A WLAN Test System Using Test Equipment With EDA Software

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Test measurements such as EVM and ORFS for transmission tests as well as Minimum Input Level Sensitivity and Adjacent Channel Rejection for receiving tests are required by WLAN (Wireless Local Area Network) standards. For such complex tests it is hard to find a system on the market to meet the requirements. A pure hardware test solution consisting of connecting a number of test instruments such as signal generators, channel emulators, interference generators, signal analyzers, and receiver testers is very expensive and difficult to be configured to meet the standard. Although some virtual analyzers in the current market can extend functionality for some basic test equipment this is not enough to meet the requirements for this type of complex testing. This article describes a test system configured from basic hardware test equipment: A signal generator and vector signal analyzer, connected with EDA software for testing WLAN systems based on the IEEE 802.11a/g standard. Results show that the connected hardware/software system works very well.

Introduction

Demand for WLAN systems is growing very fast within the worldwide wireless communications industry. New WLAN systems based on the IEEE 802.11a/g standards deliver higher data rates, better spectral efficiency, improved performance under multi-path fading conditions, and less interference in low-mobility wireless conditions than earlier systems. WLAN systems are widely used for wireless network connection.

To support high-rate data in the systems multi-carrier modulation, orthogonal frequency division multiplex (OFDM) is used. The basics of OFDM [1] is to split a high data rate stream into a number of lower rate streams that are transmitted, simultaneously, over several subcarriers. With lower data rates in the parallel subcarriers there is increased symbol duration decreasing the relative amount of dispersion in time (delay spread) caused by multi-path propagation. Inter-symbol interference (ISI) can be reduced significantly because an adequate guard interval can be inserted between successive OFDM symbols.

In practice, components such as power amplifiers (PAs) in WLAN should be chosen based on low cost. On the other hand the effects of non-linear distortion must be considered very carefully because the OFDM system is very sensitive to it. So for both R&D and manufacturing phases the WLAN system must be tested and verified by using measurements to see the system meets the requirements of the IEEE standards. The tests must include measurements such as Error Vector Magnitude (EVM), Complementary Cumulative Distribution Function (CCDF), and Output RF Spectrum with Mask (ORFS), to test and verify key components such as the PA. For receiver tests, bit error rate (BER), packet error rate (PER), minimum input level sensitivity, and adjacent channel rejection are required.

To test a complete WLAN system, there are several possible approaches:

- Find a test system in the market that can test the complete WLAN system including the transmitter and receiver
- Design a system consisting of test equipment, such as a signal generator, interference generator, channel emulator, vector signal analyzer, receiver-tester with synchronization hardware, then connect and configure the test system
- Use a virtual measurement software package, designed as a software and hardware combination, such as Lab Windows/CVI or LabView and personal computers

For the first approach the process for measuring the whole system is complicated and it is currently hard to find a test system market to do this. In the second approach it is very expensive to buy all this equipment;also packet error rate testing, data synchronization and data rate control must be considered, and it is difficult to do this with test equipment alone. In the third approach, there is no software package available today that has the capability to measure the complete WLAN system.

In this article we want to design a WLAN test system for both transmitter and receiver to see if the system meets the IEEE standards requirements.

The test system should have the following capabilities:

- Full functionality for processing and measuring both transmission and receiver tests
- Test results must be very clear, comparing results with the required values based on the standard and displaying “pass” or “fail” designations
- Easy to use
- Relatively low cost.

The minimum requirements for the new test system are:

- An arbitrary (Arb) signal generator with 20-MHz bandwidth, 80-MHz clock rate and 6-GHz carrier with the capability of being driven by software packages for WLAN system simulation
- Vector signal analyzer for WLAN signal basic analysis, including waveform and spectrum with the ability to record the signal
- EDA simulation software with full-system functionality for WLAN
- The simulation software must communicate with the Arb generator, so it can be driven by the software package

We introduce our chosen WLAN test system in the next section.

Test System Setup

The test system can be set up as shown in Fig. 1. We used an Agilent E4438c (ESGc) signal generator, 89640A vector signal analyzer (VSA) and the Advanced Design System (ADS) software package to construct the WLAN test system.

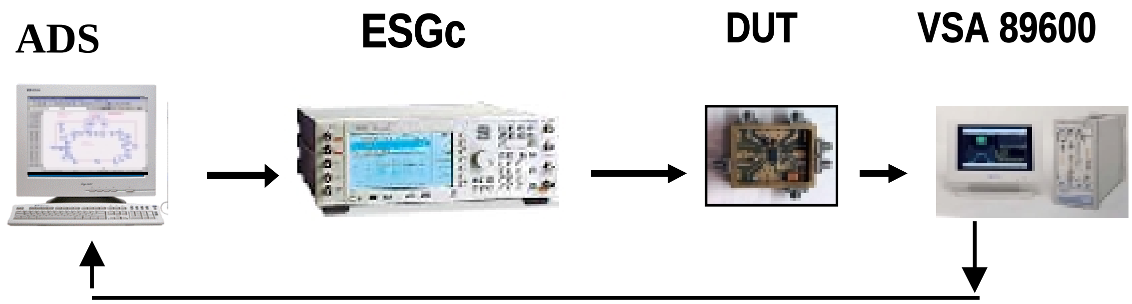


Fig. 1 WLAN Test System Setup

To cover both transmitter and receiver tests, the signal source needs flexibility and the Arb signal generator in an ESGc, driven by ADS simulation software, was chosen. It will be shown later how flexible the signal source is.

The input to the device-under-test (DUT) is from the ESGc and the DUT output is sent to the VSA for performance measurement of the transmitter. To receiver testing the output of the DUT can be recorded and sent back to the ADS software for processing.

ADS-To-ESGc Link

An I/O library used in this test provides a software channel to talk to computer interfaces such as HP-IB, VXI, and serial and it supports the Standard Instrument Control Library (SICLI) and the Virtual Instrument Software Architecture (VISA) defined by the VXIplug&play Alliance. VISA allows driver software developed by different vendors to run on the same platform.

In the test system the I/O library's VISA layer for communication over GPIB and/or LAN interfaces is employed for sending signal sequences from ADS to the ESGc Arb signal generator. Two interfaces are supported:

1. TCPIP for use of instruments across a LAN (or via a HPIB/LAN box)
2. Local or Remote GPIB for use with VISA I/O-based instrument links.

VSA-To-ADS Link

Waveforms can be recorded in the VSA as a data file in sdf format and in ADS there is a SDFReader that can read the waveform. The SDFReader can also be used as a signal source in ADS design for processing WLAN signals and measuring system performance, such as ORFS, BER, and PER.

WLAN Transmission System Test

1. The OFDM Signal

The 5-GHz WLAN standard has a physical layer based on OFDM which transmits data, simultaneously, over multiple parallel-frequency sub-bands and offers robust performance under severe radio conditions. OFDM also offers a convenient method for mitigating delay spread effects. A cyclic extension of the transmitted OFDM symbol can be used to achieve a guard interval between symbols and, provided that this guard interval exceeds the excess delay spread of the radio channel, the effect of the delay spread is constrained to frequency-selective fading of the individual sub-bands. This fading can be canceled by means of a channel compensator taking the form of a single tap equalizer on each sub-band.

In the basic block diagram (Fig. 2) of an OFDM transmitter and receiver input data is coded, converted from serial to parallel, allocated to a subcarrier, then modulated using linear modulation such as BPSK, QPSK,16-QAM, or 64-QAM. The OFDM signal is generated as the IFFT of modulated sub-symbols. OFDM symbols will be shaped and transmitted after modulation and power amplification.

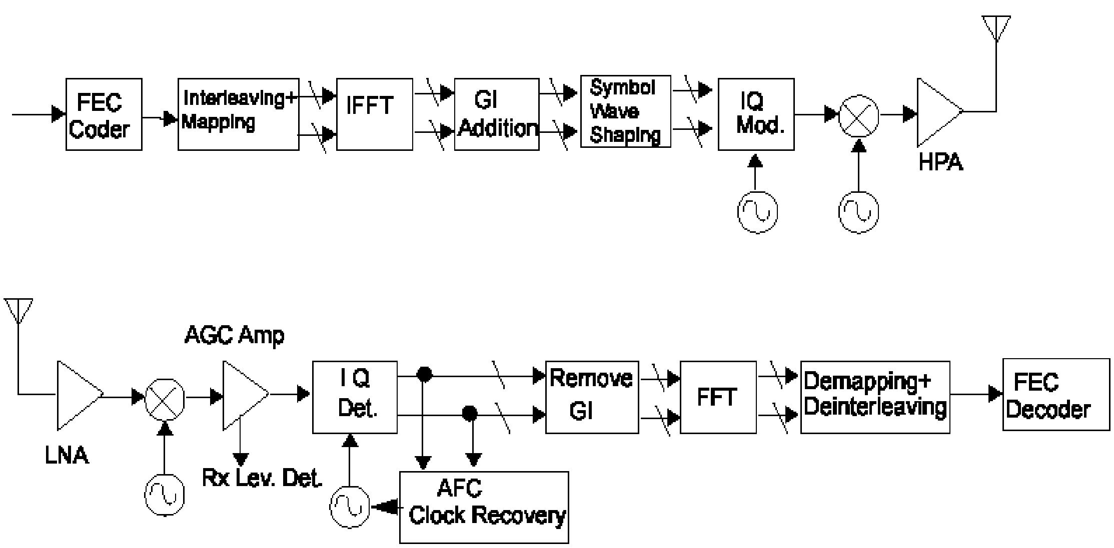


Fig. 2: Functional Diagram Of An OFDM Transmitter And Receiver

In the WLAN system packetized burst signals are transmitted without scheduling so synchronization must be established burst-by-burst. The proposed burst structure based on IEEE 802.11a [3] (see Fig. 3) shows that the OFDM burst actually has four distinct regions. The first is the short preamble (initial training sequence) followed by a long preamble (further training sequence) and, finally, by the signal and data symbols. Guard intervals are inserted between each burst section.

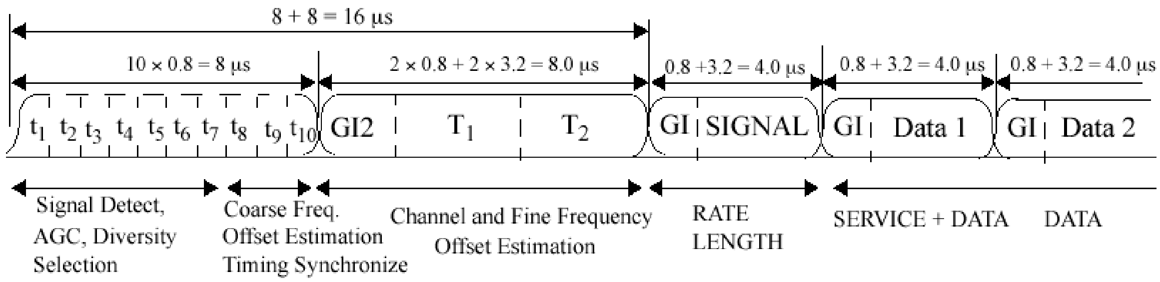


Fig. 3: OFDM Burst Structure (IEEE Std. 802.11a-1999 © 1999 IEEE)

2. Generate OFDM burst from ADS using WLAN library

OFDM burst is generated first in ADS by using a design shown in Fig. 4 (next page.)

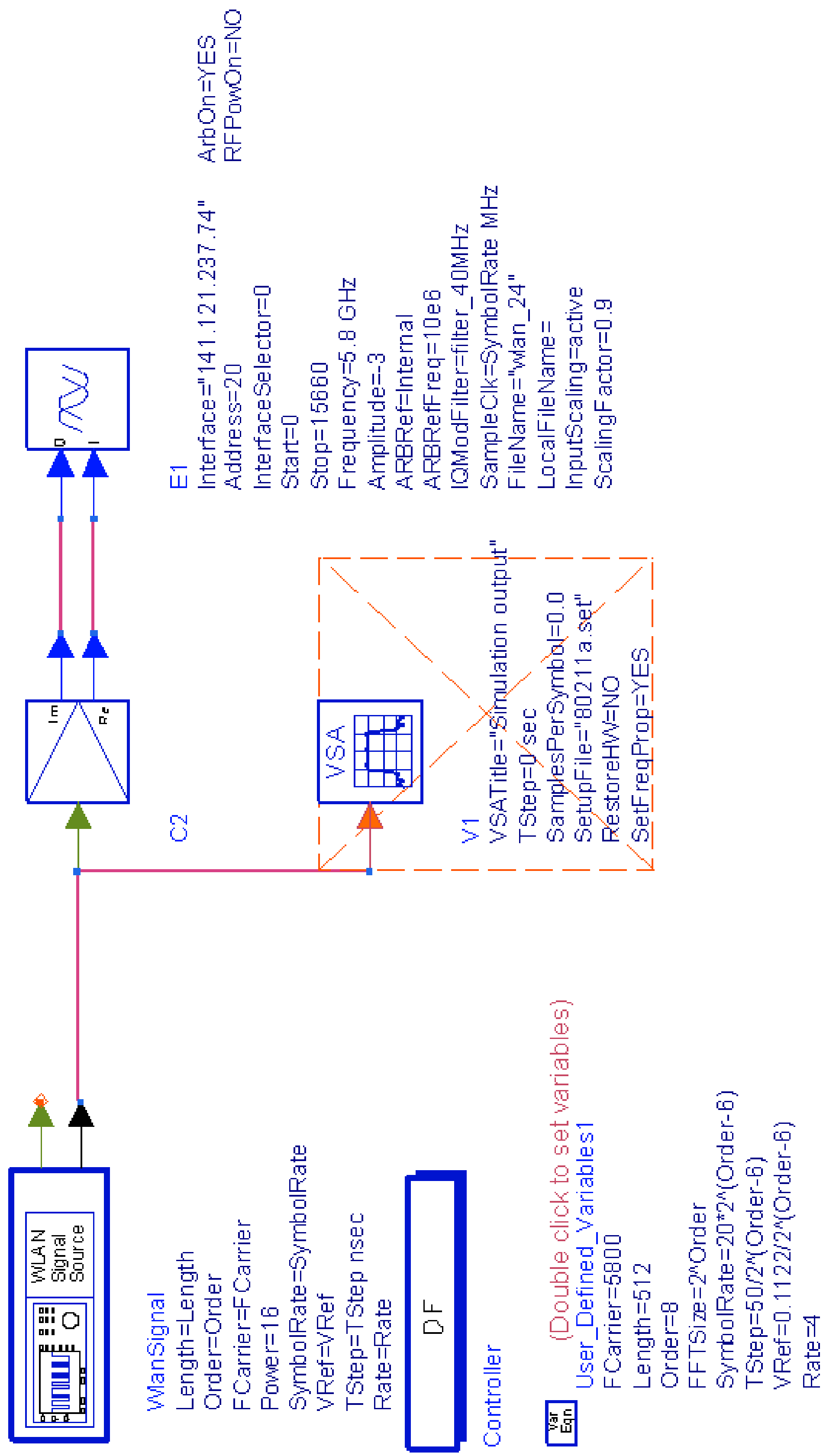


Fig. 4: Design In ADS For Generating OFDM Bursts

An ideal WLAN Signal Source with hierarchical design can generate bursted signals with specific data rate, burst length, symbol clock, carrier frequency, and power with a specific FFT order based on the IEEE 802.11a Std.[1]. All signal parameters can be easily modified in the top level of the design and then the signal is sent to "E1" the ADS-ESGc interface driving the Arb signal generator in the ESGc. Several key parameters for E1 need to be set properly:

- Interface is the HPIB/GPIB interface or IP address
- Address is the instrument address
- The start time and stop time define the signal length sent to ESGc

This needs to be set very carefully to keep the signal sequence contents as an integer number of bursts. To do this the following steps need to be taken:

- Calculate the number of symbols per burst for WLAN data,
  NDSPS = ceiling [(16 + 8 * Length + 6) /NDBPS],
  where, NDBPS is the number of data bits per OFDM symbol and Length is the octet number of PSDU (physical layer convergence procedure service data units)
- Total number of samples per burst,
  NSPB = (20 + idle +NDSPS * 4) μs/ tstep
- Decide start and stop. The waveform sent to the ESGc can start from 0. The stop = NSPB * Number of Bursts

<u>(3) The ARB Generator</u>

The ARB generator is driven by the WLAN RF signal source in ADS and sends the RF signal to the DUT. As an example we tested a PA known as TT-64 with an expected performance of 17 dBm output power at a 5.8-GHz carrier.

The VSA is connected to the output of the DUT for testing and measuring the system performance.

<u>(4) The EVM Measurement In The VSA</u>

Using the VSA, the EVM is measured at different data rates to see if the PA can be used as a transmitter PA meeting the requirements of the IEEE 802.11a Std. The test results are compared to the standard and report either a pass or fail.

Data Rate: 24 Mbit/s
Required EVM <15.8%
Test result: Passed

Input(dBm)	Output(dBm)	EVM(%)
-5	6.15	1.0
-4	7.16	1.0
-3	8.17	1.3
-2	9.19	1.4
-1	10.22	2.1
0	11.26	2.4
+1	12.29	3.4
+2	13.33	4.1
+3	14.37	5.9
+4	15.4	7.5
+5	16.4	8.7
+5.65	17.0	10.1

Data Rate: 36 Mbit/s
Required EVM <11.2%
Test results: Passed

Input(dBm)	Output(dBm)	EVM(%)
-5	6.15	1.0
-4	7.16	1.1
-3	8.17	1.3
-2	9.19	1.5
-1	10.22	2.3
0	11.26	2.5
+1	12.29	3.6
+2	13.33	4.4
+3	14.37	5.9
+4	15.4	7.8
+5	16.4	8.5
+5.65	17.0	10.8

Table 1: WLAN PA Test Results For Data rate = 24 Mbit/s and 36 Mbit/s

Data Rate: 48 Mbit/s
Required EVM <7.9%
Test result: Failed

Input(dBm)	Output(dBm)	EVM(%)
-5	6.15	1.0
-4	7.16	1.1
-3	8.17	1.3
-2	9.19	1.4
-1	10.22	2.2
0	11.26	2.4
+1	12.29	3.4
+2	13.33	4.6
+3	14.37	6.5
+4	15.4	8.3
+5	16.4	10.7
+6	17.35	11.8

Data Rate: 54 Mbit/s
Required EVM <5.6%
Test results: Failed

Input(dBm)	Output(dBm)	EVM(%)
-5	7.0	1.0
-4	8.0	1.1
-3	9.0	1.3
-2	10.0	1.5
-1	11.0	2.3
0	12.0	2.5
+1	13.0	3.6
+2	14.0	4.4
+3	15.0	6.8
+4	16.0	8.7
+5	17.0	11.2
+6	17.35	12.3

Table 2: WLAN PA Test Results For Data Rate = 48 Mbit/s and 54 Mbit/s

As seen in Table 1 for 24 and 36 Mbit/s data the EVM tests were passed. However, as seen in Table 2 the 48 and 54 Mbit/s data tests failed. So the TT-64 is only good enough for 24 and 36 Mbit/s data.

<u>(5) Receiver Test</u>

The receiver test set-up is still the same (Fig. 1, again) and for our purposes we assume the DUT is a linear amplifier. Since measurements for receiver performance are not included in theVSA, the VSA-ADS link must be used to send test data to ADS and this is then processed to evaluate performance. Sometimes a test for a receiver performance has a specific signal requirement and it is hard to generate with a hardware signal generator. For example, consider the Adjacent Channel Rejection test where the test signal must include channel and adjacent channel signals. It is easy however to use the ADS-VSA link for the test signal rather than using the signal generator alone.

Basic Principles For BER/PER Tests

There are two basic approaches for measuring BER/PER:

- Direct waveform comparison of original and decoded bits. The BER/PER estimator can be defined by:

  $$\hat{Pe} = \frac{1}{N}\sum_{i=1}^{N} I(i)$$

  where, N is the number of bits(packs), the *I(i)* is the indicate function for the BER/PER test . *I(i)* = 1 if the test data is not the same as reference data. Otherwise *I(i)* = 0

- For binary symmetric information data [2], we make the following hypothesis:
  Ho: s(i)=0 and H1: s(i) = 1. With the assumption of equal prior probabilities for Ho and H1, we have:

  $$Pe=Po=P1,$$

  where, Pe is the system error probability, Po and P1 are the error probabilities under H0 and H1, respectively

So, the BER/PER estimator can be constructed as:

$$\hat{Pe} = \hat{Po} = \frac{1}{N}\sum_{i=1}^{N} I(i)$$

where, N is the number of bits(packs), the I(i) is the indicate function for the BER/PER test . I(i) = 1 if the test data is not ‘0’. Otherwise I(i) = 0

Two Issues For Measuring BER/PER

Delay measuring

- The delay between original data and test data can be measured in ADS by comparing these two wave forms

Time step recovery

- Go through the ESGc, the DUT, and the VSA. The signal time step for test data may be changed because of different test instruments' interpolation processes
- The time step change between original data and test data can be recovered in ADS by a re-sampling process

BER/PER Accuracy

Typical PER Value

- Based on 802.11a Std, for Minimum Input level Sensitivity, Adjacent Channel Rejection and Non-adjacent Channel Rejection, 1e-2 PER is the Standard observation level

Accuracy

- Waveform recording errors caused by ADS-ESGc and VSA-ADS, including delay and sampling rate change, can be recovered in ADS, thus eliminating recording errors for BER/PER tests. The BER/PER estimation accuracy is mainly decided by the BER/PER estimation variance in ADS.

Estimation accuracy can be measured by using the relative variance of $\hat{Pe}$. In [2], the relative variance has been defined and given by:

$$\sigma_{MC} = (E[\hat{Pe}^2] - Pe^2)/(N\,Pe^2) \approx 1/(N\,Pe)$$

Based on this equation a larger number of the simulation samples yields a smaller relative variance for certain *Pe*. In terms of simulation accuracy a larger N is expected. However, a larger N corresponds to a longer simulation time. We have to make a trade off and, in practice, set a reasonable relative variance, then determine N.

For example, let us measure the WLAN minimum input level sensitivity at 1e-2 based on the requirement of the IEEE 802.11a Std. To Estimate a PER of 1e-2 1000 bursts will be used for 10% relative variance that means 95% confidence interval is received [3]. This is a reasonable setting.

The test system is as before (Fig. 1, again.) Originally the WLAN signal is generated by ADS in different ways for the system tests. Through a link the WLAN RF signal with a 5.8-GHz carrier is generated by using the ARB generator in the ESG-C which can be sent to the DUT, which can be a device in the transmitter or receiver. For most measurements for transmitter tests the VSA can be directly used but for receiver tests we need to use the VSA-ADS link as those tests are not provided by the VSA alone. To do this the signal waveforms sent from the DUT to the VSA are recorded as an sdf file, which can be read in ADS. Then a simulation can be run to measure receiver performance such as PER, BER, sensitivity, and adjacent channel rejection.

BER/PER performance test

BER is the basic performance measurement for any receiver. PER is the most important performance measurement for WLAN receivers. WLAN system designers always use this measurement to verify the receiver performance.

AWGN channel condition

To obtain the BER/PER performance ADS uses the WLAN Library. Original WLAN data can be generated by using the design in Figure 5 (next page.) The signal source block provides the WLAN with Burst structure based on IEEE 802.11a11g, then a AWGN channel model is followed to provide proper channel noise. An ESGc interphase model is used to send the ADS signal to the ESGc.

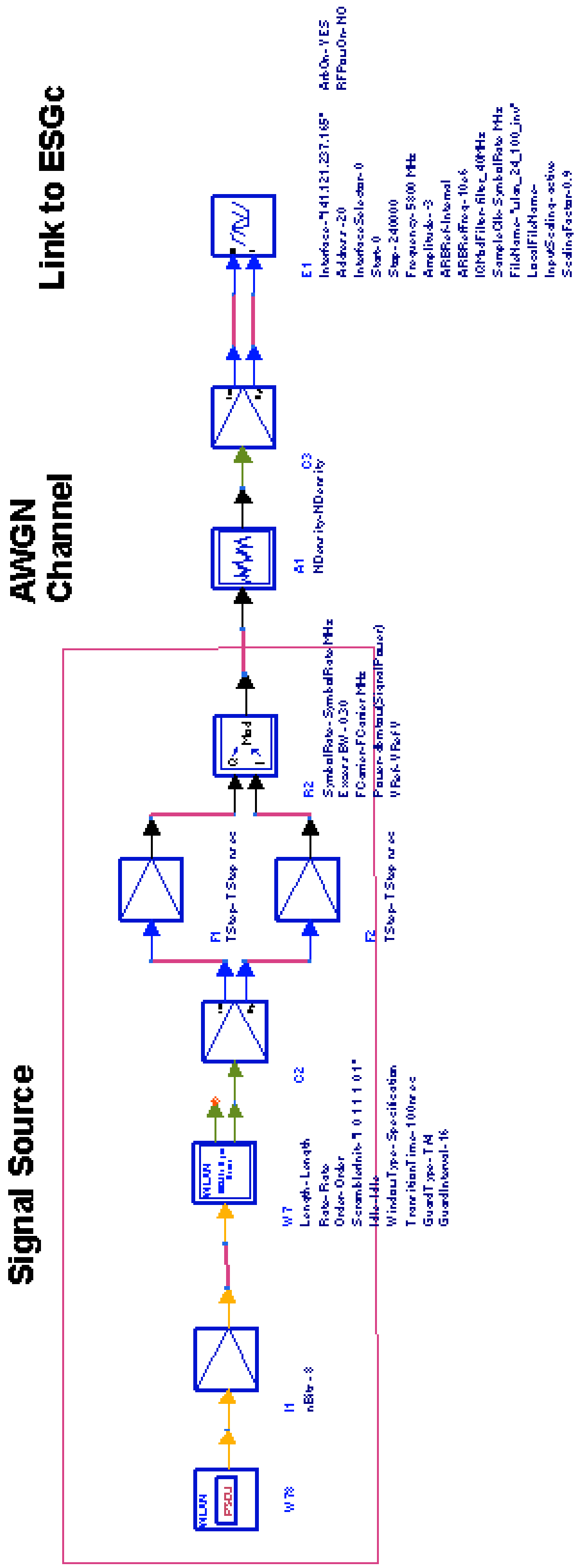


Fig. 5: ADS Design For OFDM BER/PER Test Bursts Under AWGN Conditions

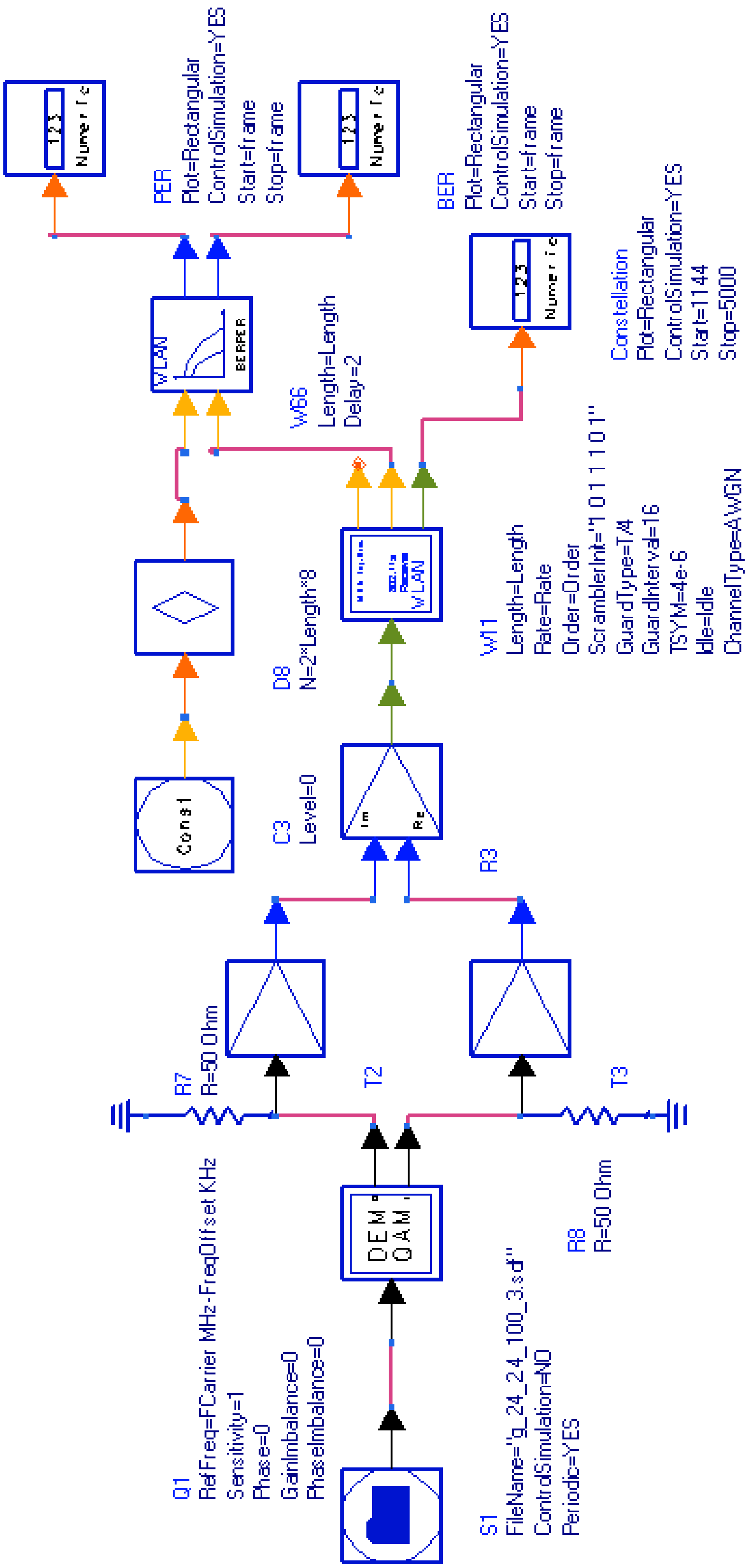


Fig. 6: BER/PER Test Under AWGN Conditions

In Figure 6, a design for testing the receiver PER and BER under AWGN condition is shown. In this test, the second 2 is used for the BER and PER and the reference data set to all ‘0’. Under this assumption, the BER estimator is calculated by

$$\hat{Pe} = \hat{Po} = \frac{1}{N}\sum_{i=1}^{N} I(i)$$

where, the *I(i)* is the indicate function for the BER test . *I(i)* = 1 if the test data is not 0. Otherwise *I(i)* = 0

The BER and PER when Eb/No = 8 dB are shown in Table 3. The test results are also compared to simulation results. The results are reasonable.

	BER	PER
Simulation Results	3.1 e -3	2.1 e-1
Test Results	4.2 e -3	3.4 e -1

Table 3: BER/PER Test/Simulation Results For Receiver Under AWGN Condition

Fading Channel Condition

For the design in Fig. 7 (on the left) 24-Mbit/s WLAN signals are generated to be sent through the Fading channel.

Based on reference [2], fading signals with five type-options have been designed. Model A, an 18-tap fading channel corresponding to a typical office environment for NLOS conditions and 50-ns average rms delay spread, is selected in this example. In order to reduce the number of taps needed, the time spacing is non-uniform; for shorter delays, a more dense spacing is used. The average power declines exponentially with time. For model A all taps have Rayleigh statistics.

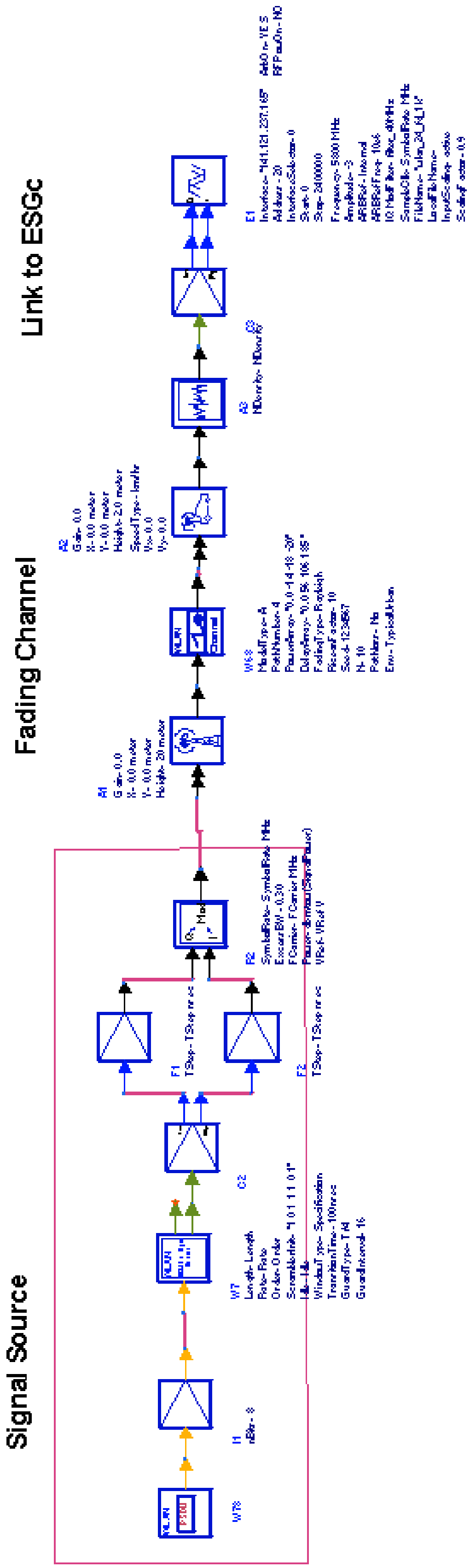
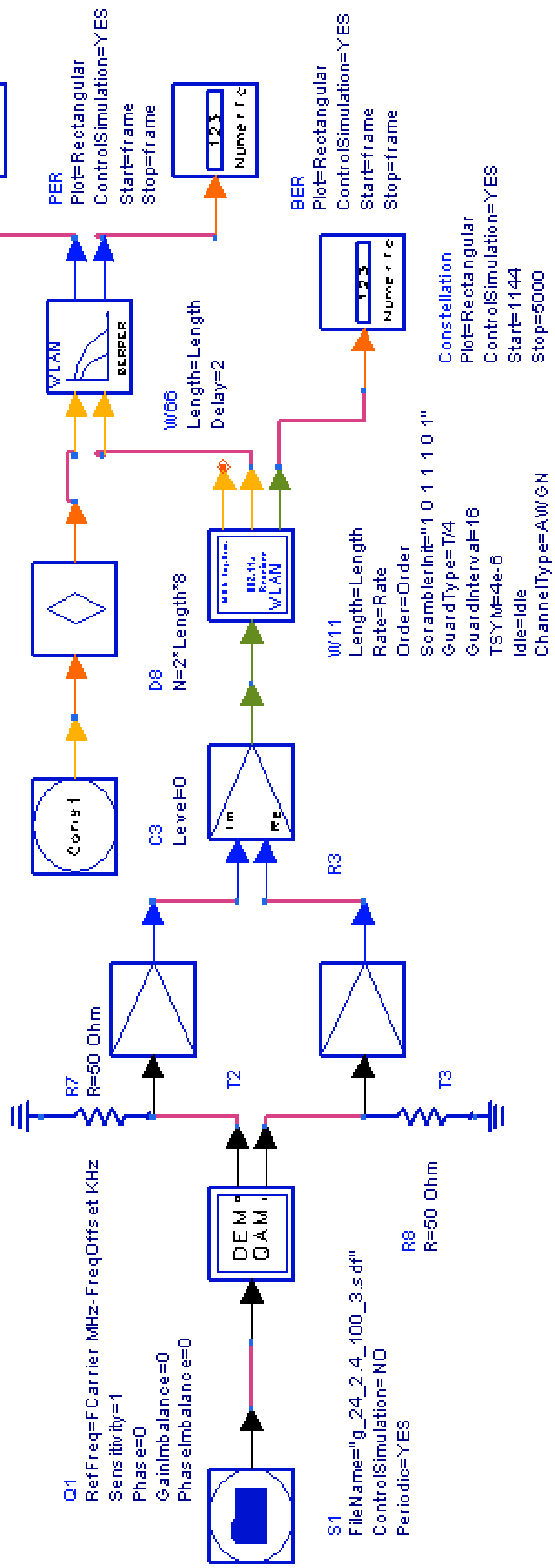


Fig. 7: ADS Design For OFDM BER/PER Test Bursts Under Multi-Path Fading

In this test set-up shown in Fig. 8, the second 2 also is used for the BER and PER, and the reference data set to all ‘0’. Under this assumption, the BER estimator is calculated by



$$\hat{Pe} = \hat{Po} = \frac{1}{N}\sum_{i=1}^{N} I(i)$$

where, the $I(i)$ is the indicate function for the BER test . $I(i)$ = 1 if the test data is not 0. Otherwise $I(i)$ = 0

Fig. 8: Receiver Test

The BER and PER Vs Eb/No are ploted in Figure 9. The test results (blue lines) are also compared to simulation results (red lines).

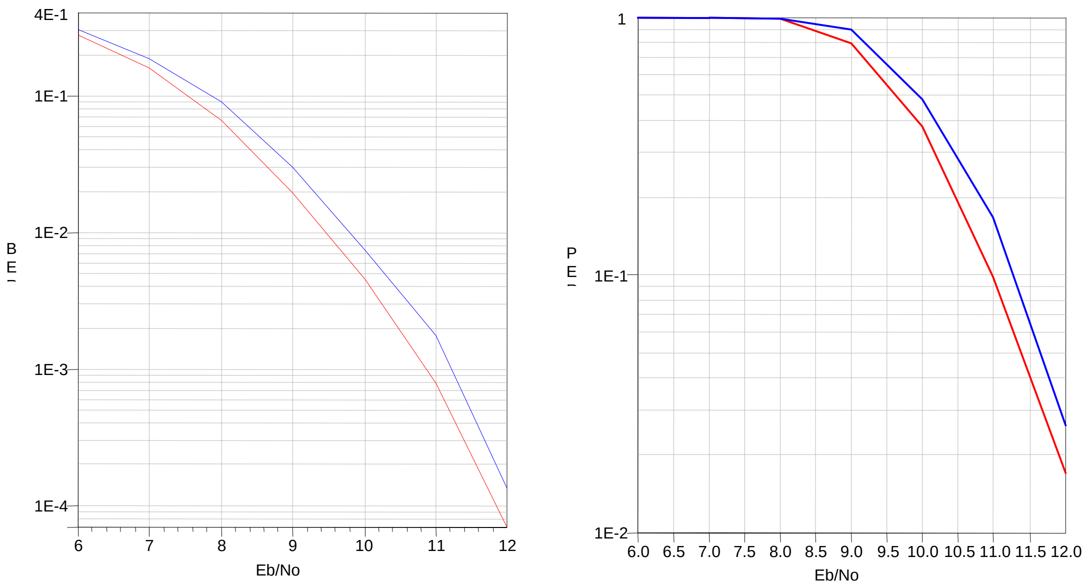


Fig. 9: Test Results

Receiver minimum input level sensitivity

Based on the requirement by section 17.3.10.1, IEEE 802.11a Std, the packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels must be the numbers listed in Table 91 of the IEEE 802.11a Std or less. The minimum input levels are measured at the antenna connector (NF of 10 dB and 5 dB implementation margins are assumed). For data rate 36 Mbit/s, the value is -70 dBm. The design in Fig. 10 is for generating signal to test WLAN receiver minimum input level sensitivity at a data rate of 36 Mbit/s. The schematic for this design is shown in Fig. 10 and Fig. 11.

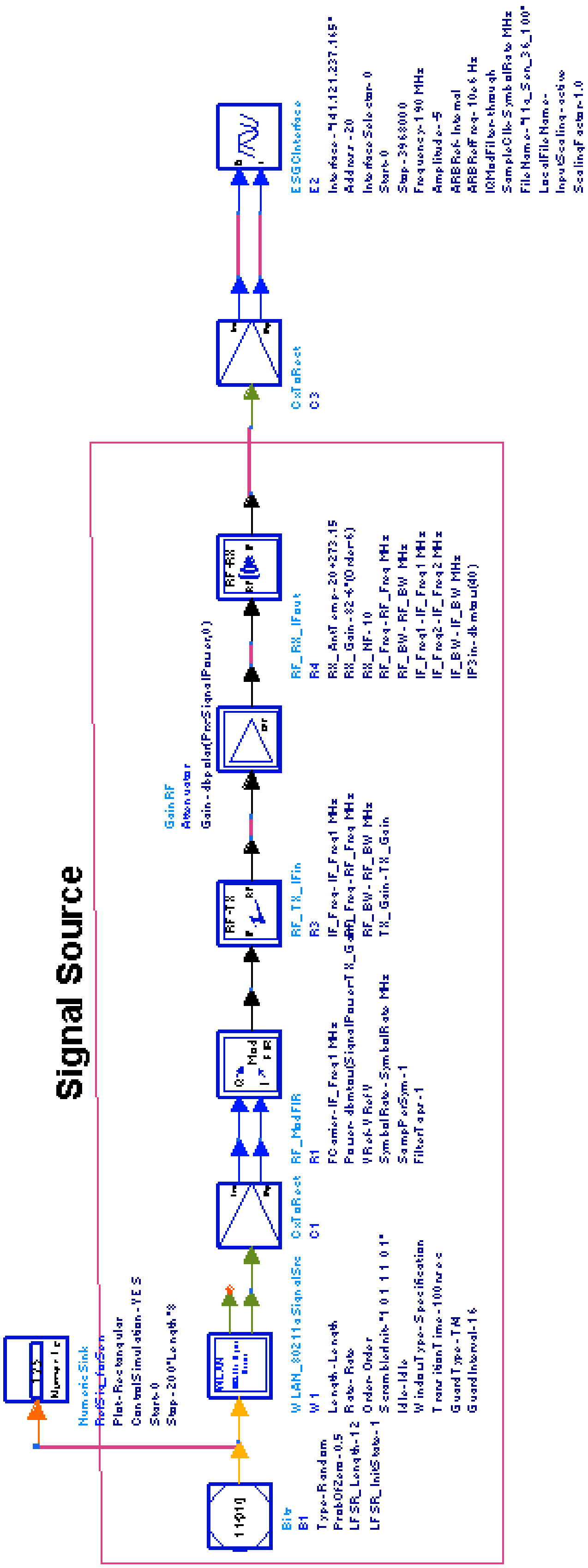


Fig. 10: Signal Generation For Minimum Input Level Sensitivity Tests

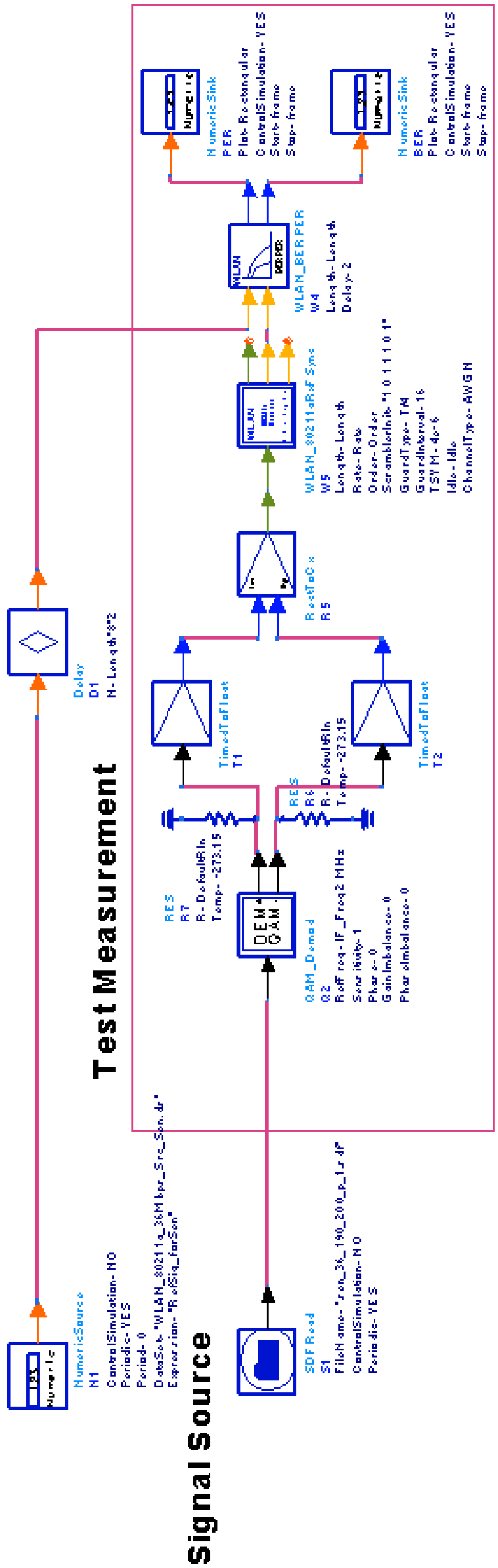


Fig. 11: Minimum Input Level Sensitivity Tests

Test results shown Table 4 indicate the receiver input level sensitivity test is passed because the PER for the system is less than 1e-1.

Receiver minimum input level sensitivity

(Section 17.3.10.1 in IEEE std 802.11a-1999):

Index	BER	PER
200	0.000	0.000

Specification requirements

The PER shall be less than 10%, when the minimum sensitivity is set to the data-rate dependent value below.

Data Rate (Mbit/s)	Minimum sensitivity (dBm)
6	-82
9	-81
12	-79
18	-77
24	-74
36	-70
48	-66
54	-65

Table 4:. Receiver Minimum Input Level Sensitivity Test result

Adjacent Channel Rejection

Based on the requirement by section 17.3.10.2, of the IEEE 802.11a Std, the adjacent channel rejection shall be measured by setting the desired signal's strength 3 dB above the rate-dependent sensitivity specified in Table 91 of IEEE Std. 802.11a-1999 and raising the power of the interfering signal until 10% PER is caused for a PSDU length of 1000 bytes.

The power difference between the interfering and the desired channel is the corresponding adjacent channel rejection. The interfering signal in the adjacent channel shall be a conformant OFDM PHY signal unsynchronized with the signal in the channel under test. For a conformant OFDM PHY the corresponding rejection shall be no less than specified in Table 91 of IEEE Std. 802.11a-1999.

In Fig. 12 a design to generate a signal for testing the adjacent channel rejection of data rate 36 Mbit/s is given; The power of the interfering signal is raised to the rate-dependent adjacent channel rejection 15 dB as specified in Table 91 of IEEE Std. 802.11a-1999, then a PER less than 10% shall be achieved.

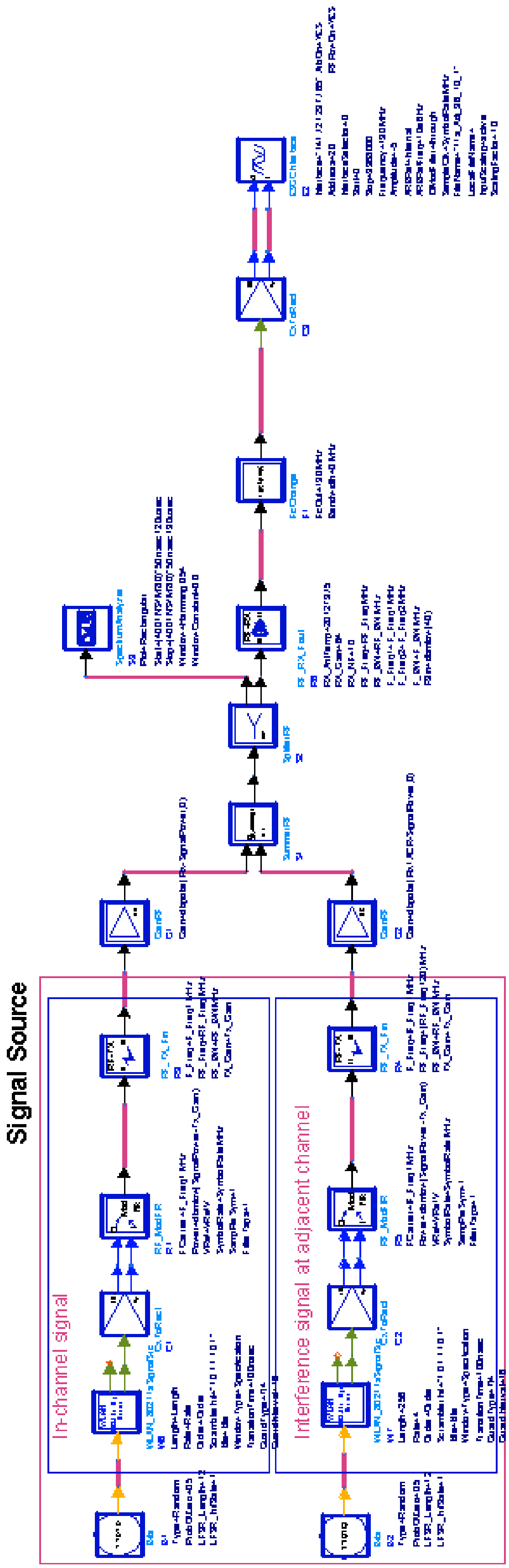


Fig. 12: Signal Generation For Adjacent Channel Rejection Test

The data captured by the VSA is read back to ADS as shown in Fig. 13. A BER/PER test is performed. In this test, the Approach 2 is also used for the BER and PER, and the reference data set to all ‘0’. Under this assumption, the BER estimator is calculated by:

$$\hat{Pe} = \hat{Po} = \frac{1}{N}\sum_{i=1}^{N} I(i)$$

where, the *I(i)* is the indicate function for the BER test . *I(i)* = 1 if the test data is not 0. Otherwise *I(i)* = 0.

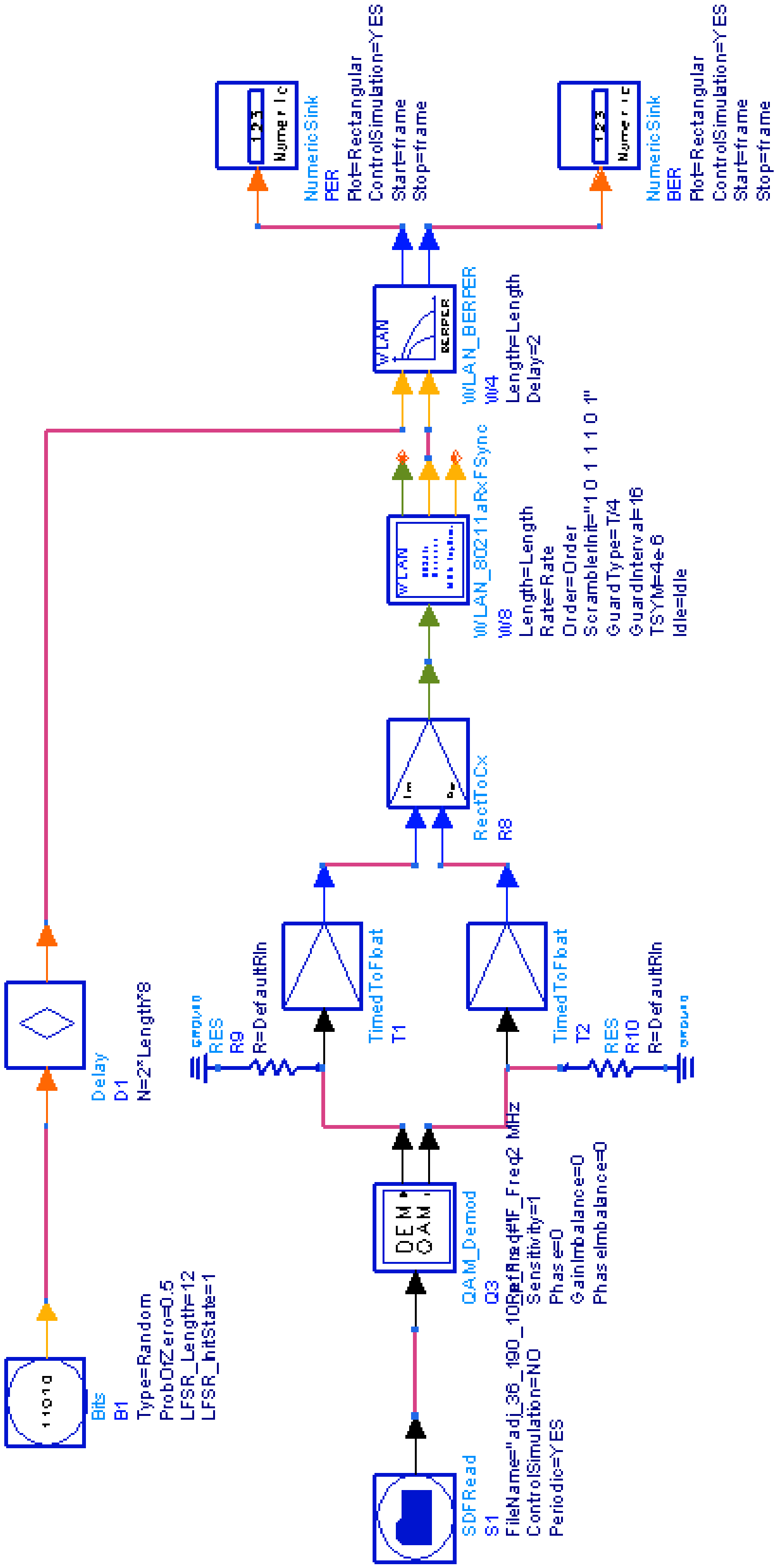
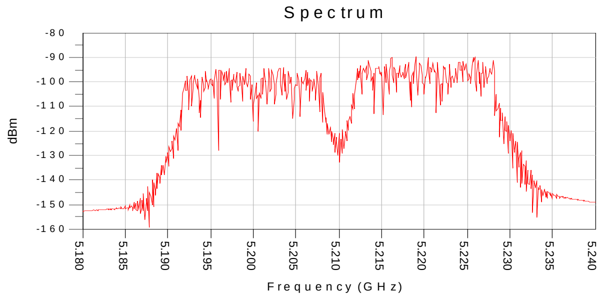


Fig. 13: Adjacent Channel Rejection Test

Test results are indicated in Table 5. As can be seen the adjacent channel rejection test was passed because the PER is less than 1e-1.

WLAN Adjacent Channel Rejection (ACR)

WLAN Specification: IEEE Std 802.11a-1999



Index	PER
200	0.000

Specification requirements

The PER shall be less than 10%, when the adjacent channel rejection (ACR) is set to the data-rate dependent value below.

Data Rate (Mbps)	Adjacent channel rejection (dB)
6	16
9	15
12	13
18	11
24	8
36	4
48	0
54	-1

Table 5. Adjacent Channel Rejection Test For WLAN Receiver

Conclusions

A good WLAN test system should be able to accurately perform key measurements required by the IEEE Standard, such as EVM, minimum level sensitivity, and adjacent channel rejection. There should be a clear, simple method for displaying results and the environment should be flexible enough for testing any component/sub-system/system. The system should be easy to use. The WLAN Test system we propose here can meet all of these important requirements. For more information on such solutions, please visit http://eesof.tm.agilent.com/products/connected_solutions.html

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