frequency response trace and therefore is affected by the choice of equalizer training data as described above.

Example results of this trace type are shown in the three traces in Figure 21,

using the same downlink recording as was used previously for the equalization discussion.

For this measurement, the adjacent difference results are shown in several ways. The top trace is the result of using only the preamble (channel estimation sequence) to train the equalizer. Accordingly, information is available for only every third OFDM subcarrier. Using the entire data portion of the subframe adds to both the information input and output of the equalization algorithm, as shown by the improved frequency resolution of the middle trace.

The adjacent difference results are also affected by the selection of data bursts for analysis. Where data bursts do not include the use of specific OFDM subcarriers, the analyzer interpolates between known data points in creating the display. This is shown in the lower trace of Figure 21 where only burst 3 of the downlink subframe is analyzed. This burst uses 10 of the 30 logical subchannels, resulting in a sparser data set for the adjacent difference calculations and the corresponding results.
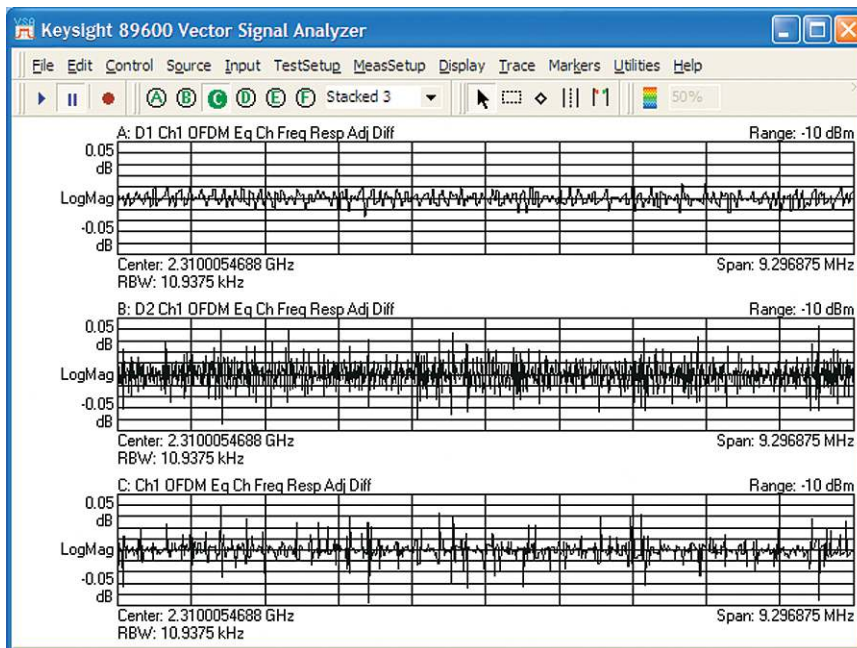

Figure 21. Channel frequency response adjacent difference measurements. Trace A results are calculated from the preamble only. Trace B results are calculated from the entire subframe, and trace C results are calculated from channel estimation sequence and data for data burst 3 only.
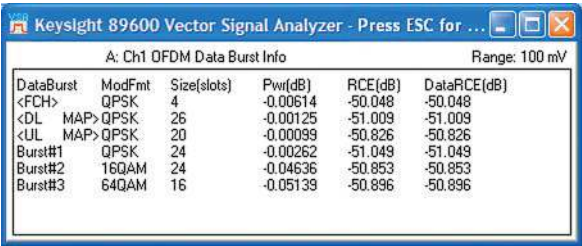
Advanced Digital Demodulation (continued)

Data burst information table
A new display associated with IEEE 802.16 OFDMA measurements in the 89600 VSA is the OFDM Data Burst Info table. This is both a measurement data type and an associated display format. Example results from the non-uniform downlink PUSC recording are shown in Figure 22.

This display is used when in the data burst analysis mode, and is most useful when you are measuring multiple data bursts. It provides a list of the subframe's data bursts, including the

FCH. Reported values for each data burst include the format, the burst size (length), average power, and the average error (RCE, in dB) of the entire signal or the data subcarriers only (DataRCE).

Like the rest of the displays available when in data burst analysis mode, this table reflects only the results of the data bursts selected for analysis.

Figure 22. The Data Burst Info trace lists the FCH and all measured data bursts in the subframe, along with their size, power, RCE, and the RCE of selected data bursts (if display space permits).

Advanced Digital Demodulation (continued)

Pilot tracking

In much the same way as for IEEE 802.11a OFDM and IEEE 802.16-2004 WiMAX, IEEE 802.16 OFDMA demodulation is performed relative to BPSK pilot carriers which are embedded in the signal. These pilot carriers replace data-carrying elements of the signal and allow many impairments to be dynamically removed or "tracked out." The pilot carriers are transmitted continuously throughout the data portion of the subframes, though their location varies according to permutation functions. The pilots for some logical subchannels will not be present for every symbol of every data burst.

Many signal impairments will be common to all pilot carriers, and can be measured and displayed as "common pilot error." This parameter is reported as part of the Symbols/Errors trace data.

In addition, the specific tracking functions can be individually switched on and off in the demodulation performed by the 89600 software. This is a very useful troubleshooting approach, since modulation errors can be examined with and without the benefit of particular types of pilot tracking.

Three types of tracking are available: Amplitude, Phase, and Timing. Selection of tracking parameters is accomplished on the Advanced tab of the OFDMA Demodulation Properties dialog box (after clearing the box for Use Default Settings), as shown in Figure 23.

Amplitude tracking (default for the 89600 VSA is Track Amplitude Off for downlink signals and On for uplink

signals). A common type of signal impairment is varying signal amplitude during a subframe. Signal changes such as variable subcarrier occupancy and modulation type over different data bursts can cause RF and microwave circuits to change temperature and gain during a subframe. For subscriber units, the combination of transmit and DSP power may cause amplitude droop. When Track Amplitude is selected, the tracking results can be analyzed by viewing the magnitude portion of the Common Pilot Error data type. Such errors could be isolated by comparing the peak error symbols with their location in the constellation and/or their location in the subframe.
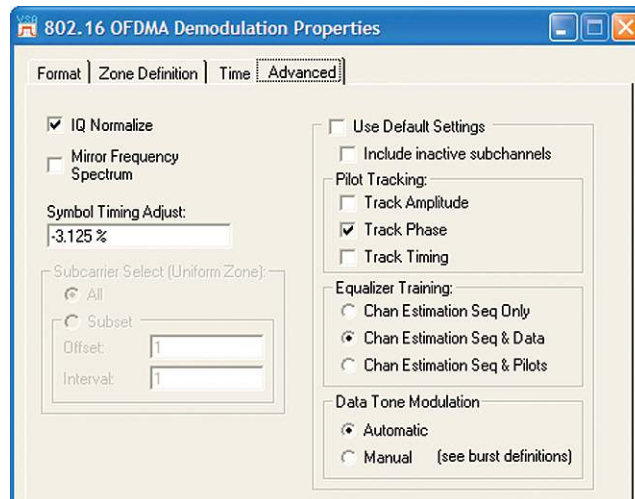

Figure 23. Pilot tracking parameters including amplitude, phase, and timing can be selected in any combination on the Advanced tab of the OFDMA Demodulation Properties dialog box.

Advanced Digital Demodulation (continued)

Phase tracking (default for the 89600 VSA is Track Phase On). Operation is similar to amplitude tracking, except that the analyzer demodulation tracks the phase of the pilot carriers. Close-in phase noise, for example, can be removed or tracked out by phase tracking. As with amplitude tracking, when phase tracking is selected, the tracking results can be analyzed by viewing the phase portion of the Common Pilot Error data type.

Timing (default for the 89600 VSA is Track Timing Off for downlink signals and On for uplink signals). When Track Timing is selected, the analyzer applies pilot subcarrier timing error correction (frequency offset correction) to the pilot and data subcarriers. Timing errors may be caused by oscillator frequency errors or DSP errors such as an improper number of samples in the guard interval. It is useful to keep in mind that both analog and digital (DSP) mechanisms can cause timing problems. DSP defects such as an improper sample rate can also affect relative timing in the subframe. One useful troubleshooting technique is to observe changes in common pilot error when timing tracking is enabled.

Symbol timing adjustment

The alignment of the analyzer's symbol demodulation within the interval defined by the OFDM symbol plus the guard interval is adjustable through a dialog box in the Advanced tab of the OFDMA Demodulation Properties dialog box. For the 89600 VSA, this positions in time the FFT used for demodulation. No specific time position is called out in the standard, and different timing settings will affect measured modulation quality. In particular, if filter ISI or multipath affects the guard interval, certain symbol timing settings will provide much better demodulation results than others.

Time-specific and frequency-specific measurements

You can use a large variety of time-specific (relative to time intervals, symbols, frames, or triggers) and frequency-specific (OFDM subcarriers or logical subchannels) analysis configurations to find problems and isolate their causes. In IEEE 802.16 OFDMA, many useful measurements are both time-specific and frequency-specific, as we will see in the examples that follow.

These techniques can help, for example, find subtle defects such as DSP errors or impulsive interference that only affect a specific carrier/frequency at a specific time or over a specific time interval.

Advanced Digital Demodulation (continued)

Customizing a Zone Definition Grid map for measuring individual data regions

The process for individually defining zones or configuring a zone map for data burst analysis can be best understood by beginning with a known signal and its associated map. We will use the same example downlink recording supplied with the 89600 VSA software as was used previously for data burst analysis: i80216e_DL10MHz.sdf. As before, remember to Preset Setup before recalling this signal, and its associated setup file i80216e_10MHz.set.

After recalling the setup file, data burst analysis is enabled and all of the data bursts are selected for measurement and display. You can verify this by examining the Zone Definition Grid map at the bottom of the Zone Definition tab of the OFDMA Demodulation Properties dialog box and noting that the outlines of all data bursts are flashing. The zone definition map reveals that the FCH data burst (upper left) is composed of 4 logical subchannels with a duration of 2 OFDM symbols. An appropriate zone definition map file for the other data bursts in this signal has been provided with the analyzer's setup file, and you can select this by selecting the Use Map File box (this selection has already been performed by the setup file).

At this point it is instructive to choose a single data burst and modify its zone map to see the measurement results in the time and frequency domain (error vector time and error vector spectrum). For this example, Zone #1 will be modified since it does not contain a preamble or UL/DL maps and is therefore simpler to edit. You can do this graphically by clicking the Edit Map Files, and then From Setup buttons to bring up the OFDMA Map File Editor. From the Downlink Zones section click Zone #1 and the Edit button. This will bring up a display of the zone 1 map, which will look different from the zone 0 map that you may have already been measuring. There you can delete data burst #3 (64QAM, middle burst, typically colored green). Simply click anywhere in the burst to highlight it and click the Delete Burst button. When the burst is selected you can verify its name and the type of modulation in the Burst area at the upper right of the display. Click OK and Close, as needed, to return to the display of the OFDMA Demodulation Properties dialog box. Then, from the Selected Zone area of the OFDMA Demodulation Properties dialog box, click Zone #1 to select it for analysis.

Advanced Digital Demodulation (continued)

Now, select only burst 2 for analysis by clicking Burst #2 in the Data Burst List on the OFDMA Demodulation Properties tab or by clicking anywhere in the graphical representation of burst 2 on the Zone Definition Grid table at the bottom of the dialog box. These changes take effect immediately. Note that only 16QAM modulation now shows in the constellation display (along with the BPSK pilots). Your display should be similar to Figure 24, where traces B and C have been changed to error vector time and error vector spectrum, respectively.

You will see from the error vector time display that only 4 symbols are being analyzed, and from the error vector spectrum display you will see that only a portion of the OFDM subcarriers are being used for the selected data burst. The OFDM subcarrier population may be viewed in greater detail by using the Select Area marker tool (chosen from the marker toolbar or by selecting Markers > Tools > Select Area) and X-axis scaling the error vector spectrum trace, focusing on perhaps the center 20% of the trace, by drawing a box and clicking Scale X. The trace can be returned to full scale by selecting it and then Trace > X Scale and clicking Full Scale.

Of course if the goal of the measurement was to analyze only burst 2 of zone 1, these parameters could have been selected directly from the OFDMA Demodulation Properties dialog box without editing the zone map. The technique described previously would normally be used to manually define zone maps to match the signal under test or to experiment with unknown signals to learn their structure.
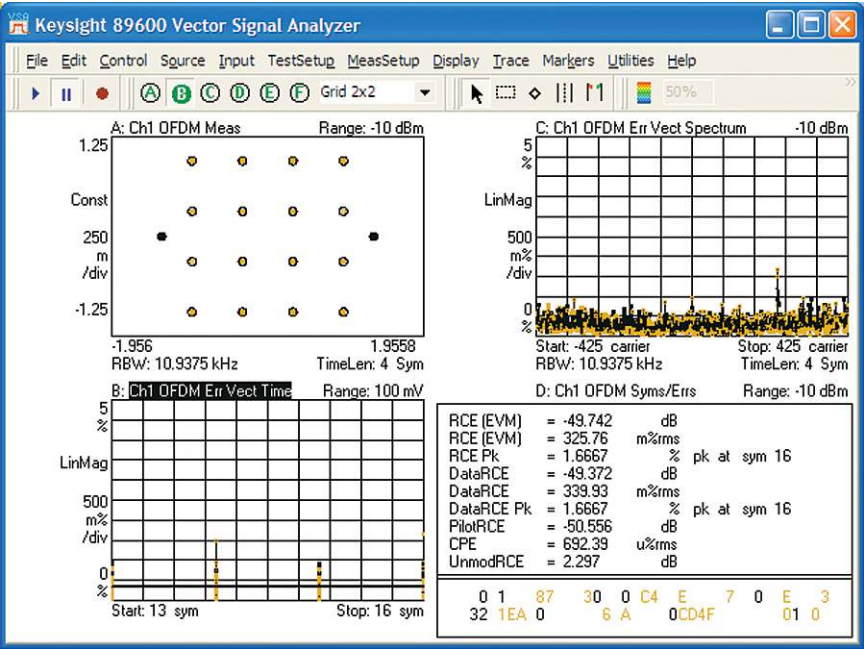

Figure 24. Data burst measurement of a single burst from a downlink FUSC signal. Burst 2, with 16QAM modulation has been chosen for analysis.

Advanced Digital Demodulation (continued)

The next step is to experiment with re-defining the data burst to include fewer logical sub-channels and/or fewer symbols. Follow the same procedure to again bring up the Edit Downlink Zone Definition Map dialog box: From the Zone Definition tab of Demodulation Properties, click Edit Map Files > Edit (with i80216e_10MHz selected). Click Zone#1 in Downlink Zones and click Edit, and then click the zone map on burst #2 (the lower burst). You will see that burst #2 is highlighted and blinking, and occupies six logical subchannels for a duration of 4 symbols or 24 slots.

Use the mouse to click and drag diagonally from corner to corner to re-define burst 2 by creating a rectangular region with a "height" of one logical subchannel and a length of 3 symbols, anywhere within the previous boundaries of burst 2. Click OK and Close, as needed, to return to the display of the OFDMA Demodulation Properties dialog box, selecting Yes when asked if you want to reload i80216e_10MHz. Click burst 2 to select only the newly-defined burst for analysis. Note the differences in the error vector time and error vector spectrum traces. The measured result in time is

now 3 symbols long, and the OFDM subcarrier population (representing a single logical subcarrier) is much more sparse. Since all the subcarriers now defined for this burst are actively modulated with the right format for the selected duration of the new burst, the error parameters should all be low, as shown in Figure 25.
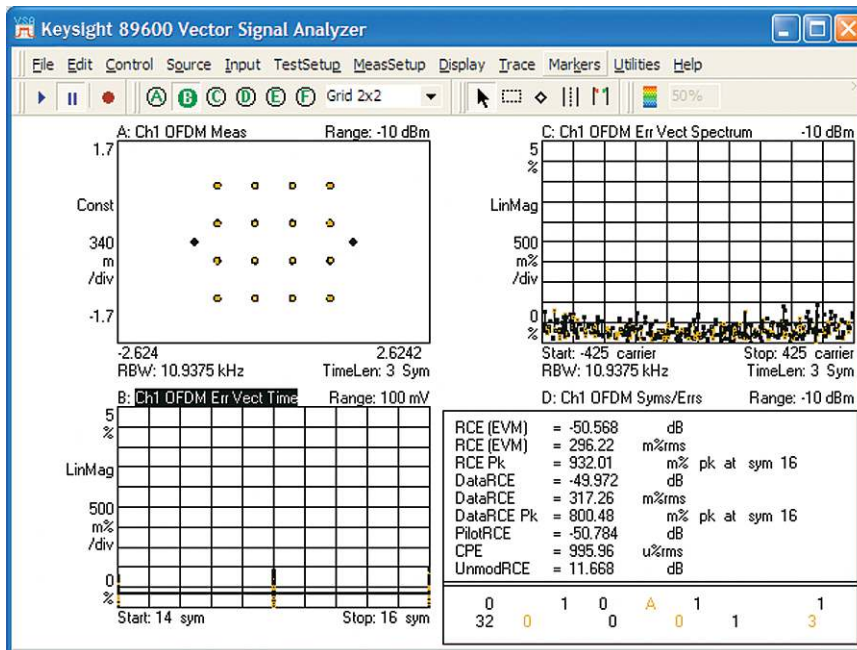

Figure 25. Data burst analysis of a portion of the original burst 2. The error vector time (lower left) trace shows that only 3 symbols are measured, and the error vector spectrum (upper right) shows the sparse OFDM subcarrier population representing the one measured logical subchannel.

Advanced Digital Demodulation (continued)

Now we can observe the result when burst 2 is defined with logical channels beyond those actually transmitted, and/or with a burst length which includes a combination of symbols and subchannels where inactive subcarriers are analyzed. For example, extending the time duration of burst 2 (beyond that previously defined) to cover 3 additional symbols in this zone will cause some inactive subcarriers (the equivalent of noise) to be demodulated as 16QAM data. Similarly, expanding burst 2 into logical subchannels previously defined as 64QAM (from the deleted burst 3) will cause these symbols to be demodulated as 16QAM instead. The resulting zone definition grid is shown in Figure 26, and the corresponding measurement results are shown in Figure 27.
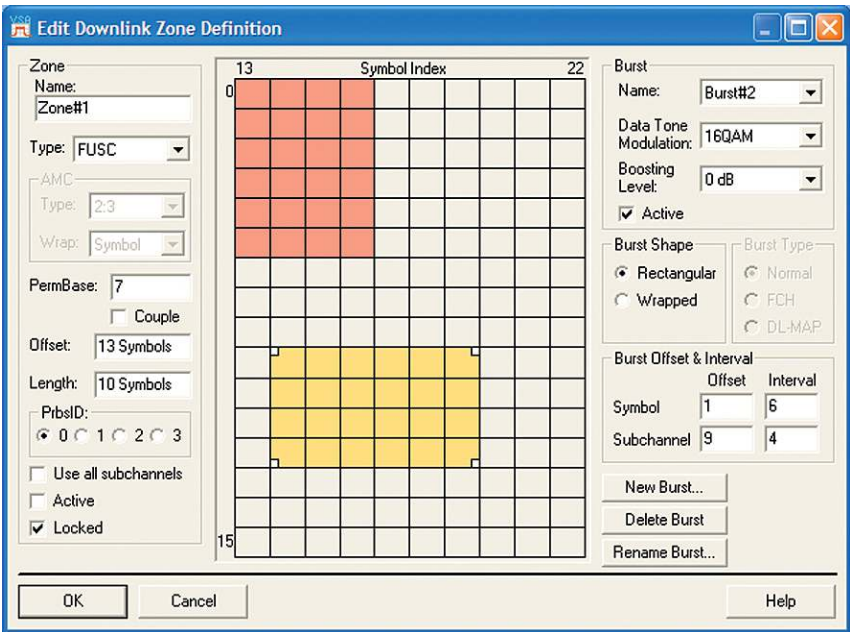

Figure 26. This zone definition grid has been modified to explore the effects of incorrect data burst length and demodulation type (16QAM instead of 64QAM). The demodulation results are shown in Figure 27.
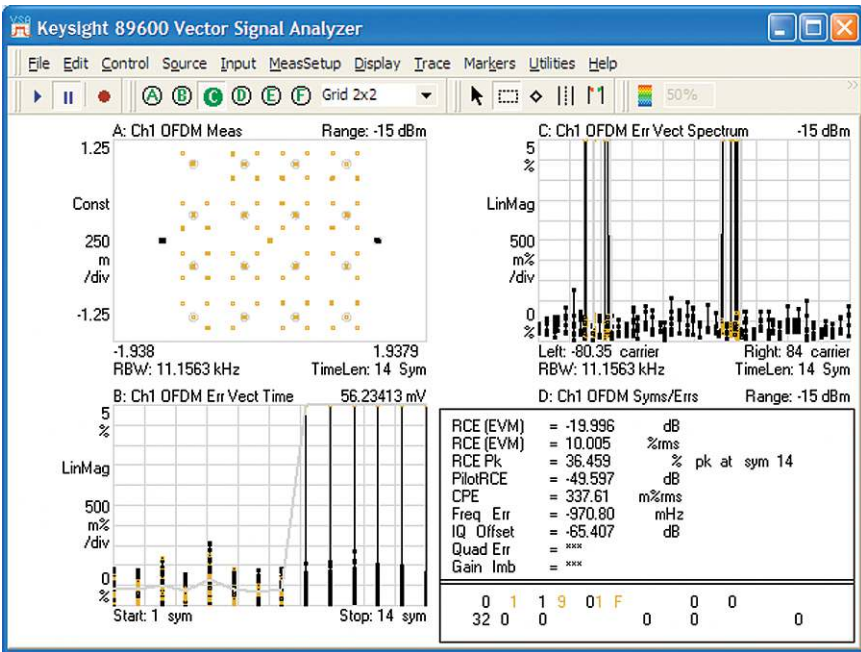

Figure 27. Incorrectly defining the zone map for data burst analysis causes large errors where 64QAM (from an adjacent burst) is demodulated as 16QAM, and symbols for inactive carriers are shown at the center of the constellation diagram.

Advanced Digital Demodulation (continued)

Several results in all of the analyzer displays are useful for troubleshooting the kind of problems introduced in this example. The constellation display now includes a number of 64QAM symbols without targets in addition to the expected 16QAM symbols and targets. The 64QAM symbols will be analyzed as 16QAM, resulting in much higher error figures. There are also symbols (without a target) at the center of the constellation diagram; this is a result of demodulating parts of the zone without active subcarriers.

The error vector time trace reveals the same errors in a different way. The average and peak errors climb sharply, starting at symbol 17, where data transmission has actually stopped. A related behavior is shown in the error vector spectrum trace, where error is either very high (64QAM or inactive carriers demodulated as 16QAM) or very low (16QAM demodulated properly and BPSK pilots).

You can edit, save, and recall these zone maps, and customize the associated data burst analysis to verify the proper composition of a zone, or to troubleshoot problems in the data burst arrangement of a zone.

Note: The analyzer will remember the (deliberately incorrect) zone map which has been created here even after analyzer Preset and Preset to Standard actions, so it is a good idea at this point to reset the map to the correct values for this example downlink signal. To do this, you will need to delete this modified i80216e_10MHz zone definition map file (these files have the extension ".omf") and recall the original preset file. From the Zone Definition tab click Edit Map Files, select the i80216e_10MHz map file and click Delete. Then recall the setup file i80216e_10MHz.set and you will see the zone definition map (for Zone 1) return to the original configuration with three data bursts.

Advanced Digital Demodulation (continued)

Measuring specific time or symbol intervals

Time-specific measurements are an essential element of troubleshooting any system using time-varying signals such as pulsed/bursted transmissions, TDMA techniques, variable power levels or boosting, etc. For OFDMA, demodulation of specific elements of a subframe is a powerful troubleshooting technique, allowing clearer isolation of errors and impairments, and therefore a clearer view of their causes. The Time tab of the OFDMA Demodulation Properties box in the 89600 VSA offers several types of time-specific analysis within the digital demodulation function. Compared with time-specific vector mode analysis, the digital demodulation function offers significant benefits in the areas of pulse and sync searching, synchronization with frames and subframes, and alignment of measurements with OFDM symbol times. In addition, the Time tab of the OFDMA Demodulation Properties dialog box includes a graphic display showing the relative timing of the measurements vs. the frame and zone timing.

For this example, we will use the same downlink recording (i80216e_DL10M-Hz.sdf) supplied with the 89600 VSA software as used above for data burst analysis and for customizing a zone map. If you have not already done so, use the instructions at the end of the previous section to delete the modified zone definition map file. As described previously, perform the Preset Setup function, recall the recording, and recall its setup file, i80216e_10MHz.set.

We will now use the recorded downlink signal (containing a PUSC zone followed by a FUSC zone) to explore time-specific measurements. After the signal and its setup file have been recalled, select the appropriate zone definition map file by selecting the Use Map File box on the Zone Definition tab of the OFDMA Demodulation Properties dialog box. It is also a good idea to configure the analyzer for the same combination of constellation, error vector time, and error vector spectrum displays as used in the previous examples. The analyzer should default to measuring the first zone in the subframe: Zone #0 (the FUSC zone).

Advanced Digital Demodulation (continued)

For a time-specific measurement relative to symbols in the subframe, it is now only a matter of selecting the Time tab of the OFDMA Demodulation Properties dialog box. From the setup file the analyzer should be configured to select all of the data bursts for analysis. If a single burst is selected, the Manual Measurement Region (on the Time tab) is limited to testing the selected burst. The graphic diagrams and entry areas of this tab are shown in Figure 28.

Note the figures in the Timing Diagram portion of the tab. The result length and its relationship to the OFDM frame are shown at the bottom, while the analysis region is shown at the top. The default is for analysis of the entire 12 symbol (1.234 mSec) data portion of the subframe, following the zone offset of 1 symbol due to the preamble.

You can perform a simple time-specific analysis of the subframe by selecting the Manual Measurement Region check box and entering a measurement interval of 4 symbols. With a measurement offset of 0 symbols, the result will be a measurement isolated to the first 4 symbols of the subframe, and a display in the Time tab similar to Figure 29.
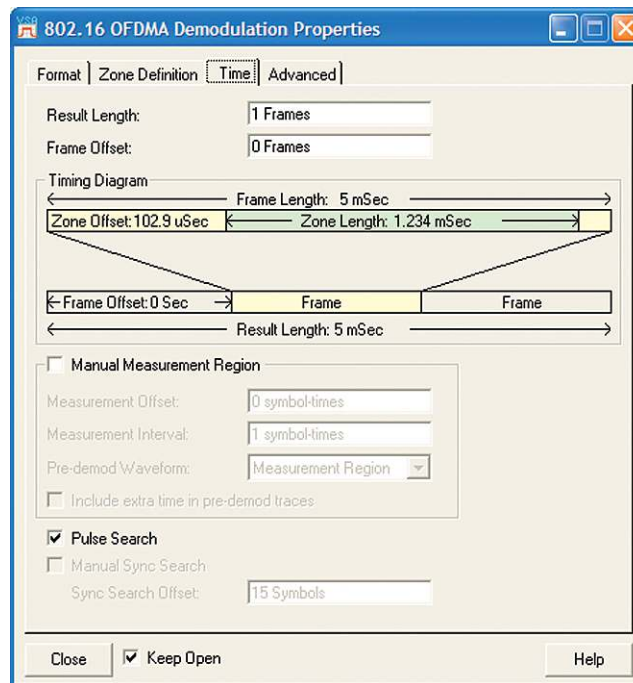

Figure 28. The Time tab on the OFDMA Demodulation Properties dialog box includes an active timing diagram (derived from the signal and user settings, and updated as the measurement configuration is changed) to help you visualize your signal for easier measurement setup.
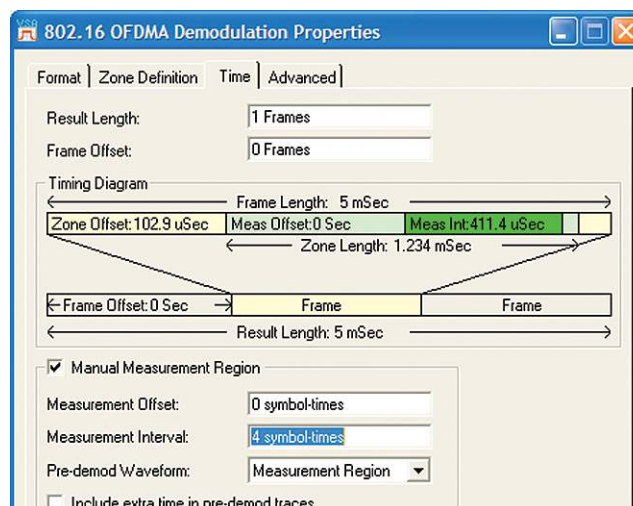

Figure 29. After selecting a manual measurement region with a length of 4 symbols and an offset of 0 symbols, the timing diagram reflects the actual measurement interval and offsets in seconds. This is a clear graphic representation of the measurement interval of 411.4 µSec and its relationship to the total result length, frame, and zone length (1.234 mSec).

Advanced Digital Demodulation (continued)

The analyzer display will now reflect only the first 4 symbols in the sub-frame, and from the map file you can see that these 4 symbols include the FCH, UL Map, DL map, and a portion of burst 1. Therefore, the only symbols shown in the constellation are either BPSK or QPSK. Close examination of the QPSK color-coding indicates that data from all four bursts are, in fact, included.

Changing the Measurement Offset to 4 symbols results in a measurement of only the last 4 symbols in this subframe and appropriate changes in the timing diagram on the Time tab. Note the Measurement Offset data in the diagram of 411.4 µSec or exactly 4 OFDM symbols.

The Timing Diagram on the Time tab now reflects the change in the time interval used for calculation and display of measurement results. Figure 30 shows the resulting constellation and OFDM Data Burst Info displays (trace C has been switched to this trace data type). Note that while all three bursts and pilots are visible in the constellation and Sym/Errs table, no FCH or MAP data is included in the data burst information table. That is because the analyzer is skipping over the first 4 symbols which, according to the zone map, are where the FCH, and the UL and DL MAP data bursts exist.

The Manual Measurement Region selection also includes additional capability. For instance, the Pre-demod Waveform and Include extra

time in pre-demod traces selections affect the time-domain gating of the signal, but only for pre-demod traces, including Time, Spectrum, and CCDF. This is useful for measuring characteristics of regions which are adjacent to the portion of the waveform used for modulation analysis. You can find more information on these and other selections on the Time tab in the 89600 VSA's extensive Help text.
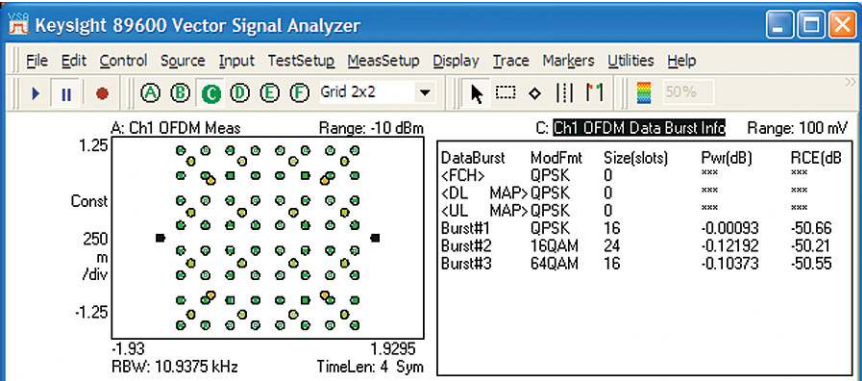

Figure 30. Manually selecting a measurement region (time interval) of 4 symbols with an offset (delay) of 4 symbols produces a result which does not include the FCH, DL-Map or UL-Map. The lack of information for these data bursts in the Data Burst Info table reflects this measurement configuration.

Advanced Digital Demodulation (continued)

Measuring a specific subcarrier or range of subcarriers

Some modulation impairments, especially those involving interference of some kind, are associated with specific frequencies or frequency ranges. Indeed, one of the benefits of OFDM techniques is their relative immunity to narrowband interference or robustness of transmission capability in environments where one frequency or a particular band of frequencies (and therefore subcarriers) is significantly impaired.

The error vector spectrum display, as described previously, can reveal error behavior that is associated with frequencies or subcarriers. Since the number of subcarriers is so large (840 active subcarriers during data bursts of the 10 MHz signal), X-axis display scaling can be very useful for focusing attention on the desired range of carriers. One application of this approach would be to examine band edges more closely to diagnose filtering problems or interference from an adjacent band.

For applications where it is desirable to focus the actual demodulation operations on a specific subcarrier or, more typically, a range of subcarriers, the Subcarrier Select function on the Advanced tab of the OFDMA Demodulation Properties dialog box will provide a solution. Since the demodulation itself is actually restricted to the selected subcarriers, the accuracy and robustness of the demodulation (including automatic recognition of modulation type, if selected) will depend on the signal quality of the selected subcarrier(s).

Selecting a specific set of subcarriers may be particularly useful when it is suspected that the signal under test has an improper configuration of the data burst map or an error in the permutation formula. Demodulating a very limited data set in this way may present problems for automatic recognition of modulation type, and it may be helpful to use a Manual setting for Data Tone Modulation as described below.

For applications where it is desirable to focus the measurement (if not the entire demodulation result) on a specific subcarrier or range of subcarriers, the Subcarrier Select function on the Advanced tab of the OFDMA Demodulation Properties dialog box will provide a solution.

This example of frequency-specific analysis will use the downlink recording i80216e_DLPuscUniformQ64.sdf supplied with the 89600 VSA software. As described previously, perform the Preset Setup function, recall the recording, and recall its setup file: i80216e_DLPuscUniformQ64.set. This setup file will automatically clear the Data Burst Analysis box on the Zone Definition tab of OFDMA Demodulation Properties, allowing for subcarrier selection.

The data tone modulation type is usually automatically detected by the 89600 VSA software. However, you can also manually set the data tone modulation, if needed, by going to the Advanced tab of OFDMA Demodulation Properties and clearing Use Default Settings. This will allow you to change Data Tone Modulation from Automatic to Manual, as well as to select the modulation format. Whether modulation type is detected automatically or set manually, the next step is to switch from All to Subset in the Subcarrier Select box, also on the Advanced tab.

Advanced Digital Demodulation (continued)

Measurement results and displays will now reflect only the desired subcarriers, as defined by the offset and interval entries. The offset (a negative or positive number) is the first numbered carrier to be included in the measurement results, and the interval (a positive number only) is the number of adjacent subcarriers to include. If, for example, the offset is set to –10 and the interval is set to 20, the 10 carriers on either side of the (untransmitted) center carrier will be displayed and measured, as shown in Figure 31. In this figure, the X-axis of the error vector spectrum display has been expanded by a factor of 20 to show these carriers more clearly. Note that you will have to change the display format of several traces in order to match Figure 31.

If desired, one can combine measurement of a specific set of subcarriers with measurement of a specific symbol or group of symbols, as described in the previous example. This may be a useful troubleshooting technique to understand the effect of an impulsive interference mechanism which affects only a narrow frequency band. The Time tab of the OFDMA Demodulation Properties dialog box is used to gain access to the Manual Measurement Region settings. In this way you can quantify the modulation quality of something as small as a single symbol on a specific range of OFDM subcarriers.

The Manual Measurement Region setting may also be needed to properly measure a subcarrier or (more typically a range of subcarriers) in a zone where different modulation formats are used for subcarriers at different symbol times in a subframe. Since the Subcarrier Select function only works in the uniform data analysis mode, the modulation analysis result must contain only a single type of modulation for accurate results. Isolating the calculation of results to a specific symbol or symbols will ensure that the result contains a single modulation type.
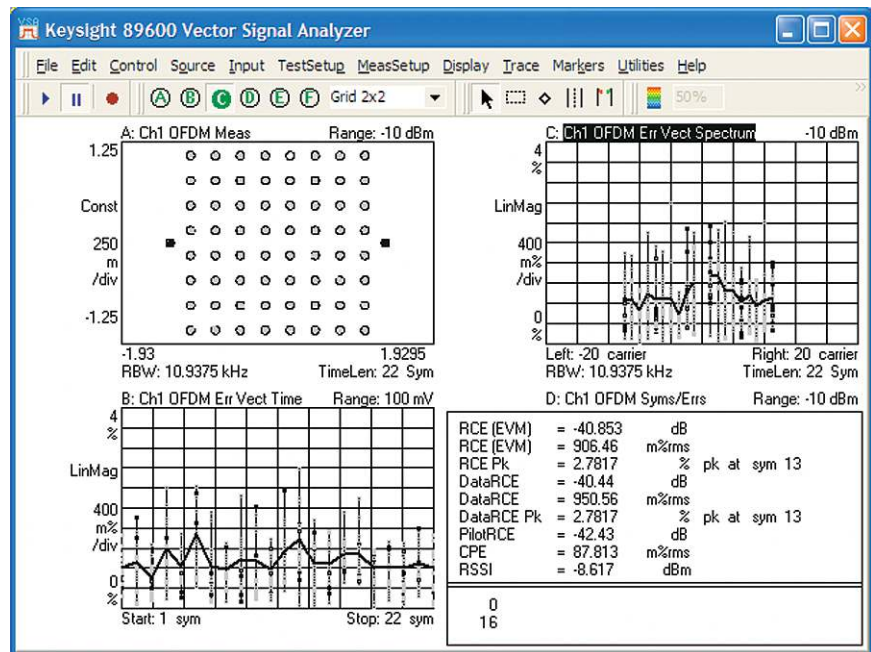

Figure 31. Analysis of a group of 20 OFDM subcarriers, centered around carrier 0. The X-axis of the error spectrum display (upper right) has been expanded to show how the selected carriers and the other measurement results are computed from only this subset of the subcarriers.

Summary

By following the discipline of an organized measurement sequence, you can uncover signal problems with your OFDMA signals. Begin with basic spectrum measurements, then add vector measurements, combining frequency and time, before switching to basic digital modulation analysis. After that, you can take advantage of advanced or standard-specific analysis.

The 89600 VSA software contains sophisticated measurement and analysis tools for time-selective or carrier-selective measurements in either the uniform data analysis or data burst analysis modes. With these tools, the VSA software can help you troubleshoot your signals quickly, and with an unmatched depth of understanding.

Resources

Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN
Hassan Yaghoobi Intel Communications Group, Intel Corporation
http://www.intel.com/technology/itj/2004/volume08issue03/art03_scalableofdma/p01_abstract.htm

RF Design OFDM impairments article
http://rfdesign.com/images/archive/0502Cutler36.pdf

RF Measurements for WiMAX (802.16-2004) eSeminar, Jan. 2005
www.keysight.com/find/WIMAXeseminar

WiMAX backgrounder article
http://www.home.keysight.com/upload/cmc_upload/All/CESept04_page13.pdf

Related Literature

Publication Title	Publication Type	Publication Number
Keysight 89600 Series Vector Signal Analysis Software for IEEE 802.16 OFDMA Evaluation and Troubleshooting	Self-Guided Demonstration	5989-2383EN
89600 Series VSA	Technical Overview	5989-1679EN
89600 VSA Software	Data Sheet	5989-1786EN
89600 VSA Software Hardware Specification	Data Sheet	5989-1753EN
WiMAX Signal Analysis; Part 1: Making Frequency and Time Measurements	Application Note	5989-3037EN
WiMAX Signal Analysis; Part 2: Demodulating and Troubleshooting the Subframe	Application Note	5989-3038EN
WiMAX Signal Analysis; Part 3: Troubleshooting Symbols and Improving Demodulation	Application Note	5989-3039EN
Keysight 89600 Series Vector Signal Analysis Software WiMAX (IEEE 802.16-2004)	Demonstration Guide and Application Note	5989-2029EN

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