Agilent WiMAX Signal Analysis
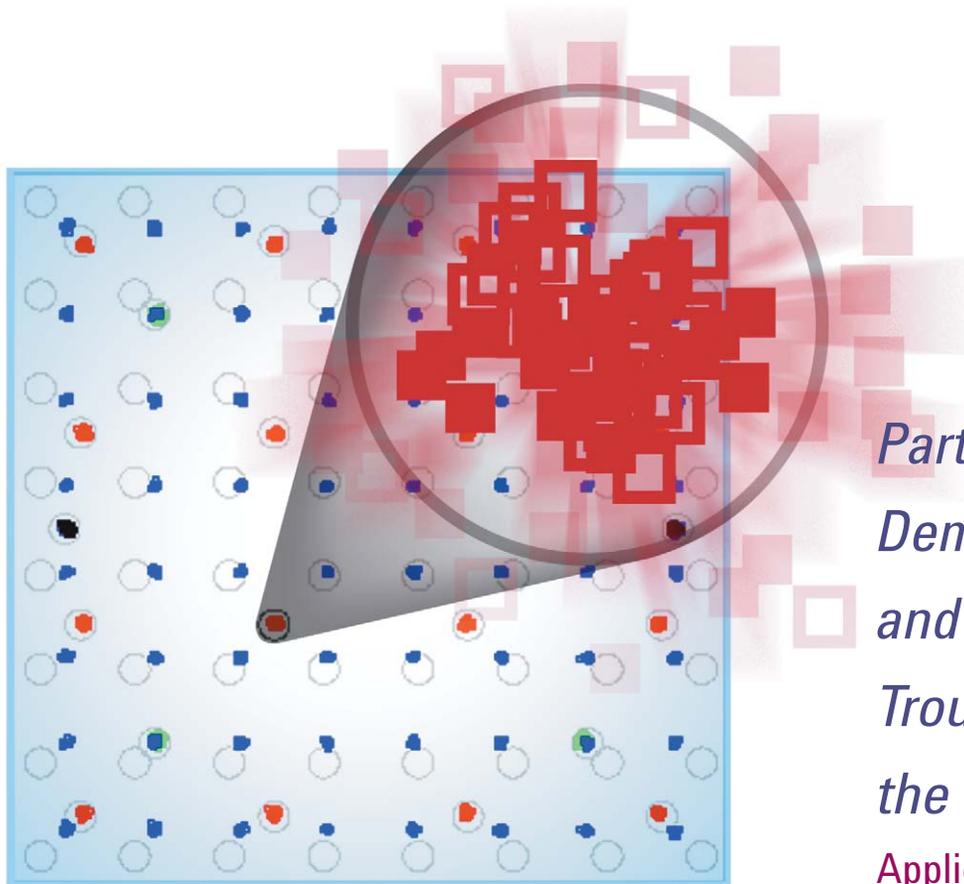
Part 2:

*Demodulating
and
Troubleshooting
the Subframe*

Application Note

Agilent Technologies

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Introduction

This application note is intended for engineers who are familiar with the IEEE 802.16-2004 (WiMAX) physical layer standard and wish to improve their measurement understanding and capabilities using a vector signal analyzer. This note will provide information on how to improve WiMAX signal analysis and includes measurement tips when designing and troubleshooting a new or an existing product. In order for the RF engineer to successfully test and troubleshoot a WiMAX device, a well-organized approach to the signal analysis will yield the greatest level of understanding and reliability in the measurement. This application note is the second in a three note series that provide the framework for the preferred measurement approach that includes frequency and time measurements, digital demodulation, and analysis of the advanced functionality within the WiMAX physical layer definition. If you are familiar with the 802.16-2004 standard but not necessarily familiar with WiMAX measurements, you may find reading all the application notes in this series very useful for expanding your knowledge of testing and troubleshooting this complex signal. For the engineer that is relatively new to the 802.16-2004 standard, a brief review of the standard will be provided which includes many technical references for those wishing to gain additional background into the IEEE standard and OFDM structure of the WiMAX physical layer.

Reviewing the WiMAX physical layer

The IEEE 802.16-2004 [1] and 802.16a-2003 standards, often referred to as WiMAX, define the physical layer (PHY) and medium access control (MAC) protocol that define products that extend broadband wireless access (BWA) from the local area network (LAN) to the metropolitan area network (MAN). These standards contain specifications for licensed and unlicensed BWA operating between 2 and 11 GHz. Initially licensed operation will cover the frequency ranges from 2.5 to 2.69 GHz and 3.4 to 3.6 GHz and unlicensed operation will use 5.725 to 5.850 GHz. In order to address the international wireless market and regional spectrum regulations, the WiMAX standard includes varying channel bandwidths. The channel bandwidths are selectable from 1.25 to 20 MHz. The 802.16-2004 standard, sometimes referred to as 802.16d, includes minor improvements over the earlier 802.16a-2003 standard. The 802.16-2004 standard also provides system profiles that can be used for product compliance testing. These profiles include minimum performance requirements for such parameters as transmitted power level, adjacent channel rejection, dynamic range, and bit error rate (BER). This application note will review signal analysis and measurement techniques relative to the 802.16-2004 standard.

The need for inexpensive and flexible commercial deployment of this technology has driven the requirement for multiple user access under non-line-of-sight (NLOS) operation and over distances up to 30 km. The 802.16 specifications define three different PHYs optimized for different wireless operation and conditions. These include a single-carrier modulation, a 256-carrier orthogonal frequency division multiplexing (OFDM) format, and a 2048-carrier OFDM format. The current industry focus [2], and the heart of this application note, is on the 256-carrier OFDM format.

OFDM subcarriers

The WiMAX specifications for the 256-carrier OFDM PHY define three types of subcarriers; data, pilot, and null. Two hundred carriers are used for data and pilot subcarriers. Eight pilot subcarriers are permanently spaced throughout the OFDM spectrum. Data subcarriers take up the remaining 192 active carriers. The remaining 56 potential carriers are nulled and set aside for guard bands and removal of the center frequency subcarrier [3].

Modulation types

The IEEE 802.16-2004 standard defines a set of adaptive modulation and coding rate configurations that can be used to trade-off data rate for system robustness under various wireless propagation and interference conditions. The allowed modulation types are binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16QAM), and 64QAM [3]. Pilot subcarriers always use BPSK modulation. During RF transmission, robust modulation types, such as BPSK and QPSK, are sent first followed by less robust modulation types, such as 16 and 64QAM. As a measurement example, Figure 1 shows several measurements for a demodulated DL subframe. This figure includes constellation, time-domain, spectrum, and subframe summary traces. The composite or overlay constellation trace (upper left) shows that this WiMAX subframe contains all the possible modulation formats, namely, BPSK, QPSK, 16QAM, and 64QAM. Note that the corner state constellation points for different modulation formats do not overlay each other (that is, they do not have the same power) in an effort to keep the average signal power constant among the various formats as specified in the 802.16 standard.

Duplexing techniques

The IEEE 802.16-2004 standard allows for a flexible burst transmission format with an adaptive frame structure within fixed frame durations. Duplexing is provided by means of either time division duplex (TDD), frequency division duplex (FDD), or half-duplex FDD (H-FDD) [3]. In licensed bands, the duplexing method shall be either TDD or FDD. FDD subscriber stations (SS) may use a H-FDD format. Unlicensed operation is limited to using the TDD format.

Frame structure

A WiMAX frame consists of a downlink (DL) RF subframe (subframes are generally RF bursts) and an uplink (UL) subframe. The TDD frame consists of one DL subframe followed by one or multiple UL subframes. There are currently seven supported frame durations in the IEEE 802.16-2004 standard ranging from 2.5 to 20 ms. The flexible frame structure of the TDD signal consists of an adaptive boundary between the DL and UL subframes.

A short transition gap is placed between the DL and UL subframes and is called the transmit/receive transition gap (TTG). After the completion of the UL subframes, another short gap is added between this subframe and the next DL subframe. This gap is called the receive/transmit transition gap (RTG). The time durations of the transition gaps are called out in the 802.16 standard and are a function of the channel bandwidth and the OFDM symbol time [4]. Figure 1 shows the time domain response (the RF burst envelope) of a DL subframe (lower left trace). This time domain response also shows the RTG leading the DL subframe.
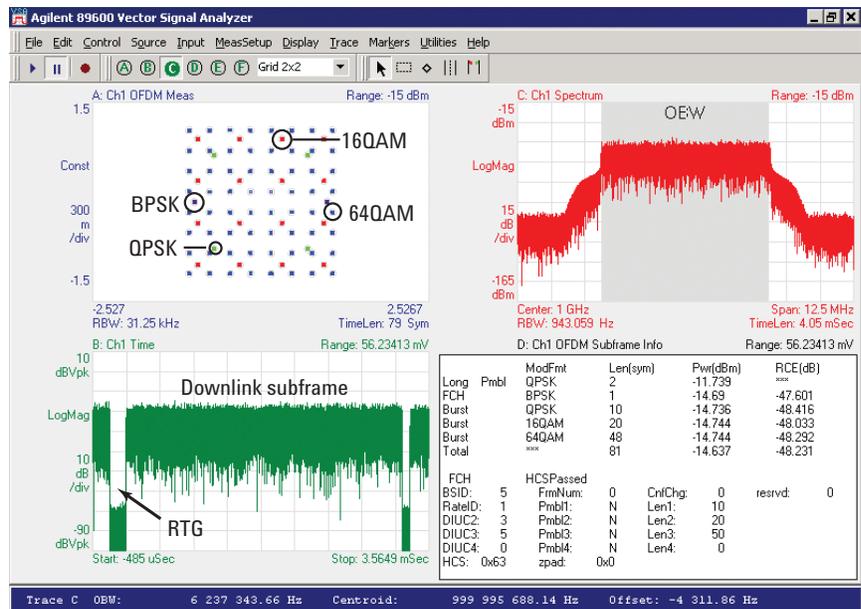
Figure 1. Multi-trace display of a demodulated WiMAX signal showing the constellation (upper left), spectrum response (upper right), time-domain response (lower left), and subframe summary table (lower right)

Long and short preambles

The DL subframe begins with two OFDM symbols used for synchronization and channel estimation at the SS. These two symbols together represent the preamble of the DL subframe and are referred to as the long preamble. The long preamble is followed by the frame control header (FCH), which contains decode information for the SS. User data follows the FCH and contains one or more symbols of payload data. The UL subframe begins with one OFDM symbol that is used at the base station (BS) for synchronization to the individual SS. This single symbol is referred to as the short preamble. The time duration of the long and short preambles are determined by the specified length of the OFDM symbol [4].

OFDM symbol

The OFDM waveform in the frequency domain is created by the inverse Fourier transform of the OFDM symbol in time. The OFDM symbol of duration, Ts, includes the *useful* symbol time, Tb (Tb = 1 ÷ carrier spacing), and a prefix, Tg. The prefix, termed the cyclic prefix (CP), is a copy of the end of the symbol appended to the beginning. The guard interval, G, is defined as the ratio of the CP length to the useful symbol time (G = Tg/Ts). The IEEE 802.16-2004 standard specifies four ratios for the guard interval, 1/4, 1/8, 1/16, and 1/32 [4]. The guard interval is used by the receiver to collect multipath and improve system performance [1].

Adopting the best measurement approach

It is often more useful to have a clear understanding of the signal and a reliable analysis approach than to know all the technical details of the standard. A well-organized measurement approach to WiMAX signal analysis will reduce setup and measurement errors, find problems at the earliest stages in the analysis, and provide the quickest path to complete troubleshooting of the WiMAX component or system. Measurement of the WiMAX signal is best accomplished with a vector signal analyzer (VSA) capable of measuring the RF and modulation quality of the digitally modulated signal. The measurement approach begins with basic spectrum and vector analysis using frequency and time domain measurements. Once the basic spectrum characteristics, such as center frequency, span, and amplitude have been verified, digital demodulation can be applied to the WiMAX signal under test.

Configuring the VSA for Demodulating a WiMAX Signal

The flexible burst type frame of the WiMAX signal can often be challenging when analyzing this complex signal using most general-purpose test equipment. Fortunately, vector signal analyzers (VSA), such as the Agilent 89600 Series VSAs, offer automatic and adaptable measurements including digital demodulation for IEEE 802.16 compliant waveforms. The 89600 VSA provides built-in presets for demodulating WiMAX waveforms, which require minimal user input. There are a few basic VSA settings, such as center frequency, frequency span, and input range that are required to be configured before beginning the digital demodulation process. Following a well-organized measurement approach, it has been suggested that vector signal analysis begin with basic time domain and spectrum measurements [5]. Once spectrum analysis is complete, the VSA will generally have the proper frequency and amplitude settings that are required prior to activating the demodulation mode of operation. In addition, these preliminary measurements may uncover problems such as malformed or missing preambles that would prevent successful demodulation but which would be harder to see in digital demodulation mode.

Digital demodulation begins with the assumption that the center frequency, span, and input range are configured correctly for the WiMAX signal under test. Demodulation is activated by selecting the Broadband Wireless Access and 802.16 OFDM options on the 89600 VSA. Verifying that the demodulation settings are correctly configured is done using the 802.16 OFDM Demodulation Properties menu. Three menu tabs for Format, Time, and Advanced will allow the user to change measurement parameters or accept the instrument defaults. Figure 2 shows the property selections for the Format and Time menus. The available presets and automatic detection capabilities of the VSA will speed the process to successful digital demodulation. There are several properties that the user should configure based on the WiMAX signal under test. These include selecting the appropriate standard, nominal bandwidth, and guard interval. Properly configuring these three parameters is necessary for the analyzer to lock on to and demodulate the test signal. In cases where there is some question about the correct value for a parameter, different values can be used on a trial basis (such as with guard interval) or the actual values for a parameter can be determined through the time and frequency domain analysis approaches discussed in the first note in this series [5].
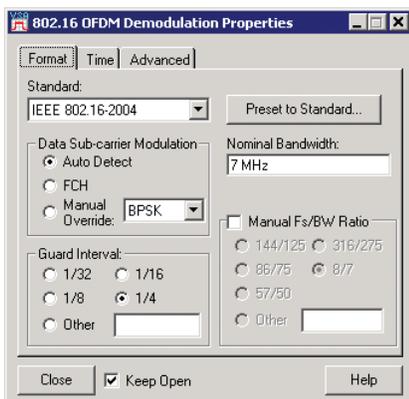
Figure 2A.
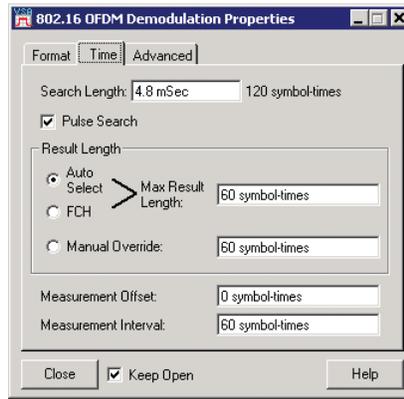
Figure 2B.

Figure 2. Agilent 89600 vector signal analyzer OFDM demodulation properties menu for the Format (Figure 2A) and Time (Figure 2B) instrument settings

Configuring the user selectable settings

As part of the demodulation process, you must properly configure three parameters related to the WiMAX signal under test. The parameters are the version of the IEEE standard, the nominal bandwidth, and the guard interval. These parameters are set using the Demodulation Properties format menu on the 89600 VSA. To begin, the Demodulation Properties menu defaults to the IEEE 802.16-2004 standard, which will also be the focus of this application note. Alternately, the instrument can be configured to demodulate signals based on the earlier 802.16a-2003 standard. Next, the nominal bandwidth for the signal under test must be entered on the format menu. There are two ways to enter the value for nominal bandwidth; the first allows the user to manually enter the value into the property box and the second technique provides a pull-down menu under the Preset to Standard selection button. There are 18 standard presets available with nominal bandwidths ranging from 1.25 to 28 MHz. The specified nominal bandwidths are related to the carrier spacing, symbol time, guard interval, and sampling factor [4]. Entering the nominal bandwidth will automatically set the value of several test parameters including the subcarrier spacing and sampling factor (Fs/BW). The nominal bandwidth is a descriptive term and its value is slightly larger than the actual bandwidth of the outermost carriers of the signal. If the nominal bandwidth of the signal is not known, a basic spectrum measurement can be used to determine the value.

The VSA has several measurement tools, such as marker offset and the occupied bandwidth calculation that can be used when determining the nominal bandwidth. For example, Figure 1 shows the spectrum of a WiMAX signal (upper right). This figure also shows the occupied bandwidth measurement for this spectrum trace which is determined to be 6.24 MHz. Knowing that the nominal bandwidth is slightly larger than the actual bandwidth, a good choice for the nominal bandwidth would be the 7 MHz setting chosen from the 18 available presets. By using the techniques described in the previous note in this series a more exact measurement of bandwidth and carrier spacing can be easily made, if these parameters are in question[5].

The guard interval is another parameter that must be set based on the properties of the WiMAX signal. The VSA default setting is 1/4. If the value is unknown, it can be measured in the time domain using the measured length of the long or short preamble. A preamble symbol has a power level that is 3 dB higher than the data symbol. When examining the beginning of a subframe, it is possible to visually pick out the portion of the preamble from the rest of the subframe. A measurement of the preamble length can be used to determine the guard interval by comparing the measured preamble length to the guard interval selections on the WiMAX Frequency and Time Parameter Table [4]. For example, the long preamble length for the DL subframe in Figure 1 was measured to be 80 μs using a basic time domain measurement. Knowing that the nominal bandwidth was previously determined to be 7 MHz, then the guard interval is1/4 using the Frequency and Time Parameter Table [4].

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Observing the automatic demodulation parameters

The 89600 vector signal analyzer will automatically configure two parameters from the Format tab on the 802.16 OFDM Demodulation Properties menu. They are the Sampling Factor and Data Subcarrier Modulation. As with most of the menu parameters, these values can be modified from their automatic selection and other values can be entered in their place when necessary.

The Sampling Factor, identified as Fs/BW on the 89600 VSA, is related to the ratio of OFDM sampling rate, Fs, to the selected nominal bandwidth. The IEEE 802.16-2004 specification defines this parameter using a set of ratios related to integer multiples of a frequency value; see Table 1.

Table 1: Sampling ratio and nominal bandwidth multiples

If BW is a multiple of	then Fs/BW
1.75 MHz	8/7
1.5 MHz	86/75
1.25 MHz	144/125
2.75 MHz	316/275
2.0 MHz	57/50
all others	8/7

The VSA will automatically select the appropriate ratio based on the user input for nominal bandwidth. For example, if the nominal bandwidth was selected as 7 MHz then the sampling ratio will be 8/7 based on the fact that 7 MHz is an integer multiple of 1.75 MHz. The VSA also provides the option for manual selection of the sampling ratio when prior knowledge of the exact sampling ratio is known for the WiMAX signal under test.

The data subcarrier modulation for a WiMAX signal can vary between four different modulation types, namely, BPSK, QPSK, 16QAM, and 64QAM. The VSA is capable of automatically detecting the modulation types within the OFDM burst and displaying the measured results using various traces such as constellation and subframe summary table. This auto-detection feature speeds the OFDM demodulation process with minimal intervention by the user. In addition, the data subcarrier modulation can be manually configured to use the information contained in the FCH if the FCH symbol is not present in the signal then the subcarrier modulation format is switched to Auto-Detect. Manual override is another option that allows the user to specify the modulation format expected during the OFDM burst. Manual override provides only one setting for modulation, so the demodulation will be performed with the assumption that the data burst contains the same modulation throughout.

Searching for pulses

Most WiMAX signals are bursted (or pulsed) transmissions. Successful digital demodulation of these signals is performed by aligning the VSA demodulator with the pulses in time. One way to align the instrument to the RF bursts is to use the Pulse Search function of the VSA. Selection of this function is performed on the OFDM Demodulation Properties menu under the Time tab. By default, the Pulse Search function is active. When Pulse Search is active, the analyzer searches for the location of the first complete pulse within a defined length of time. Pulses beyond the first complete pulse are disregarded and are not demodulated. In order for the pulse search algorithm to detect a pulse edge, the pulse must be at least 15 dB above the noise floor. The total search time is specified in the Search Length entry box on the Time menu. The default search time is 120 symbols, allowing it to adjust automatically with signal bandwidth. Since it is necessary for the VSA to measure one complete pulse using this option, a good rule of thumb is to set the search length to twice the maximum pulse on time plus one off time (2x "on" + "off"). This will ensure that one complete pulse is always present during the signal acquisition. Verification of the proper setting for search time can be accomplished by examining the Search Time trace on the VSA. This display shows the raw time domain data before pulse searching and signal demodulation is applied. The Search Time trace should include at least one complete RF burst for the signal under test. If a complete pulse is not found then a PULSE NOT FOUND status message is displayed and the VSA may not demodulate the signal. For this case the search time should be increased while examining the Search Time display until a complete pulse is observed.
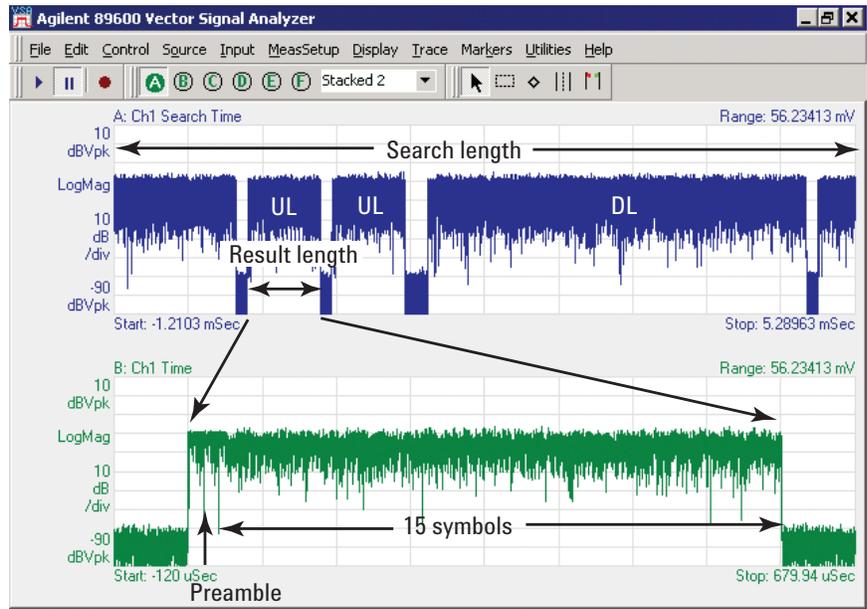
Figure 3. Search Time trace (upper trace) showing two uplink and one downlink subframe. For this display, the search length was set to approximately twice the longest pulse "on" time. The lower trace shows the portion of the time domain waveform to be demodulated based on a result length setting of 15 symbols

As a measurement example, Figure 3 shows the Search Time trace (upper trace) using a Search Length of 6.5 ms, which is equivalent to 162.5 symbols based on the anticipated OFDM symbol time of 40 µs. This figure shows that the first complete pulse occurs over the left-most UL sub-frame. Once this pulse has been found, the amount of time domain data that is actually demodulated is determined by another instrument parameter called the Result Length. Continuing with the measurement example and using a Result Length of 15 symbol-times, the actual time domain data that is analyzed is shown in the lower trace of Figure 3. For this case the first entire UL sub-frame including the preamble symbol and the 15 data symbols will be used during the demodulation analysis.

Some WiMAX signals are continuously modulated, and the 89600 VSA can demodulate these as well. Normally, a trigger is supplied and the 89600 trigger delay is adjusted so that the preamble is near the beginning of the analysis time record. Non-triggered (free-run) measurements may also be made on live input data or recorded (time captured) signals, though demodulation will only be successful when the preamble is near the beginning of the time record.

The Result Length parameter on the 89600 VSA sets the total number of symbols to be included in the acquired and demodulated data. There are three modes for specifying the Result Length; they are Auto-Select, FCH, and Manual Override. When Auto-Select is chosen, which is the default setting, the analyzer automatically determines the result length value up to the maximum value specified on the menu. The VSA compares the number of symbol-times detected within the first complete burst to the Max Result Length parameter and uses the smaller value as the analysis time. For example, Figure 4a shows the RF burst for an UL subframe (lower trace) that contains the "short" preamble followed by 15 data symbols. For this measurement, Auto-Select was used and the result length was automatically determined to be 15 symbol-times. In this example the Max Result Length was set to 60 symbols, therefore the analysis will cover the smaller of the two values or 15 symbol-times. If the max result length is greater than the burst length, the Time trace data shows the entire burst ±10 percent of the burst length as shown in Figure 4a.

If the max result length is less than the burst length, the Time trace data shows the number of symbol-times specified by the Max Result Length parameter plus 10 percent of the length added to the start of the burst. Figure 4a also shows the associated constellation diagram (upper trace) using the same 15 data symbols positioned around the IQ plane. It is suggested when measuring a WiMAX signal for the first time that the Auto-Select option is used for determining the result length and that the max result length is chosen large enough to gather an adequate number of symbols for the analysis.

An alternate way to determine the result length is to configure the VSA to select the result length based on the FCH. The FCH contains a prefix that specifies the burst profile and length of the one or several OFDM symbols immediately following the FCH. For this case, the VSA will determine the result length based on the number of symbols stored in the FCH. For the RF bursts that do not contain a FCH, as in an UL subframe, Auto-Select will then be substituted. Using the FCH to set the result length also requires the user to specify the max result length as done in the Auto-Select mode.

The final option available for configuring the Result Length is known as Manual Override. Manual Override is ideal for burst lengths that are well characterized or if only a few symbols from the burst are required for the analysis. When using this option it is important to correctly enter the number of symbols for the Result Length, as it is possible to introduce errors in the measurement. For example, if Manual Override is selected and the result length value entered is larger than the total number of symbols in the subframe, then it is possible that errors will occur during the demodulation as the VSA attempts to recover symbols that are not part of this subframe. As a measurement example for an incorrectly configured Result Length, Figure 4b shows the same UL burst as in Figure 4a with the only change that the Result Length was manually set to 18 symbols. For this case, errors occur in the constellation as the VSA attempts to demodulate the noise following the subframe. These errors can be easily corrected by decreasing the manually selected Result Length to 15 or less.
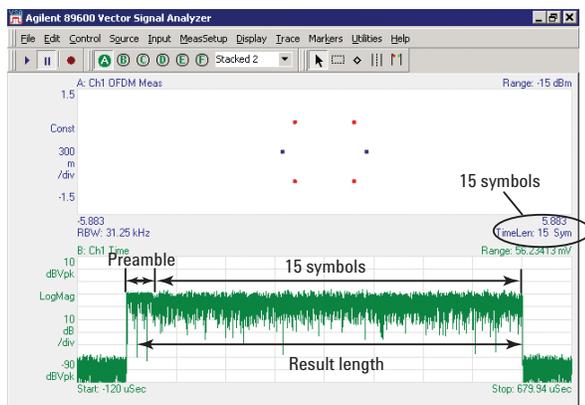
Figure 4a. Time domain waveform (lower trace) for a WiMAX uplink subframe using an automatically selected result length. The length was properly set to 15 symbols. Also shown is the correctly demodulated constellation (upper trace) for this waveform
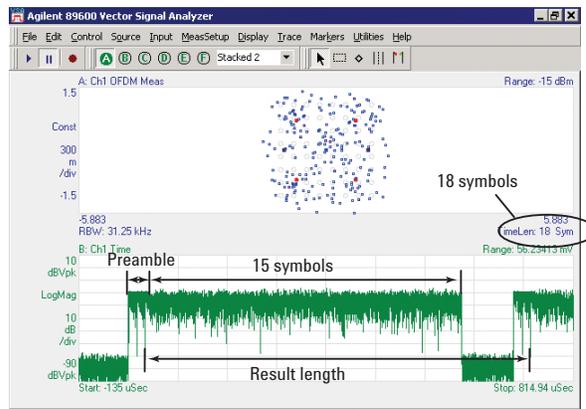
Figure 4b. Time domain waveform (lower trace) for a WiMAX uplink subframe using the Manual Override selection for result length. The length was incorrectly set to 18 symbols. Also shown is the demodulated constellation (upper trace) for this waveform including data errors

Deciding between Pulse Search or Magnitude Triggering

As previously discussed, finding OFDM pulses can be easily accomplished in the digital demodulation mode using the Pulse Search function in the VSA. In addition, the VSA can also be configured (typically with a hold-off value) to trigger a measurement on a pulse by measuring magnitude changes to the RF envelope of the input signal. The main differences between the two functions, is that Pulse Search requires a complete pulse having both rising and falling edges and Magnitude Triggering requires only a rising or falling edge. In addition, the Pulse Search function automatically centers the pulse on the display based on the result length while the Magnitude Triggering requires the user to manually position the pulse on the display. Pulse searching will provide measurements on all types of RF bursts within the WiMAX frame as they are acquired by the instrument. Alternately, Magnitude Triggering limits the data acquisition to specific RF bursts based on the trigger setup. In order to use Magnitude Triggering to examine all the various RF bursts, numerous changes to the VSA trigger settings will be required. Also, pulse searching is only available during demodulation while Magnitude Triggering is also useful when performing basic spectrum measurements as well as demodulation [5]. In general either technique can be used during demodulation analysis but the Pulse Search function configures several instrument settings automatically. It does not provide any additional benefit to use both types of triggering simultaneously, therefore the user should select only one for the demodulation process.

Viewing the demodulated data

For a complex signal such as WiMAX, there is a considerable amount of measurement data available once the VSA has successfully demodulated the OFDM signal. The 89600 VSA provides colorful multi-trace displays that allow the user to quickly verify the proper operation of the signal and rapidly identify any problems that may exist. Numerical measurement of modulation quality and visual evaluation of potential errors are easier with the use of these multiple simultaneous displays. Linking measurements across multiple domains also provides a powerful verification and troubleshooting tool. For example, Figure 5 shows a multi-trace display consisting of the Constellation, Error Vector Spectrum and Error Vector Time, Time waveform, and subframe and error tables. This multi-domain display is just one example of the extremely large number of measurement combinations that can be performed on the WiMAX signal. Signal verification and troubleshooting details using several of these measurement traces will be provided in this application note including techniques that couple markers between different measurement domains.
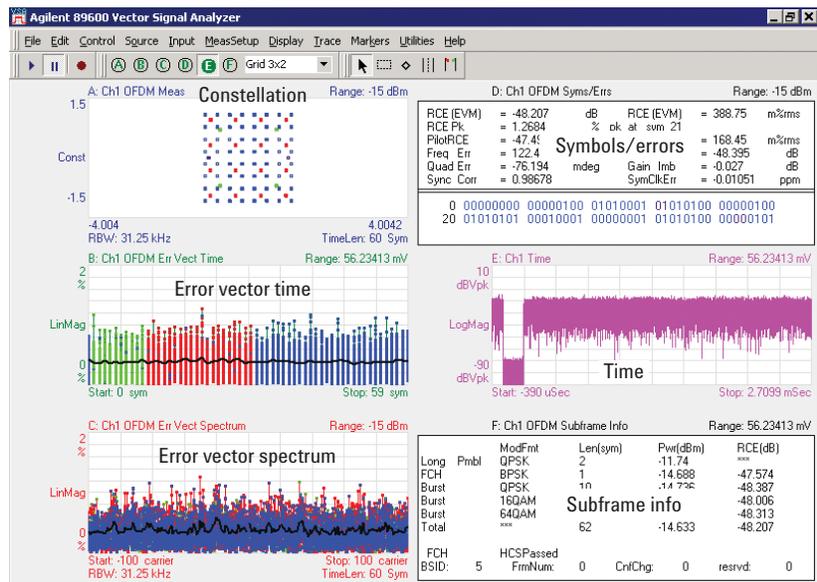
Figure 5. Multi-trace display showing several different measurement domains including symbol, time and spectrum analysis

Verifying and Troubleshooting the Demodulated WiMAX Signal

Verification that proper demodulation has occurred usually begins with examining a few measurement traces including the Constellation trace and Symbols/Errors table. A clear constellation is an excellent starting point for indicating a successful demodulation. Compared to those of traditional digital modulation formats, the WiMAX constellation may appear to have an unusual configuration. Depending on the structure of the subframe and the number of symbols used in the analysis, the constellation may be comprised of an overlay of BPSK, QPSK, 16QAM, and 64QAM. The 89600 VSA uses a color-coding scheme to visually show the different multi-modulation formats simultaneously in the same constellation trace. Here, the constellation is color coded by modulation type and signal element. For example, the QPSK part of the constellation is displayed in one color and the BPSK pilot 10 element has another. This color-coding is consistent across different measurement displays, providing valuable troubleshooting insights through correlation of different error measurements as shown below.

Circles are placed around the ideal constellation locations for each modulation type. This size of the circles represents the error vector magnitude (EVM) as a percentage. By default, the circles are set to a 5 percent EVM and this can be adjusted as desired. Measurement points that fall outside the circles are indicative of problems within the WiMAX signal or in the demodulation process. As a measurement example, Figure 6 shows the constellation of a DL subframe containing all possible modulation types over the total of 42 symbols. This constellation is representative of a valid demodulation result but reveals significant errors for the symbols using a 64QAM format. When examining the expanded view in Figure 6, it is observed that BPSK pilot and 16QAM data-modulated symbols fall inside the 5 percent EVM circles but none of the 64QAM symbols fall inside the appropriate circles. This display indicates errors possibly resulting from limiting, scaling, or compression problems that only affect the 64QAM symbols.

In this case, it was later found that scaling errors in the DSP resulted in improper amplitude levels for all the 64QAM data symbols, though these scaling errors did not affect the other modulation types. There are several clues to the problem in the constellation, and in other measurements. In the constellation, for example, it can be seen that amplitude errors are proportional to the signal's amplitude (represented by the distance from the center of the constellation) and are not larger for higher-amplitude states such as the corner ones. If the errors were due to amplitude compression in an amplifier, the errors would be much larger for the corner states than for the center ones, and other modulation types would be affected. In addition, the effects of pilot amplitude tracking (described in the next application note in this series) would provide other information about this error and the modulation it is associated with [6]. More detail on a troubleshooting approach for this signal is provided later in this application note.
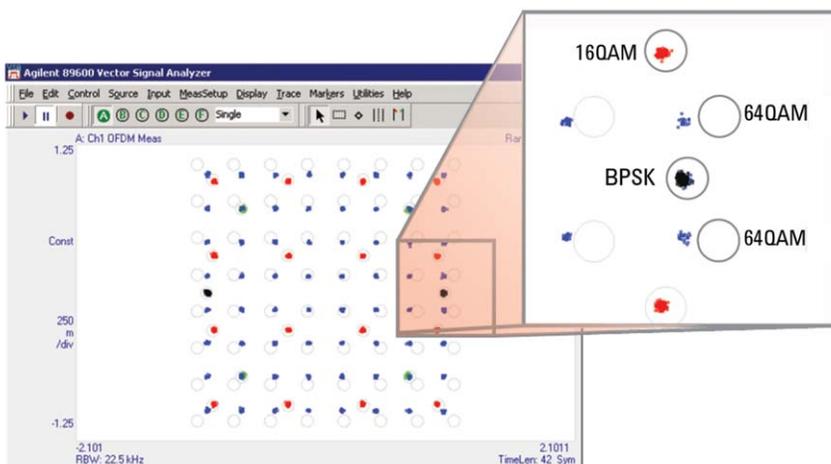
Figure 6. Constellation trace for a WiMAX downlink subframe including a close-up showing large errors for symbols using the 64QAM format

Examining the Symbols/Errors Table

The Symbols/Errors table is another very useful display to verify the operation of the VSA demodulator and the modulation quality of the WiMAX signal. The upper portion of the table shows several error statistics for all the demodulated symbols included in the analysis. The bottom section shows the raw OFDM detected symbols (physical layer symbols) without any de-interleave, decoding, or descrambling. At this stage in the demodulation process, examining the upper error summary provides the most useful verification and troubleshooting information.

One of the most powerful statistics for determining the modulation quality of the signal is the measured value for Relative Constellation Error (RCE). RCE is a term defined in the IEEE 802.16 standard and is calculated as the RMS value of the EVM over the entire burst. The RCE is calculated using all preamble and data symbols in the burst. The RCE is shown as a percentage and as a value in decibels (dB). The 802.16 standard lists the RCE for specific modulation types and coding rates [1, 3] but the RCE value supplied on this summary table provides an overall figure of merit of the modulation quality for the entire WiMAX burst. The VSA can also provide the RCE values for individual modulation types using the Subframe Info trace that will be reviewed later in this application note. The peak level of EVM and the symbol associated with it is shown on this table as the RCEPk. The RCEPk provides both the percentage RCE and the number of the symbol in which the peak occurred. Peak values that deviate substantially from the total RCE may indicate problems with only a few symbols within the burst. Figure 7 shows the Symbols/Error Table for a good WiMAX uplink subframe resulting with a RCE value of better than –40 dB.

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Agilent 89600 Vector Signal Analyzer

File  Edit  Control  Source  Input  MeasSetup  Display  Trace  Markers  Utilities  Help

▶  II  ●   Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ  Single              ▶  ▯ ◇  �|¦|  M

               A: Ch1 OFDM Syms/Errs                          Range: -15 dBm

RCE(EVM)    = -47.628      dB      RCE(EVM)    = 415.52     m%rms
RCE Pk      = 1.2456       %   pk  at  sym  7
PilotRCE    = -46.689      dB      CPE         = 183.69     m%rms
Freq  Err   = 365.48       mHz     IQ  Offset  = -47.877    dB
Quad Err    = -119.25      mdeg    Gain  Imb   = -0.029     dB
Sync  Corr  = 0.96867             SymClkErr   = 0.14598    ppm

   0  03030201  03000101  00000302  00000000  02030202  00000002  01010002
  28  00010003  03020102  00010301  02000103  02030201  00010101  03030201
  56  00010203  01020003  00030003  03020102  03020301  00020100  03020103
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 196  03030101  03030000  02000002  03010200  00010302  02030302  02020300
 224  02020000  00030102  02020301  03000000  03030000  01030003  03030303
 252  03000300  02020203  00010201  02020002  03010200  01030101  02020300
 280  01020003  02020100  00000300  02000302  03010002  02    0203  01020301
 308  00000200  03000100  01020203  03020200  00030000  03020300  01000001
 336  01000101  00030002  03010301  01020100  00010201  03000201  03010101
 364  01000301  02000101  02000003  00010001  01020302  03000002  01010202
 392  00010203  01030101  00020001  00020002  03010103  01020000  01010300
```

Figure 7. Symbols/Errors trace for a good WiMAX uplink subframe

The Symbols/Errors trace also displays statistics based on errors found within the pilot subcarriers. Pilot subcarriers are used for a continuous demodulation reference during the burst and therefore it is important to verify the performance of these transmitted subcarriers using the composite statistical values such as PilotRCE and Common Pilot Error (CPE). The PilotRCE is the RMS value (in dB) of the EVM for the eight pilot subcarriers over all symbols in the entire burst. The CPE is a measure of the residual magnitude, phase, and frequency changes that occur following the preamble and the RMS value for this error is shown on this table (in percent). It is also possible to examine the CPE as a function of symbol-time, which is very useful when examining the pilot tracking behavior of the demodulator [7].

Frequency Error (Freq Err) is another Symbols/Errors trace parameter that shows the carrier frequency error relative to the analyzer's center frequency. The frequency error reported in the table is the value determined from the final frequency estimation based on the channel estimation sequence and any frequency error detected in the pilot tracking. Errors in RF frequency, LO frequency, or digitizer clock rate could all appear as carrier frequency error.

IQ Offset, displayed on the Symbols/Errors trace, indicates the magnitude of the carrier feedthrough. The DC offset tends to reduce the dynamic range of the receiver as well as introduce noise into each subcarrier signal, especially for high data rate systems [9]. Carrier feedthrough can also result in degraded performance in systems that use zero-IF architectures, as the downconverted carrier may result in a large DC offset, which would reduce dynamic range in the A/D converters.

Gain Imbalance (Gain Imb) and Quadrature Skew Error (Quad Err) are two additional values shown on the Symbols/Errors trace that represent the gain difference and the orthogonal error between the I and Q channels respectively. OFDM signals differ from single-carrier modulated signals in that these errors cause each subcarrier to interfere with adjacent subcarriers, which results in the spreading of each constellation point. Spreading of the constellation points will result in an increase in EVM and reduced system performance. In some cases, this state spreading will spread the points into a distorted miniature picture of the entire constellation [7, 8], though the structure of the spread points may be impossible to recognize, especially for higher-order modulation types and where the data on frequency-symmetrical carriers is uncorrelated. The Symbols/Errors table also provides a value for the Symbol Clock Frequency Error (SymClkEr), which is the difference between the ideal and actual symbol clock frequency in ppm. A symbol clock frequency that is lower than specified will make the OFDM symbol time longer than required and cause the OFDM subcarrier spacing to decrease. A symbol clock frequency that is greater than specified will make the symbol times shorter than required and cause the OFDM subcarrier spacing to increase. In either case this creates subcarrier interference and increases the signal's EVM. In many cases this will produce a distinctive V-shaped error vector spectrum display if "Track Timing" is not enabled in the pilot tracking of the VSAs demodulator. This pilot tracking function is described in the last note in this series [6].

The last value on the Symbols/Errors trace shows a figure of merit indicating the quality of the preamble segment used for synchronization and is termed the Sync Corr. Sync Corr is a cross correlation between the measured signal and an ideal signal using the synchronization segment of the preamble. A value of 1 indicates perfect correlation and a value of 0 indicates no correlation. Large frequency errors (approximately 100 kHz or more) may cause the analyzer to show incorrect low Sync Corr values. These values are a result of frequency error and do not necessarily indicate poor signal quality. Therefore, for low Sync Corr values you always need to validate the cause of the low Sync Corr data result. If the Sync Corr is low and the frequency error is large, check the RCE. If the RCE is low, the measured signal data is good and the low Sync Corr value can generally be ignored. To correct for frequency errors, adjust the center frequency of the analyzer or the transmitter so that the freq err decreases to approximately 0 Hz. If the Sync Corr increases in value then the contributing factor to the initial low Sync Corr value was the frequency error and not the measured signal.

Lastly, the lower portion of the Symbols/Errors trace shows the raw data bits for each symbol and subcarrier following the preamble. These bits are not decoded and include bits for all subcarrier symbols including the pilot subcarriers. The first bit in the table corresponds to the first OFDM symbol, which begins at the subcarrier index equal to –100. This first bit represents the first data symbol following the preamble (the FCH in downlink signals). The default symbol table display shows the data subcarrier symbol bits in color and all the bits for subcarriers with index equal to 0 are blanked. The color of the symbol table bits indicates the modulation format of that symbol and matches the color coding for other demodulation displays such as constellation, error vector time, error vector spectrum, etc.

Measuring the Error Vector Spectrum and the Error Vector Time

Error Vector Spectrum and Error Vector Time measurements are two extremely useful tools when verifying and troubleshooting WiMAX signals. Both displays show the magnitude of the distance (vector error) between the measured symbol data and the nearest ideal constellation point as a function of either carrier frequency or symbol-time. Error Vector Spectrum shows the signal RCE (EVM) for each of the 200 subcarriers for all symbols within the burst. The compliment to the Error Vector Spectrum is the Error Vector Time, which shows the signal RCE for each of the symbol-times measured for all the carriers in the burst. Another way to describe these measurements is to examine the diagrams in Figure 8. The top curve of Figure 8 shows two OFDM symbols sampled in time at positions labeled with a square for symbol 1 data and a circle for symbol 2 data (step 1). The OFDM symbol-times are transformed into the frequency domain using a FFT (step 2). The resulting spectrum response can be shown as a function of subcarrier frequency starting at –200 and ending with 200.

The subcarrier frequency with index 0 is not used as this represents the RF carrier and is not used in OFDM systems. The frequency response is represented by a complex number that can be mapped to the IQ plane also known as the constellation (step 3). As the various subcarriers can have multiple modulation formats, the constellation will be a composite overlay of BPSK, QPSK, 16QAM, and 64QAM formats. Noise and interference moves the constellation points away from the ideal locations and the distance between the two represent the error vector magnitude (EVM). The absolute magnitude of the set of EVM values associated with each symbol can be plotted in a column as a function of symbol-time (1, 2, ...) (step 4). This trace is known as the Error Vector Time. Alternately, the set of EVM values can also be grouped as a function of subcarrier frequency (–200, –199, ..., 200) and this trace is known as the Error Vector Spectrum. In this case, the data in the columns represent EVM values from different symbols in the burst but at common subcarrier frequencies. Note, that the different constellations of step 3 would be overlaid on a VSA measurement display for the Constellation trace. The VSA Constellation trace generally shows all the pilot and data symbols for the entire burst over all subcarriers simultaneously on one display. The demodulation displays can be limited to certain carrier frequencies, symbols, or ranges of symbols; this is described in the third note in this series [6].

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Step 1

Symbol 1   Symbol 2

Time

Step 2

−5 −4 −3 −2 −1 0 1 2 3 4 5
subcarrier

−5 −4 −3 −2 −1 0 1 2 3 4 5
subcarrier

Step 3

Q

I

Q

I

Step 4

Error vector time

1   2

Symbol-time

Error vector time

−5 −4 −3 −2 −1 0 1 2 3 4 5
subcarrier
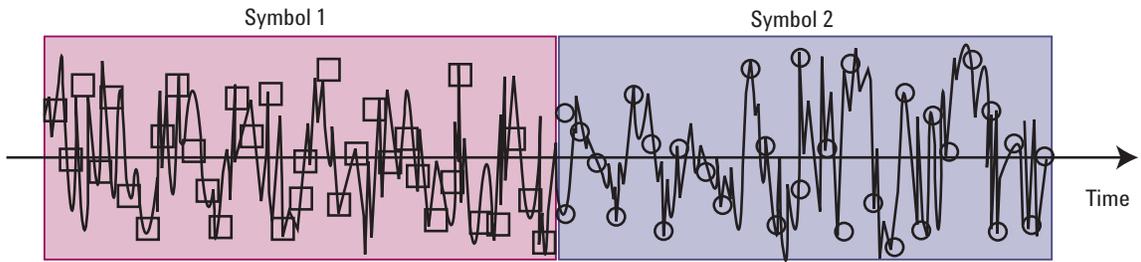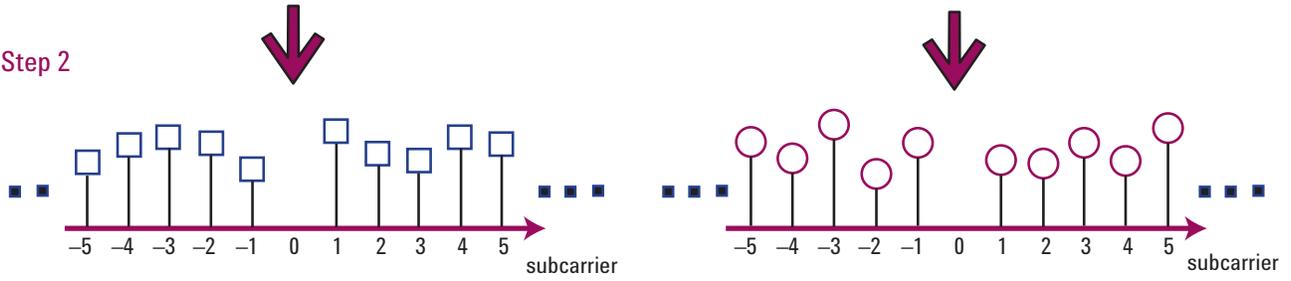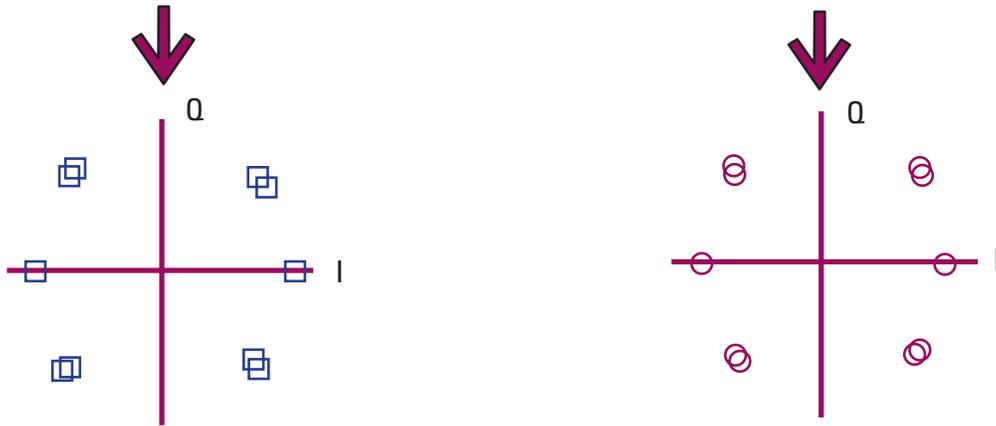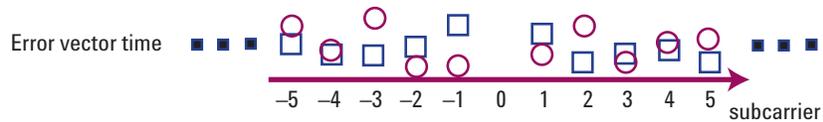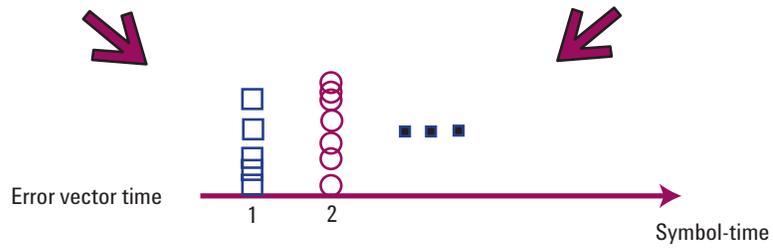
Figure 8. Diagram showing the progression of measurements to display the Error Vector Time and Error Vector Spectrum traces

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The Error Vector Time and Spectrum traces also show the RMS errors for these two measurements as a heavy line. The Error Vector Time trace shows the RMS average EVM at each symbol-time, which includes all 200 subcarriers at that symbol. This same data can be plotted separately using the RMS Error Vector Time trace data display. The Error Vector Spectrum shows its RMS average EVM but at each subcarrier frequency, which includes all symbols measured at that subcarrier. This same data is available using the RMS Error Vector Spectrum data display. The Error Vector Spectrum and Error Vector Time trace data on the 89600 VSA use multi-color trace data to assign a unique color to the pilot subcarriers, the data subcarriers, and the RMS (average) EVM trace. There are also separate colors assigned for the different data modulation types, namely BPSK, QPSK, 16QAM, and 64QAM.

The Error Vector Time and Spectrum traces when displayed together provide a powerful troubleshooting tool for both time-variant and frequency-variant problems within the WiMAX signal. Spurious signals and other frequency selective errors will affect individual or small groups of subcarriers and often create clusters of subcarrier dependent errors that can be observed on the Error Vector Spectrum display. As an example, a signal with faulty pilot modulation will experience high EVM at the eight pilot subcarrier frequencies (pilot indices occur at ±88, ±63, ±38, and ±13) and these errors can easily be observed on the Error Vector Spectrum trace. Alternately, time-related problems such as impulse interference, DSP-related problems, amplitude variation along the burst and power supply transients, can be observed using the Error Vector Time trace. As a measurement example, Figure 9 shows the Error Vector Spectrum (top trace) and Error Vector Time (lower trace) for an UL burst containing 15 data symbols. To simulate an error at the end of the subframe, the Result Length was incorrectly set to 18 symbols using the manual override setting. This was the same configuration previously used for the constellation measurement example in Figure 4b.

The first noticeable errors occur in the Error Vector Spectrum trace where the EVM value dramatically increases for the eight pilot subcarriers. These large errors result from the demodulator attempting to recover the BPSK pilots from the three noise-only symbols. A marker placed on a peak value can be used to verify that these errors are from the last three symbols as shown on the marker readout using the Error Vector Spectrum trace. Alternately, the Error Vector Time trace (lower trace) shows a substantial increase in the EVM at the end of the burst. Again, the increase in EVM results from demodulation of noise for the last three acquired symbols. As described below, coupling the markers between different trace/measurement types can make this identification of an error source easier.
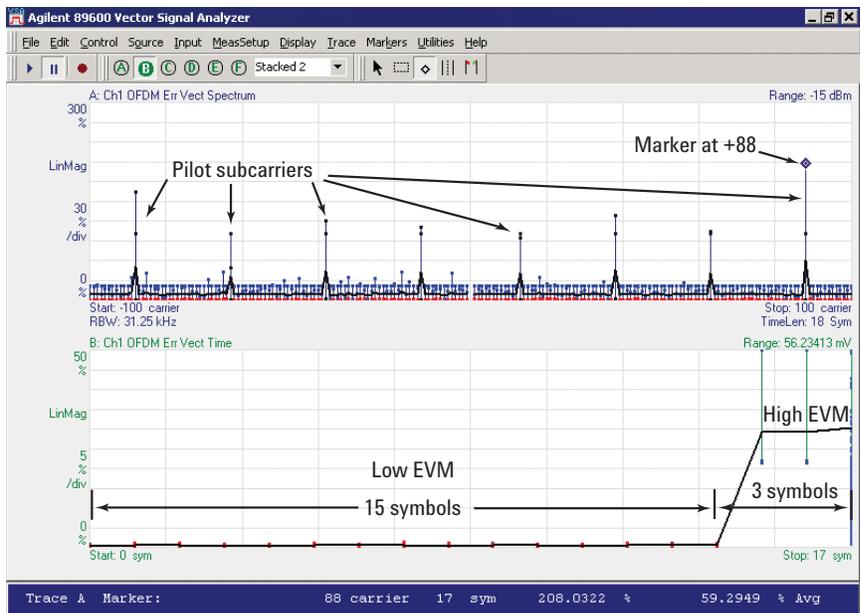
Figure 9. Error Vector Spectrum (upper trace) and Error Vector Time (lower trace) displays for a WiMAX uplink subframe with large symbol errors at the end of the burst

Coupling OFDM Markers

Demodulation of a WiMAX OFDM signal on a vector signal analyzer can provide several unique measurements using three-dimensional data. The Error Vector Spectrum, Error Vector Time, and Constellation traces result in data covering symbol-time, subcarrier frequency, and measurement value. It was previously shown that the Error Vector Time and Spectrum measurements display EVM values as a function of symbol-time and subcarrier frequency. Constellation measurements, such as IQ Meas and IQ Ref, show complex values of amplitude and phase (real and imaginary) over the same time and frequency ranges. Markers and several marker functions can be used in all of these traces with the result that the displayed marker readout is also three-dimensional. In general, marker movement and operation is similar to the typical two-dimensional data displays with the added capability for three-dimensional data. For example, a marker positioned on a Constellation trace will provide a complex marker value as a function of subcarrier index and symbol-time. The marker can be moved around the trace using the mouse or by using the marker search functions, the marker position menu or the arrow keys on the keyboard. The position menu found under the Marker Properties window provides direct entry of the marker location in terms of subcarrier index (x-position) and symbol (z-position or column data) for Constellation and Spectrum traces. The marker's x and z entry positions are swapped for time traces where the symbol is located in the x-position for time and the subcarrier index is in the z-position (column data). This menu also provides the selection for marker coupling between the various traces, which is another powerful feature for troubleshooting WiMAX signals.

Marker coupling is an often overlooked feature that is very useful when relating results across different domains or when using different display types and scaling. Marker coupling means that the markers associated with two or more traces will move together and be linked to the same symbol-time and subcarrier index. For example, the coupled marker function can be used to link the markers placed on any combination of the four following traces; Constellation, Error Vector Spectrum, Error Vector Time and Symbols/Errors table. Identifying the worst case errors and where they occur in both time and frequency provides very useful information when examining specific causes for problems concerning modulation type, compression, and signal interference to name a few.

As mentioned above, marker position can be moved using the mouse, the Marker Properties menu, search functions, or arrow keys. The arrow keys provide many shortcuts to marker movement such as the left arrow, which will move the marker to the next smaller value along the selected axis. The selected axis can be either the symbol-time or subcarrier frequency index. Additional information about the marker function shortcuts can be found in the 89600 help menu [7].

Verifying and Troubleshooting WiMAX Signals

An important benefit of the 89600 VSA software is the ability to change measurement and display parameters without the need to acquire new data. This feature greatly improves the ease of use and eliminates the signal variability that may exist between different measurement segments. This measurement capability is activated by simply "pausing" the VSA and making the appropriate changes to the instrument settings as required. This feature applies to both live and time-captured signals. Changing instrument parameters without the need to acquire new data provides an excellent opportunity to troubleshoot a signal problem over the same measurement segment. This is especially useful for signals that exhibit non-periodic or burst errors where the signal can be stored into the VSA memory or a time-capture file and examined under numerous instrument settings and displays.

Demodulating a complex signal such as WiMAX can sometimes lead to problems locking to and troubleshooting the signal under test. Demodulation problems may result from problems found in two categories, those associated with an improper setting of the instrument and those inherent to the signal itself. The following troubleshooting information may be useful when problems exist during the initial demodulation setup on the VSA. This troubleshooting information is in addition to the various VSA configurations discussed previously in this application note. It is assumed that basic spectrum and time domain measurements have been successfully made prior to activating signal demodulation.

Uncovering demodulation problems

The following is a partial list of possible problems that may be observed when attempting to demodulate a WiMAX signal for the first time. Demodulation problems may occur due to signal-related problems or an incorrectly configured instrument. Incorrect instrument settings often result in a failure to lock onto the signal and result in a poor constellation trace. If the analyzer's center frequency and span, and input range are set correctly, signal-related issues that create problems during digital demodulation are typically discovered by examining the Symbols/Errors table, Error Vector Spectrum and Error Vector Time traces. This list is not intended to cover all the possible causes for demodulation problems but should serve as a guide into the process for uncovering issues with OFDM demodulation. Please keep in mind that following the well-organized approach to VSA measurements begins with basic time and spectrum analysis (vector measurements). It has been shown [5] that performing vector measurements prior to digital demodulation can provide verification of the quality of the WiMAX signal and ensure that the VSA has been properly configured. These preliminary vector measurement techniques can also be used to uncover signal problems that may create difficulties when demodulating the WiMAX waveform.

Table 2. WiMAX problems and troubleshooting

Problem: Demodulation fails to lock on signal
Symptom: Bad constellation trace and very high RCE (EVM), but time & spectrum measurements ok.
Examine: The Sync Corr in the Symbols/Errors table. If the Sync Corr value is close to 1, then it is possible that the "Guard Interval" is incorrectly set.
Solution: Modify the guard interval

Problem: Demodulation fails to lock on signal
Symptom: Bad constellation trace and very high RCE (EVM)
Examine: If measurements are being made on a downconverted signal with the down converter's local oscillator set higher than the RF frequency of the signal under test, then it is quite possible that the frequency spectrum has been flipped or mirrored.
Solution: select the option for Mirror Frequency Spectrum on the Advanced tab from the Demodulation Properties menu.

Problem: Demodulation fails to lock on signal
Symptom: Bad constellation trace and very high RCE (EVM)
Examine: Check the Data Sub-carrier Modulation setting (on the Format tab of 802.16 OFDM Demodulation Properties dialog).
Solution: If it is set to Auto Detect, the signal may be too noisy for auto-detection to work reliably. The FCH or Manual Override settings may be used to work around this problem. If it is set to FCH, the FCH symbol may be incorrect, in which case you should switch to auto-detection. If it is set to Manual Override, it may be specifying the wrong modulation type, in which case you should specify the correct modulation type or switch to auto-detection.

Problem: PULSE NOT FOUND message displayed on the VSA
Symptom: Bad Constellation trace and very high RCE (EVM)
Examine: Verify the setting for VSA Search Length and compare it to an estimate of the length resulting from (2x "on" time plus "off" time). Verify that the VSA is not also using IF Magnitude Triggering (as it might be in spectrum or time domain analysis)
Solution: Increase the search length on the Time tab from the Demodulation Properties menu in order to have one complete pulse observable on the Search Time trace

Problem: Signal is transmitting incorrect pilot bits.
Symptom: RCE (EVM) larger than expected
Examine: The CPE level will be high, both in the Symbols/Errors trace and in the Common Pilot Error trace.
Solution: Turn off the Pilot Timing Tracking, and possibly Pilot Phase Tracking.

Problem: Signal has longer transition gaps between symbols than expected
Symptom: RCE (EVM) larger than expected
Examine: The TTG and RTG timing using a time domain trace.
Solution: Change Symbol Timing Adjustment to be more negative. Symbol timing can be modified on the Advanced tab from the Demodulation Properties menu.

Problem: Signal amplitude varies during burst
Symptom: RCE (EVM) larger than expected
Examine: The Error Vector Time trace to shows an increase in EVM from beginning to end of the burst.
Solution: Turn on Pilot Amplitude Tracking. Pilot tracking is covered in the third application note of this series [6].

Problem: Center frequency of signal not correct
Symptom: Sync Corr value is low, Freq Err is large but RCE is good
Examine: The Freq Err on the Symbols/Errors trace, large frequency errors result when the instrument's center frequency does not match the signals.
Solution: Adjust the center frequency on the VSA.

Verifying the WiMAX signal using a measurement example

Once the vector signal analyzer has successfully demodulated the WiMAX signal, it is then possible to verify the quality of the signal and troubleshoot any inherent problems using the numerous measurement tools available in the VSA. As an example of the process that may be used to measure and verify a WiMAX signal, an UL subframe containing 44 symbols will be examined. This same signal was previously examined and the Constellation trace was shown in Figure 6. This signal was found to contain problems associated with the 64QAM formatted symbols. Assuming that basic time and spectrum measurements appear correct and the VSA is properly configured for 802.16 OFDM demodulation, then the next step is to examine several measurement traces in the time and frequency domains.

A typical demodulation measurement often begins with a 2x2, 3x2, or 2x3 grid showing multiple traces from the same acquired signal. Figure 10 shows a 2x3 grid with the constellation, Error Vector Time, Error Vector Spectrum, Symbols/Errors summary, Spectrum and Subframe Info traces selected. As noted earlier, the constellation shows errors for the 64QAM modulation that could be the result of compression, limiting, or scaling problems in the transmitter. The Symbols/Errors summary shows that the RCE (EVM) is 3.8 percent and peaks over 14 percent. These values appear quite high and in addition, the large difference in value between the total RCE and peak RCE leads one to believe that the problem does not exist across the entire subframe.
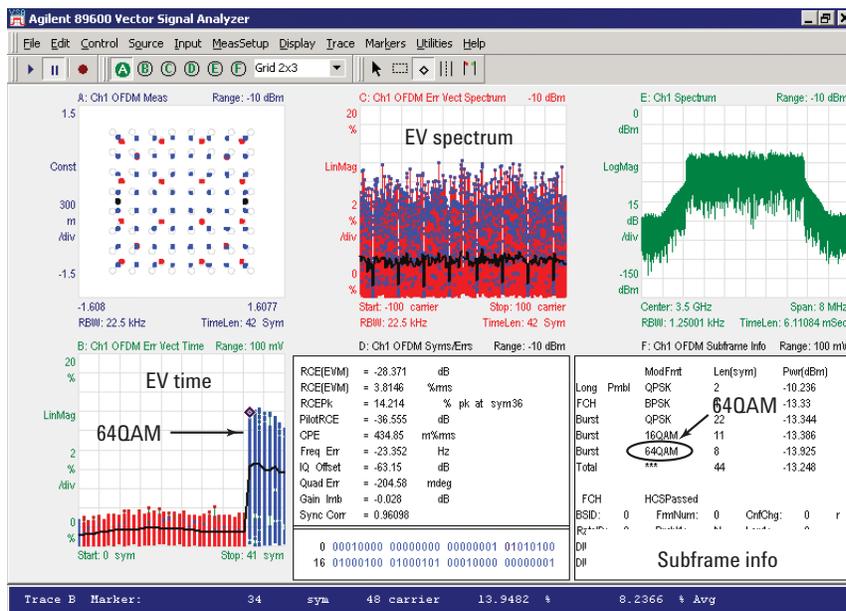
Figure 10.

The PilotRCE and CPE are both low in value implying that the BPSK modulated pilots distributed throughout the entire OFDM subframe are good. The remaining values on the summary table are also good verifying that the preamble, frequency settings, and IQ modulation are correct and working as expected. The Error Vector Spectrum shows a higher level of EVM for the 64QAM formatted symbols, which confirms the errors found on the constellation measurement.

Color-coding on this spectrum trace provides visual markers for the different types of modulation shown. For this trace, the BPSK, QPSK, and 16QAM formats show peak EVM values that are one-fifth of the values found for the 64QAM modulation. As the peak EVM values remain approximately the same across all the subcarriers on the spectrum trace, then it can be assumed that there is not a frequency specific problem, such as spurs, present in this signal.

At this point, it is difficult to determine the cause of the high EVM solely from this trace. Fortunately, the complement to the spectrum trace, namely the Error Vector Time trace, tells a much different story. The Error Vector Time trace in Figure 10 shows that the EVM increases dramatically at the end of the burst. Color-coding on this trace quickly shows that only the 64QAM symbols experience high EVM peaks and that these peaks are approximately uniform across all the 64QAM symbols. The uniformity in the EVM over the 64QAM symbols implies that impulsive effects such as power supply transients are not the cause for the large errors. In addition, the BPSK pilot symbols are not affected during these symbol-times, which means that the problem is probably not an IQ modulator or compression issue. The first symbol index for the 64QAM time segment can be measured using the basic marker function and is found to occur at symbol 34. This symbol also contains the peak EVM value as displayed on the Symbols/Errors trace.

Lastly, identifying the root cause of the error requires examination of one more trace. Here, the Subframe Info trace shows a listing of the modulation format, length, and power level of the individual bursts that make up a subframe. The Subframe Info trace in Figure 10 shows that the power levels for the FCH, QPSK burst, and 16QAM burst are all approximately –13.3 dBm. In comparison, the power level for the 64QAM burst is lower by 0.6 dB and measured to be –13.9 dBm. As it was previously determined that compression was not a concern, then the most likely cause for the error is due to scaling problems within the DSP.

To confirm if the proposed DSP scaling problem is a linear function, the VSA software also provides user-definable Math Functions that operate on trace data. In this case, the trace data can be multiplied by a constant in order to verify that the 64QAM constellation points scale to the proper locations on the IQ plane. Before creating the math function, it would be beneficial to reduce the length of trace data to cover only the 64QAM symbol portion of the subframe. Using the Measurement Offset and Measurement Interval features found on the Demodulation Properties menu (Time tab), the Constellation trace is centered over the last 8 symbols in the subframe.

In this case, the Measurement Offset is set to the beginning of the 64QAM burst, which was previously found to be at symbol-time 34 using the marker function. The Measurement Interval is set to the length of 8, which covers the last part of the subframe. All the displayed traces should now reflect measurements using a length of 8 symbol-times. A math function can now be created which applies a linear multiplier to the IQMeas data. By experimentation, it was found that multiplying the IQMeas trace by a value of 1.08 provides a good Constellation trace for the 64QAM data. Figure 11 shows the improved constellation plot using the Math Function. This verifies that the DSP scaling problem found in this signal is a linear function for 64QAM data. Note that this manual change in scaling has caused an error in the amplitude of the BPSK pilots.

As discussed, verifying and troubleshooting a WiMAX signal in the demodulation mode often requires viewing measurements in multiple domains. The flexibility of the vector signal analyzer's measurement capability provides a powerful tool when designing WiMAX components and systems.
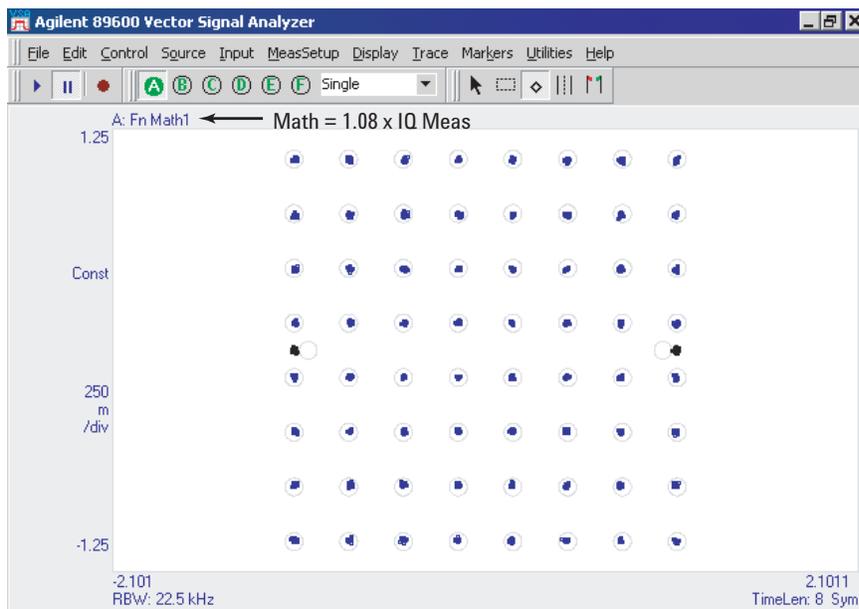
Figure 11. Improved Constellation trace for a WiMAX signal with poor DSP scaling for the 64QAM format

Glossary

OFDM   orthogonal frequency division multiple
OFDMA orthogonal frequency division multiple access
MAC   medium access control
TDMA   time division multiple access
TDM   time division multiplexing
TDD   time division duplex
FDD   frequency division duplex
H-FDD   half-duplex frequency division duplex
BPSK   binary phase shift keying
QPSK   quadrature phase shift keying
QAM   quadrature amplitude modulation
IEEE   Institute of Electrical and Electronics Engineers
BS   base station
SS   subscriber station
TTG   transmit/receive transition gap
RTG   receive/transmit transition gap
BWA   broadband wireless access
MCM   multi-carrier modulation
PHY   physical layer
FEC   forward error correction
LAN   local area network
MAN   metropolitan area network
NLOS   non-line-of-sight
LOS   line-of-sight
RS   Reed-Solomon block code
CP   cyclic prefix
DL   downlink (base station to subscriber transmission)
UL   uplink (subscriber to base station transmission)
FCH   frame control header
BER   bit error rate
PMP   point-to-multipoint
RCE   relative constellation error
EVM   error vector magnitude
CPE   common pilot error
DLFP   downlink frame prefix
HCS   header check sequence
DIUC   downlink interval usage code
DCD   downlink channel descriptor
STC   space-time coding
AAS   adaptive antenna system
ISI   inter-symbol interference

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