

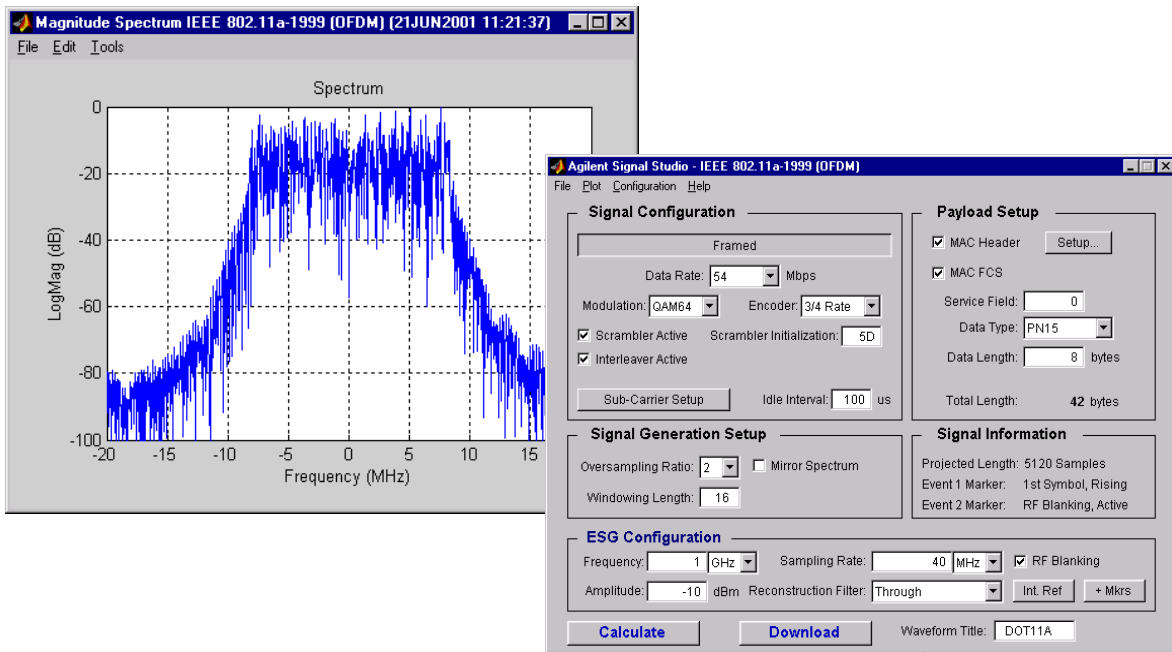


# Agilent Technologies

## Signal Studio-802.11a for the ESG

### Option 410

## Product Note



## Use Signal Studio to Create IEEE 802.11a Test Signals

Signal Studio-802.11a software is a powerful tool for creating IEEE 802.11a baseband I/Q waveforms for use with the Agilent ESG digital series signal generator's dual arbitrary waveform generator.

### Main Features

- Intuitive user interface makes waveform creation fast and easy
- Plot spectrum and I/Q components
- Selectable framing includes Preamble and Header
- Raised cosine windowing
- Customize modulation and encoder settings including data rate, scrambling, interleaving, convolutional encoding, and MAC header
- Enable/disable FCS
- Remote control of basic ESG-digital series RF signal generator functions from software

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 [References](#) section at the end of this document.

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## Software Overview

Signal Studio-802.11a software is a tool for creating an IEEE 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 dual arbitrary waveform generator for playback.

Try before you buy! Signal Studio can be downloaded free of charge for evaluation. A license key is required to load the signals created by the software into the ESG Digital Series RF Signal Generator. 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 signal generator over the GPIB or RS-232 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 re-enabled 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 waveform files can be saved in the ESG dual arbitrary waveform generator non-volatile memory for later recall. If multiple waveforms are being created and the ESG non-volatile memory capacity becomes an issue, the Signal Studio-802.11a configuration can be saved to the host computer's local hard drive. The Signal Studio software configuration can then be recalled at any time to re-calculate 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.

The Signal Studio-802.11a signal can be used to test baseband components 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.

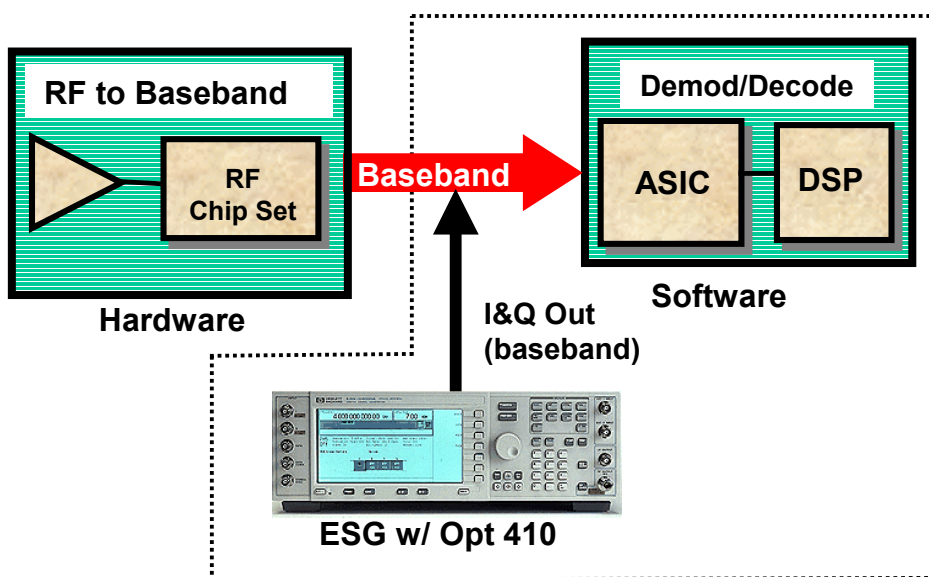


Figure 1: Generating a Baseband Test Signal

IEEE 802.11a operates in the 5.150 to 5.350 GHz, and 5.725 to 5.825 GHz frequency bands. The maximum frequency range of the ESG is 4 GHz. The ESG can only be used to test 802.11a components at baseband or IF frequencies, not in the 5 GHz band. If it is desired to transmit the signal in the 5 GHz frequency range, a mixer can be used to convert the 802.11a signal to the desired frequency range, see Figure 2 below. The actual frequency parameters that would be used for each source, bandpass filter, and amplifier vary according to the specific mixer that is chosen.

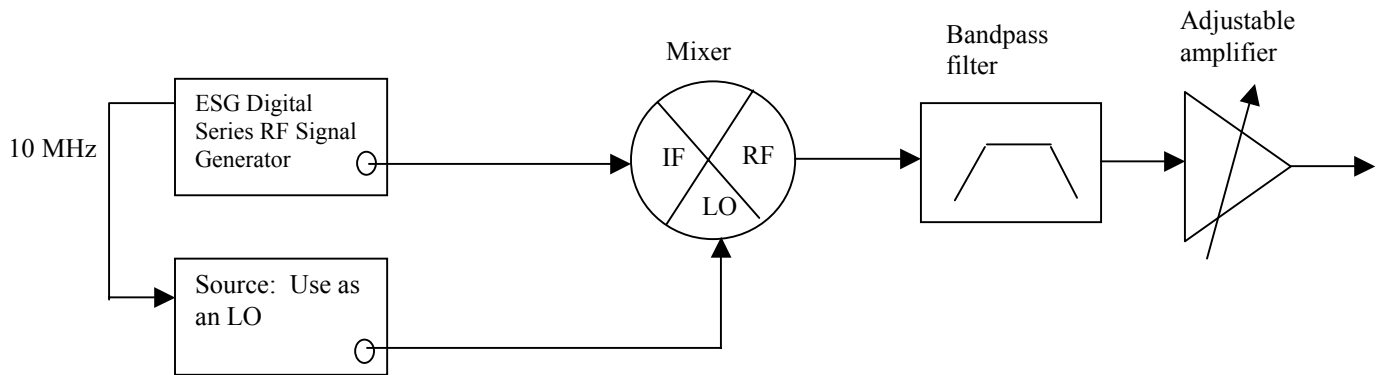


Figure 2: Converting a Test Signal to the 5 GHz Frequency Band

## Benefits

Signal Studio-802.11a simplifies the user's role in creating 802.11a test signals for use with the ESG digital series RF signal generator. Instead of wasting valuable time writing code to create a proprietary test signal, Signal Studio-802.11a provides the ability to quickly configure a standard-based test signal via an intuitive graphical user interface. Furthermore, the Signal Studio-802.11a frame configuration can easily be modified to create the desired test signal, without re-writing 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 by providing statistically correct signals. Signal parameters, including the number of active subcarriers and modulation type, can be modified to provide adequate stress on the components being tested.

### **Receiver Test**

In order to thoroughly test a receiver's demodulation capabilities, a test signal with full channel coding is necessary. Full 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 to verify performance.

The designer will be able to use this as a test signal 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.

Another benefit of using the Signal Studio-802.11a as a test signal is that it allows the designer to verify that the receiver decodes an independently generated 802.11a test signal correctly.

## IEEE 802.11a OFDM Overview

802.11a is an orthogonal frequency division multiplexed (OFDM) multicarrier signal. In traditional FDM systems, the spacing between channels is greater than the symbol rate to avoid overlapping the spectrums. However, in OFDM systems, the carriers overlap, which conserves bandwidth, but subcarriers don't interfere with one another because they are orthogonal to one another. Orthogonality implies that there is a mathematical relationship between the subcarriers, and there is. Each subcarrier has an integer number of cycles in the FFT interval, and there is a difference of one cycle between adjacent subcarriers, and this is the reason orthogonality exists between the subcarriers. Each subcarrier has a spectral null at all the other subcarrier frequencies

The high rate data OFDM signal is divided into 52 slower parallel signals (subcarriers), and then an IFFT is applied to the signal, and these subcarriers are transmitted simultaneously. The symbol duration increases for the lower rate parallel subcarriers, 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 intercarrier interference (ICI). A guard interval is added to help prevent ICI, as well as intersymbol interference (ISI). ICI will cause ISI. However, ISI will not cause ICI. A signal with a slower data rate is more resistant to multipath fading and interference.

### ***802.11a Occupied Bandwidth***

All the subcarriers are spaced equidistant to one another. For 802.11a, the subcarriers are 312.5 kHz apart. This spacing is determined by dividing the FFT sampling rate, 20 MHz, by the total number of samples in the FFT, which is 64 points in 802.11a. One 802.11a symbol is comprised of 48 data subcarriers, and 4 pilot subcarriers, and one nulled subcarrier (zero subcarrier). Thus the occupied bandwidth is 53 subcarriers multiplied by the spacing of 312.5 kHz, which is 16.56 MHz. The 802.11a standard specifies that the occupied bandwidth is 16.6 MHz.

## Signal Studio-802.11a Baseband Data OFDM Symbol Creation

Signal Studio-802.11a encodes the data according to the standard, which is shown in Table 1 on page 12. The user's 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 adds robustness to the symbol in the event the amplitude of any of the subcarriers diminish 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 FFT is applied to the data, see Figure 3. The data is mapped onto 48 data subcarriers, which are identified as subcarriers -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 Subcarrier Setup Menu. Each group of 48 data subcarriers makes up one OFDM data symbols. Four pilot subcarriers 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 commonly experienced over-the-air interface channel. The guard interval needs to be larger than the delay spread to prevent ISI.

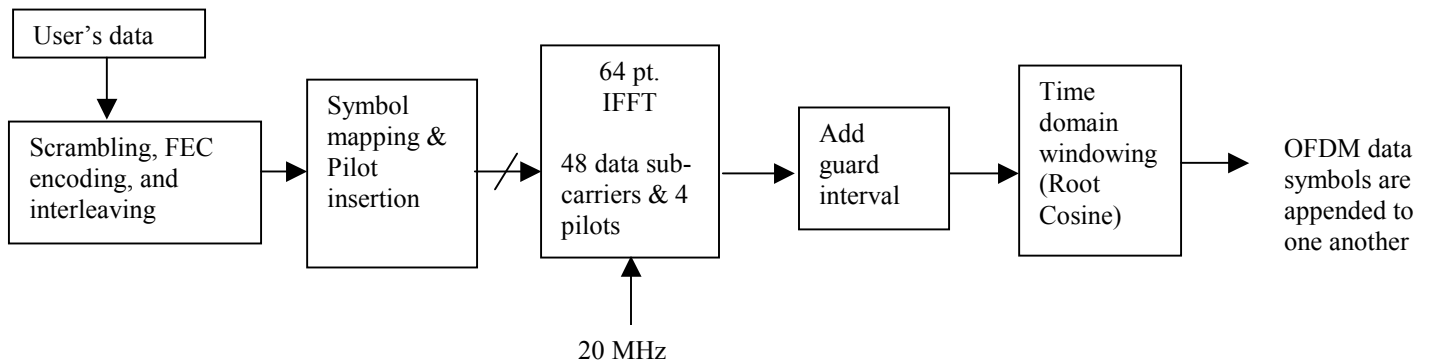


Figure 3: Creation of an OFDM symbol

The following diagram, Figure 4, illustrates the OFDM symbol structure. Once the 64 point IFFT is performed, the last 16 bits of the symbol are appended to the front of the IFFT interval (called the guard interval or cyclic prefix) to create the symbol, which is 80 samples long. Then the first 16 bits of the IFFT are inserted at the end of the symbol. This cyclic post-fix allows the user to apply a raised cosine window to each OFDM symbol. At the symbol boundaries, the modulation creates sharp phase transitions that increase the out-of-band energy of the signal. The raised cosine window smoothes these transitions, thus reducing the out-of-band energy. This can be demonstrated with the Signal Studio-802.11a software by varying the range of the window, and plotting the spectrum, as shown in Figures 5 and 6.

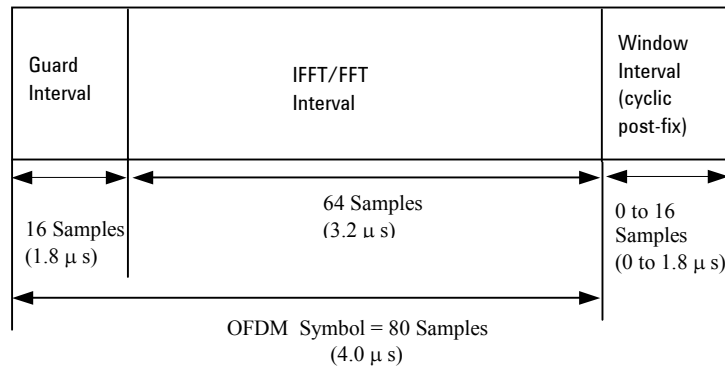


Figure 4: One OFDM symbol time representation

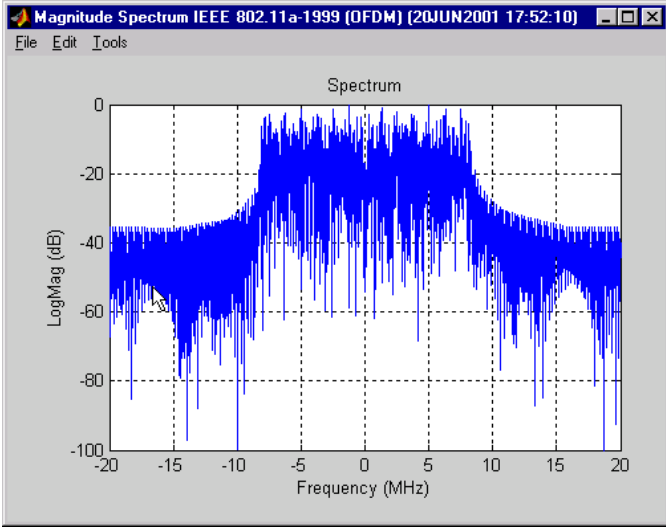


Figure 5: Spectrum plot of 802.11a I/Q waveform with Windowing Length=0 samples (no windowing)

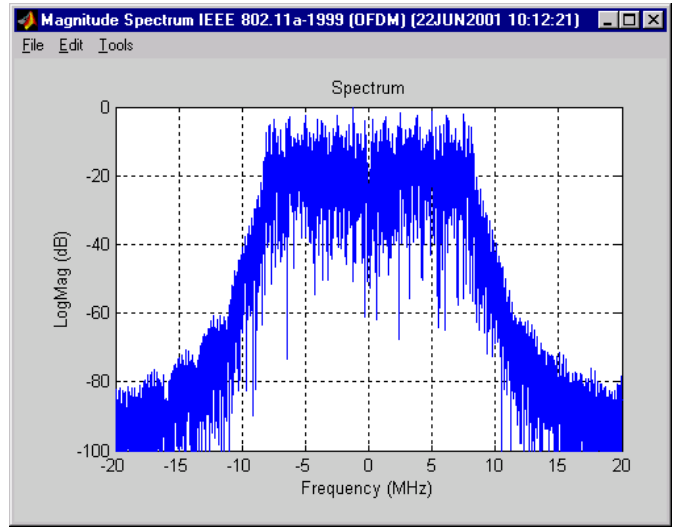


Figure 6: Spectrum plot of Signal Studio-802.11a I/Q waveform with Windowing Length = 16 samples (maximum)

### ***Raised Cosine Windowing***

The individual OFDM symbols are appended to one another as illustrated in Figure 7. The post-fix interval can be multiplied by a raised cosine window function. The length of the window interval is adjustable from 0 to 16 samples. The window function is applied to reduce any discontinuities that result when appending one symbol to another, which would result in spectral splatter and increases out-of-band power of the subcarriers. The OFDM symbol itself, is left unchanged. The larger the length of the window, the more the out-of-band power is reduced, see Figures 5 and 6. However, windowing reduces the guard interval, which reduces the sensitivity to interference from multipath delay.

The out-of-band power can also be reduced using filtering techniques. The standard does not specify how to reduce the out-of-band energy, as long as the signal meets the spectral mask requirements. However, windowing is easier to implement in practice. Also, filtering may introduce rippling in the IFFT/FFT interval, which could create bit errors.

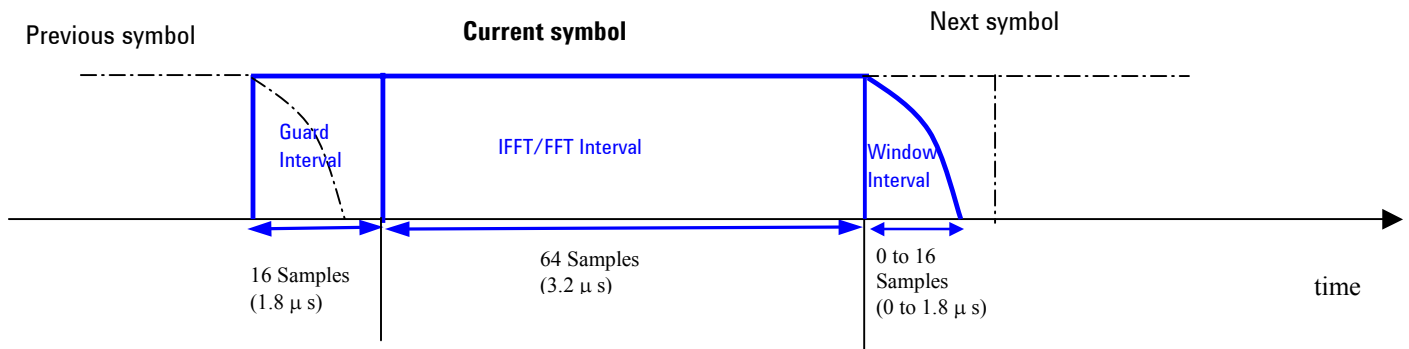


Figure 7: Appended OFDM data symbols

# Signal Structure

## ***PMD Layer***

The Signal Studio-802.11a creates the physical layer PMD (physical medium dependent) test signals, which contain PLCP (physical layer convergence procedure) Preamble, PLCP Header, and payload data, see Figure 8.

Although the signal does not provide MAC or PLCP protocol handling, it does enable testing of the PMD for receiver and component tests.

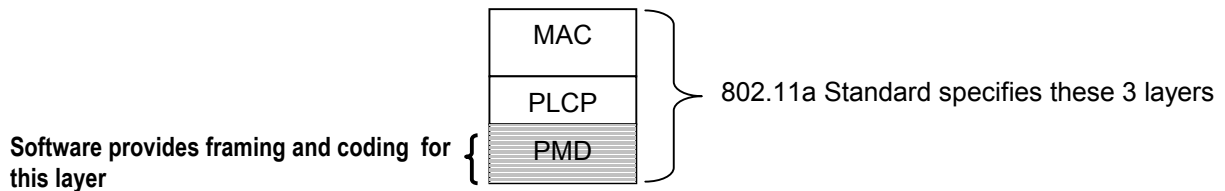


Figure 8: 802.11a Standard Protocol Stack

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 coding 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 in the MAC header to append to the payload data, see Figure 10. 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, which is burst. 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 9 illustrates the frame structure of the signal created by Signal Studio-802.11a software. The signal is created according to IEEE-802.11a specifications.

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

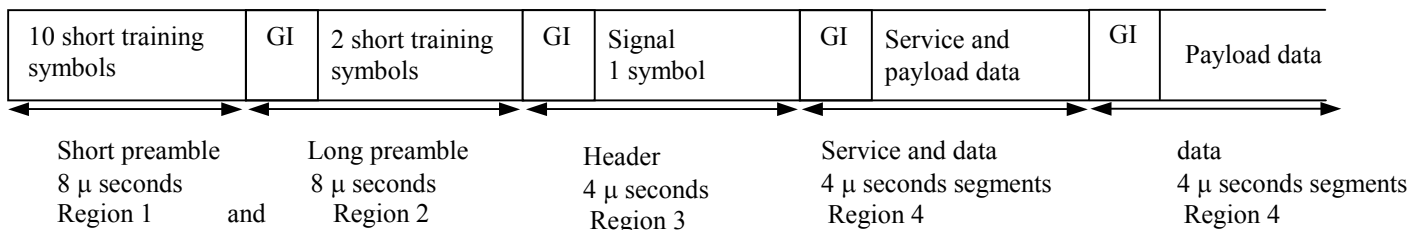


Figure 9: 802.11a Frame

Figure 10 shows the detailed diagram of the Signal Studio-802.11a framing.

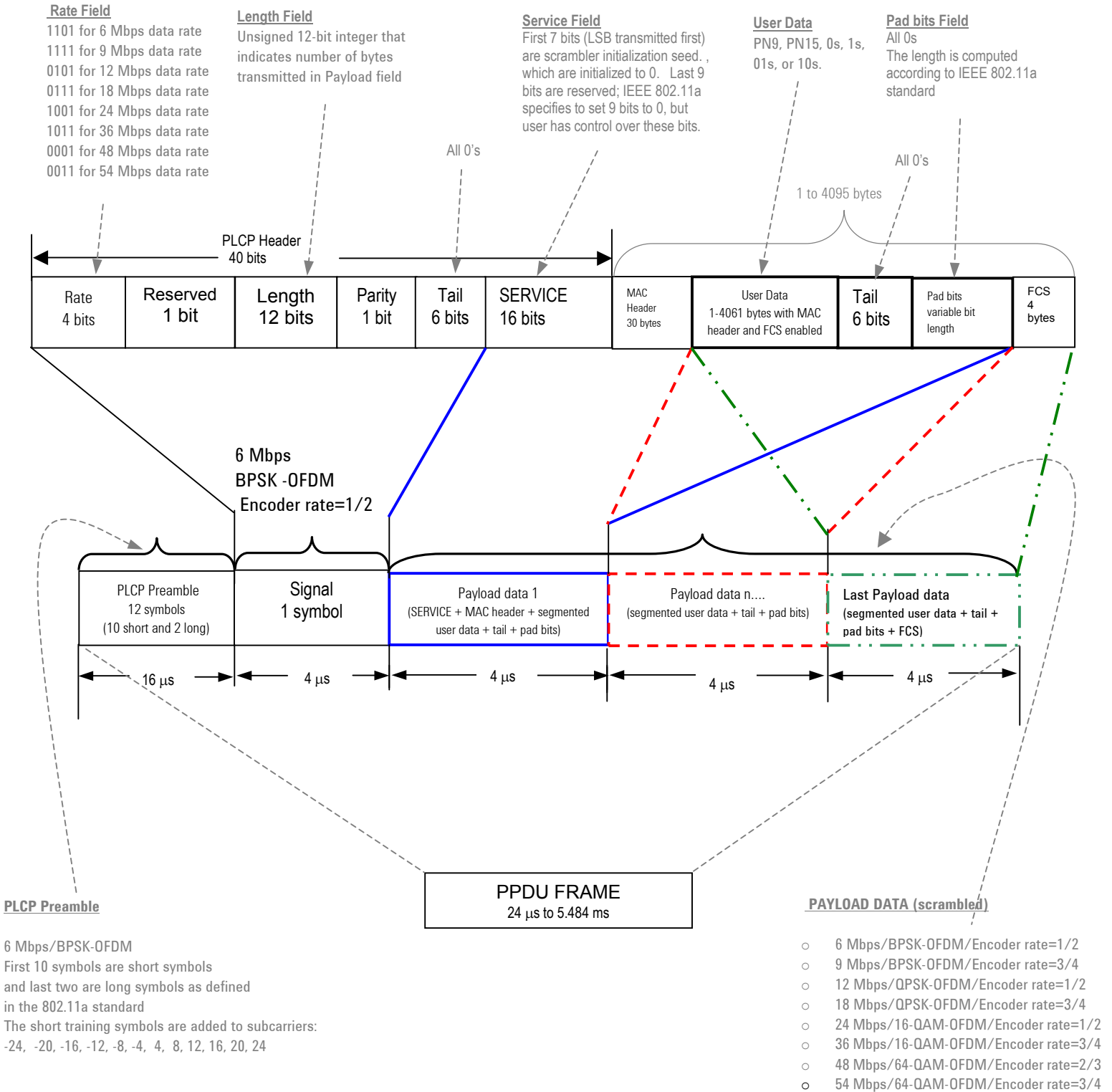


Figure 10: Signal Studio-802.11a Framed Signal

## 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 subcarrier	Coded bits per symbol
6	BPSK	1/2	1	48
9	BPSK	3/4	1	48
12	QPSK	1/2	2	96
18	QPSK	3/4	2	96
24	QAM-16	1/2	4	192
36	QAM-16	3/4	4	192
48	QAM-64	2/3	6	288
54	QAM-64	3/4	6	288
Custom	Variable	Variable	Variable	Variable

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

Figure 11 is an illustration of the payload 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.

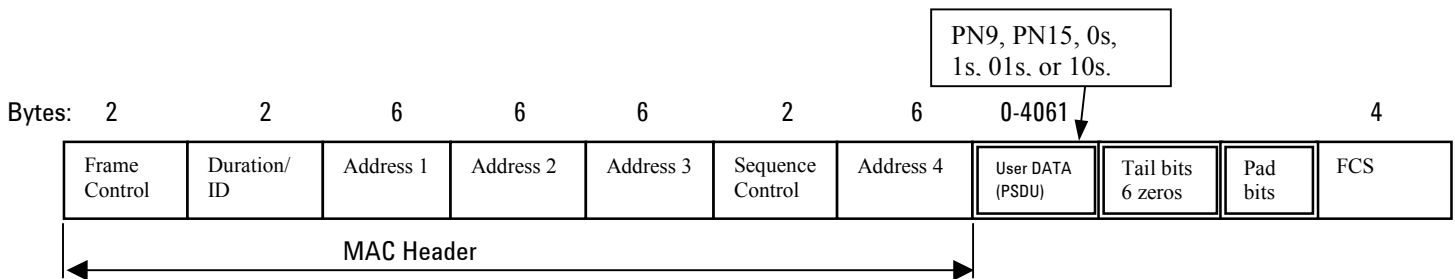


Figure 11: Payload Structure

# Creating Signals

An 802.11a waveform 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 subcarrier setup

**Step 2** - Setup the Signal Generation Options

**Step 3** - Configure the ESG

**Step 4** - Calculate & Download

## Step 1 – Configure 802.11a signal, including the MAC Header and Subcarrier Setup

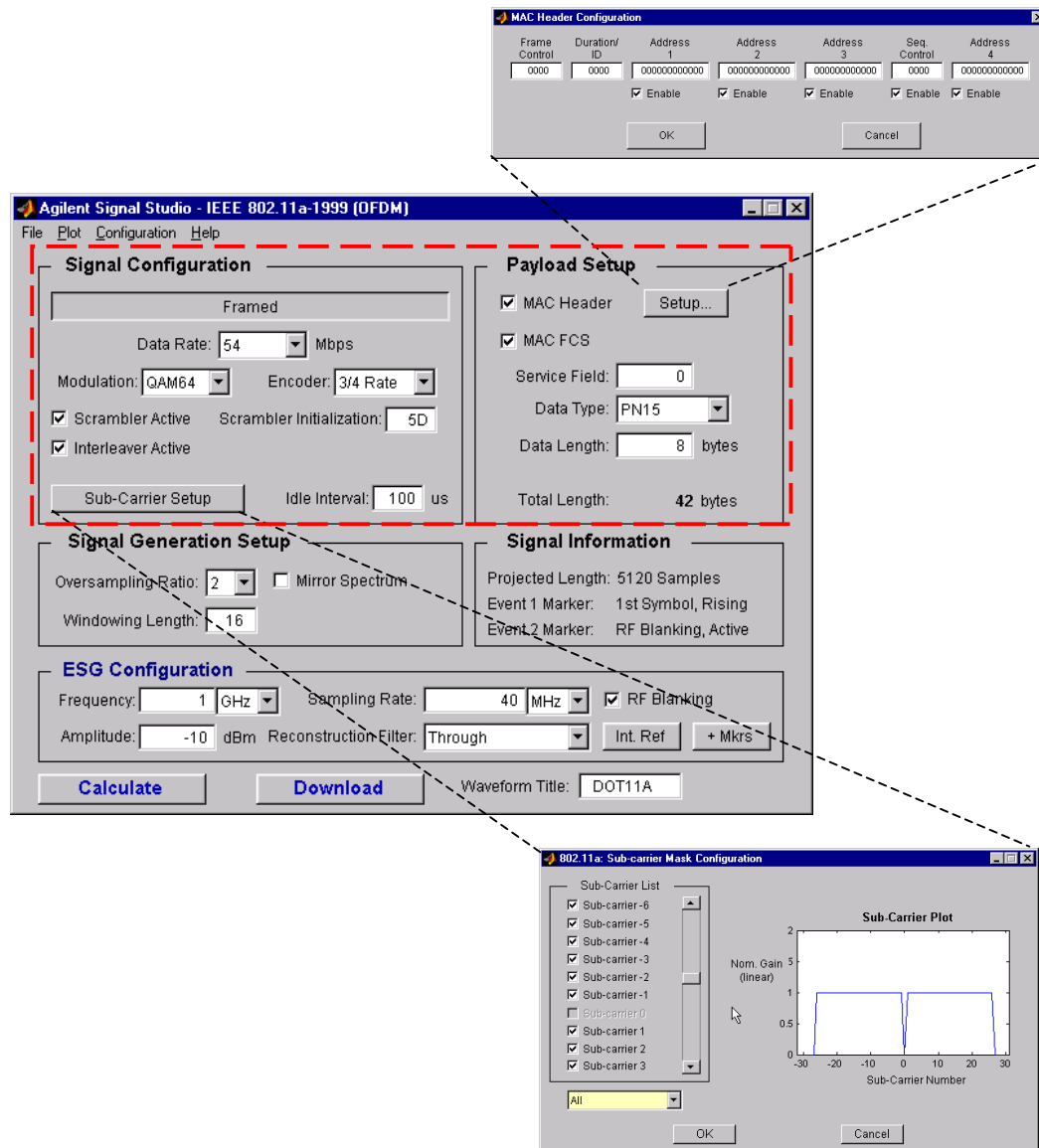


Figure 12: Signal Studio-802.11a Signal Configuration menu

## Signal Configuration

The Signal Configuration user interface section allows the user to choose specific parameters for the framing of the signal. Notice that you can choose framing, or turn it off. A framed signal is needed in receiver tests, and an unframed signal would be useful in component tests, or other instances where continuous, opposed to bursted, modulation of unframed data is desired.

**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 and non-bursting 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. Otherwise, the data rate selected will automatically set the modulation and encoder rate according to the 802.11a standard.

**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:** Toggles the activity state of the scrambler.

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

**Interleaver Active:** Toggles the activity state of the interleaver.

**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 subcarriers, and 4 are pilot subcarriers. The center frequency, which is the zero subcarrier, is nulled. The state of each of the subcarriers can be toggled On/Off, or the user can select from some predefined set-ups as follows:

- All
- Every 2<sup>nd</sup>
- Every 4<sup>th</sup>
- Upper band
- Lower band
- Outer band
- Outer pair
- None (not allowed)

### Payload Setup

This section allows the user to configure the MAC header and choose to have an FCS added 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 entire payload is displayed.

**Setup menu:** Configures the MAC header.

**MAC Header:** Enables/disables prepending the MAC header to the data payload. The user can set all these individual fields with the desired data, and the user can disable these fields if the data is no longer desired.

**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, and can contain the following data:

- 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

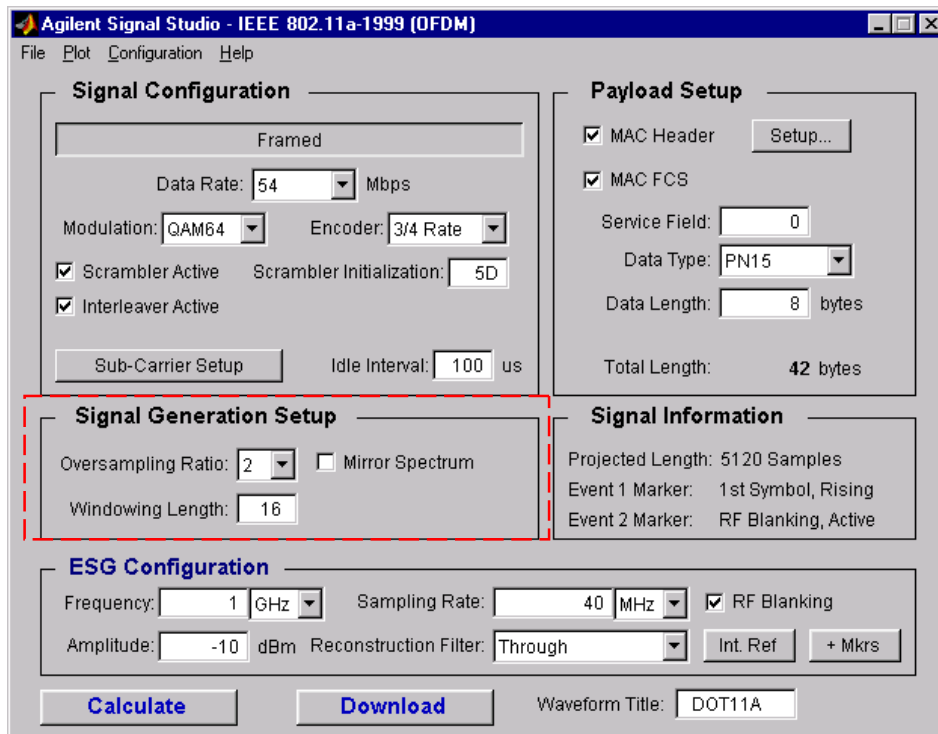


Figure 13: Signal Studio-802.11a Signal Generation Options menu

### Signal Generation Setup

As illustrated in Figure 13, the Signal Studio software provides a simple interface for defining the following signal generation options: Oversampling Ratio, Windowing Length, and Mirror Spectrum.

#### Oversample Ratio

The over sampling 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. However, the improved image rejection comes with a price. 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 software offers two different OSRs of 1 and 2. When an OSR is selected, this automatically sets the Sampling Rate in the ESG Configuration section. The lower the sample rate, the less space the waveform takes up in memory, and the faster the signal can be generated and downloaded.

The maximum sampling rate on the ESG is 40 MHz. The ESG provides three reconstruction filters (250kHz, 2.5MHz, 8MHz) and a no filter option (through). The bandwidth of the baseband signal dictates the minimum reconstruction filter bandwidth to be used. The reconstruction filters remove frequency images. These low-pass filters are intended to transmit the baseband signal while rejecting the higher frequency images.

When using the reconstruction filters available on the ESG, part of the desired higher frequency components of the 8.3 MHz wide baseband 802.11a signal will be cut off. To prevent this from happening, it is suggested that an external reconstruction filter be used, see Figure 14. When using an external reconstruction filter, set Reconstruction Filter in the ESG Configuration section to *Through*.

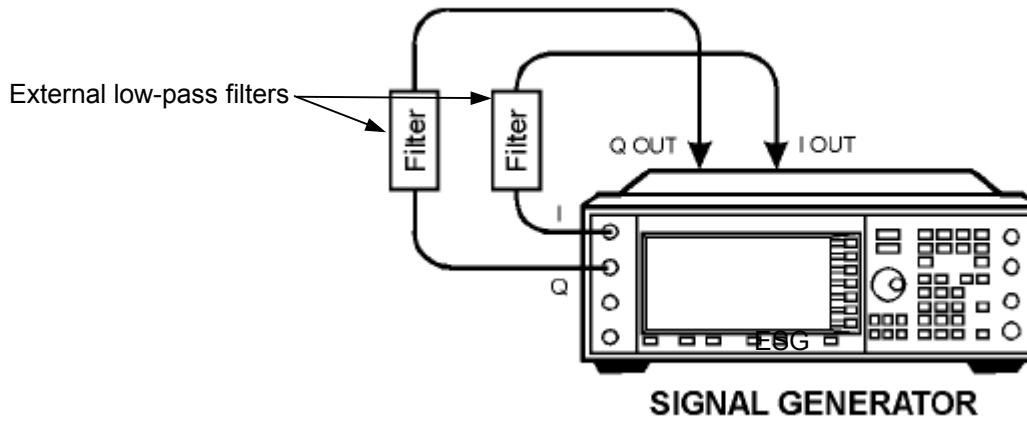


Figure 14: ESG Set Up with External Reconstruction Filters

The reconstruction filter should have at least 8.3 MHz bandwidth, which is the baseband bandwidth of 802.11a. These reconstruction filters allows the entire desired signal to pass through, while rejecting the images that occur at multiples of the OSR.

For more information on reconstruction filters, and oversample ratios, refer to [\[4\]](#).

### Windowing Length

A raised cosine time-domain window is applied to the baseband signal after the inverse Fourier transform is applied to the signal to reduce out-of-band power. The user can select the length of the raised cosine window. The range is 0 to 16 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 RF signal to the 5 GHz frequency band.



## Step 3 – Configure the ESG

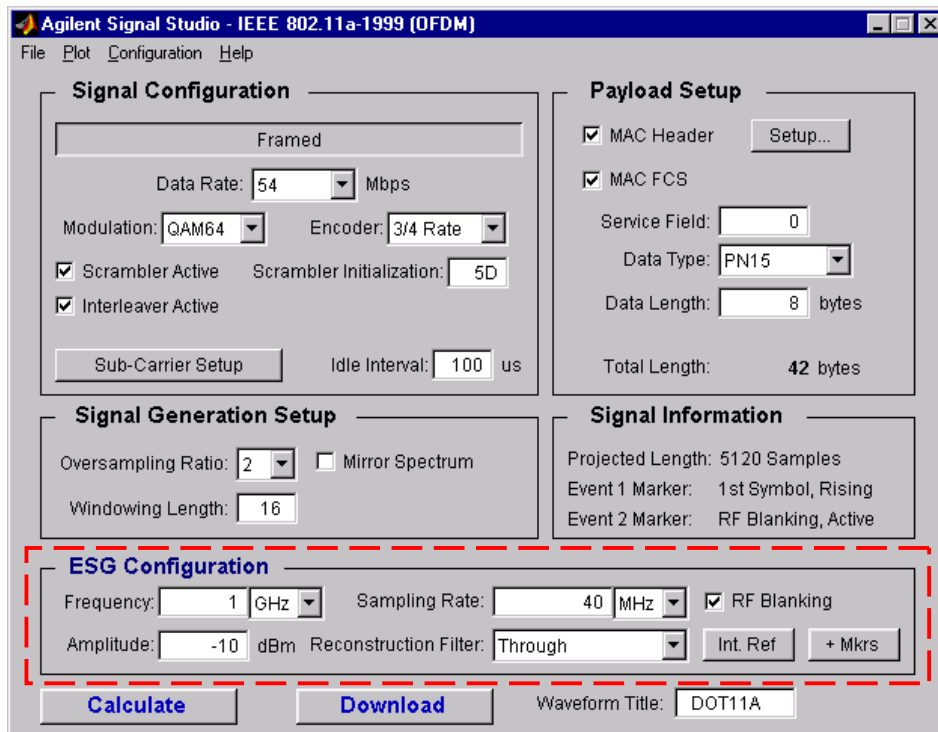


Figure 15: Signal Studio-802.11a Signal Generation ESG menu

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:

<b><i>ESG Configuration Parameters</i></b>	
<b>Frequency</b>	Defines the frequency at which the ESG will generate the signal.
<b>Amplitude</b>	Defines the power at which the ESG will generate the signal.
<b>Sampling Rate</b>	This parameter is automatically set when the over sampling ratio is defined in the Signal Generation Options menu. It is the rate at which the waveform I/Q samples are read from the dual arbitrary waveform generator memory during playback.
<b>Reconstruction Filter</b>	The ESG provides three reconstruction filters (250kHz, 2.5MHz, 8MHz) and a no filter option (through). The bandwidth of the baseband signal dictates the minimum reconstruction filter bandwidth to be used. Depending on the over sampling ratio and where the image frequencies appear, a wider bandwidth reconstruction filter may be selected. For more information on reconstruction filters refer to <a href="#">[4]</a>

<b>RF Blanking</b>	<p>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.</p> <p>Note: When RF Blanking is enabled, the Marker Polarity, the +Mrkrs button, must be set to positive or the wanted RF signal will be blanked resulting in no RF output from the ESG.</p>
<b>Internal/External Reference Frequency</b>	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.
<b>Marker Polarity</b>	Toggles between positive/negative and sets the polarity of the Event 1 and Event 2 markers. When RF Blanking is activated, the Event 2 marker is internally routed to provide access to the RF Blanking signal. Access to these signals is provided on the Event 1 and Event 2 ports on the rear panel of the ESG.

After the waveform and instrument settings have been downloaded to the instrument, only 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

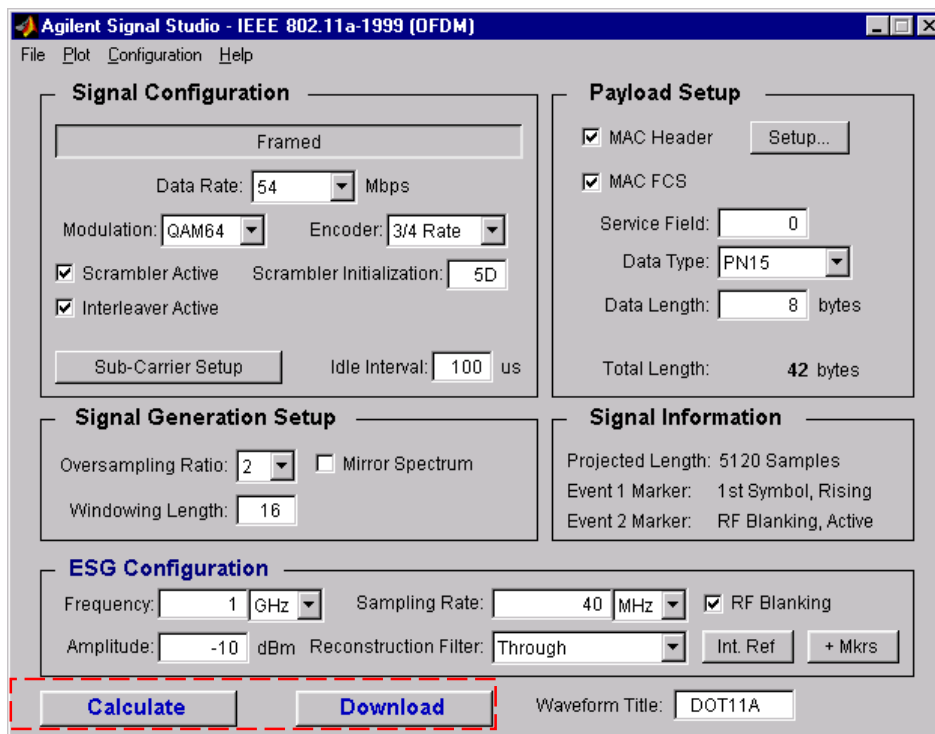


Figure 16. Signal Studio-802.11a Calculate and Download menu.

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

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, data length of the payload, and the computer's processing speed. Creating the maximum frame length of 5.84 ms took 10 minutes with a PC with clock speed of 533 MHz and with a <sup>2</sup>Pentium®III processor.

After the I/Q waveform has been calculated, the Signal Studio software is capable of generating a plot of the baseband spectrum and the I/Q waveforms. To plot the spectrum, choose Plot→ Spectrum from the menu keys at the top of the window, Figure 17. 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 waveforms can be generated in a similar manner.

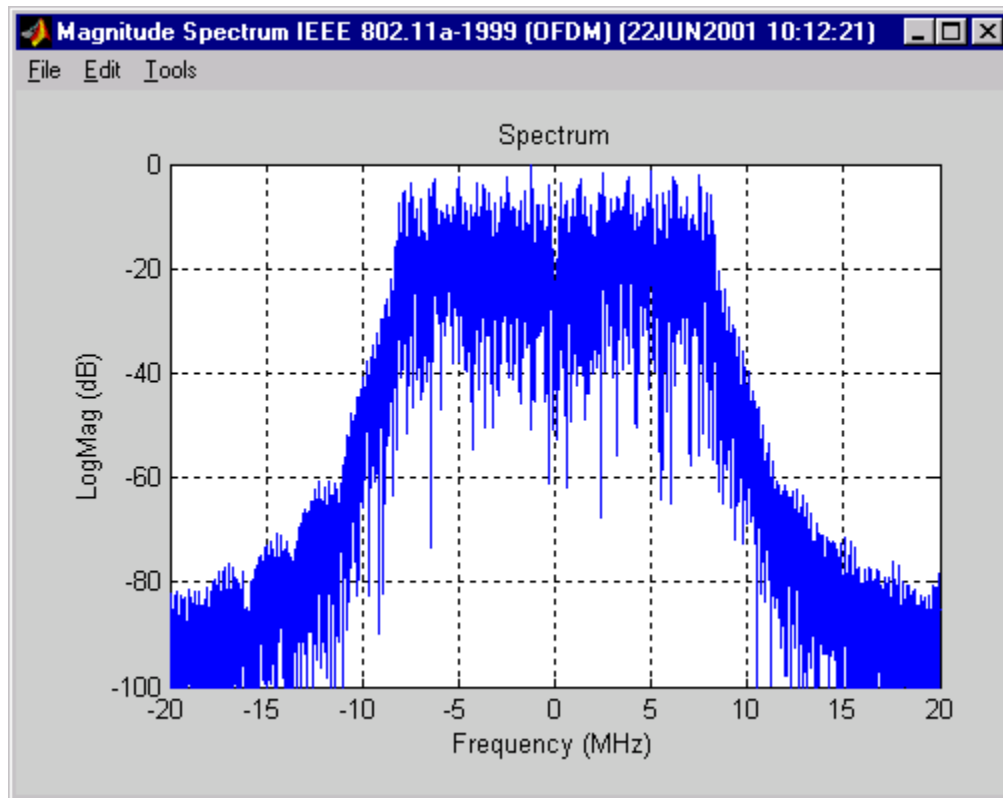


Figure 17. Spectrum plot of Signal Studio-802.11a I/Q waveform.

## Signal Studio Configuration and Setup

See the *Signal Studio Installation Guide* [\[1\]](#) for more details on connecting the computer to the ESG.

The ESG will be connected to the PC as shown in Figure 18.

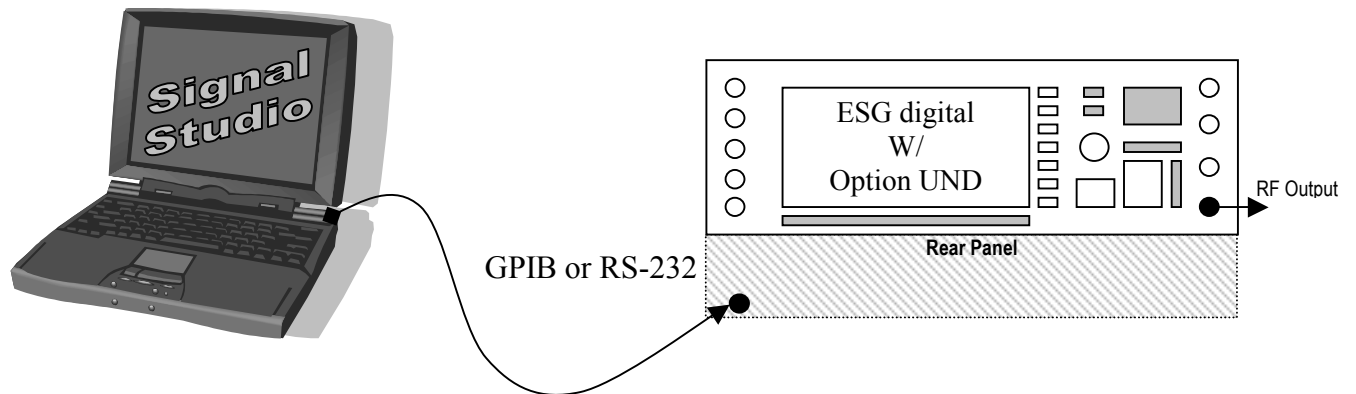


Figure 18. PC to ESG Configuration

### **Step 4b - Download**

**Select Download button** (see Figure 16) 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 16, choose File → Save As, and then name the file and save it in the ESG-B/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. For more information on saving waveforms to the instrument, refer to the ESG Family Signal Generator Option UND Dual Arbitrary Waveform Generator Users and Programming Guide. *The I/Q waveform files created by the Signal Studio software cannot be stored outside the instrument.*

# Basic Measurements

Required equipment:

E443xB ESG Digital Series RF Signal Generator. (x=0 through 7).

Arbitrary Waveform Generator, Option UND

Signal Studio-802.11a, Option 410 License Key

89600 Series Vector Signal Analyzer

The following measurements illustrate some of the typical characteristics of the Signal Studio-802.11a waveform that was generated and transmitted from the ESG. Most of these measurements were set up with the same parameters as shown in Figure 16.

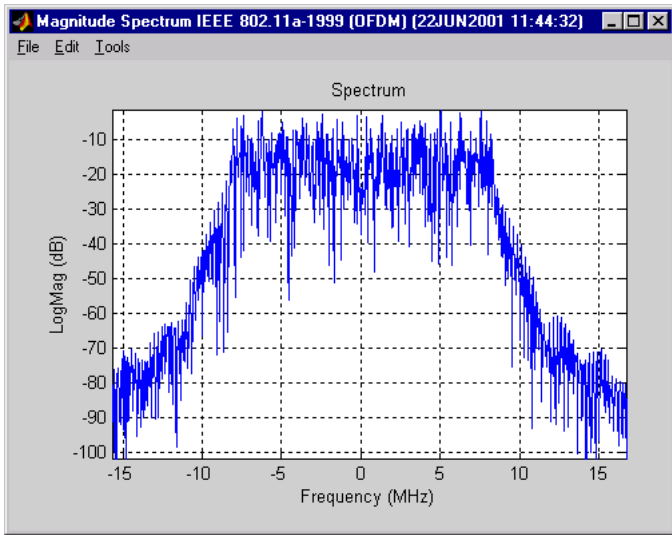


Figure 19: Spectrum plot of Signal Studio-802.11a I/Q waveform with all 52 Subcarriers On

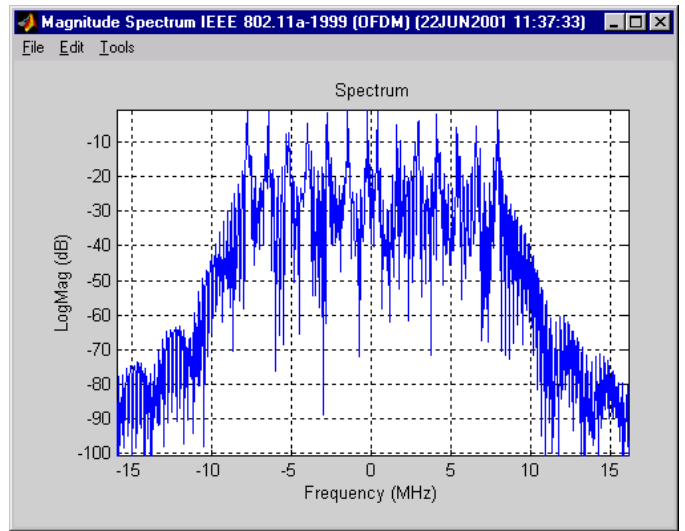


Figure 20: Spectrum plot of Signal Studio-802.11a I/Q waveform with every 4th Subcarrier On

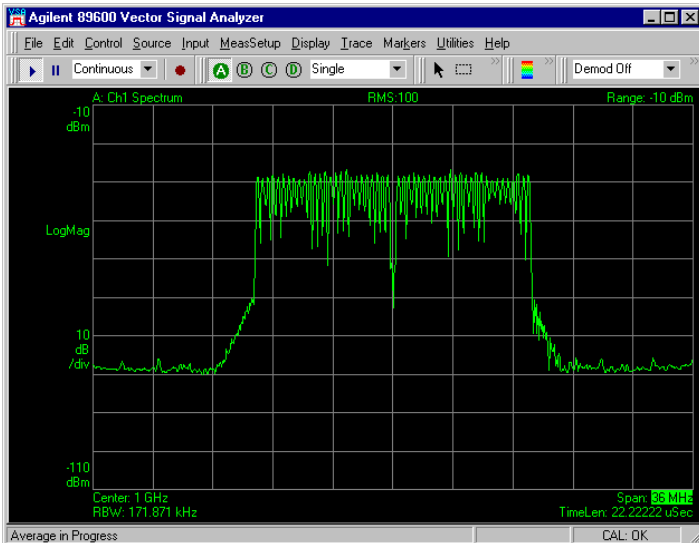


Figure 21: 89640A VSA Spectral Measurement of Signal Studio-802.11a signal with all 52 Subcarriers On  
Note: Averaging is on

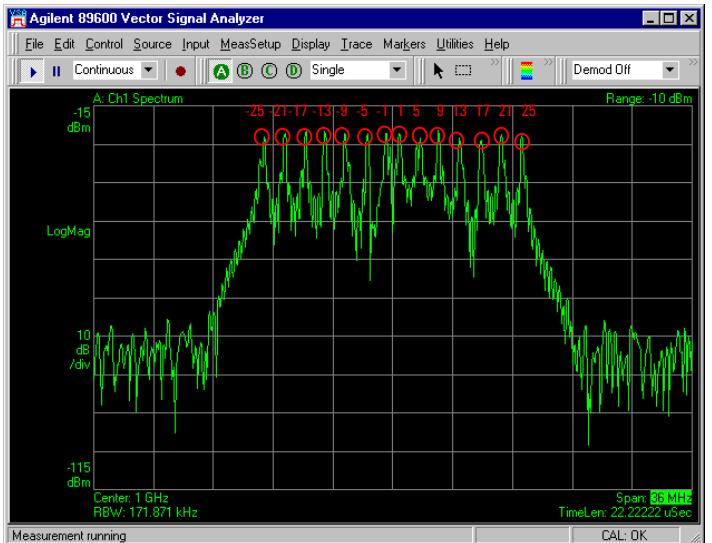


Figure 22: 89640A VSA Spectral Measurement of Signal Studio 802.11a signal with every 4th Subcarrier On



Figure 23: 89640A VSA Power Spectral Density Measurement of Signal Studio-802.11a Signal

Figure 23 shows a power spectral density (PSD) measurement of the Signal Studio-802.11a signal. The VSA span is set to 30 MHz. The frequency start begins at 1 GHz and stop frequency is set to 1.03GHz. The above span only shows the half of the transmitted signal at  $f_c$  (center frequency of the signal) + 30 MHz. The measurement shows the signal is  $-52.77$  dB<sub>r</sub> at 1.03 GHz. The transmitted signal must be  $\geq -40$  dB<sub>r</sub> at  $f_c > \pm 30$  MHz and greater (see Table 2 below). To reject the undesired higher frequency components and images (not shown in the above measurement), it is recommended to use an external reconstruction filter. The IEEE 802.11a standard specifies that the 802.11a PSD measurements meet the requirements shown in Table 2.

dB relative to maximum spectral density of signal	Frequency offset
-20 dB <sub>r</sub>	$f_c > \pm 9$ to 11 MHz
-20 to -28 dB <sub>r</sub>	$f_c > \pm 11$ to 20 MHz
-28 to -40 dB <sub>r</sub>	$f_c > \pm 20$ to 30MHz
$\geq -40$ dB <sub>r</sub>	$f_c > \pm 30$ MHz and greater

Table 2: IEEE 802.11a Transmitted Spectral Requirements

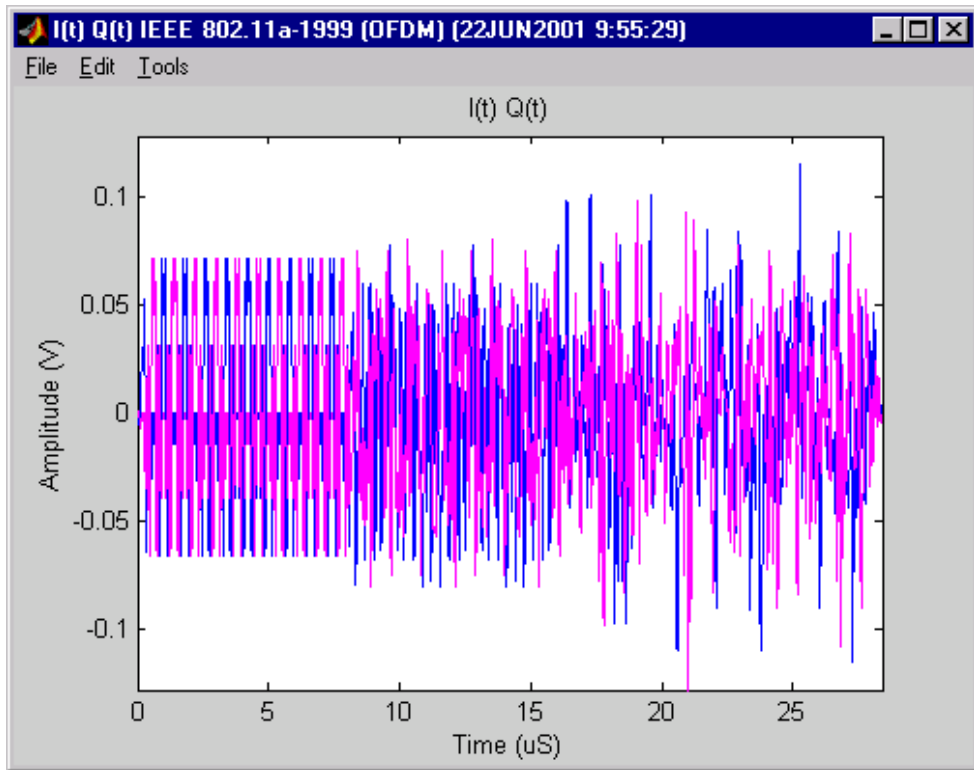


Figure 24: Signal Studio-802.11a I/Q Components Plot

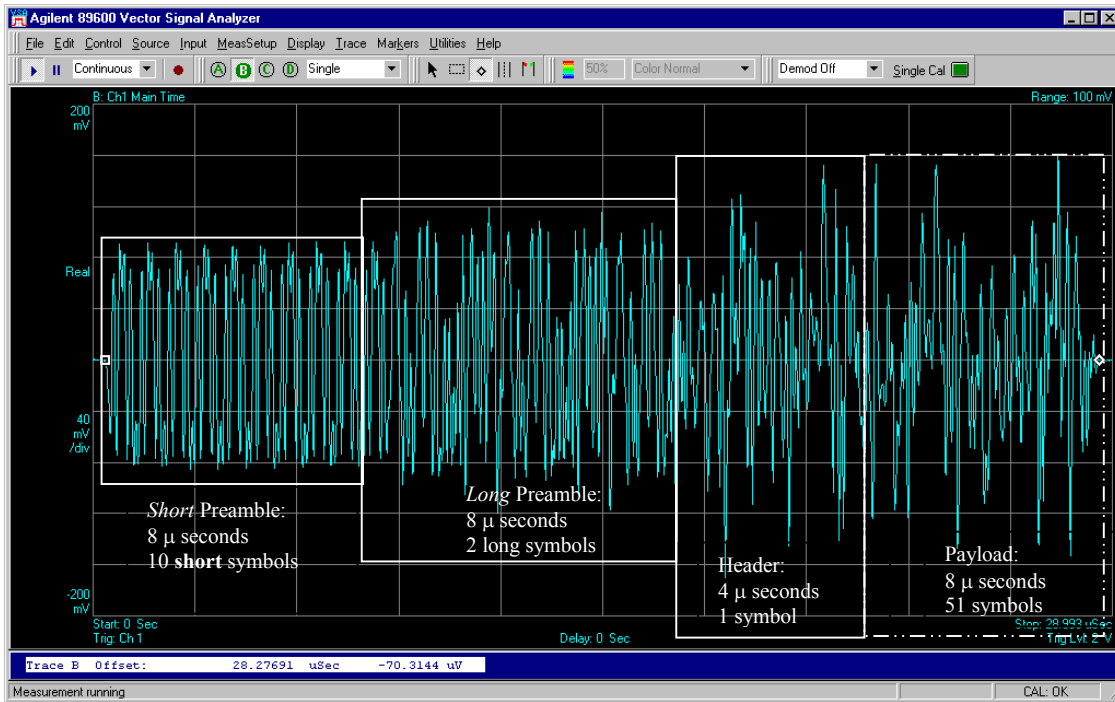


Figure 25: 89640A VSA Time Domain Measurement of Signal Studio-802.11a Signal

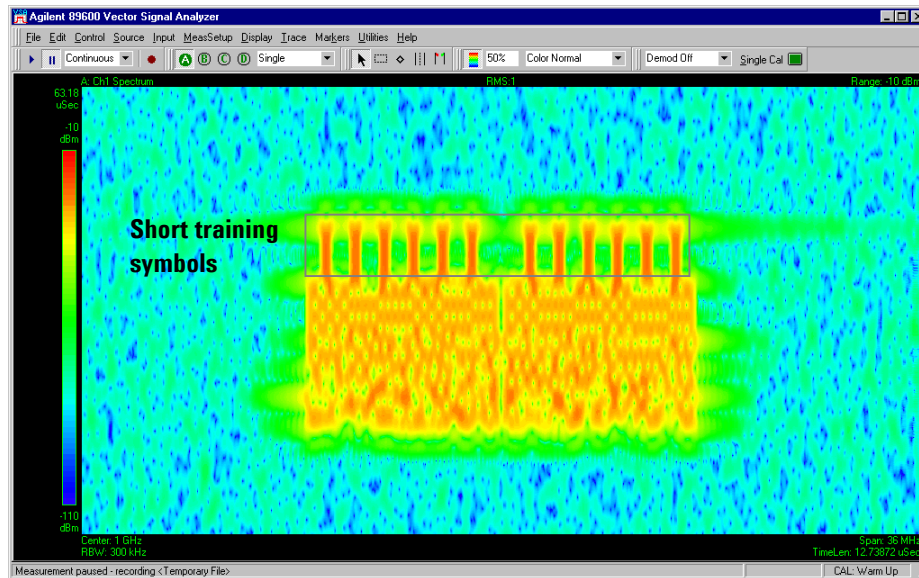


Figure 26: 89640A VSA Spectrogram of Signal Studio-802.11a Signal

The spectrogram shown in Figure 26 shows a burst of 802.11a packet that is 28  $\mu$  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 in the above plot
- 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 subcarriers: -24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24, and the subcarriers show the most energy.



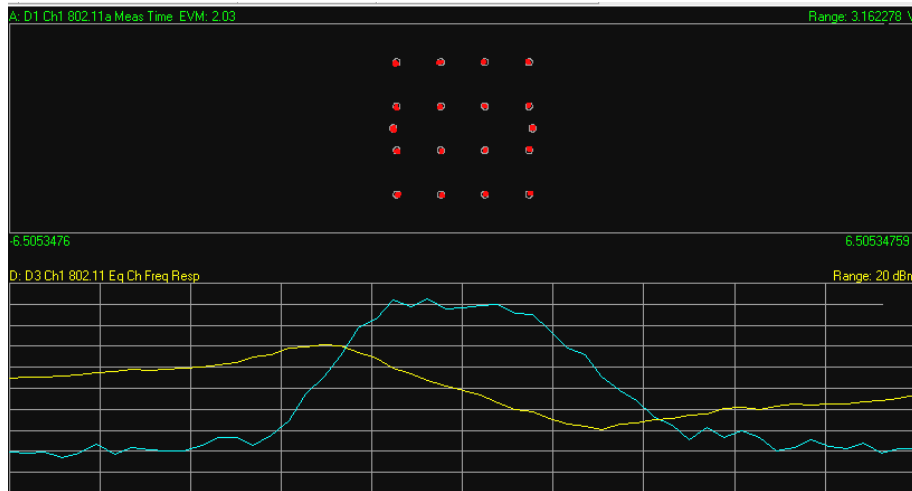


Figure 27: 89640A VSA Constellation and Equalizer Measurements of Signal Studio-802.11a Signal

For 802.11a, the constellation will change depending on the data rate. Unlike QPSK, the OFDM constellations don't have all of the symbols at the same amplitude (distance from the origin). The OFDM constellations are normalized to unity power. For this reason, the EVM computation does not need to be normalized -- provided the transmitted data produces a uniform distribution of constellation points. A more rigorous approach to EVM computation (than provided by the standard) would not assume a uniform distribution of transmitted symbols and would instead factor in the average power level of the ideal symbols actually transmitted.

This plot, see Figure 27, shows an OFDM constellation in the upper trace. It is a composite plot of all carriers over all symbols. The constellation is a composite of the BPSK carriers and the 16-QAM carriers. Also shown in the lower trace, is the adaptive equalizer response. In 802.11a, the long training symbol is used to train an equalizer. This is a required step in the measurement process. The complex equalizer result can be viewed as magnitude, phase or group delay. The magnitude and phase responses are shown above. The equalizer result is a good measure of transmitted flatness and carrier power levels.

## Data Sheet for Signal Studio-802.11a

<b>Framing</b>	<ul style="list-style-type: none"> <li>Framed: bursted packets includes a PLCP Preamble (short and long) and Header (Signal field)</li> <li>Non-framed: Continuous non-bursted payload data (no PLCP Preamble and Header added to payload)</li> </ul>																								
<b>Raised cosine windowing</b>	Range: 0-16 samples																								
<b>Convolutional encoding</b>	$\frac{1}{2}$ , $\frac{2}{3}$ , and $\frac{3}{4}$ rate																								
<b>Modulation formats</b>	BPSK, QPSK, 16-QAM, 64-QAM																								
<b>Data source</b>	1s, 0s, 01s, 10s, PN9, PN15																								
<b>Data rates</b>	6,9,12,18,24,36,48,54 Mbps and Custom data rate																								
<b>Custom data rate</b>	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Modulation: BPSK</td> <td style="width: 33%;">Encoder: Inactive</td> <td style="width: 33%;">Data rate: 12 Mbps</td> </tr> <tr> <td>Modulation: QPSK</td> <td>Encoder: Inactive</td> <td>Data rate: 24 Mbps</td> </tr> <tr> <td>Modulation: 16-QAM</td> <td>Encoder: Inactive</td> <td>Data rate: 48 Mbps</td> </tr> <tr> <td>Modulation: 64-QAM</td> <td>Encoder: Inactive</td> <td>Data rate: 72 Mbps</td> </tr> <tr> <td>Modulation: BPSK</td> <td>Encoder: 2/3</td> <td>Data rate: 8 Mbps</td> </tr> <tr> <td>Modulation: QPSK</td> <td>Encoder: 2/3</td> <td>Data rate: 16 Mbps</td> </tr> <tr> <td>Modulation: 16-QAM</td> <td>Encoder: 2/3</td> <td>Data rate: 32 Mbps</td> </tr> <tr> <td>Modulation: 64-QAM</td> <td>Encoder: 1/2</td> <td>Data rate: 36 Mbps</td> </tr> </table>	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
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																							
<b>Data length</b>	<p>Maximum</p> <ul style="list-style-type: none"> <li>Without MAC Header and FCS: 4061 Bytes</li> <li>With MAC Header and FCS: 4095 Bytes</li> </ul> <p>Minimum</p> <ul style="list-style-type: none"> <li>1 Byte</li> </ul>																								
<b>Idle interval between frames</b>	Range: 0-1000 microseconds																								
<b>Subcarrier setup</b>	Range: -1 to -26, and 1 to 26. Individually selectable. All or any subcarrier configuration; except none.																								
<b>Service field</b>	16 bit Hex (First 7 LSB are masked to zero).																								
<b>Scrambler seed initialization value</b>	7 bits Hex																								
<b>Oversample ratio</b>	1,2																								
<b>Frame length</b>	Range: 24 microseconds to 5.484 milliseconds																								
<b>Sample length</b>	Maximum: 259,360 samples																								

## 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
fc	center frequency
FCS	frame check sequence.
FDM	frequency division multiplexing
ICI	intercarrier interference
ISI	intersymbol interference
I/Q	in-phase/quadrature
IEEE	Institute of Electrical and Electronics Engineers
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

[1] *Signal Studio Installation Guide*

Available @ <http://www.tm.agilent.com/data/downloads/eng/tmo/EP5G084705.pdf>

[2] [Agilent ESG Family of RF Signal Generators - Data Sheet](#)

Literature Number 5965-3096E

[3] [Agilent ESG Family/RF Signal Generators - Configuration Guide](#)

Literature Number 5965-4973E

[4] [Generating Digital Modulation with the Agilent ESG-Digital Series Dual Arbitrary Waveform Generator](#)

Literature Number 5966-4097E

[5] *ESG Family Signal Generators Option UND Dual Arbitrary Waveform Generator Users and Programming Guide*

Literature Number E4400-90328

[6] [Agilent 89600 Series Wide Bandwidth Vector Signal Analyzers](#)

Literature Number 5980-0723E

More information on the 89600 VSAs can be found at: [www.agilent.com/find/89600](http://www.agilent.com/find/89600)

## 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 ISBN # 0-89006-530-6

## Ordering Information

Signal Studio-802.11a is Option 410 for the Agilent ESG digital series signal generators.

### ESG digital: Standard Models

**E4430B** – ESG digital series RF signal generator, 1 GHz

**E4431B** – ESG digital series RF signal generator, 2 GHz

**E4432B** – ESG digital series RF signal generator, 3 GHz

**E4433B** – ESG digital series RF signal generator, 4 GHz

### ESG-digital: High Spectral Purity Models

**E4434B** – ESG digital High Spectral Purity series RF signal generator, 1 GHz

**E4435B** – ESG digital High Spectral Purity series RF signal generator, 2 GHz

**E4436B** – ESG digital High Spectral Purity series RF signal generator, 3 GHz

**E4437B** – ESG digital High Spectral Purity series RF signal generator, 4 GHz

The Signal Studio software requires that the ESG is equipped with the optional dual arbitrary waveform generator (Option UND). Firmware Revision B.03.75 is required to activate the License Key on the ESG-signal generator.

**Try before you buy!** Download the software free of charge for evaluation by visiting [http://www.agilent.com/find/signal\\_studio](http://www.agilent.com/find/signal_studio). 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 ESG and are interested in obtaining an upgrade kit only (license key), order: E4430BK Option 410.

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<sup>1</sup>Windows is a U.S. registered trademark of Microsoft Corporation

<sup>2</sup>Pentium is a U.S. registered trademark of Intel Corporation.

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