

# Using the E4438C ESG Signal Generator and Signal Studio for 802.11 WLAN Receiver Testing

## Application Note

### Introduction

To ensure the reliable operation of wireless devices, it is important that the receiver be cost-effectively tested. A key method for screening receivers is the use of frame error rate/packet error rate (FER/PER) analysis. This paper describes how Signal Studio for 802.11 WLAN (Option E4438C-417) can be used to generate correctly constructed packets for FER/PER analysis. (For more information use the hyperlinks found at [www.agilent.com/find/signalstudio](http://www.agilent.com/find/signalstudio).) It then explains how these packets are transmitted by the Agilent E4438C signal generator to optimize receiver testing. To aid test developers in creating and applying FER/PER analysis, checklist and troubleshooting measures also are defined.

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# Generating Correctly-Formatted Packets

For testing integrity, the signal generator must transmit correctly-constructed packets. Properly constructed packets consist of a medium access control (MAC) header with correct frame control, addresses, and sequence control; the frame body, or data payload; and a frame check sequence (FCS).

## MAC header

Using Signal Studio software, the first step in developing packets for FER/PER testing is to correctly format the MAC header. The MAC header provides the device under test (DUT) with information about the data being transmitted. If the header is formatted incorrectly the DUT will not recognize the frame, preventing FER/PER testing (unless the device is in ad hoc/promiscuous mode). This section describes how to generate correct MAC headers with frame control, addresses, and sequence control to ensure receiver reliability.

Using Signal Studio software, click on **Setup** next to the MAC Header box in the Payload Setup portion of the Signal Configuration screen. (Refer to Figure 5.)

Earlier versions of Signal Studio for 802.11 WLAN (Options 405, 410, 415) may not behave in the same manner as Option 417 – Signal Studio for 802.11 WLAN. Specifically, the MAC header bit ordering is handled differently, so MAC headers need to be recoded when adapted to Signal Studio for 802.11 WLAN. This modification allows easier use of user files and automatic generation of the FCS.

### Frame control

It is critical that the frame control in the MAC header be set properly to obtain valid packets. However, the structure of the MAC header is rather convoluted, so one of the first things to understand is how to use frame control to identify the type of frame that will follow the header. *IEEE 802.11, 1999, paragraph 7. Frame formats* defines several frame types, of which we will use only a few to illustrate the process. The table of bit values is critical to setting the type, so that will be presented in some detail.

The MAC header fields as defined by IEEE are as follows:

b0	b1	b2	b3	b4	b7	b8	b9	b10	b11	b12	b13	b14	b15
Protocol version		Type		Subtype		To DS	From DS	More frag	Retry	Power management		More data	WEP

Per IEEE standards, these bits are transmitted in the order represented below. In compliance with these standards, this output format is how Signal Studio and commercially-available sniffer software automatically structure the MAC header.

b7	b6	b5	b4	b3	b2	b1	b0	b15	b14	b13	b12	b11	b10	b9	b8	802.11 bit and field definitions
Subtype				Type		Protocol version		Order	WEP	More data	Power mgmt.	Retry	More frag	From DS	To DS	

To set the frame for data, the MAC header would be formatted as follows:

b7	b6	b5	b4	b3	b2	b1	b0	b15	b14	b13	b12	b11	b10	b9	b8	802.11 bit and field definitions
Subtype				Type		Protocol version		Order	WEP	More data	Power mgmt.	Retry	More frag	From DS	To DS	
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Data frame
0				8				0				0				

Figure 1 illustrates how the specification for a data frame appears using the Signal Studio software.

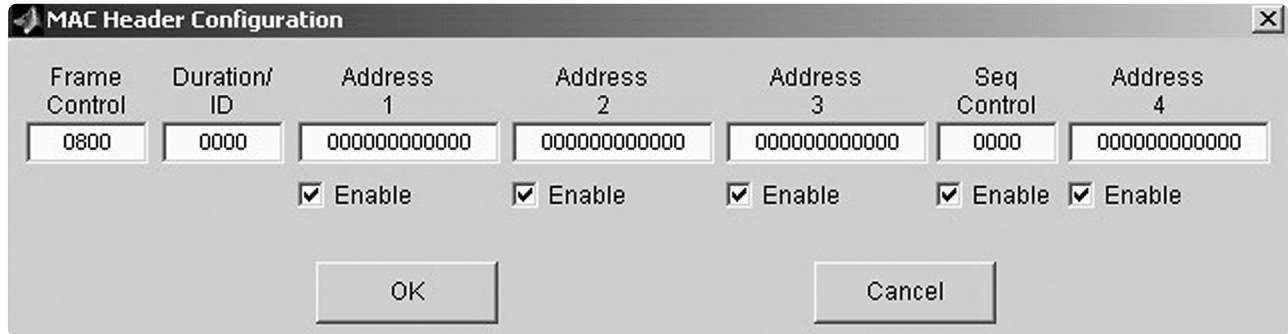


Figure 1: Frame Control value "0800" indicates data frame

Another frame format, such as a management frame with retry, would be specified by:

b7	b6	b5	b4	b3	b2	b1	b0	b15	b14	b13	b12	b11	b10	b9	b8	802.11 bit and field definitions
Subtype				Type		Protocol version		Order	WEP	More data	Power mgmt.	Retry	More frag	From DS	To DS	
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	Management retry frame
0				0				0				8				

The frame format illustrated in Figure 2 shows how this data would appear using Signal Studio software.

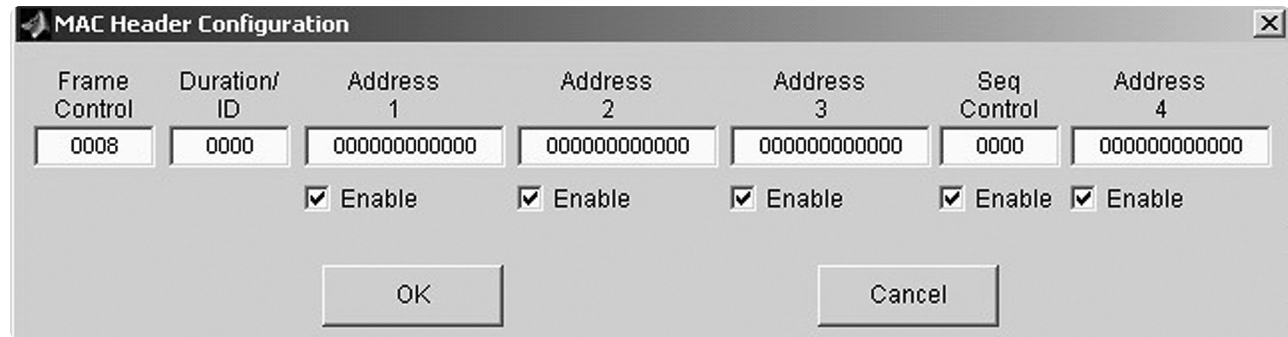


Figure 2: Frame Control value "0008" indicates management frame with retry

Using Signal Studio, the FCS will be calculated properly for the various configurations when the MAC FCS is checked on the Payload setup section of the main menu.

**Addresses**

The second portion of the MAC header specifies addresses. Not all frame types use all the address fields. Signal Studio provides a checkbox that can be cleared if that is desired. Note that the frame length changes when the addresses are not selected. If the address of the DUT is not the same as that being transmitted, the frame will be ignored by the DUT, unless the device is in ad hoc mode.

As illustrated in Table 1, the address field contents depend on the To DS and From DS settings of the frame control format, which are respectively found in position b8 and b9 of the MAC header per the 1999 IEEE standards for 802.11. (Details of the use of fields are contained in the standards document.)

To DS (b8)	From DS (b9)	Address 1	Address 2	Address 3	Address 4
0	0	DA	SA	BSSID	N/A
0	1	DA	BSSID	SA	N/A
1	0	BSSID	SA	DA	N/A
1	1	RA	TA	DA	SA

Table 1: IEEE address values (see Glossary for term definitions)

Using this format, the addresses can be configured in the MAC header and subsequently be reflected directly in the transmitted frame. For example, the MAC header for a data frame with addresses would be as follows:

b7	b6	b5	b4	b3	b2	b1	b0	b15	b14	b13	b12	b11	b10	b9	b8	802.11 bit and field definitions
Subtype				Type		Protocol version		Order	WEP	More data	Power mgmt.	Retry	More frag	From DS	To DS	Data frame
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
0				8		0				0						

Referring to Table 1, the "0800" value indicates that the data frame will have the DA value in address 1, the SA value in Address 2, the BSSID value in Address 3 and that Address 4 will not be used. Figure 3 illustrates how data sent in this configuration is displayed by the Signal Studio software. A sniffer would decode this data as:

**Address 1 (DA)** 12:34:56:78:90:12  
**Address 2 (SA)** 98:76:54:32:12:34  
**Address 3 (BSSID)** FF:FF:FF:FF:FF:FF

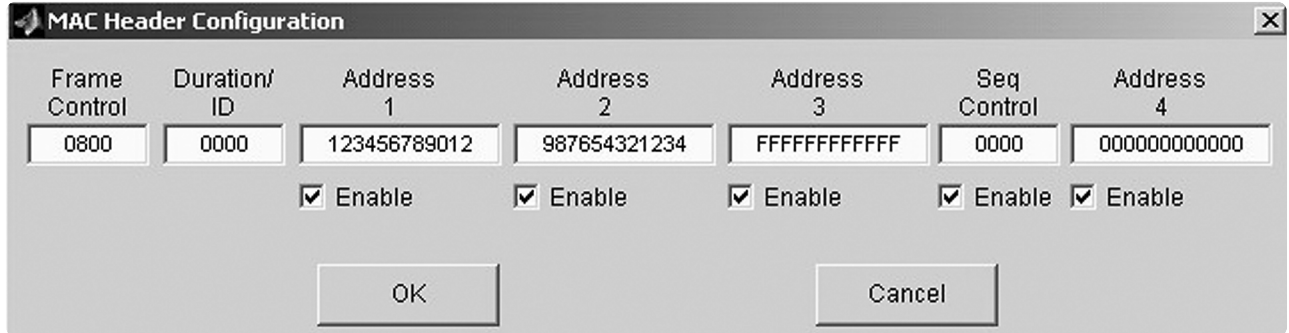


Figure 3: MAC header frame control for a data frame using "0800" with addresses specified by setting From DS to "0" and To DS to "0"

To provide another example, the values for From DS and To DS are set to one as shown:

b7	b6	b5	b4	b3	b2	b1	b0	b15	b14	b13	b12	b11	b10	b9	b8	802.11 bit and field definitions
Subtype				Type		Protocol version		Order	WEP	More data	Power mgmt.	Retry	More frag	From DS	To DS	Data frame
0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	
0				8				0				3				

In this header format, frame control is now 0803, indicating a data frame format with To DS and From DS each set to "1". Based on these settings Figure 4 illustrates how this data is represented using Signal Studio software. Again referring to Table 1, a sniffer decodes the data as:

Address 1 (RA) 12:34:56:78:90:12  
 Address 2 (TA) 98:76:54:32:12:34  
 Address 3 (DA) FF:FF:FF:FF:FF:FF  
 Address 4 (SA) 12:34:12:34:12:34

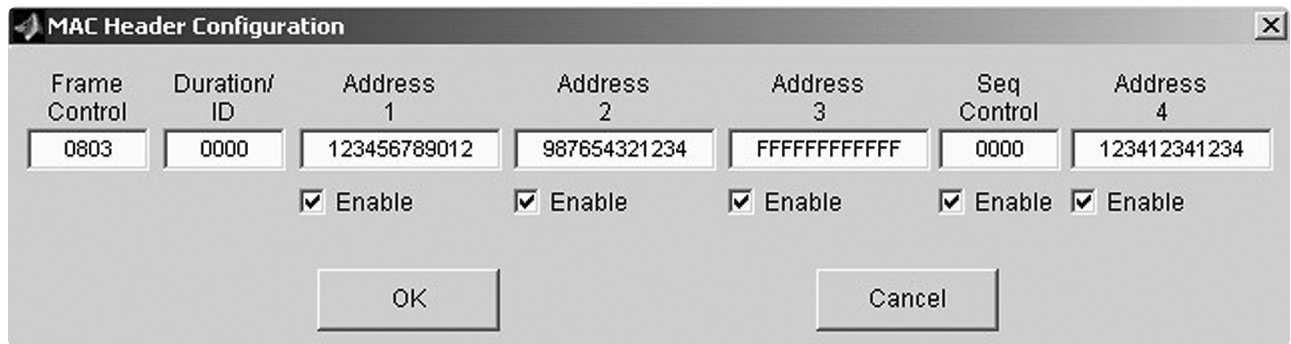
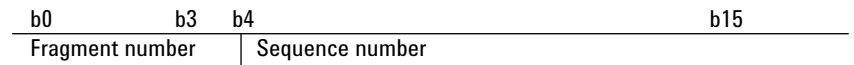


Figure 4: Frame control value of "0803" indicates the use of four address values From DS to "1" and To DS to "1"

**Sequence control**

The Sequence Control portion of the MAC header contains both the sequence number and the fragment number:



In both Signal Studio and sniffer software, these bits are represented as shown here:

Four hexadecimal character format in MAC header defining **Sequence Control**

b7	b6	b5	b4	b3	b2	b1	b0	b15	b14	b13	b12	b11	b10	b9	b8	802.11 bit and field definitions
Part of sequence number				Fragment number				Part of sequence number								Example: Value of sequence = 16, fragment = 2
8	4	2	1	8	4	2	1	2048	1024	512	256	128	64	32	16	
0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	
0				2				0				1				

## Frame configuration

After the MAC header is correctly formatted, the rest of the frame must be configured. The frame body, also referred to as the payload, determines the validity of the frame. The first step in defining the frame configuration is to select the desired signal from the Data Rate drop-down window (refer to Figure 5). The Data Rate selection is how the user defines a 802.11a or 802.11b or 802.11g signal.

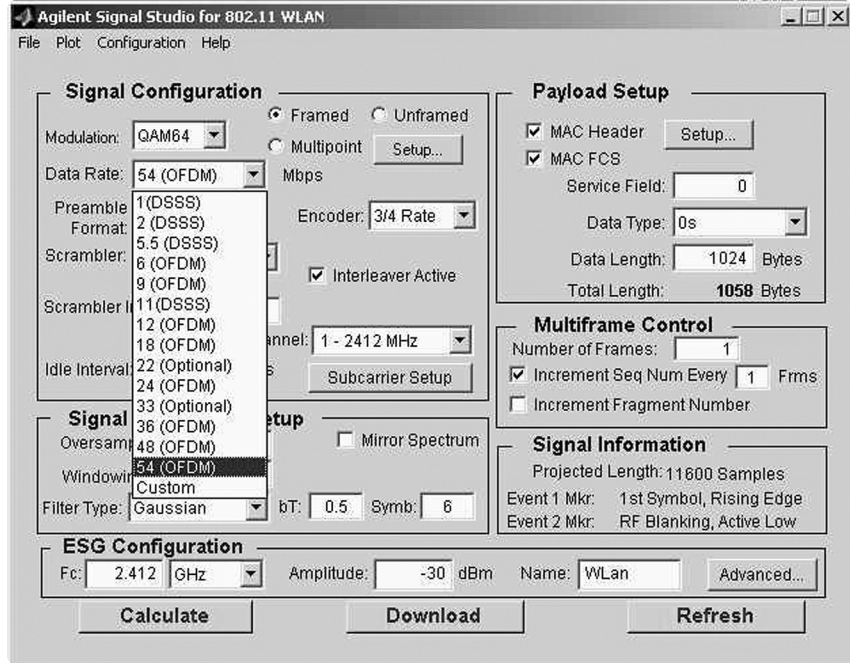


Figure 5: Signal Studio provides a drop-down window to simplify signal selection

After the desired data rate is selected, Signal Studio software automatically defines values in the Signal Configuration screen. These default values can be adjusted by the test engineer. The frame parameters will make significant differences in the PER.

For example, changes to the modulation setting and data rate on the Signal Configuration screen change the receiver sensitivity. Figure 6 shows a Signal Studio screen capture that generated 0.04% PER for the 802.11a (Data Rate: 54 (OFDM)) settings shown. When the idle interval is reduced to 10 microseconds, there is no impact on PER for good receivers. Note: a valid MAC FCS must be generated or included in a user file if not generated automatically. Ad hoc mode is used by the receiver.

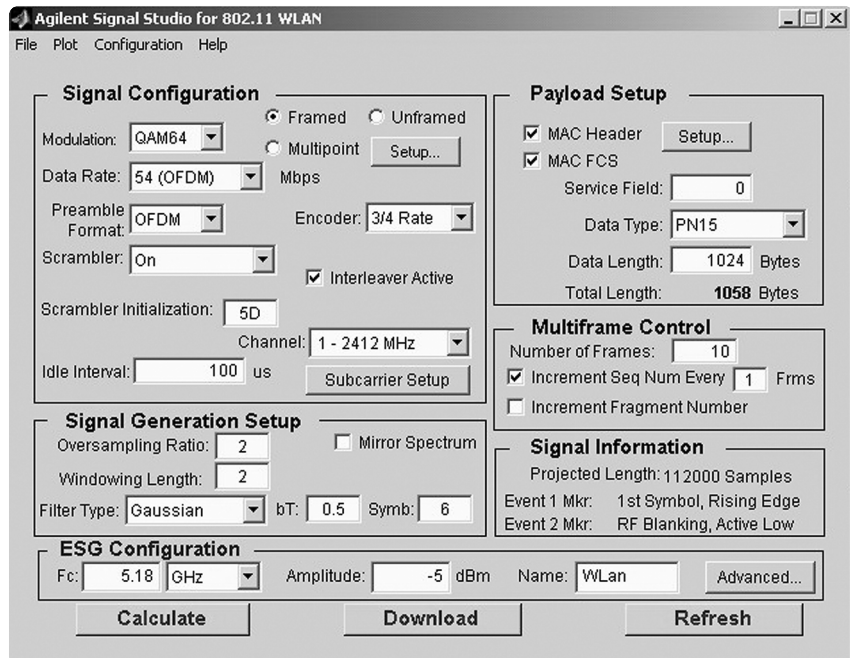


Figure 6: Frame set up for 802.11a 54 Mbps test

Using a PCI/WLAN card and Signal Studio to test a 802.11b receiver at 11 Mbps, a 0.03% PER is easily obtained. It is worth noting that PER can be higher if testing is not conducted in a shielded environment. Additionally, at turn-on a burst of errors is generated between the DUT and the sniffer software, which seems to be related to synchronization. The signal generator has been in steady state long enough to ensure it is not causing the burst of errors. Again, ad hoc mode is used.

Using Signal Studio software to change the MAC header and frame for an 11 Mbps DSSS signal does not impact the PER in our experiments (Figures 7 and 8).

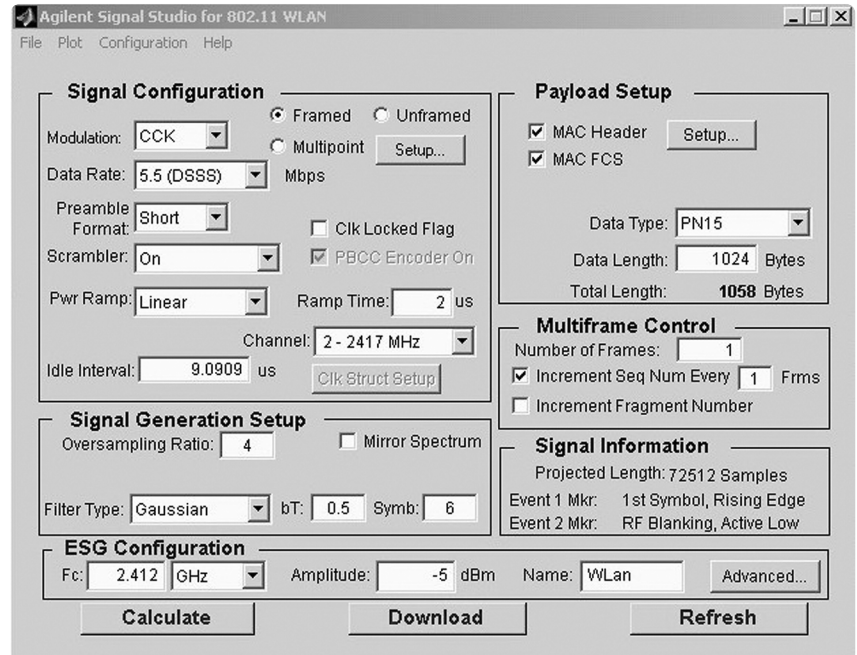


Figure 7: Data rate selection of 5.5 Mbps DSSS

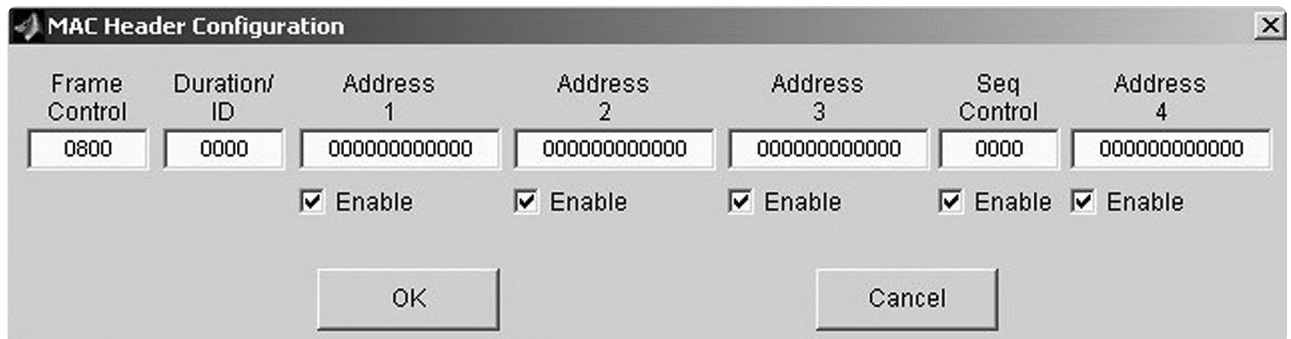


Figure 8: MAC header set for 5.5 Mbps DSSS frame

## Generating and applying user files

Signal Studio software also allows users to define additional packet functionality beyond that determined using the MAC header and MAC FCS. This is done using user files. Depending on test requirements, user files may be used in conjunction with the MAC header and MAC FCS, or they can be used in place of them.

To utilize user files, this selection must be chosen from the Data Type drop-down window in the Payload Setup screen (Figure 9).

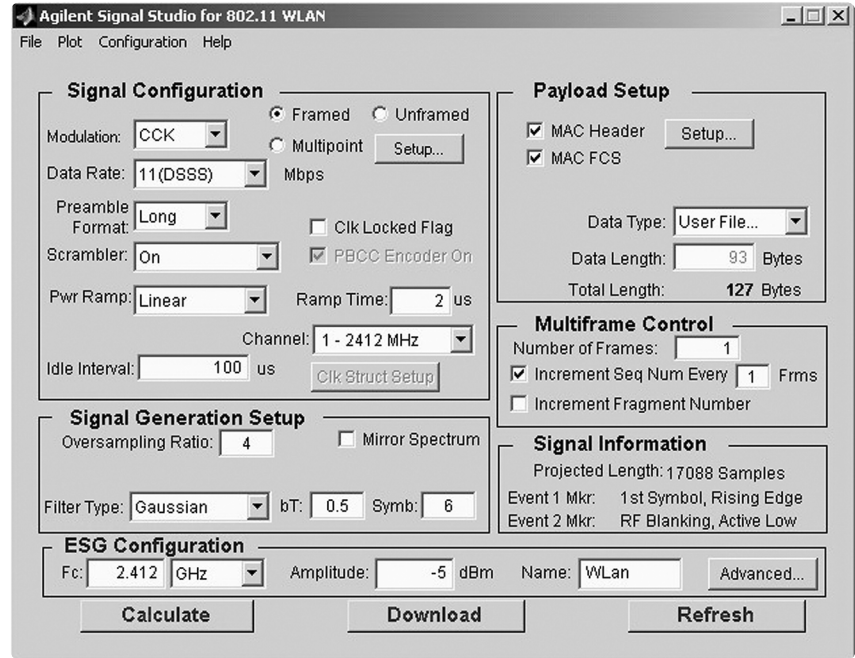


Figure 9: Selecting “User Files” for Data Type provides user-defined testing capabilities

User files can be simply generated and applied using Notepad (Figure 10). In the following example, the MAC header and FCS are supplied by the Signal Studio application, to ensure that each is correctly formatted.

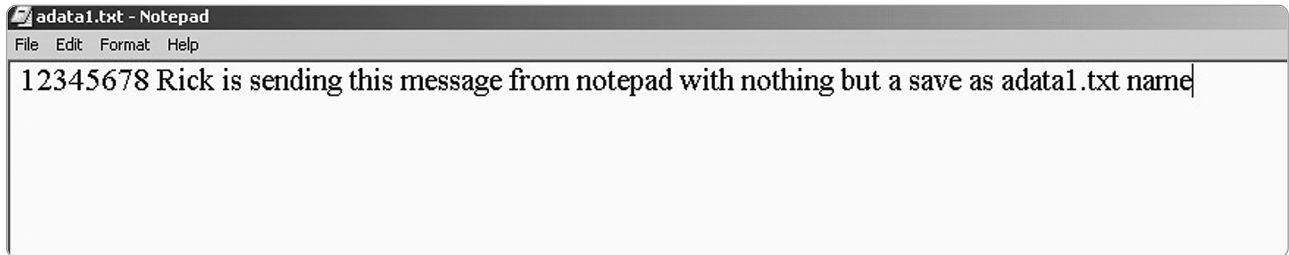


Figure 10: An example of a user file generated in a Notepad file



Using a commercially available sniffer, the data transmitted and received is:

```
0000: 08 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
0016: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 31 32 .....12
0032: 33 34 35 36 37 38 20 52 69 63 6B 20 69 73 20 73 345678 Rick is s
0048: 65 6E 64 69 6E 67 20 74 68 69 73 20 6D 65 73 73 ending this mess
0064: 61 67 65 20 66 72 6F 6D 20 6E 6F 74 65 70 61 64 age from notepad
0080: 20 77 69 74 68 20 6E 6F 74 68 69 6E 67 20 62 75 with nothing bu
0096: 74 20 61 20 73 61 76 65 20 61 73 20 61 64 61 74 t a save as adat
0112: 61 31 2E 74 78 74 20 6E 61 6D 65 00 00 00 00 al.txt name....
```

Figure 11: Sniffer decoding of transmitted data

Notice that the MAC header in Figure 11 begins with 0800, which indicates a data only frame and that all addresses are left as zeros. The addresses could be filled with other values. The FCS is not shown in the data field, but was calculated and received correctly by the sniffer.

Notice that the notepad file is .txt format. It may be necessary to translate the file to binary under certain circumstances. This would be the case if the data field has been captured from a transmitter by a sniffer because sending the hexadecimal field in text mode does not yield the same results.

### Building multiframe sequences

To perform packet error rate testing more than one frame is required. Using the Signal Studio application, users can define the number of frames to be generated in the waveform. Often a single frame is all that is necessary (it can be repeated continuously by the ESG). If more frames are desired, enter the number, then indicate whether the sequence number should be incremented, and if so, select a desired frame interval. If the fragment number should be incremented, indicate that as well.

It should be noted that calculating and downloading tens of thousands of independent/different frames is not practical for time and memory reasons. However, using a smaller number (even just repeating one frame) does not impact the FER/PER significantly.

Some FER/PER software requires multiple frames containing different/independent MAC header and data. These may be created in Signal Studio as individual files then downloaded to the ESG, where they can be linked in the ARB file program area. This is explained in detail in the "Building different/independent multiple frames in the ESG" section of this document.

### Fading

Multipoint reflection is built into Signal Studio for 802.11 WLAN. Full multi-path reflection can be obtained with the Agilent N5115A Baseband Studio for fading, which works with Signal Studio for 802.11 WLAN. (Contact your Agilent representative for application information or visit [www.agilent.com/find/basebandstudio](http://www.agilent.com/find/basebandstudio).) Each technique has value, depending on the needs of the application.

# FER/PER Testing

Once correctly-formatted packets are developed using Signal Studio software, the information can be downloaded to an E4438C signal generator and used to test WLAN receivers. FER/PER can quickly be determined using commercially available sniffer software, which counts valid frames/packets generated by the E4438C. Figure 12, which illustrates this test configuration, shows the use of independent PCs for Signal Studio and the DUT and PER software. However, they may be co-resident in a single PC.



Figure 12: Setup for FER/PER using commercial sniffer software

There are a variety of methods for evaluating FER/PER in 802.11 WLAN receivers. The transmitted frame check sequence (FCS) can be compared with the FCS computed by the receiver. Sequence numbers received by the receiver can be reviewed to determine if frames have been rejected. Data payload received by the DUT can be compared with data known to be transmitted. Another technique compares the frame type received with the frame type transmitted. Finally, a simple comparison can be made between the number of frames received and the number of frames that were transmitted. The following sections provide insights about various testing methods.

## Making a FER/PER measurement using a commercial sniffer

The sniffer may be put into a mode which simply evaluates any packets intercepted by the DUT. This means that only one frame type is necessary, which simplifies the measurement greatly. For example, the MAC header may indicate data frames (0800), to the broadcast address (FF:FF:FF:FF:FF:FF). Data may be anything (eg, PN9). Frames/packets can be received by the DUT and evaluated with the count of frames received and total frame check sequence (FCS) or CRC errors detected. FER is calculated from these numbers.

## An example of an FER measurement

This example uses an E4438C ESG, a commercial PCI/WLAN card, and commercial sniffer software. The standard requires 802.11b performance to be measured at 2 Mbps, using a specified frame size, specified amplitude, and looking for a particular FER.

The plot below (Figure 13) shows a flat portion of the FER curve, with a relatively straight line roll-off as signal level decreases. The errors in the first 20 dB of the plot arise partly from residual error rate, but more dramatically from interfering signals in the unshielded workspace environment.

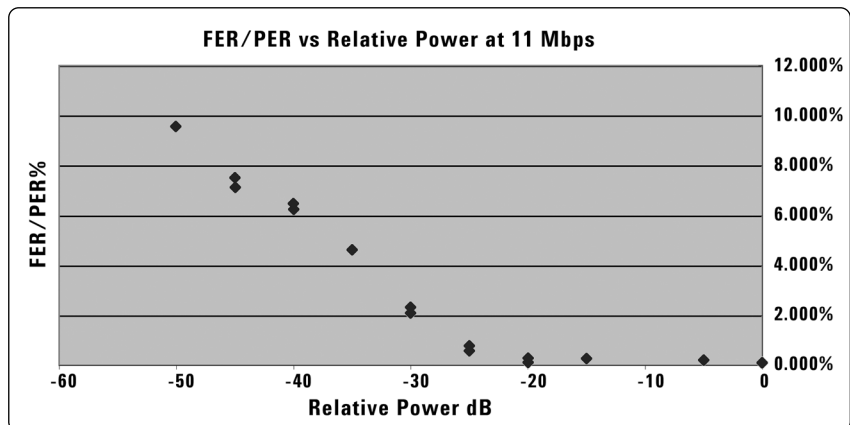


Figure 13: FER/PER versus relative power at 11 Mbps

As Figure 14 illustrates, decreasing the signal only slightly causes an abrupt increase in error rate.

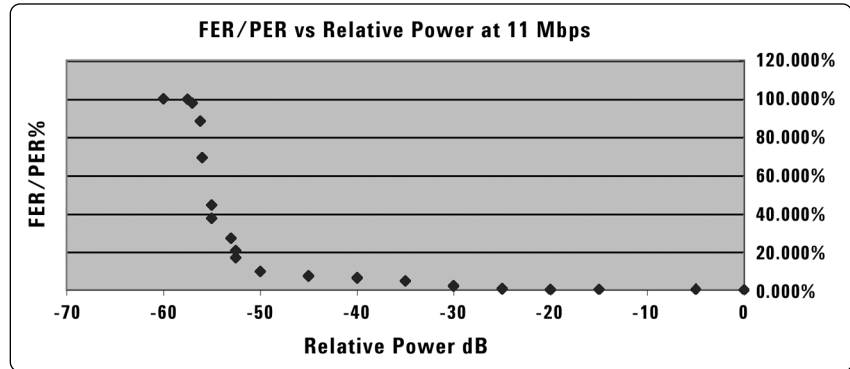


Figure 14: PER versus relative power at 11 Mbps. Note difference in PER% scale

### Replacing the golden radio with a calibrated signal generator

Using the ESG as a golden transmitter requires knowing the criteria for good packets in the PER software. Some FER/PER software has special criteria buried in the payload to enable FER/PER calculation. Other software strictly uses the criteria from the standard, calculating the FCS or CRC, and applying that value to determine valid packets.

As the testing illustrated in Figures 13 and 14 illustrates, as signal generator can be used in place of a golden radio, without compromising test results. Using the signal generator, we have obtained PER in the range of .03% to .05% consistently in 54 Mbps OFDM and 11 Mbps DSSS with commercially available WLAN cards and sniffers. The advantages of using the signal generator include excellent and time-stable RF calibration, ultimate flexibility in generating signals for today and tomorrow, and ongoing technical service and support.

### Using standard elements to measure FER/PER

It is possible to build a sequence of frames to measure error rates. For example, a sequence containing a beacon, a probe request, and several data frames may be monitored by a DUT using the software driver for the DUT, the standard Windows® WLAN interface, and software which monitors the sequence number of the frames received. The frames are all carefully created according to the appropriate standard. There must be delays between the frames to allow the DUT to respond (which the signal generator ignores). Once the DUT is receiving data, the WLAN interface simply tracks which frame sequence numbers do not appear and counts them as errors. The technique outlined below allows construction of such sequences.

## Building different/independent multiple frames in the ESG

When the DUT needs to have an association request preceding the data, multiple frames containing different/independent MAC header and data is required. To build and use this kind of file for an ESG using Signal Studio :

1. Set the Signal Studio parameters and select the data source (if a user file contains the data, follow the user file procedure below; multi-packets and multipoint reflection can be included).
2. Calculate the file as explained in “*Generating correctly formatted packets*”. Give this file a name.
3. See Figure 9 showing where the file name (WLAN) is placed.
4. Download the file to the ESG.
5. Repeat steps 1 – 4 for each desired signal.
6. On the ESG front panel, press the **Local** hard key.
7. Press the **Mode Setup** hard key.
8. Turn off the ARB by pressing the **ARB OFF ON** softkey.
9. Press the **Waveform Sequences** soft key.
10. Press the **Insert Waveform** soft key.
11. Insert each desired segment by selecting (use up and down arrow hard keys) and pressing **Insert Selected Waveform**.
12. Press the **Done Inserting** soft key when finished.
13. Highlight each segment in the sequence on the right side of the display and use toggle markers. **Toggle Marker 1** and **Toggle Marker 2** for each sequence. Stepping through the segments is done using the up and down arrow hard keys.
14. Press the **Return** hard key when finished toggling markers.
15. Press **Name and Store** to identify and save the sequence in the ESG. The alphabet and special keys are entered using soft keys. Press **Enter** when done.
16. Press the **Mode Setup** hard key.
17. Press **Select Waveform** and highlight the waveform just generated. On this new screen press the **Select Waveform (xxx:xxx)** soft key to activate this waveform.
18. Turn on the ARB by pressing the **ARB OFF ON** soft key.
19. Look at the DUT and its controlling software or the sniffer to see the results.

More information on this sequence-building process is given in the ESG User’s Guide.

## Using chip manufacturer software

If the chipset vendor software uses non-standard formats or is content dependent, there may not be a way to do PER without emulating those items. They will be found only by using commercially-available sniffers. Sniffers typically need special drivers to enable general receipt of signals, but these are easily purchased on the Web. Signals discovered in this manner may be coded into user files which may then be built into the multi-frame sequences as defined above. Note that these user files may need to be converted to binary to be loaded into Signal Studio.

# Checklists and Troubleshooting

The following guidelines are provided to help users with FER/PER testing:

## Checklist for generating good packets and measuring FER/PER

1. Is the MAC header representing the kind of frame desired?
  - a. Select frame type from *IEEE standard, clause 7, table 1*.
  - b. Set duration/ID if desired (not usually necessary).
  - c. Set address bits as appropriate (critical if not using ad-hoc mode).
  - d. Set sequence control if desired (not usually necessary).
2. Select data type.
  - a. PN9 or PN15 provide pseudorandom data as required by the standard.
  - b. Set data length if desired.
  - c. If custom PER software demands a user file, create and load the user file.
3. Enable MAC FCS automatic calculation.
4. If multi-frames or multipoint reflection are desired, set those checkboxes and values.
5. Download the waveform and check the results with a sniffer or other software.
6. Vary the power level to plot a FER/PER graph.

## Checklist for setting up to use manufacturer-supplied FER/PER software

1. Try the device under test with the software according to the manufacturer's instructions.
  - a. If it does not work, debug the system.
  - b. If it does work, do you know enough about the needed signal to set up the ESG as noted in "Generating correctly formatted packets"?
    - i. If not, use a sniffer to determine the file setup/exchange required.
    - ii. Build the required MAC headers and user files in Signal Studio.
    - iii. If multiple files are needed, they can be downloaded one at a time and sequenced.
2. Using the file(s) generated, send the signal from the ESG to the DUT.
  - a. Does it work?
    - i. If yes, great!
    - ii. If no, check the troubleshooting suggestions below.
  - b. Vary the signal level on the ESG and watch the error rate change.

## Troubleshooting suggestions

1. Check the connections.
  - a. Does the FER/PER software see the DUT?
  - b. Is the ESG transmitting (RF ON, for example)?
  - c. Are the RF connections solid?
  - d. Does the commercial sniffer see the signal?
2. Check the parameters of the data and signal.
  - a. Does the data rate need to be lower?
  - b. Does scrambling need to be turned off/on?
  - c. Is incrementing sequence needed?
  - d. Is the multipoint reflection interfering?
  - e. Is the channel set properly?
3. Is the environment hampering the measurement?
  - a. Are interfering signals present, such as other WLAN or Bluetooth™ or microwave oven or radar signals?
  - b. If you are not sure, a signal analyzer or spectrum analyzer tuned to the channel being used is very helpful observing these signals.
4. If a user file is being transmitted, does it need to be converted to binary?

## Glossary

<b>ARB</b>	Arbitrary waveform generator
<b>BSSID</b>	Basic service set identification
<b>CRC</b>	Cyclic redundancy check. (Same as frame check sequence.)
<b>DA</b>	Destination address
<b>DS</b>	Distribution system
<b>DSSS</b>	Direct sequence spread spectrum
<b>DUT</b>	Device under test
<b>FCS</b>	Frame check sequence
<b>FER</b>	Frame error rate
<b>Golden radio</b>	A selected commercial device (e.g. PCMCIA WLAN module) used to transmit signals. This device needs regular calibration/characterization to ensure signal amplitude accuracy.
<b>MAC</b>	Medium access control
<b>N/A</b>	Not applicable
<b>OFDM</b>	Orthogonal frequency division multiplexing
<b>Payload</b>	The data portion, or data with the CRC/FCS
<b>PBCC</b>	Packet binary convolutional coding
<b>PCI</b>	Personal computer interface
<b>PCMCIA</b>	Personal computer memory card international organization
<b>PER</b>	Packet error rate
<b>RA</b>	Receiver address
<b>SA</b>	Source address
<b>Sniffer</b>	Software which uses commercially available WLAN modules to analyze the signals sent over the air
<b>TA</b>	Transmitter address
<b>WLAN</b>	Wireless local area network

## References

Current copies of the 802.11 standards are available from IEEE and various public locations. Relevant standards include:

IEEE Std 802.11, 1999 Edition (R2003) (ISO/IEC 8802-11: 1999) IEEE Standard for information technology – Telecommunications and Information Exchange between Systems – Local and Metropolitan Area Network – Specific Requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

IEEE 802.11a-1999 (R2003) (ISO/IEC 8802-11:1999/Amd 1:2000(E)), Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications – Amendment 1: High-speed Physical Layer in the 5 GHz band. (An errata is available).

IEEE 802.11b-1999 (R2003) Supplement to 802.11-1999, Wireless LAN MAC and PHY specifications: Higher speed Physical Layer (PHY) extension in the 2.4 GHz band.

IEEE 802.11g-2003 IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications – Amendment 4: Further Higher-Speed Physical Layer Extension in the 2.4 GHz Band.

## Related Literature

"E4438C Signal Studio for 802.11a WLAN," application note,  
Literature number 5988-5414EN\*

"E4438C Signal Studio for 802.11b WLAN," application note,  
Literature number 5988-5415

\*These applications notes provide an overview of the 802.11a and 802.11b signals with a more global perspective, although the versions of Signal Studio to which they refer are obsolete.

The literature is accessed from [www.agilent.com/find/signalstudio](http://www.agilent.com/find/signalstudio), by using the "E4438C ESG Signal Studio Software" and "Discontinued RF Source Products" hyperlinks.

## Online

For information on Signal Studio and to download the free software for evaluation, including the Help files, a user's guide, and application information visit:

[www.agilent.com/find/signalstudio](http://www.agilent.com/find/signalstudio)

For access to IEEE information visit:

<http://standards.ieee.org/catalog/olis/lanman.html>

Information on E4438C can be accessed using hyperlinks found at:

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