WiMAX– Market, technology and early solutions for the physical layer

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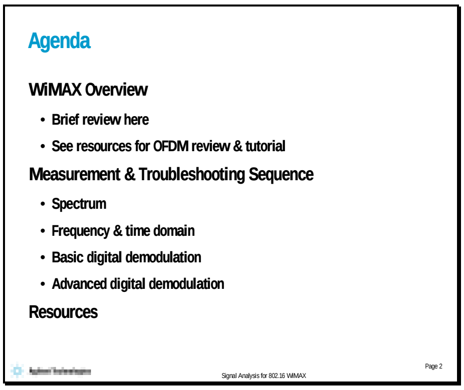
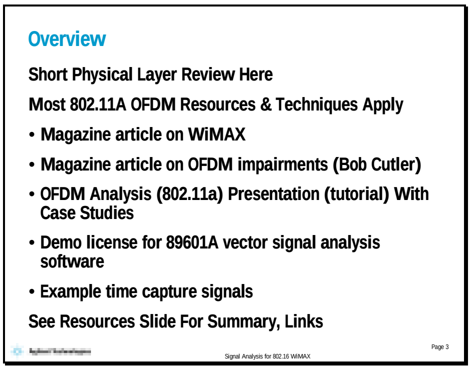
This presentation will cover some of the technical issues and measurements of 802.16 WiMAX signals. A variety of digital modulation analysis measurements and displays will be covered, and a general structure of signal analysis will be presented.

Slide 1



In this presentation some familiarity with OFDM and WiMAX is assumed. The material presented here will be useful to anyone interested in WiMAX signal analysis, but it is not a general or comprehensive review of the WiMAX standard. This presentation is structured around a simple measurement & troubleshooting sequence (the 4 steps shown here), as a way to improve understanding and make the measurement and troubleshooting process more efficient.

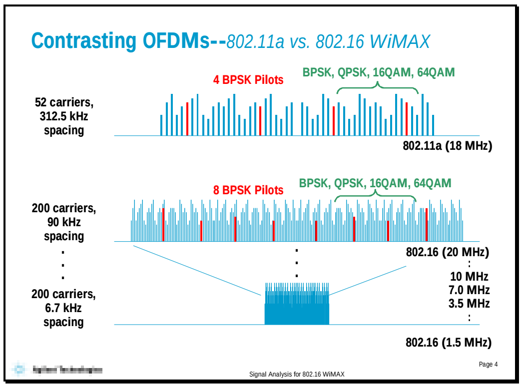
Slide 2



802.11a, a major previous OFDM LAN standard, provides very good background for understanding the new 802.16 standard. Much of what you may have already learned about 802.11a applies here, but the systems are somewhat different and these differences may cause some confusion.

OFDM technologies are increasingly used as the physical layer in major communications standards due to their efficiency in transporting information in typical RF environments with multipath distortion and various sources of interference. However, understanding signal quality and determining the source of signal impairments is more difficult for OFDM signals than for single-carrier modulation techniques

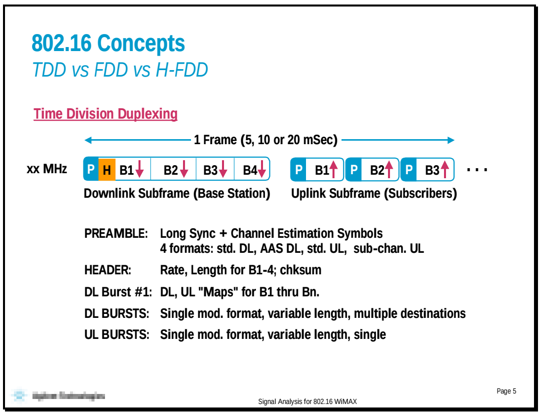
Slide 3



This slide contrasts 802.11a WLAN (Wireless LAN) and 802.16 (WiMAX). In WLAN, 52 carriers are actually used. 48 provide data and 4 provide pilots. In WiMAX, only 200 of the possible 256 carriers are actually used. These are numbered –100 to +100. The centre frequency carrier (#0) is not used. Of the 200 carriers, 192 of these are used for Data and 8 are used for Pilots. WiMAX can be configured to use nominal bandwidth ranging between 1.25 and 20 MHz. The bottom of this drawing shows an example at 1.5 MHz BW where carriers are spaced only 6.7 kHz apart. Contrast this with WLAN where the individual subcarriers are spaced over 300 kHz apart. While WiMAX has significantly more subcarriers and therefore more data in each symbol, it does not have a significantly higher data rate than WLAN. This is because in OFDM, when the carriers become more closely spaced, the symbol period must be increased proportionately to maintain the orthogonality of the individual carriers. The benefit of using more closely spaced carriers, and thus a longer symbol period, is a longer symbol period, which is more resistant to channel impairments such a multipath.

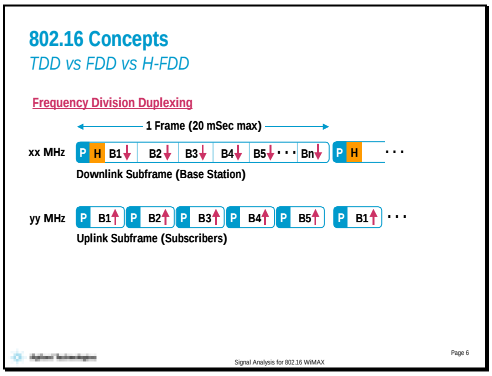
This longer symbol period allows WiMAX to be used more effectively than WLAN over longer distances and in non-line-of-sight applications. For spectral efficiency, WLAN and WiMAX are approximately equal.

Slide 4



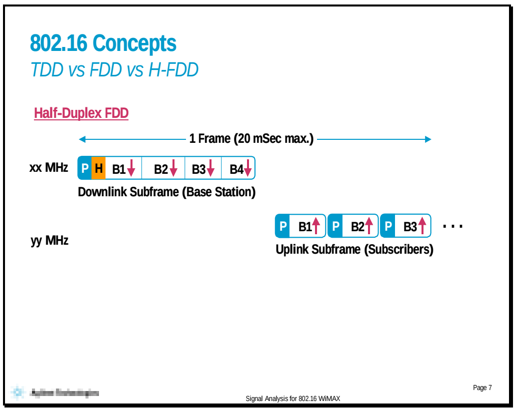
WiMAX systems can be deployed as TDD, FDD, or Half Duplex FDD. This slide shows a typical frame in a TDD configuration where the Basestation and Subscriber Equipment each transmit on the same RF frequency, separated in time. The basestation transmits a downlink subframe, followed by a short gap called TTG, and then the Uplink subframes are transmitted by individual subscribers. The subscribers are accurately synchronised such that their transmissions do not overlap each other as they arrive at the basestation. Following all Uplink subframes, another short gap called RTG is allocated before the Basestation can again start transmitting. Note that each uplink subframe is preceded by a preamble. This is called a “short preamble” and allows the basestation to synchronise on each individual subscriber. The downlink subframe is covered in significantly more detail in the upcoming slides.

Slide 5



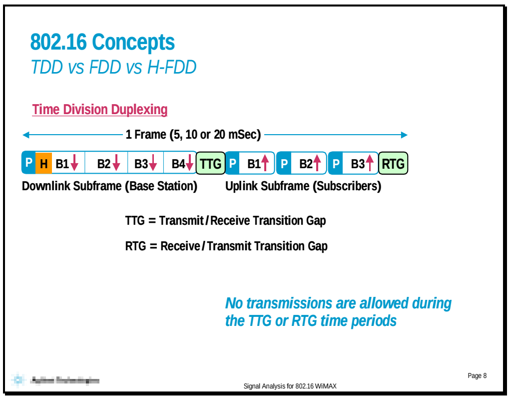
This slide shows a FDD configuration. The downlink and uplink frames are identical to the previous slide, however they are transmitted on separate RF frequencies and overlap in time. There are no TTG or RTG gaps required.

Slide 6



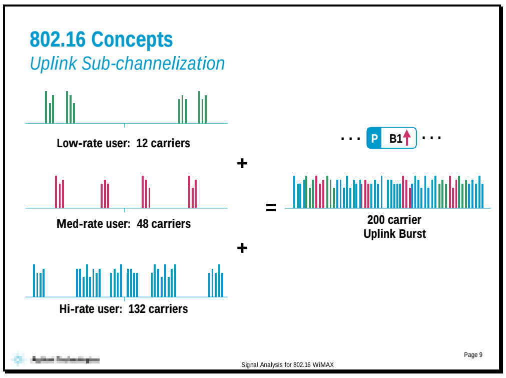
This is half-duplex FDD, which combines the characteristics of FDD and TDD. Notice the basestation and subscriber equipment transmit on different frequencies (like FDD) but they don’t transmit at the same time (like TDD).

Slide 7



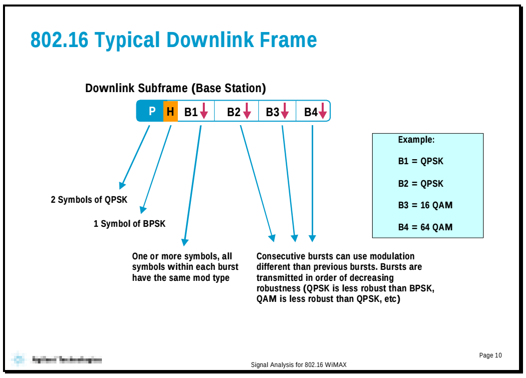
This slide highlights the TTG and RTG gaps that separate downlink and uplink subframes. The purpose of these is to allow equipment to switch between transmitting and receiving (and visa-versa). The switching requirement of the subscriber station is provided by the SS to the BS upon entry to the network. These times are set by the network and are not necessarily required to be the same length. The gaps only are used in TDD systems and is not applicable to FDD or H-FDD configurations.

Slide 8



Subchannelisation is an optional capability that can be supported by subscriber and base stations. One subchannel is 12 carriers. Because WiMAX has 192 active data carriers, there are a total of 16 subchannels . These are allocated in various combinations such that there are 31 different configurations, which can be assigned to a user. In the most basic operation, all 16 subchannels (all 192 carriers) are assigned to a single user. In the most complex configuration with 16 users each assigned 1 subchannel, the downlink symbol would still contain all 192 carriers, but user data for any individual user would only be placed on 12 of the carriers. In the uplink, all 16 users would transmit simultaneously such that their signals all arrive at the BS at the same time with (hopefully) approximately the same power. Clearly this is going to be a challenge to get subscriber stations time, frequency, and amplitude aligned such that the BS can receive, demodulate, and decode information from 16 different transmitters simultaneously. Much of the 802.16 standard is optional. Examples of this are features such as advanced antenna systems, subchannelisation, and turbo coding. This significantly adds to the complexity of the implementation. The remainder of this presentation is primarily focused on required or basic functionality that is implemented in all 802.16 compatible devices.

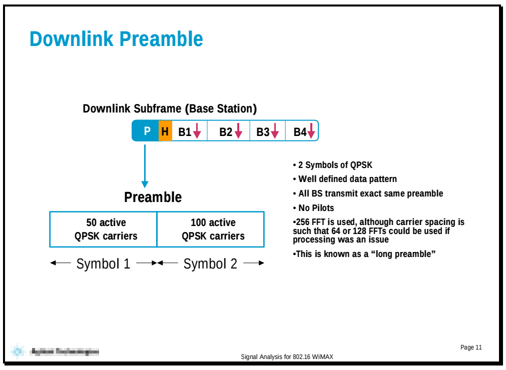
Slide 9



This slide summarises the structure of a downlink subframe. A downlink subframe always begins with a preamble, followed by a header, and one or more downlink bursts of data. These downlink bursts are generally made up of multiple symbols within the burst. Within each burst, the modulation type is constant, however, from burst to burst the modulation type can change. “Robust” bursts such as BPSK and QPSK are required to be transmitted first, followed by less robust modulation types (QAM). The order is BPSK followed by QPSK followed by 16QAM

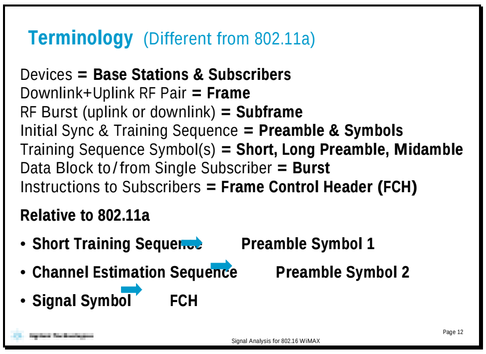
Midambles are sometimes inserted between Data Bursts.

Slide 10



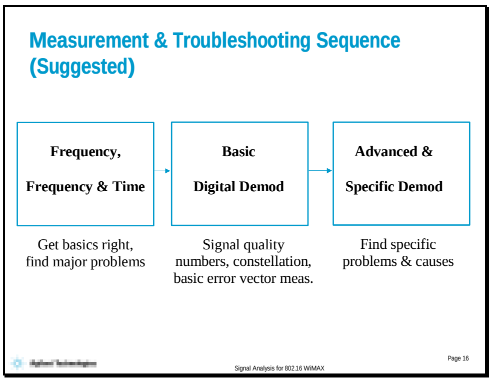
The downlink preamble is always 2 symbols long. The first symbol is composed of every 4^{th} carrier from –100 to +100 (total of 50 carriers). The second symbol is composed of all the even carriers from –100 to +100 (total of 100 carriers). These carriers are all QPSK modulated with a data pattern described in the 802.16 standard. This combination of 2 symbols is known as a “long preamble.”

Slide 11



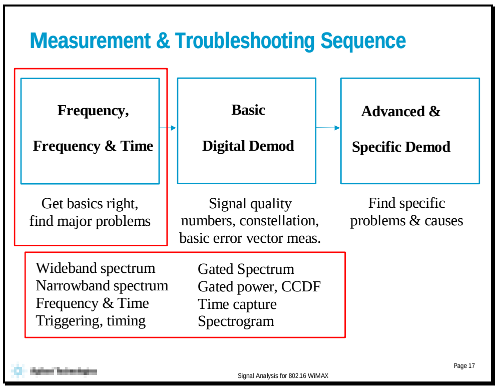
You may not know all of the terminology in the standard, but knowing a few of the major terms will be helpful in discussing test techniques. Discussions involving WiMAX may be a bit more tricky because the obvious technical similarity to 802.11a does not extend to the terms used. Several important equivalent terms are shown here.

Slide 12



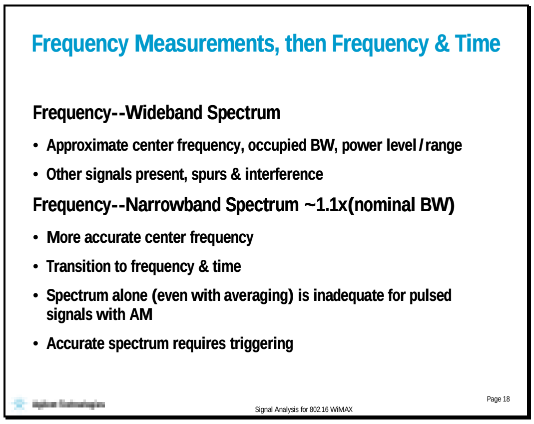
When measuring and troubleshooting digitally modulated systems it is tempting to go directly to digital demodulation and the measurement tools provided in that mode. We have learned that it is usually better to follow a measurement sequence instead; one that begins with basic spectrum measurements and continues with vector (combined frequency and time) measurements before switching to digital modulation analysis. The sequence of measurements is especially useful because it reduces the chances that important signal problems will be missed. It is certainly useful to make a variety of measurements on a system in question, watching for things that look wrong or questionable, and many problems are found that way. However some important things can be missed this way, and a great deal of time can be wasted in unproductive or inefficient measurement approaches.

Slide 13



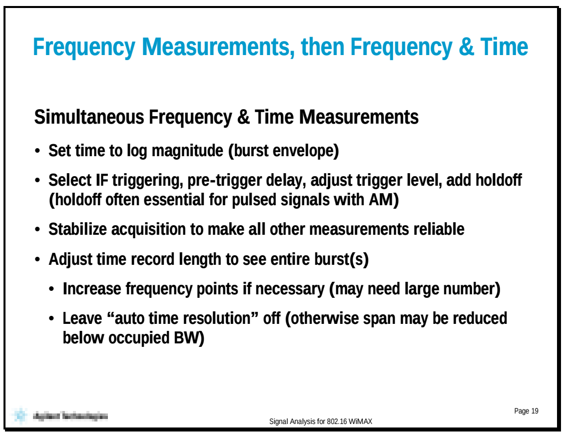
Our approach begins with frequency (basic spectrum) measurements and progresses to vector measurements that combine frequency and time domain analysis. A great deal can be learned about digitally modulated signals before digital demodulation is employed, and some important signal characteristics are not readily visible during digital demodulation. Some examples of problems with digitally modulated signals, which can be found through vector analysis, include truncated training sequences (which can cause compatibility issues even if digital modulation is successful) and improper amplitude or ranging (which may disguise itself as digital modulation problems such as timing errors). Even some problems which arise in the digital modulation process itself may be seen more readily in a vector (and not digital demodulation) mode. Vector analysis also provides a good opportunity to set triggering and pulse search length to optimum values. This ensures, for example, that a “pulse not found” message during digital demodulation actually indicates a signal problem and not just a setup problem or variations in signal amplitude due to modulation. Attaching clear meanings to errors reported by the analyser enhances the value of the analyser’s results and makes the analysis itself more comprehensive.

Slide 14



It is usually a good idea to begin with wideband spectrum analysis, and to use tools such as peak hold (usually implemented as a type of averaging) to ensure that no significant signals are missed, either in band or out of band. This is especially important for any signals, which involves pulses or bursts, or where there are channel changes or hops. Note the progression from broadband to narrower signal analysis, and efforts to avoid missing signals in the time domain as well. Making accurate spectrum measurements of bursted signals such as most WiMAX signals requires triggering, and benefits greatly from time-gated measurements as well.

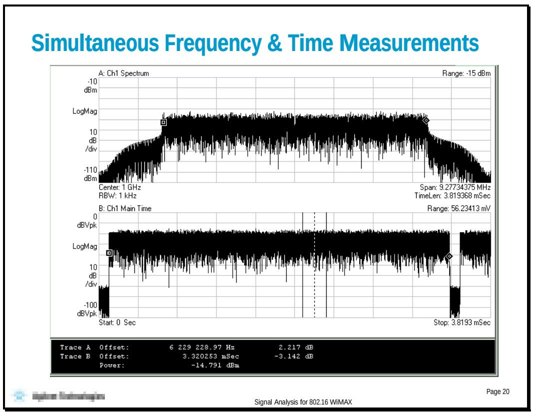
Slide 15



The power of vector analysis is most evident when frequency and time domain measurements are linked. Time domain setup uses tools similar to those in oscilloscopes, including negative trigger delay and trigger holdoff. The most useful time domain display for the RF engineer is the envelope or log magnitude data format type.

For very long bursts (such as may be found in WiMAX signals) you may need a very large number of points to obtain sufficient time record length while maintaining adequate BW. The number of time points is likely to be much larger than would be needed for an adequate spectrum display.

Slide 16



Vector mode measurements such as this one are valuable for verification of many basic signal parameters in both the frequency and time domains. Many features can be combined in these measurements such as: Linked frequency & time displays and measurements, Triggering (both live signals and recordings), trigger holdoff, Variable overlap in playback, Variable block size (51,200 points in this measurement) and time resolution, Offset markers in time and frequency, Band power markers, Time-gated spectrum, CCDF, etc. Multiple average types (exponential, time, peak hold). In this measurement offset frequency markers are used in the upper display to show the approximate occupied bandwidth. In the lower display offset time markers are used to measure the length of the “on” time of the burst, while band power markers are used to measure the power of a specific portion of the burst.

Slide 17

Measure and Verify

Frequency & Time Measurements

- **Center frequency, occupied bandwidth**
- **Amplitude--average, and variations during burst (transients, drift)**
- **Turn-on & turn-off behavior, on / off ratio**
- **Burst length, duty cycle, unanticipated frequency / time variations**
- **Band power measurements**
- **New 89601A occupied bandwidth marker** (use carefully on signals with essential sidebands)

Signal Analysis for 802.16 WiMAX Page 22

These may seem like relatively basic measurements, but a significant number of system problems are traced to this behaviour. Such problems may come from analogue or digital circuits, or interactions between them.

Slide 18

Time-Gated Spectrum Measurements

Time-Gating Setup

- **Set main time length to approximately 5 symbol times (number of points does not need readjustment)**
- **Enable gating, set gate length for desired signal segment and RBW, then set gate to 1x(“OFDM symbol time”) to see preamble symbols**
- **Set initial gate delay to match pre-trigger delay**

Select Appropriate Gate Windows (RBW Shape)

- **Flat Top for amplitude accuracy, Uniform for frequency resolution**

Time-Gated CCDF

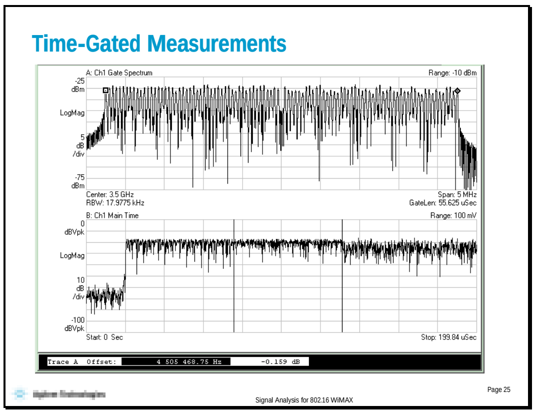
- **Preamble vs. data**

Averaging types

Signal Analysis for 802.16 WiMAX Page 24

The flexible and precise time gating in the vector signal analysers is particularly useful for signals such as these. For example, in some measurements it is important that time gates be aligned with specific symbols in the preamble. Note that in a signal such as WiMAX the frequency and amplitude behaviour of the signal changes at different times during the burst. Dynamic amplitude behaviour (measured as peak/average power or CCDF) changes between the preamble and data portions of the subframe, and even between different data portions of the subframe. Time-gated measurements, including power and CCDF are essential for accurate measurements of individual portions of the signal.

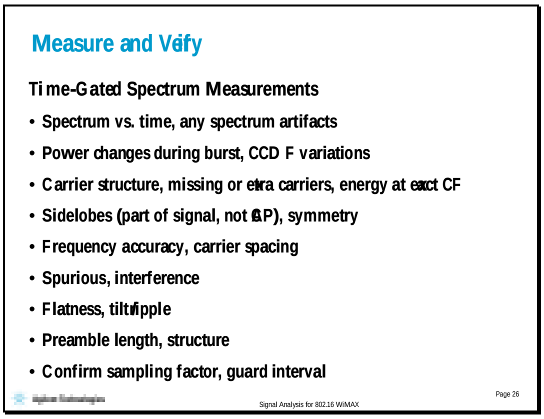
Slide 19



This is a time-gated spectrum measurement of symbol #2 (composed of every 2nd OFDM carrier, QPSK modulation) of the preamble. The gate time is defined by the vertical gate markers in the lower (time envelope) trace.

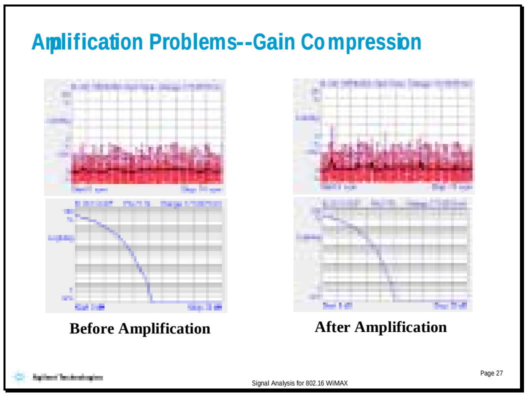
A uniform gate window is used, to obtain maximum frequency resolution by trading away some amplitude accuracy. This increased frequency resolution allows the individual carriers to be easily resolved.
The offset markers in the upper (spectrum) trace measure the frequency difference between the "corner" OFDM carriers.
This measurement is different from an occupied bandwidth measurement, and would be useful in troubleshooting both analogue and digital signal generation problems. The analyser frequency span is reduced from the span at which the recording was made. This post-capture centre frequency and zoom adjustment capability can be extremely useful in situations where the signal has frequency problems or when the capture was made with sub-optimal settings or when the user wishes to focus analysis on a different portion of the signal.

Slide 20



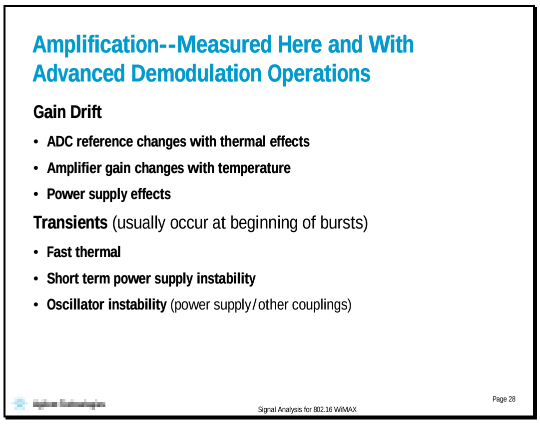
With time gating, measurement setup is complete and many specific measurements can now be made with confidence. Digital modulation or DSP-related measurements such as carrier spacing can easily be made in vector rather than digital demodulation mode. Modulation errors such as carrier spacing may in some instances be easier to spot at this point rather than later, when they may prevent digital modulation from succeeding at all.

Slide 21



CCDF measurements can be made in a relative fashion, and do not require a perfect stimulus signal. Time-gated CCDF measurements can be easily made, to evaluate CCDF changes depending on signal level and modulation type. For example, the amplitude of the WiMAX preamble is 3 dB above the rest of the subframe, and this is likely to change CCDF. These measurements are presented side-by-side, but might be easier to interpret if overlaid. The grey line represents additive white Gaussian noise (AWGN) and is a common reference point. AWGN is a challenging signal for amplifiers, and many OFDM signals behave in a similar way to AWGN.

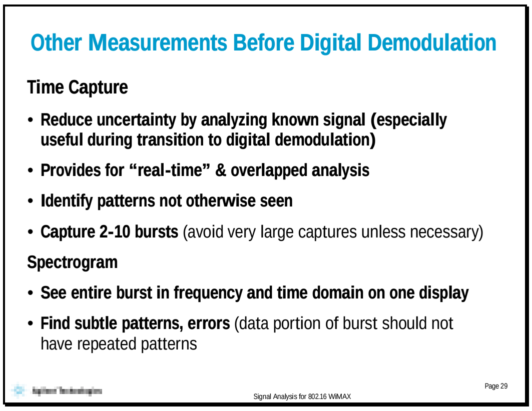
Slide 22



Some measurements can be made (though in slightly different ways) in both vector and digital demodulation modes. Vector mode measurements correlate these behaviours with RF burst timing, while digital demodulation measurements correlate these measurements with symbols or carriers. Transients and drift are common with pulsed systems, and are often seen in microwave systems where physical device geometries are small and thermal time constants are short. Indeed, WiMAX demodulation is designed to account for (or "track out") some of these phenomena through the use of pilot carriers embedded in the signal.

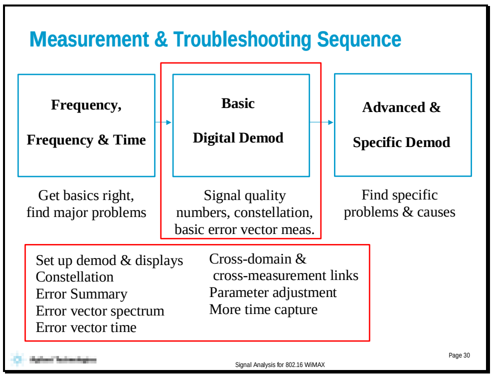
In many cases, the information produced by the tracking algorithms is itself useful as a diagnostic tool. We will demonstrate this in the advanced digital demodulation portion of this presentation.

Slide 23



Always consider making and using (and saving!) a time capture of signals such as these. Time capture is especially useful for spectrogram measurements, where it provides gap-free "real-time" analysis for the length of the capture. Extremely long time captures are possible, but usually unnecessary. One benefit of starting with a good set of vector measurements is the ability to choose a time capture length which is long enough for complete analysis, but not so long as to cause slow analysis due to excessively large capture files.

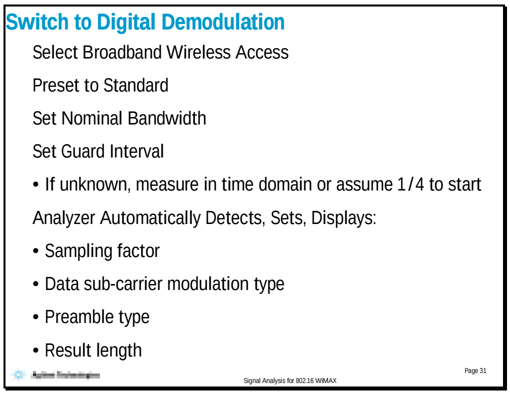
Slide 24



The reliability of digital demodulation measurements and the insight provided by them is enhanced by the information gained during initial vector measurements. For some measurement tasks, especially design verification; basic digital demodulation will be sufficient. The error summary table provides a complete numeric summary of signal quality and the magnitude of major error types. A large amount of measurement data is available at this stage, and significant troubleshooting can be performed as well.

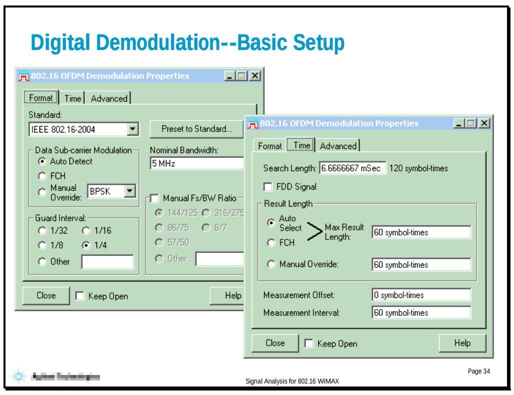
Error vector time and frequency measurements, in particular, are an excellent way to begin tracking down potential problem sources. One powerful technique (often overlooked, and not available in many other solutions) is to use marker coupling to link error measurements across different domains. Errors sources may be invisible in one measurement type and obvious in another. This is particularly true in multicarrier formats such as OFDM.

Slide 25



The physical layer flexibility in WiMAX makes setup a little more complex than it would otherwise be, but the available presets and automatic detection/setup which are performed by the analyser will limit this complexity. Once input range, centre frequency and span are set, the steps shown here will properly configure the analyser for demodulation. Several parameters, which are set up by default or from information embedded in the signal can also, be set manually. Some of these manual settings will be covered in the upcoming section on advanced digital demodulation.

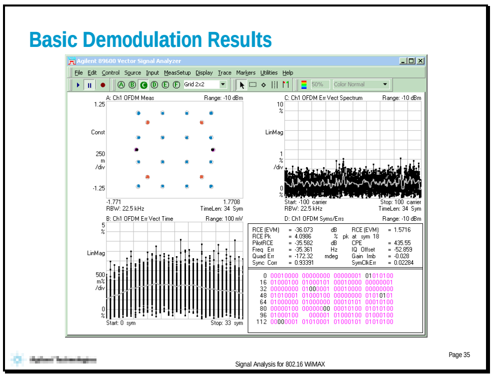
Slide 26



After selecting "Broadband Wireless Access" as the demodulator type, the individual demodulation parameters are selected. For this part of the presentation, we will focus on the Format and Time tabs in this menu.

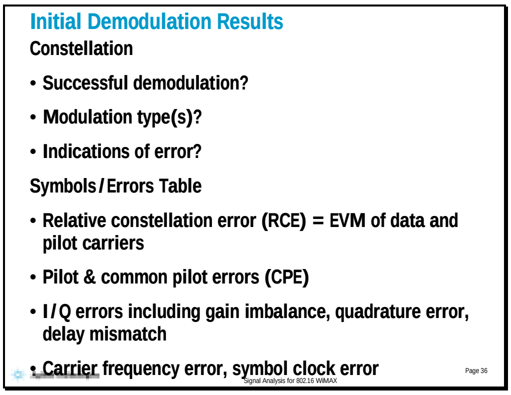
The format tab contains standards-based presets and a drop-down box with the available signal bandwidths.
Sampling factor (Fs/BW ratio) and the type of data sub-carrier modulation are normally set automatically. The setting for guard interval is variable, but 1/4 is a good place to start. At this stage of analysis, the main parameter to set under the time tab is search length. This figure tells the analyser the time interval over which it should search for an entire pulse or a preamble.

Slide 27



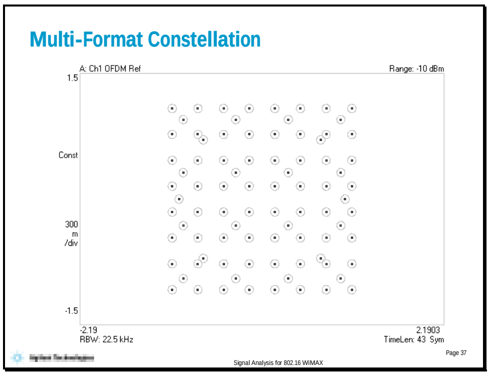
This is a typical basic demodulation result. For a signal such as WiMAX there is considerable complexity even in the basic demodulation results. Multiple modulation formats are shown in the composite constellation, which represents both an interval in time and a frequency span. The trace at the lower right is a combination of an error (modulation quality measurements) table and a portion of the demodulated bit sequence in the subframe. The displays in the lower left and upper right are complimentary in terms of time and frequency. The error vector time trace represents time (in symbols) on the X-axis, while all carriers (frequencies) are shown for each moment in time (symbols). The error vector spectrum trace represents frequency (in carrier number) on the X-axis, while all symbols (time points) are shown for each individual frequency. Understanding and using the relationships between these measurements and displays is extremely powerful in terms of understanding signal characteristics and any impairments, and ultimately in optimising the factors that lead to commercial success.

Slide 28



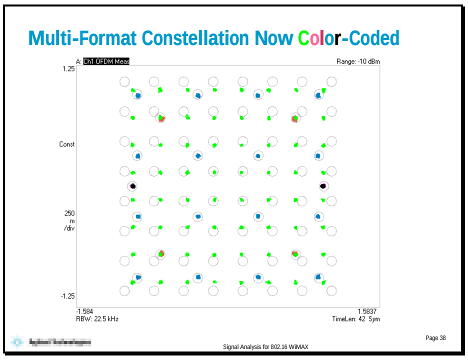
The most-used displays in basic digital demodulation are constellation diagrams and the error summary table. The use of OFDM and the potential for multiple modulation types makes the composite constellation diagram more difficult to interpret. Nonetheless it remains an essential display, and one that engineers frequently consult first. Note that the constellation display and symbol table in the 89601A are colour-coded according to modulation type. WiMAX uses the term relative constellation error (RCE) rather than EVM, and the two terms are equivalent. They are expressed in percentage terms and in dB.

Slide 29



This is an example of a WiMAX constellation containing all possible modulation types: BPSK, QPSK, 16QAM and 64QAM. As always, this is both an I/Q and a polar representation of the signal, where RF power is shown by the radial distance from the centre of the diagram to a constellation point. The constellation points for the different modulation types (QPSK and 16QAM, for example) do not overlay exactly, due to the effort to keep average signal power constant between different modulation types. Therefore the nominal (outer state) constellation points are not the same magnitude. While average power should remain relatively constant, peak power and peak/average power (CCDF statistics) will vary significantly, and can contribute to different error behaviour.

Slide 30



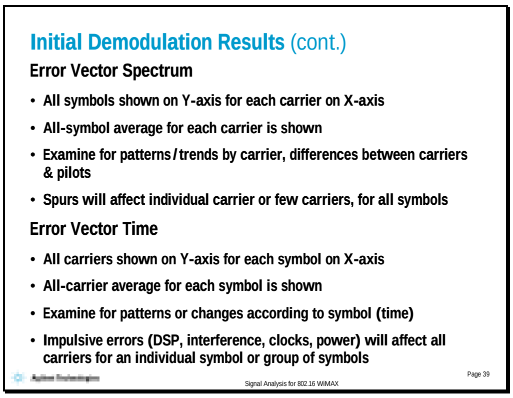
Agilent invented and patented the colour coding used in our CDMA code domain power displays, and we are extending that benefit to this multi-modulation format. The constellation is coded both by modulation type and by signal element (preamble vs. data vs. FCH vs. pilots) so that you can tell them apart. This signal shows some amplitude compression and also some signal scaling errors, so some elements/colours fall on top of each other when they should be separate. Other elements such as the BPSK pilots and the BPSK in the FCH fall on top of each other because they are supposed to (in a display such as this, anyway) and are separated by colour. When using an actual 89601A display you would be able to zoom in close to pick out these individual signal elements.

Colour coding:

FCH = Pink (BPSK, behind the pilots)
Pilots = Black (BPSK)
Data-QPSK = Red
Data-16QAM = Blue
Data-64QAM = Green

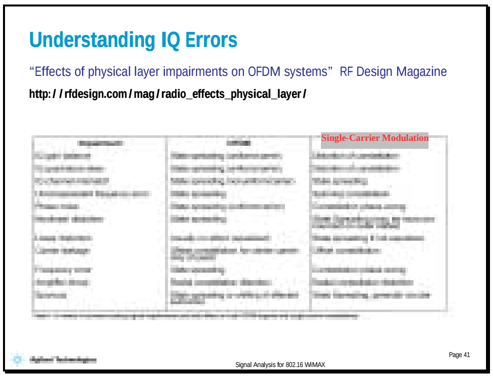
Colour coding is adjustable. Here the default "display appearance" file was used, though it was modified for generating for screen shots that will be reproduced in monochrome. You will find that this colour coding has been added to bits in the symbol table, and that the colours match.

Slide 31



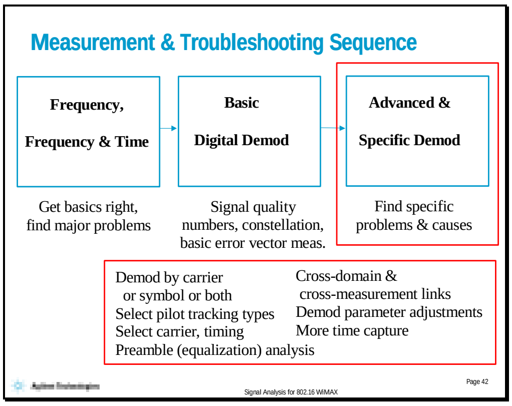
As with all multicarrier modulation types, error vector spectrum and error vector time measurements are valuable and complimentary. It is often useful to look at these two types of measurement results at the same time, and to couple markers between them.

Slide 32



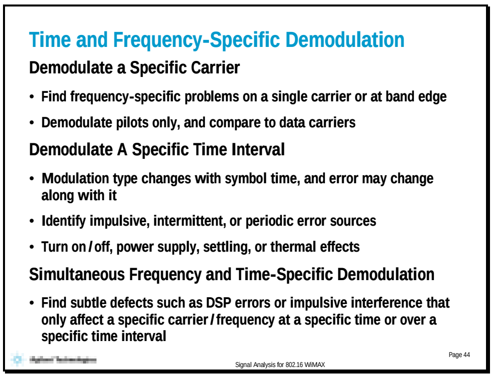
Note, however, that many types of signal impairments do not provide the distinctive error displays in OFDM that they would in single-carrier modulation. Understanding the specific type of error is a primary use of many of the 89601A digital demodulation measurement displays.

Slide 33



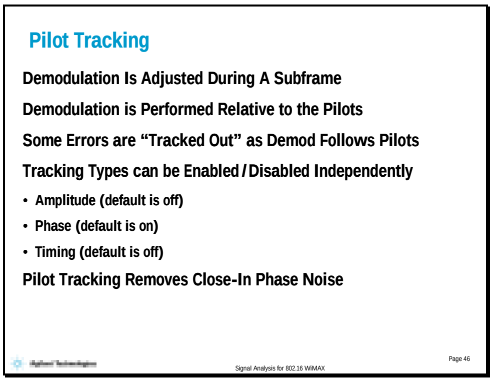
The last step in our measurement and troubleshooting sequence is the most powerful for finding and measuring subtle or more complex problems. A variety of demodulation techniques are available, including demodulation of specific portions of the signal and adjustment of demodulation parameters. Some of these analysis techniques take advantage of specific characteristics of the WiMAX signal, including the built-in equalisation training sequences and pilot carriers.

Slide 34



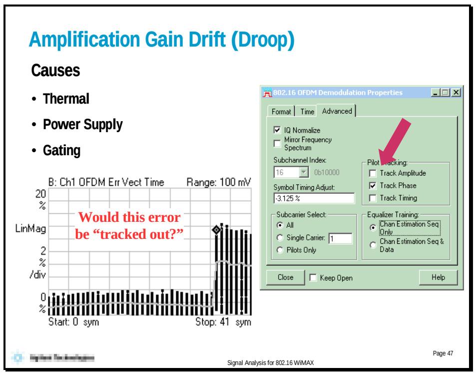
Demodulation of specific elements of a subframe is a powerful troubleshooting technique. It allows clearer isolation of errors and impairments, and therefore a clearer view of their causes. The selection of which technique to use will often be determined by an engineer's knowledge or suspicion of the behaviour of their own system. For example, an engineer might be particularly concerned about spurious distortion or DSP errors, and would choose specific demodulation techniques accordingly.

Slide 35



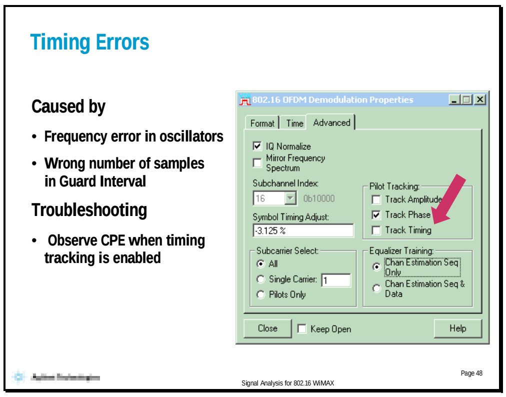
In much the same way as 802.11a OFDM, WiMAX performs demodulation relative to the data in pilot carriers, which are embedded in the signal. These pilot carriers replace data-carrying elements of the signal and allow some kinds of impairments to be removed or "tracked out." The pilot carriers are transmitted continuously throughout the data portion of the subframes. Many signal impairments will be common to all pilot carriers, and can be measured and displayed as "common pilot error." In addition, the specific tracking functions can be individually switched on and off in the demodulation performed by the 89600 software. This is a very useful troubleshooting approach, since modulation errors can be examined with and without the benefit of particular types of pilot tracking.

Slide 36



A common type of signal impairment is non-constant amplitude error during a subframe. Circuits may change temperature and gain during an RF burst, and the combination of transmit and DSP power may cause amplitude droop. The amplitude behaviour of a circuit may also change due to the modulation type of the signal being used. In this example the modulation type changes to 64QAM about three quarters of the way through the subframe. In this case the change primarily affects the scaling and peak power of the signal, causing a dramatic increase in the amplitude component of the error. This error could be isolated by comparing the peak error symbols with their location in the constellation. In this case we would not expect the amplitude problems to be removed by amplitude tracking since the tracking operates on the pilot carriers, which do not use (and therefore do not correct for the effects of) the troublesome 64QAM modulation type.

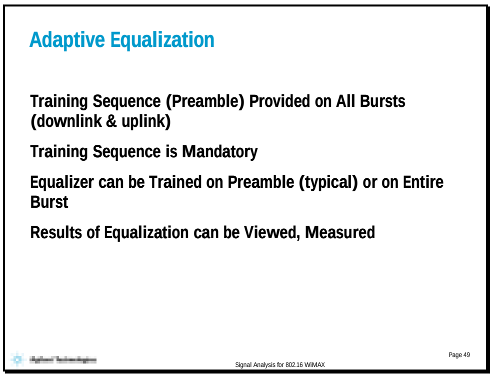
Slide 37



Other pilot tracking types compensate for phase and timing problems. Phase errors, for example, may be caused by phase noise. Close-in phase noise can be removed or tracked out by phase tracking.

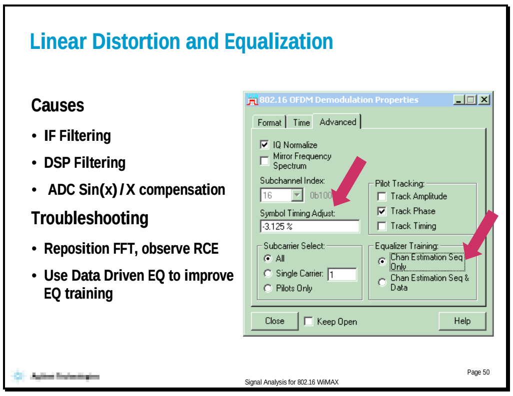
Timing errors, for example, may be caused by oscillator frequency errors or DSP errors such as an improper number of samples in the guard interval. Both analogue and digital sources can cause timing problems.
DSP defects such as an improper sample rate can also affect timing in the subframe.

Slide 38



A sophisticated equalisation facility is essential when using broadband signals (because of possible frequency response problems) and when significant multipath distortion is anticipated. The adaptive equalisation in WiMAX is similar to that used in 802.11a. Unlike 802.11a, WiMAX may use a midamble as well. This equalisation and its results (filter coefficients) are very useful for troubleshooting.

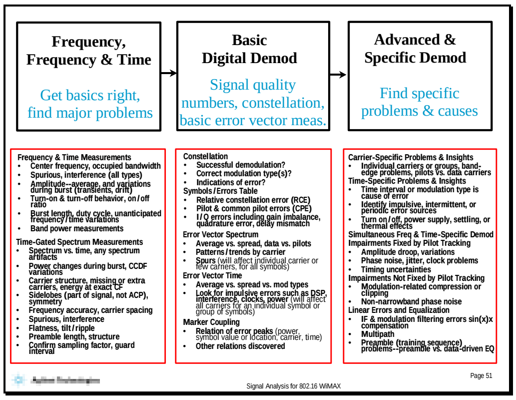
Slide 39



Adaptive equalisation can compensate for linear errors such amplitude and phase flatness. These errors may be caused by multipath or by tilt or ripple in the frequency response of a system. Noise, intermodulation, and the effects of amplifier compression are nonlinear forms of distortion, and are not corrected by adaptive equalisation. Note also the ability to adjust the symbol timing used for demodulation. This positions, in time, the FFT used for demodulation. No specific time position is called out in the standard, and different timing settings will affect measured modulation quality.

In particular, if filter ISI or multipath affects the guard interval, certain symbol timing settings will provide much better demodulation results than others.

Slide 40



This is a summary of many of the measurements described in this presentation. These measurements are organised around the measurement and troubleshooting sequence used in this presentation.
This list of measurements does not include all possible measurements for a signal such as WiMAX, but it gives some indication of the measurements and problems, which are associated with WiMAX signal analysis.
Please consult the materials described in the References slide for more information.

Slide 41