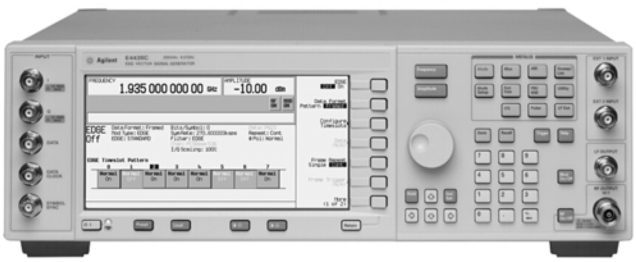
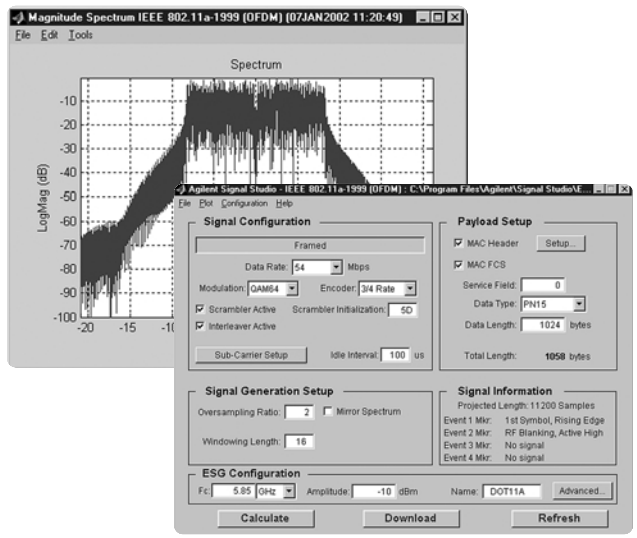
Agilent
802.11a WLAN
Signal Studio Software for the E4438C ESG Vector Signal Generator

Option 410
Product Note





Use Signal Studio with the ESG to create IEEE 802.11a test signals

Signal Studio 802.11a software is a powerful tool for creating 802.11a baseband I/Q waveforms for the Agilent E4438C ESG vector signal generator's internal baseband generator.

E4438C ESG vector signal generator Main Features

- 6 GHz to 250 kHz frequency range
- 80 MHz RF bandwidth
- 160 Mbytes (32 Msamples) playback memory
- 6 GB storage memory
- Hardware digital interpolation filters
- Fast microprocessor
- LAN connectivity
- Differential I/Q Outputs

Signal Studio 802.11a Key Features

- Selectable framing includes Preamble and Header with Signal field
- Raised cosine windowing
- Customize modulation and encoder settings including data rate, scrambling, interleaving, convolutional encoding, and MAC header
- Enable/disable FCS
- Intuitive user interface makes waveform creation fast and easy
- Plot spectrum, I/Q components, and CCDF

Agilent Technologies

Table of contents

This *Product Note* is a self-guided tutorial that describes the test signals that can be created with the Signal Studio 802.11a software. This document is not meant to be an IEEE 802.11a technology tutorial. For additional information on 802.11a technology, refer to the *Additional Literature* and *References* section at the end of this document.

Introduction

Signal Studio 802.11a software is a tool for creating an 802.11a waveform in an intuitive Windows®-based environment. The software calculates a baseband I/Q waveform file based on the user-defined 802.11a frame. The waveform file can then be downloaded to the ESG's baseband generator (option 001 or 002) for playback through the I/Q modulator and upconversion to RF. The RF range is from 250 kHz to 6 GHz.

Download Signal Studio from **www.agilent.com/find/signalstudio** to evaluate the signal configuration and plotting capabilities of the software. A license key is required to load the signals created by the software into the ESG. The license key can be ordered through your sales engineer or your local sales office, which can be found at **http://www.agilent.com/find/assist.**

In addition to creating waveform files, the software provides basic configuration menus for signal generator settings, including frequency, amplitude, and marker polarity. The instrument settings, along with the waveform files, are passed to the ESG over the LAN or GPIB interface.

After downloading the waveform file and instrument settings, the ESG automatically begins generating the 802.11a RF signal. Local control of the instrument is then reenabled and signal generator settings, like frequency and amplitude, can be modified from the instrument's front panel. The waveform files themselves cannot be modified once they have been downloaded to the instrument.

The Signal Studio software configuration can be recalled at any time to recalculate and download the waveform to the signal generator. The waveform itself cannot be saved on the PC, but waveforms can be re-calculated quickly from stored settings. Once downloaded, the waveform files can be saved on the 6 GB hard drive.

The Signal Studio 802.11a signal can be used to test any portion of the receiver chain during the design process. Some software engineers may require a baseband signal to perform demodulation and decoding verification on ASIC and DSP chips, see Figure 1. RF designers may want to test components such as amplifiers or the RF chip set.

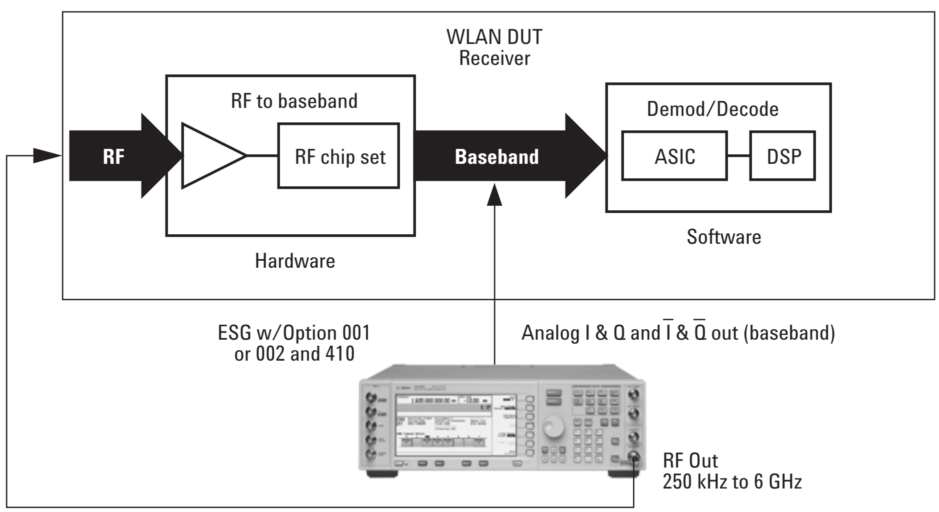


Figure 1. Test setup with ESG

Signal Studio Overview

Signal Studio 802.11a simplifies the user's role in creating 802.11a test signals for use with the ESG and provides the ability to quickly configure a standards-based test signal via an intuitive graphical user interface. The Signal Studio 802.11a frame configuration can easily be modified to create the desired test signal, without rewriting code.

Component test

The performance characteristics of 802.11a components – including preamplifiers, combiners, filters, and amplifiers – is determined using a stimulus that provides statistically correct signals. The Signal Studio 802.11a software meets this need. Signal parameters, including the number of active sub-carriers and modulation type, can be modified to provide adequate stress on the components being tested.

Receiver test

A test signal with channel encoding is necessary to thoroughly test a receiver's demodulation and decoding capabilities. Complete channel coding allows test engineers to determine if each functional stage of a receiver is operating correctly. This level of channel coding enables PER and BER testing on the signal received by the access point. The designer will be able to use this to perform standards-based tests such as receiver minimum input level sensitivity, receiver maximum input level, and receiver adjacent and non-adjacent channel rejection measurements.

Using Signal Studio 802.11a as a test signal allows the designer to verify that the receiver correctly decodes an independently generated 802.11a test signal.

IEEE 802.11a OFDM overview

802.11a is an orthogonal frequency division multiplexed (OFDM) multi-carrier signal. In traditional FDM systems, the spacing between channels is greater than the symbol rate to avoid overlapping spectrums. However, in OFDM systems, the carriers overlap, which conserves bandwidth, but sub-carriers don't interfere with one another because they are orthogonal to one another. The high rate data OFDM signal is divided into 52 slower parallel signals (sub-carriers), and then an IFFT is applied to the signal, and these sub-carriers are transmitted simultaneously. Orthogonality implies that there is a mathematical relationship between the sub-carriers. Each sub-carrier has an integer number of cycles in the FFT interval, and there is a difference of one cycle between adjacent sub-carriers. The transmitted burst of the 802.11a packet creates a sin(x)/x spectrum in the frequency domain. The nulls in each sub-carrier's spectrum are located at the centers of every other sub-carriers spectrum. This is the reason orthogonality exists between the sub-carriers.

The symbol duration for an OFDM symbol increases for the lower rate parallel sub-carriers, thus the relative amount of dispersion in time caused by multipath delay spread is reduced. Phase noise and non-linear distortion contribute the most to loss of orthogonality, which results in inter-carrier interference (ICI). A guard interval is added to help prevent ICI, as well as intersymbol interference (ISI). A signal with a slower data rate is more resistant to multipath fading and interference (see RF Testing Wireless LAN Products Application Note 1380-1 for more details about OFDM) [7].

Signal structure

PMD layer

The Signal Studio 802.11a creates the physical layer PMD (physical medium dependent) test signals, which contain Preamble, Header, and payload data, see Figure 2. Although the signal does not provide MAC or PLCP protocol handling, it does enable testing of the PMD for receiver and component tests.

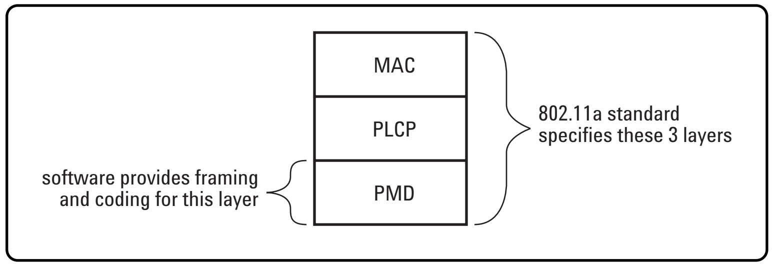


Figure 2: 802.11a Standard Protocol Stack

The PMD sublayer is the physical layer, which provides the transmission of the signal over the air interface. The PMD layer provides the framing, scrambling, modulation, and channel encoding of the signal. Measurements can be made on the physical layer signal, such as spectral measurements, which can be used as trouble shooting tools in design and development. Also, this test signal may be used to make standards-based measurements. To make these measurements, the MAC and PLCP layers are not needed.

The user does have the capability to add a MAC header and FCS to the data payload. This is useful if the user needs to add addresses or other MAC fields, see Figure 3. Also the FCS can be used to perform packet error ratio tests (PER).

Frame structure

In 802.11a systems, information is transmitted in frames. This framed information makes up a packet. During the burst the entire packet is transmitted, then the carrier is blanked or idle for a certain interval. This interval can be set in the software. All data in the frame is OFDM encoded. The total frame length is variable. Figure 3 illustrates the frame structure of the signal created by Signal Studio 802.11a software. The signal is created according to IEEE 802.11a standard.

The 802.11a burst has four distinct regions. The first region consists of a short preamble. The short preamble contains 10 short symbols assigned to sub-carriers -24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24. The second region contains 2 long symbols that are assigned to all 52 sub-carriers. The preamble is BPSK modulated at 6 Mbps. It contains no channel coding, and is not scrambled. The third region of the packet is the Signal field, which consists of one OFDM symbol assigned to all 52 sub-carriers. This symbol is BPSK modulated at 6 Mbps and is encoded at a 1/2 rate. The Signal field is not scrambled. The last region of the packet consists of the Service field and multiple data payload segments. This region is scrambled. The data rate, encoding rate, and modulation varies, see Figure 5. Notice that guard intervals (GI) are added to the long preamble, header, and the Service and payload data.

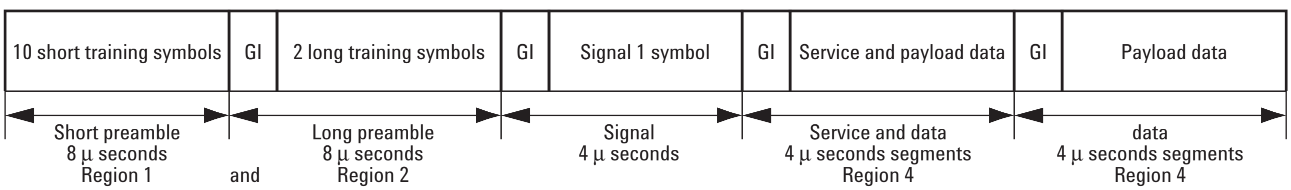


Figure 3. 802.11a frame

Payload structure

The payload field is within the PPDU frame. A MAC header and FCS can be added to the user's data. Table 1 provides a summary of the payload characteristics in 802.11a.

Data rate Mbps	Modulation	Encoding rate	Coded bits per sub-carrier	Coded bits per symbol
6	BPSK	1/2	1	48
9	BPSK	1/2	1	48
12	QPSK	1/2	2	96
18	QPSK	1/2	2	96
24	QAM-16	1/2	4	192
36	QAM-16	1/2	4	192
48	QAM-64	2/3	6	288
54	QAM-64	1/2	6	288
custom	variable	variable	variable	variable

Table 1. Key 802.11a payload characteristics supported with the Signal Studio 802.11a software

Figure 4 is an illustration of the MAC header structure. The payload data (user's data) is called PLCP service data unit (PSDU) in the standard. The description and details of the medium access control (MAC) header and frame check sequence (FCS) can be found in the IEEE 802.11 standard. The MAC header and FCS state can be toggled On/Off. All the fields in the MAC header can be modified.

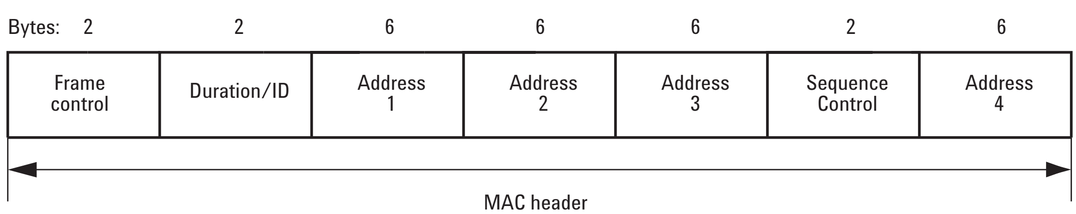


Figure 4. MAC header structure

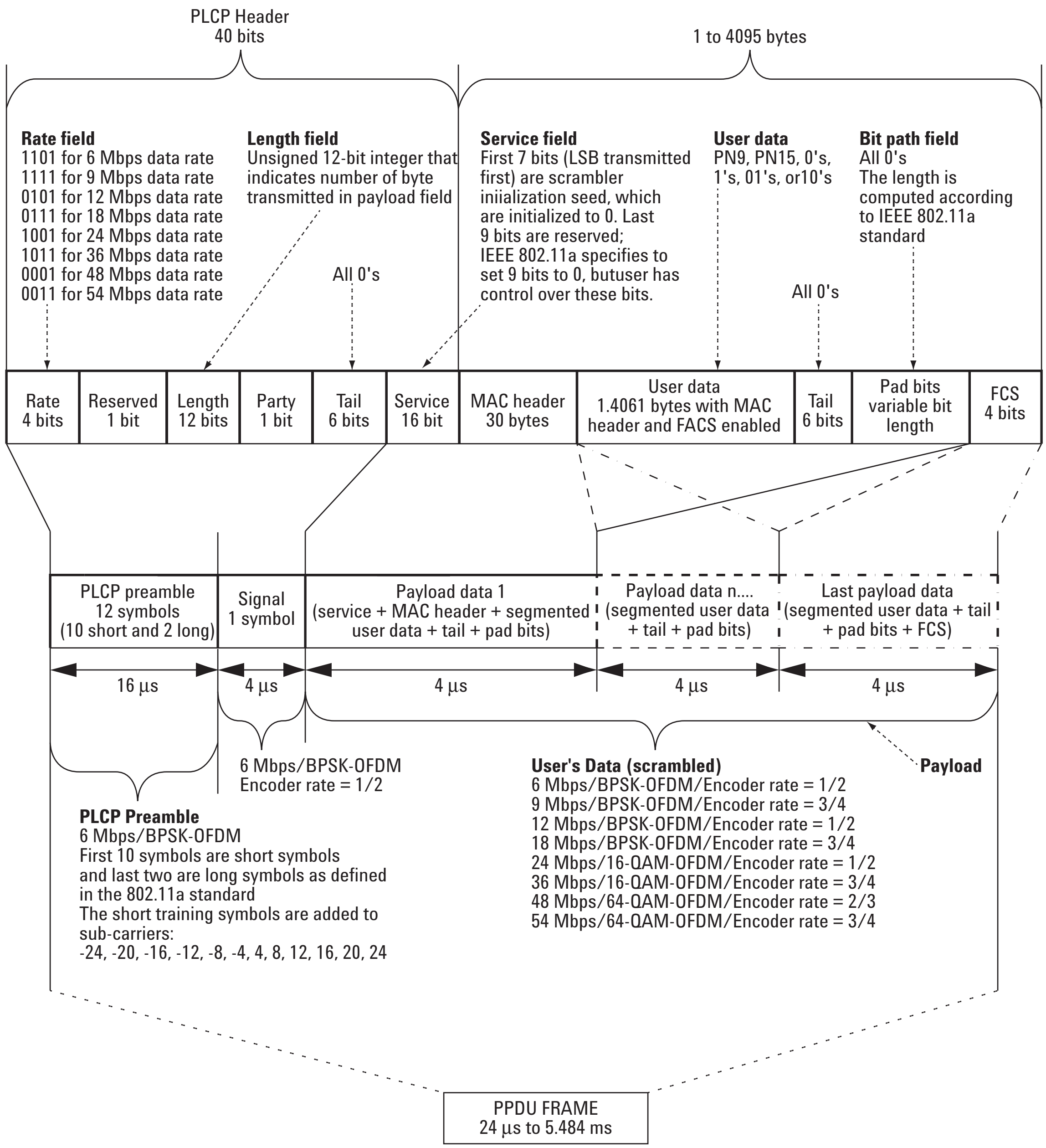


Figure 5. Signal Studio 802.11a detailed packet structure

Signal Studio 802.11a payload data encoding

Signal Studio 802.11a encodes the data according to the table shown on page 7. The payload data is scrambled, encoded, and interleaved. Interleaving and scrambling can be toggled On/Off. The forward error correction (FEC) that is added to the signal increases robustness to the symbol in the event the amplitude of any of the sub-carriers diminishes enough to create bit errors.

The data rate and the modulation format are coupled in the Signal Studio software, so that when a data rate is selected, this will automatically select the modulation format as defined in the standard.

After channel coding has been added to the data, and symbol mapping has been performed, a 64-point IFFT is applied to the data, see Figure 2. The data is mapped onto 48 data sub-carriers, which are identified as sub-carriers -26 to -22, -20 to -8, -6 to -1, 1 to 6, 8 to 20, and 22 to 26. This is shown in the Signal Studio software in the Sub-carrier Setup Menu. Four pilot sub-carriers are inserted for timing information for the receiver. Afterwards, a guard interval is added to the symbol. This guard interval helps prevent intersymbol interference from signal delay spreads caused by multipath transmission commonly experienced over-the-air interface channel. The guard interval needs to be larger than the delay spread to prevent ISI.

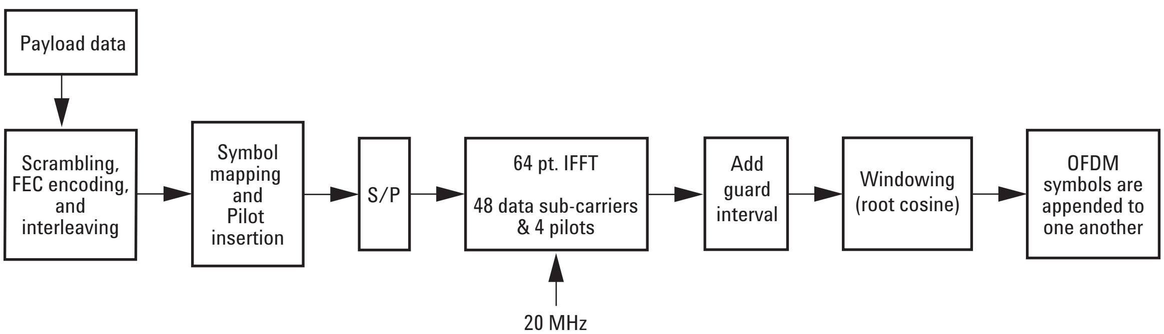


Figure 6. Creation of an OFDM data symbol

Raised cosine windowing

Signal Studio 802.11a software calculates one OFDM symbol at a time, using a 64 point IFFT. To create the guard interval at the front of the symbol, it appends the last 16 samples of the 64 point IFFT to the front of the symbol, creating a composite symbol that is 80 samples long (see figure 7). Using the last 16 samples has the effect of making the composite symbol appear continuous in time; that is, the 64 point FFT of the symbol will be identical regardless of which 64 samples we choose out of the 80 available. These 16 additional symbols are what produce multi-path fading immunity, since we can slide in time by up to 0.8 uS without causing a decoding error.

This would be fine if all we needed was one symbol. But of course we need a whole long string of symbols appended to one another, so we require a means of assembling consecutive symbols without causing spectral regrowth. Spectral regrowth arises from the fact that consecutive symbols rarely begin with the same amplitude and phase that the prior symbol ended with. To avoid this, we must create a smooth transition between the last sample of one symbol and the first sample of the next symbol. We do this with a combination of two tools: a cyclic suffix, and windowing.

Assume we have selected a window length of 16. To create the cyclic suffix, we append the first 16 samples of a given symbol to the end of that symbol, so that now the symbol is effectively 96 samples long. This has the desired effect of making the symbol appear continuous going into the transition. However, if we are to comply with the 802.11a standard, we cannot arbitrarily lengthen the symbol in this way. Instead, this cyclic suffix overlaps in time (and is effectively summed) with the cyclic prefix of the next symbol. This overlapped segment is where windowing is applied. In fact, two windows are applied, one being the mathematical inverse of the other. The first raised cosine window is applied to the cyclic suffix of symbol 1, and rolls off from 1 to 0 over its duration. The second raised cosine window is applied to the cyclic prefix of symbol 2, and rolls on from 0 to 1 over its duration. This gives the desired smooth transition from one symbol to the next.

There is one more variable in the equation: the window length. In this example, we used a window length of 16, so the cyclic suffix was 16 samples long. However, the length of the cyclic suffix is adjusted along with the window length setting, so any suffix length between 1 and 16 may be set. The effect of windowing is that it improves spectral regrowth, but at the expense of multipath fading immunity. This occurs because redundancy in the guard band is reduced due to the fact that the guard band sample values are compromised by the smoothing.

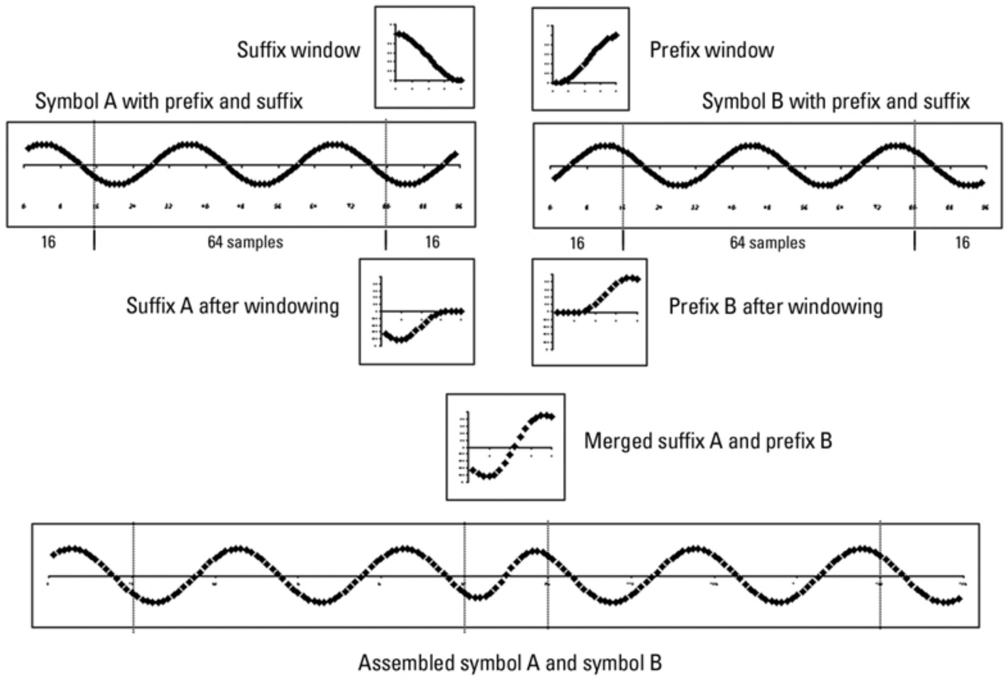


Figure 7: Application of Raised Cosine Windowing

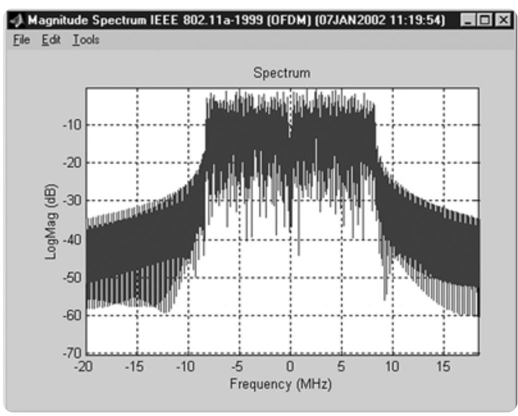


Figure 8: Spectrum plot of 802.11a I/Q waveform with Windowing Length = 0 samples (no windowing)

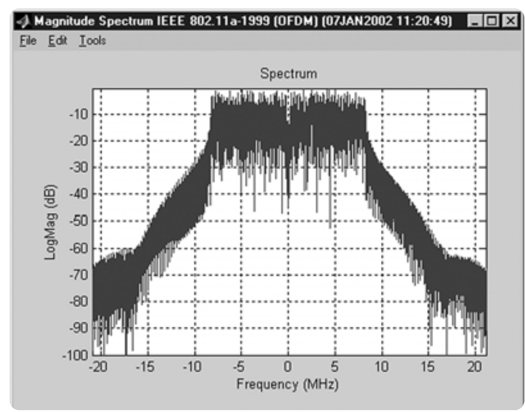


Figure 9: Spectrum plot of Signal Studio 802.11a I/Q waveform with Windowing Length = 16 samples (maximum)

Creating signals

An 802.11a waveform can be can be configured and downloaded to the ESG digital series RF signal generator in four easy steps:

Step 1 – Configure the 802.11a signal, including the MAC Header and sub-carrier setup
Step 2 – Setup the Signal Generation Options
Step 3 – Configure the ESG
Step 4 – Calculate & Download

Step 1 – configure 802.11a signal

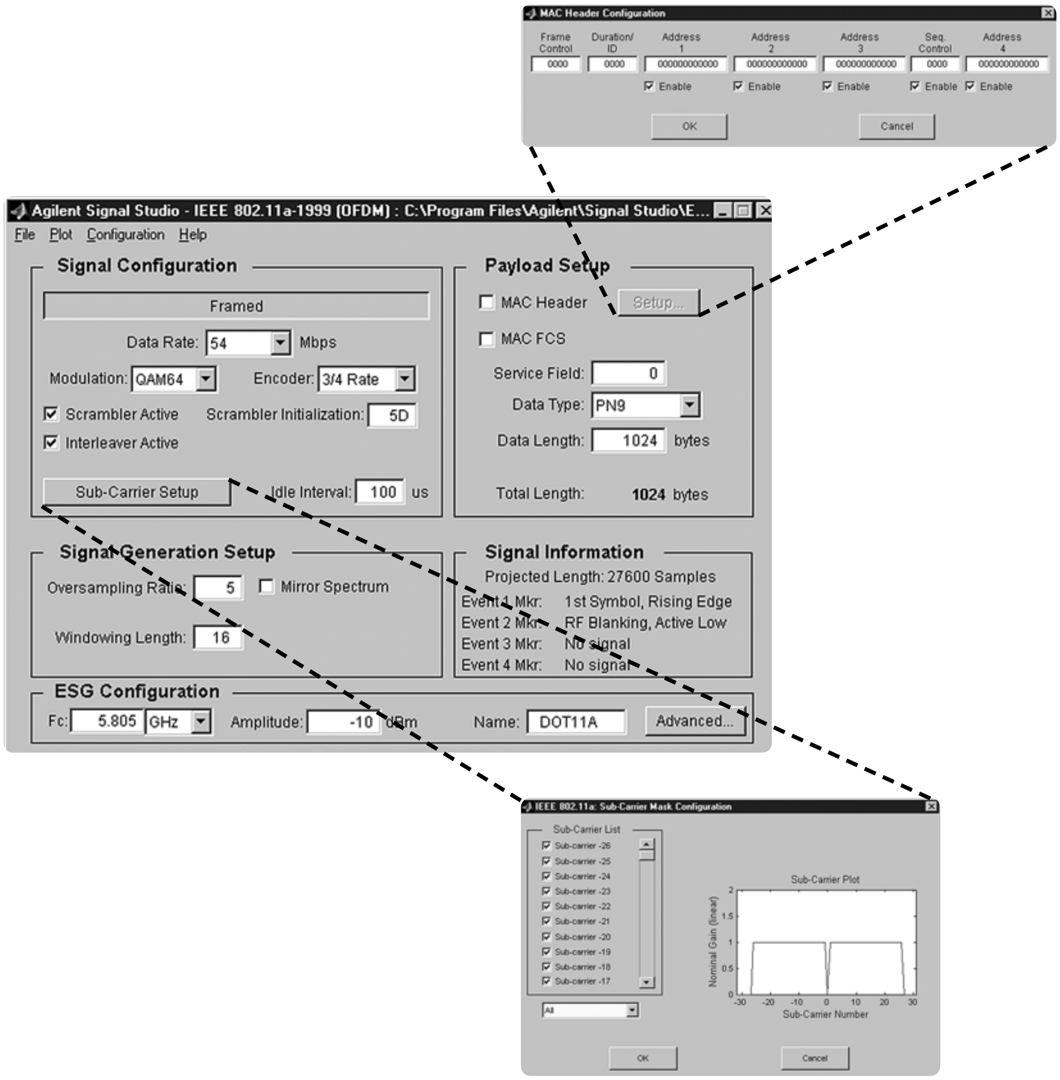


Figure 10. Signal Studio 802.11a signal configuration menu

Signal configuration

The Signal Configuration user interface section allows the user to choose specific parameters for the framing of the signal.

Framed
Toggles between framed and unframed mode. In framed mode the user can generate a test signal to make measurements according to the standard. In unframed mode, the user can perform measurements where non-framed, non-bursted data is desired.

Data rate
Selects the data rate. Nine different data rates are available:
6 Mbps, 9 Mbps, 12 Mbps, 18 Mbps, 24 Mbps, 36 Mbps, 48 Mbps, 54 Mbps and Custom. Custom allows arbitrary selection of encoding rates and modulation schemes.

Note: Given data rates are for the payload data and are valid when all 48 data subcarriers are on. The data rate will decrease as the individual subcarriers are turned off from the Subcarrier menu. Example calculation of data rate:

Data rate for 64-QAM with 3/4 rate coding:

Data rate for 48 subcarriers:
54 Mbits/sec

Reduce to 40 subcarriers:

$$\text{Data Rate} = 54\,\frac{\text{Mbits}}{\text{sec}} \times \frac{40}{48} = 45\ \text{Mbits/sec}$$

This value is not displayed on the User Interface.

Modulation
For all the data rates, except Custom, the modulation formats are set according to the 802.11a specification and cannot be changed. The following modulation formats are available:

- BPSK
- QPSK
- 16-QAM
- 64-QAM

Encoder
For all data rates, except Custom, the encoder rate automatically sets the data rate and modulation scheme. When inactive is selected, Custom data rate allows the user to select the desired modulation scheme and no encoding rate. The following encoding rates are available:

- Inactive
- 1/2
- 2/3
- 3/4

Scrambler active
Turns the scrambler on or off

Scrambler initialization
Sets the initial value of the scrambler. Valid range is any 7-bit value, Hexadecimal representation.

Interleaver active
Turns the scrambler on and off

Idle interval
Sets the length (in microseconds) of the idle time between frames. This is only relevant in framed mode.

Sub-carrier setup
This menu configures the individual sub-carriers. There are a total of 52 sub-carriers for an 802.11a signal, 48 of those signals are data sub-carriers, and 4 are pilot sub-carriers. The center frequency, which is the zero sub-carrier, is nulled. The state of each of the sub-carriers can be toggled On/Off, or the user can select from some predefined setups as follows:

- All
- Every 2nd
- Every 4th
- Upper band
- Lower band
- Outer band
- Outer pair
- None (but at least one subcarrier must be reactivated)

Payload setup
This section allows the user to configure the MAC header and to add on a FCS to the packet. The maximum data length of the user data in the payload is 4095 bytes, which includes the MAC header and FCS. Notice that the total length of the payload is displayed.

Setup menu
Configures the MAC header.

MAC header
Enables/disables prepending the MAC header to the data payload. The user can fill these individual fields with the desired data, or disable these fields.

MAC FCS
Enables/disables appending the MAC FCS to the data payload. The FCS (frame check sequence) is automatically calculated by the software if this field is selected.

Data type
Selects the payload data stream, from the following types:

- PN9
- PN15
- All zeros
- All ones
- Alternating zeros and ones
- Alternating ones and zeros

Data length
Sets the number of data bytes in a frame. This excludes MAC header and FCS.

Total length
Displays the total number of bytes in the payload. This includes the data and MAC header and FCS.

Step 2 – setup the signal generation options

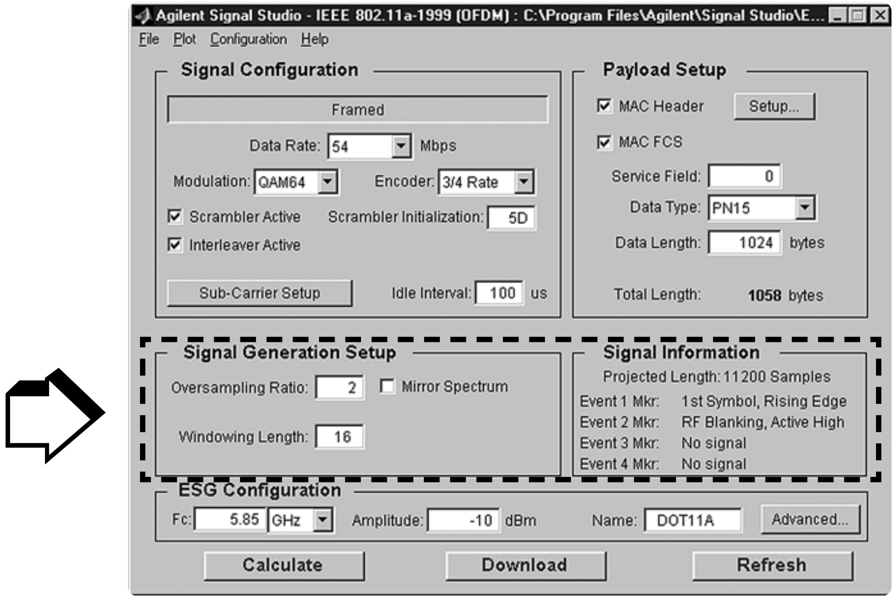


Figure 11. Signal Studio 802.11a signal generation options menu

Signal generation setup

As illustrated in Figure 11, the Signal Studio software provides a simple interface for defining the following signal generation options: Oversampling Ratio, Windowing Length, and Mirror Spectrum.

Oversampling ratio

The oversampling ratio (OSR) defines the number of samples calculated per I/Q symbol. Increasing the over sampling ratio of the constructed signal increases the separation of the sampling images from the desired signal. This allows for better image rejection by the baseband reconstruction filters. With the E4438C, there is no need to oversample more than 2X. Hardware resampling will separate the images by 50 MHz, where they are easily removed by the reconstruction filter.

Increasing the over sampling ratio increases the waveform calculation time and file size. Notice that the projected file length in the Signal Information section is affected by the over sampling ratio setting.

The ESG baseband generator (option 002) is capable of storing and playing back a waveform or waveform sequence of up to 32 M samples in length.

Windowing length
A raised cosine time-domain window is applied to the baseband signal to reduce out-of-band power. The user can select the length of the raised cosine window. The range is 0 to16 samples.

Mirror spectrum
This allows the user to invert the spectrum. If this option is selected, then the Q channel is inverted. This feature may be useful if the user plans to use a mixer to up convert the signal.

Signal information

Projected length
The length of the waveform is in samples. The ESG's baseband generator can playback waveforms up to 32 Msamples.

Markers
The signal generator has four markers that can be placed on a waveform segment; markers provide timing signals that are synchronized with a waveform segment. Default settings are explained below. Markers can be set from the software, or from the ESG User Interface; see Users Guide for more details.

Event 1 Mkr
The Event 1 marker can be accessed from the rear panel BNC connector. The Event 1 marker is set to the 1st symbol of the 802.11a waveform on the rising edge. The signal out the Event 1 port can be used as a trigger signal. Default marker polarity is positive. The user can invert the polarity of marker under the Advanced button.

Event 2 Mkr
When the 802.11a signal is framed, RF blanking increases the on/off ratio of the RF bursts. The Event 2 marker is internally routed to provide the RF blanking signal. The default marker 2 polarity is set to positive. If the polarity is inverted, the desired RF signal will be blanked, resulting in no RF output from the ESG.

Event 3 Mkr
Signal Studio-802.11a does not create a marker for Event 3. This can be done from the ESG user interface. See Users Guide for more details.

Event 4 Mkr
Signal Studio-802.11a does not create a marker for Event 4. This can be done from the ESG user interface. See Users Guide for more details.

Step 3 – Configure the ESG

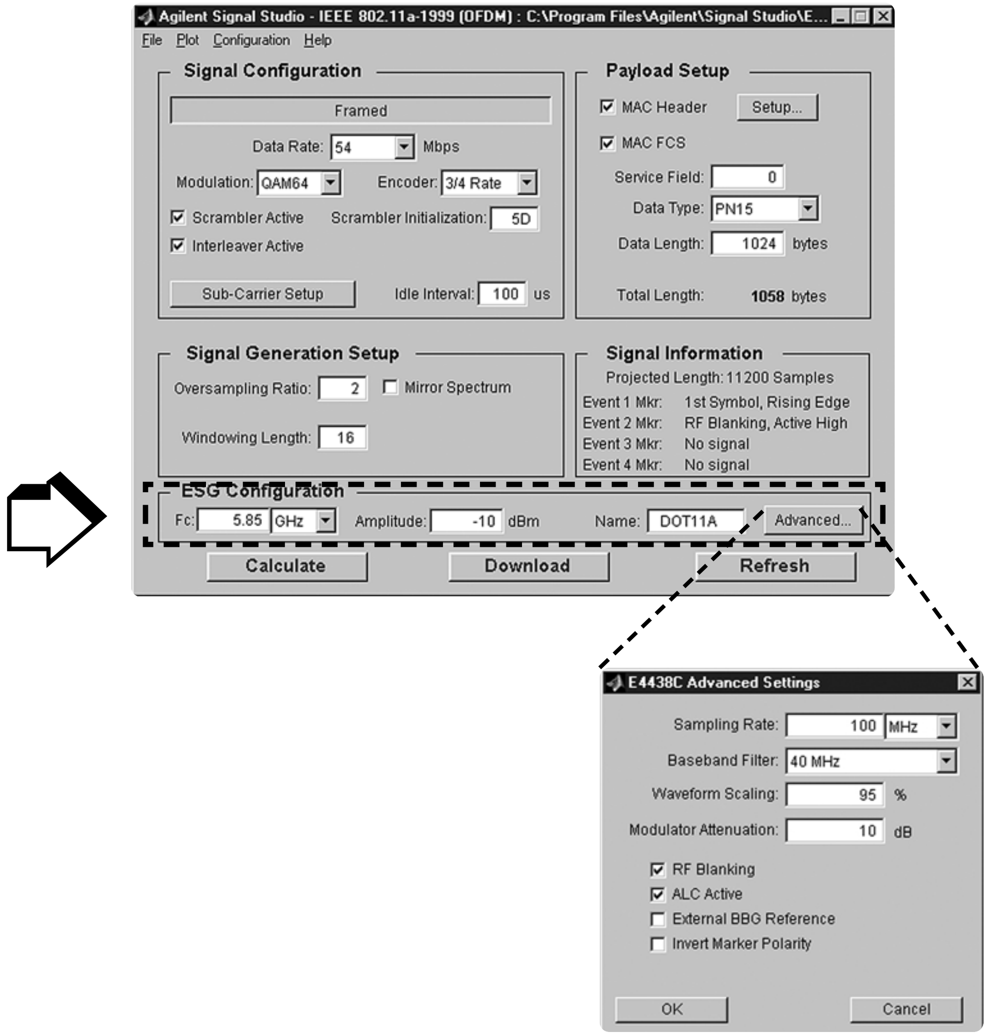


Figure 12. Signal Studio 802.11a configuration menu

Along with the compiled waveform, the Signal Studio software passes instrument settings to the ESG signal generator. These are defined in the ESG Configuration menu. The following settings can be made:

ESG configuration parameters

Frequency	Defines the RF frequency at which the ESG will generate the signal.
Amplitude	Defines the RF power level at which the ESG will generate the signal.
Sampling rate	Defines the rate at which the waveform I/Q samples are read from the dual arbitrary waveform generator memory during playback.
Baseband reconstruction filter	Reconstruction filters allow the entire desired signal to pass through, while rejecting the images that occur at multiples of the OSR. The ESG provides one 50 MHz analog reconstruction filter. This filter is sufficient to eliminate any images or aliasing.
Waveform scaling	Scaling maximizes dynamic range into the DAC, while preventing overflow errors. The waveform data is scaled as it passes through the baseband generator and the DAC interpolating filters. Scaling does not alter the original waveform data file. Scaling range is from 1 to 100%.
Modulator attenuation	Sets the attenuation level before the signal is sent through the IQ modulator.
RF blanking	When the 802.11a signal is framed, RF Blanking improves the on/off ratio of the RF bursts. The ESG Event 2 marker is internally routed to provide the RF Blanking signal. Note: When RF Blanking is enabled, the Marker Polarity is set to positive by default. If this is set to negative, the wanted RF signal will be blanked resulting in no RF output from the ESG.
ALC active	The default setting is ALC (automatic level control) on. To turn ALC off, uncheck the box. The RF output power of the signal generator is constantly monitored and controlled by the ALC circuit. Its purpose is to hold output power at its desired level in spite of drift due to temperature and time.
External BBG (baseband generator) reference	Sets reference frequency for the ESG dual arbitrary baseband generator to internal or external. If an external reference is used, it should be connected to the ESG before the waveform and instrument settings are downloaded to the instrument. The default setting is internal. Note that this is not the 10 MHz RF oscillator frequency reference.
Marker polarity	When RF Blanking is enabled, the Marker Polarity is set to positive by default. This is set to positive, otherwise the wanted RF signal will be blanked resulting in no RF output from the ESG.

For more details for the ESG configuration, please refer to the user’s guide.

After the waveform and instrument settings have been downloaded to the instrument, the instrument settings can be modified from the signal generator front panel. The waveform itself cannot be modified, except by recalculating with new settings in the Signal studio software.

Step 4a – Calculate

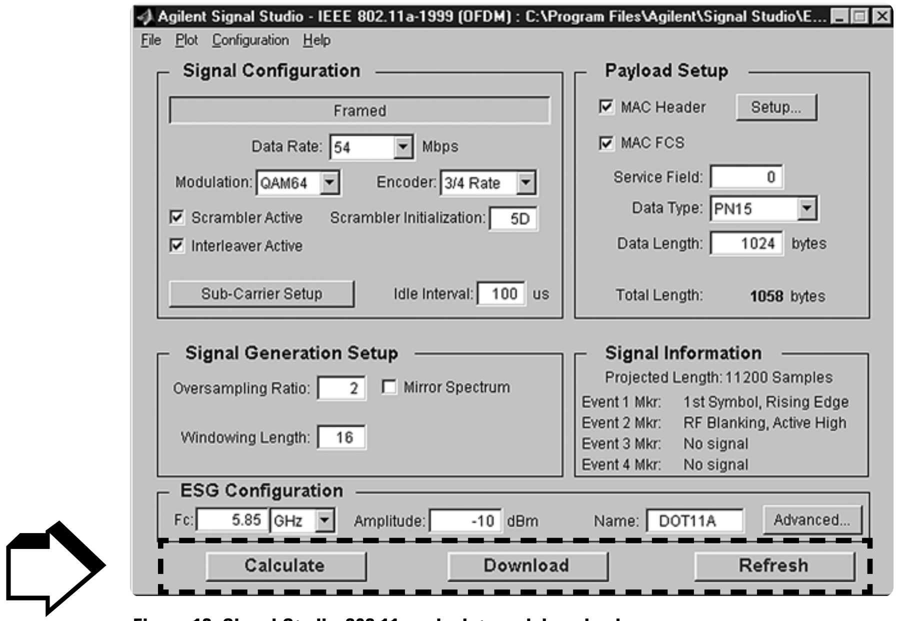


Figure 13. Signal Studio-802.11a calculate and download menu

Once the waveform and ESG settings have been configured, the final step is to calculate the waveform and download it to the instrument.

Name the waveform

First name the waveform in the Waveform Title field. This is the name that will appear in the ESG user interface after the waveform is downloaded to the instrument. The ESG only recognizes waveforms that are named using the following alphanumeric characters: A thru Z, 0 thru 9, $&_#+-[ ]. There is a 20-character maximum name length for waveform files. If un-supported alphanumeric characters are used to name the waveform, the ESG will generate a File Name Not Found Error (Error: -256) when the waveform is downloaded to the instrument.

Select the calculate button

The software will generate an I/Q waveform file in accordance with Signal Studio settings. Waveform calculation time varies according to the selected data rate, OSR, length of the payload, and the computer's processing speed.

Signal studio configuration and setup

See the Signal Studio Installation Guide [1] for more details on connecting the computer to the ESG. **(www.agilent.com/find/signalstudio)**

The ESG will be connected to the PC as shown in Figure 14.

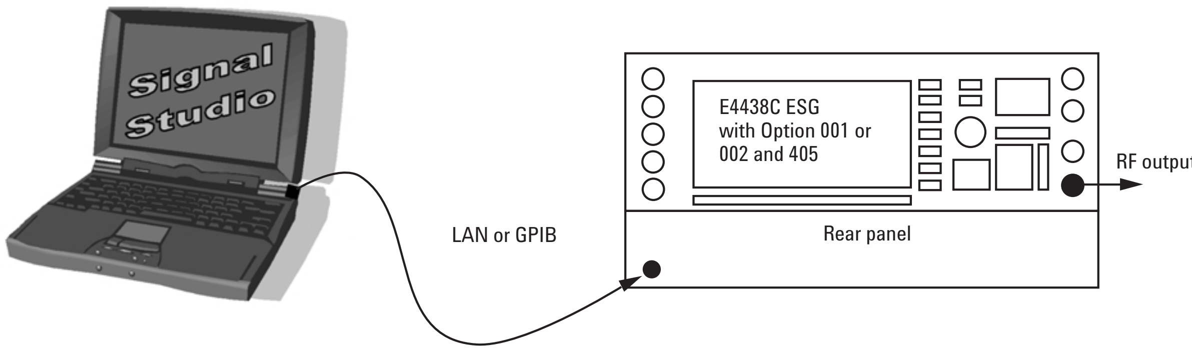


Figure 14. PC to ESG Configuration

Step 4b – download and refresh

Select download button

(See Figure 13) to send the calculated I/Q waveform file representing the 802.11a and the signal generator settings to the instrument. The signal generator automatically begins producing the 802.11a RF signal. Local control of the instrument is then re-enabled and signal generator settings can be modified from the instrument's front panel. The waveform files themselves cannot be modified once they have been downloaded to the instrument.

The Signal Studio-802.11a software configuration can be saved to the host computer's local hard drive. The configuration can then be recalled at any time to re-calculate and download the waveform to the signal generator. This is especially useful when complex configurations have been created in the software. From the menu keys at the top of the window in Figure 14, choose File → Save As, and then name the file and save it in the ESG-A/Dot11a directory. The software configuration can be recalled anytime by choosing the following menu options: File → Open, then the file name.

After the calculated I/Q waveform has been downloaded to the signal generator for playback, it can be saved in the instrument's non-volatile memory for storage and later recall. The signal generator's state must also be saved to recall the instrument settings. The I/Q waveform files created by the Signal Studio software cannot be stored outside the instrument.

The following window, Figure 15, appears after a successful download. This window must be closed by clicking OK to access the main menu again.

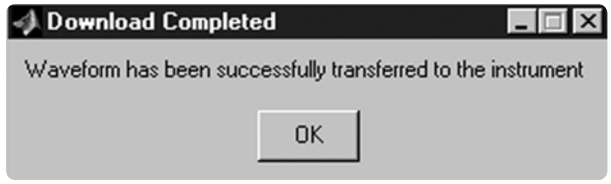


Figure 15. Window to indicate a successful waveform transfer to the ESG

Refresh button

This button refreshes the frequency and amplitude settings on the ESG. This button allows the user to modify the frequency and amplitude settings any time during operation.

Verify ESG generating waveform

The signal generator is now generating the 802.11a modulated RF signal. Verify this by viewing the ESG user interface.

ESG Instruction	Front panel buttons and menu selections
Verify that the 802.11a signal that was just created and named DOT11A is being generated, Figure 16.	[Mode] [Dual ARB]

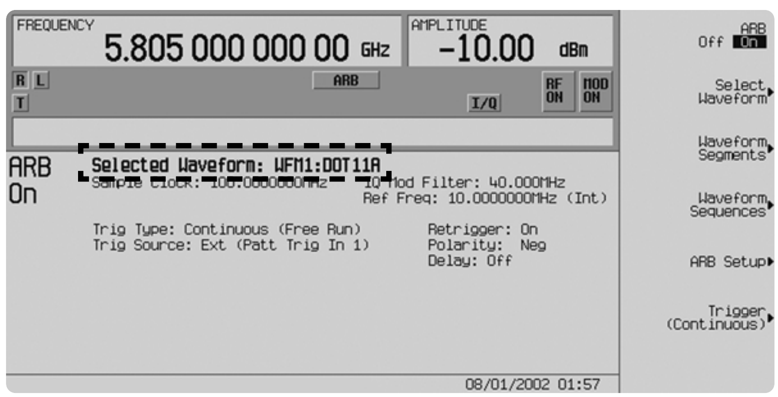


Figure 16. ESG ARB baseband generator user interface

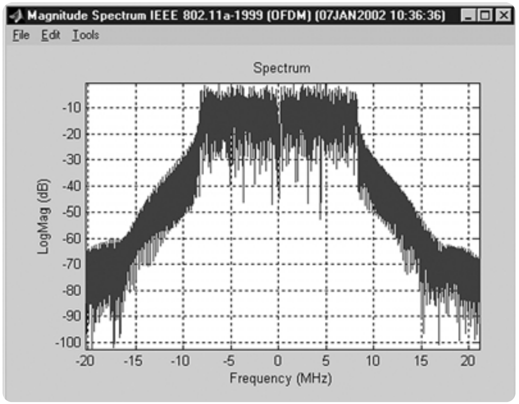


Figure 17. 802.11A spectrum plot generated by Signal Studio

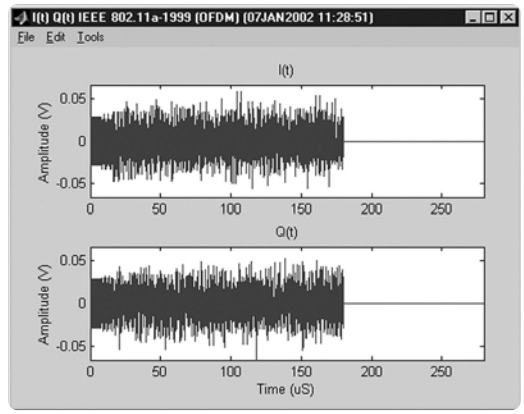


Figure 18. 802.11A I/Q waveform plot generated by Signal Studio

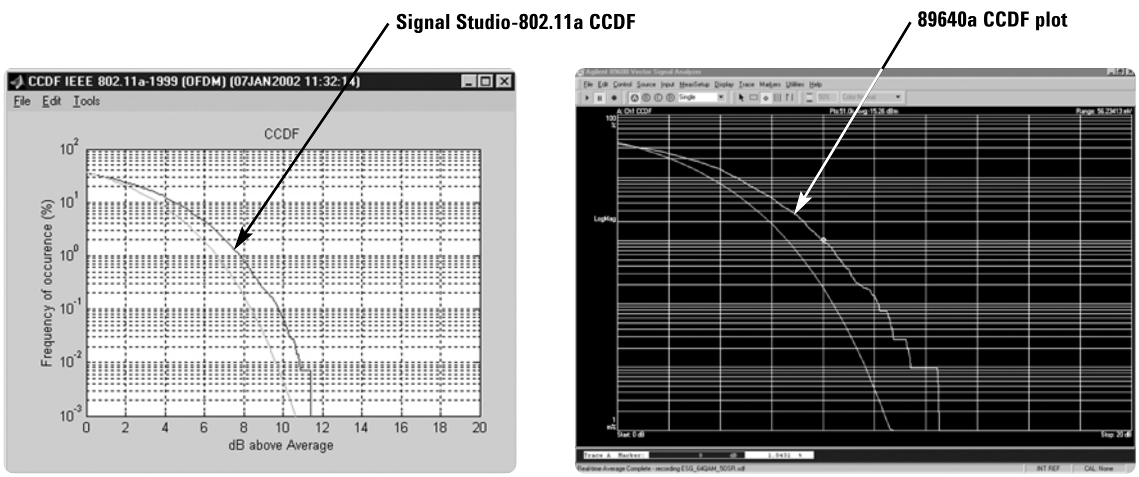


Figure 19. CCDF plots of an Signal Studio-802.11a signal and 89640A measurement

Generate plots

After the I/Q waveform has been calculated, the Signal Studio software is capable of generating a plot of the baseband spectrum, I/Q waveforms, and CCDF curves, see Figures 17 and 18. To plot the spectrum, choose Plot→ Spectrum from the menu keys at the top of the window. The plot can be magnified using the zoom feature in the Tools pull-down menu at the top of the plot. Simply select the zoom feature and use the mouse pointer to select the section of the plot to be affected. Plots of the I/Q and CCDF waveforms can be generated in a similar manner.

The best way to look at power statistics is using the complementary cumulative distribution function (CCDF), see Figure 19. For details, see [6]. The above CCDF plot shows dB above average power on the horizontal axis, and percent probability of occurrence on vertical axis. This blue trace shows that, for this one packet, the signal exceeds the average by 8 dB 1% of the time. The grey curved graticule line represents the statistics for Gaussian noise. Note that the signal CCDF is higher than the AWGN CCDF. This occurs because there is an idle interval in the signal (when the burst is off) which artificially depresses the average power. Setting the idle interval to 0 gives a more Gaussian CCDF.

Bit error rate tests

Bit error rate (BER) is not a specified metric in the 802.11a standard, but it is a common measure of signal quality for digital communication systems. BER is the number of corrupted bits received divided by the total number of bits received. The BER analyzer (option UN7) in the ESG can perform this measurement on the payload data. The ESG's internal BER analyzer is capable of analyzing framed and unframed continuous PN9 baseband data sequences. The BER analyzer on the ESG requires data and clock signals when performing BER on unframed data. Framed data requires three signals to the ESG's BER analyzer: data, clock, and gate.

The clock signal indicates the data rate of the incoming data sequence. The gate signal enables the BER analyzer when a valid segment of the PN9 baseband data sequence is present for analysis in a framed data structure. When performing BER measurements, the gate signal is used to strip off header information and recover the continuous PN (pseudorandom noise)sequence payload data portion of the WLAN packet. The data length of the payload must be an integer multiple of a PN9 sequence as defined by ITU 0.153. This allows the BER tester to keep track of a continuous PN9 sequence. Example: Maximum data length for Signal Studio is 4095 bytes and PN9 = 511 bits. An integer multiple of PN9 that would fit in the data payload would be equal to 4088 bytes (8* 511 = 4088).

An example BER measurement setup for a framed 802.11a signal is illustrated in Figure 20. This example shows an RF test signal that consists of a standards compliant 802.11a modulated packet with a continuous PN9 sequence.

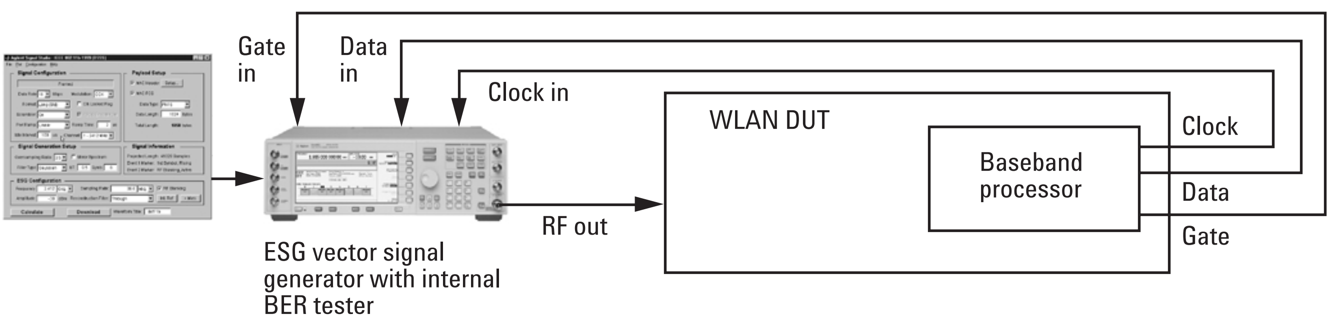


Figure 20. BER test setup to measure a framed 802.11a signal

The WLAN receiver must demodulate and decode the signal transmitted by the ESG and provide access to the WLAN payload signal at the baseband processor output. This TTL/CMOS signal is routed to the ESG internal BER analyzer data input.

See [8] for more details on performing receiver tests using the ESG and Signal Studio.

Packet error rate tests

While the ESG doesn't have the capability to perform packet error rate (PER) tests, Signal Studio 802.11a creates standards compliant 802.11a packets. PER is the number of corrupted packets received divided by the total number of packets received. These test signals have all the framing and coding as defined in the standard. The framing of the 802.11a includes a MAC FCS, which can be used to determine the PER. The device under test (DUT) will need to demodulate and decode the test signal. The FCS can be used by the DUT to determine how many packets that were sent from the source were lost. The number of sent packets can then be compared to the received packets to determine the PER.

Multipacket capability

Multiple 802.11a packets can be created using the waveform sequencer in the ARB menu in the ESG. The ARB sequencer can "play" an ordered series of individual waveforms. Waveforms can be generated using the Signal Studio software, renamed as "waveform segments," and built into user-defined waveform sequences that are modulated to the RF output. Waveform sequencer features include waveform clipping, markers, and triggering useful for synchronizing the output of the signal generator with other devices. For more details on how to create multipacket, refer to the User's Guide [9].

Transmitter measurements

Some basic transmitter measurements were made with the 89640A and the PSA Series High Performance Spectrum Analyzer. The Agilent 89640A consists of two separate applications for Microsoft Windows NT® or Windows 2000®. The 89600 series vector signal analyzer (VSA) performs vector analysis of complex signals in the time, frequency and modulation domains.

Please see [5] for detailed product information for the 89600 series Vector Signal Analyzer.

Equipment list:

ESG configuration

E4438C ESG Vector Signal Generator

- Options 506, frequency range up to 6 GHz
- Option UNJ, enhanced phase noise
- 001 or 002, Baseband generator
- Signal Studio-802.11a, Option 410 License Key

PSA configuration

E4440 PSA High Performance Spectrum Analyzer

VSA configuration

89640A: DC to 2.7 GHz Vector Signal Analyzer

- Option AYA, vector modulation analysis
- Option B7R, 802.11a OFDM and HiperLAN2 modulation analysis

Alternate instrument configuration

ESG configuration

E4438C ESG Vector Signal Generator

- Options 506, frequency range up to 6 GHz
- Option UNJ, enhanced phase noise
- 001 or 002, Baseband generator
- Signal Studio-802.11a, Option 410 License Key

PSA configuration

E4440 PSA High Performance Spectrum Analyzer

- Option H70, 70 MHz IF

VSA configuration

89611A: 70 MHz IF Vector Signal Analyzer

- Option AYA, vector modulation analysis
- Option B7R, 802.11a OFDM and HiperLAN2 modulation analysis

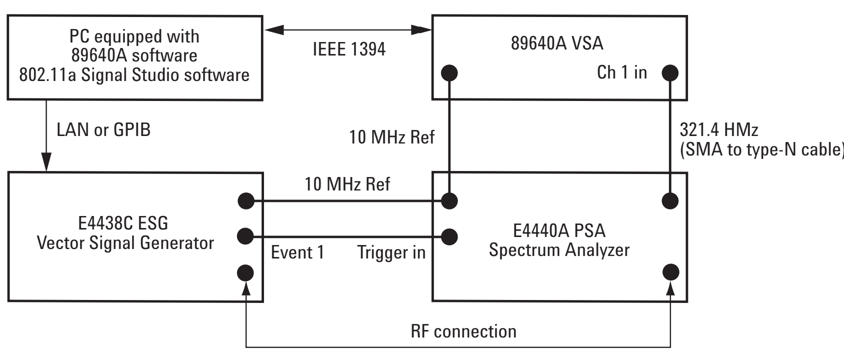


Figure 21. Equipment setup used to make measurements

The measurements in this section were set up with the same parameters as shown in Figure 14.

Spectral measurement

The following figures compare the spectrum generated mathematically by Signal Studio to the spectrum measured experimentally using the 89640 VSA.

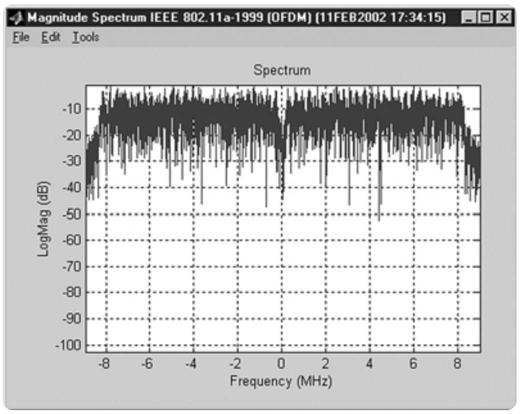


Figure 22. Spectrum plot of Signal Studio 802.11a I/Q waveform with all 52 sub-carriers on

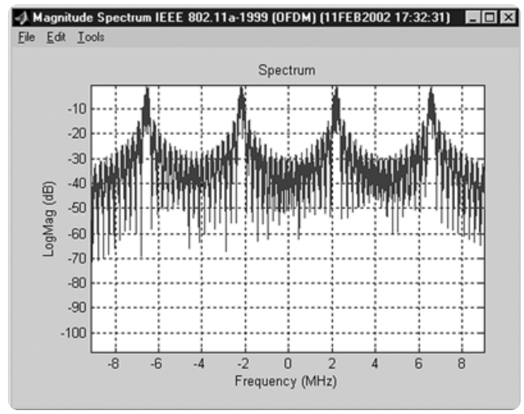


Figure 23. Spectrum plot of Signal Studio 802.11a I/Q waveform with just the 4 pilots on

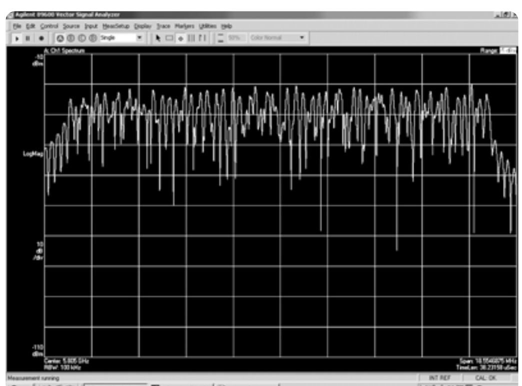


Figure 24. 89640A VSA Spectrum Signal Studio 802.11a of all 52 sub-carriers

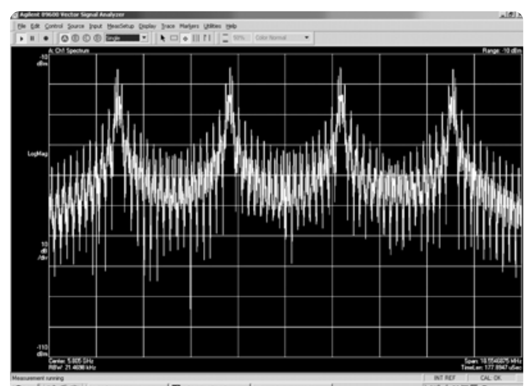


Figure 25. 89640A Spectrum of Signal Studio 802.11a signal of the pilots

www.agilent.com/find/esg

Transmit spectral mask

PSA instruction	Front panel buttons and menu selections
Set the PSA to Spectrum analysis mode	[MODE] {Spectrum Analysis}
Set the PSA center frequency to match your ESG output	[Frequency Channel] {5.805} {GHz}
Set other parameters	[Span] {100 MHz}, [BW/Avg] {Res BW Man} {100 kHz} {Video BW Man} {30 kHz} [Trig] {Ext Rear}

The transmitted 802.11a signal must fit in the spectral mask as defined in the standard, see Table 2. This is to help ensure that the transmitter is not interfering with adjacent and alternate channels. A spectral mask was drawn around the transmitted 802.11a signal in the measurement shown in Figure 26. The specified spectral density levels and offsets are listed in Table 2.

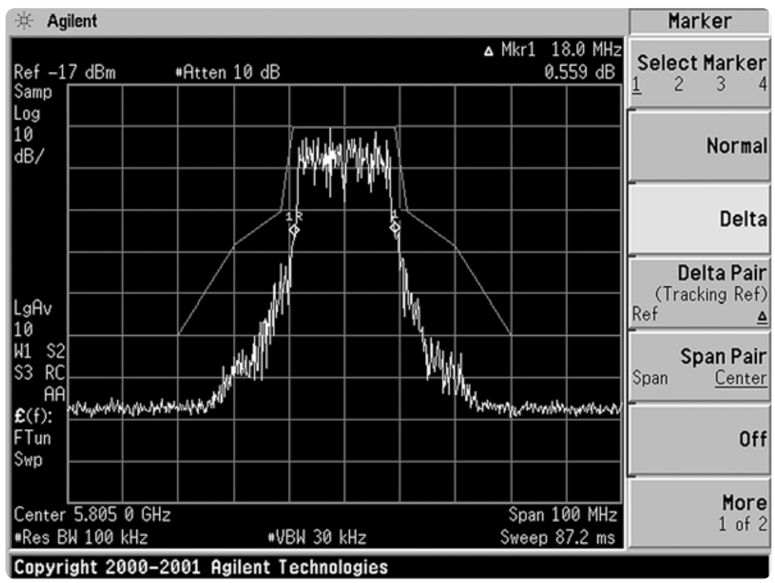


Figure 26. 89640A VSA spectrum of Signal Studio-802.11a Signal showing the ACP

dB relative to maximum spectral density of signal	Frequency offset
-20 dBr	fc >± 9 to 11 MHz
-20 to -28 dBr	fc >± 11 to 20 MHz
-28 to -40 dBr	fc >± 20 to 30MHz
≥ -40 dBr	fc > ± 30 MHz and greater

Table 2. IEEE 802.11a Transmitted Spectral Requirements

Power vs. time measurement

PSA instruction	Front panel buttons and menu selections
Set PSA to zero span to stop the sweep	[Span] {Zero Span}

VSA software instructions	Menu selections
Setup the VSA to work with an external down converter	Utilities/Calibration/External Frequency/ Use External Down Converter and enter the following values: External Center Frequency: {PSA center freq-5.805 GHz} Intermediate Frequency (IF): 321.4 MHz External Bandwidth: 36 MHz. Click Mirror Frequency
Adjust the range	Right click on the Range: Enter -15 dBm
Change trace A to main time	Right click on trace A Ch1 Spectrum/Edit/Main Time
Trace A: Change display in trace A from LogMag to LinMag	Right click on trace A LogMag/Edit/LinMag
Trace A: Auto scale	Trace/Y Auto Scale
Trace A: Change scaling to that similar to that of Figure 28	Trace menu "Y scale" Reference level 135 mV "Y per division" 15 mV
Trace B: Auto scale Trace B	Trace/Y Auto Scale
Adjust the RBW to 13.83 kHz	MeasSetup/ResBW. Enter the following values in the menu: Frequency Points: 12801 ResBW: 13.83 kHz ResBW Mode: Arbitrary ResBW couple: Offset Window Type: Flat top
Setup signal triggering	Input/Trigger. Enter the following values in the menu: Type: IF Mag Mag Level: 10 mv Slope: Positive Hold-off: 10 uSec Delay: -2 uSec
Trace B: click on the dotted box (select area box) from the menu at the top of the screen and zoom in on beginning of trace	Choose "select area" icon from top of menu (will see a three arrowed icon)/zoom in on desired area/ release mouse/click on scale x&y/click on okay

NOTE: For any additional questions regarding the VSA, please see the Help menu from the 89600 software.

Power-versus-time measurement

Figure 27 and Figure 28 both show an 802.11a burst. Figure 27 was created in Signal Studio, and shows a zoomed in portion of amplitude versus time.

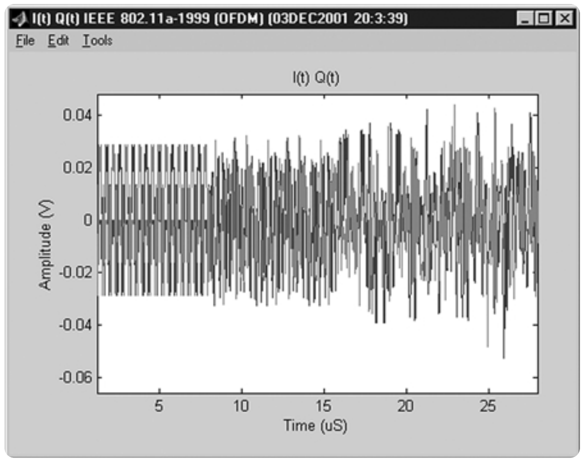


Figure 27. I(t)Q(t) Overlayed plot (zoomed in to 30 ms) from Signal Studio 802.11a

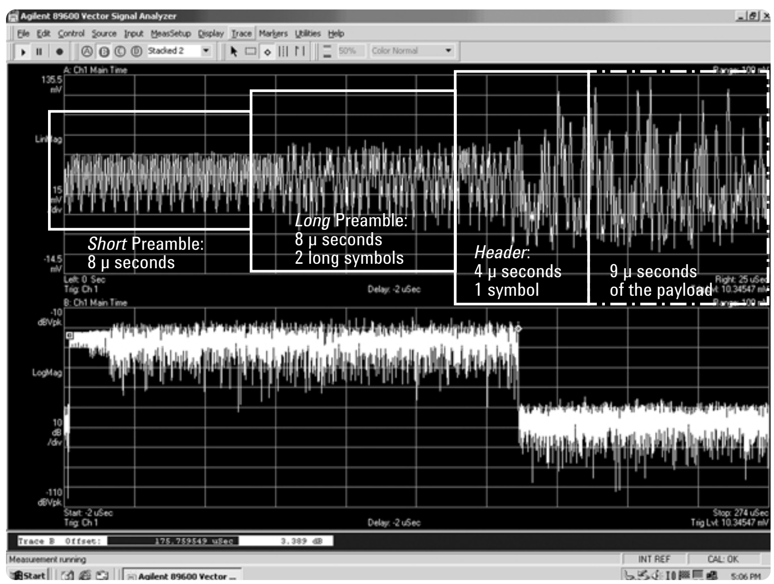


Figure 28. 89640A VSA Time Domain Measurement of Signal Studio 802.11a Signal. Top plot is "zoomed in" portion from the bottom plot.

Figure 28 shows the power-versus time measurement. The upper plot is a zoomed in portion of the lower plot. Notice that three distinct regions of the burst are visible. An 802.11a burst actually has four distinct regions, as shown in Figure 3.

Spectrogram

The spectrogram shown in Figure 29 shows a bursted 802.11a packet that is 28 milli-seconds long. Each spectrum measurement is flattened to one row of pixels. Since height can no longer be used to represent amplitude, color is used instead. The spectrogram display is useful for looking at the time-varying spectral characteristics of a burst. The following are some of the attributes of this display:

- Red represents a large signal level
- Green represents a mid signal level, the bursting of the packet
- Blue represents a low signal level
- The (horizontal) frequency axis is the same as for a regular spectrum display.
- The vertical axis is now time instead of amplitude.
- The top of the spectrogram trace is the start of the burst and the bottom, the end.
- Notice that the short training symbols are added to sub-carriers:-24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24, and the sub-carriers show the most energy.

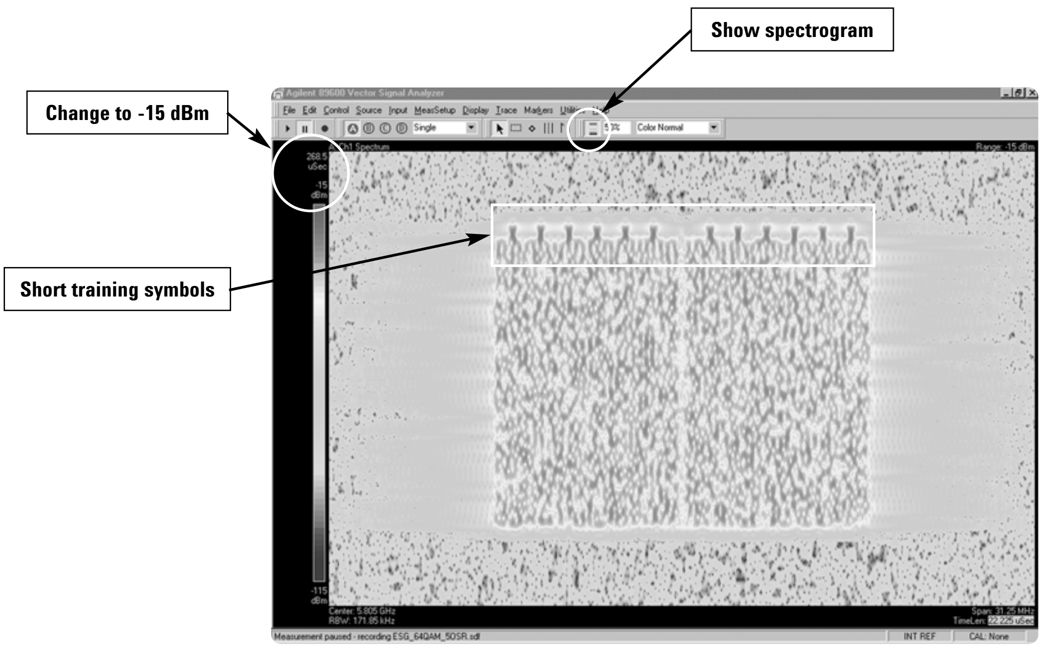


Figure 29. 89640A VSA Spectrogram of Signal Studio 802.11a signal

VSA instruction	Menu selections
Preset instrument	File/Preset/Preset Setup
Change view of display	Display/Layout/Single
Click on Spectrogram icon at top of menu	Show spectrogram
Change Measure Setup parameters	Measure Setup/Time/Max Overlap (Avg Off): 98%
Change power resolution to -15 dBm	Right click on power level above power level display bar on left of spectrogram display-Edit/ -15 dBm.

EVM measurement

The most widely used modulation quality metric in digital communications systems is Error Vector Magnitude. When performing EVM measurements, the analyzer samples the transmitter output to capture the actual signal trajectory. The signal is demodulated and a reference signal is mathematically derived. The error vector is the vector difference at a given time between the ideal reference signal and the measured signal. The error vector is a complex quantity that contains a magnitude and a phase component. Table 3 lists the specified EVM levels as defined by the IEEE 802.11a standard.

Data rate (Mbit/sec)	Relative constellation error (dB)	EVM (%RMS)
6	-5	56.2
9	-8	39.8
12	-10	31.6
18	-13	22.3
24	-16	15.8
36	-19	11.2
48	-22	7.9
54	-25	5.6

Table 3. EVM requirements for an 802.11a signal

VSA instruction	Menu selections
Preset instrument	File/Preset/Preset Setup
Activate OFDM demodulator	MeasSetup/Demodulator/OFDM
Select 802.11a demodulation	MeasSetup/Demod Properties/Format (tab)/ Standard /802.11a/Preset to Standard/IEEE 802.11a
Select four trace "quad" display layout	Display/Layout/Quad 4

EVM is shown in the lower right quadrant of Figure 30. The description of all four quadrants is given below.

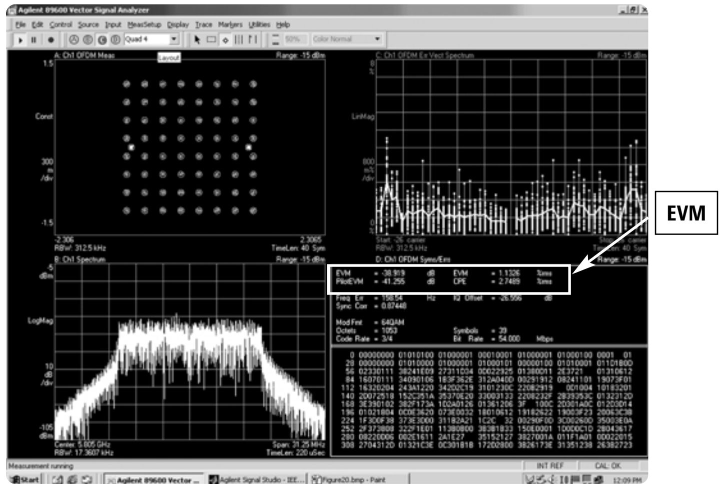


Figure 30. 89640A with OFDM digital demodulation measurement personality

Upper left quadrant: compound constellation
The WLAN signaling formats allow multiple modulation formats in a burst. For 802.11a signaling the pilot carriers are always BPSK, the data sub-carriers are BPSK in the signal symbol and one of four formats (BPSK, QPSK, 16QAM, 64QAM) in the payload.

Option B7R provides a compound constellation diagram that shows all the modulation formats present in a burst at the same time using different colors for the sub-carriers. The colors are pre-set to white for the pilot sub-carriers, and red for the data sub-carriers.

Upper right quadrant: EVM spectrum
This OFDM-specific composite EVM display provides instantaneous and average readings of the quality of the modulation on WLAN signals. The Error Vector Spectrum display measures the EVM of each sub-carrier over a number of symbol periods. The dark line shows the average EVM across the carriers.

Lower left quadrant: spectrum
Frequency domain representation of the signal.

Lower right quadrant: symbol/Error Table
Along with the demodulated data bits, this table provides the following information:

- EVM: payload EVM in dB and % rms
- PilotEVM: pilot carrier EVM
- CPE: common pilot error shows how much pilot carrier variation was "tracked out" by the equalizer in the process of demodulating the signal. View phase noise, incidental AM/PM and anything that was common to all four pilots.
- Freq Err: frequency error at the center of the channel
- I/Q Offset: for measuring carrier leakage
- Sync Corr: Synchronization correction compares the captured short training sequence to the ideal short sequence (defined in the standard) to indicate sequence quality.
- information about payload data
    - Mod Fmt: modulation format
    - Octects: bytes in the payload
    - Symbols: symbols in payload
    - Code Rate: encoding rate of convolutional encoder
    - Bit Rate: bit rate of payload

802.11a Signal Studio Features

Framing	• Framed: bursted packets includes a PLCP Preamble (short and long) and Header (Signal field) • Non-framed: Continuous non-bursted payload data (no PLCP Preamble and Header added to payload
Raised cosine windowing	Range: 0-16 samples
Convolutional encoding	1/2, 2/3, and 3/4 rate
Modulation formats	BPSK, QPSK, 16-QAM, 64-QAM
Data source	user file, 1s, 0s, 01s, 10s, PN9, PN15
Data rates **Custom data rate**	6, 9,12,18, 24, 36, 48, 54 Mbps and Custom data rate Modulation: BPSK Encoder: Inactive Data rate: 12 Mbps Modulation: QPSK Encoder: Inactive Data rate: 24 Mbps Modulation: 16-QAM Encoder: Inactive Data rate: 48 Mbps Modulation: 64-QAM Encoder: Inactive Data rate: 72 Mbps Modulation: BPSK Encoder: 2/3 Data rate: 8 Mbps Modulation: QPSK Encoder: 2/3 Data rate: 16 Mbps Modulation: 16-QAM Encoder: 2/3 Data rate: 32 Mbps Modulation: 64-QAM Encoder: 1/2 Data rate: 36 Mbps
Data length	Maximum • Without MAC Header and FCS: 4095 Bytes • With MAC Header and FCS: 4061 Bytes Minimum • 1 Byte
Idle interval between frames	Range: 0-1000 microseconds
Sub-carrier setup	Range: -1 to -26, and 1 to 26. Individually selectable. All or any sub-carrier configuration; except none.
Service field	16 bit Hex (First 7 LSB are masked to zero).
Scrambler seed initialization value	7 bits Hex
Oversample ratio	1-5
Frame length	Range: 24 microseconds to 5.484 milliseconds
Sample length of 802.11 a waveform	Maximum: 259,360 samples with 6 Mbps data rate and 4095 bytes payload

Acronyms and abbreviations

16-QAM	16 point quadrature amplitude modulation
64-QAM	64 point quadrature amplitude modulation
BPSK	binary phase shift keying
dBr	dB relative to the maximum power spectral density of the signal
DUT	device under test
fc	center frequency
FCS	frame check sequence.
FDM	frequency division multiplexing
ICI	intercarrier interference
IF	intermediate frequency
ISI	intersymbol interference
I/Q	in-phase/quadrature
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
OFDM	orthogonal frequency division multiplexing
QPSK	quadrature phase shift keying
MAC	medium access control
OSR	oversample ratio
PHY	physical layer
PLCP	physical layer convergence procedure
PMD	physical medium dependent
PPDU	PLCP protocol data unit
PSD	power spectral density
PSDU	PLCP service data unit
RF	radio frequency
WLAN	wireless LAN

Additional literature

E4438C Signal Studio Installation Guide, 199 kB
Available @ **http://www.agilent.com/find/signalstudio**
E4438C Data Sheet, 489 kB
Literature Number 5988-4039EN
E4438C Configuration Guide, 221 kB
Literature Number 5988-4085EN
E4438C Brochure, 5.2 MB
Literature Number 5988-3935EN
ESG Vector Signal Generator User's Guide
Part number E4400-90503
Using the 89600 to Make OFDM Measurements Product Note, 464 kB
Literature Number 5988-4094EN
89600 Series Brochure, 1.7MB
Literature Number 5980-0723E
E4440A Data Sheet, 683KB
Literature Number 5980-1284E
Characterizing Digitally Modulated Signals with CCDF Curves, 548 kB
Literature Number 5968-6875E
RF Testing Wireless LAN Products Application Note, 6.6 MB
Literature Number 5988-3762EN
IEEE 802.11 Receiver Test Guidelines, 81.7 kB
Wireless Systems Design November 2001 Issue **www.wsdmag.com**

Agilent products: web addresses

- Signal Studio Software for the ESG web site: **www.agilent.com/find/signalstudio**
- E4438C ESG Vector Signal Generator web site: **www.agilent.com/find/esg**
- PSA Series High-Performance Spectrum Analyzer web site: **www.agilent.com/find/psa**
- 89600 Series Vector Signal Analyzer web site: **www.agilent.com/find/89600**
- Advanced Design System E8874a 5 GHz 802.11a WLAN Design Library **http://www.agilent.com/find/ADVANCED**

References

IEEE Std 802.11 1999 Standard
IEEE Std 802.11a-1999 Standard
IEEE 802.11 Handbook
By Bob O'Hara and Al Petrick ISBN # -0-7381-1855-9
OFDM For Wireless Multimedia Communications
By Richard Van Nee and Ramjee Prasad ISBM # 0-89006-530-6

Ordering information

Signal Studio-802.11a is Option 410 for the Agilent E4438C ESG Vector Signal Generator.

E4438C ESG
Option 506, 250 kHz to 6 GHz frequency range
Option UNJ, improved phase noise
Option 001 or 002, baseband generator

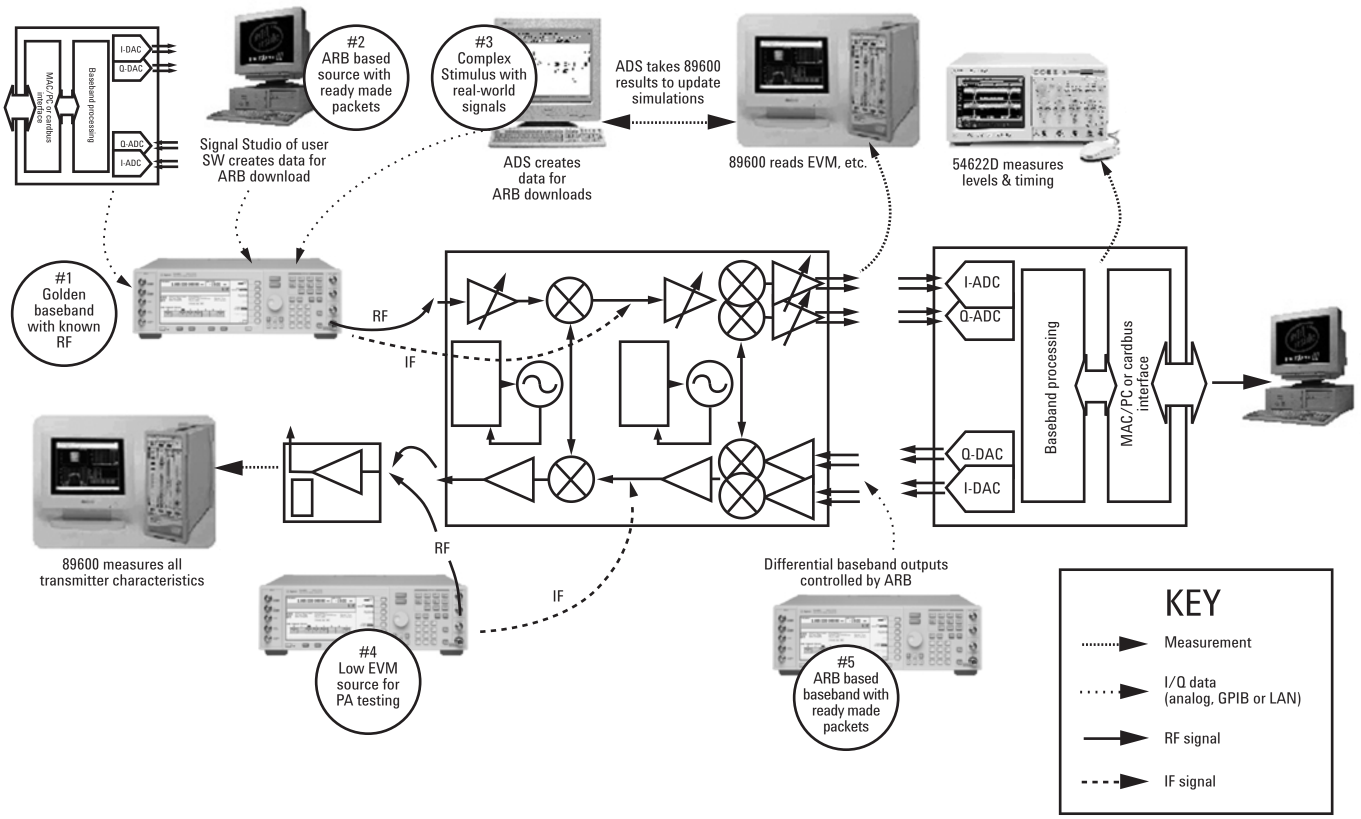
Try before you buy!
Download Signal Studio from **www.agilent.com/find/signalstudio** to a PC to evaluate the signal configuration and plotting capabilities of the software However, to load the signal created by the software into the ESG, a license key must be purchased. The license key can be ordered through a sales engineer or local sales office. Contact information for both can be found at **http://www.agilent.com/find/assist.**

Upgrade kits

If you already currently own an E4438C ESG Vector Signal Generator and are interested in obtaining an upgrade kit only (license key), order: E4438CK Option 410.

The following diagram illustrates the various ways an E4438C ESG may be used in an 802.11a test setup. Agilent Technologies makes a variety of WLAN test and measurement instruments that allow testing through out the entire design cycle, from simulation to transmitter measurements and everywhere in between.

802.11a Wireless LAN Interface Points For E4438C



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Our Promise
Our Promise means your Agilent test and measurement equipment will meet its advertised performance and functionality. When you are choosing new equipment, we will help you with product information, including realistic performance specifications and practical recommendations from experienced test engineers. When you use Agilent equipment, we can verify that it works properly, help with product operation, and provide basic measurement assistance for the use of specified capabilities, at no extra cost upon request. Many self-help tools are available.

Your Advantage
Your Advantage means that Agilent offers a wide range of additional expert test and measurement services, which you can purchase according to your unique technical and business needs. Solve problems efficiently and gain a competitive edge by contracting with us for calibration, extra-cost upgrades, out-of-warranty repairs, and on-site education and training, as well as design, system integration, project management, and other professional engineering services. Experienced Agilent engineers and technicians worldwide can help you maximize your productivity, optimize the return on investment of your Agilent instruments and systems, and obtain dependable measurement accuracy for the life of those products.

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For more assistance with your test & measurement needs or to find your local Agilent office go to

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