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802.11g RF Testing

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presented by:

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Abstract: Wireless LAN technologies are enjoying rapid adoption by both businesses and the private sector, and the new 802.11g standard promises to accelerate this trend. The new standard incorporates elements of the prior 802.11b and 802.11a standards, adding its own set of test and troubleshooting challenges. This paper covers RF testing and modulation quality analysis of 802.11 components and systems, with a focus the most effective test techniques and on what engineers need to know beyond the needs of 802.11b design. The paper covers a wide variety of test approaches, including RF spectrum and power, transient effects, modulation quality, and some aspects of interoperability. The paper deals primarily with OFDM modulation due to its demanding nature and its position as a key enabler of the highest data rates that are a primary driver for 802.11g acceptance. The paper describes troubleshooting techniques to quickly isolate problems, with an eye toward accelerating both design and system integration.

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Macro Scale Goals

Delivering on the Promise

802.11g Benefits

- Higher data throughput
- Compatibility with 802.11b installed base
- Improved range in difficult environments
- Lowest possible cost

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As this advertisement indicates, primary advantages of 802.11g implementations include much higher data throughput, compatibility with existing 802.11b installations, and the greater coverage afforded by operation at lower frequencies.

Delivering these benefits will demand efficient design and troubleshooting, whether the task is design of chipsets, implementation of reference designs, or integrating the 802.11g solutions into end products.

Poor implementation of 802.11g solutions will have considerable negative consequences, impairing the public perception of wireless LAN technology in general, and slowing its broad adoption. Interoperability or interworking is a particular challenge, as there is a large and rapidly growing installed base of 802.11b hardware and “hot spots” and 802.11b/g interoperation problems are potentially very troublesome.

What We Need to Know to Do It

Solving Problems, Perfecting Designs

Getting a Product or a Subsystem Working

Solving Product/Sys. Integration Problems

- Interactions between blocks
- Marginal blocks, isolating performance limitations

Testing for Conformance to Standards

Optimizing Performance or Manufacturability

Solving Interference Problems

Solving Interoperability Problems

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A critical element in testing is to understand the purpose of the testing itself. The types of testing that can be performed are mostly universal, but the order and the way they are used will vary depending on the desired task or outcome.

Thus the test approach used to get a new solution operating at its initial implementation phase is very different from verifying the compliance of an operating solution with applicable standards. In the same way, the analysis approach would also be different if the task was to optimize and improve performance or manufacturability of an existing implementation.

Therefore it is important to clearly establish the test goals at the beginning, to choose the best tools and techniques for the task at hand.

Agenda

An Organized Approach

Spectrum and Time Domain Testing

Advanced Spectrum and Power Testing

Finding Problems with Pulsed/Bursted Signals

Beginning Digital Demodulation

Using Equalization and Training Sequences

Isolating Demodulation to a Specific Time Interval or Frequency

Conclusions

References

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Organized Approach is Most Productive

Some Problems Obscure and Complicated

Many are Not, Especially if Seen Clearly

- Apparent frequency, power, timing defects
- Use wide-bandwidth vector analyzers, not spectrum analyzers, oscilloscopes

Even Difficult Problems Often Provide Straightforward Clues

Keep First Things First

- "Smoke test," heartbeat, presence of signal
- Confirm frequency, bandwidth, power, burst timing
- Use these results to establish what is working well, and to set up/guide modulation quality analysis

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With such complex systems, it is tempting to assume that the problems one faces are similarly complex or obscure. This is often not the case, though some problems are difficult to see because of the nature of traditional swept spectrum analyzers and oscilloscopes.

Swept spectrum analyzers, for example, often do not have the information bandwidth necessary to fully analyze these wideband signals. Oscilloscopes are available with very wide bandwidth, but do not have the resolution and accuracy for precise power or frequency domain tests.

Verifying basic operating parameters such as frequency, power, bandwidth, and burst timing is usually the best place to begin. Even difficult problems often provide clues in these basic measurements.

Complex Signals, Complex Testing

Understand Complex Tests in Terms of Their Basic Elements
- Frequency
- Power
- Timing
- Modulation Quality

For Example
- Frequency+Power = Spectrum
- Power+Timing = Burst Structure
- Frequency+Timing+Power = Settling/Stability
- Modulation Quality+Everything = Necessary

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Even the most complex tests can be understood in terms of their primary elements.

A major source of complexity in these measurements, however, is that the elements are almost always combined.

Some measurements, in particular, are both complex and demanding. Settling and stability measurements of bursted signals, for example, require high resolution analysis of signal frequency, timing, and power.

Vector Signal Analyzers

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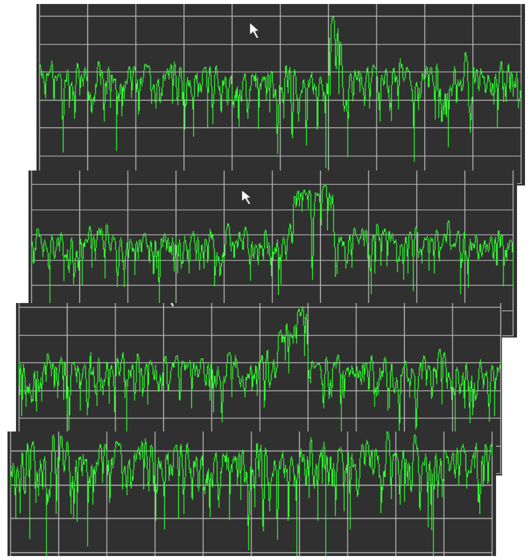
Swept Spectrum Analysis

Fundamental Issues

- Insufficient Info. BW
- Not Real Time
- Envelope Time Only
- No Time Capture for Gap-Free Single-Shot Burst Analysis
- Lack of Combined Analysis Modes
- Still Good Tool for Spectrum, Spurious, Occupied Bandwidth



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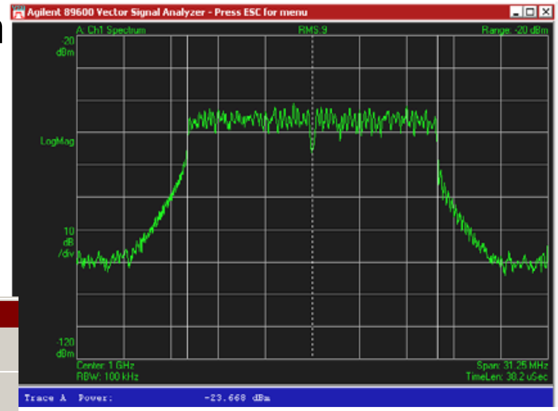
Swept spectrum analysis may be used for some measurements on WLAN signals, but its usefulness is limited. Swept analyzers are prevented from comprehensive analysis of these signals by their information bandwidth, non real-time nature, limited time domain capability, and lack of a gap-free signal capture capability.

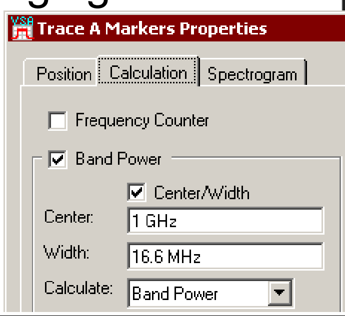
Nonetheless, when properly configured, swept spectrum analyzers can perform some important tests very well, and can serve to verify basic functioning of WLAN devices or their elements.

Begin with Spectrum Analysis

Verify Center Freq., Bandwidth, Spectrum Shape (flatness, sidelobes)

Use IF Magnitude Triggering, Holdoff, Averaging





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Before attempting more advanced tests such as burst analysis or digital demodulation, it is always advisable to confirm basic signal parameters such as center frequency, bandwidth, and spectral shape.

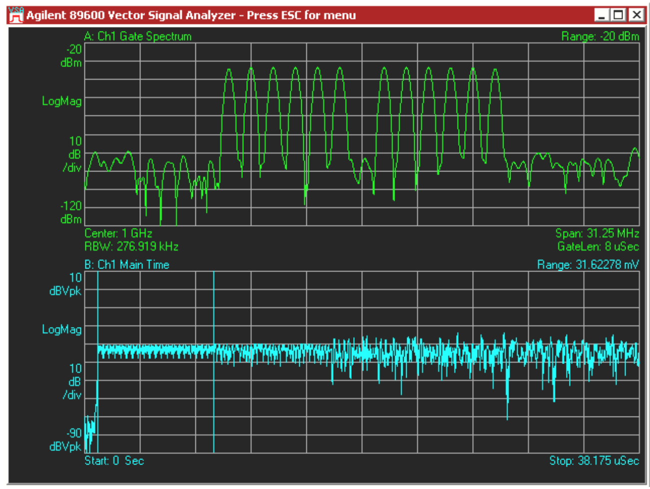
Accurate measurement of these parameters may require features such as triggering, trigger holdoff, averaging, and band power integration.

Time Domain, Burst Env., Time Gating

Correct Burst Shape, Timing

Turn On/Off Behavior

Gated Spectrum



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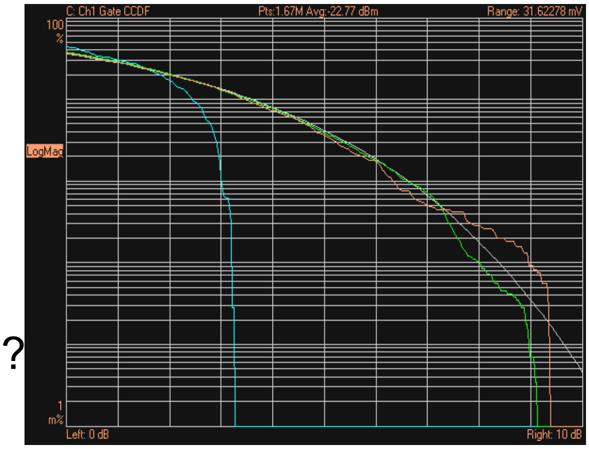
Measurement of burst shape and timing parameters is especially important in signals such as these, as errors here may create interoperability or compatibility problems.

For spectrum measurements of these dynamic signals, time gated signal analysis and a clear display of the time domain (envelope) of the signal is very helpful.

This measurement shows the spectrum of the short training sequence of an OFDM signal, where every 4th carrier is transmitted, and the center carrier (carrier number 0) is not. The gate markers on the bottom trace show the portion of the signal selected for spectrum analysis.

CCDF, Gated CCDF

- Quantitative Analysis of RF Power Behavior
- Normalized--Pk/Avg Pwr Ratio
- Measure Before, After Amplifiers
- Can Old Amplifiers Handle New Signals?
- Choose Operating Point, Power Ratings



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OFDM signals make particularly high demands of power amplifiers. Their peak/average power ratios are much higher than CCK signals and many other types of digitally modulated signals.

For this reason, power amplifier design and selection of operating point is critical for efficient OFDM operation.

Perhaps the best tool for analyzing signal power behavior and power amplifier effects is the complimentary cumulative distribution function (CCDF) of the signal.

Three measurements are shown here. The red trace shows the high demands placed on the power amplifier by the OFDM signal when transmitting data, while the green trace shows the same measurement on a signal that has been clipped or compressed by an amplifier. The blue trace shows the reduced demands from the channel estimation sequence. The CCDF measurement here is a gated one.

Time Capture

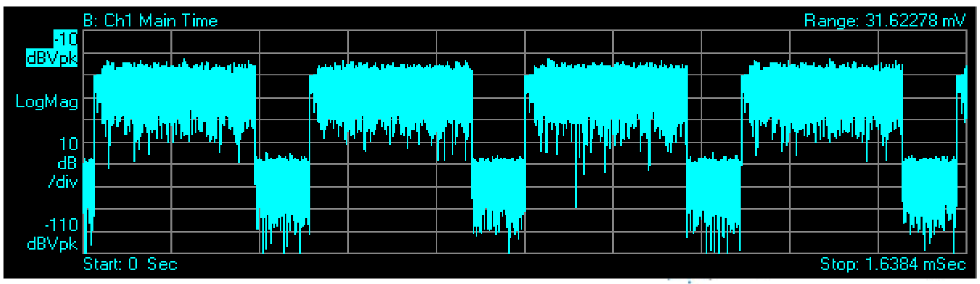
Full Bandwidth Acquisition Direct to Memory

Gap-Free in Time and Frequency

Acquire Once, Measure Many Times

Post-Acquisition Center Freq., Span Changes

Single-Shot, Can Be Triggered, Ensures Data Repeatability



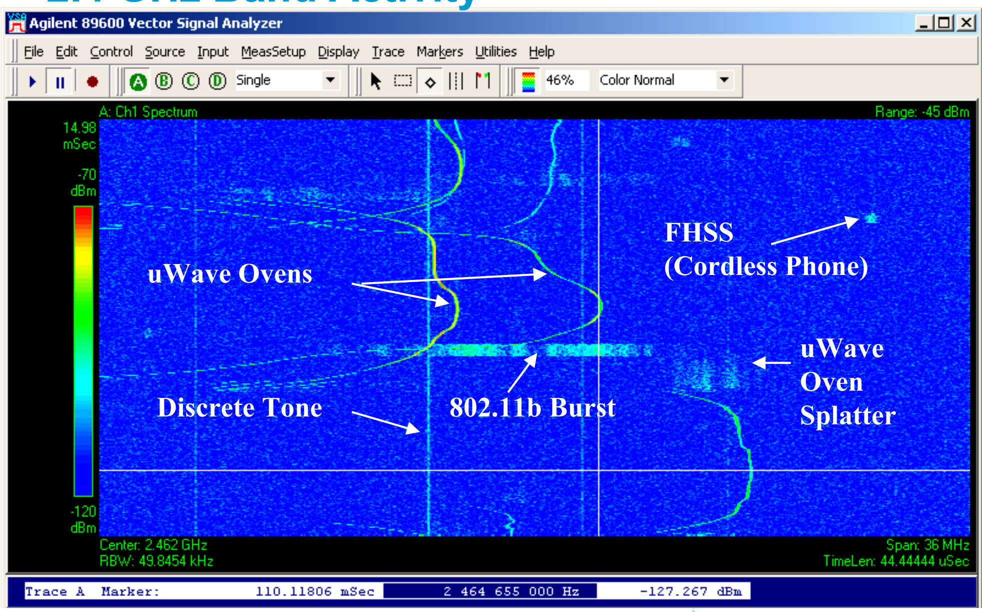
Time capture is a particularly powerful function for measurements such as these. It ensures that no information is missed during the capture, and that all data in the measured bandwidth is available for any type of post-acquisition analysis.

Once the capture is complete, many different types of measurements can be made on the same data set or any portion of it. This simplifies troubleshooting, as different results due to changes in measurement type or settings can be isolated from results differences due to a changing signal.

In this capture 4 frames of the signal are shown. All or any portion of this signal can be measured in the frequency domain, time domain, or using digital modulation analysis.

Time Capture Example

2.4 GHz Band Activity

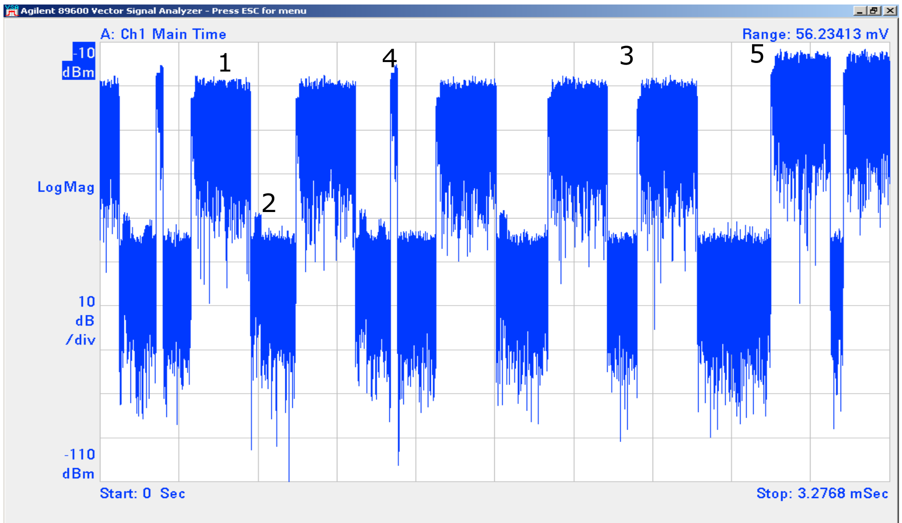


This is a spectrogram of a portion of a time capture from the 2.4 GHz band where 802.11b and 802.11g operate. It shows the challenges facing designers of this equipment. Many different sources of interference may be present at the same time, and need to be understood and dealt with.

Post-capture center frequency and span changes are very beneficial if they are possible. They allow the engineer to better identify and understand any emitter in the band.

Pulse Structure of an 11a Data Transfer

From Time Capture, Approx. 1 Mbyte



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Using the recorded waveform, it would be simple to zoom in to examine every part of the burst in detail.

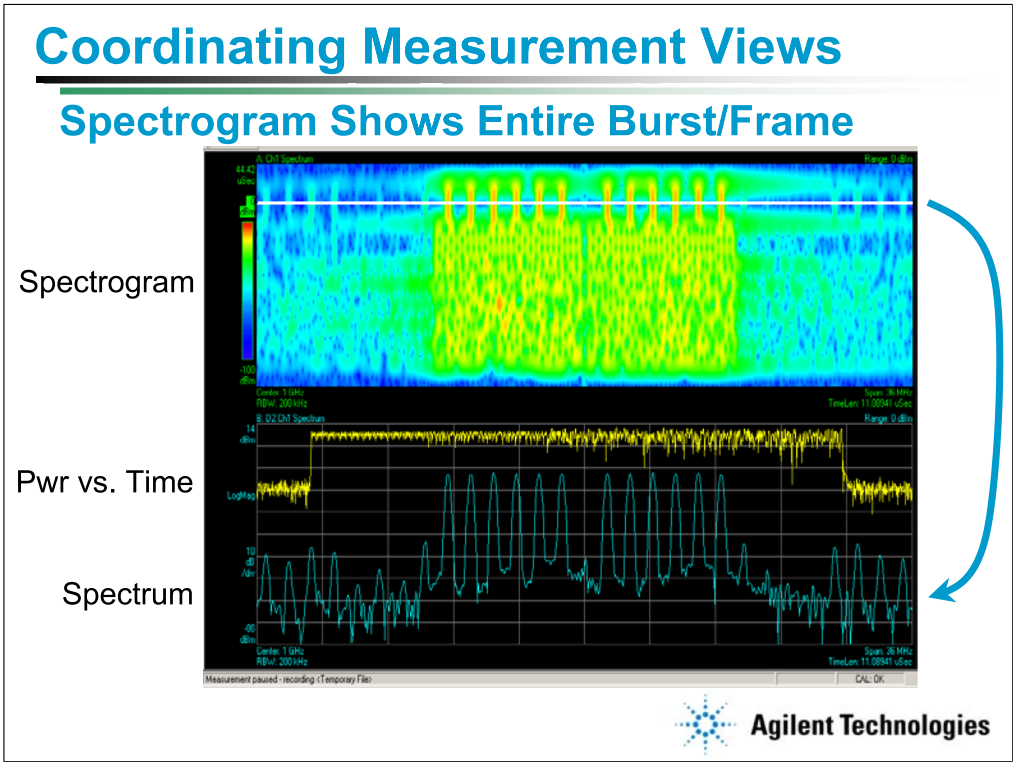
1) This a frame of data being transmitted from the AP to the NIC

2) The level of the return signal from the Network Interface card is 30dB lower. The Acknowledgement can just be seen.

3) A frame is retransmitted, presumably because the acknowledgement from the NIC was not received by the AP

4) The short bursts are beacons. They are spaced approximately every 100ms.

5) It can also be seen how the power level can jump from frame to frame. This could be a consequence of changes in the path loss [power control], or use of different power levels for different modulation rates. The way a system adapts to a real environment is not specified ion the standard.



Even for measurements not involving digital demodulation, multiple simultaneous displays of different signal characteristics are very useful.

The spectrogram measurement shows the beginning of the frame at the top of the screen, with the short training sequence obvious due to the transmission of only every 4th carrier. A specific spectrum measurement from the spectrogram has been selected by the white cursor line in the spectrogram and is displayed in more detail in the bottom trace.

The burst is shown in its entirety in the center trace.

Note the red spot in the spectrogram about halfway through the the data portion of the frame, signifying a high power peak. It is not clear if this is normal power variation or a malfunction. It could indicate a problem such as a DSP error.

Using time markers and time capture, this particular power peak could be investigated in time and frequency. Analysis could then shift to digital demodulation, where the data and modulation error associated with this power excursion could be analyzed.

An advantage of signal capture operation for a signal such as this is the ability to perform many different sorts of analysis on a single captured signal, and to send the signal (in digital capture form) to others for their analysis and insight.

Problems of Pulsed/Bursted Signals

Stability challenges

- Stability difficult to achieve with fast switching, narrow set-up times
- Stability especially important with narrowband, orthogonal carriers

Power challenges

- Turn off as many circuits as possible, whenever possible, so many contributors to instability
- Limited current available for simultaneous demands
- Different current limits = different behavior

Keeping everything synchronized is a challenge

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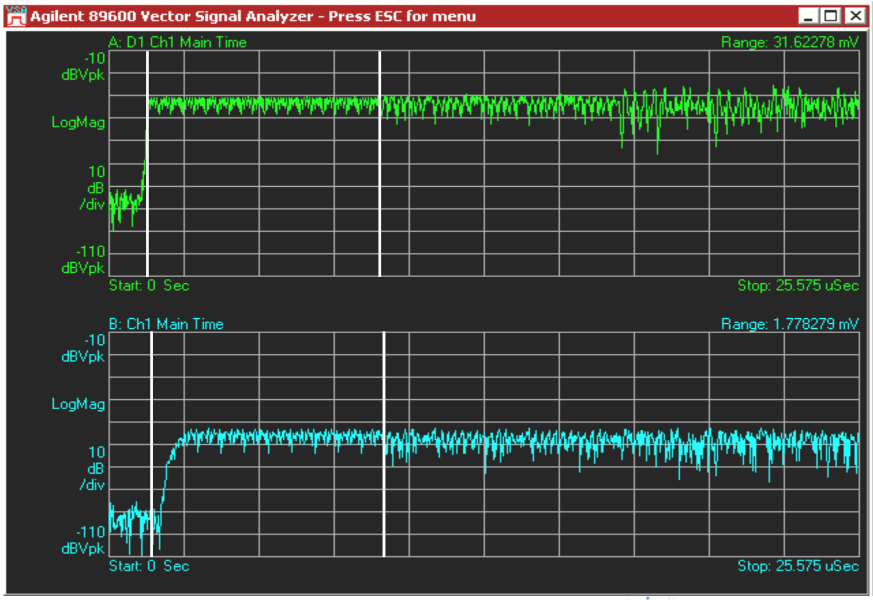
Signal stability is a challenge in any pulsed or bursted system.

The challenge is particularly acute in wireless LAN systems, and especially with portable battery-powered devices. Space and power (available current) are at a premium, and designs must be very well optimized.

The challenge is further increased in OFDM systems, where narrower carrier spacing and orthogonality places a special demand on phase and frequency stability.

Shortened Short Training Sequence



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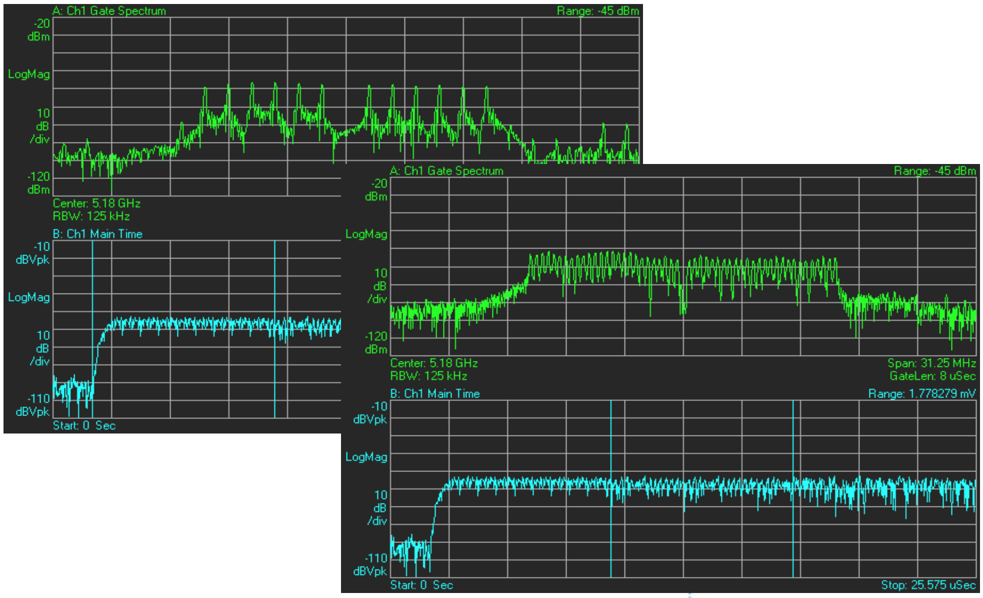
This is an example of a real signal (bottom trace), with a problem in the short training sequence. The sequence is truncated, as shown by the 8 us gate markers and the reference signal at the top.

This system is working, at least with one manufacturer's solutions. However interoperability and signal acquisition in difficult environments may be impaired.

Time-Gated Spectrum Analysis

Gates Synchronized with Preamble Elements



Two gated spectrum measurements are shown, both of the OFDM signal in the previous slide.

The measurement on the left shows the spectrum of the short training sequence, and selected by the gate markers in the bottom time domain (envelope) trace.

The measurement on the right shows the spectrum of the channel estimation sequence, where every active carrier is transmitted at the same amplitude and phase. This signal is used to train the equalizer in the receiver, once per burst or frame.

Note that the transmitter and/or the channel shows some ripple in the frequency response, but an amount and a periodicity that the resolution provided by the 52 carriers should be able to handle (correct for) through adaptive equalization.

From Time/Frequency to Digital Demod

Main Signal Characteristics Established

- Frequency
- Timing
- Power

Analyzer Setup

- Use demodulation presets if appropriate
- Center frequency, analysis bandwidth
- Trigger, holdoff if necessary
- Time capture if desired

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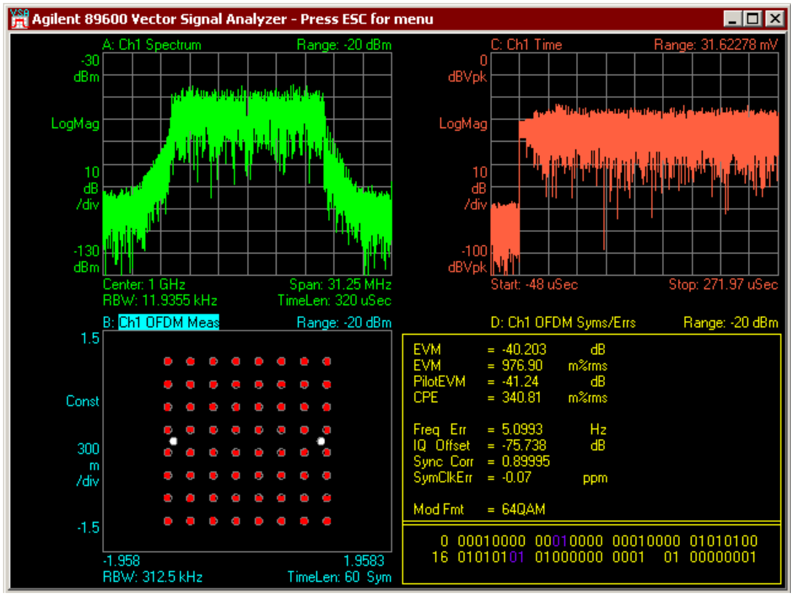
Before beginning digital demodulation (and modulation quality analysis) it is important to verify the main signal characteristics.

These complex signals can require a complex analyzer setup. Modulation parameter presets, if available, can simplify this set up and reduce errors.

Using time capture data as the basis for digital demodulation should be considered, as it eliminates the measurement result variance that can be the consequence of frames which are not exact duplicates (repeats) of each other.

Demod and Spectrum/Time Domain

Verify Signal Characteristics During Demod

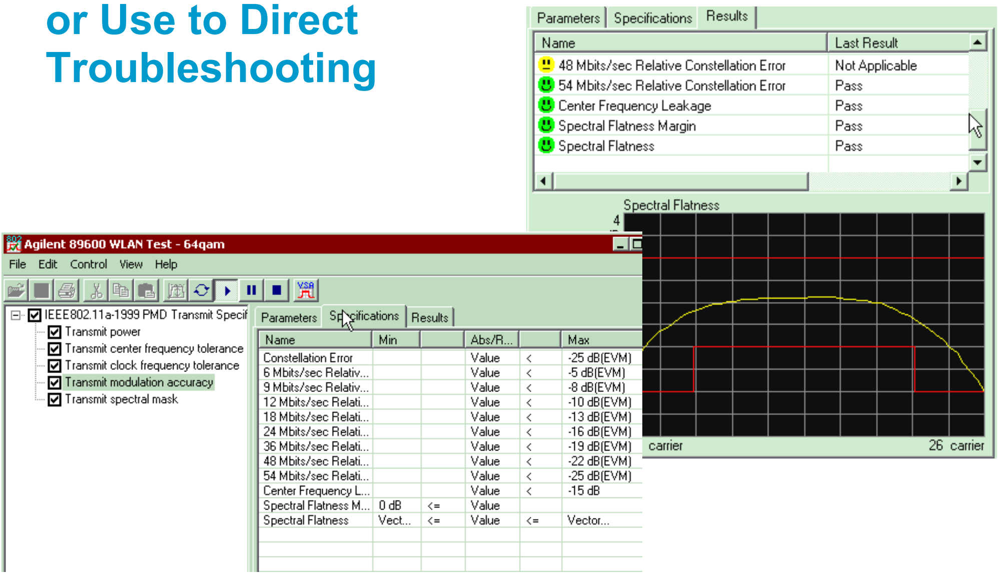


This is a high quality reference signal.

For initial demodulation it is beneficial to view the signal in the frequency and time domain, simultaneously with the modulation domain. This helps verify the validity of the demodulation and identify some setup problems such as center frequency or timing.

1-Button Automated Tests

Fast, Easy Test to Standards or Use to Direct Troubleshooting

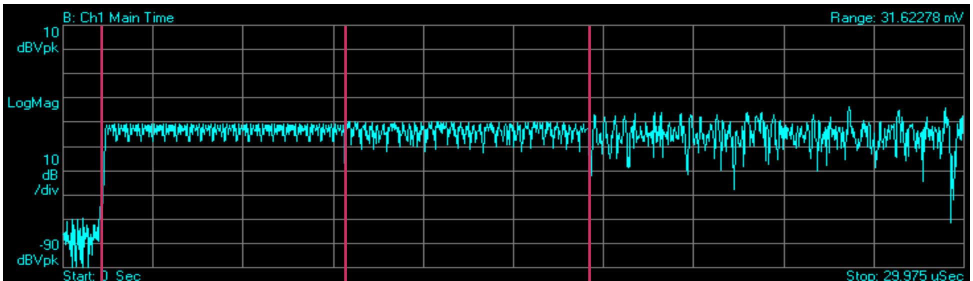


1-button automated tests, if available, are very useful for verifying compliance with standards or performance goals.

The results of these 1-button tests are also very useful for quickly identifying problems as a way to direct further troubleshooting.

Some beneficial features can include adjustable pass/fail parameters and graphical (as well as pass/fail tabular) display of measurement results.

Potential Problems Listed by Location



Short Training

Phase bumps
Freq.bumps
Thermal effects
Power droop
Pulse shaping
Gain variation

Channel Estimation

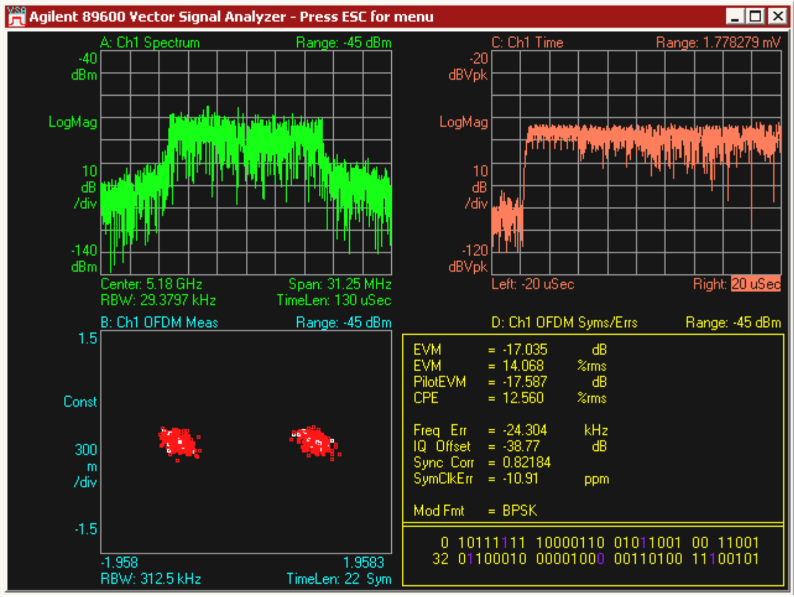
Distortion
I/Q errors
Extended settling effects

Data

Distortion
Phase noise
I/Q errors
Amplitude droop
Coding errors
Inter-symbol-interference

Real Signal Example:

Truncated Short Training Sequence



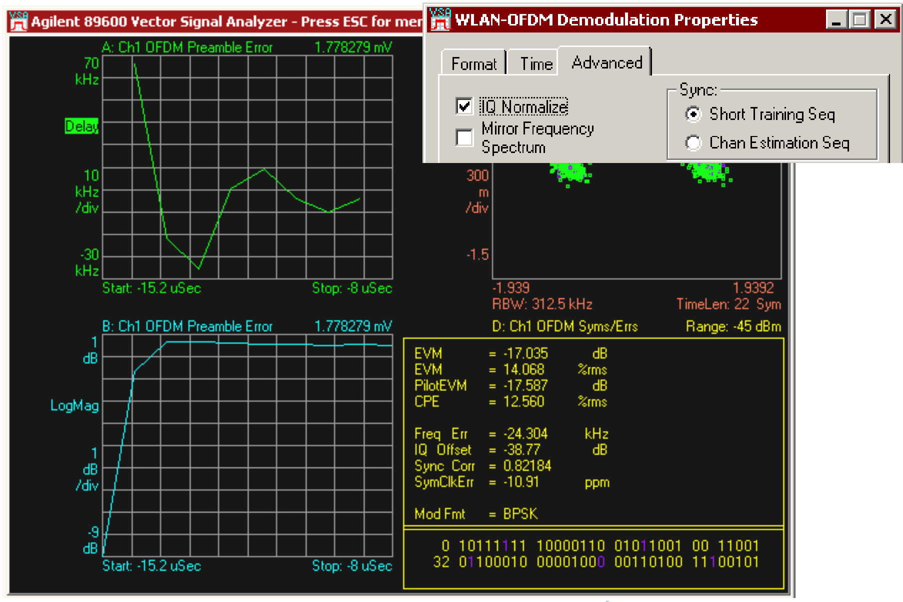
This slide shows demodulation results from a real signal, on a system that is working. This is the signal with a truncated short training sequence as shown on a previous slide.

Demodulation is performed on the digitally modulated part of the signal and not the preamble. No bit errors are evident and data is correctly transmitted, but the signal does have a problem.

Whether this problem is significant depends on the goals of the designer and the specifics of the applicable standard. Even if the system is working and the signal is acceptable in some environments, it is useful to understand the behavior in detail. Signal problems such as this may compromise transmission efficiency in difficult environments, or create interoperability problems.

Measuring Preamble Error

Analog Problems Measured in Dig. Demod



The analyzer is performing digital demodulation, but is also displaying measurements of the preamble.

The two traces on the left measure preamble error in terms of magnitude and frequency error (measured as group delay) during the short training sequence.

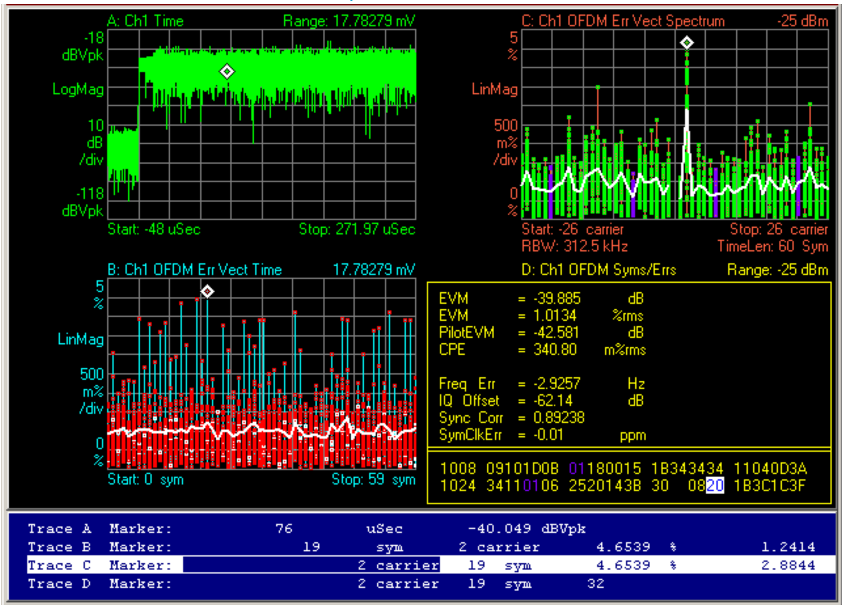
The truncation of the short training sequence is clearly shown in the magnitude error trace, and a frequency error is shown as well.

Different parts of the preamble can be measured, including the channel estimation sequence. However in most cases the short training sequence can be expected to have the most significant stability problems, as the signal is just completing the turn-on process at this time.

Possible exceptions to this assumption would include thermal effects in amplifiers that would increase as the frame progressed.

Multiple Signal Views, Marker Coupling

Search Peak Error, Link to Other Measurements



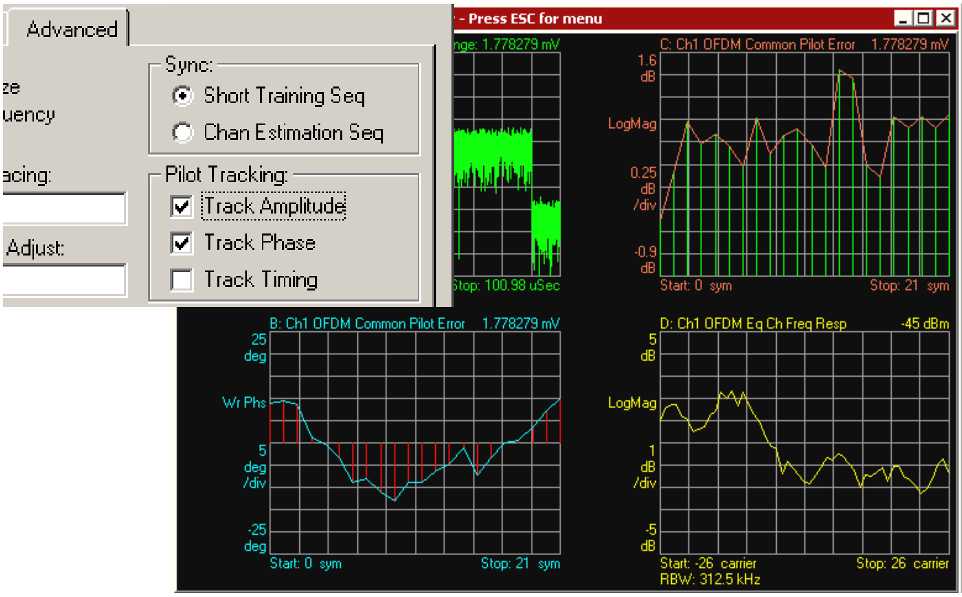
One of the most powerful diagnostic tools is the coupling of results from different simultaneous measurements.

In this example the markers are coupled and a search is made for the peak error. This reveals that the error peak does not correspond to a large or small magnitude value, but does correspond (as do many of the other large errors) to a particular carrier frequency. Spurious interference is suspected.

One could alternatively search for peak signal magnitude (in the upper left trace) to see the effects of compression.

Use Corrections Built into Standard

Equalizer Coefficients, Common Pilot Error



In OFDM, demodulation is performed relative to the pilot signals, after correction by the adaptive equalizer.

The effects of equalization and the characteristics of the pilots can hide or change the appearance of problems.

The channel response derived from the equalizer parameters can be displayed in terms of frequency response, magnitude, phase and group delay.

The error common to all the pilots can also be displayed, and is an important additional tool for troubleshooting.

How Should Equalizer Be Trained?

Channel Estimation Sequence (2 sym.)

Better match to real receiver

Shows effects of early burst settling (resulting in “bad” EQ coefficients)

Short vulnerability, does not carry errors from data portion of burst into equalizer training

Entire Burst (including all data symbols)

Potentially lower meas error (if error primarily noise) due to better computation of EQ coefficients*

More sensitive measurement of component effects such as amplifier nonlinearity

*Coefficient variance due to noise is proportional to the square root of the number of independent samples

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How to Train Analyzer's Equalizer

What is Your Measurement Goal?

To Predict receiver performance:
  Use channel estimation sequence

To Measure with lowest error:
  Use entire burst

To Troubleshoot problems:
  Use channel estimation sequence
  Examine Equalizer Result and
  Common Pilot Error vs. Time

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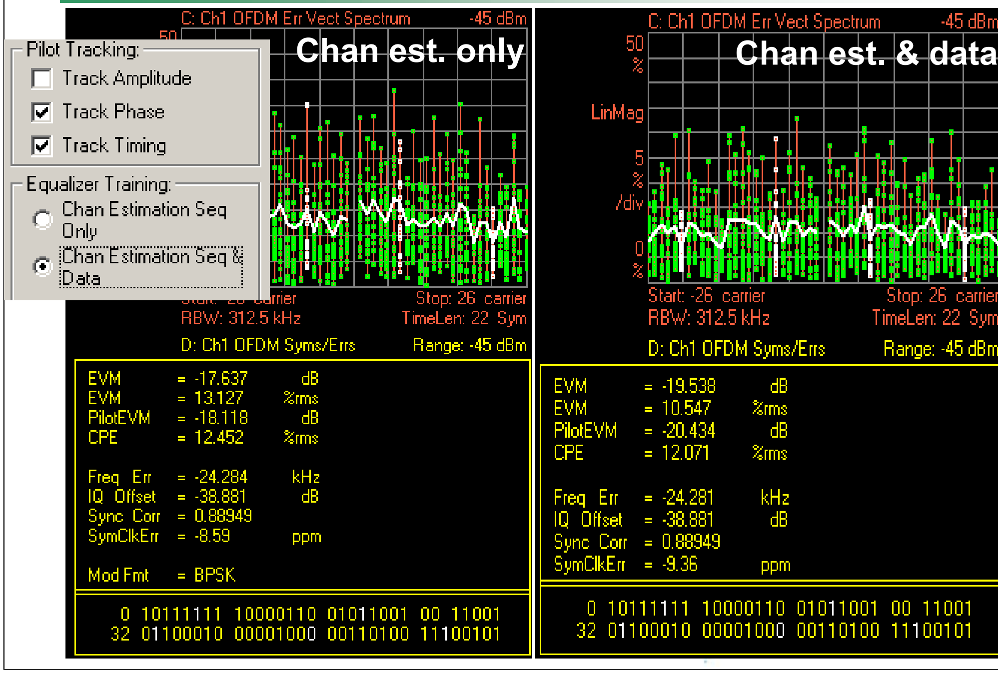
Selecting the Equalizer Training Data



Equalization and Troubleshooting

Use Corrections Built Into Standard

Examine Equalizer Response

- Time domain--Equalizer impulse response
- Frequency domain--channel frequency response
- Look for consistent & reasonable response

Examine Common Pilot Error (CPE)

- Amplitude vs. time or symbol
- Phase/frequency vs. time or symbol

Examine Preamble Error

- Preamble problems impair demod of data burst

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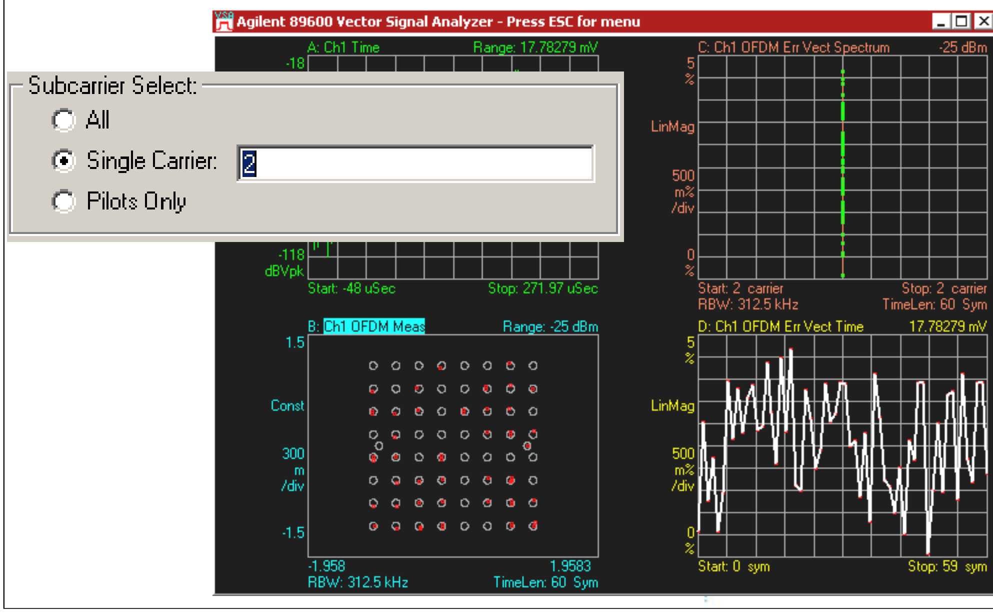
Demodulate Only a Portion of the Signal

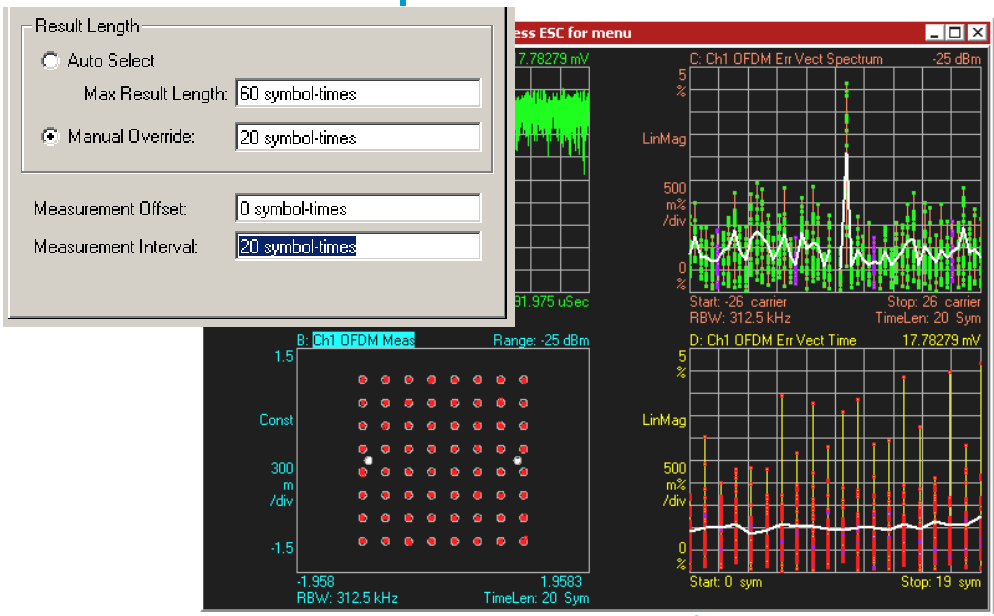
Results From Specific Carrier Number or Freq.



In an OFDM signal it can be useful to look at a limited set of demodulation results. In this case demodulation, and the errors and symbols to be measured, are limited to a single carrier number. The data from this carrier only is shown in the constellation in the lower left.

Demodulate Only a Portion of the Signal

Results From a Specific Time Interval



Demodulation results can be limited to a specific time period, to investigate impulsive errors or interference, for example.

In this case the demodulation is limited to the first 20 symbols of the data portion of the frame.

Conclusions

802.11g Testing Builds on Knowledge, Techniques and Tools used for 802.11b and 802.11a

An Organized Approach to Testing and Troubleshooting Will Be the Most Productive

Simultaneous Displays of Multiple Measurements in Different Domains Are Very Useful in Finding Problems

Some Parts of Testing and Troubleshooting for Interoperability Will Require Creative Combinations of Tests and Analysis, and Careful Study of the Evolving Standard and Implementations

Resources

"Vector Modulation Analysis and Troubleshooting for OFDM Systems," by Ken Voelker, Agilent Technologies, Proceedings of the 2002 Wireless Systems Design Conference

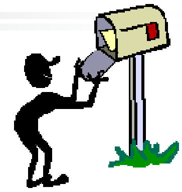
Agilent Technologies Application Note 1380-4 "Making 802.11g Transmitter Measurements

Agilent Technologies Application Note 1380-2 "IEEE 802.11 Wireless LAN PHY Layer (RF) Operation and Measurement

Agilent Technologies Application Note 1380-1 "RF Testing of Wireless LAN Products" Lit #5988-3762

OFDM Troubleshooting Tutorial and Demonstration Video (.AVI) Files on Agilent 89600 Series Software Disk v.4 Lit #5980-1989E (available without charge)

FREE Agilent Email Updates



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