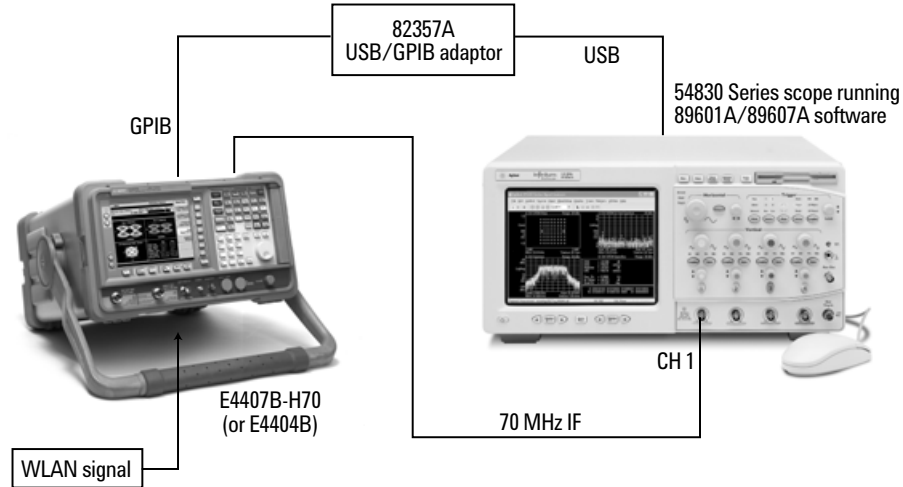


WLAN RF and Baseband Transmitter Analysis Using Agilent Infiniium Oscilloscopes and 89600 Software

Application Note 1486



Troubleshoot and verify 802.11a/b/g designs with flexible and cost effective Agilent test solutions



Agilent Technologies

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Introduction

This application note will demonstrate how a variety of analysis tools from Agilent Technologies can be used to provide flexible and standards-based WLAN transmitter analysis.

It is assumed that you already have a basic understanding of 802.11a, b, and g WLAN technologies. For more information on WLAN technologies and measurements, please refer to the Related Literature section at the end of this application note.

This WLAN transmitter analysis toolkit will be based on :

- **89600 software**
 - 89601A Vector signal Analysis software with WLAN Option B7R provides in-depth and flexible WLAN signal and modulation analysis
 - 89607A WLAN Test Suite provides standards-based WLAN transmitter testing only
- **Infiniium 54830 Series oscilloscopes** for baseband analysis and digitization for low cost RF analysis
- **ESA-E Series spectrum analyzers with Option H70** for cost effective RF down-conversion and 802.11a,b, and g spectral emissions mask testing

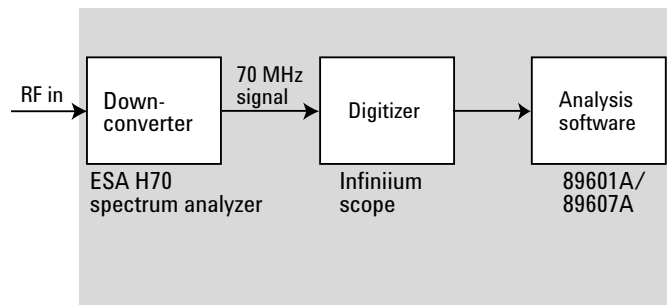


Figure 1. WLAN transceiver test setup block diagram

For RF analysis, the ESA-E spectrum analyzer with Option H70 is used to down-convert the wideband WLAN signal. The scope digitizes the down-converted signal. The 89601A or 89607A software provides control, display, and all analysis and test tools.

For baseband IQ analysis, the Infiniium scope provides two-channel IQ baseband inputs and the 89601A Option B7R software provides the control, display and analysis of the WLAN baseband signals.

While this application note deals primarily with Agilent's Infiniium scope-based hardware solution and the 89607A standards-based WLAN Test Suite software, Agilent offers several other solutions with more advanced performance. See *Appendix A* for a summary table.

Brief Introduction to Wireless LAN

Wireless local area network (WLAN) is a system designed to transfer packets of digital data wirelessly and is basically an extension of the functionality of wired LAN. Wireless LANs allow mobile computer users to connect to a network and access resources while on the move, or without being physically connected to the network.

Over the past few years, several different Wireless LAN technologies and standards have been developed. This application note will concentrate on the IEEE 802.11 standards: 802.11a, 802.11b, and 802.11g.

There are various modulation schemes, data rates, and frequency ranges contained in the IEEE 802.11 WLAN standards, as summarized in the table below.

Table 1. IEEE 802.11 WLAN standards

IEEE Standard	Frequency band	Max data rate (Mbps)	Transmit scheme			
			CCK	PBCC	OFDM	CCK-OFDM
802.11b	2.4 GHz	11	■	Opt		
802.11g	2.4 GHz	36, Opt to 54	■	Opt	■	Opt
802.11a,h	5 GHz	36, Opt to 54			■	

These IEEE 802.11 systems use either direct sequence spread spectrum techniques (DSSS) or orthogonal frequency division multiplexing (OFDM) schemes.

IEEE 802.11b operates in the 2.4 GHz band and uses DSSS techniques to spread the energy in a single carrier over a wider spectrum. Two coding schemes are used in 802.11b to spread the spectrum of a single carrier. CCK (complementary code keying) is mandatory, while PBCC (packet binary convolutional coding) is optional. CCK is used to increase the 802.11b peak data rate to 11Mbps using QPSK modulation. PBCC makes use of forward error correction to improve the link performance when noise is the limitation.

The 802.11g standard is an extension of the 802.11b standard. The 802.11g standard adds 802.11a OFDM transmission modes to the 802.11b standard. This provides the 802.11a throughput improvements in the 2.4GHz band. In addition to the 802.11a OFDM modes, 802.11g also defines optional modes of increased throughput PBCC utilizing 8PSK, and an optional CCK-OFDM mode, which combines the 802.11b preamble with an OFDM packet.

802.11a uses orthogonal frequency division multiplexing (OFDM) as its transmission scheme. OFDM uses multiple carriers. For 802.11a there are 52 carriers in all, 48 of which are used to carry data and 4 which are used as pilots.

The RF carriers in these schemes must be modulated. All the WLAN systems described here use fixed modulation formats for the preamble. Varying data rates are achieved by changing the modulation for the data transmission portion of a packet. In some cases, the modulation format changes during the data transmission. Simpler modulation formats (such as BPSK) are often used in the early part of the burst, which contains important information such as frequency and burst length, because these formats are less prone to bit errors.

802.11b and 802.11g use differentially encoded (D)BPSK and (D) QPSK for data transmission. 802.11a, h, and 802.11g OFDM modes map data symbols using BPSK and QPSK or lower data rates and quadrature amplitude modulation (QAM) schemes for faster bit rates.

Unless you have access to control software for your WLAN device, and can put it into a special test mode, it will not be straightforward to make the device transmit pre-defined data, set frequency channel, or change power levels.

For more detailed information on modulation schemes employed in WLAN standards, please refer to *Application Note 1380-1 RF Testing of Wireless LAN Products*, literature number 5988-3762EN.

Description of a WLAN device

The most common format of a WLAN device is that of a PC (PCMCIA) card suitable for direct connection to a laptop computer.

Electrically, the WLAN card is split into two major sections: the analog RF (PHY layer) and the digital baseband (MAC) processing. The diagram below illustrates a block diagram of a typical WLAN transceiver.

In many cases the baseband transceiver and processing is on a separate chip from the IF and RF transceiver chain, although newer designs may have higher levels of integration.

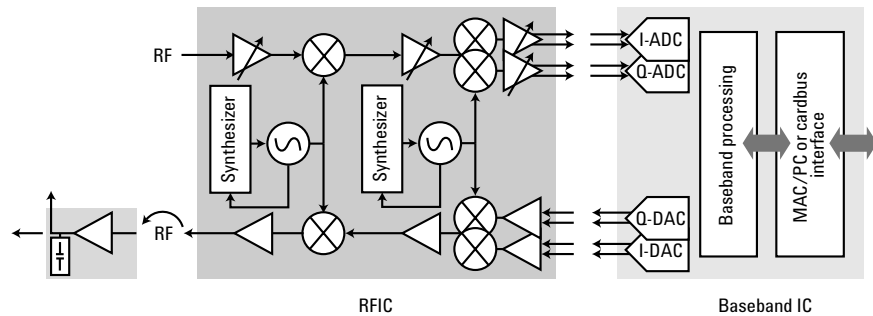


Figure 2. Block diagram of a typical WLAN transceiver

Getting started: Tips on using the Infiniium 54830 Series oscilloscope with the 89601A & 89607A software

In this application note, we will explain how the Infiniium oscilloscope and 89600 software based solutions can be used for transmitter performance verification and troubleshooting at baseband (IQ), IF, and RF points in the WLAN system.

There is a perception that a scope does not have enough resolution for WLAN applications. This is not necessarily the case. The over-sampling performed by the oscilloscopes produces a higher effective resolution than the 8-bit resolution of the scope ADC and provides performance that is much better than originally apparent. Also, the 89601A or 89607A software filters the deep memory records captured by the Infiniium 54830 Series scope down to a narrow span (relative to the scope capture bandwidth). This effectively reduces the noise floor and is analogous to using a narrow resolution bandwidth in a spectrum analyzer to get a lower noise floor. For more information on this subject, the following application note is very helpful: *Spectral Analysis Using a Deep-Memory Oscilloscope Fast Fourier Transform (FFT)*. <http://cp.literature.agilent.com/litweb/pdf/5988-4368EN.pdf>

Running 89600 software inside Infiniium scopes

It is possible to install and run the 89601A and 89607A software on Infiniium scopes that run on a Windows XP® open architecture. This can result in improved measurement speed as data transfer between the scope and an external PC is eliminated.

You can switch between the 89600-based operation and standalone scope operation. The **Disconnect** function in the **Control** menu will allow you to switch to the Infiniium scope display and use it for probing and troubleshooting digital signals. Clicking the 4 key in 89600 tool bar will re-connect the hardware and restart the measurements in the 89600 software.

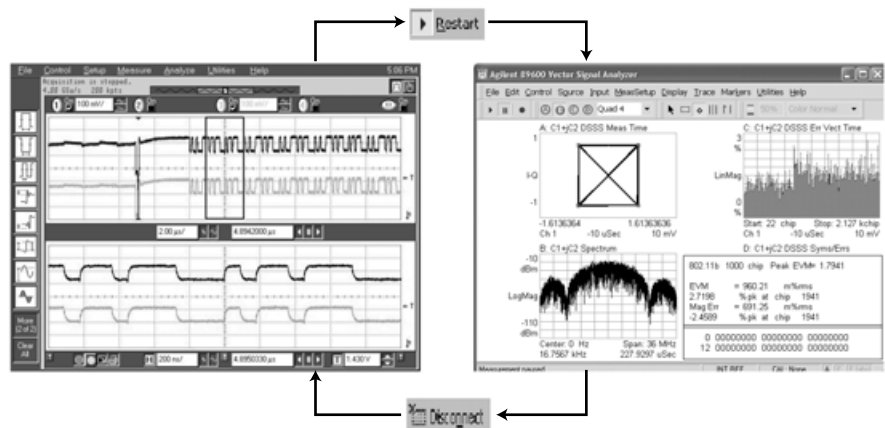



Figure 3. Disconnect and restart of measurement

In this application note, it is assumed that you have the 89601A or 89607A software installed on your Infiniium scope. If you are using PC-based 89600 software and for more in-depth details on the setup of the Infiniium oscilloscopes and the 89601A vector signal analyzer software or 89607A WLAN Test Suite, please refer to *Agilent Infiniium Oscilloscopes Performance Guide using 89601A Vector Signal Analysis Software* (Application Note, literature number 5988-4096EN).

1. Selecting the correct range

It is important to select the optimum amplitude range for the Infiniium 54830 scope to get the best dynamic range and measurement accuracy. If you set the input range too low (more sensitive than necessary), the scope's ADC circuitry can clip the signal and introduce distortion into the measurement. But if you set the input range too high (less sensitive than necessary), there may be a loss of dynamic range due to a poor signal-to-noise ratio.

The autorange function (click the  icon in the 89607A toolbar, or select **Control|AutoRange**) in the 89607A WLAN Test Suite provides a quick and simple way to set the appropriate range for the signal under test. Autorange selects the appropriate range and trigger level for the Infiniium scope to digitize the signal under test.

When using the 89601A software, the range can be selected and changed in the **Input|Range** menu.

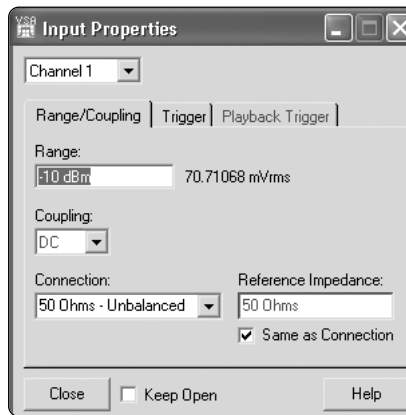


Figure 4. Selecting input properties

The **OVI** indicator on the 89601A display indicates that the scope Channel 1 ADC is over range, and the range should be increased.

Hint: A quick way to change range in 89601A software is to highlight the current range setting in the upper right hand corner of spectrum display, and use the Up/Down arrow keys on your keyboard to increase or decrease the range. Refer to Figure 5.

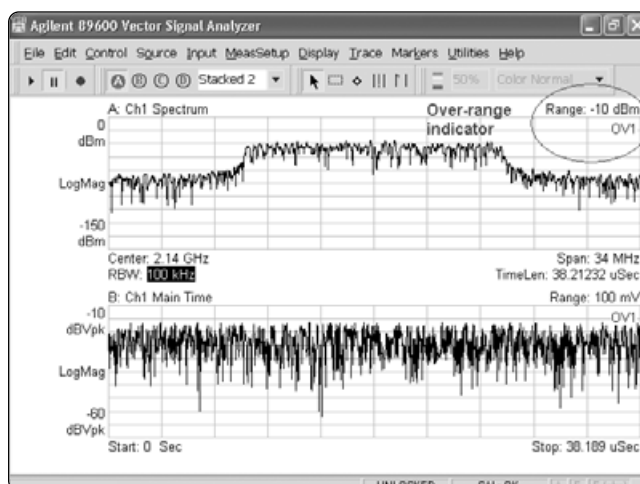



Figure 5. Changing the range

It is sometimes useful to check the signal range on the Infiniium oscilloscope itself. The **Disconnect** function in the **Control** menu will allow you to switch to the Infiniium scope display and view the voltage of the input signal. Hitting the  key in the 89600 tool bar will re-connect the hardware and restart the measurement. Refer to Figure 6.

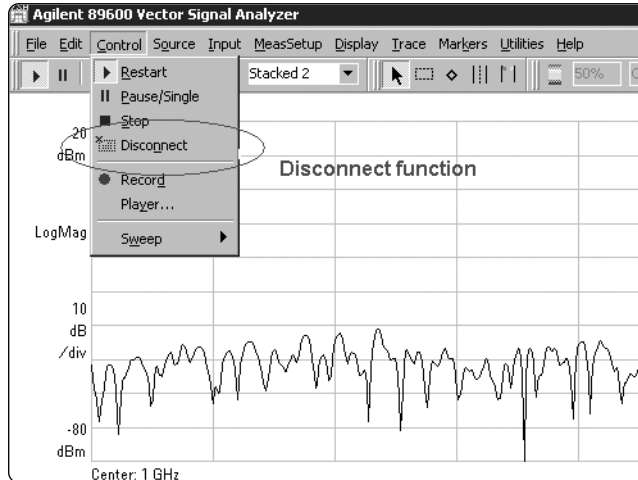



Figure 6. Location of disconnect and restart

2. Triggering

In the 89607A software, using the autorange function  (previously described) also sets up the correct trigger conditions based on the signal under test.

When using the 89601A software, trigger parameters can be selected and changed in the **Input|Trigger** menu. The following tips will help to set up reliable triggering:

- **Trigger Level:** Set the trigger level to be approximately 20 dBm below the average power level of the 802.11a/b/g signal. This should ensure that the trigger level is well above the noise floor but not so high as to cause mis-triggering on the 802.11 signal.

The following table can be used as a guide for setting the appropriate trigger level, assuming a connection with 50 Ω impedance:

Table 2. Recommended trigger levels

Average power of signal (dBm)	Recommended trigger level (mV)
-15	5.6
-10	10
-5	17.8
0	31.6
+5	56.2
+10	100
+15	177.8

- **Trigger Delay:** Set a small trigger delay, say $-10\ \mu\text{s}$, to make sure there is enough data for the 89601A software to correctly detect the start of the burst and use just the burst portion of the signal for modulation analysis.
- **Trigger Hold-off:** Trigger hold-off lets you configure the system to ignore trigger signals for a specified period of time. The next trigger cannot occur for the length of time specified.

Trigger hold-off has two modes in the 89600 software: burst and low duty cycle. Low duty cycle is the traditional hold-off mode, where trigger signals are ignored for a specified period of time. This is the default setting for the 89601A and 89607A when used with Infiniium hardware (can be selected or changed by clicking **Utilities|Hardware|ADC1 Infiniium|Configure|Hold Off Type|Edit|Low Duty Cycle**).

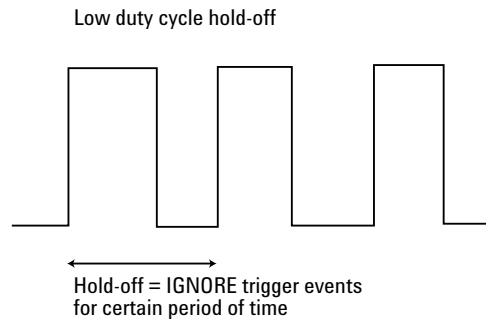


Figure 7. Low duty cycle hold-off

Set a trigger hold-off in low duty cycle mode to prevent re-triggering in the middle of the burst, which will lead to errors in the analysis of the 802.11 burst. Depending on the power transitions in the pulse, it may be appropriate to set a trigger hold off to a length just greater than that of the burst itself. For example, if the burst is $180\ \mu\text{s}$ long, a trigger hold-off of $200\ \mu\text{s}$ should result in the most reliable results.

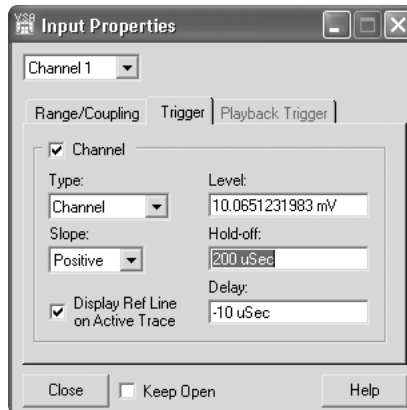


Figure 8. Setting the hold-off time

Burst mode is suited to signals with a high duty cycle. In this mode, hold-off is defined as the amount of time the pulsed carrier signal must be off before a trigger signal can occur.

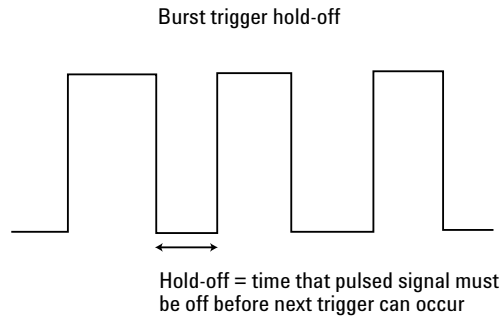


Figure 9. Burst trigger hold-off

If Burst mode trigger is being used (can be selected or changed by clicking **Utilities|Hardware|ADC1 Infiniium|Configure|Hold Off Type|Edit|Burst|Hi Duty Cycle**), set the hold-off time to the minimum “off” time of the pulse, e.g. 1 μ s. Triggering is then independent of the length or “on” time of the signal burst. See the 89600 interactive help for more description on the Burst hold-off mode.

3. Choosing sampling rate

When using the Infiniium 54830 Series oscilloscope as a digitizer, there are trade-offs to be made in terms of sampling rate, measurement speed, and accuracy.

Why does a high sampling rate (at or above the Niquist rate of the scope) produce the best results from a noise perspective? Noise has uniform spectral density and therefore the noise power per Hertz, given a fixed number of frequency bins, is a function of the bandwidth. The inherent noise in the system is “spread” by acquiring the signal using the full bandwidth of the scope. Sampling at less than the bandwidth of the scope distributes the noise over a smaller bandwidth, resulting in more noise per Hertz. Remember, unlike traditional vector signal analyzer hardware, a scope doesn’t have band-pass filters to reduce the noise as the span or bandwidth is reduced.

So, a high sampling rate gives the best accuracy (in terms of demodulation performance like EVM), but due to the increased amount of data to be processed, results in slower measurement speed. The length of available time capture is also affected by sampling rate. Using the highest sampling rate will limit the time record available for analysis.

Figures 10, 11, and 12 show the difference in 802.11a demod performance with sampling rates of 250 Msa/s, 1 Gsa/s and 4 Gsa/s, respectively.

As you can see, the EVM with the 250 Msa/s sampling rate has degraded significantly to approximately 2.6% as opposed to 1.5% with 1 Gsa/s and 1.1% with 4 Gsa/s rates.

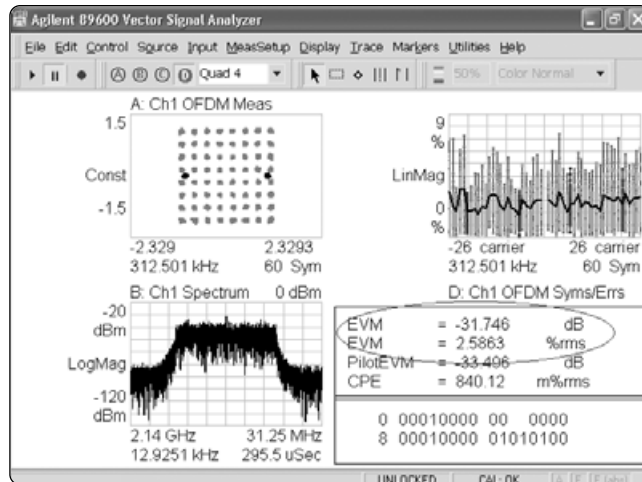


Figure 10. EVM measured with sample rate of 250 Ms/s

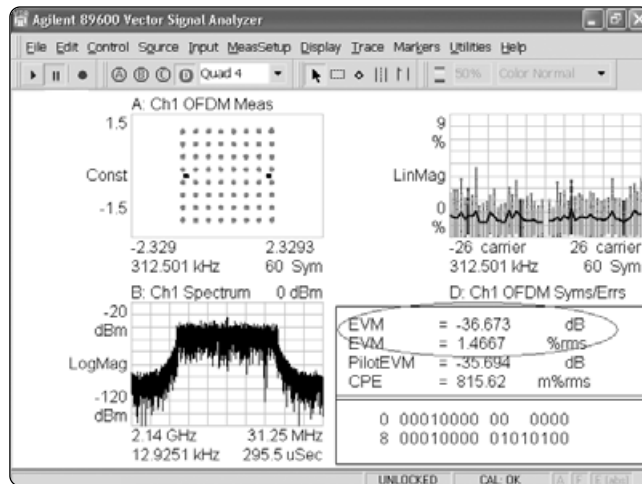


Figure 11. EVM measured with sample rate of 1 Gsa/s

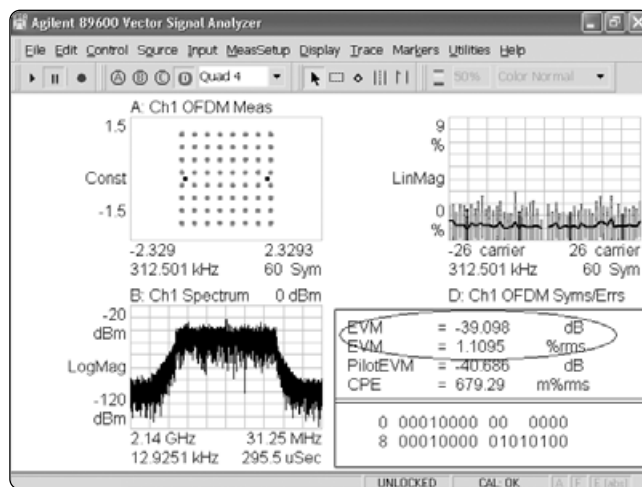


Figure 12. EVM measured with sample rate of 4 Gsa/s

Any limitation to Main Time, Result Length, or Search Time for modulation analysis in the 89601A software will be indicated by an inability of the software to increase the Main Time or decrease the resolution bandwidth (RBW) when the number of frequency points is increased. Maximum Main Time length is normally adjusted by setting the **Number of frequency points** in the **MeasSetup|Res BW** menu. Please refer to *Agilent Infiniium Oscilloscopes Performance Guide Using 89601A Vector Signal Analyzer Software* (Application Note, literature number 5988-4096EN) for details of time capture/sampling rate/span combinations for Infiniium scopes. This application note also explains the relationship between using less than full rate sampling and the effect on the alias-free span using the 89600 software.

Figure 13 shows the relationship between sampling rate, span, and number of frequency points for a 54830 Series scope with 8 M sample memory. A setting of 6401 frequency points with a sample rate of 1 Gsa/s and a span of 36 MHz provides several milliseconds of time capture which is sufficient for most WLAN analysis.

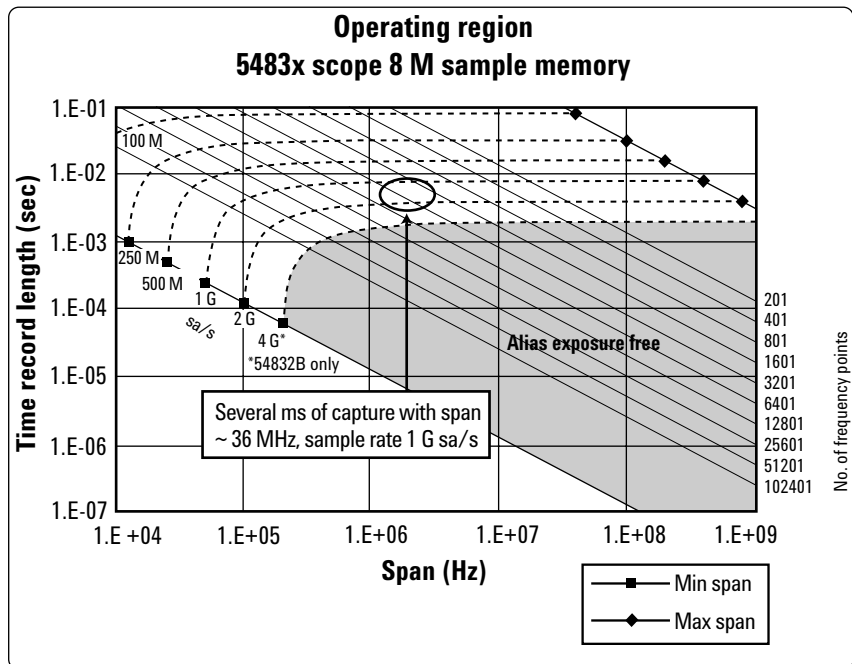


Figure 13. Relationship between span, sample rate, and time record length

We recommend that deep memory oscilloscopes are used because these maximize the amount of data that can be stored and processed. For the 54830 Series scopes, Option 080 provides 16 Mbytes of memory with either single channel or two channel I+jQ (Channel 1 and Channel 3) operation.

Changing sampling rate

When using the 89601A and 89607A software, the default sample rate for the 54830 Series oscilloscopes is 1 Gsa/s. This gives both good accuracy and a reasonable measurement speed. You can, however, change the sample rate to suit your test needs. The sample rate can be changed to a user-selectable value by changing the Sampling Rate parameter in the **Utilities|Hardware|ADC** menu.

To change the sampling rate, select the Infiniium scope in the **Utilities|Hardware|ADC** menu and click on the **Configure** tab. Ensure that the **Sample Mode** is set to **User Rate**. Then enter the desired rate in the User Sample Rate dialog box. Refer to Figure 14.

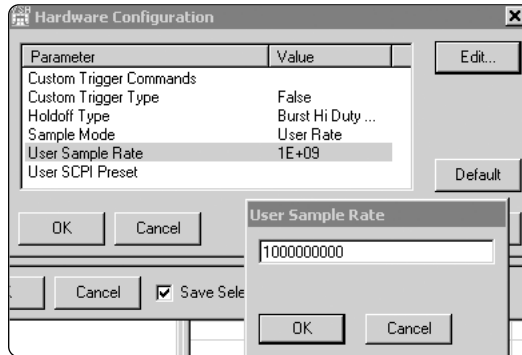


Figure 14. Changing User Sampling Rate

4. Baseband and Zoom mode

The 89600 software makes measurements on signals in the time and frequency domains using either Baseband mode or Zoom mode. The term “baseband” identifies a measurement that has real time-domain data. In baseband mode the signal is analyzed from 0 Hz to the stop frequency. The term “zoom” identifies a measurement that has complex time-domain data. In zoomed mode the signal is analyzed within a specified bandwidth or span, usually centered on the frequency of interest. Zoomed measurements can start at 0 Hz or other frequencies. To view IQ data, you must be in “Zoom” mode. A small number of trigger and trace functions depend on the mode you are in. To view a “real” voltage vs time trace, similar to a traditional scope display, you must be in “baseband” mode and set the Trace format to Real.

To change between baseband and zoom modes, go to the **MeasSetup|Frequency** menu in the 89600 control bar and select **Zoom** or **Baseband** in the **Time Data** dialog box.

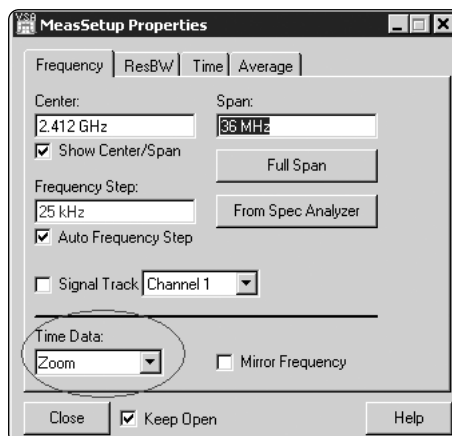


Figure 15. Changing the time data mode

Note: Time Data automatically toggles to Zoom if the start frequency is non-zero.

Low Cost WLAN RF Analysis: Using the Infiniium 54830 Series Oscilloscope, ESA-E Spectrum Analyzer and 89600 Software

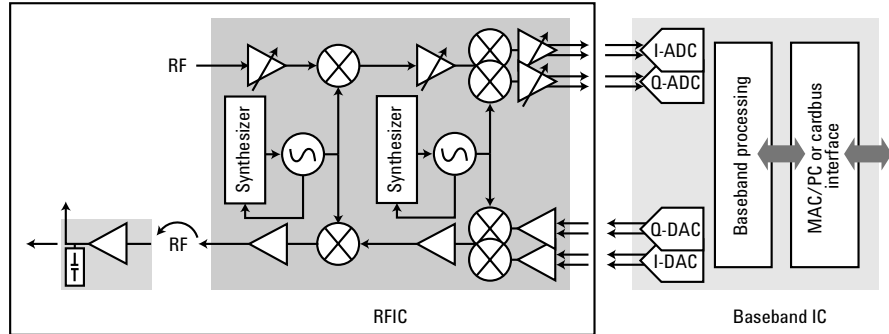


Figure 16. Testing the RF portion of the WLAN transceiver

The WLAN RF transmitter analysis solution used is based on the ESA-E Series spectrum analyzers, the Infiniium 54830 Series oscilloscope, and the 89601A vector signal analysis software or 89607A WLAN Test Suite software. The setup is shown in the diagram below.

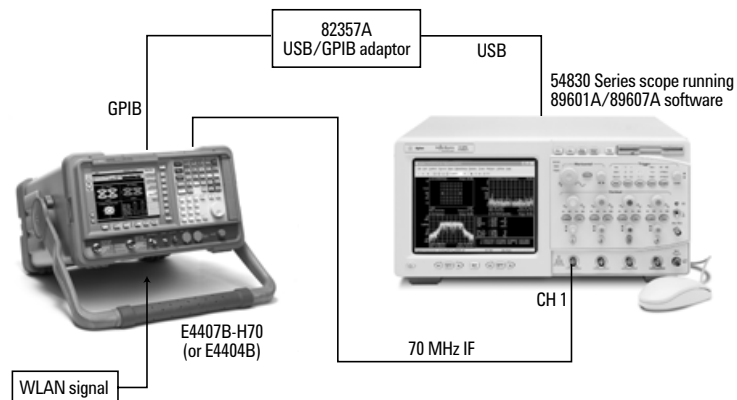


Figure 17. Setup of ESA-E H70 spectrum analyzer and 54830 Series scope running 89601A software

In this setup, the ESA-E spectrum analyzer with Option H70 (70 MHz IF output) is used to down-convert the wideband WLAN RF signal to a 70 MHz IF signal. The scope digitizes the IF signal. The ESA-E spectrum analyzer is controlled by the Infiniium scope via the Agilent 82357A USB to GPIB converter. The 89601A or 89607A software running in the Infiniium scope provides control, display, and all analysis and test tools.

Compensating for clock references within the measurement system

Most RF test equipment has a reference clock signal available for tying together references in a test system.

The Infiniium scopes, being geared toward DC analysis, do not have a clock reference input for synchronization. Although some Infiniium 54830 Series scopes have a 10 MHz reference signal available from the Aux Out port, this reference is not as accurate as the clock reference in the ESA-E spectrum analyzers. Therefore, improvements in timing accuracy will not be achieved in tying the ESA-E reference to the scope Aux Out clock signal.

However, when the spectrum analyzer and the Infiniium scope are not tied together with a common reference, the measurement system will have a constant frequency error offset. This frequency error offset will result in a Symbol Clock Error in 802.11 demod measurements, as shown in Figure 18. Note that the lack of frequency lock also cause a “V” shape in the EVM Spectrum display.

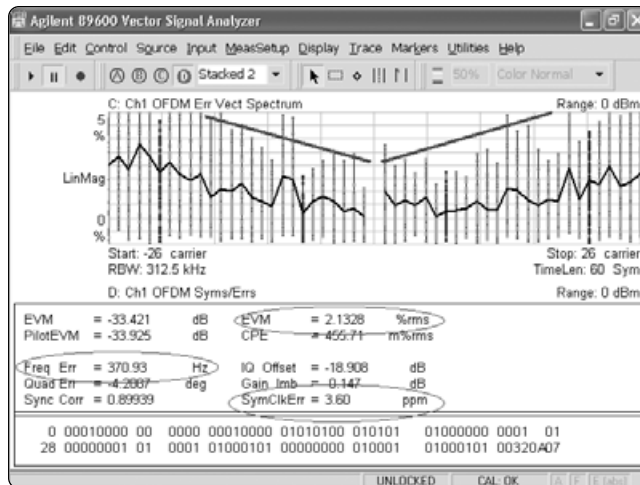


Figure 18. EVM of 2.1%, Symbol Clock Error of 3.6 ppm and Freq Error of 371 Hz with no measurement system reference lock

It is therefore recommended that any offset in reference frequencies is calibrated out of the measurement system.

The 89607A software (version 5.01 and above) provides the facility to compensate for this frequency offset between the ESA-E and the scope. Click on **Utilities|Single Cal.**

This routine leads you through the process of connecting a 10 MHz reference signal from the tuner (from ESA-E 10 MHz Ref Out port) to Channel 1 of the scope.

The 89607A software then calculates the offset (in ppm) between the tuner 10 MHz reference and that measured by the scope. This offset, called the ADC Clock Offset parameter, is then used to pre-compensate the results in the 89607A WLAN Test Suite to remove this frequency offset from the center frequency tolerance and chip/symbol clock tolerance results. Refer to Figure 19.

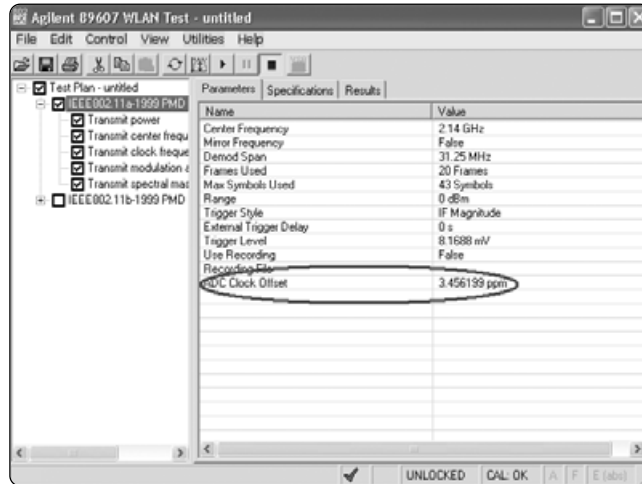


Figure 19. ADC Clock Offset

Please note that if the Test Plan or Test Set is preset, this parameter will be deleted and won't be applied to the measurements.

The calculated ADC clock offset can also be used to pre-compensate results in the 89601A Option B7R software (i.e. not the 89607A Test Suite). See step 7 for details.

If you are not using the 89607A version 5.01 or above, the flexible modulation analysis capabilities of the 89601A Option AYA can be used to determine the frequency offset. The following steps show how:

1. Connect your 10 MHz reference signal (e.g. from ESA 10 MHz Ref Out) to the scope Input channel 1.
2. In 89601A, click on: **MeasSetup|Center Freq** and set it to 10 MHz. Set the **Span** to approximately 300 kHz.
3. Turn on FM Analog Demod. Go to **MeasSetup|Demod|Analog Demod**. Select **FM** and click on the **Auto Carrier Frequency** check box.
4. Display the demodulated spectrum. Click on **Trace|Data|Ch1:Demod|Spectrum**.

5. Use the auto carrier frequency marker function to measure the deviation from the 10 MHz reference signal. Click on **Marker|Function| auto carrier frequency**.
6. In the example, Figure 20, the marker readout was 10,000,035.9 Hz, giving a deviation of 36 Hz which equates to 3.6 ppm.

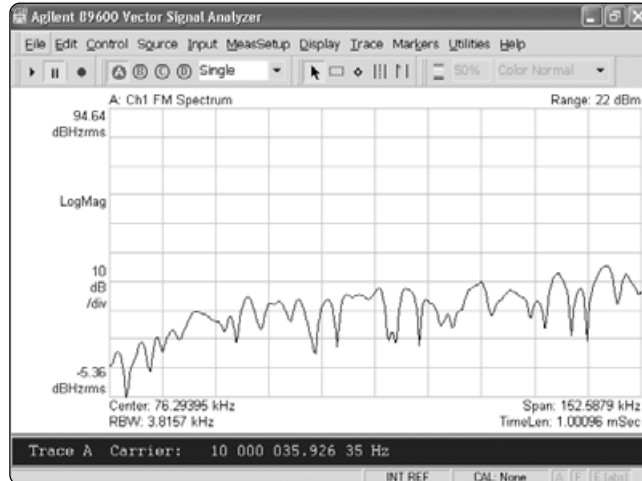


Figure 20. Calculating deviation from 10 MHz reference signal

7. Use this ppm offset figure to pre-compensate symbol clock error and frequency error results. Symbol clock error can be pre-compensated by modifying the subcarrier spacing (for OFDM) or symbol clock (chip rate) in 802.11b. Frequency offset can be pre-compensated by adding a correction factor to the center frequency.
 - a. For subcarrier spacing adjustment in OFDM: 3.6 ppm offset on a subcarrier spacing of 312.5 kHz = 1.1 Hz
 - i. In **MeasSetup|Demod Properties|Advanced|Subcarrier Spacing**, enter 312.5011 kHz

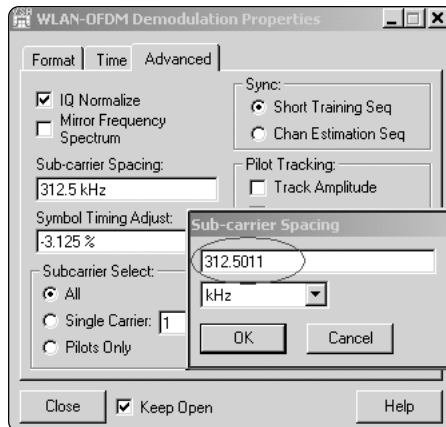


Figure 21. Setting the subcarrier spacing in MeasSetup

- b. For chip rate adjustment in 802.11b: 3.6 ppm offset on a chip rate of 11 MHz = 39.6 Hz
 - i. In **MeasSetup|Demod Properties|Advanced|Symbol Rate**, enter 11.0000396 MHz

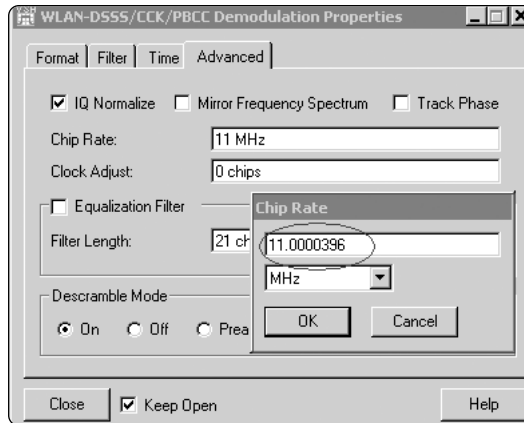


Figure 22. Setting the chip rate

c. For frequency adjustment with the ESA H70/Infinium system, the offset will be from the 70 MHz IF frequency that is connected to the scope input. You must calculate the frequency offset of that (3.6 ppm of 70 MHz = 252 Hz), and then apply this correction factor to the measured center frequency. For example, add 252 Hz to a center frequency of 2.14 GHz

- i. Click **MeasSetup | Frequency Center**, enter 2.140000252 GHz

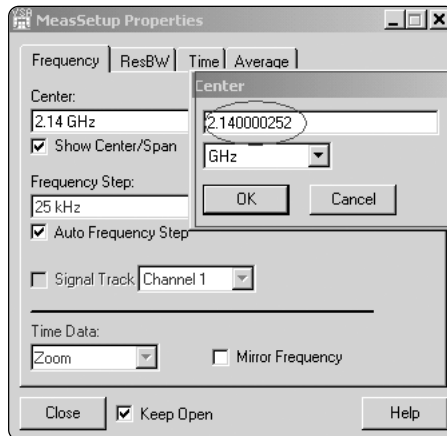


Figure 23. Adding correction factor to center frequency

Figure 24 shows the difference in demod results when the frequency offset has been calibrated out. As you can see, the EVM has improved and both frequency error and symbol clock error have been reduced.

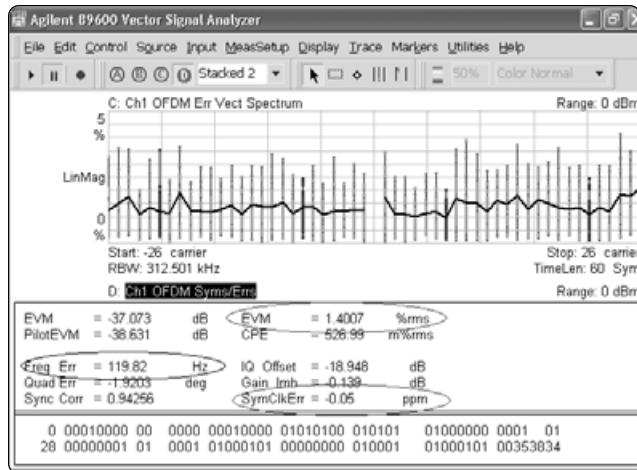


Figure 24. EVM of 1.4%, frequency error of 120 Hz, symbol clock error of -0.05 ppm once reference clock offset has been calibrated out

89600 software analysis solutions

The 89601A vector signal analysis software with WLAN Option B7R provides in-depth flexible 802.11a, b, and g vector modulation analysis.

89607A WLAN Test Suite provides standards-based WLAN transmitter testing only. The 89607A WLAN Test Suite is included in 89601A Option B7R.

To perform in-depth WLAN analysis using the 89601A Option B7R, follow the tips on triggering, range, sampling rate, and so forth, given in the previous section.

Go to the **MeasSetup** Menu and set the desired center frequency (e.g. 2.14 GHz for 802.11b analysis). Set the measurement **Span** to between 30 to 36 MHz.

Once you have set up range and triggering you should be able to see the characteristic spectrum shape of your 802.11a, b, or g signal.

To perform modulation analysis on your WLAN signal, go to **MeasSetup|Demod|Wireless Networking** and either **OFDM** (for 802.11a or 802.11g OFDM analysis) or **DSSS/CCK** for 802.11b analysis. You can now view the constellation diagram, modulation metrics, demodulated symbols, search time, or any other of the results available in the **Trace|Data** menu. The screen shots below show modulation metrics and search time for a 802.11b QPSK signal.

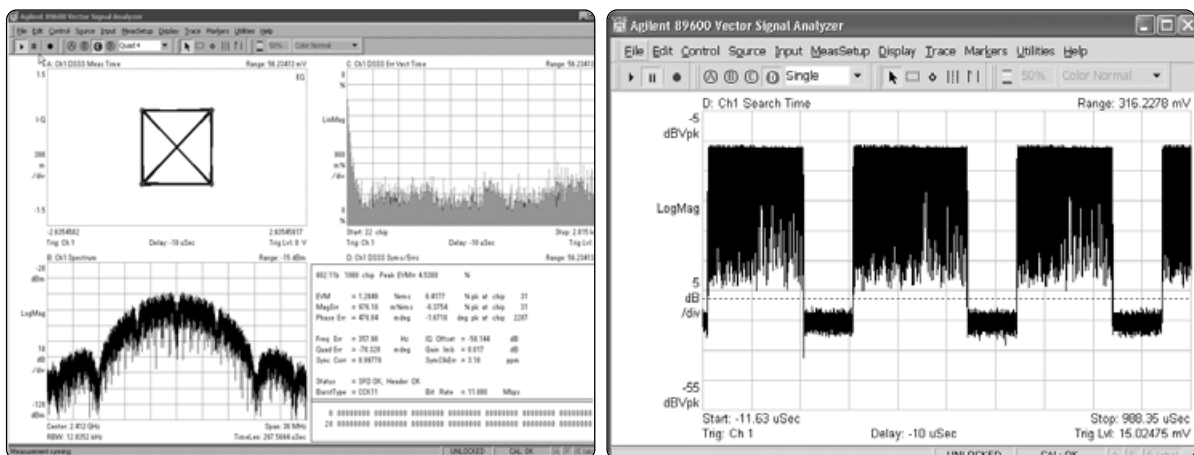


Figure 25. Modulation metrics and search time for 802.11b QPSK signal

The 89607A WLAN Test Suite software provides automatic one-button tests based on the parameters and specifications set out on the 802.11a, b, and g standards. The 89607A software is ideal for characterizing overall PHY layer performance of your WLAN transmitter. Its features include:

- Pre-sets for 802.11a WLAN PHY layer transmitter tests
- Pre-sets for 802.11b WLAN PHY layer transmitter tests
- 802.11g WLAN PHY layer transmitter tests
- Simple test setup and activation
- Pass/Fail test with measured data
- Display of test values and test results
- Test report generation capability
- Complete help text
- User settable test limits and parameters
- COM interface for integration with other applications

Running 89607A WLAN Transmitter tests

In this section, we will focus on the 89607A WLAN Test Suite software.

The following transmitter tests are provided by the 89607A WLAN Test Suite software:

802.11a

- Transmit power
- Transmit center frequency tolerance
- Transmit clock frequency tolerance
- Transmit modulation accuracy
- Transmit spectral mask

802.11b

- Transmit power
- Transmit center frequency tolerance
- Chip clock frequency tolerance
- Transmit RF carrier suppression
- Transmit modulation accuracy
- Transmit power up ramp
- Transmit power down ramp
- Transmit spectral mask

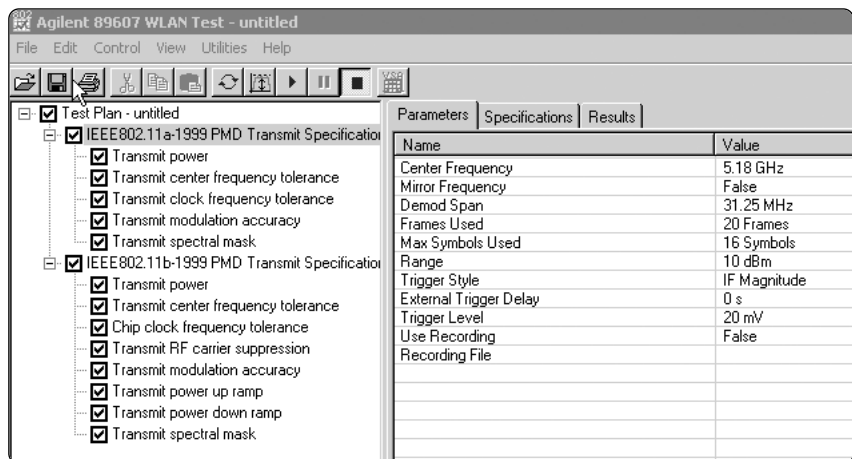




Figure 26. Selecting and de-selecting tests

The tests can be selected and de-selected by checking the tick box beside the test.

Once the desired tests have been selected, click the  key and the test sequence will be carried out and the pass or fail result given.

The test sequence can be continually run (click the  key), or set to run until a fail occurs (select **Stop on Failure** in the **Control** menu). Refer to Figure 27.

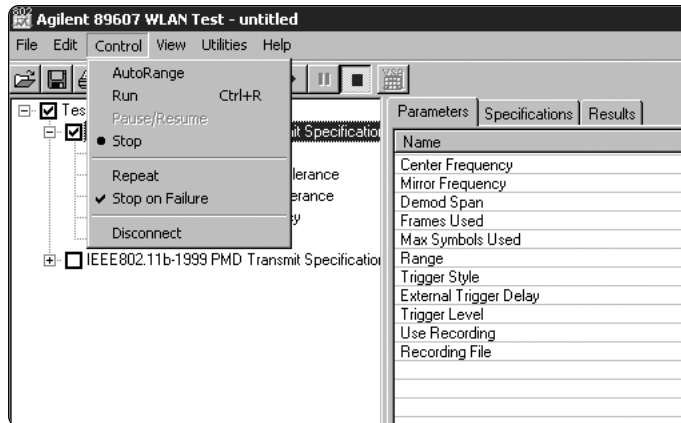


Figure 27. Running the test sequence

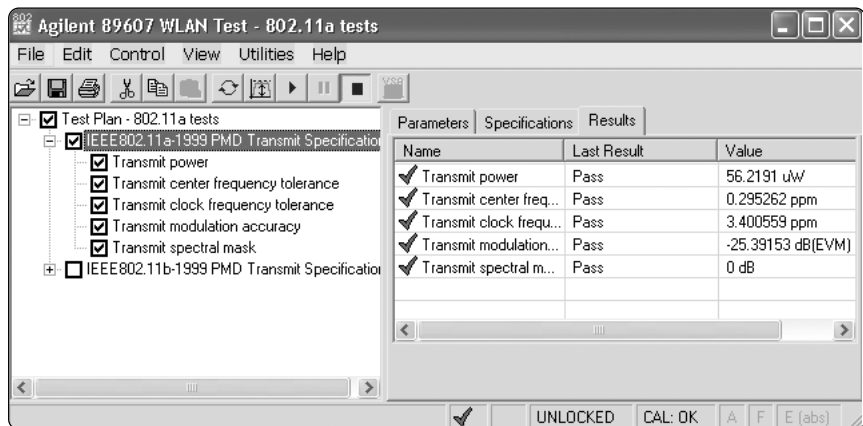


Figure 28. All tests passed

The acquisition data can also be displayed by selecting **View|Acquisition Data**.

The display then shows the captured data. This is useful as a quick check that the captured data looks correct.

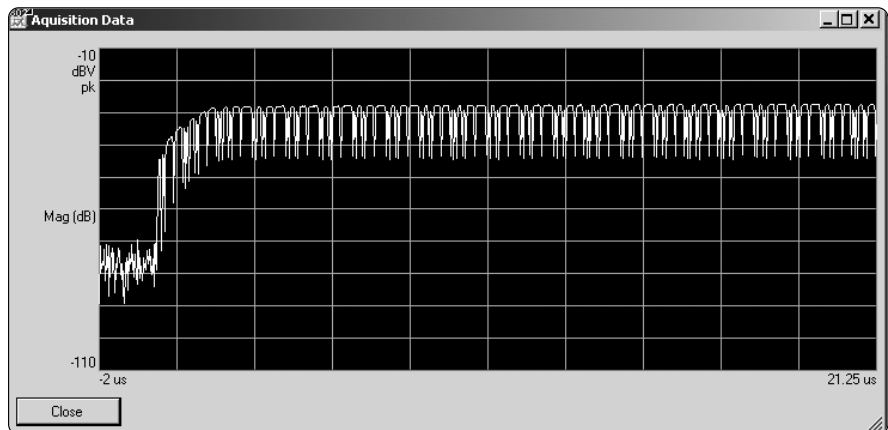


Figure 29. Captured data viewed by selecting View, Acquisition Data

Setting system parameters

System parameters such as frequency, span, and trigger levels can be changed in the **Parameters** tab.

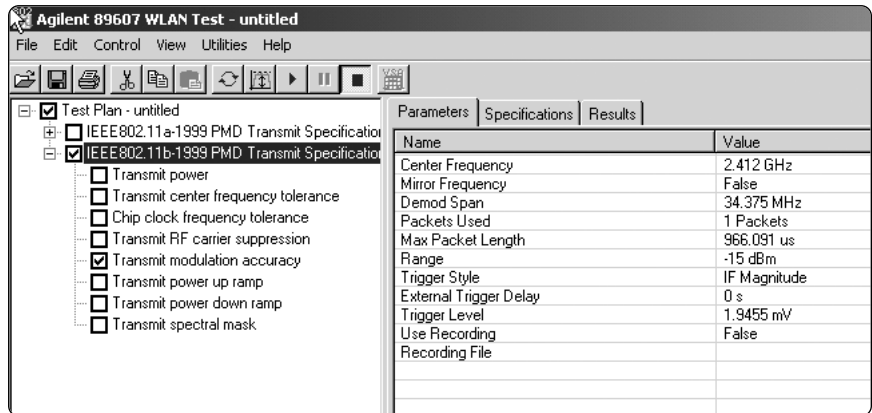



Figure 30. Setting system parameters

The autorange function  provided in the 89607A WLAN Test Suite provides a quick and simple way to set the appropriate range for the signal under test. AutoRange selects the appropriate range and trigger level for the Infiniium 54830 Series scope to digitize the signal under test.

Setting test limits

Clicking on the **Specifications** tab lets you set your own test limits for each of the transmitter tests. The default settings are taken from the IEEE 802.11a - 1999 and IEEE 802.11b - 1999 standard specifications.

For example, to set the test limit for transmit average power, click on the **Transmit Power** test, and then the **Specifications** tab. Click on the Total Power entry in the list.

You can then choose to change the maximum average power limit from 40 mW to a limit of your choice.

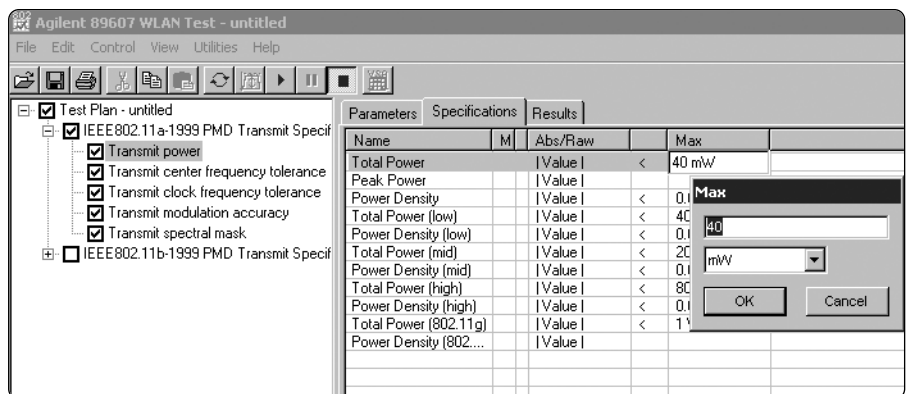


Figure 31. Setting test limits

Viewing test results

By highlighting an individual test and clicking on the **Results** tab, more detail is given on the individual test results.

The display below shows 802.11a spectral mask test results and the test limits.

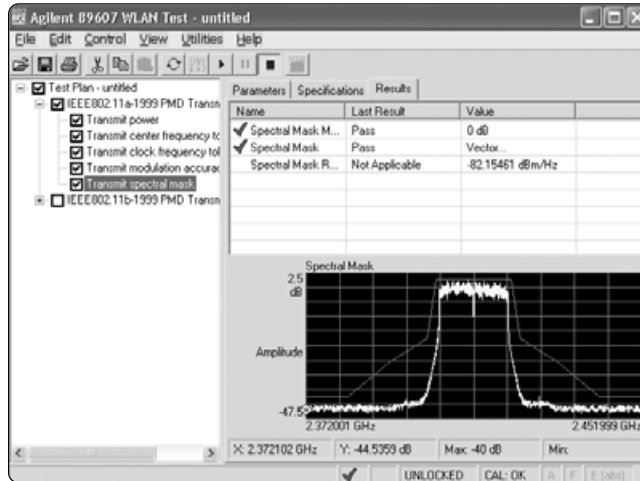


Figure 32. Viewing test results

802.11g testing

IEEE 802.11g defines two different OFDM modulation formats. One, which is mandatory in 802.11g, is an exact copy of the 802.11a format except that the carrier frequencies are in the 2.4 GHz band. Use the 802.11a tests for measuring 802.11g OFDM mode transmissions. You must modify the **Center Frequency** to match your transmitter. Because the channels are assumed to be 802.11a channels (based off 5 GHz instead of 2 GHz), enter the Center Frequency in “Hz” rather than in “Channel” units. Also, remember that 802.11g channel separation is 25 MHz compared to 20 MHz for 802.11a.

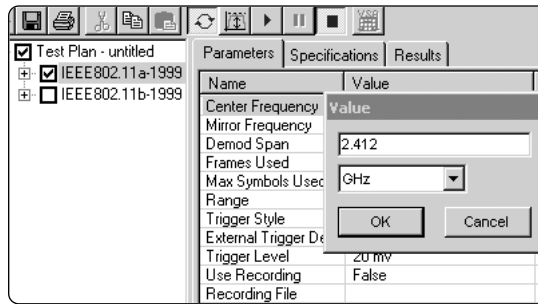


Figure 33. Changing the Center Frequency to measure 802.11g OFDM

The specification limits for the **Center Frequency Tolerance** and **Clock Frequency Tolerance** can be relaxed to ± 25 ppm, less stringent than the 802.11a standard.

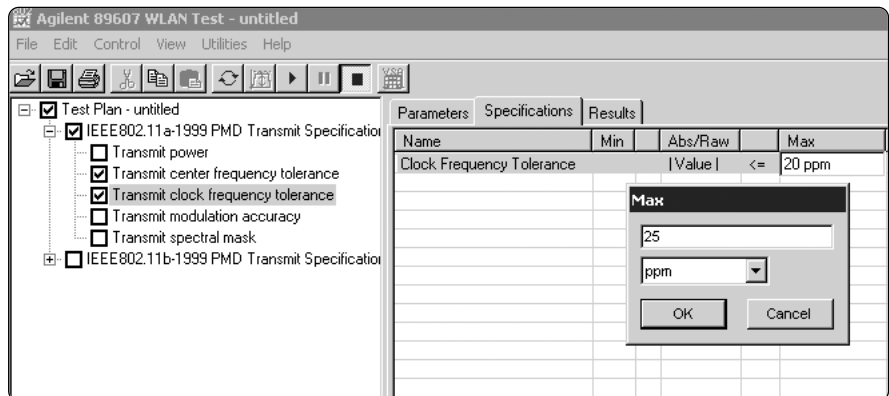


Figure 34. Setting the Clock Frequency Tolerance

Spectral mask testing using the ESA-E spectrum analyzer

The ESA-E spectrum analyzer may be used “stand alone” to make measurements. Its >52 dB dynamic range exceeds that needed for 802.11a/b/g spectrum emissions mask testing.

The ESA-E Power Suite default settings allow mask tests according to the basic IEEE specs. It is also possible to adjust RBWs, detector types and mask limits for specific regulatory regions. ESA firmware revision A.10.00 with Power Suite revision A.06.03 or above is required for automated setup of WLAN spectrum emissions testing.

The following takes you through the steps needed to activate the Spectrum Emissions Mask function from the front panel of the ESA-E spectrum analyzer. You must use the 89607A **Disconnect** function from the **Control** menu before operating the ESA in this mode.

- Press **Mode**, {**Spectrum Analysis**}
- Select **Mode Setup**, {**Radio Standard**}, {**More 1 of 3**}, {**More 2 of 3**}, {**WLAN**}
- Select the appropriate standard: **802.11a**, **802.11b**, **802.11g**
- Select **Measure** {**More 1 of 2**}, {**Spectrum Emissions Mask**}

The ESA-E spectrum analyzer will then step through the appropriate frequency bands and indicate a pass or fail result in relation to the relevant standard.

Note: The average power is also displayed. For bursted signals, it needs to be corrected by $10 \log [t_{ON} / (t_{ON} + t_{OFF})]$.

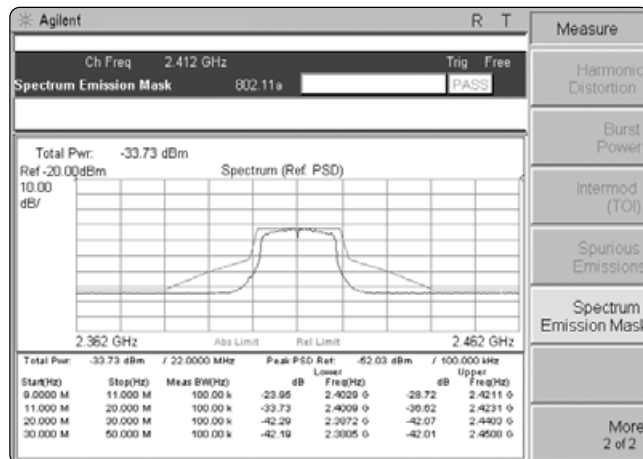


Figure 35. 802.11a spectrum emissions test using ESA spectrum analyzer

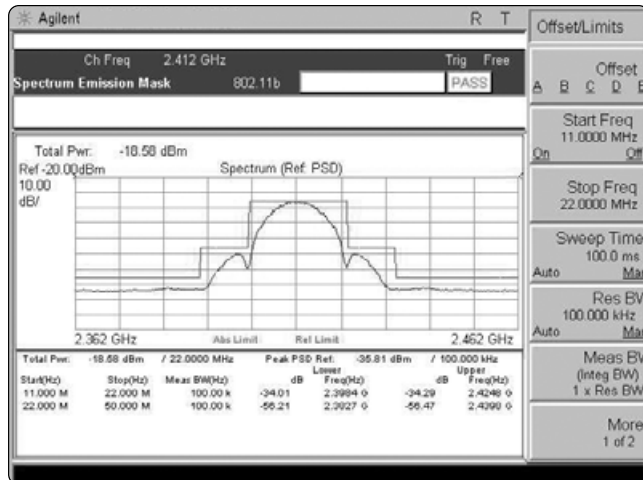


Figure 36. 802.11b spectrum emissions test using ESA spectrum analyzer

ETS 300-328 maximum power spectral density test

The maximum power spectral density test in ETS 300-328 [section 7.2.2] calls for a 1 MHz resolution bandwidth (RBW), and a positive peak detector. The power spectral density measurement is made as part of the Power Suite WLAN spectrum emissions mask function. To make the ETS 300-328 maximum power spectral density test, the settings for RBW and detector type can be changed to comply with this standard.

The RBW needs to be set to 1 MHz and the detector type changed from average to peak.

After following the steps given above for enabling the Power Suite spectrum emissions measurement:

- Press **MeasSetup**, **{Ref Channel}**, **{Res BW}**, and set to **1 MHz**
- Press **Det/Demod**, **{Detector}** and set to **Peak**

The spectrum analyzer then gives a reading of PSD/MHz.

The characteristics of the detector function in 89607A WLAN Test Suite are similar, but not identical to the ESA-E spectrum analyzer. We therefore recommend using Powersuite in the ESA-E spectrum analyzer to run critical WLAN spectral mask tests.

If you do prefer to use the spectral mask test contained in the 89607A WLAN Test Suite, the techniques listed below will enable testing in cases where only the side lobes close to the carrier are of interest.

- Ensure the dynamic range is optimized according the steps listed in the 89607A Troubleshooting section.
- Change the “spectral mask span” parameter to fit the region of interest (e.g. 34 MHz). This will remove the portion of the mask that requires high dynamic range.
- Modify the spectral mask to use a less restrictive noise floor value for 802.11b tests.

Spurious testing using the ESA-E spectrum analyzer

If you need to perform spurious emissions tests, the E4407B ESA-E spectrum analyzer provides swept spectrum analysis up to 26.5 GHz – ideal for 3rd or 5th harmonic searching in 802.11 systems.

Using Infiniium 54830 Series Scope & 89601A Software for WLAN Baseband IQ Analysis

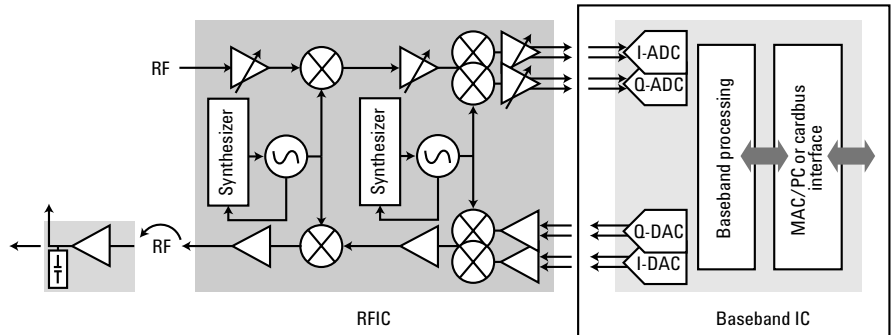


Figure 37. Testing the baseband portion of the WLAN transceiver

Using 89641 VXI hardware vs Infiniium scopes for baseband analysis
 There are various configurations available for baseband (I/Q) analysis using the 89601A vector signal analysis software.

The 89641 VXI hardware with baseband modules offers 36 MHz bandwidth which is ideal for WLAN analysis, along with first-rate phase noise, dynamic range and amplitude accuracy. Combine this with an optional 384 MSa signal capture memory and you can easily analyze WLAN signals.

The Infiniium scope offers wide bandwidth (>36 MHz) and general analog and digital scope-based analysis capabilities BUT has lower resolution and dynamic range. The Infiniium scope is also less expensive than the 89641 VXI hardware.

This application note will focus mainly on the Infiniium oscilloscope-based solution for WLAN analysis. For more information on the 89641 VXI solutions, visit: <http://www.agilent.com/find/89600>

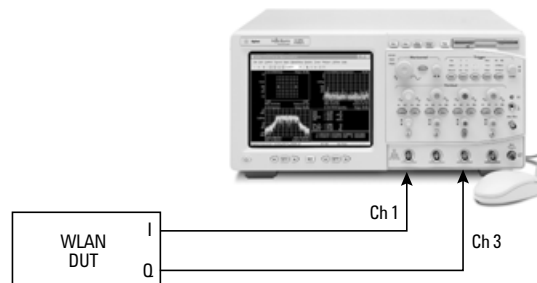



Figure 38. Setup of Infiniium and 89601A software for baseband analysis

In this setup the Infiniium 54830 scope is running 89601A vector signal analysis software with Option B7R WLAN modulation analysis software. The baseband I and Q signals are connected to Channel 1 and Channel 3 of the scope.

Note: You must use Channels 1 and 3 on the scope for the 89601A software to operate correctly. This is because 54830 Series scopes “interleave” memory, meaning that you will only get half the memory and half the sample rate if you use channels 1 and 2, instead of Channels 1 and 3. Such reductions in memory and sampling rate will lead to poorer EVM performance and eventually aliasing, which can give incorrect results or result in no demodulation at all.

Remember that you can switch between the 89600-based operation and standalone scope operation. The **Disconnect** function in the 89600 **Control** menu will allow you to switch to the Infiniium scope display and use it for probing and troubleshooting digital signals. Hitting the  key in the 89600 tool bar will re-connect the hardware and restart the measurements.

Baseband analysis: Optimizing your measurement system

Probe calibration for single ended measurements

If you are using oscilloscope probes to directly probe your baseband signal and plan to operate the scope both standalone and with 89601A software, it is good practice to carry out the standard probe calibration process.

Note: we recommend using the Agilent InfiniiMax 1130 Series active probing system with the 11314A probe amplifier for direct probing as these probes offer enough bandwidth to cover both baseband and IF probing for WLAN systems. Each InfiniiMax probe amplifier supports both differential & single-ended measurements for a more cost effective solution

Connect your Channel 1 probe to the calibration signal connector on the scope front panel (indicated by a square wave signal). Press the Autoscale key and adjust the timebase to view the square wave pulse. Using the accessory “screwdriver” provided with the probe, adjust the probe until you get a “perfect” square wave with no overshoot or slew on the rising edge. Then repeat this process with the Channel 3 probe.

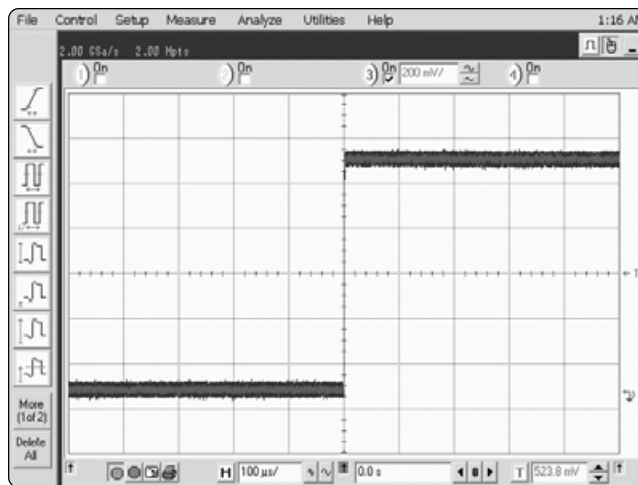


Figure 39. Infiniium scope display showing square wave during probe calibration

If the probes are not well calibrated, the measurement results will be degraded. As shown in Figure 40, the results are degraded because one of the scope probes has not been calibrated, as can be seen by the “slewed” square wave.

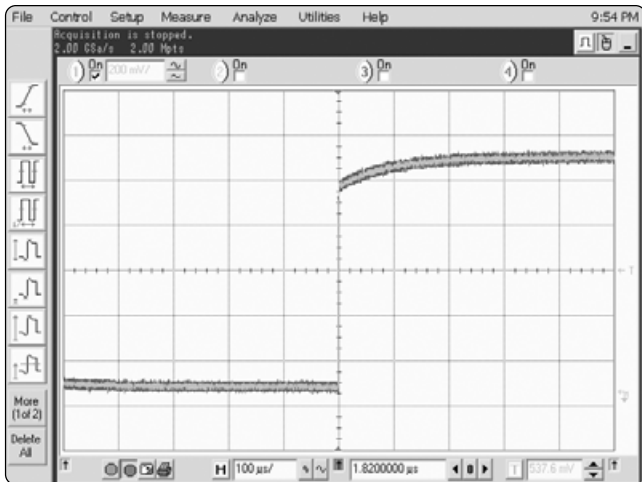


Figure 40. Displays show degrading due to uncalibrated probe

Once the probe has been calibrated, a much improved measurement result is possible.

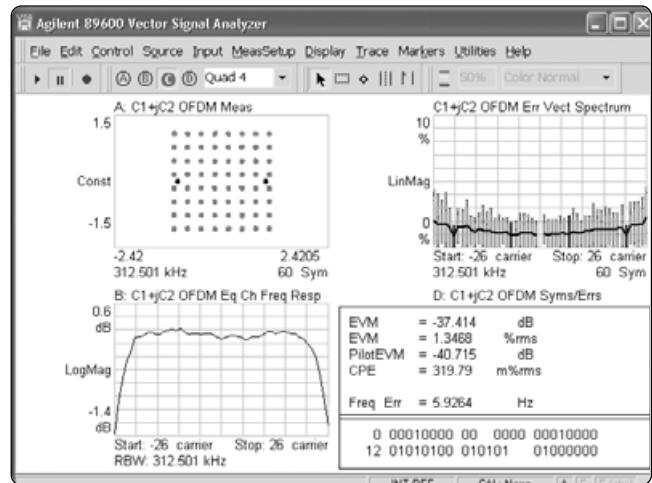
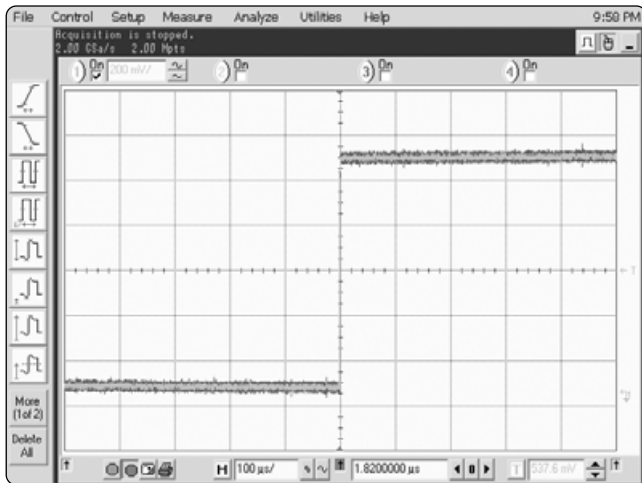
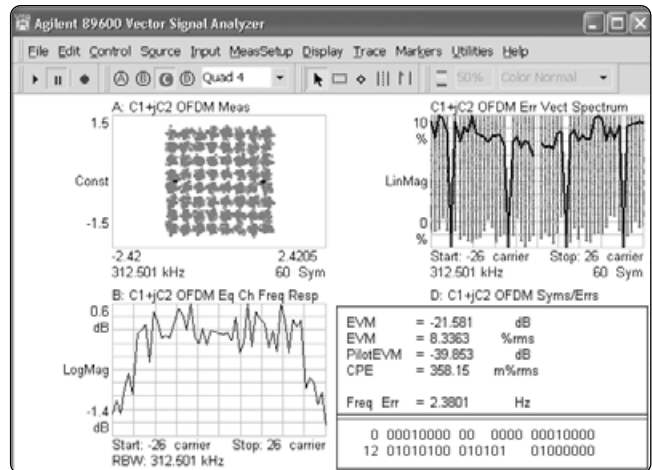


Figure 41. Improved measurement results after calibrating probes

Calibrating Infiniium scope channels for IQ gain, imbalance, and DC offset

It is important to calibrate the two 54830 scope channels for IQ gain, imbalance, and DC offset to ensure you have the optimum measurement system.

Effects of gain & delay imbalance between I and Q channels

IQ errors result in a loss of orthogonality between subcarriers. IQ gain imbalance causes interference between frequency mirror-image subcarriers. This shows up on constellation diagrams, as shown below. Here you can see that each QPSK subcarrier has suffered from QPSK interference with its mirror-image. This results in a spreading to four constellation points in each corner. The BPSK pilots are split into two horizontal dots.

In addition to delay, different cables can have different losses and other different characteristics. Therefore, we recommend that you use identical cables to connect to the scope channels in order to minimize the effects of channel gain and delay mismatch.

For more information on the effects of IQ errors in OFDM systems, refer to Bob Cutler's article *Effects of physical layer impairments in OFDM systems*, RF Design magazine.

As with any IQ signal paths, gain or delay imbalance between the two channels of the Infiniium 54830 Series scope will adversely affect the measurement results. Therefore, before starting IQ baseband measurements, it is advisable to calibrate the scope channels to compensate for any such channel mismatch.

Note that, depending on the sampling rate used, the value that may be entered for channel delay compensation is limited by the sampling rate of the scope. For I +jQ measurements, a sampling rate of 1 Gsa/s should be sufficient.


Calibration process to remove effects of delay and imbalance

The following procedure should be followed to calibrate the scope channels 1 and 3 to remove effects of channel delay and gain imbalance:

Using the 89601A software:

1. Change to I+jQ mode
 - a. **Input|Channels|I+jQ**
2. Set range and impedance
 - a. **Input|Range/Coupling**
 - b. You should choose the same range for both channel 1 and channel 3. The Infiniium scope display will update to reflect the range settings. Choose the maximum range possible, i.e., a range that is "full display" on the scope but is not over-ranging (not causing the OV warning on the 89600 display).
 - c. Coupling mode is forced to DC for I+jQ.
3. Set required span. For WLAN measurements, 36 MHz is more than sufficient.

Select **MeasSetup|Frequency**. Enter 36 MHz into **Span** dialog box.
4. Perform a frequency response measurement
 - a. Generate a baseband noise-like signal which has a bandwidth greater than the signal of interest. The E4438C ESG vector signal analyzer with Option 403 (calibrated noise personality) can be used to generate the baseband signal.
 - b. Connect a power splitter to either the I output or Q output connector on the rear panel of E4438C ESG vector signal generator), then connect the signals to channel 1 (I) and channel 3 (Q) of the Infiniium scope. If you are using scope probes, be sure to include them in this measurement.
 - c. Change channel mode to 2 channel: **Input|Channels|2 Channels**

- d. Measure frequency response of channel 2 versus channel 1
 - i. Select trace data: **Trace|Data|ChX|Freq Resp**
 - ii. Make data format log magnitude: **Trace|Format|Log Mag (dB)**
- e. Turn off calibration constants for both channels: Uncheck **Utilities|Calibration|Amplitude|Calibration Constants** for Channel 1 and Channel 2.
- f. Verify measurement looks correct
 - i. Within the span of the signal of interest, the frequency response should be near 0 dB, and should appear stable.
 - ii. If this is not the case, check the cabling, and be sure your signal has the correct bandwidth and power.
- g. Turn on RMS averaging
 - i. **MeasSetup|Average|Average Type| RMS (Video) Exponential**
 - ii. **MeasSetup|Average|Count100**
- h. Start measurement by pressing 
- i. Place a marker on the frequency response trace at a point near the desired analysis half-bandwidth point (18 MHz for a 36 MHz double-sided-bandwidth signal). The value of this marker (near 0 dB) represents the required channel 1 gain. Write this value down.

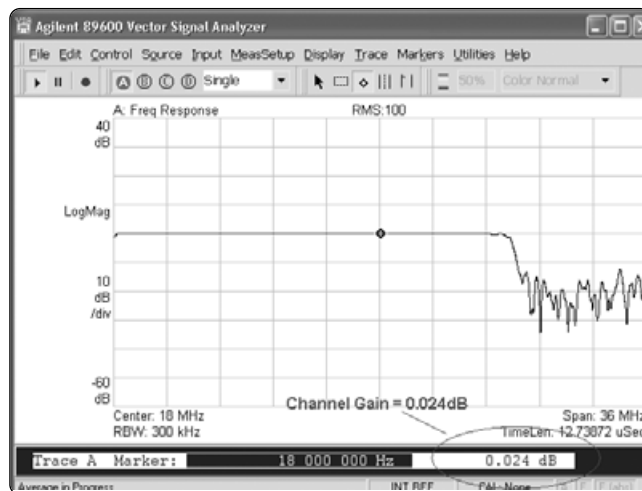


Figure 44. Frequency response of scope channels

- j. Change trace format to display group delay: **Trace|Format|Group delay**
- k. Lengthen the delay aperture to 16%: **Trace|Format|Delay Aperture|16%** Place a marker on the frequency response trace at a point near the desired analysis half-bandwidth point (e.g. 18 MHz for a 36 MHz double-sided-bandwidth signal). The value of this marker (near 0 sec) represents the required Channel 1 delay. This value should be in the <10 nsec region. Write this value down.

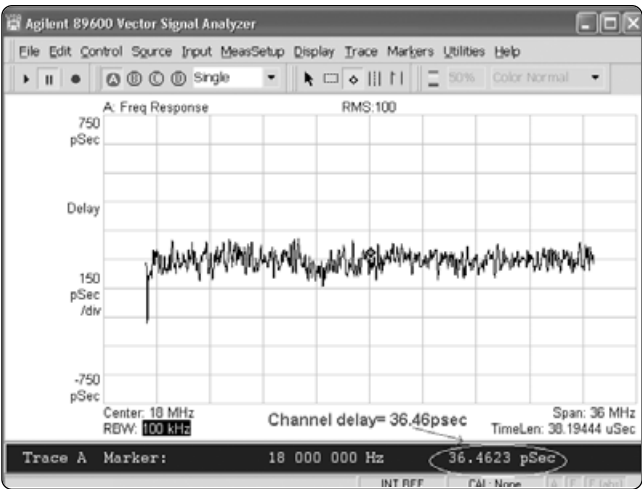


Figure 45. Channel delay between scope channels

- i. Adjust the calibration constants
 - i. Place the channel 1 gain value into **Utilities|Calibration|Amplitude|Calibration Constants|Gain** for channel 1.
 - ii. Place the channel 1 delay value into **Utilities|Calibration|Amplitude|Calibration Constants|Delay** for channel 1.
 - j. Enable calibration constants using the **Utilities|Calibration|Amplitude|Calibration Constants** check box for channel 1.
5. Reselect I+jQ mode from **Input|Channels|I+jQ**

Removing DC offset from the input signal

It is also important to remove DC components such as carrier leakage from the measurement setup. Any significant DC component will limit the dynamic range of the measurement. Figure 46 shows a significant DC component in the spectrum diagram.

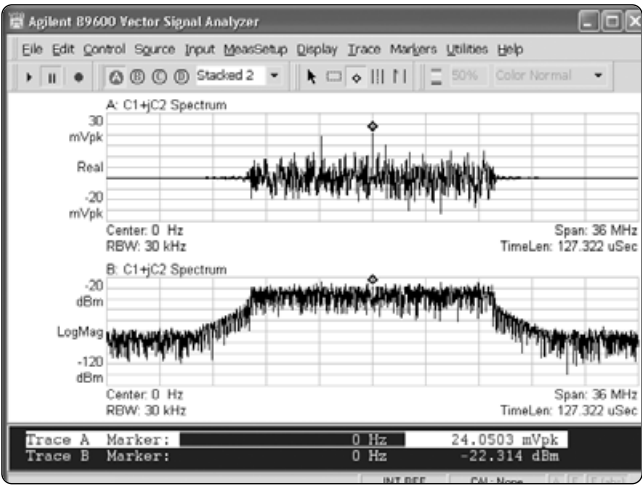


Figure 46. Carrier feedthrough results in a DC component

In demodulated measurements, IQ offset error indicates the magnitude of carrier feedthrough. In this example, the carrier feedthrough causes IQ offset error of approximately -18 dB.

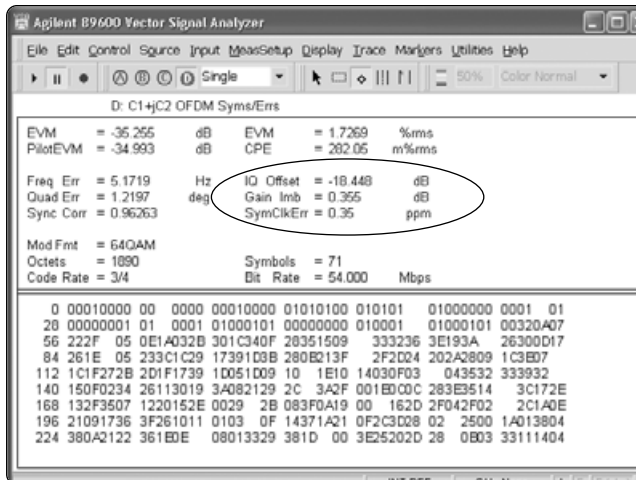


Figure 47. IQ offset error caused by carrier feedthrough

When the DC component due to carrier feedthrough is removed, as shown in the spectrum diagram below, the IQ offset error is reduced to approximately -39 dB.

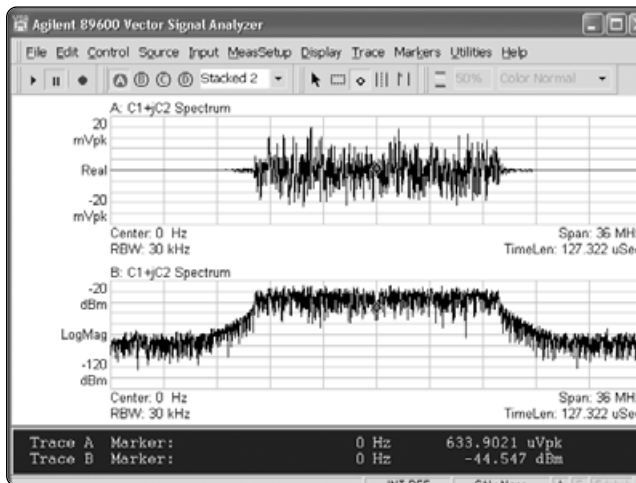


Figure 48. DC component removed

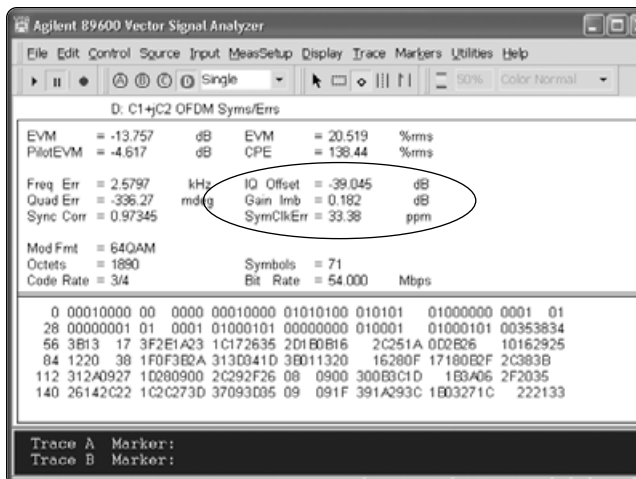


Figure 49. Carrier feedthrough removed

Using the 89601A/89607A cancel IQ DC macro

The 89601A VSA software and 89607A WLAN Test Suite software both contain a macro to automatically compensate for DC offset.

With the 802.11 baseband signals connected to the scope channels, click **Utilities|Macros** and select the Cancel IqDC macro from the list (the file should be located in 89600A VSA/Examples/Macros directory).

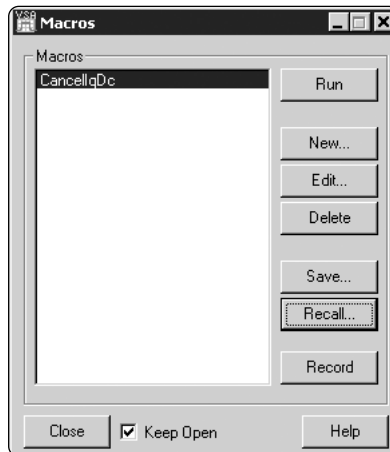


Figure 50. Selecting "Cancel IqDC" macro

The macro will run, calculate the DC offset calibration constant to be used, and automatically enter the value into the Calibration constant menu. The following pop-up window tells you when the macro has completed.

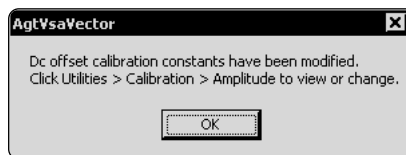


Figure 51. Window pops up when done

Click **OK**, and close the macro window. You can view the DC offset value under **Utilities|Calibration|Amplitude**.

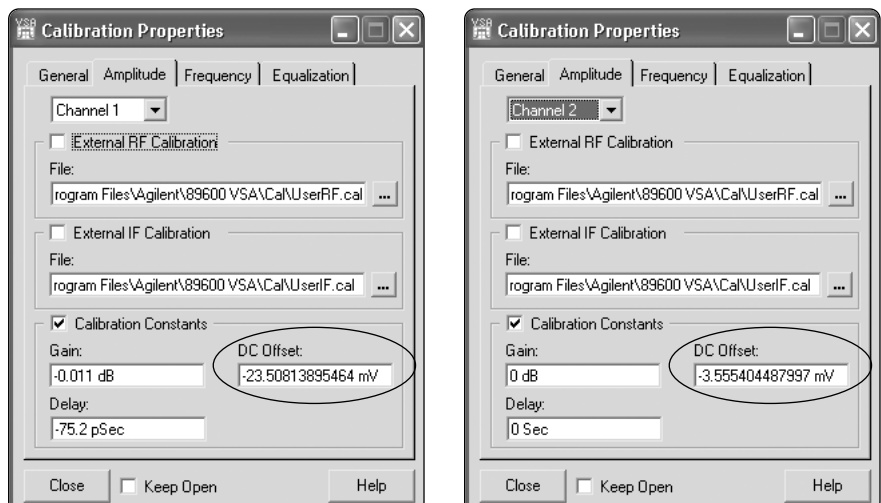


Figure 52. DC offset values for Channels 1 and 3 after running the Cancel IqDC macro

Making WLAN baseband measurements with the 89601A software

Once the scope channels have been calibrated, you are ready to start making measurements.

For baseband measurements, you must make sure you are in **I+jQ mode**.

Select **Input|Channel|I+jQ mode**

Select the **MeasSetup** Menu. The center frequency will have automatically been set to 0 Hz. Set the measurement **Span** to around 36 MHz.

Once you have set up range and triggering, you should be able to see the characteristic spectrum shape of your 802.11a, b, or g signal.

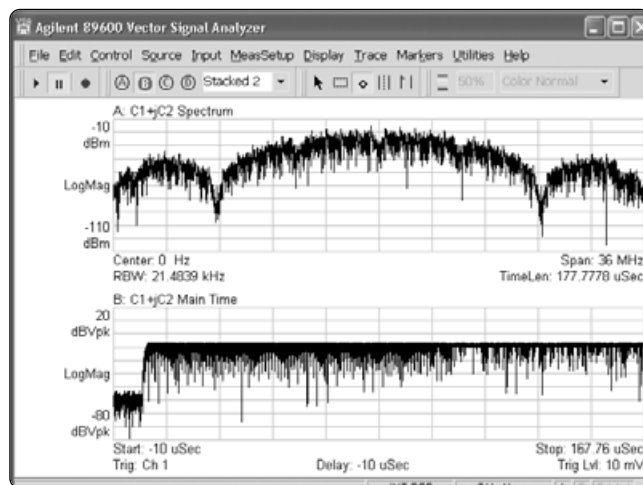


Figure 53. Spectrum and time display of 802.11b baseband signal

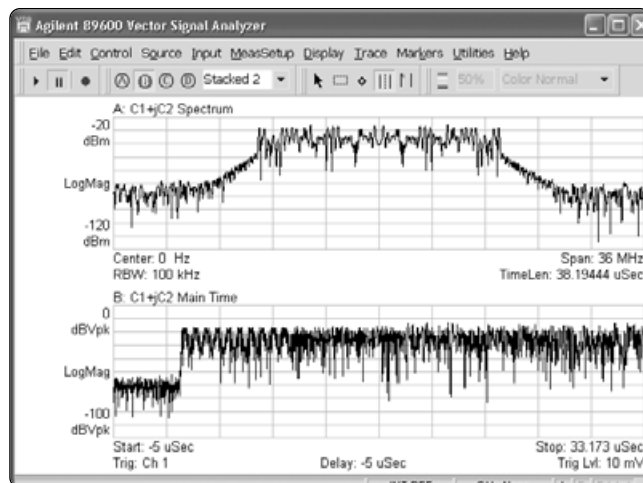


Figure 54. Spectrum and time display of 802.11a baseband signal

Modulation analysis

To perform modulation analysis on your 802.11 baseband signal, go to **MeasSetup | Demod | Wireless Networking** and either **OFDM** (for 802.11a or 802.11g analysis) or **DSSS/CCK** for 802.11b analysis.

You can now view the constellation diagram, EVM spectrum, modulation metrics, demodulated symbols, or any other of the results available in the **Trace | Data** menu.

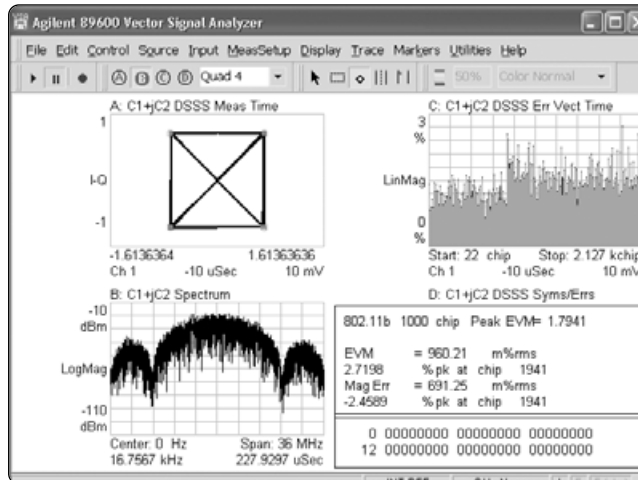


Figure 55. 802.11b signal with QPSK modulation

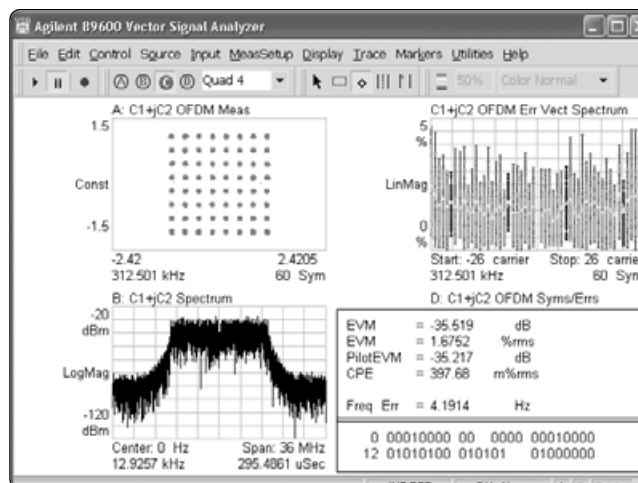


Figure 56. 802.11a signal with 64QAM modulation on the subcarriers

Summary

You should now be able to understand the powerful RF and baseband analysis provided by these standard test and analysis tools.

These everyday test tools, when combined with the 89600 software solutions, open up many possibilities for troubleshooting and verifying WLAN devices from standards-based pass /fail testing to advanced RF and baseband modulation analysis.

For more information on the products featured in this application note, please contact your local Agilent representative.

Appendix A: WLAN Transmitter Test Instrument/Software Combination Selection Guide

	Combination A	Combination B	Combination C	Combination D
Main task	Chipset and component design	Reference circuit evaluation and integration		
Wideband down-converter	PSA spectrum analyzer	ESA spectrum analyzer		
	Highest accuracy Fastest RF measurements Highest dynamic range Lowest phase noise	Performance suited to test a complete WLAN card		
Wideband digitizer	89611 VSA		54838B	
	Fastest measurement throughput 36 MHz bandwidth Very long time capture Optional baseband inputs		Suite constrained budget Analog and digital oscilloscope based measurements Baseband inputs (some operational constraints)	
Software	89691 vector signal analysis software			89607A WLAN test suite
	Extensive signal evaluation and troubleshooting Signal recoding and playback for later diagnosis Links to Agilent advanced design system 89607A WLAN test suite included			Suite constrained budget Standards based test only Evaluation and pass/fail testing Does not require WLAN testing knowledge
Price range	++++	+++	++	+

Appendix B: Instrument/Software Combination Performance

	Combination A	Combination B	Combination C	Combination D
Wideband	E4440A (H70)	E4407B (H71)	E4407B (H70)	E4407B (H71)
Down-converter⁵	(high-performance spectrum analyzer)	(mid-performance spectrum analyzer)	(mid-performance spectrum analyzer)	(mid-performance spectrum analyzer)
Wideband digitizer⁶	89611 (IF VSA)	89611 (IF VSA)	54830B⁴ (Infiniium oscilloscope)	54830B⁴ (Infiniium oscilloscope)
Software	89601 ⁷	89601 ⁷	89601 ⁷	B8607A
Price range	++++	+++	++	+
RF and baseband capabilities				
RF frequency range	10 MHz to 26.5 GHz	10 MHz to 26.5 GHz	10 MHz to 26.5 GHz	10 MHz to 26.5 GHz
Baseband (I/Q) frequency range	DC to 39 MHz ³	DC to 39 MHz ³	–	–
Max analysis bandwidth	36 MHz	36 MHz	36 MHz	36 MHz
Residual constellation error (EVM) 802.11a	-43 dB/-45 dB ²	-43 dB/-45 dB ²	-40 dB/-42 dB ²	-40 dB
Residual RMS EVM, 802.11b	2%	2%	3%	3%
Spectral flatness	±0.2dB	±0.2dB	±0.4/-1.0 dB	±0.4/-1.0 dB
Signal capture memory	Up to 384 Msa (complex)	Up to 384 Msa (complex)	Up to 8 Msa	Up to 8 Msa
Software capabilities				
WLAN troubleshooting and evaluation tools	■	■	■	
802.11a/b/g standards-based testing	■	■	■	■
Test time 802.11a (using 89607A software)	3 to 13 sec	3 to 13 sec	6 to 41 sec	6 to 41 sec
Test time 802.11b (using 89607A software)	7 to 14 sec	7 to 14 sec	11 to 48 sec	11 to 48 sec

1. All specifications are typical.
2. Using channel estimation + payload equalizer mode.
3. 89811 must include additional IF/baseband channel.
4. Used at 1 Gsa/s.
5. Specifications apply to any spectrum analyzer listed in Appendix A.
6. Specifications apply to any Infiniium oscilloscope listed in Appendix A.
7. Requires Option 87R WLAN modulation analysis.

Related Literature

ESA-E Series spectrum analyzers

Data sheet, literature number 5968-3386

89600 Vector Signal Analyzer

Brochure, literature number 5980-0723

89600 Vector Signal Analyzer

Data sheet, literature number 5988-7811

89607A WLAN Test Suite Software

Technical Overview, literature number 5988-9574EN

Infiniium

Brochure, literature number 5988-3788

*Agilent Infiniium Oscilloscopes Performance Guide Using 89601A
Vector Signal Analyzer Software*

Application Note, literature number 5988-4096EN

RF Testing of Wireless LAN Products

Application Note 1380-1, literature number 5988-3762EN

IEEE 802.11 Wireless LAN PHY Layer (RF) Operation and Measurement

Application Note 1380-2, literature number 5988-5411EN

Effects of physical layer impairments in OFDM systems

Bob Cutler, RF Design magazine, May 2002

http://rfdesign.com/ar/radio_effects_physical_layer/index.htm

*Spectral Analysis Using a Deep-Memory Oscilloscope Fast Fourier
Transform (FFT).*

Application Note, literature number 5988-4368EN

Web Resources

For additional literature and product information about visit:

www.agilent.com/find/wlan



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(tel) (31 20) 547 2323	Countries:
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