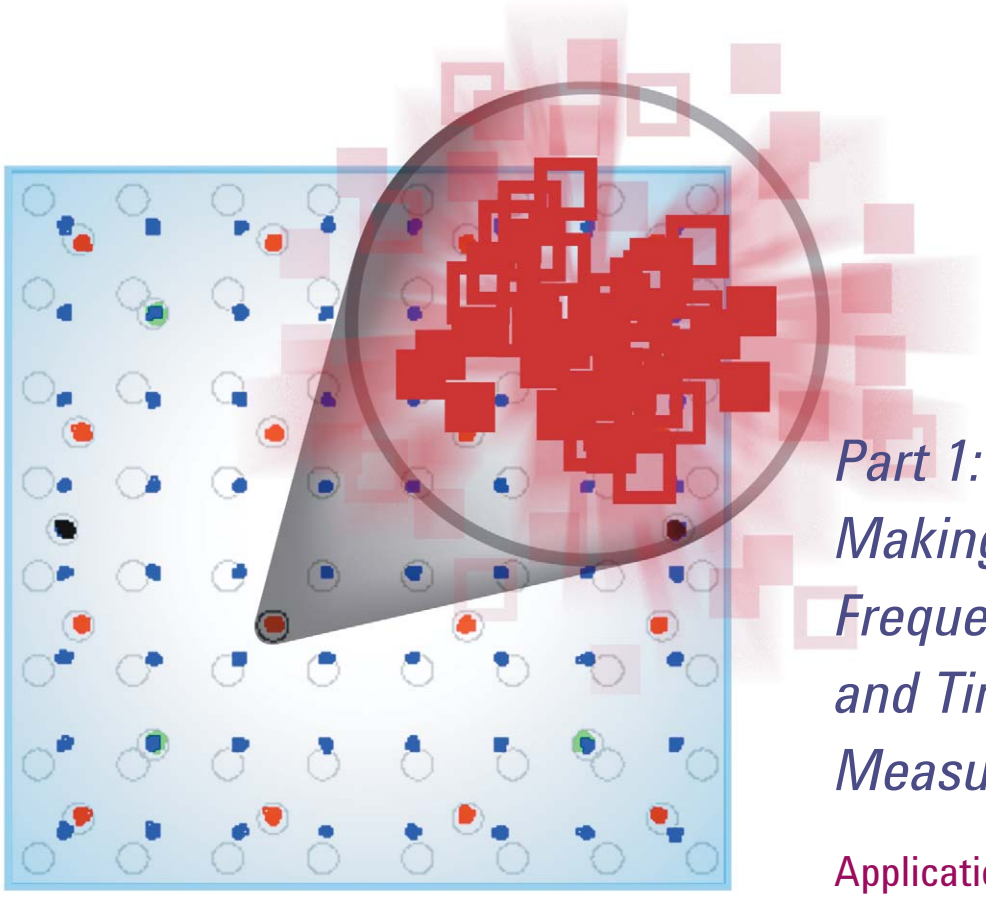
Agilent WiMAX Signal Analysis



Part 1: Making Frequency and Time Measurements

Application Note

Agilent Technologies

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Introduction

This application note is intended for engineers that 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 first part 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 standard [1], often referred to as WiMAX, defines the physical layer (PHY) and medium access control (MAC) protocol for products that extend broadband wireless access (BWA) from the local area network (LAN) to the metropolitan area network (MAN). The standard contains 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 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. When the radio link quality is good, the WiMAX system can use a higher-order modulation scheme (more bits/symbol) that will result in more system capacity. When link conditions are poor due to problems such as signal fading or interference, the WiMAX system can change to a lower modulation scheme to maintain an acceptable radio link margin. The allowed modulation types are binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16 quadrature amplitude modulation (16QAM) and 64QAM [3].

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) 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 receiver/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]. A typical WiMAX frame is shown in Figure 1. This figure shows the time domain response of the DL and UL subframes. It also shows the TTG and RTG spacing between the subframes.

Long and short preambles

The downlink 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 uplink 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 is 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 symbol time, Tb (Tb = 1 ÷ carrier spacing), and the guard interval, Tg. The guard interval or cyclic prefix is a copy of the end of the symbol appended to the beginning. The guard interval is used to collect multipath and improve system performance [1].

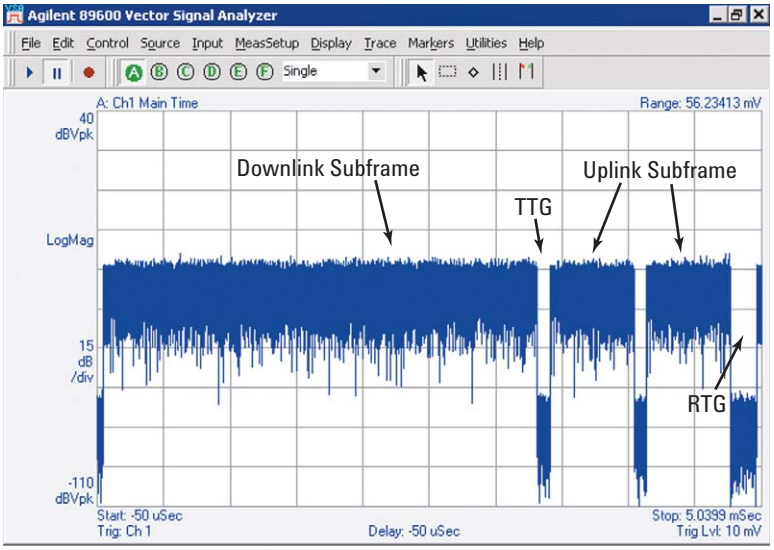

Figure 1. Time domain response of a WiMAX frame including downlink subframe, uplink subframe, transmit/receive transition gap and receive/transmit transition gap.

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. These DSP-based signal analyzers provide FFT-based spectrum analysis, wideband flexible vector demodulation, and scope measurements on RF signals. The number of potential measurement types and analysis configurations available within the VSA is extremely large. Properly selecting measurement configurations specific to WiMAX signal analysis will improve the process to successful and reliable testing. The measurement approach detailed in this series of application notes begins with basic spectrum and vector analysis using frequency and time domain measurements. These basic measurements will verify many WiMAX signal parameters such as center frequency, channel bandwidth, carrier spacing, amplitude levels, transient behavior, frame and subframe lengths, and TTG and RTG durations. A great deal can be learned about digitally modulated signals before digital demodulation analysis is employed and this application note will detail the steps to successful spectrum and vector measurements using the vector signal analyzer.

Measuring the Frequency Spectrum

The VSA can perform spectrum analysis using either a scalar measurement, also called stepped FFT measurements, or a vector measurement. Scalar measurements provide amplitude-only information over the full frequency range of the instrument. Vector measurements provide both phase and amplitude information over the processing bandwidth of the instrument. For example, the Agilent 89641A (part of the 89600 Series VSAs) can perform scalar analysis from DC to 6 GHz (and up to 50 GHz using a PSA Series spectrum analyzer in place of the 89641A VXI hardware) and vector analysis over a 36 MHz frequency span. Knowing that the selectable bandwidths of the WiMAX 256-carrier OFDM PHY is within the 36 MHz span for the vector measurement mode, this application note will focus the discussion to vector analysis of the digitally modulated signal.

Acquiring the signal

A vector signal analyzer such as the 89600 Series VSAs typically has two ways to process an RF signal for analysis and display. Measurements can be made on “live” signals or time captured waveforms. All VSA measurements including vector (frequency and time) and digital demodulation can be made on both signal acquisition types.

Measurements from “live” signals can be made directly on the hardware using signals delivered from a WiMAX radio system or component. In this case, the VSA processes the measurement from blocks of digitized time data. The length of the time block is related to the instruments settings such as span and resolution bandwidth (RBW). The instrument settings also determine if the displayed spectrum is processed from contiguous blocks of time data. Real-time bandwidth (RTBW) is a specification used to characterize the performance of analyzers such as VSAs. RTBW is the maximum frequency span that can be continuously processed without missing any event on the input signal. The actual real-time bandwidth achieved varies with the amount of processing time required by the analyzer to calculate the FFT and to perform any other selected operations such as averaging the results, updating the marker calculations, and displaying the data.

Time capture is a second approach to signal acquisition that involves recording a large block of continuous time data into the instruments capture memory. The VSA application lets you record time data from your measurement hardware directly to memory and to your PC's disk drive if desired. You can then play the data back or import it into another application. This technique allows “real-time” analysis of the WiMAX signal at the full-specified bandwidth without any gaps in the time record. Additional details on time capturing and playback will be covered later in this application note.

Once the type of signal acquisition is decided, the VSA can be configured to measure the basic parameters of the WiMAX signal. The high resolution digitized time domain measurement is the most basic type of signal analysis and will provide the foundation for all subsequent measurements including vector and demodulation analysis and signal verification.

Measuring the wideband spectrum

Analysis of a WiMAX signal typically starts with a wideband spectrum measurement. This measurement is used to verify the center frequency, nominal signal bandwidth, amplitude level, and sidelobe level of the WiMAX signal. It is also an opportunity to verify the level of any spurs and other interference signals present in the frequency band that may cause errors during digital demodulation. Verifying the spectral content is typically made using a maximum-hold detection scheme.

For peak amplitude and spurious measurements of the WiMAX signal, the VSA is configured with a large frequency span (perhaps using the scalar measurement mode) and max-hold averaging. Continuous peak-hold averaging is a measurement function used by the VSA to measure and display the largest magnitude (determined over many measurements) for each frequency point in the span. Continuous peak-hold averaging is not really a type of averaging, because the results are not mathematically averaged. But it is still considered a type of averaging because it combines the results of several measurements into one final measurement result. Measurement of low level spurious and interference signals should be performed using a Gaussian window, which provides the highest dynamic range in the measurement. The Gaussian window offers the lowest sidelobe level of any VSA window at slightly reduced amplitude accuracy. Combining peak hold averaging and Gaussian windowing is ideal to ensure that no significant signals are missed either in the band or out.

Lastly, the VSA's input range must also be correctly set in order to obtain accurate measurements. If the input range testing is too low (more sensitive than necessary), the VSA's analog-to-digital converter (ADC) circuitry is overloaded and introduces distortion into the measurement. If the range is set too high (less sensitive than necessary), there may be a loss of dynamic range due to additional noise. If the wideband spectrum for the WiMAX test signal appears acceptable, the instrument can be re-configured for the next analysis step, which is a narrowband spectrum measurement.

Measuring the narrowband spectrum

For narrowband spectrum analysis of the WiMAX signal, the instrument's frequency span should be approximately set to 1.1 times the nominal bandwidth of the signal. Alternately the span can be configured to match the bandwidth of a typical WiMAX front-end filter. Using a frequency span close to a typical receiver's RF bandwidth allows the VSA measurements to be performed with similar input noise and interference levels as would be seen in practice. Narrowband measurements also provide improved frequency resolution and greater accuracy in setting the center frequency of the instrument or verifying the center frequency of the signal under test. The improved frequency resolution results from the inverse relationship between span and RBW [5].

Accurate amplitude measurements of the WiMAX signal are required for system verification, troubleshooting, and compliance with local regulations. Amplitude measurements as a function of frequency for these noise-like signals should be performed using RMS (video) averaging and RMS detection. The detection mechanisms in the VSA are always RMS. The VSA calculates the frequency spectrum using a Fast Fourier Transform (FFT) that directly results in the true RMS power of the signal whether it is a single tone, noise, or any complex signal. RMS averaging produces a statistical approximation of the true power level over the measured time record(s), which includes on/off times and the transient effects of the bursted WiMAX signal.

Time-variant signals such as WiMAX often require spectral analysis over a smaller portion of the entire waveform, for example, during a subframe. In this case, the measurement needs to be stabilized using the trigger control in the VSA. Triggering the VSA can easily be accomplished in vector mode and the details will be provided in the next section of this application note.

The importance of triggering for a time-variant waveform can be seen in Figure 2, which shows the difference between the spectrum of a WiMAX signal when the instrument is not triggered (upper display) and when it is triggered (lower display). The sidelobe levels for the untriggered response rapidly change from individual measurement to measurement as the spectrum measurement is made on different parts of the time-variant waveform. In comparison, the triggered response maintains the spectral shape as the instrument is triggered at the beginning of each OFDM frame. Both measurements were made with the averaging disabled. Both measurements are accurate, but the change in trigger conditions changes the portion of the signal that is measured.

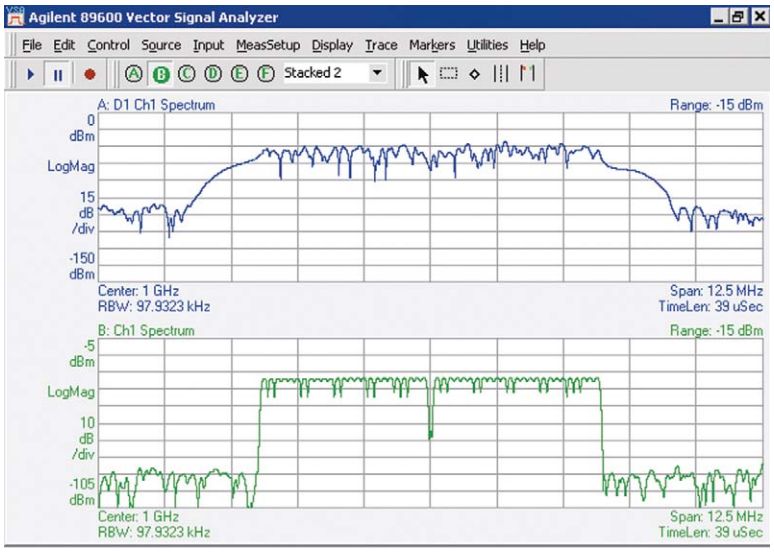

Figure 2. Frequency domain response of a WiMAX signal without using an instrument trigger (upper trace) and using a trigger set to the beginning of the downlink frame (lower trace).

Linking Time and Frequency Using Vector Analysis

Traditional spectrum analysis alone does not provide enough information when analyzing the complex, time-variant nature of the WiMAX signal. Because these signals contain both magnitude and phase information, verification and troubleshooting of the waveform require vector signal analysis. In addition, the OFDM waveform is directly related to the time domain response through the inverse-FFT process. For this case, measurements made in both the frequency and time domains are necessary to cover the broad range of required measurements.

Vector analysis on the VSA begins with the process of digitizing the input RF signal and performing quadrature detection of the complex signal in the DSP. The in-phase (I) and quadrature phase (Q) time domain samples can be processed into a variety of formats and displayed as a time domain waveform. This time-record of digitized data can be further processed using an FFT to display the associated frequency response. A time-record consists of all the time-domain samples that go into the FFT. The outputs from the FFT are the frequency-domain samples referred to as measurement points. For RF vector measurements, the output of the FFT yields as many measurement points as there are time-domain I/Q sample pairs. The time-record and its FFT are the building blocks for all subsequent measurements.

The power of vector analysis is most evident when frequency and time domain measurements are linked, a natural process for the Agilent vector signal analyzers. Many features can be combined in these measurements such as linked frequency and time displays and measurements, triggering (both live signals and recordings), variable block size and time resolution, band power markers, and time-gated spectrum measurements.

Finding frames and triggering measurements

Composite signals such as the WiMAX OFDM waveform can be challenging to measure accurately in both time and frequency. Due to time-varying characteristics such as unequal bursts, unequal off-times, and changes in the statistics of amplitude variations due to different types of modulation, time-domain triggering and/or time-capture are often used in order to achieve a stable measurement for analysis. Time capturing a signal to memory does not require any instrument trigger and allows you to progressively step through the measurement in time until an appropriate record is found for analysis. Time-domain triggering is a powerful, easy to use feature on the Agilent 89600 Series VSAs. It operates much like that of an oscilloscope, which provides positive or negative trigger delay and trigger hold-off. These trigger functions can be used on both live and recorded signals.

The flexibility of time domain triggering provides all the necessary capabilities required for verification and troubleshooting digitally modulated signals such as WiMAX. In certain specialized applications, such as spectrum monitoring and surveillance, it may be necessary to trigger a measurement based on a frequency domain response. For these specific measurements, you can use the Agilent E3238S/35688E Signals Intercept and Collection System .

When first examining the pulsed characteristics of the WiMAX signal, it is often necessary to adjust the time record length in order to see the entire frame or several frames within the waveform display. A very large number of data points are often necessary to obtain a sufficient time record length while maintaining adequate measurement bandwidth [5]. The number of time points is likely to be much larger than would be needed for an adequate spectrum display. The time tab on the VSA contains an auto time resolution feature that causes the VSA to automatically reduce or increase the frequency span if the value of main length exceeds that allowed by the current span. The auto time resolution defaults to "*off*" and should not be used in these measurements because it will likely reduce frequency span below the bandwidth required by the WiMAX signal under test. There is no automatic feature to change the number of points in vector analysis (though it exists in digital demodulation) and so the appropriate number must be selected manually. For WiMAX, the typical number of points should be between 12,801 points and 51,201 points, though it can be set much higher if desired, to measure multiple frames.

A time-domain display using a large number of points and showing 1 to 2 frames can be used to measure the subframe lengths and transition gaps. These measurements can also be used to verify the measured OFDM frame duration against the IEEE 802.16-2004 standard. As a measurement example, Figure 3 shows the frequency and time domain response of the WiMAX signal using 51,201 measurement points with a time record length of 6 ms. The upper trace shows the frequency response of the WiMAX signal calculated from the complete time-record shown on the lower time domain trace. The lower trace shows one complete OFDM frame consisting of one DL and two UL subframes. The offset marker function is used to measure the gap time at the beginning of the DL subframe. This gap represents the RTG, and is measured to be around 200 µs for this waveform. It also shows that the gap for the TTG is approximately half the duration of the RTG. Using the offset marker function centered on the TTG, this gap is measured to be 100 µs. These two gap times will later be used to properly set the trigger hold-off in order to stabilize the VSA measurements. In addition, triggering the VSA at specific time intervals within the WiMAX waveform will require setting the trigger type and magnitude level. Once the VSA is properly triggered, analysis of different parts within the waveform can then be made using the trigger delay function of the instrument. On the next page is a summary of the various trigger functions for the VSA. Additional information on the trigger settings and software interface can be found in the Agilent 89600 demonstration guide and application note for WiMAX signal analysis [6].

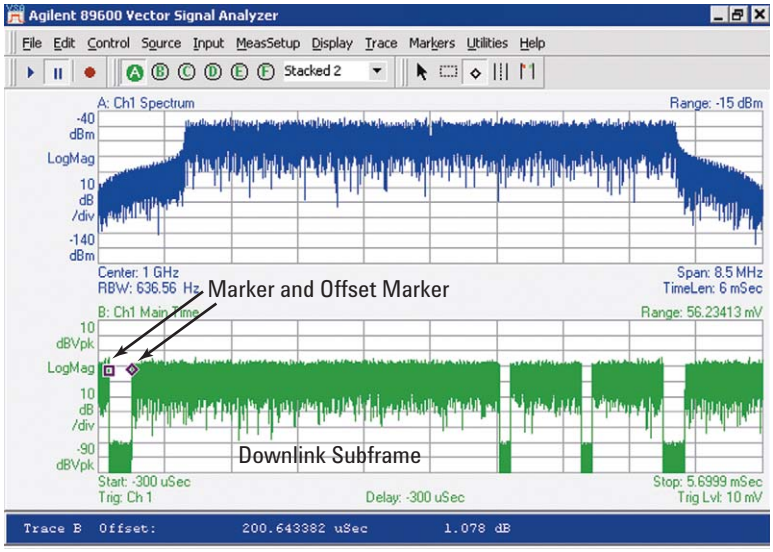

Figure 3. Measurement of RTG time using marker functions. Upper trace shows the frequency response of the displayed time domain record (the lower trace).

Selecting the trigger type

The IF Mag and Magnitude type triggers are unique because they are both level and frequency qualified triggers based on the actual signal. These trigger types only trigger when the signal is both large enough and within the specified frequency span. The IF Mag and Magnitude trigger are typically used with amplitude modulated (AM) or burst signals such as the WiMAX formatted signal. For live measurements the trigger should be set to IF Mag. For recorded signals, the playback trigger should be set to Magnitude.

Finding the trigger level

The trigger level is typically set (in linear voltage units) to a percentage of the total signal range. One way to determine this level, prior to triggering, is to examine the time domain waveform in a LinMag format. A level setting that is 10 to 50 percent of the approximate voltage maximum is a good start for bursted signals. This assumes that the voltage is close to zero during the "*off*" times in the waveform. Note that once the trigger level is determined, changing the format back to LogMag for subsequent time domain measurements provides the most useful display for the RF engineer wishing to examine the RF envelope of this bursted signal.

Optimizing the trigger hold-off

Trigger hold-off allows the analyzer to ignore trigger signals for a specified period of time. The measurement will not occur until after the hold-off time has passed and a valid trigger is found. Trigger hold-off is used with IFMag and Magnitude trigger types for live and recorded signals respectively. The hold-off function is particularly useful for pulsed or bursted signals that also have amplitude variations due to modulation, since these variations would cause undesired triggers without the use of hold-off..

Using the example from Figure 3, the VSA can be triggered on this WiMAX signal using a hold-off that is shorter than the measured RTG and longer than the TTG duration. For this waveform, the RTG was measured as 200 µs and the TTG was 100 µs. Using a hold-off between these two values, such as 150 µs, would trigger the VSA at the start of the DL subframe just following the RTG. In this case, the VSA would provide a stable measurement display in both the time and frequency domains. Inappropriately setting the hold-off on the measurement from Figure 3 to less than 100 µs would result in the instrument alternating the trigger between the start of the DL and the two UL subframes. This shortened hold-off is not adequate to properly stabilize the VSA and would result in measurement difficulties. Hold-off times longer than 200 µs for the example in Figure 3 would result in the instrument not being triggered at all.

Introducing a trigger delay

Trigger delay allows detailed measurements of specific parts of the signal. If trigger delay is zero, the VSA takes data immediately after the trigger conditions are satisfied and then processes the results. If trigger delay is positive, called post-trigger delay, the VSA waits the delay amount before data is acquired. The post-trigger delay allows the VSA to begin the measurement at any time into the waveform, for example, at the beginning of the first uplink frame. A trigger delay that is negative, called pre-trigger delay, allows measurement of the rising edge of the RF burst including any transient effect that may occur prior to the trigger.

Stabilizing the displayed measurement using the trigger functions allows you to verify and troubleshoot the WiMAX signal using time and frequency domain analysis. For example, by measuring signal level changes such as amplitude droop in the time domain or flatness and ripple effects in the frequency domain, you may uncover thermal problems in the amplifiers power stages or improper analog or digital filtering respectively. Unexpected frequency tilt and poor center frequency accuracy may be the result of poor component or synthesizer performance. Turn on and turn-off transients may create demodulation errors in the WiMAX receiver. These may seem like relatively basic measurements, but a significant number of system problems can be traced to these behaviors. Such problems may come from analog or digital circuits, or interactions between them. Linking time and frequency measurements with proper triggering can provide a high level of confidence in the signal quality before any digital demodulation takes place.

Measuring bandwidth and band power

Vector measurements are valuable for verifying many characteristics of the WiMAX signal that may not be obvious during digital demodulation measurements. For example, it is important to verify that the power levels within various portions of the frame conform to the IEEE 802.16-2004 specifications. Also it is necessary to confirm that the occupied frequency bandwidth falls within the local regulatory requirements. Indeed, in many cases these basic measurements may reveal problems in the WiMAX signal that digital demodulation may fail to uncover.

Measuring the power of any modulated signal cannot be accomplished at one frequency or time data point. These measurements require the integration of the frequency or time domain data over a specified band. The occupied bandwidth and band power marker functions can be used to determine the power over a percentage or subset of the total displayed measurement.

Measuring the occupied bandwidth

The occupied bandwidth (OBW) marker allows you to easily perform generic occupied bandwidth measurements. The OBW measurement determines the band of frequencies that contain a specified percentage of the total power within the measurement span. OBW measurements are only available on frequency-domain displays. As a measurement example, Figure 4 shows a measurement of a 256-carrier OFDM signal. The upper trace is the frequency response for this WiMAX signal. Using the OBW marker function, the calculated bandwidth (set to 99.5 percent of the total span power) is shown to be 6.25 MHz at an integrated power level of –14.67 dBm. For this waveform, the OFDM carrier spacing was set to 31.25 kHz. Knowing that 200 carriers are active in this OFDM signal, the theoretical bandwidth should be 6.25 MHz, which is consistent with the measured result. The middle trace in Figure 4 displays a summary table for the OBW calculations. This table shows that the centroid of the measured signal is 2.65 kHz lower than the center frequency setting on the VSA. The centroid is a power-weighted calculation of the center of the OBW, and is most accurate when averaging is used. A large difference between these two values may reveal problems with the transmitter synthesizer and could result in poor digital demodulation. If necessary, the VSA's center frequency can be easily adjusted to the centroid by using the marker functions.

Using band power markers

The average power of the individual WiMAX signal elements such as a subframe, preamble, FCH, and data symbols can be measured with the band power marker feature. Band-power markers provide a quick way to make power computations in the frequency and time domains. For frequency-domain data, band power is the total power within the selected band with results similar to the automatic OBW calculation. Here the VSA sums the powers of the signal between the band markers and displays the result in the current Y-axis units. For time-domain data, band power is the sum of the powers within the time band divided by the total number of points in the band. As a measurement example, the lower trace of Figure 4 shows the time domain response of the UL subframe and a portion of the following DL subframe. This measurement was created using a large positive trigger delay in order to start the measurement at the beginning of a UL subframe. Band power markers are placed around the UL subframe and the total power in this subframe is calculated to be –14.5 dBm. This technique is very useful when verifying the power level of subframes and symbols and comparing the results to the requirements of the IEEE 802.16-2004 specifications.

It becomes apparent that a compound approach is often required to make accurate and stable measurements. For the above examples, both frequency and time domain measurements were required in order to optimize the measurement for each individual domain. It was shown that proper triggering, including trigger hold-off and delay, were required to stabilize the measurement in order to examine the frequency and time domain response. This stabilization is also useful in some cases to enable averaging for more accurate and consistent results. Lastly OBW and band power markers were added to verify the bandwidth and power of the WiMAX signal under test. The next section of this application note continues with another powerful tool called time-gating, which provides isolation of a portion of a time record for further viewing and analysis in the frequency domain.

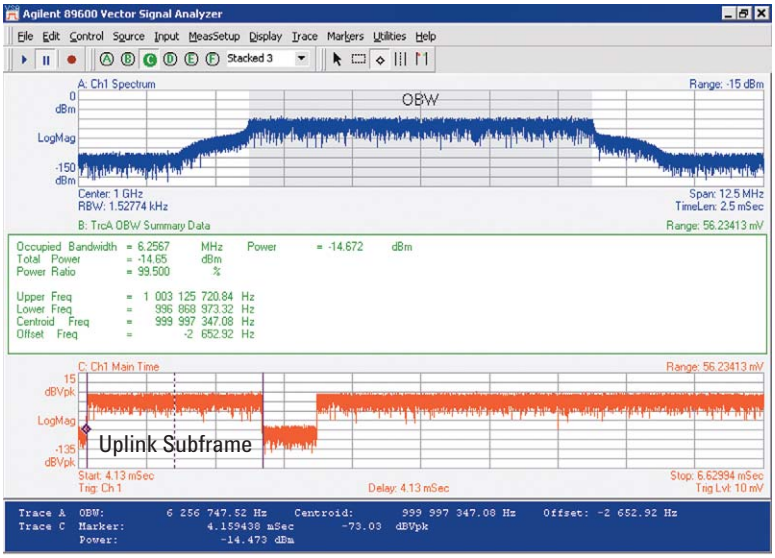

Figure 4. Measurements of the occupied bandwidth and band power of a WiMAX signal. The upper trace shows the occupied bandwidth using the complete time record shown on the lower trace. A summary table for the occupied bandwidth measurement is shown on the middle trace. The lower trace shows a power measurement for the uplink subframe using the band power marker function.

Gating the Time Waveform

The characteristics of the WiMAX signal have closely linked amplitude and frequency behaviors that can vary at different times during the RF burst. For example, the active sub-carrier frequency spacing is different between the first and second preamble symbols of the DL subframe. Also, the amplitude statistics of the waveform changes between the preamble and the data portions of the subframe, likely leading, for example, to different amounts of amplifier compression. It is necessary to measure these characteristics in order to verify the signal quality and uncover any problems that may exist in these waveforms.

To examine the frequency and power statistics of individual portions within the subframe or symbol, the VSA provides a flexible and precise function called time gating. The time gating function is used to select a subset of the main time-record to be used for frequency-domain displays and CCDF, PDF, and CDF measurements. The term main time-record identifies the entire time record; the term gate time-record identifies only the portion of the main time record that is selected by the gate markers. When time gating is active, the analyzer uses only the gated time-record for all frequency-domain displays. As a measurement example, the upper trace of Figure 5 shows the frequency response of the first preamble symbol within the DL subframe. For this trace, the time-gate was positioned over the first portion of the subframe by using the vertical markers on the time domain response (lower trace). This positioning can be performed graphically by drawing an area with the computer mouse or by entering specific numeric values. The spectrum display (upper trace in Figure 5) shows the 50 active carriers used by a WiMAX receiver for coarse signal acquisition and initial equalizer setup. These 50 sub-carriers are transmitted on every fourth OFDM carrier frequency out of the 200 possible carriers. The center carrier is not used as determined in the IEEE 802.16-2004 specification. The active carrier peak amplitudes are approximately the same providing the mechanism for estimating the channel frequency response. The upper trace in Figure 5 also shows a measurement of the corner frequencies using the offset marker function. The offset marker shows a frequency difference of 6.25 MHz. This same value was previously determined using the OBW calculation. Time-gated spectrum measurements can often uncover signal problems created by the DSP section of a WiMAX transmitter. Measuring the carrier spacing, amplitude levels, center frequency feed-through, corner frequencies, and spectrum symmetry of the individual symbols can often reveal many DSP-related problems.

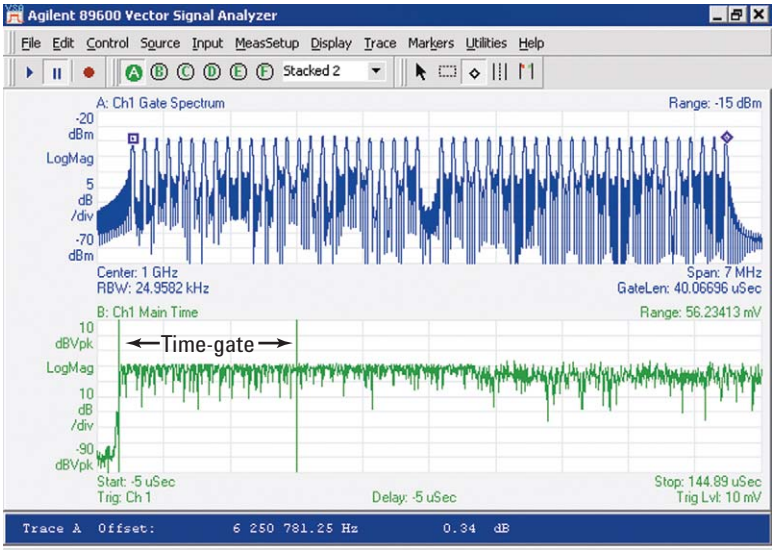

Figure 5. Time-gated spectrum measurement of the first preamble in a downlink subframe. The upper display shows the 50 active carriers of this preamble.

Optimizing frequency resolution

It is important to mention that the resolution bandwidth for spectrum measurements cannot be independently adjusted using time-gating because the resolution bandwidth is determined by the length of the gate time-record, not the main time-record. Longer gate time-records provide higher resolution in the frequency domain. Because the symbol length is set by system design and the carriers are close together, it may be important to optimize the frequency resolution when using time gating. Optimization is provided by a set of time-gate "*windows*" that provide tradeoffs between amplitude accuracy, dynamic range, and frequency resolution. The highest frequency resolution is achieved using the "*uniform*" window type. This window type has an equivalent noise bandwidth (ENBW) equal to 1 Hertz-second (Hz-sec). The actual frequency resolution is determined by the resolution bandwidth (RBW) setting. The RBW is proportional to the ENBW and inversely proportional to the time record length (T), thus (RBW = ENBW / T). This calculation can be used for gated and non-gated measurements. Using the measurement example from Figure 5, the gate-time was set to the symbol length of 40 µs. In this case, the RBW equals 25 kHz, which is the highest frequency resolution that can be achieved using this record length and uniform window type. As shown in Figure 5, it is easy to see the 50 individual active carriers of the first preamble because they are spaced by 125 kHz (6.25 MHz ÷ 50). The use of the uniform window also allows for the measurement of individual carriers in the second symbol of the downlink preamble, where twice as many carriers (100) are transmitted and they are therefore twice as close together in frequency. Traditional Gaussian and flat-top window shapes (RBW filters) would not allow this.

Graphing amplitude statistics

The basic, complementary cumulative density function (CCDF) measurement is just one of the statistical-power calculations that can be performed on a time domain signal. CCDF curves can be used to completely specify the power characteristics of the signals that will be mixed, amplified, and decoded in the WiMAX system. Understanding the power characteristics at each stage in a system allows engineers to design and specify components that meet the stringent performance requirements and to focus cost and effort where it will be the most beneficial. For example, power control algorithms are implemented at the SS so that all the uplink subframes are received at equal power levels at the BS. This dynamic power control may create compression or expansion of the signal at the SS due to non-linearities in the components. Measurement of the CCDF curves under various power levels, both statically and dynamically, may reveal problems in the radio design and may allow the best choice of amplifier operating point to achieve the desired performance. The VSA graphs the CCDF using units of percent for the y-axis and power (dB) for the x-axis. Power on the x-axis is relative to the signal's average power, so the x-axis value of 0 dB is actually the average power of the signal. Therefore, a marker readout of 2 dB/12 % means there is a 12 percent probability that the signal power will be 2 dB or more above the average power.

Time gating CCDF measurements provide a technique for measuring the amplitude statistics within portions of the frame. Modulation types and average power levels vary for different subframes and symbols contained in the WiMAX waveform. For example, Figure 6 shows the CCDF curves for different symbols within the UL subframe. Two separate time-gated CCDF measurements are overlaid for comparison (this overlay display is easily performed by the VSA software). Also shown is an additional reference curve showing the CCDF of additive white Gaussian noise (light gray curve). The CCDF curve on the right that closely approximates the Gaussian curve is a measurement of the time-gated data symbol. As expected, because of the large number of independent carriers, the UL data symbols should provide a near Gaussian distribution of peak to average power. Here the average level is measured to be –14.8 dBm. The left curve is the time-gated CCDF measurement for the preamble symbol of the UL subframe. This curve shows that the peak signal level does not statistically reach levels much higher than 3dB above the average. It is known that the preamble for the UL is a 100-subcarrier OFDM signal that is used for synchronization and equalization at the BS. The QPSK modulated data of this preamble does not change and should not provide a large variation in peak-to-average statistics as shown in the figure. The average signal level for the preamble is measured to be –11.7 dBm, which is approximately 3 dB higher than the data symbol. The 3 dB higher power level of the preamble is specified in the IEEE 802.16-2004 standard. The CCDF measurement provides a powerful tool for determining the types of peak power levels that the system components may experience. Figure 6 shows that there is a very small probability (< 1 percent) that the preamble's peak signal level will exceed –8.7 dBm (–11.7 dBm + 3 dB) but in contrast, the data symbol has approximately a 1.7 percent chance of reaching this same power level (–14.8 dBm + 6.1 dB). It is very important that the engineer understand the peak-to-average levels so that adequate margin can be designed into the components. These basic types of measurements are invaluable when verifying and troubleshooting the quality of WiMAX systems and components.

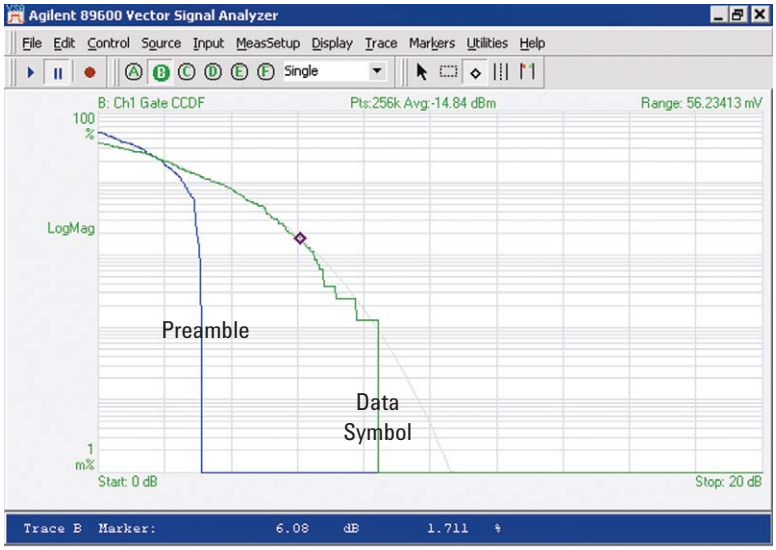

Figure 6. Time-gated CCDF measurement of the uplink preamble (left curve) and the uplink data symbol (right curve). Also included is the theoretical CCDF for Gaussian noise.

Capturing Signals In Real-time

In general, vector signal analyzers are not real-time receivers but rather they are block-mode receivers. They capture a time record, process and display the result before capturing the next block of data. Typically the processing and analysis time is longer than the capture time so there may be a gap between the end of one time record and the beginning of the next. Those gaps in time imply that the VSA is not a real-time processor. This also applies to a VSA that is configured to trigger on an event such as the change in the amplitude at the beginning of a burst. It may take the VSA longer to process the current record than the time it takes for the next trigger event to occur. Here again, the VSA is not operating in real-time.

Fortunately, many vector signal analyzers, such as the 89600 VSA, provide a way to get real-time measurements for a limited length of time by using a time capture or recording of the input waveform. Time capturing allows the storage of complete time records with no time gaps produced in the record. The time capture is performed prior to data processing and once the waveform is captured, the signal is played back for analysis. The 89600 VSA captures the time record directly from the measurement hardware and stores the record in memory for immediate analysis and for later transfer to the disk drive of a personal computer. Capturing the time record has the added benefit that the same signal can be analyzed over many different combinations of instrument settings including all the time and frequency measurements discussed in this application note. One benefit of starting with a good set of vector measurements is the ability to choose a time capture length that is long enough for complete analysis, but not so long as to cause slow transfer due to excessively large capture files.

Finding Patterns In a Spectrogram

A spectrogram is a unique way to examine frequency, time, and amplitude on the same display. The spectrogram shows the progression of the frequency spectrum as a function of time where color or gray scale represents the amplitude of the signal at both a specific frequency and a specific moment in time. In a spectrogram, each frequency trace occupies a single, horizontal line (one pixel high) on the display. Elapsed time is shown on the vertical axis resulting in a display that scrolls upwards as time progresses. Time capture is especially useful for spectrogram measurements providing real-time, gap-free analysis over the length of the captured recording. Spectrograms can be used to find subtle patterns that should or should not be present in the burst. For example, during the two preambles in the UL subframe, patterns should emerge resulting from the various sub-carriers that are either active or nulled. For the data portion of the burst, one would expect to find randomness in the spectrogram display. Figure 7 shows the spectrogram of a 256-carrier OFDM frame. The frame includes one long DL subframe (top portion of the display) and two shorter UL subframes. The bottom of the spectrogram shows the beginning of the next DL subframe. For the measurement in Figure 7, it is apparent that the subframes have a random pattern for most of the subframe except near the beginning. It is here that patterns emerge resulting from the preamble structure of these symbols (see insert in Figure 7 with an expanded time scale). As a troubleshooting tool, it is possible to time-gate the VSA on a certain portion of the frame and examine the frequency spectrum as a function of time. This technique can be used to verify that the preamble or transition gap characteristics maintain the expected pattern structure over the measurement time.

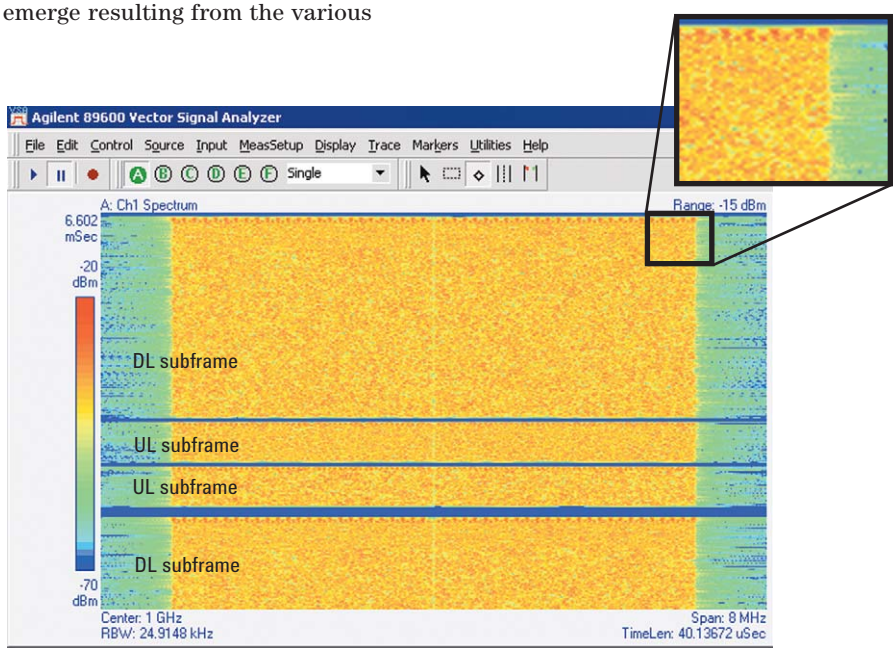

Figure 7. Spectrogram of a 256-carrier OFDM waveform showing one complete downlink subframe and two uplink subframes.

Verifying and Troubleshooting the WiMAX Signal

It has been shown that performing vector measurements can provide verification of the quality within the WiMAX signal. The well-organized approach, beginning with vector measurements provides the groundwork for proper instrument configuration and successful signal analysis. These measurement techniques can also be used to uncover signal problems that may create difficulties when demodulating the WiMAX waveform.

Below is a summary of some of the measurements and signal impairments that can be analyzed using basic frequency and time domain measurements. The associated VSA function or instrument configuration is listed to the left.

Frequency domain analysis	
Bandwidth	marker offset, OBW
Center frequency	OBW
Sidelobe level	marker, peak hold
Spurious	marker, peak hold
Amplitude level and flatness	marker, band power, peak hold
Time domain analysis	
Frame timing	marker offset, triggering
DL subframe timing	marker offset, triggering
UL subframe timing	marker offset, triggering
TTG timing	marker offset, triggering
RTG timing	marker offset, triggering
Symbol timing	marker offset, triggering
Symbol power	band power, triggering
Pulse droop	marker offset, triggering
Turn-on and turn-off transients	marker offset, triggering
Frequency and time domain analysis using time-gated measurements	
All measurements listed above including	
Pilot subcarrier structure	time-gated spectrum, spectrogram
Missing pilots	time-gated spectrum
Carrier leakage	time-gated spectrum, spectrogram
Sub-carrier spacing	time-gated spectrum, marker offset
Spectrum symmetry	time-gated spectrum
Subframe and symbol bandwidth	time-gated spectrum, marker offset, OBW
Symbol center frequency	time-gated spectrum, OBW
Symbol peak-to-average power	time-gated CCDF
Real time analysis	time capture 2 to 10 frames
Oscillator settling time	spectrogram, marker offset
Missing transition gaps	spectrogram
Faulty data modulation	spectrogram with non-random data patterns

Glossary

OFDM - orthogonal frequency division multiplexing
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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