Agilent Technologies

Advanced Design System 2011.01

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WLAN DesignGuide

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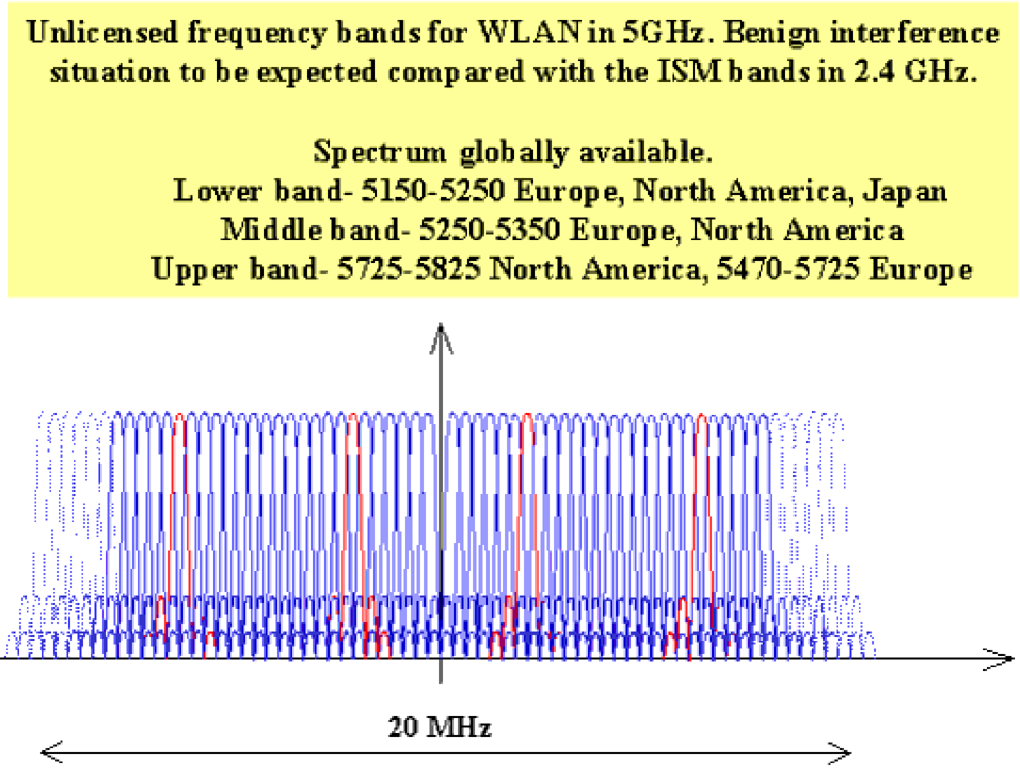
WLAN Standard

The 802.11a Standard

- 802.11 was adopted in July 1997 as a worldwide standard.
    - Supports 1 and 2 Mbps operation at 2.4 GHz band
    - Physical layers: DSSS, FHSS and Infrared
- 802.11b high rate extension adopted in 1999
    - Supports 5.5 Mbps and 11 Mbps at 2.4 GHz
    - CCK modulation, bandwidth compatible with DSSS
- 802.11a specs approved at the beginning of year 2000
    - Supports up to 54 Mbps at 5 GHz band
    - Uses OFDM modulation

Frequency Allocations

Following is a summary of the frequency allocations for this standard.



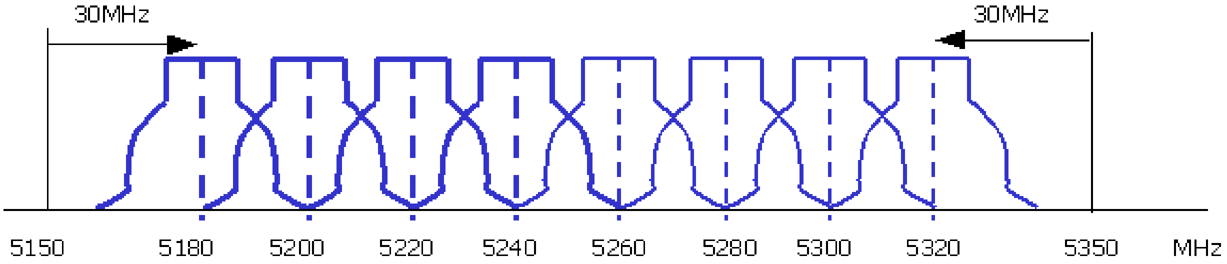
Unlicensed frequency bands for WLAN in 5GHz. Benign interference situation to be expected compared with the ISM bands in 2.4 GHz.

Spectrum globally available.
Lower band- 5150-5250 Europe, North America, Japan
Middle band- 5250-5350 Europe, North America
Upper band- 5725-5825 North America, 5470-5725 Europe

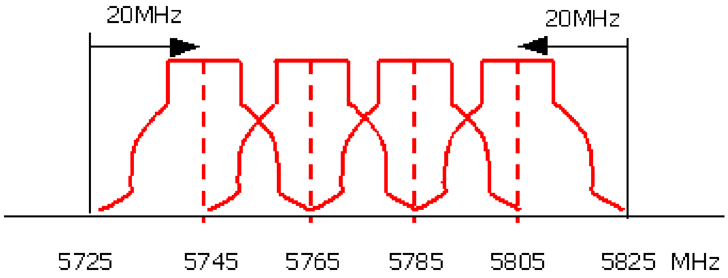
- Modulation: OFDM
- Uses 52 subcarriers: 48 data + 4 pilots
- Convolutional coding rate: 2/3
- The carries can be BPSK, QPSK, 16QAM or 64QAM modulated. The RF bandwidth is approximately 16.6Mhz.
- OFDM frame duration: 4 ms with guard interval: 0.8 ms
- Data rate: 6, 9, 12, 18, 24, 36, 48, 54Mbps (6, 12 and 24Mbps mandatory)

OFDM Signal Spectrum

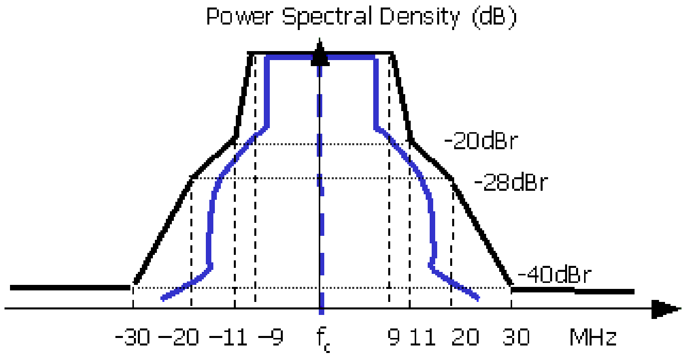
Following are examples of OFDM Signal Spectrum.



Lower and Middle U-NII Band – 8 carriers in 200MHz / 20MHz spacing



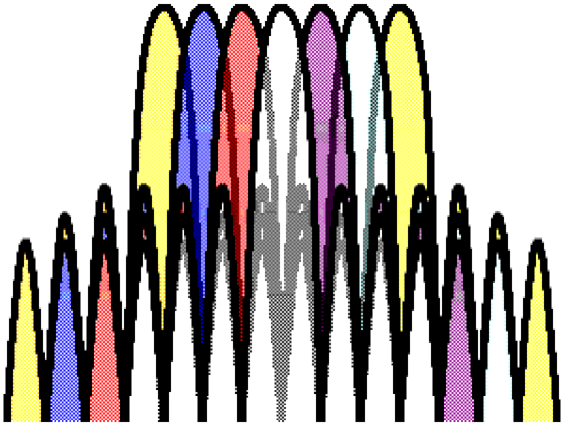
Upper U-NII Band – 4 carriers in 100MHz / 20MHz spacing



Transmit Spectrum Mask

OFDM Modulation

Concepts of OFDM:



- A type of multi-carrier modulation
- Single high-rate bit stream is converted to low-rate N parallel bit streams
- Each parallel bit stream is modulated on one of N sub-carriers
- Each sub-carrier can be modulated differently, e.g. BPSK, QPSK or QAM
- To achieve high bandwidth efficiency, the spectrum of the sub-carriers are closely spaced and overlapped
- Nulls in each sub-carrier's spectrum land at the center of all other sub-carriers (orthogonal)
- OFDM symbols are generated using IFFT

Advantages of OFDM:

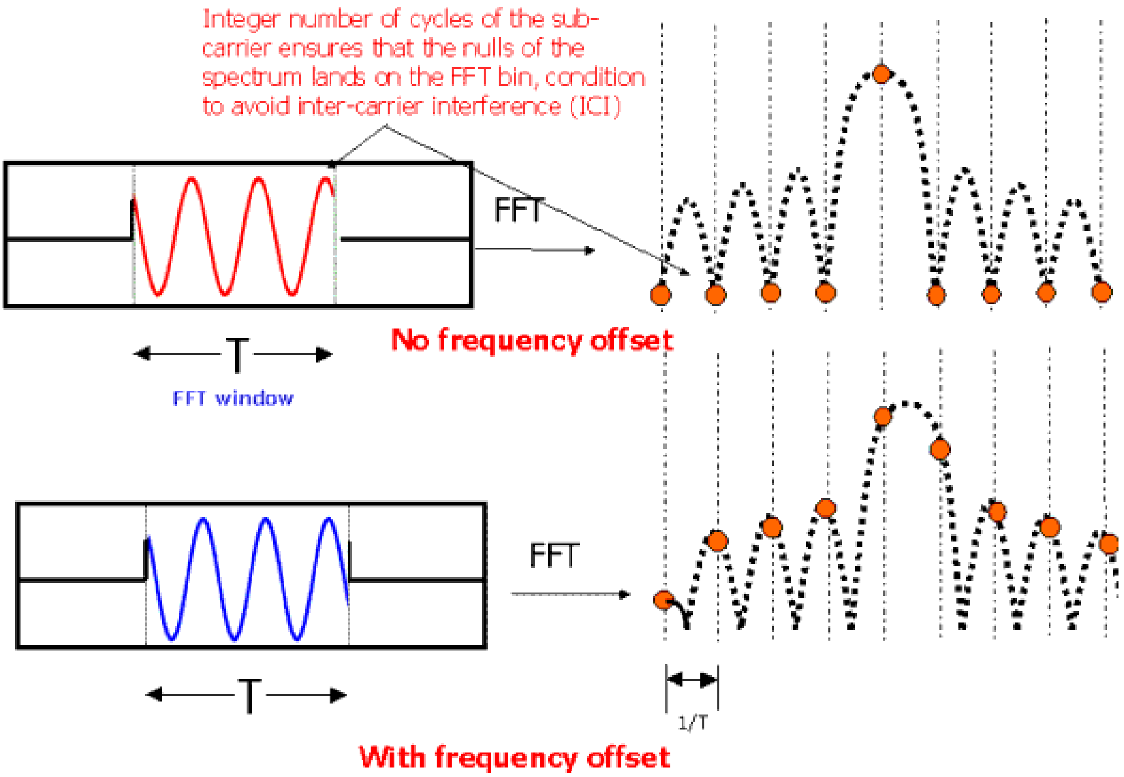
- Robustness in multipath propagation environment
- More tolerant to delay spread:
- Due to the use of many sub-carriers, the symbol duration on the sub-carriers is increased, relative to delay spread.
- Intersymbol interference is avoided through the use of guard interval.
- Simplified or eliminate equalization needs, as compared to single carrier modulation.
- More resistant to fading. FEC is used to correct for sub-carriers suffer from deep fade.

Design challenges of OFDM modulation:

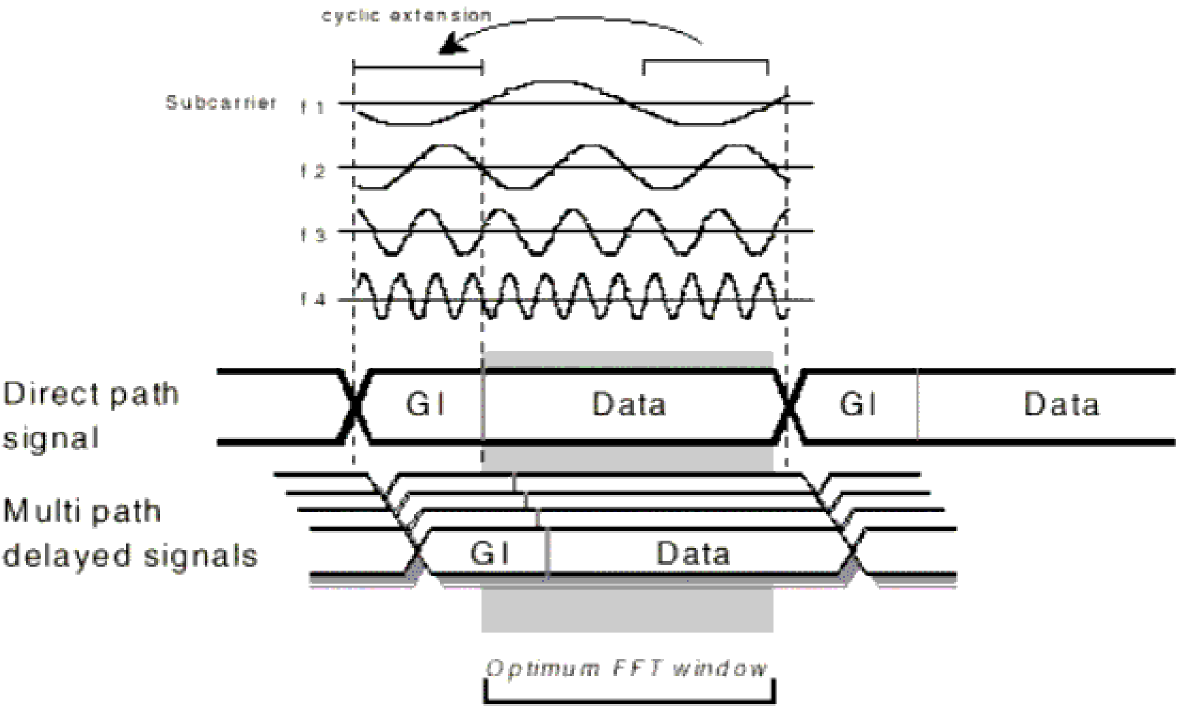
- Sensitive to frequency offset; need frequency offset correction in the receiver.
- Sensitive to oscillator phase noise- clean and stable oscillator required.
- Large peak to average ratio; amplifier back-off, reduced power efficiency.
- IFFT/FFT complexity; fixed point implementation to optimize latency and performance.
- Intersymbol Interference (ISI) due to multipath; use guard interval.

Inter-Carrier Interference Due to Frequency Offset

From an ADS Schematic window toolbar, select **DesignGuide > WLAN > Tutorial: Understanding OFDM Modulation > Inter-Carrier Interference (ICI) due to Freq. Offset.**

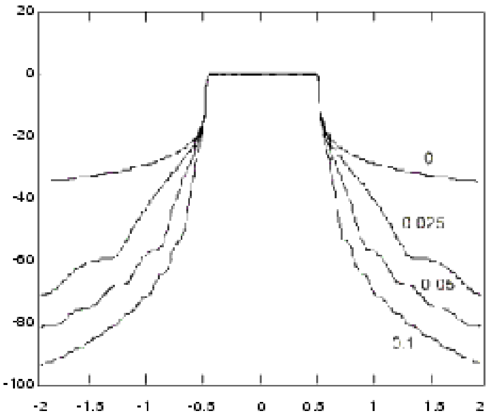


Guard Interval



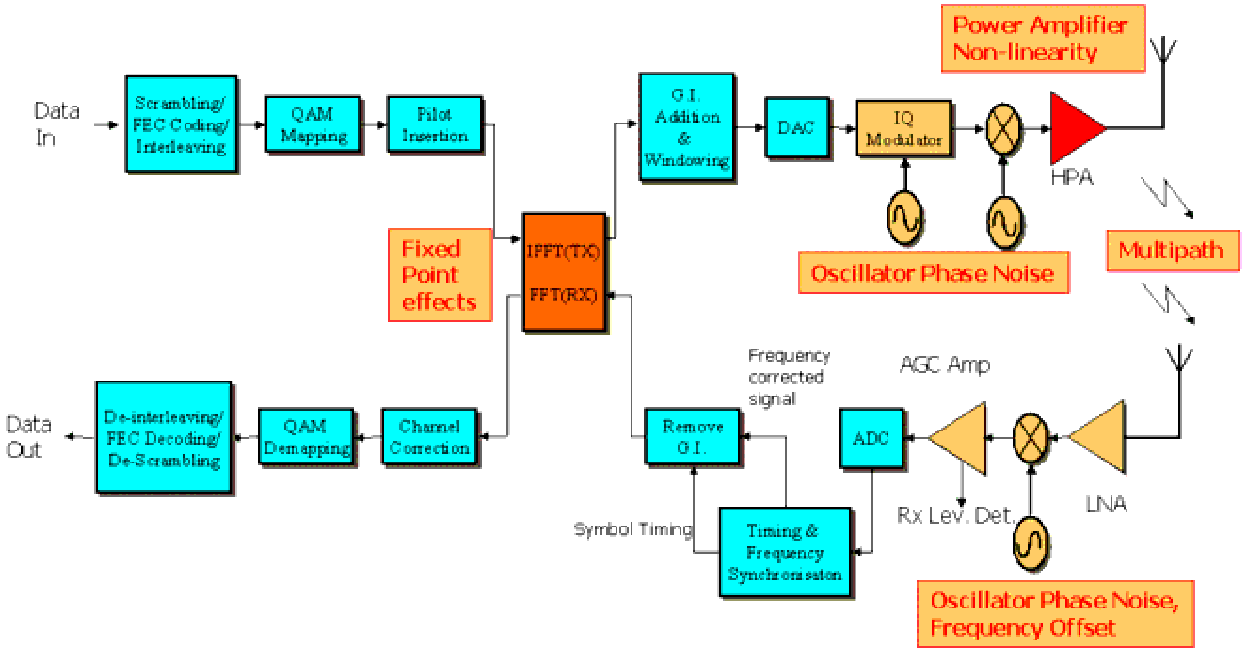
- Multipath delays up to the guard time do not cause inter-symbol interference.
- Subcarriers remain orthogonal for multipath delays up to guard time (no inter-carrier interference).

Windowing



- To reduce spectrum splatter, the OFDM symbol is multiplied by a raised-cosine window, w(t) before transmission to more quickly reduce the power of out-of-band subcarriers.
- Preceding illustration shows spectra for 64 subcarriers with different values of the rolloff factor, β of the raised cosine window.
- Larger β, better spectral roll-off.
- However, a roll-off factor of β reduces delay spread tolerance by a factor of βTS.

OFDM Transceiver Block Diagram

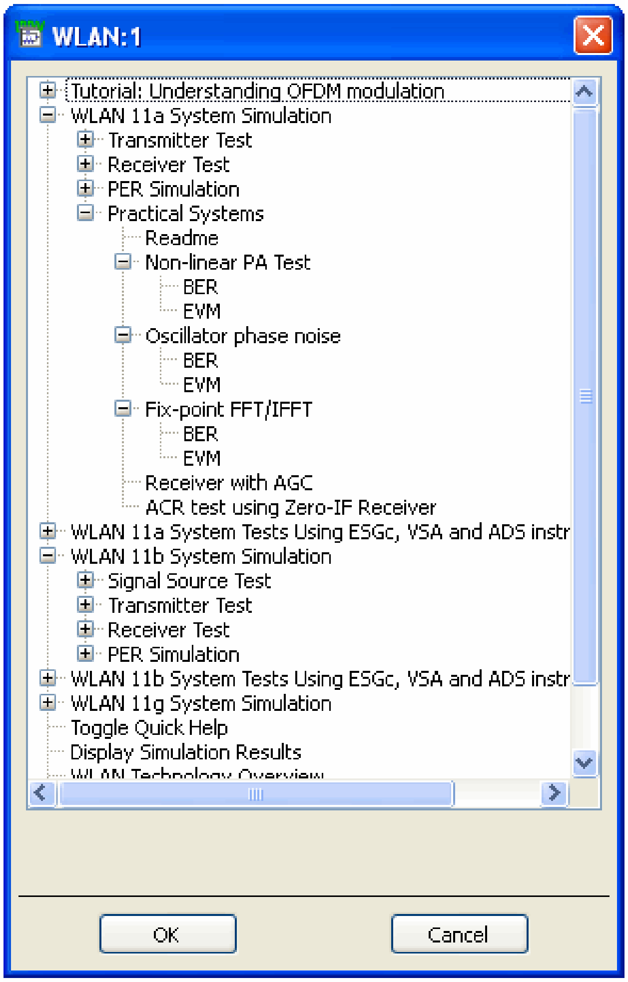


Effects of Link Impairments on OFDM Modulation

This section summarizes the evaluation of the effects of link impairment when using the

WLAN Design Library and the WLAN DesignGuide.

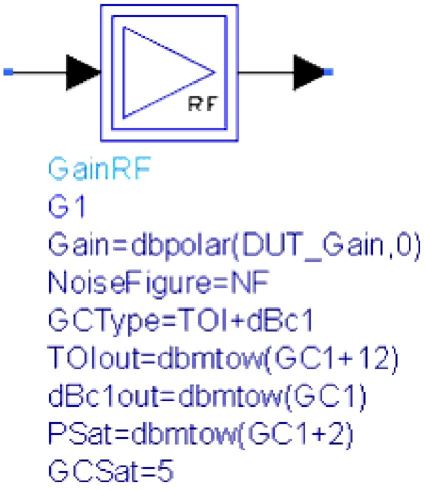
The following WLAN DesignGuide menu is shown as it appears when you have configured your program for dialog *box access* vs. *cascading menus* .



Effects of Power Amplifier Nonlinearity

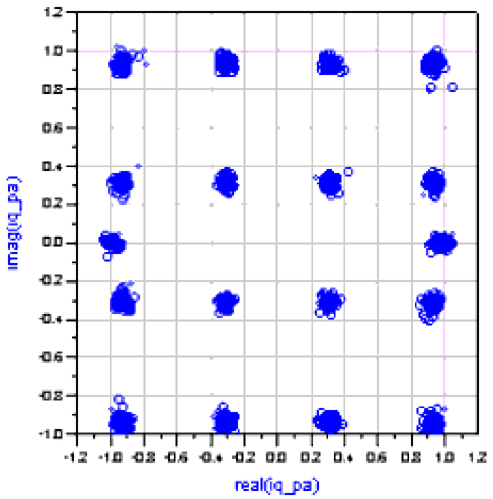
From an ADS Schematic window toolbar, select **DesignGuide > WLAN > WLAN 11a System Simulation > Practical Systems > Non-linear PA Test** .

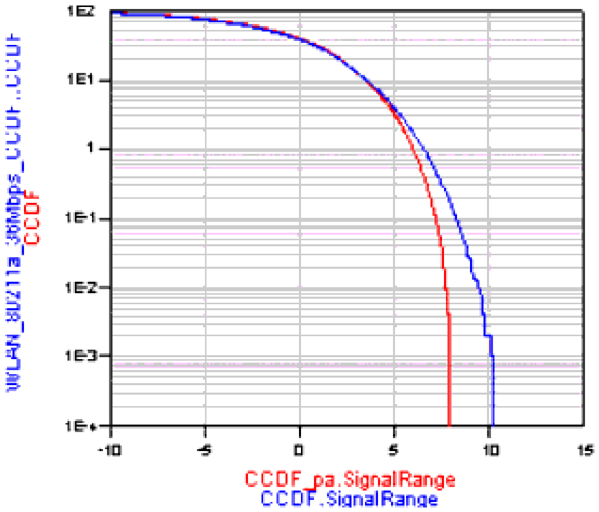
The following is the behavioral model used in the PA non-linearity simulation:



Here the output 1-dB Compression Point (dBc1out) is used along with the output Third-Order Intercept (TOIout) derived from it by adding 12 dB. The results can be evaluated for their effect on EVM (Error Vector Magnitude), Constellation diagram, spectrum and CCDF (Complementary Cumulative Density Function).

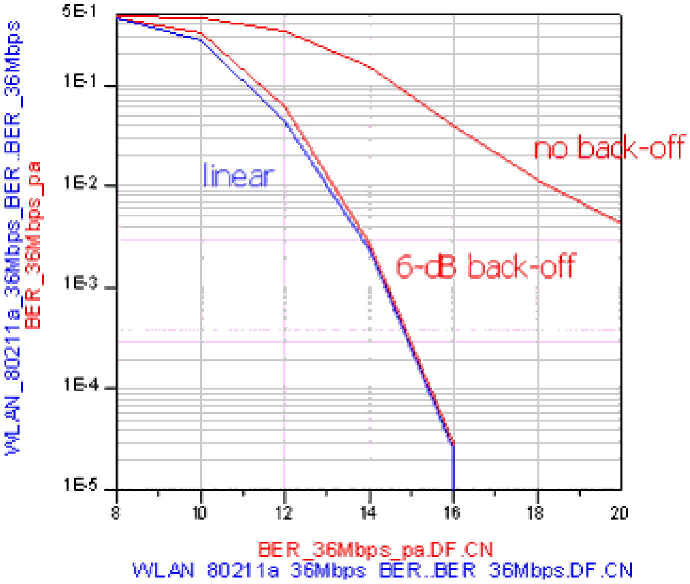
Here is a Constellation diagram at 6 dB backoff:





CCDF indicates the probability (starting from 100%) of the signal's peak value in dB. The CCDF plot for the power amplifier response, operated at 6 dB backoff from saturation, indicates signal clipping at 7.8 dB, compared to the unamplified signal's peak of 9.4 dB at 0.01%.

The bit error rate (BER) and packet error rate (PER) can also be measured against a particular impairment. For the non-linear PA, the BER can be shown to degrade when the amplifier is not sufficiently backed-off, as shown here.

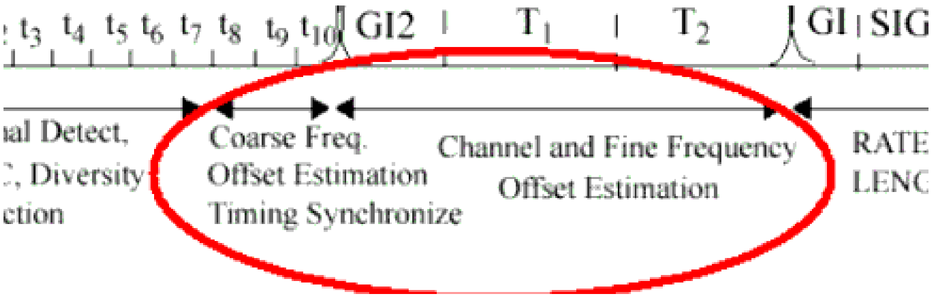


Requirement for BER/PER Simulations

Due to the use of coding and the presence of non-linear impairments, a Monte Carlo BER simulation method must be used. Since a PSDU length of 1,000 bits is required, these simulation can be quite lengthy. Therefore, most of the saved datasets included with this DesignGuide reflect simulations performed with a much smaller length, e.g. 10 or 100, and will show degradation as the signal is more greatly impaired in some way. However, reliable estimates of the BER or PER for less-impaired signals will require multiple 1,000-bit packets to be simulated.

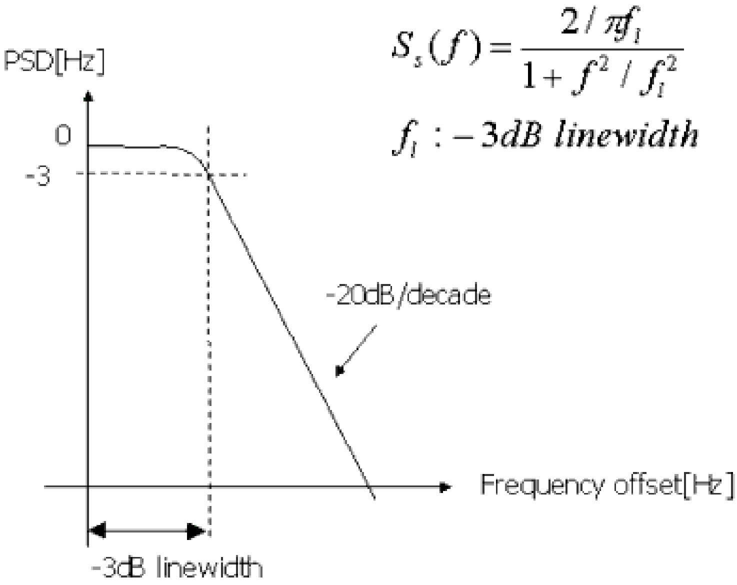
Effects of Frequency Offset

Frequency offset due to differences between the transmit and receive reference oscillators is expressed as a percentage of the 312.5 kHz sub-carrier frequency spacing. The receiver can perform frequency offset estimation and correction using preambles:

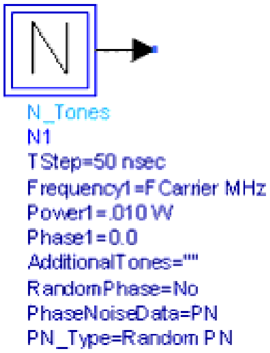


- Make use of short preamble for coarse frequency offset estimation and long preamble for fine frequency offset estimation.
- Short preamble symbol duration of 0.8 us allows frequency correction up to 1/(2x0.8 ms)=±625kHz
- Assume RF frequency=5.8GHz, the tolerable frequency offset (worst case) =0.5x625k/5.8G=±53.8ppm > ±20ppm specified in 802.11a.

Effects of Oscillator Phase Noise



An N_Tones model is used to model the phase noise.

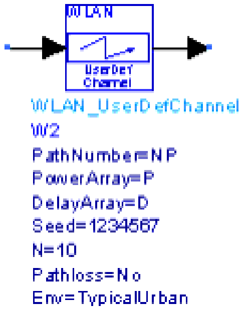

N_Tones
N1
TStep=50 nsec
Frequency1=FCarrier MHz
Power1=.010 W
Phase1=0.0
AdditionalTones=""
RandomPhase=No
PhaseNoiseData=PN
PN_Type=Random PN

Effects of Fixed Point implementation of IFFT/FFT

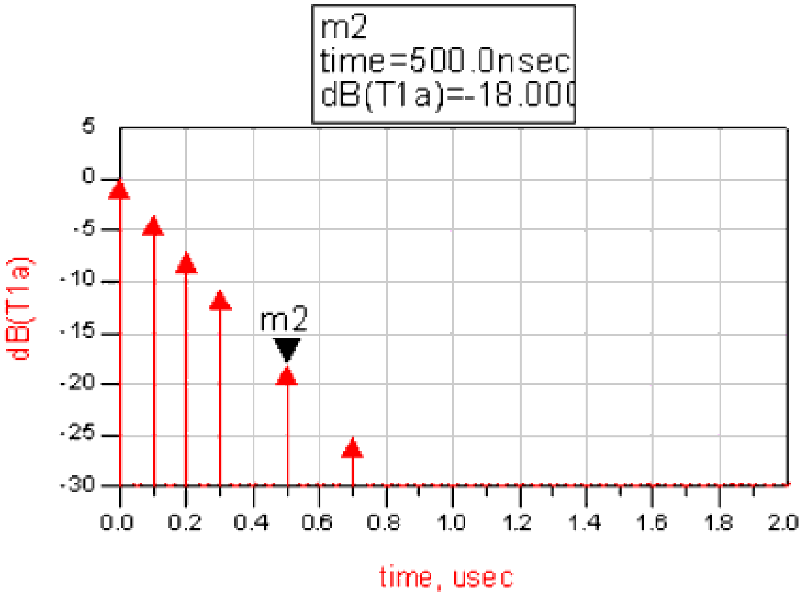
The IFFT and FFT function in the transceiver will have a fixed bit-width. This might have an effect on the system performance. The WLAN DesignGuide provides a 64-point implementation which uses the bit width as a parameter, so it can be changed or swept. It uses a decimation in frequency, Radix-2 algorithm.

Effects of Multipath

Multipath propagation is simulated using the user-defined channel model.



This defines an impulse response.



The RMS delay spread (defined as follows) varies. Typical values are 100-200 nsec.

$$\overline{\tau} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

$$\overline{\tau^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}$$

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\overline{\tau})^2}$$

DesignGuide Examples Overview

Design examples are provided in the **/examples/wlan** directory. Workspaces and their corresponding design examples are:

802.11a Transmitter Test and Verification Design Examples: WLAN_80211a_Tx_wrk

- WLAN_80211a_Demo: signal source that complies with Annex G of IEEE Standard 802.11a-1999.
- WLAN_80211a_SignalSource: generates 802.11a burst with different data rates.
- WLAN_80211a_Src_Glacier: generates 802.11a burst with idle, and co-simulation with VSA89600.
- WLAN_80211a_TxSpectrum: measures the transmit spectrum mask.
- WLAN_80211a_TxEVM: measures error vector magnitude and relative constellation error and tests the transmit modulation accuracy.

802.11a Receiver Test and Verification Design Examples: WLAN_80211a_Rx_wrk

- WLAN_80211a_RxSensitivity_6Mbps: minimum receiver sensitivity measurement of 6 Mbps data rate.
- WLAN_80211a_RxSensitivity_24Mbps: minimum receiver sensitivity measurement of 24 Mbps data rate.
- WLAN_80211a_RxSensitivity_54Mbps: minimum receiver sensitivity measurement of 54 Mbps data rate.
- WLAN_80211a_RxAdjCh_9Mbps: adjacent channel rejection measurement of 9 Mbps data rate.
- WLAN_80211a_RxAdjCh_18Mbps: adjacent channel rejection measurement of 18 Mbps data rate.
- WLAN_80211a_RxAdjCh_36Mbps: adjacent channel rejection measurement of 36 Mbps data rate.
- WLAN_80211a_RxNonAdjCh_12Mbps: non-adjacent channel rejection measurement of 12 Mbps data rate.
- WLAN_80211a_RxNonAdjCh_48Mbps: non-adjacent channel rejection measurement of 48 Mbps data rate.

802.11a BER/PER Performance Design Examples: WLAN_80211a_PER_wrk

- WLAN_80211a_24Mbps_AWGN_System: BER and PER performance for 24 Mbps systems under AWGN channel.
- WLAN_80211a_24Mbps_PN_System: BER and PER performance for 24 Mbps systems under phase noise distortion.
- WLAN_80211a_24Mbps_Fading_System: BER and PER performance for 24 Mbps systems under fading channel.
- WLAN_80211a_36Mbps_AWGN_Perfect: raw BER performance for 16-QAM modulation with perfect channel estimator under AWGN channel.
- WLAN_80211a_36Mbps_AWGN_System: BER and PER performance for 36 Mbps systems under AWGN channel.
- WLAN_80211a_36Mbps_Fading_System: BER and PER performance for 36 Mbps systems under fading channel.
- WLAN_80211a_48Mbps_AWGN_Perfect: BER performance for 64-QAM modulation with perfect channel estimator under AWGN channel.

80211a Practical Systems: WLAN_80211a_Practical_wrk

- 802.11a Receiver Specifications - Sensitivity
- 802.11a Receiver Specifications - Adjacent Channel Rejection
- 802.11a Receiver Specifications - Alternate Channel Rejection

802.11a ESGc Link Design Examples: WLAN_80211a_ESGc_wrk

- WLAN_PA_80211a_Src_ESGc: testing CCK power amplifier based on 802.11a Std using ADS-ESG 4438C link.

802.11b Signal Source Design Examples: WLAN_80211b_SignalSource_wrk

- WLAN_80211_LowRate: generates 802.11 burst with different data rates.
- WLAN_80211b_CCK: generates 802.11b CCK burst with different data rates.
- WLAN_80211b_PBCC: generates 802.11b PBCC burst with different data rates.

802.11b Transmitter Test and Verification Design Examples: WLAN_80211b_Tx_wrk

- WLAN_80211b_TxEVM: measures EVM and tests the transmit modulation accuracy.

802.11b Receiver Test and Verification Design Examples: WLAN_80211b_Rx_wrk

- WLAN_80211b_RxMinInput_Sensitivity: receiver minimum input level sensitivity measurement for 802.11b.
- WLAN_80211b_RxMaxInput_Sensitivity: receiver maximum input level sensitivity measurement for 802.11b.

802.11b CCK BER/PER Design Examples: WLAN_80211b_PER_wrk

- WLAN_80211b_5_5Mbps_AWGN_System: BER and PER performance for CCK 5.5 Mbps systems under AWGN channel.
- WLAN_80211b_11Mbps_AWGN_System: BER and PER performance for CCK 11 Mbps systems under AWGN channel.

802.11b System Test Using Instrument Links Design Examples: WLAN_80211b_ESGc_wrk

- WLAN_80211b_CCK_ESG4438C: demonstrates how to use the ADS-ESGc link to test a WLAN 802.11b/802.11g CCK transmitter system.
- WLAN_80211b_25M_Esgc: tests a WLAN IEEE 802.11b CCK transmitter under adjacent channel environment.

802.11g Design Examples: WLAN_80211g_wrk

- WLAN_80211g_OFDM_TxEVM: measures error vector magnitude and relative constellation error and tests the transmit modulation accuracy for OFDM signal.
- WLAN_80211g_CCK_TxEVM: measures error vector magnitude and relative constellation error and tests the transmit modulation accuracy for CCK signal.
- WLAN_80211g_OFDM_36Mbps_Fading_System: BER and PER performance for 36 Mbps systems under fading channel.
- WLAN_80211g_CCK_11Mbps_AWGN_System: BER and PER performance for 802.11g 11Mbps systems with CCK modulation under AWGN channel.

80211a Transmitter

Introduction

WLAN_80211a_Tx_wrk IEEE 802.11a transmitter test and verification design examples are described in this section.

- WLAN_80211a_Demo: WLAN signal source at 36 Mbps data rate where all data matches Annex G of IEEE 80211a.
- WLAN_80211a_SignalSource: generates IEEE 802.11a burst with different data rates.
- WLAN_80211a_Src_Glacier: generates IEEE 802.11a burst with idle, and co-simulation with VSA89600.
- WLAN_80211a_TxSpectrum: measures the transmit spectrum mask.
- WLAN_80211a_TxEVM: measures error vector magnitude and relative constellation error and tests the transmit modulation accuracy.

36 Mbps Signal Source Implementation

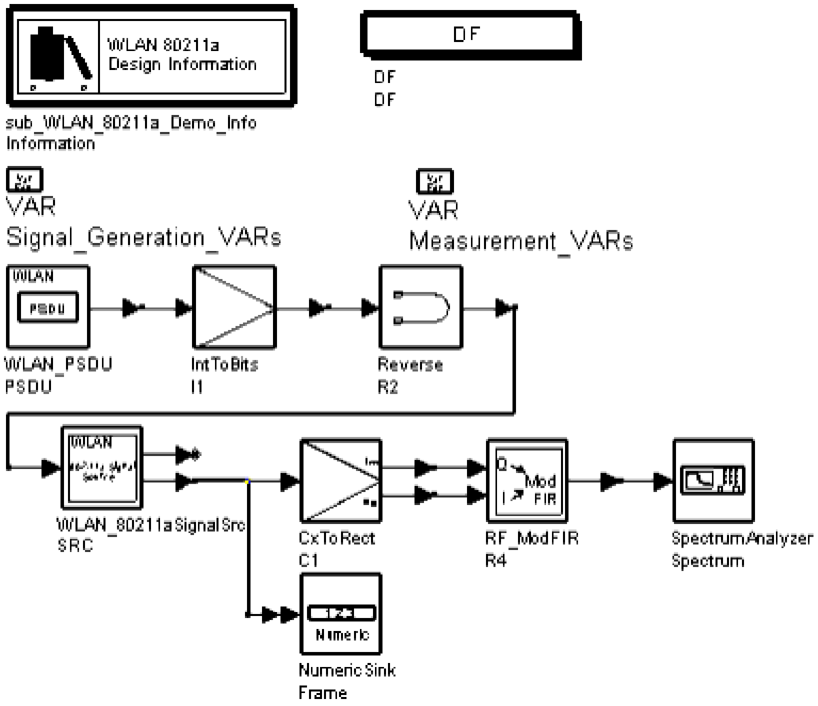
WLAN_80211a_Demo

Description

This design demonstrates a WLAN signal source at a data rate of 36 Mbps. The PSDU bits and all parameters settings comply with annex G of IEEE Std 802.11a-1999.

The top-level schematic for this design is shown in the following figure. Parameters that can be user-modified are contained in VAR Signal_Generation_VARs. Other parameters are set according to the specification and should not be changed.

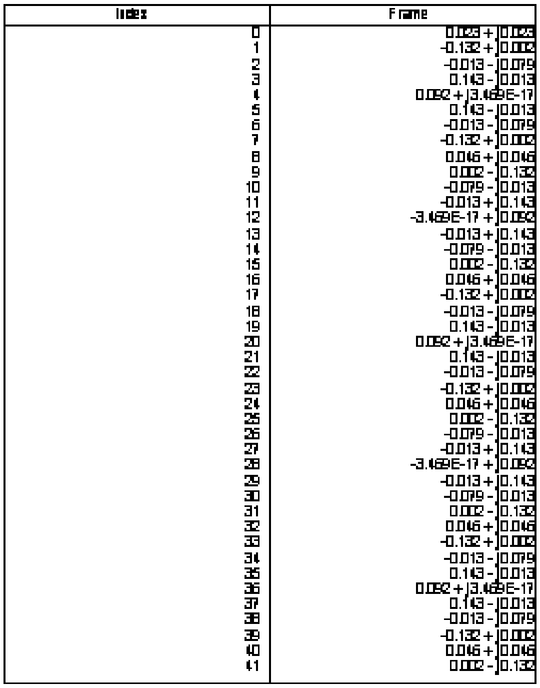
The mapping mode is rate related; for 36 Mbps, 16-QAM mapping is used.



WLAN_80211a_Demo Schematic

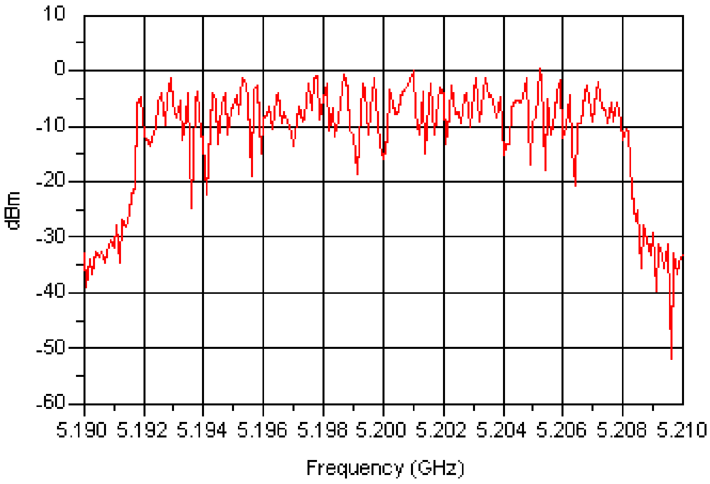
Simulation Results

Simulation results displayed in WLAN_80211a_Demo.dds are the baseband burst (frame) data results in accordance with the IEEE specification (the first of the following two figures) and the transmit spectrum (the second figure).



Index	Frame
0	0.023 + j0.023
1	-0.132 + j0.002
2	-0.013 - j0.079
3	0.143 - j0.013
4	0.092 + j3.469E-17
5	0.143 - j0.013
6	-0.013 - j0.079
7	-0.132 + j0.002
8	0.046 + j0.046
9	0.002 - j0.132
10	-0.079 - j0.013
11	-0.013 + j0.143
12	-3.469E-17 + j0.092
13	-0.013 + j0.143
14	-0.079 - j0.013
15	0.002 - j0.132
16	0.046 + j0.046
17	-0.132 + j0.002
18	-0.013 - j0.079
19	0.143 - j0.013
20	0.092 + j3.469E-17
21	0.143 - j0.013
22	-0.013 - j0.079
23	-0.132 + j0.002
24	0.046 + j0.046
25	0.002 - j0.132
26	-0.079 - j0.013
27	-0.013 + j0.143
28	-3.469E-17 + j0.092
29	-0.013 + j0.143
30	-0.079 - j0.013
31	0.002 - j0.132
32	0.046 + j0.046
33	-0.132 + j0.002
34	-0.013 - j0.079
35	0.143 - j0.013
36	0.092 + j3.469E-17
37	0.143 - j0.013
38	-0.013 - j0.079
39	-0.132 + j0.002
40	0.046 + j0.046
41	0.002 - j0.132

Baseband Burst (Frame) Data Results



Transmit Spectrum

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 1 minute

References

1. IEEE Std 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Signal Source without Idle between Two Consecutive Bursts

WLAN_80211a_SignalSource Design

Features

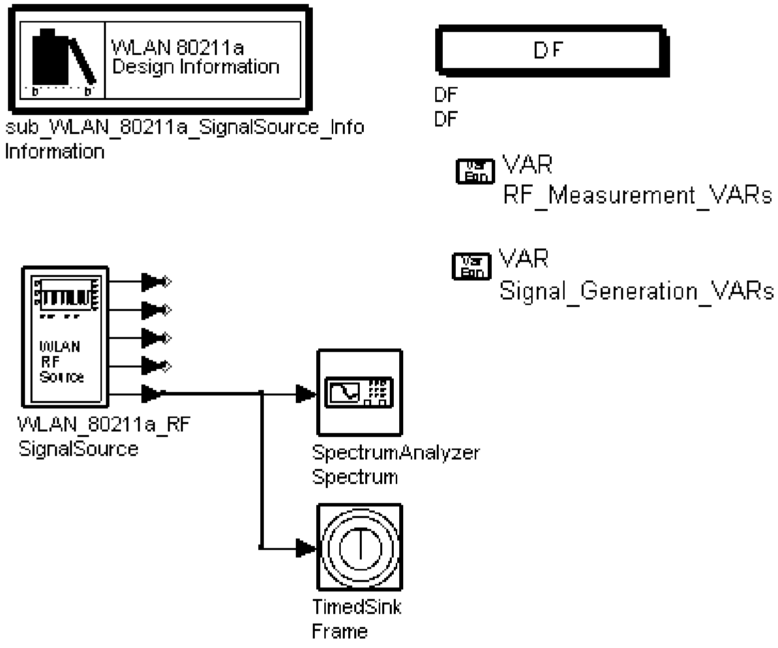
- Configurable signal source sub-network model
- Various data rates can be simulated by setting the Rate variable in the schematic
- Sampling rate (T, T/2, T/4, T/8 and so on) is controlled by setting the Order variable

in the schematic

Description

This design is an example of WLAN signal source at various data rates without idle between two consecutive bursts.

The top-level schematic for this design is shown in the following figure. Parameters that can be user-modified are contained in VAR Signal_Generation_VARs.



WLAN_80211a_SignalSource Schematic

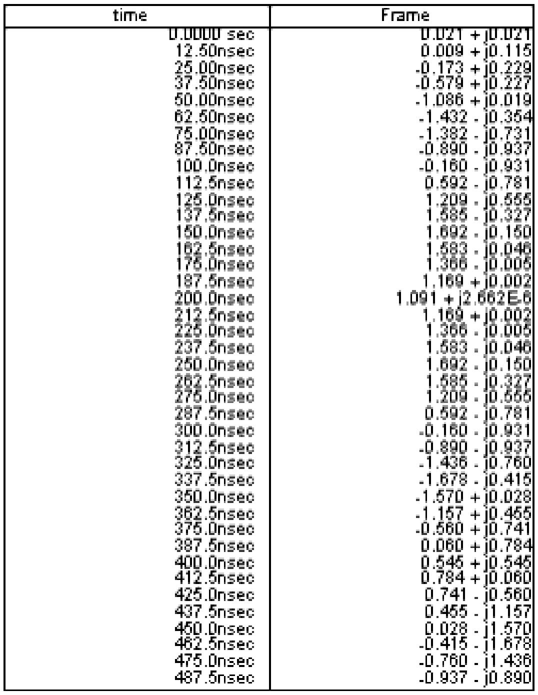
The modulation mode is rate related, which is controlled by the Rate variable in the schematic. The following table shows the modulation mode with various data rates.

Rate Dependent Parameters

Rate	Data Rate (Mbps)	Modulation
0	6	BPSK
1	9	BPSK
2	12	QPSK
3	18	QPSK
4	24	16-QAM
5	27	16-QAM
6	36	16-QAM
7	48	64-QAM
8	54	64-QAM

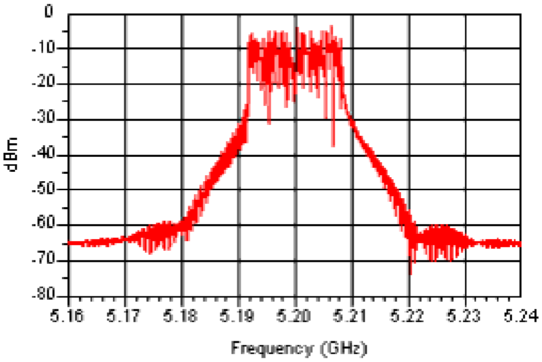
Simulation Results

Simulation results displayed in WLAN_80211a_SignalSource.dds are shown in the following two figures.



time	Frame
0.0000 sec	0.021 + j0.021
12.50nsec	0.009 + j0.115
25.00nsec	-0.173 + j0.229
37.50nsec	-0.579 + j0.227
50.00nsec	-1.086 + j0.019
62.50nsec	-1.432 - j0.354
75.00nsec	-1.382 - j0.731
87.50nsec	-0.890 - j0.937
100.0nsec	-0.160 - j0.931
112.5nsec	0.592 - j0.781
125.0nsec	1.209 - j0.555
137.5nsec	1.585 - j0.327
150.0nsec	1.692 - j0.150
162.5nsec	1.583 - j0.046
175.0nsec	1.366 - j0.005
187.5nsec	1.169 + j0.002
200.0nsec	1.091 + j2.662E-6
212.5nsec	1.169 + j0.002
225.0nsec	1.366 - j0.005
237.5nsec	1.583 - j0.046
250.0nsec	1.692 - j0.150
262.5nsec	1.585 - j0.327
275.0nsec	1.209 - j0.555
287.5nsec	0.592 - j0.781
300.0nsec	-0.160 - j0.931
312.5nsec	-0.890 - j0.937
325.0nsec	-1.436 - j0.760
337.5nsec	-1.678 - j0.415
350.0nsec	-1.570 + j0.028
362.5nsec	-1.157 + j0.455
375.0nsec	-0.560 + j0.741
387.5nsec	0.060 + j0.784
400.0nsec	0.545 + j0.545
412.5nsec	0.784 + j0.060
425.0nsec	0.741 - j0.560
437.5nsec	0.455 - j1.157
450.0nsec	0.028 - j1.570
462.5nsec	-0.415 - j1.678
475.0nsec	-0.760 - j1.436
487.5nsec	-0.937 - j0.890

Random Burst of 802.11a



Transmit Spectrum

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 1 minute

References

1. IEEE Std 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Signal Source with Idle between Two Consecutive Bursts

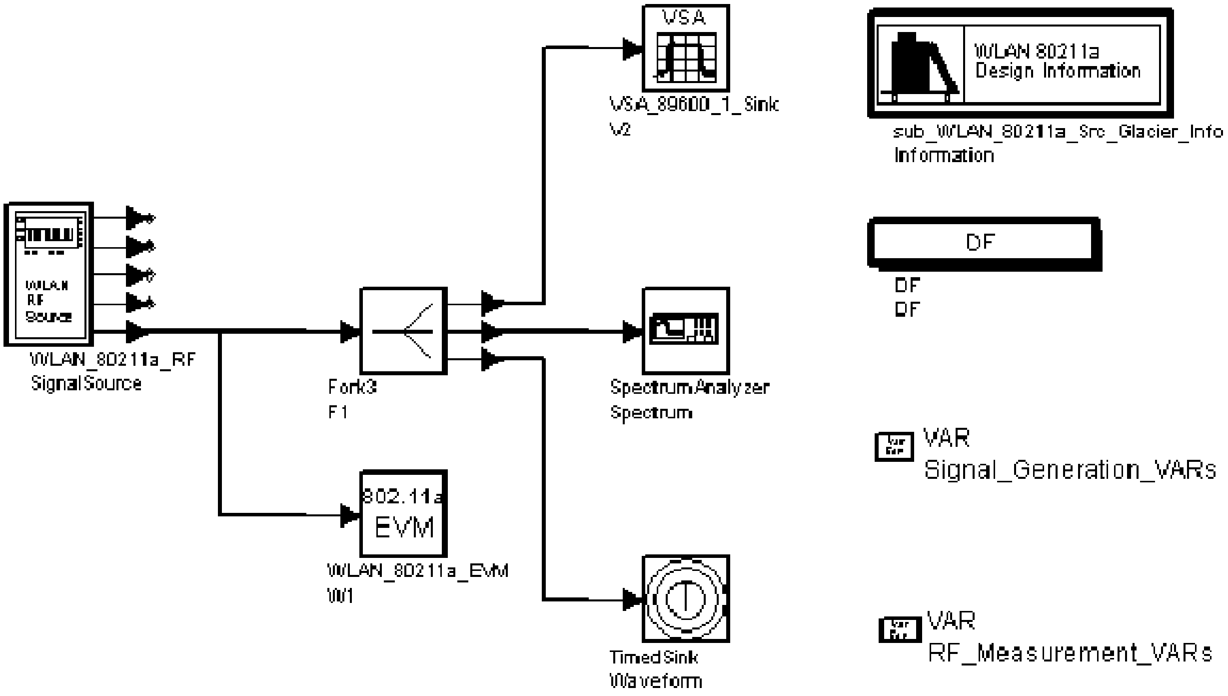
WLAN_80211a_Src_Glacier

Features

- Configurable signal source sub-network model
- Various data rates can be simulated by setting the Rate variable in the schematic
- Sampling rate (T, T/2, T/4, T/8, and so on) is controlled by setting the Order variable in the schematic
- The Idle between two consecutive bursts can be set by the Idle variable in the schematic

Description

This design is an example of WLAN signal source at various data rates with idle between two consecutive bursts and co-simulation with Agilent VSA89600.
The top-level schematic for this design is shown in the following figure. Parameters that can be user-modified are contained in VAR Signal_Generation_VARs.



WLAN_80211a_Src_Glacier Schematic

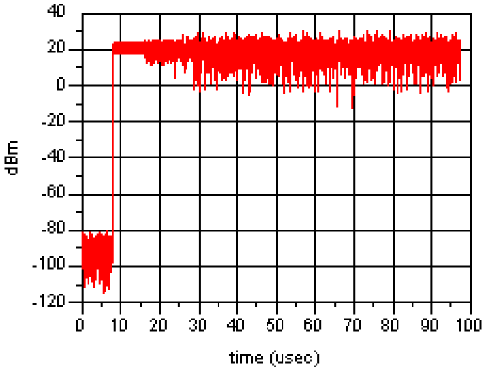
The modulation mode is rate related, which is controlled by the Rate variable. The following table shows the modulation mode with various data rates.

Rate Dependent Parameters

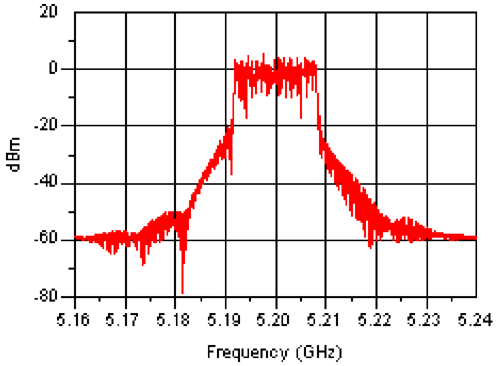
Rate	Data Rate (Mbps)	Modulation
0	6	BPSK
1	9	BPSK
2	12	QPSK
3	18	QPSK
4	24	16-QAM
5	27	16-QAM
6	36	16-QAM
7	48	64-QAM
8	54	64-QAM

Simulation Results

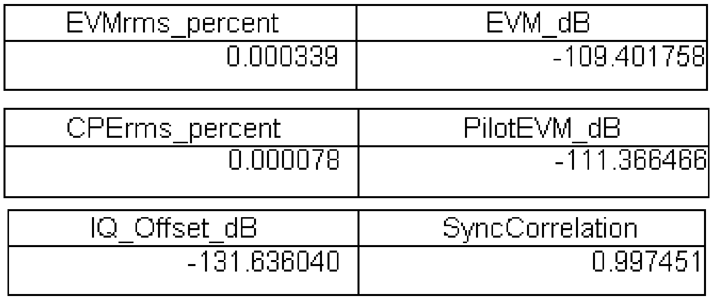
Simulation results displayed in WLAN_80211a_Src_Glacier.dds are shown in the following three figures.



Time Waveform of One Burst with Idle



Transmit Spectrum



EVMrms_percent	EVM_dB
0.000339	-109.401758

CPErms_percent	PilotEVM_dB
0.000078	-111.366466

IQ_Offset_dB	SyncCorrelation
-131.636040	0.997451

EVM, CPE, and IQ_Offset

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 1 minute

References

1. IEEE Std 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Transmit Spectrum Mask Measurement

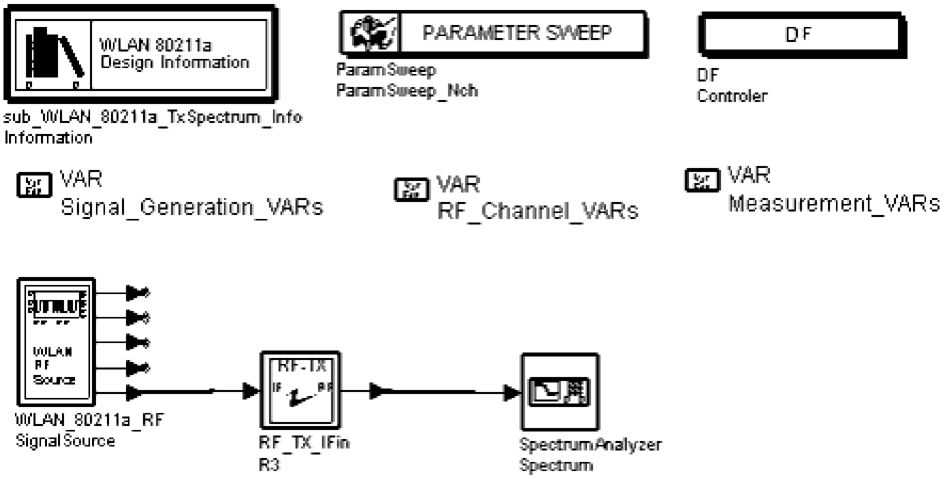
WLAN_80211a_TxSpectrum

Features

- IEEE 802.11a configurable signal source, adjustable data rate
- Adjustable sample rate
- Spectrum analysis
- Integrated RF section

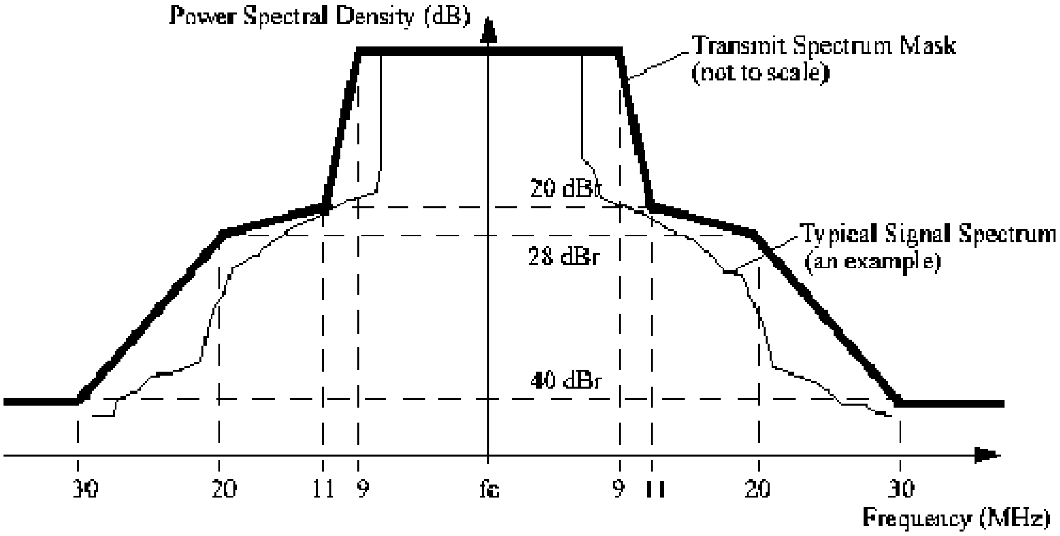
Description

This design demonstrates the IEEE 802.11a transmitter signal spectrum due to modulation and wideband noise.
The schematic for this design is shown in the following figure.



WLAN_80211a_TxSpectrum Schematic

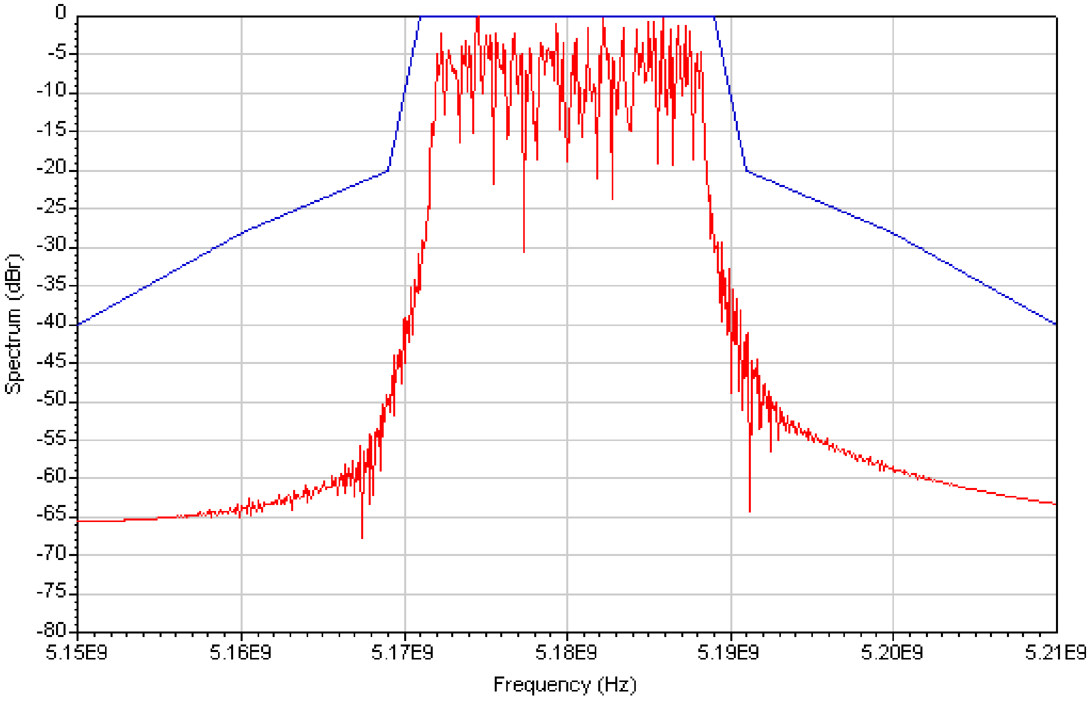
Measurements in this design are based on IEEE Standard 802.11a-1999 section 17.3.9.2. The transmitted spectrum must have a 0 dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 18 MHz, -20 dBr at 11 MHz frequency offset, -28 dBr at 20 MHz frequency offset, and -40 dBr at 30 MHz frequency offset and above. The transmitted spectral density of the transmitted signal must fall within the spectral mask, as shown in the following figure.



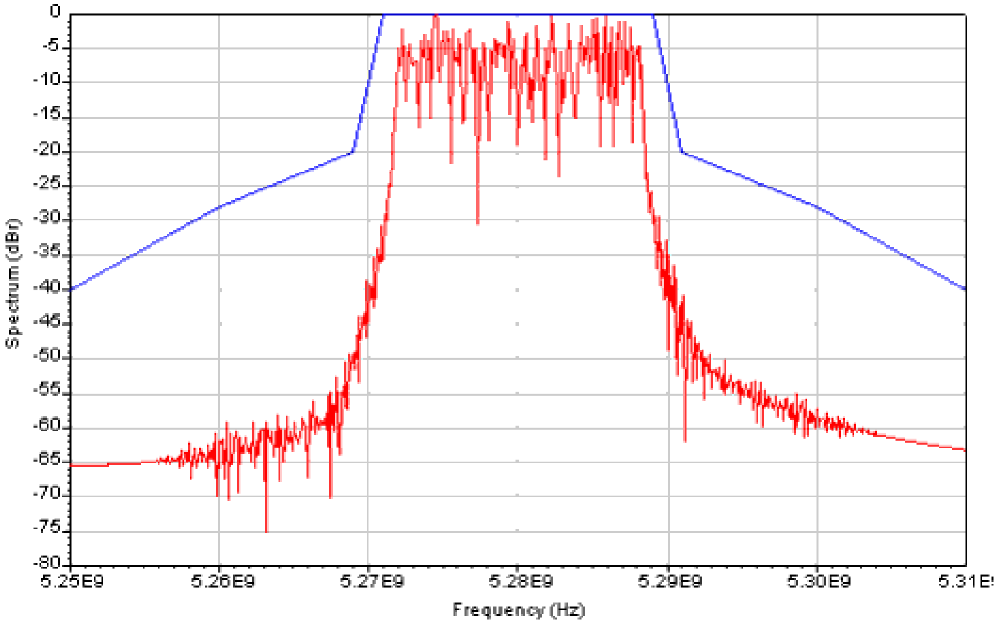
Transmit Spectrum Mask

Simulation Results

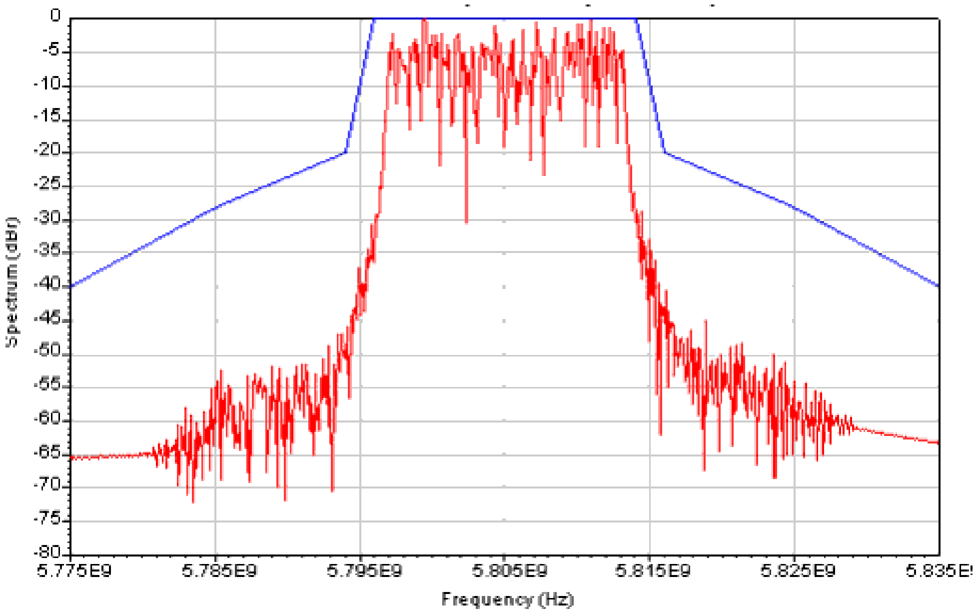
Simulation results displayed in WLAN_80211a_TxSpectrum.dds are shown in the following three figures for 5180 MHz (36 operating channels), 5280 MHz (56 operating channels), and 5805 MHz (161 operating channels) frequencies.



Transmit RF Spectrum, 5180 MHz



Transmit RF Spectrum, 5280 MHz



Transmit RF Spectrum, 5805 MHz

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 1 minute

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Error Vector Magnitude and Relative Constellation Error Measurements

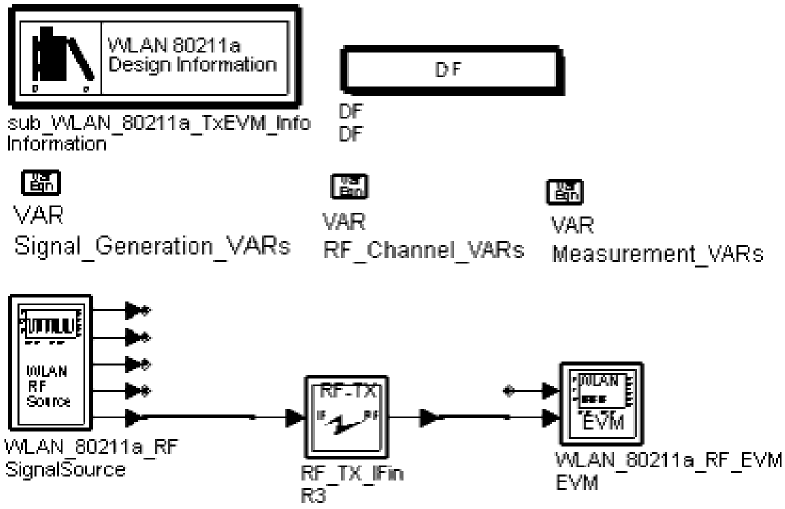
WLAN_80211a_TxEVM

Features

- IEEE 802.11a configurable signal source, adjustable data rate
- Adjustable sample rate
- Constellation display
- Integrated RF section

Description

This design tests IEEE 802.11a transmit modulation accuracy and transmitter constellation error by measuring the EVM. The schematic for this design is shown in the following figure.



WLAN_80211a_TxEVM Schematic

Measurements in this design are based on IEEE Standard 802.11a-1999 section 17.3.9.6. The transmit modulation accuracy test must be performed by instrumentation capable of converting the transmitted signal into a stream of complex samples at 20 Msamples per second or more, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, dc offsets, phase noise, and so on. A possible embodiment of such a setup is converting the signal to a low IF frequency with a microwave synthesizer, sampling the signal with a digital oscilloscope and decomposing it digitally into quadrature components. The sampled signal must be processed in a manner similar to an actual receiver, according to the following, or equivalent steps:

- Start of frame must be detected.
- Transition from short sequences to channel estimation sequences must be detected, and fine timing (with one sample resolution) must be established.
- Coarse and fine frequency offsets must be estimated.
- The packet must be de-rotated according to estimated frequency offset.
- The complex channel response coefficients must be estimated for each subcarrier.
- For each data OFDM symbol: transform the symbol into subcarrier received values, estimate the phase from the pilot subcarriers, de-rotate the subcarrier values according to estimated phase, and divide each subcarrier value with a complex estimated channel response coefficient.
- For each data-carrying subcarrier, find the closest constellation point and calculate the Euclidean distance from it.
- Calculate the RMS average of all errors in a packet:

$$Error_{RMS} = \frac{\displaystyle\sum_{i=1}^{N_f} \sqrt{\frac{\displaystyle\sum_{j=1} \left[\sum_{k=1} \{ (I(i,j,k) - I_0(i,j,k))^2 + (Q(i,j,k) - Q_0(i,j,k))^2 \} \right]}{52 L_P \times P_0}}}{N_f}$$

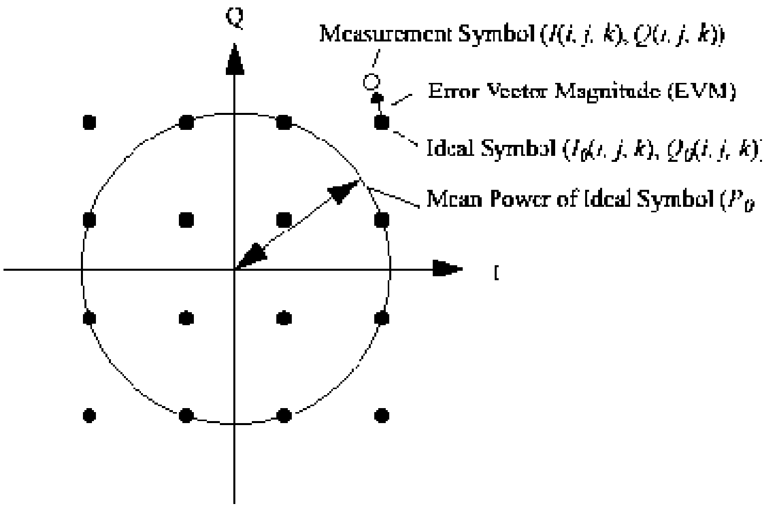
where
L_P is the length of the packet

N_f is the number of frames for the measurement

(I_0 (*i, j, k*), Q_0(*i, j, k*)) denotes the ideal symbol point of the *i* th frame, *j* th OFDM symbol of the frame, *k* th subcarrier of the OFDM symbol in the complex plane
(*I* (*i, j, k*), *Q* (*i, j, k*)) denotes the observed point of the ith frame, jth OFDM symbol of the frame, *k* th subcarrier of the OFDM symbol in the complex plane (see the following figure)
P_0 is the average power of the constellation.

The vector error on a phase plane is shown in the following figure.

The test must be performed over at least 20 frames (N_f) and the RMS average must be taken. The packets under test must be at least 16 OFDM symbols long. Random data must be used for the symbols.



Constellation Error

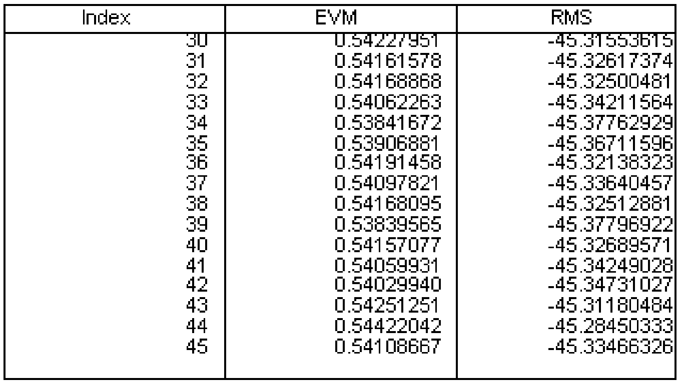
The EVM and relative constellation RMS error, averaged over subcarriers, OFDM frames, and packets, cannot exceed a data-rate dependent value according to the following table.

Allowed EVM and Relative Constellation Error

Data Rate (Mbps)	Relative Constellation Error (dB)	EVM (% RMS)
6	-5	56.2
9	-8	39.8
12	-10	31.6
18	-13	22.3
24	-16	15.8
36	-19	11.2
48	-22	7.9
54	-25	5.6

Simulation Results

Simulation results displayed in WLAN_80211a_TxEVM.dds are shown in the following figure for EVM and relative constellation error of 54 Mbps. The EVM is less than 0.6%; the constellation error is approximately -45dB which is much smaller than the specification requirements given in the preceding table.



Index	EVM	RMS
30	0.54227951	-45.31553615
31	0.54161578	-45.32617374
32	0.54168868	-45.32500481
33	0.54062263	-45.34211564
34	0.53841672	-45.37762929
35	0.53906881	-45.36711596
36	0.54191458	-45.32138323
37	0.54097821	-45.33640457
38	0.54168095	-45.32512881
39	0.53839565	-45.37796922
40	0.54157077	-45.32689571
41	0.54059931	-45.34249028
42	0.54029940	-45.34731027
43	0.54251251	-45.31180484
44	0.54422042	-45.28450333
45	0.54108667	-45.33466326

EVM and Relative Constellation Error of 54 Mbps

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2001
- Simulation time: approximately 30 minutes

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

80211a Receiver

Introduction

WLAN_80211a_Rx_wrk Workspace for IEEE 802.11a receiver test and verification design examples are described in this section.

- WLAN_80211a_RxSensitivity_6Mbps minimum receiver sensitivity measurement of data rate 6 Mbps.
- WLAN_80211a_RxSensitivity_24Mbps minimum receiver sensitivity measurement of data rate 24 Mbps.
- WLAN_80211a_RxSensitivity_54Mbps minimum receiver sensitivity measurement of data rate 54 Mbps.
- WLAN_80211a_RxAdjCh_9Mbps adjacent channel rejection measurement of data rate 9 Mbps.
- WLAN_80211a_RxAdjCh_18Mbps adjacent channel rejection measurement of data rate 18 Mbps.
- WLAN_80211a_RxAdjCh_36Mbps adjacent channel rejection measurement of data rate 36 Mbps.
- WLAN_80211a_RxNonAdjCh_12Mbps non-adjacent channel rejection measurement of data rate 12 Mbps.
- WLAN_80211a_RxNonAdjCh_48Mbps non-adjacent channel rejection measurement of data rate 48 Mbps.

Specification requirements

Receiver performance requirements are listed in the following table.

Receiver Requirements

Data Rate (Mbps)	Minimum Sensitivity (dBm)	Adjacent Channel Rejection (dB)	Alternate Adjacent Channel Rejection (dB)
6	-82	16	32
9	-81	15	31
12	-79	13	29
18	-77	11	27
24	-74	8	24
36	-70	4	20
48	-66	0	16
54	-65	-1	15

Receiver Minimum Input Level Sensitivity Measurement at 6 Mbps

WLAN_80211a_RxSensitivity_6Mbps

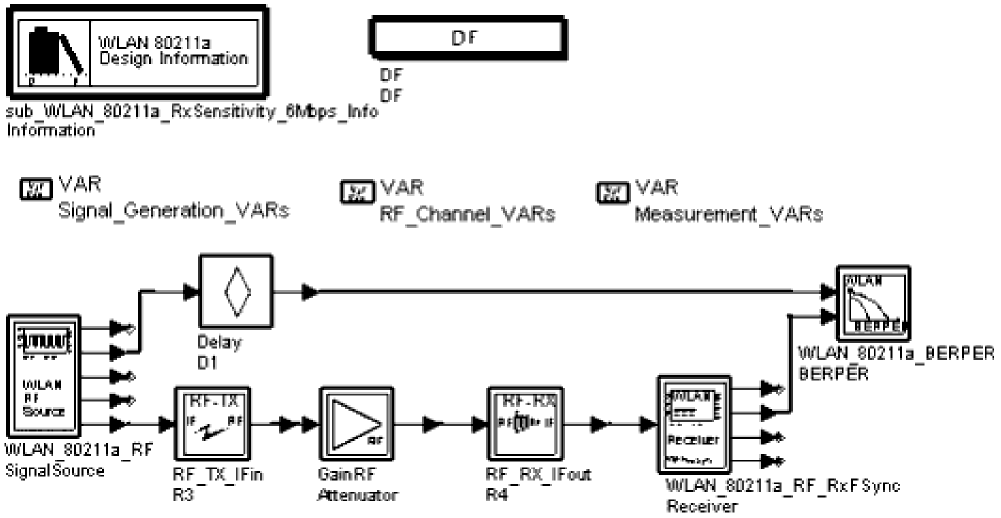
Features

- BPSK mapping
- Coding rate is 1/2
- Data rate is 6 Mbps
- NF is 10 dB

Description

This design is an example of WLAN receiver minimum input level sensitivity measurement at a data rate of 6 Mbps. According to specification [1] 17.3.10.1, the packet error rate (PER) must be less than 10% at a PSDU length of 1000 bytes and rate-dependent input levels (or less) according Table 91. The minimum input levels are measured at the antenna connector (NF of 10 dB and 5 dB implementation margins are assumed). For data rate of 6 Mbps, the value is -82 dBm.

The schematic for this design is shown in the following figure. Parameters that can be changed by users are contained in Signal_Generation_VARs, RF_Channel_VARs, and Measurement_VARs.



WLAN_80211a_RxSensitivity_6Mbps Schematic

Simulation Results

Simulation results displayed in WLAN_80211a_RxSensitivity.dds are shown in the following figure. BER and PER at given input levels are simulated.

Index	BER	PER
200	0.000	0.00

WLAN_80211a_RxSensitivity.dds

Benchmark

- Hardware platform: Pentium II 400 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 8 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Receiver Minimum Input Level Sensitivity Measurement at 24 Mbps

WLAN_80211a_RxSensitivity_24Mbps

Features

- 16-QAM mapping
- Coding rate is 1/2
- Data rate is 24 Mbps
- NF is 10 dB

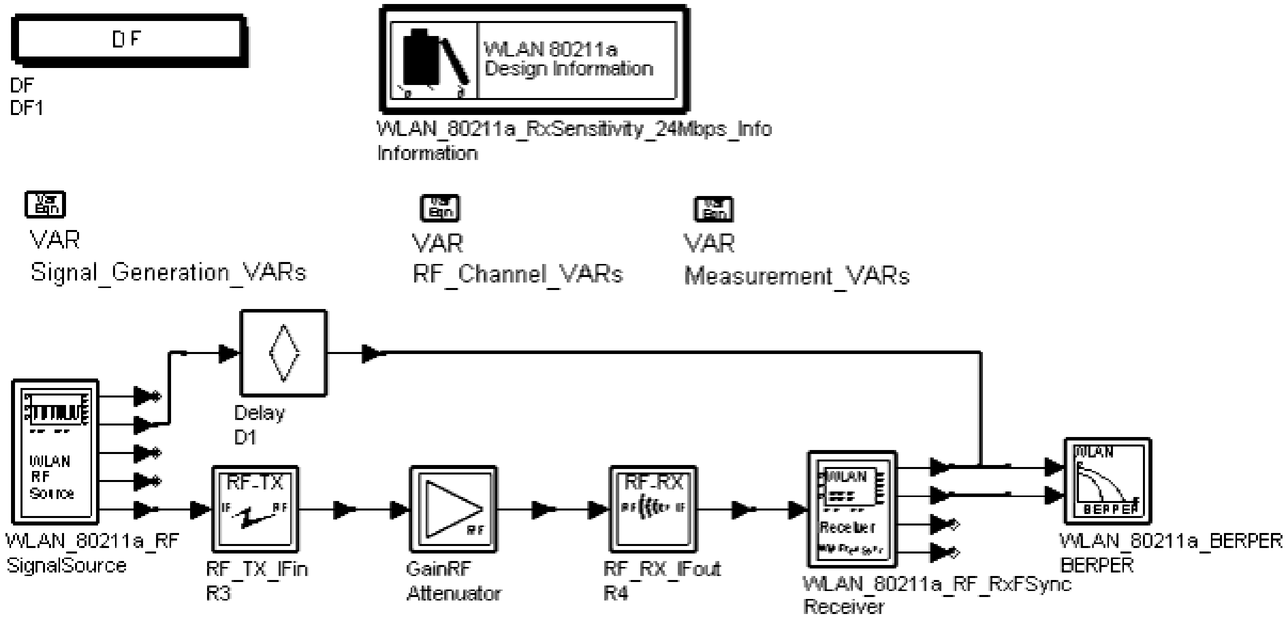
Description

This design is an example of WLAN receiver minimum input level sensitivity measurement at a data rate of 24 Mbps.
According to specification [1] 17.3.10.1: the packet error rate (PER) must be less than 10% at a PSDU length of 1000 bytes; for rate-dependent input, levels must be according to Table 91 (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 of 24 Mbps, the value is -74 dBm.

The RF signal is generated in two stages: first, to modulate a baseband signal to IF;

second, to up-convert an IF signal to an RF signal. The first stage is implemented by subnetwork WLAN_80211a_RF. RF_Tx_Ifin is used to upconvert the IF signal to an RF signal. In the receiver, the RF signal is downconverted to IF frequency; then, an IF signal is demodulated in WLAN_80211a_RF_RxFSync.

The schematic for this design is shown in the following figure.



WLAN_80211a_RxSensitivity_24Mbps

In the schematic, Signal_Generation_VARs defines key transmitter variables, and RF_Channel_VARs defines key variables for up- and down-conversion.

Rate, Length, Order and Idle are used to define a baseband burst. Users can change Rate from 0 to 8 to perform sensitivity tests for 6, 9, 12, 18, 24, 27, 36, 48, and 54 Mbps data rates, respectively. SignalPower determines the transmitted power for an IF transmitter. VRef is the reference voltage for output power calibration. IF_BW is set to 20MHz for 802.11a systems.

There are seven key variables: IF_Freq1, IF_Freq2, RF_Freq, RF_BW, Tx_Gain and Prx in RF_Channel_VARs. IF_Freq1 and IF_Freq2 are two IF frequency. RF_Freq means center frequency of IEEE 802.11a system in simulation system. RF_BW is set to 20MHz for 802.11a systems. Prx denotes 802.11a receiver power. Power=dbmtow(SignalPower-Tx_Gain) in the WLAN_80211a_RF signal source component and TX_Gain=Tx_Gain in the RF_TX_IFin component. So, the total transmitted power is the Signal_Generation_VARs SignalPower setting after up-conversion. Table 89 in the specification defines the maximum allowable output power for different frequency bands:

- SignalPower=16 dBm (40 mW) if RF_Freq is 5.15-5.25GHz
- SignalPower=23 dBm (200 mW) if RF_Freq is 5.25-5.35GHz
- SignalPower=29 dBm (800 mW) if RF_Freq is 5.725-5.825GHz.

Users can set SignalPower and RF_Freq as needed.

The GainRF attenuator subnetwork's Gain parameter is set as dbpolar(Prx-SignalPower,0). After GainRF, the power of 802.11a is Prx-SignalPower+Tx_Gain+SignalPower-Tx_Gain=Prx. In the specification, NF of 10 and 5dB implementation margins are assumed. So, Rx_NF=10 in RF_RX_IFout.

The RF_RX_IFout subnetwork's RX_AntTemp is the receiving antenna noise temperature (in Kelvin). RX_AntTemp=20+273.15 means the test is performed in an office environment; users can change the temperature setting. Moreover, RX_Gain in RF_RX_IFout varies with the Order parameter and the relation is described by equation 82-6*(Order-6).

The following table lists minimum sensitivity performance according to data rate in the 802.11a specification. Users can sweep Prx, run the design and observe the PER. If the Prx is less than the value in the table when PER is less than 10%, the sensitivity measurement passes.

Minimum Sensitivity Performance

Data Rate (Mbps)	Minimum Sensitivity (dBm)
6	-82
9	-81
12	-79
18	-77
24	-74
36	-70
48	-66
54	-65

Simulation Results

Simulation results displayed in WLAN_80211a_RxSensitivity.dds are shown in the following figure. BER and PER at different input levels are simulated.

Index	BER	PER
200	0.000	0.000

WLAN_80211a_RxSensitivity.dds

Benchmark

- Hardware platform: Pentium II 400 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 3 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Receiver Minimum Input Level Sensitivity Measurement at 54 Mbps

WLAN_80211a_RxSensitivity_54Mbps

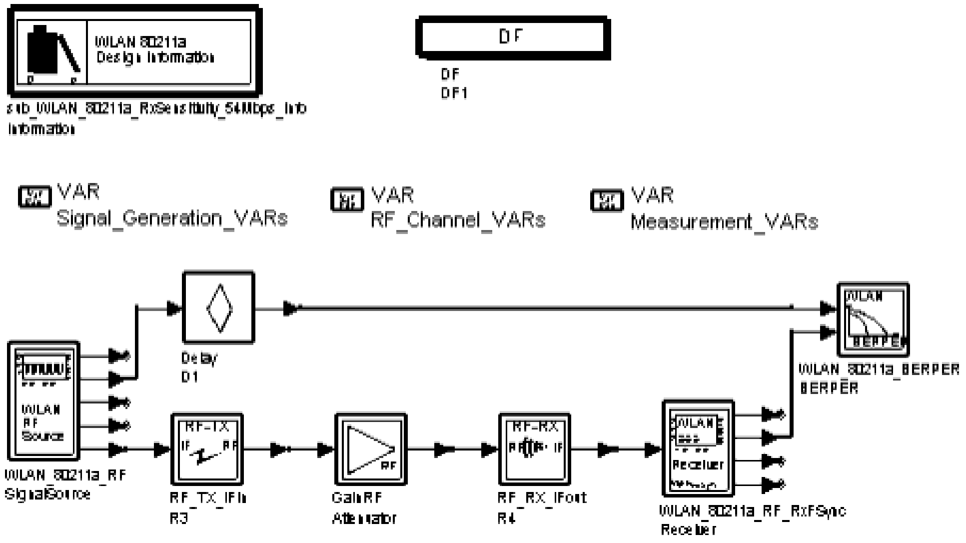
Features

- 64-QAM mapping
- Coding rate is 3/4
- Data rate is 54 Mbps
- NF is 10 dB

Description

This design is an example of WLAN receiver minimum input level sensitivity measurement at data rate of 54 Mbps. According to specification [1] 17.3.10.1, the packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels shall be the numbers listed in Table 91 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 of 54 Mbps, the value is -65 dBm.

The schematic for this design is shown in the following figure. Parameters that can be changed by users are contained in Signal_Generation_VARs, RF_Channel_VARs, and Measurement_VARs.



WLAN_80211a_RxSensitivity_54Mbps

Simulation Results

Simulation results displayed in WLAN_80211a_RxSensitivity.dds are shown in the following figure. BER and PER at different input levels are simulated.

Index	BER	PER
200	0.000	0.000

WLAN_80211a_RxSensitivity.dds

Benchmark

- Hardware platform: Pentium II 400 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 2 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Adjacent Channel Rejection Measurement at 9 Mbps

WLAN_80211a_RxAdjCh_9Mbps

Features

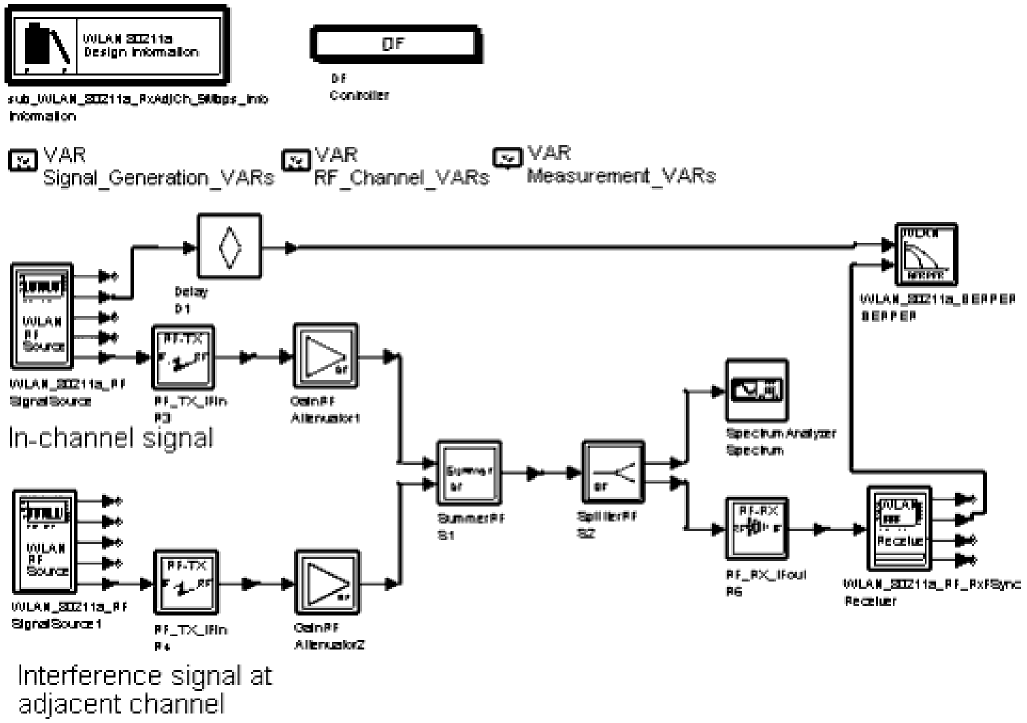
- PSDU length of 1000 bytes
- NF set to 10 dB (upper limit of implementation margins assumed in specification)
- 200 frames simulated to test PER
- Data rate of interfering signal is 24 Mbps with PSDU length of 256 and 20 MHz apart from the desired signal

Description

The adjacent channel rejection shall be measured by setting the desired signal's strength 3 dB above the rate-dependent sensitivity as specified in Table 91 of IEEE Standard. 802.11a-1999 and raising the power of the interfering signal until the 10% packet error rate (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 conforming OFDM PHY signal, unsynchronized with the signal in the channel under test. For a conforming OFDM PHY the corresponding rejection shall be no less than specified in Table 91 of IEEE Standard. 802.11a-1999.

In this design, the adjacent channel rejection of data rate 9 Mbps is measured; The power of interfering signal is raised to the rate-dependent adjacent channel rejection 15 dB as specified in Table 91 of IEEE Standard. 802.11a-1999, then a PER less than 10% shall be achieved.

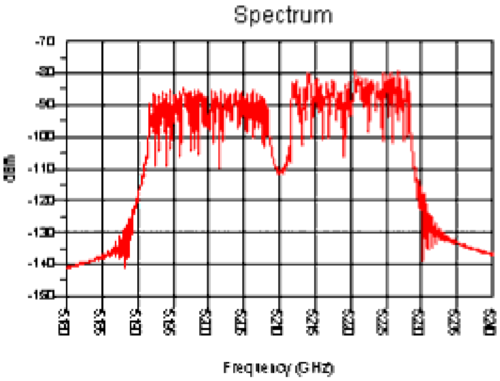
The top-level schematic for this design is shown in the following figure.

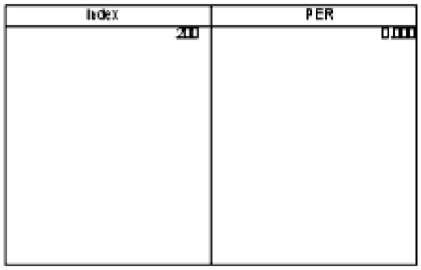


WLAN_80211a_RxAdjCh_9Mbps Schematic

Simulation Results

Simulation results are shown in the following figure.





Index	PER
200	0.000

Simulation Results

The simulation results show that when the adjacent channel rejection value (ACR) is set to 15 dB according to the table of specification requirements, the PER is 0.000 which is much lower than 10%, so this system is consistent with the requirements of adjacent channel rejection of the IEEE Standard. 802.11a-1999.

Benchmark

- Hardware platform: Pentium III 800 MHz, 512 Mb memory
- Software platform: Windows NT, ADS 2002
- Simulation time: approximately 7 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Adjacent Channel Rejection Measurement at 18 Mbps

WLAN_80211a_RxAdjCh_18Mbps

Features

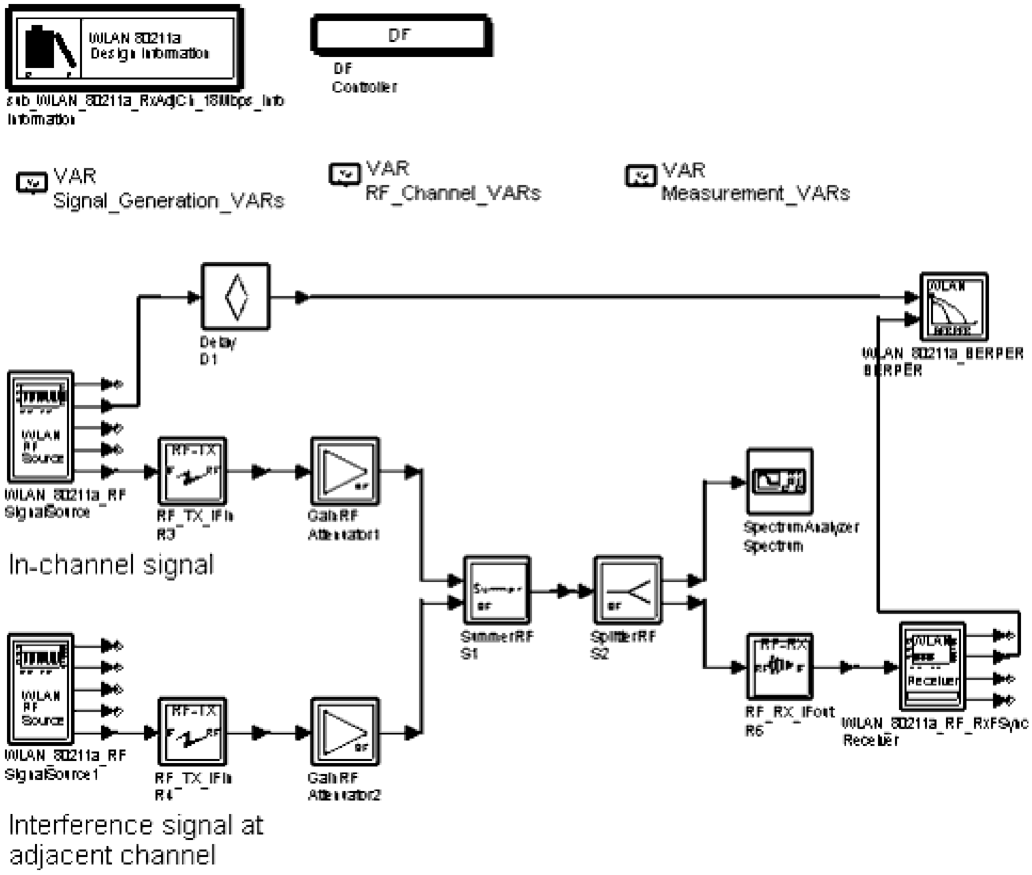
- PSDU length of 1000 bytes
- NF is set to 10 dB (the upper limit of implementation margins as assumed in specification)
- 200 frames simulated to test PER
- Data rate of interfering signal is 24 Mbps with PSDU length of 256 and 20 MHz apart from desired signal

Description

The adjacent channel rejection shall be measured by setting the desired signal's strength 3dB above the rate-dependent sensitivity as specified in Table 91 of IEEE Standard. 802.11a-1999 and raising the power of the interfering signal until the 10% packet error rate (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 conforming OFDM PHY signal, unsynchronized with the signal in the channel under test. For a conforming OFDM PHY the corresponding rejection shall be no less than specified in Table 91 of IEEE Standard. 802.11a-1999.

In this design, the adjacent channel rejection of data rate 18 Mbps is measured; The power of interfering signal is raised to the rate-dependent adjacent channel rejection 11dB as specified in Table 91 of IEEE Standard. 802.11a-1999, then a PER less than 10% shall be achieved.

The top-level schematic for this design is shown in the following figure.

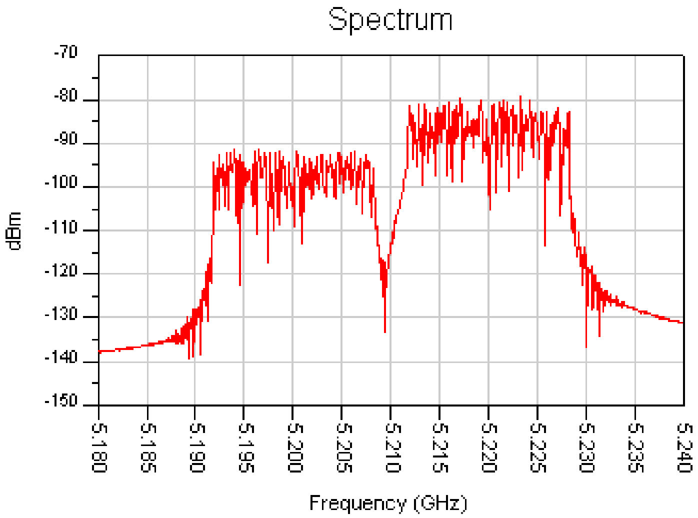


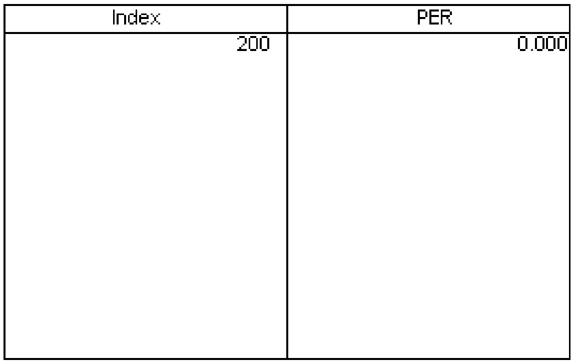
WLAN_80211a_RxAdjCh_18Mbps Schematic

Simulation Results

Simulation Results

Simulation results are shown in the following figure.





Index	PER
200	0.000

Simulation Results

The simulation results show that when the adjacent channel rejection value (ACR) is set to 11 dB according to the table of specification requirements, the PER is 0.000 which is much lower than 10%, so this system is consistent with the requirements of adjacent channel rejection of the IEEE Standard. 802.11a-1999.

Benchmark

- Hardware platform: Pentium III 800 MHz, 512 Mb memory
- Software platform: Windows NT, ADS 2002
- Simulation time: approximately 3 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Adjacent Channel Rejection Measurement at 36 Mbps

WLAN_80211a_RxAdjCh_36Mbps

Features

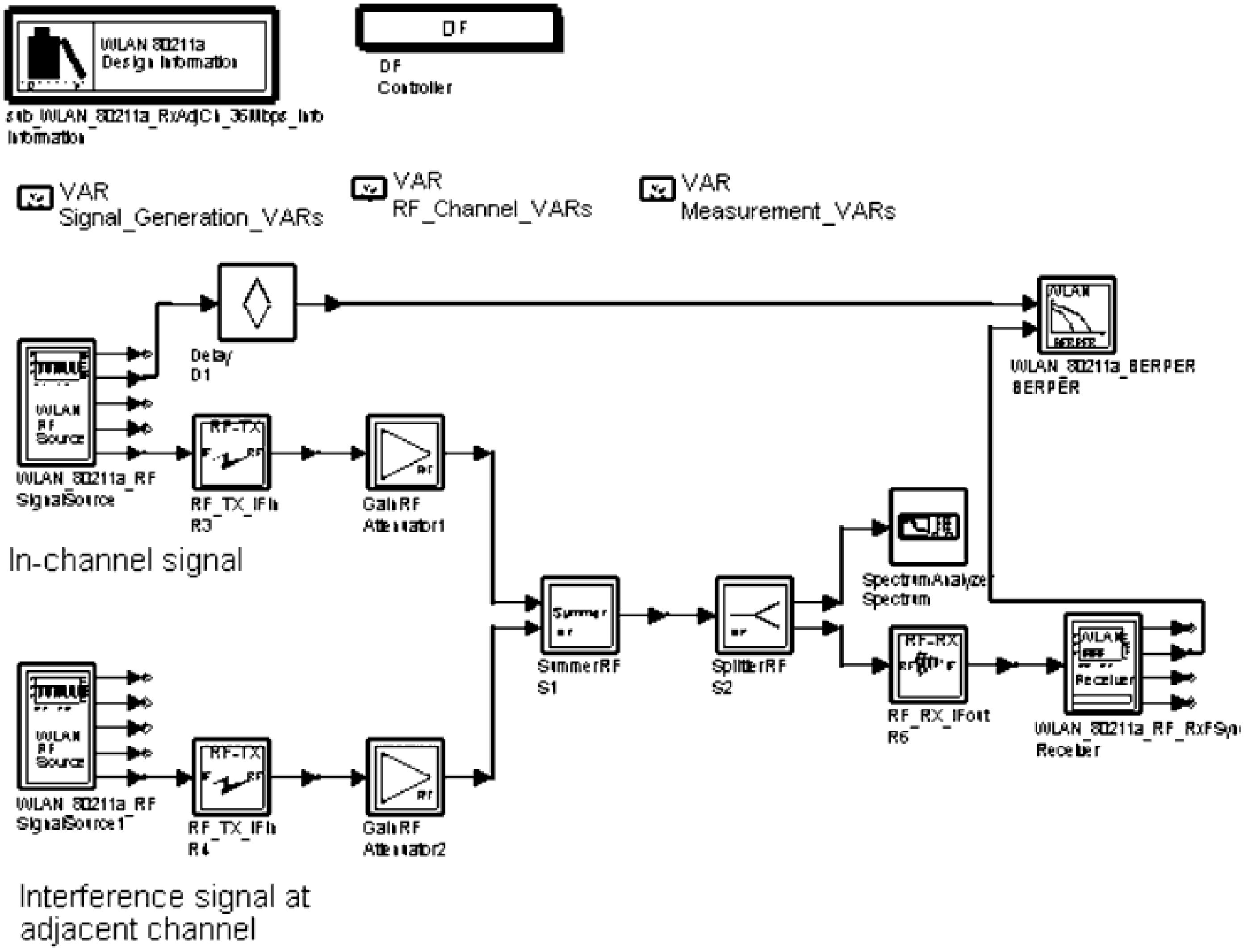
- PSDU length of 1000 bytes
- NF is set to 10 dB (upper limit of implementation margins assumed in specification)
- 200 frames simulated to test PER
- Data rate of interfering signal is 24 Mbps with PSDU length of 256 and 20 MHz apart from desired signal

Description

The adjacent channel rejection shall be measured by setting the desired signal's strength 3dB above the rate-dependent sensitivity as specified in Table 91 of IEEE Standard. 802.11a-1999 and raising the power of the interfering signal until the 10% packet error rate (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 must be a conforming OFDM PHY signal, unsynchronized with the signal in the channel under test. For a conforming OFDM PHY the corresponding rejection cannot be less than specified in Table 91 of IEEE Standard. 802.11a-1999.

In this design, the adjacent channel rejection of data rate 36 Mbps is measured. The power of interfering signal is raised to the rate-dependent adjacent channel rejection 4 dB as specified in Table 91 of IEEE Standard. 802.11a-1999, then a PER less than 10% shall be achieved.

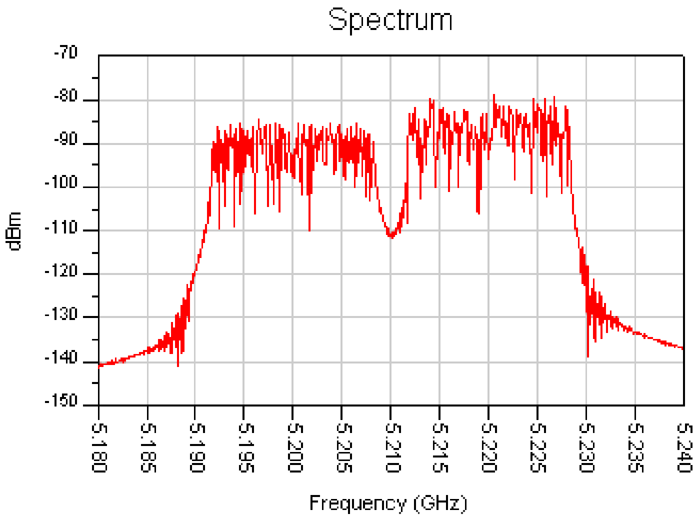
The top-level schematic for this design is shown in the following figure.

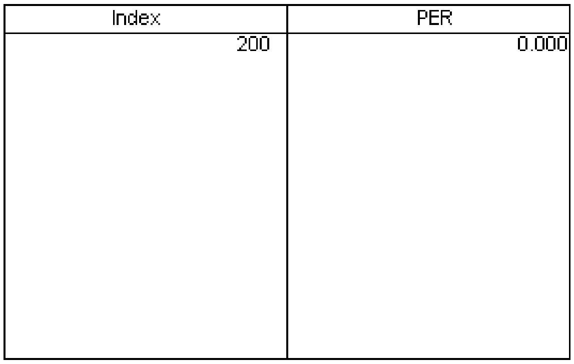


WLAN_80211a_RxAdjCh_36Mbps Schematic

Simulation Results

Simulation results are shown in the following figure.





Index	PER
200	0.000

Simulation Results

The simulation results show that when the adjacent channel rejection value (ACR) is set to 4 dB according to the table of specification requirements, the PER is 0.000 which is much lower than 10%, so this system is consistent with the requirements of adjacent channel rejection of the IEEE Standard. 802.11a-1999.

Benchmark

- Hardware platform: Pentium III 800 MHz, 512 Mb memory
- Software platform: Windows NT, ADS 2002
- Simulation time: approximately 3 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Non-Adjacent Channel Rejection Measurement at 12 Mbps

WLAN_80211a_RxNonAdjCh_12Mbps

Features

- PSDU length of 1000 bytes

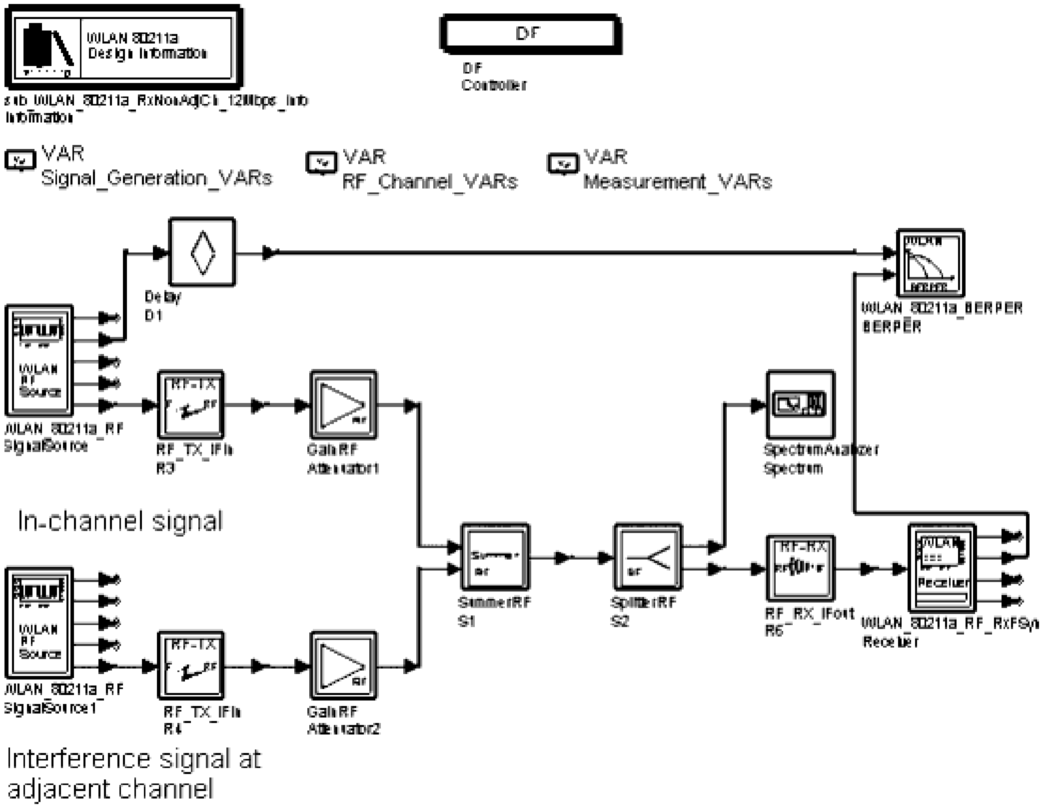
- NF is set to 10 dB (upper limit of implementation margins as assumed in specification)
- 200 frames simulated to test PER
- Data rate of interfering signal is 54 Mbps with PSDU length of 100 and 40 MHz from desired signal

Description

The non-adjacent channel rejection shall be measured by setting the desired signal's strength 3dB above the rate-dependent sensitivity as specified in Table 91 of IEEE Standard. 802.11a-1999 and raising the power of the interfering signal until the 10% packet error rate (PER) is caused for a PSDU length of 1000 bytes. The power difference between the interfering and the desired channel is the corresponding non-adjacent channel rejection. The interfering signal in the non-adjacent channel shall be a conforming OFDM PHY signal, unsynchronized with the signal in the channel under test. For a conforming OFDM PHY the corresponding rejection shall be no less than specified in Table 91 of IEEE Standard. 802.11a-1999.

In this design, the non-adjacent channel rejection of data rate 12 Mbps is measured; The power of interfering signal is raised to the rate-dependent adjacent channel rejection 29 dB as specified in Table 91 of IEEE Standard. 802.11a-1999, then a PER less than 10% shall be achieved.

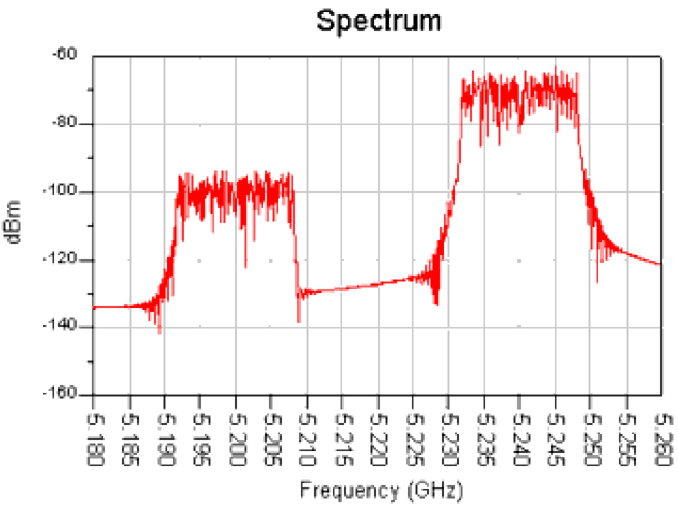
The top-level schematic for this design is shown in the following figure.

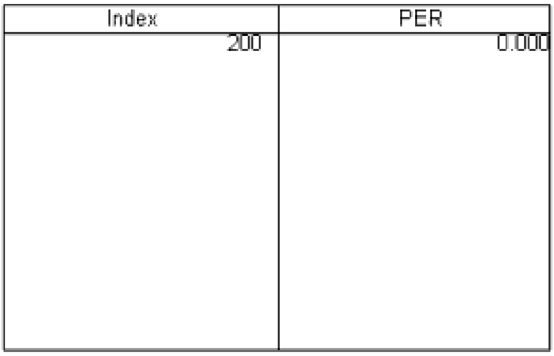


WLAN_80211a_RxNonAdjCh_12Mbps Schematic

Simulation Results

Simulation results are shown in the following figure.





Index	PER
200	0.000

Simulation Results

The simulation results show that when the non-adjacent channel rejection value (NACR) is set to 29 dB according to the table of specification requirements, the PER is 0.000 which is much lower than 10%, so this system is consistent with the requirements of non-adjacent channel rejection of the IEEE Standard. 802.11a-1999.

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 Mb memory
- Software platform: Windows NT 4.0, ADS 2002
- Simulation time: approximately 13 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band,"1999.

Non-Adjacent Channel Rejection Measurement at 48 Mbps

WLAN_80211a_RxNonAdjch_48Mbps

Features

- PSDU length of 1000 bytes
- NF is set to 10 dB (upper limit of implementation margins as assumed in specification)
- 200 frames simulated to test PER
- Data rate of interfering signal is 12 Mbps with PSDU length of 300 and 40 MHz from desired signal

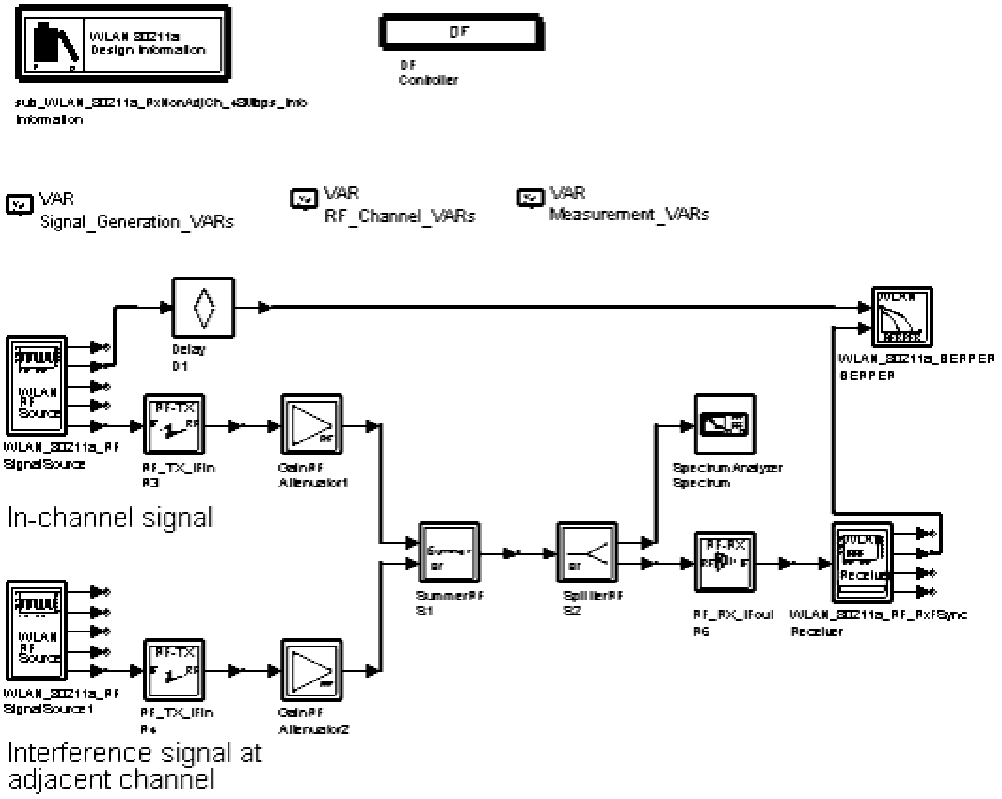
Description

The non-adjacent channel rejection must be measured by setting the desired signal strength 3dB above the rate-dependent sensitivity as specified in IEEE Standard. 802.11a-1999, Table 91, and raising the power of the interfering signal until the 10% packet error rate (PER) is caused for a PSDU length of 1000 bytes. The power difference between the interfering and the desired channel is the corresponding non-adjacent channel rejection.

The interfering signal in the non-adjacent channel must be a conforming OFDM PHY signal, unsynchronized with the signal in the channel under test. For a conforming OFDM PHY the corresponding rejection must not be less than specified in IEEE Standard. 802.11a-1999, Table 91.

In this design, the non-adjacent channel rejection of data rate 48 Mbps is measured. Power of the interfering signal is raised to the rate-dependent adjacent channel rejection 16 dB as specified in IEEE Standard. 802.11a-1999, Table 91, to achieve a PER less than 10%.

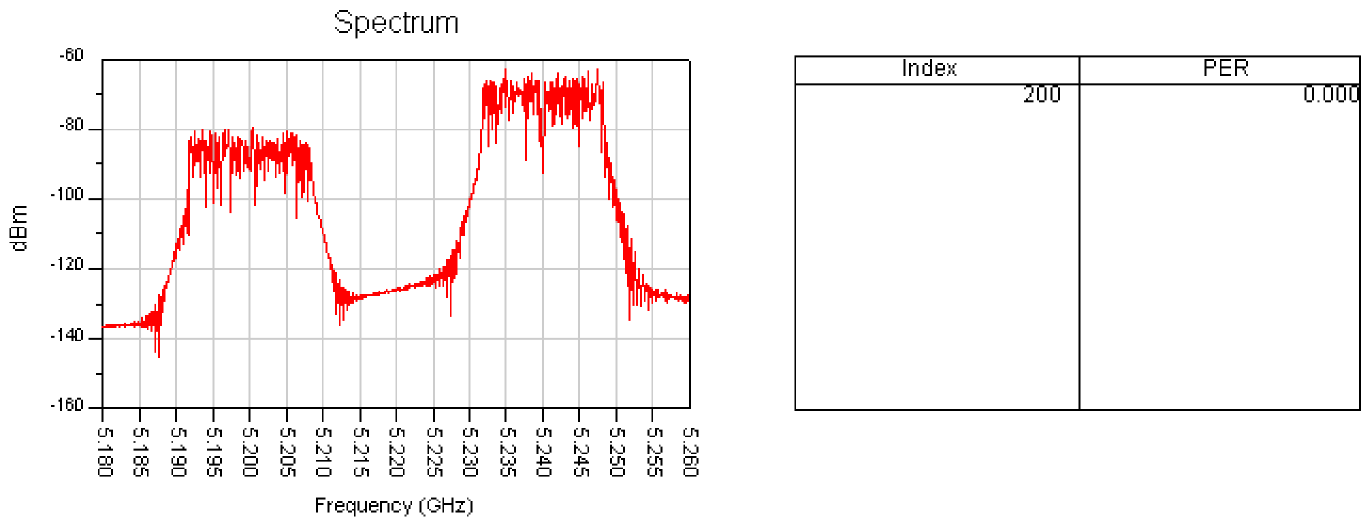
The top-level schematic for this design is shown in the following figure.



WLAN_80211a_RxNonAdjCh_48Mbps Schematic

Simulation Results

Simulation results are shown in the following figure.



Index	PER
200	0.000

Simulation Results

Simulation results show that when the non-adjacent channel rejection value (NACR) is set to 16 dB according to the table of specification requirements, the PER is 0.000 which is much lower than 10%; this system is consistent with the requirements of non-adjacent channel rejection of IEEE Standard. 802.11a-1999.

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 Mb memory
- Software platform: Windows NT 4.0, ADS 2002
- Simulation time: approximately 4 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

80211a BER and PER Performance

Introduction

WLAN_80211a_PER_wrk design examples are described in this section.

- WLAN_80211a_24Mbps_AWGN_System: BER and PER performance for 24 Mbps systems under AWGN channel.
- WLAN_80211a_24Mbps_PN_System: BER and PER performance for 24 Mbps systems under phase noise distortion.
- WLAN_80211a_24Mbps_Fading_System: BER and PER performance for 24 Mbps systems under fading channel.
- WLAN_80211a_36Mbps_AWGN_Perfect: BER performance for 16-QAM modulation with perfect channel estimator under AWGN channel.
- WLAN_80211a_36Mbps_AWGN_System: BER and PER performance for 36 Mbps systems under AWGN channel.
- WLAN_80211a_36Mbps_Fading_System: BER and PER performance for 36 Mbps systems under fading channel.
- WLAN_80211a_48Mbps_AWGN_Perfect: BER performance for 64-QAM modulation with perfect channel estimator under AWGN channel.

When baseband simulation is performed, the signal power per bit can be calculated:

$$E_b = \frac{P_s \times T_{FFT}}{N_{DBPS}} = \frac{P_s \times \frac{FFTSize}{FFTSize + Guard} \times T_{SYM}}{N_{DBPS}}$$

where Ps = received signal power, T_{FFT} = IFFT/FFT period (3.2 μ in IEEE802.11a), T_{SYM} = one OFDM symbol interval (4.0 μ in IEEE802.11a), N_{DBPS} = number of data bits per OFDM symbol (refer to Table 78 in IEEE802.11a specification). The relation between N_{DBPS} and T_{SYM} is

$$R_b = \frac{N_{DBPS}}{T_{SYM}}$$

where R_b = data rate.

E_b can be calculated:

$$E_b = P_s \times \frac{FFTSize}{FFTSize + Guard} \times \frac{1}{R_b}$$

The noise power per bit can be calculated:

$$N_0 = \frac{2 \times \sigma^2}{f_s} = 2 \times \sigma^2 \times T_s$$

where T_s is the sample rate.

So, E_b/N_0 can be calculated:

$$E_b/N_0 = \frac{P_s \times \frac{FFTSize}{FFTSize + Guard} \times \frac{1}{R_b}}{2 \times \sigma^2 \times T_s}$$

And noise variance σ^2 is

$$\sigma^2 = \frac{P_s \times \frac{FFTSize}{FFTSize + Guard} \times \frac{1}{R_b}}{2 \times T_s \times E_b/N_0}$$

When RF simulation is performed, noise density is modeled using the AddNDensity component. According to the defining equation for parameter NDensity:

$$NDensity = 2 \times T_s \times \sigma^2$$

So, in WLAN_80211a_PER_wrk, NDensity can be calculated:

$$NDensity((dBm)/(Hz)) = SignalPower(dBm) + 10 \times \log\left(\frac{FFTSize}{FFTSize + Guard}\right)$$

$$- 10 \times \log(R_b) - (E_b/N_0)(dB)$$

BER and PER Performance, AWGN Channel 24 Mbps WLAN_80211a_24Mbps_AWGN_System

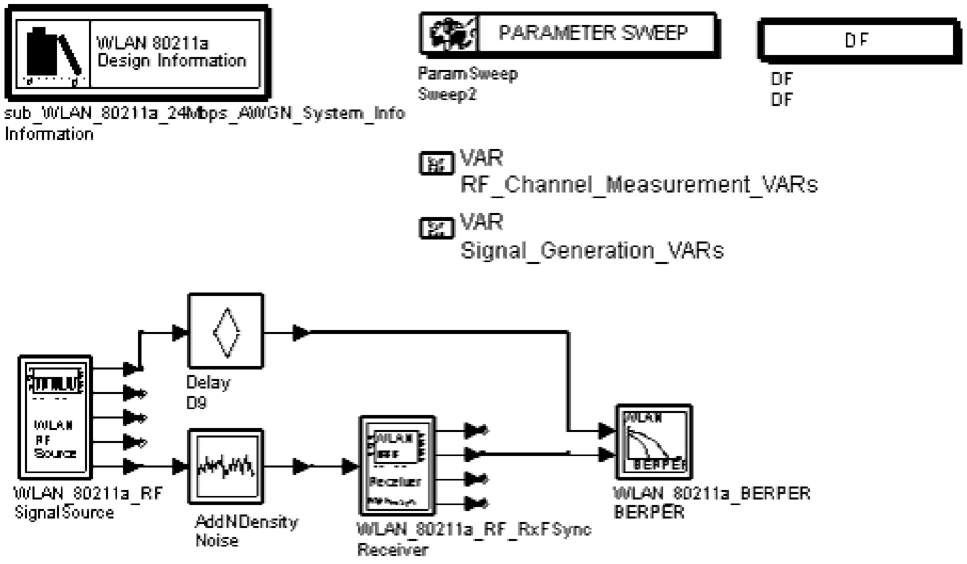
Features

- Data rate = 24Mbps, coding rate = 1/2, modulation = 16-QAM
- Carrier frequency offset between transmitter and receiver is 100 kHz
- BER and PER vs. Eb/N0 under AWGN channel curves displayed

Description

This design shows system performance with 24 Mbps data rate and channel coding under AWGN. A burst length of 1000 bytes is simulated.

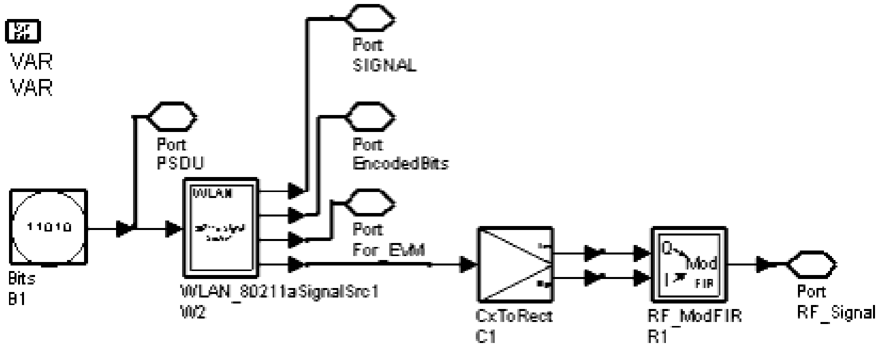
The top-level schematic is shown in the following figure. This design contains four subnetworks named SignalSource, Noise, Receiver, and BERPER.



WLAN_80211a_24Mbps_AWGN_System Schematic

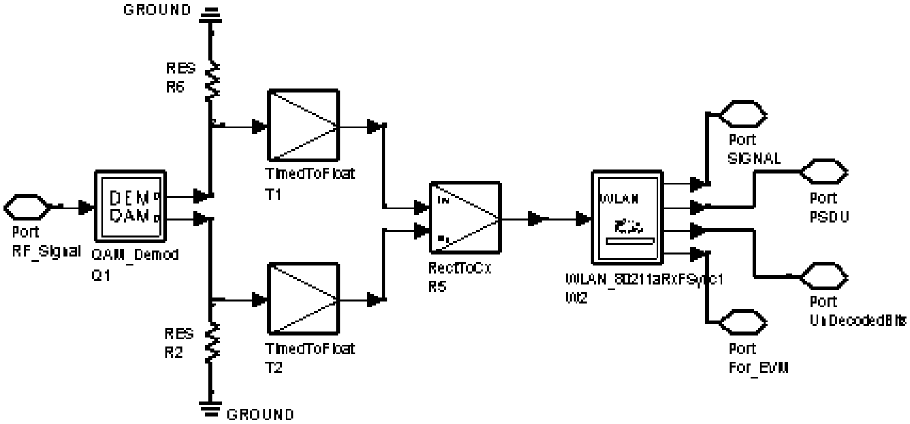
SignalSource parameters are contained in Signal_Generation_VARs; Noise, Receiver, and BERPER parameters are contained in RF_Channel_Measurement_VARs.

The SignalSource subnetwork (see the following figure) generates an IEEE 802.11a signal source based on user settings.



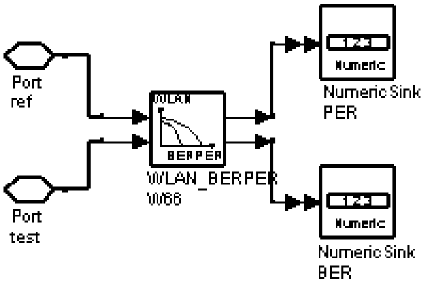
WLAN_80211a_RF Schematic

The Receiver subnetwork (see the following figure) receives an IEEE 802.11a RF signal and demodulates the signal as bits stream; it also detects the start of frame and the transition from short sequences to channel estimation sequences, estimates complex channel response coefficients for each subcarrier, transforms the symbol into subcarrier received values; it performs phase estimation from the pilot subcarrier, subcarrier derotation according to the estimated phase, and division of each subcarrier value with a complex estimated channel response coefficient.



WLAN_80211a_RF_RxFSync Schematic

The BERPER subnetwork (see the following figure) measures system BER and PER.



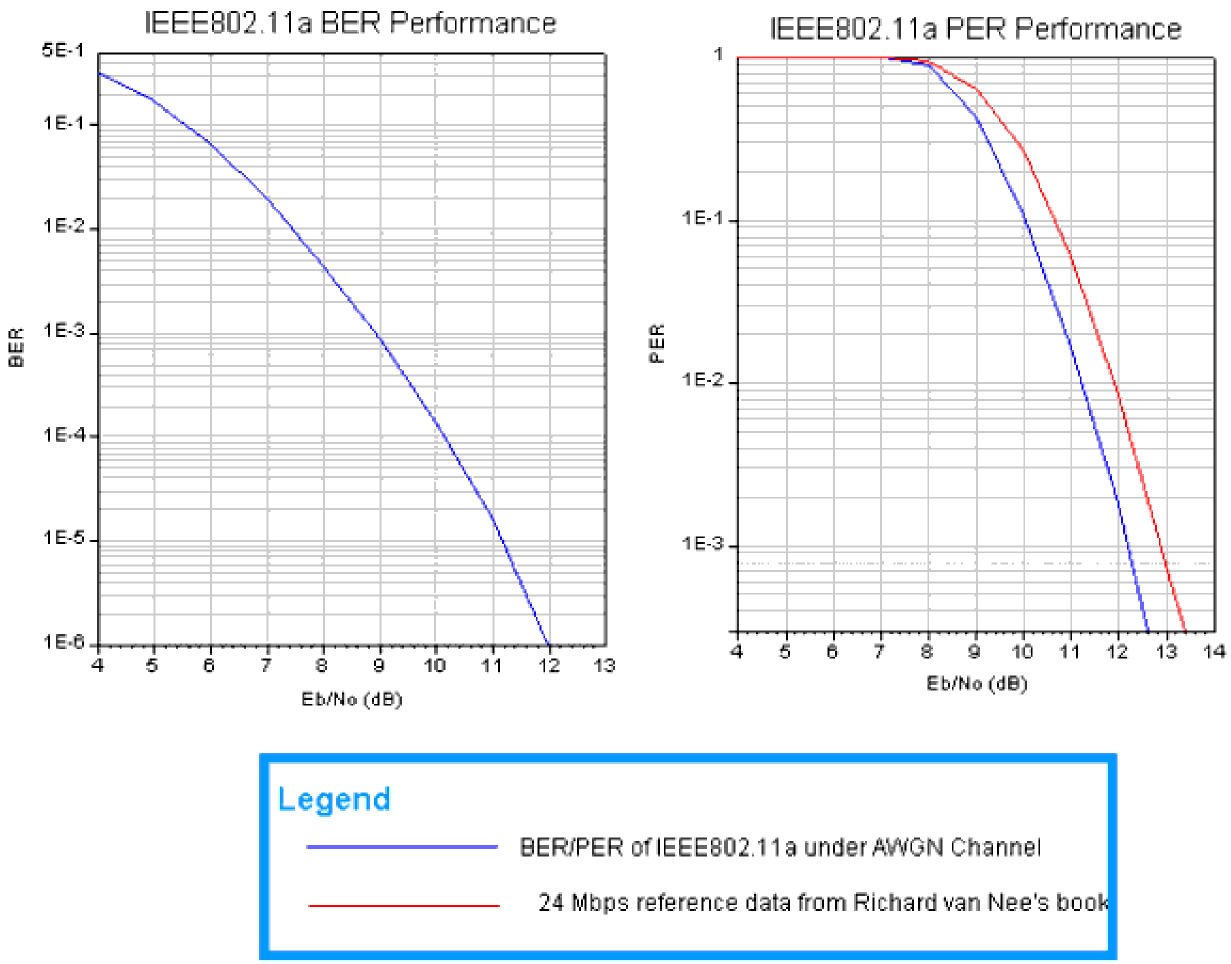
WLAN_80211a_BERPER Schematic

Simulation Results

Simulation results displayed in WLAN_80211a_24Mbps_AWGN_System.dds are shown in the following figure.

For PER performance, it shows that WLAN_80211a_24Mbps_AWGN_System is approximately 0.5 dB better than that of Richard van Nee's text book (page 251 in [2]).

Reference data points are shown in page Equations.



WLAN_80211a_24Mbps_AWGN_System Simulation Results

Benchmark

- Hardware platform: Pentium IV, 1.8 GHz, 512 MB memory
- Software platform: Windows XP, ADS 2002
- Data points: Eb/N0 values is set from 4 to 15 dB
- Simulation time: 10 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. Richard van Nee, Ramjee Prasad, OFDM Wireless Multimedia Communications, Artech House, 2000.

BER and PER Performance, Phase Noise Distortion 24 Mbps

WLAN_80211a_24Mbps_PN_System

Features

- Data rate = 24Mbps, coding rate = 1/2, modulation = 16-QAM
- Phase noise distortion was added in the transmitter by the N_Tones model
- BER and PER vs. E_b/N_0 under phase noise distortion curves displayed

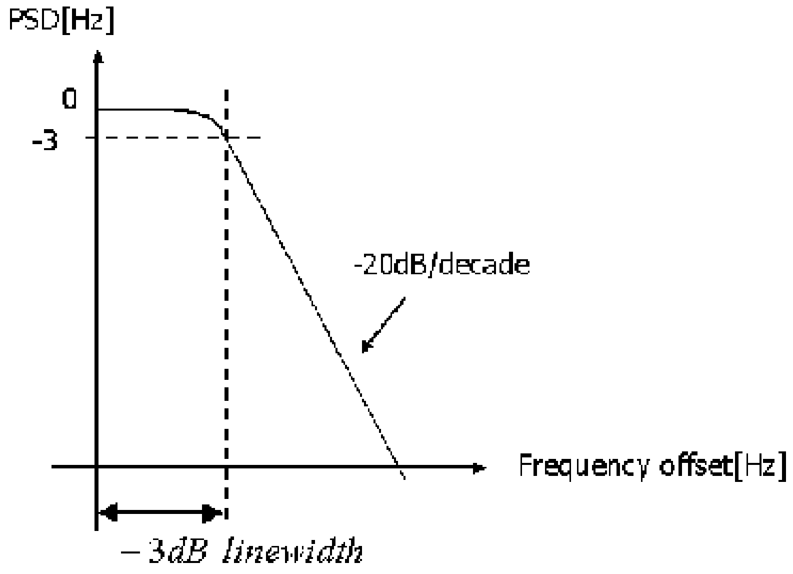
Description

This design demonstrates system performance with 24 Mbps data rate and channel coding under phase noise distortion. A burst length of 128 bytes is simulated.

The power density spectrum of an oscillator signal with phase noise is modeled by a Lorentzian spectrum. The single-sided spectrum S_s (f) is given by

$$S_s(f) = \frac{2/(\pi f_l)}{1+f^2/f_l^2}$$

The following figure illustrates a Lorentzian phase noise spectrum with a single-sided -3 dB line width of the oscillator signal. The slope per decade is -20 dB.

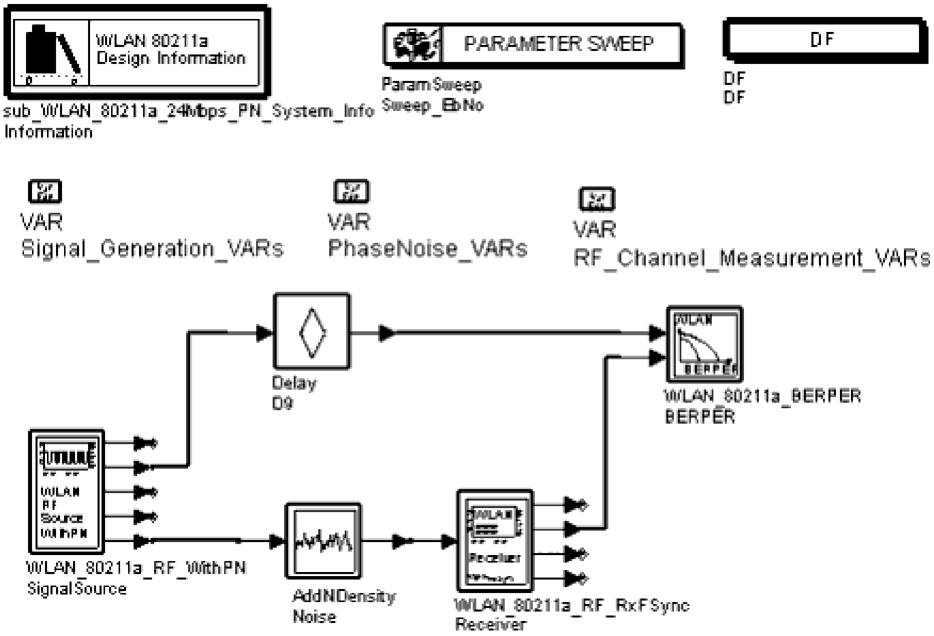


Phase Noise Power Spectral Density (PSD)

In this phase noise distortion test, two cases of phase noise are used to measure

PER/BER. The -3 dB line width of phase noise 1 is 30.0 Hz (=0.01% of subcarrier space of IEEE 802.11a); the -3 dB line width of phase noise 2 is 3.0 Hz (=0.001% of subcarrier space of IEEE 802.11a). And, an Ideal test case (no phase noise) is used as a reference.

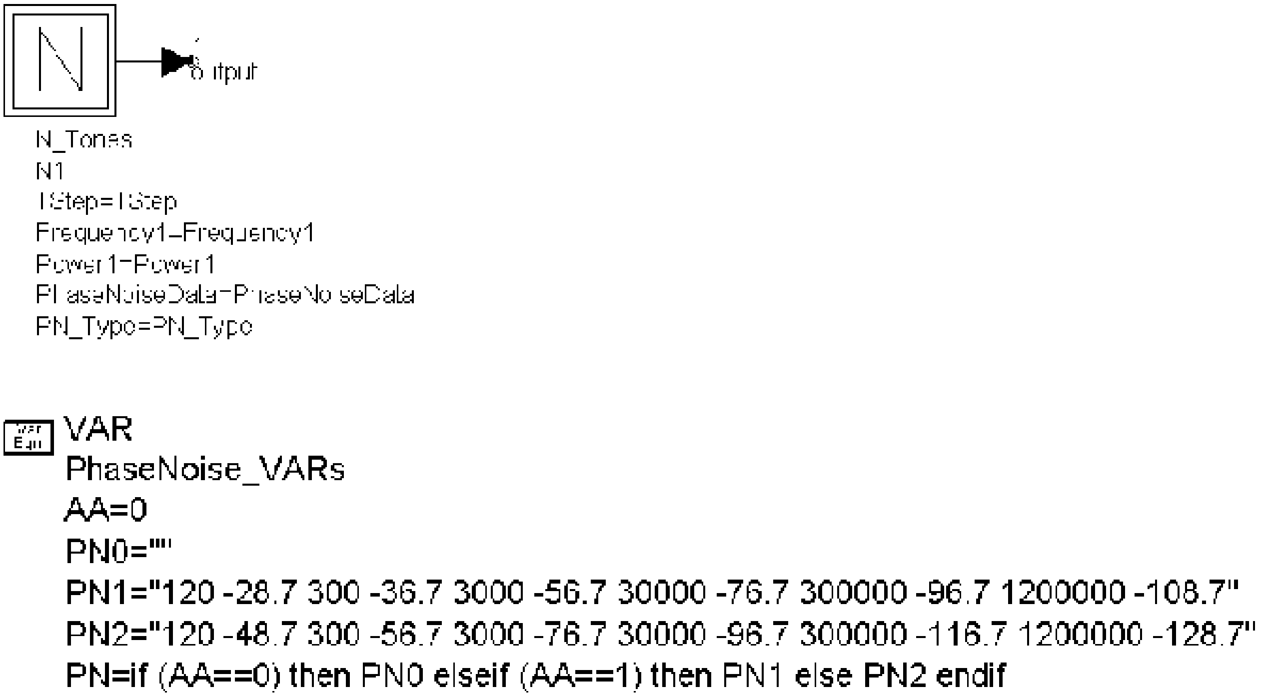
The schematic for this design is shown in the following figure.



WLAN_80211a_24Mbps_PN_System Schematic

N_Tones is used to model the phase noise. The following figure shows the N_Tones parameters and phase noise test cases of the oscillator used in this design. A variable AA is used to control the case of phase noise.

- AA=0, Ideal (no phase noise)
- AA=1, phase noise case 1
- AA=2, phase noise case 2
  The phase noise of N_Tones is implemented based on the Lorentzian spectrum and is characterized by -3dB line width.

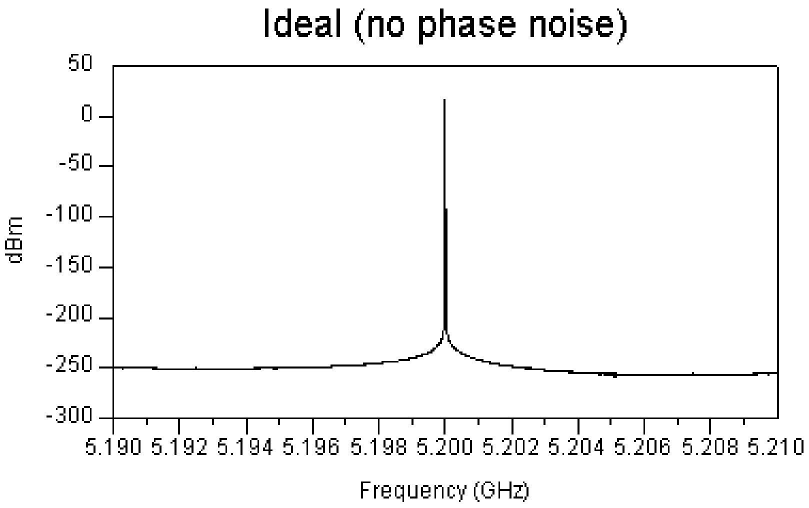


N_Tones
N1
TStep=TStep
Frequency1=Frequency1
Power1=Power1
PhaseNoiseData=PhaseNoiseData
PN_Type=PN_Type

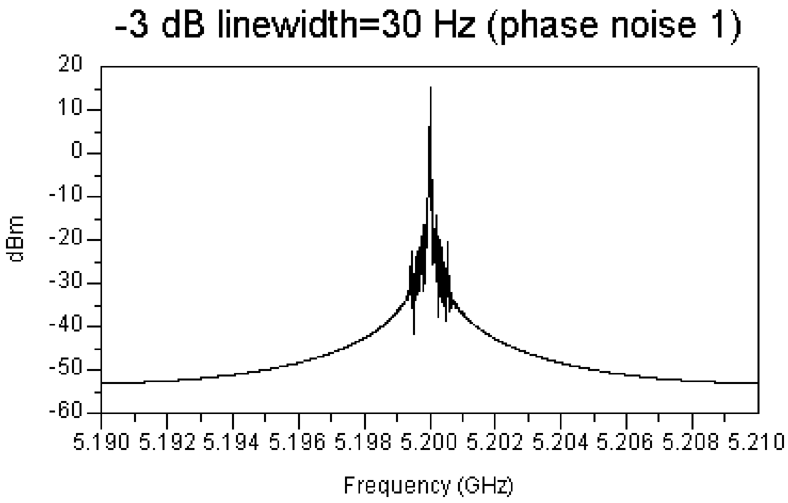
VAR
PhaseNoise_VARs
AA=0
PN0=""
PN1="120 -28.7 300 -36.7 3000 -56.7 30000 -76.7 300000 -96.7 1200000 -108.7"
PN2="120 -48.7 300 -56.7 3000 -76.7 30000 -96.7 300000 -116.7 1200000 -128.7"
PN=if (AA==0) then PN0 elseif (AA==1) then PN1 else PN2 endif

N_Tones Parameters

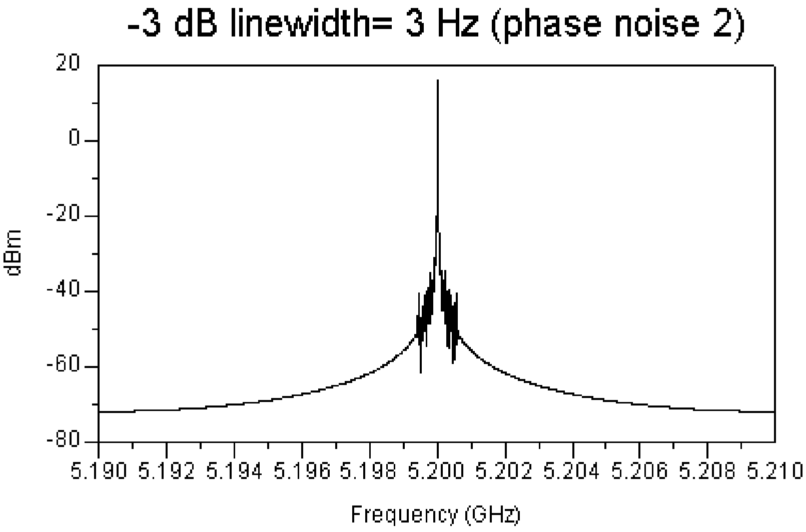
Ideal, phase noise 1, and phase noise 2 results are shown in the following three figures.



Spectrum of Ideal Case



Spectrum of Phase Noise 1



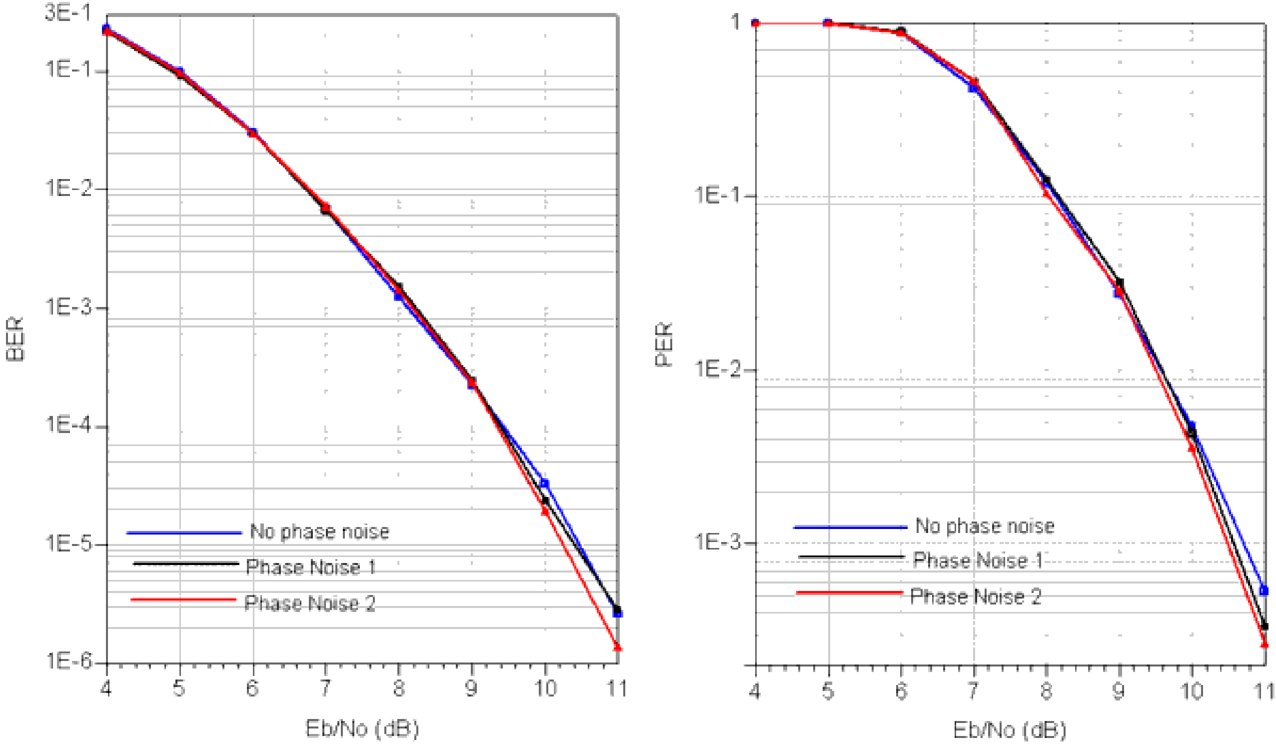
Spectrum of Phase Noise 2

Simulation Results

Simulation results displayed in WLAN_80211a_24Mbps_PN_System.dds are shown in the following figure for BER and PER.

The BER performance of 3Hz -3dB line width is almost the same as that of no phase noise case (Ideal); the BER performance of 30 Hz -3dB line width is much poorer than those of 3Hz -3dB line width and no phase noise case.

The PER performance of 3Hz -3dB line width is a little gain lose than that of no phase noise case (Ideal); the PER performance of 30 Hz -3dB line width is much poorer than those of 3Hz -3dB line width and no phase noise case. In fact, frequency synchronization, phase tracking, and channel estimation functions, and so on, in the IEEE 802.11a receiver will cause phase noise. The phase noise of 3Hz -3dB line width is not very serious. So, its BER and PER performances are almost the same as those of Ideal case because the receiver will cause phase noise which is reasonable. For 30Hz -3dB line width, it causes serious phase noise; BER and PER performances are very poor.



BER and PER Results for 3 Test Cases

Benchmark

- Hardware platform: Pentium III, 1.8 GHz, 512 MB memory
- Software platform: Windows XP, ADS 2002
- Data points: Eb/N0 values is set from 4 to 14 dB
- Simulation time: 33 hours for phase noise 1 and phase noise 2; 20 minutes for no phase noise

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. Richard van Nee, Ramjee Prasad, OFDM Wireless Multimedia Communications, Artech House, 2000.

BER and PER Performance, Fading Channel 24 Mbps

WLAN_80211a_24Mbps_Fading_System

Features

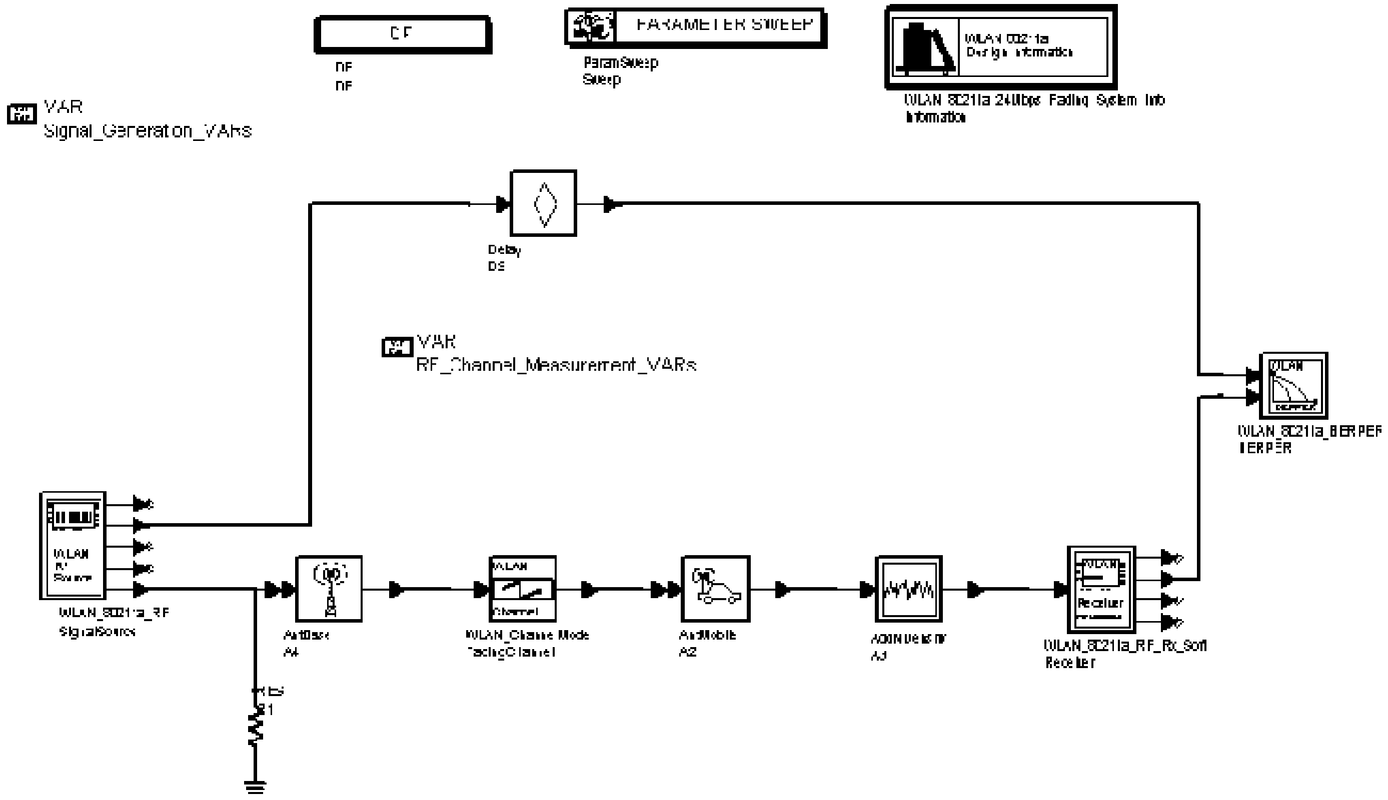
- Data rate = 24Mbps, coding rate = 1/2, modulation = 16-QAM, velocity = 0 km/hr
- Length and Order parameter default settings = 512 and 7, respectively
- BER and PER vs. Eb/N0 under fading channel curves displayed

Description

This design shows system performance with 24 Mbps data rate and channel coding under fading channel. A burst length of 512 bytes is simulated.

The top-level schematic for this design is shown in the following figure.

SignalSource parameters are contained in Signal_Generation_VARs; Receiver, and BERPER parameters are contained in RF_Channel_Measurement_VARs.



WLAN_80211a_24Mbps_Fading_System Schematic

According to reference 2, five model types have been designed. Model A, an 18-tap fading channel corresponding to a typical office environment for NLOS conditions and 50ns 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. The characteristics of this model are shown in the following table.

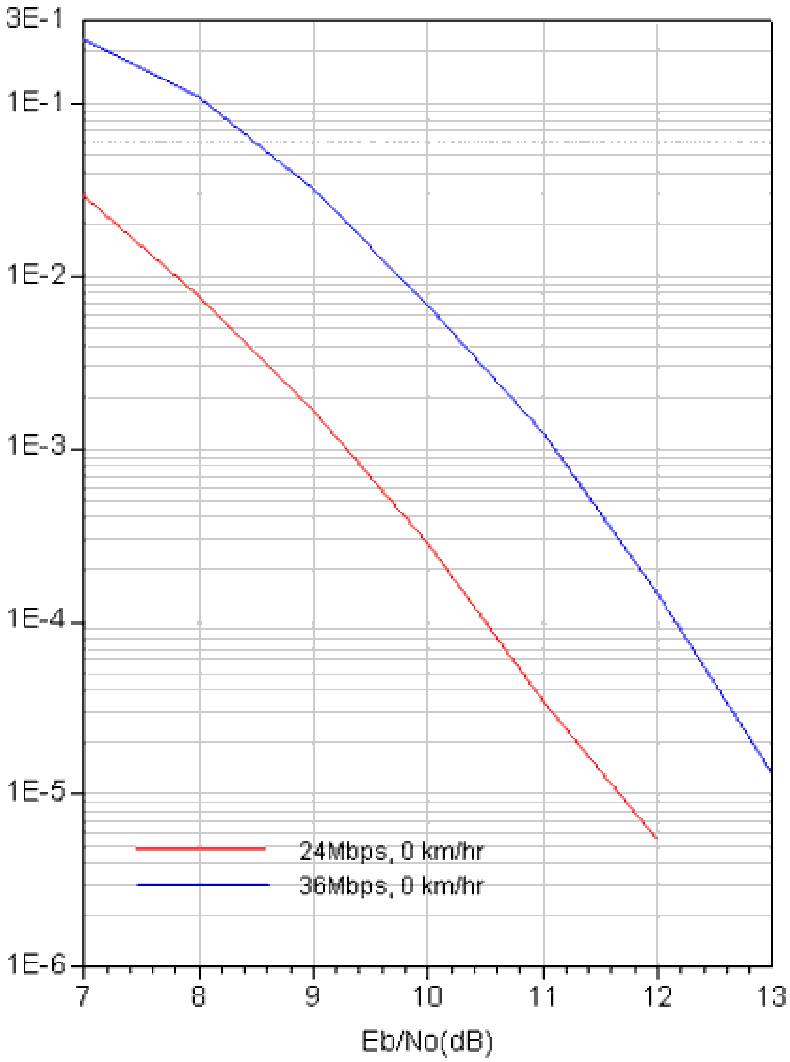
Model A Characteristics

Tap Number	Delay(ns)	Average Relative Power (dB)	Ricean K	Doppler Spectrum
1	0	0.0	0	Class
2	10	-0.9	0	Class
3	20	-1.7	0	Class
4	30	-2.6	0	Class
5	40	-3.5	0	Class
6	50	-4.3	0	Class
7	60	-5.2	0	Class
8	70	-6.1	0	Class
9	80	-6.9	0	Class
10	90	-7.8	0	Class
11	110	-4.7	0	Class
12	140	-7.3	0	Class
13	170	-9.9	0	Class
14	200	-12.5	0	Class
15	240	-13.7	0	Class
16	290	-18.0	0	Class
17	340	-22.4	0	Class
18	390	-26.7	0	Class

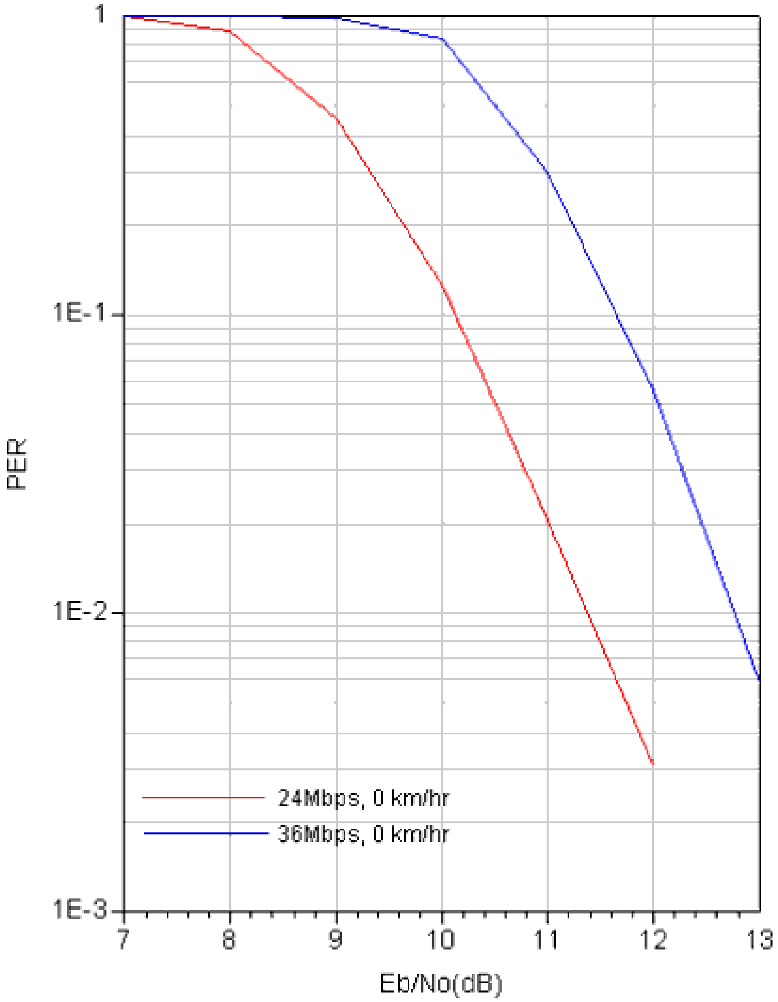
Simulation Results

Simulation results displayed in WLAN_80211a_24Mbps_Fading_System.dds are shown in the following two figures.

For PER performance, it shows that WLAN_80211a_24Mbps_Fading_System is approximately 2 dB better than that of WLAN_80211a_36Mbps_Fading_System.



802.11a Fading Channel BER Performance



802.11a Fading Channel PER Performance

Benchmark

- Hardware platform: Pentium III, 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0, ADS 2002
- Data points: Eb/N0 values is set from 10 to 15 dB
- Simulation time: 50 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. Channel Models for HIPERLAN/2 in Different Indoor Scenarios, ETSI EP BRAN 3ER1085B 30 March 1998.

BER Performance, AWGN Channel 16-QAM Modulation

WLAN_80211a_36Mbps_AWGN_Perfect

Features

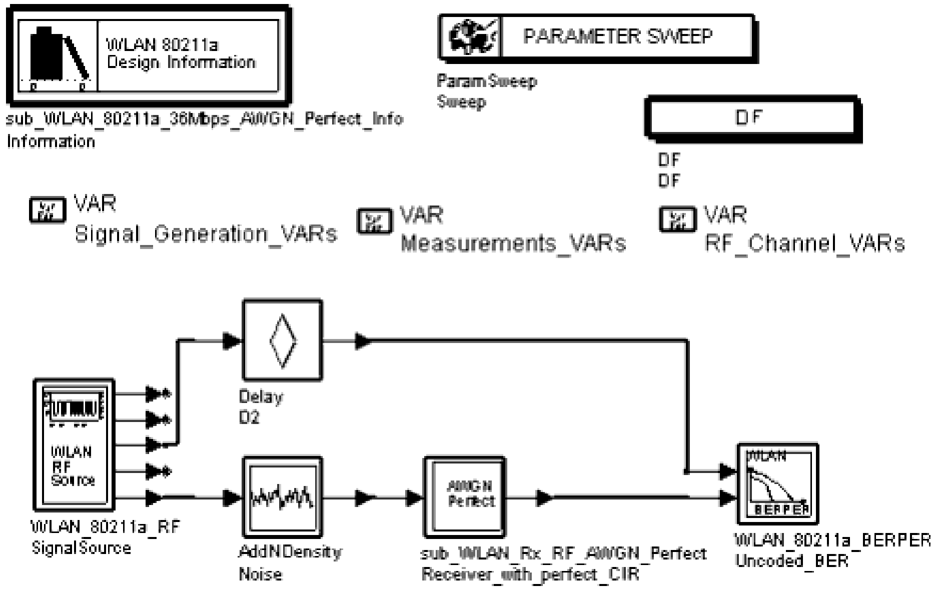
- Raw data rate = 48Mbps, modulation = 16-QAM
- Length and Order parameter default settings = 128 and 6, respectively
- Gaussian simulation channels
- Without channel coding and interleaving
- BER curve displayed

Description

This design shows raw BER performance under AWGN channel with perfect channel estimator. In this design, the data rate is 36 Mbps; the raw data rate is 48 Mbps because there is no channel coding. The guard interval ratio is 1/4 and modulation mode is 16-QAM. The number of frames is set according to Eb/No.

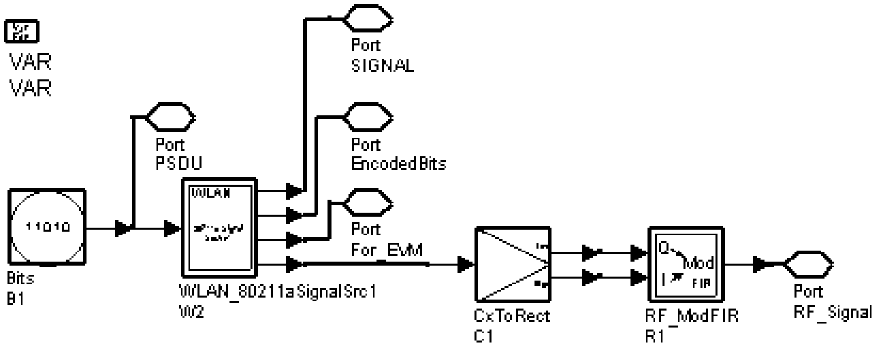
Schematic

The top-level schematic for this design is shown in the following figure.



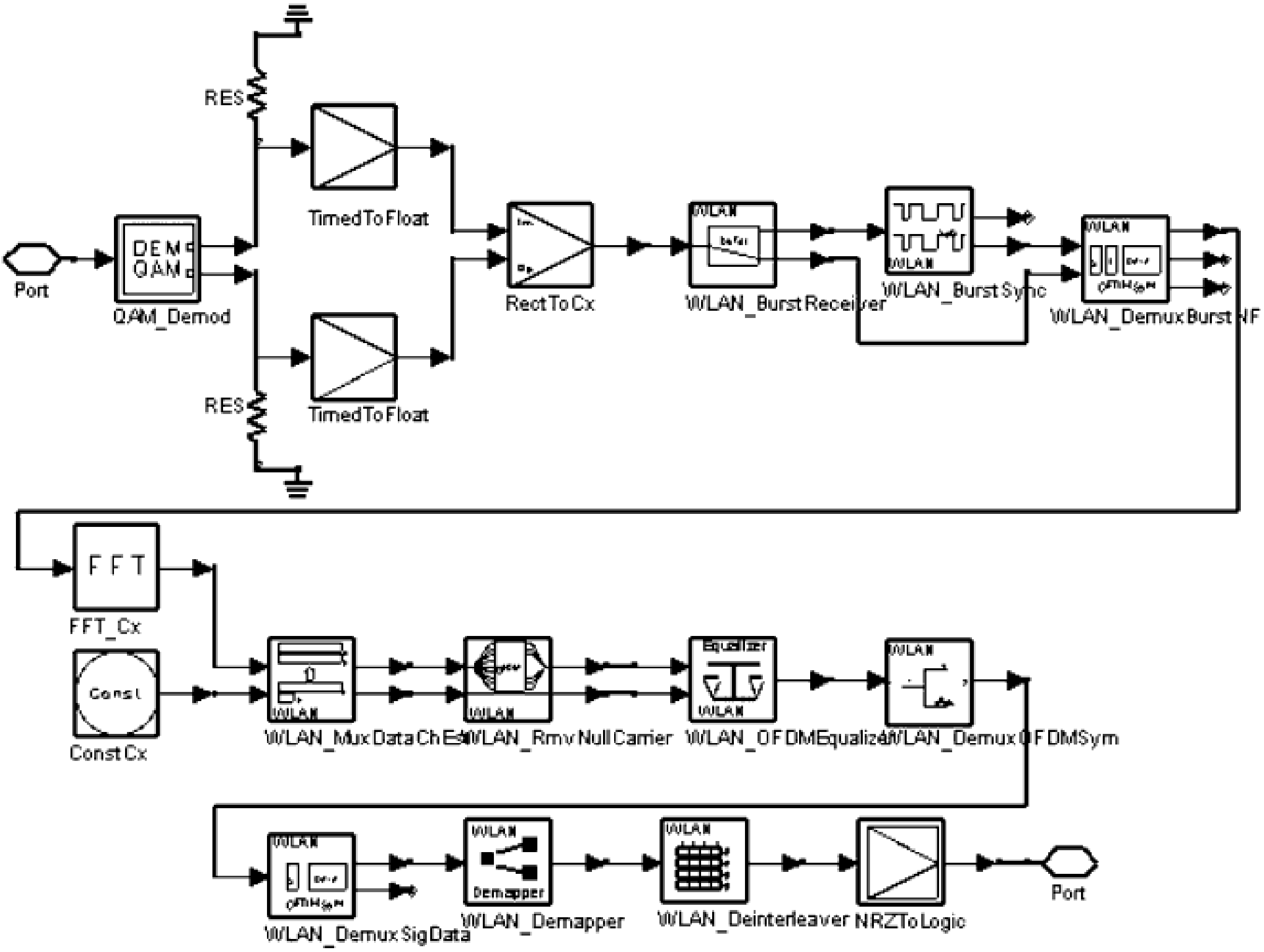
WLAN_80211a_36Mbps_AWGN_Perfect Schematic

The SignalSource subnetwork (see the following figure), multiplexes short and long preambles, one signal symbol and data OFDM symbols into a burst frame.



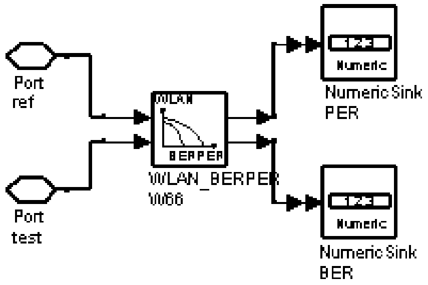
WLAN_80211a_RF Schematic

The sub_WLAN_Rx_RF_AWGN_Perfect subnetwork (see the following figure) performs the start of frame and the transition from short to channel estimation sequences detections, establishment of fine timing (with one sample resolution), and division of each subcarrier value with an ideal channel response coefficient.



sub_WLAN_Rx_RF_AWGN_Perfect Schematic

The BERPER subnetwork (see the following figure) measures system BER and PER.



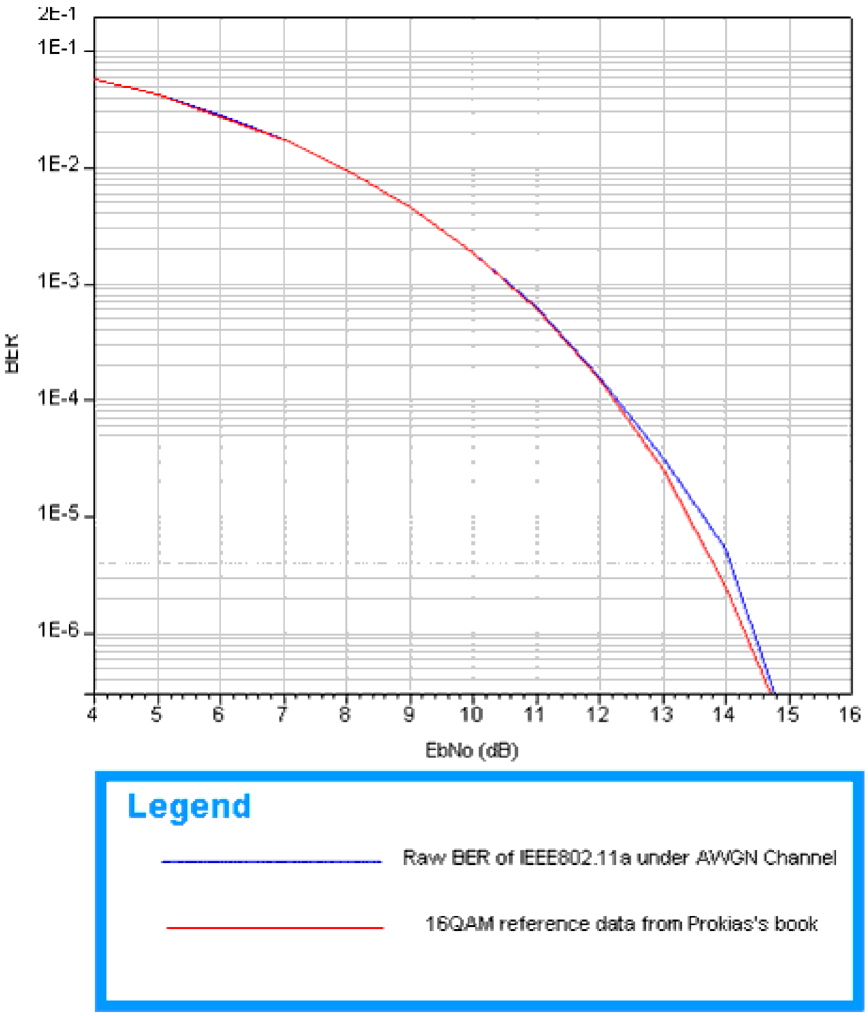
WLAN_80211a_BERPER Schematic

Notes

Order can be set to 6, 7 or 8 in Signal_Generation_VARs.

Simulation Results

The following figure shows Gaussian channel BER of different Eb/N0.



Raw BER Measurements

The red curve, which represents the symbol error rate from Figure 5-2-16 [2], is converted using a dividing factor of 4 into the bit error rate of this design; for 16-QAM modulation, n_b=4. The blue curve shows the BER of this design. The difference in the two curves is less than 0.2 dB. The WLAN Design Library simulation result is consistent with the theoretical result.

To convert symbol error rate into bit error rate, ps is the probability of a symbol error, pb is the probability of a bit error. The relation between ps and p_b is

$$p_s = 1 - (1 - p_b)^{n_b}$$

where nb = number of bits per symbol. Assuming the modulation signal is Gray coded, p_b <<1,
then,

$$p_s = 1 - (1 - p_b)^{n_b} \approx 1 - (1 - n_b \times p_b)$$

So,

$$p_b \approx \frac{1}{n_b} \times p_s$$

Benchmark

- Hardware platform: Pentium III, 800 MHz, 512 MB memory
- Software platform: Windows NT 4.0, ADS 2002
- Data points: Eb/N0 value is set from 4 to 16 dB
- Simulation time: approximately 2 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. John G. Proakis, Digital Communications, third edition, McGraw-Hill, Inc. 1995.

BER and PER Performance, AWGN Channel 36 Mbps

Design Name

WLAN_80211a_36Mbps_AWGN_System

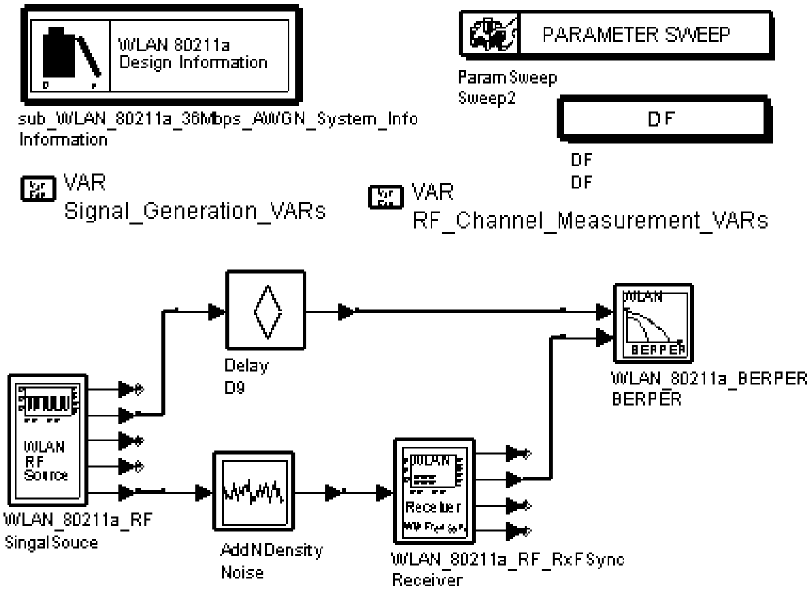
Features

- Data rate = 36 Mbps, coding rate = 3/4, modulation = 16-QAM
- Carrier frequency offset is 100 kHz between transmitter and receiver
- BER and PER vs. Eb/N0 under AWGN channel curves displayed

Description

This design shows BER and PER performance with 36 Mbps data rate and channel coding under AWGN. Burst lengths of 128, 256, and 512 bytes are simulated.

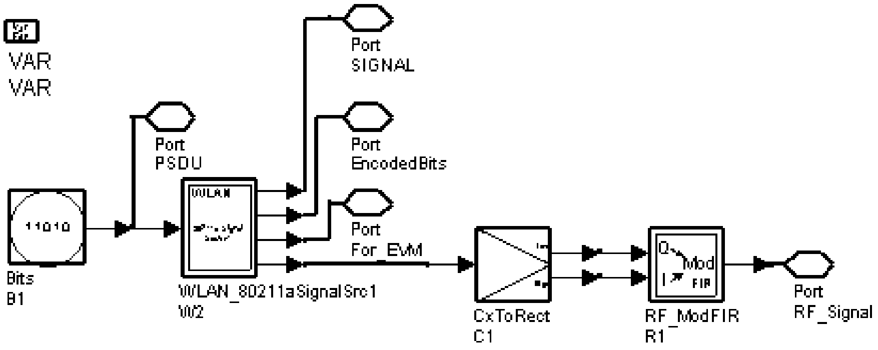
The top-level schematic is shown in the following figure. This design contains four subnetworks named SignalSource, Noise, Receiver, and BERPER.



WLAN_80211a_36Mbps_AWGN_System Schematic

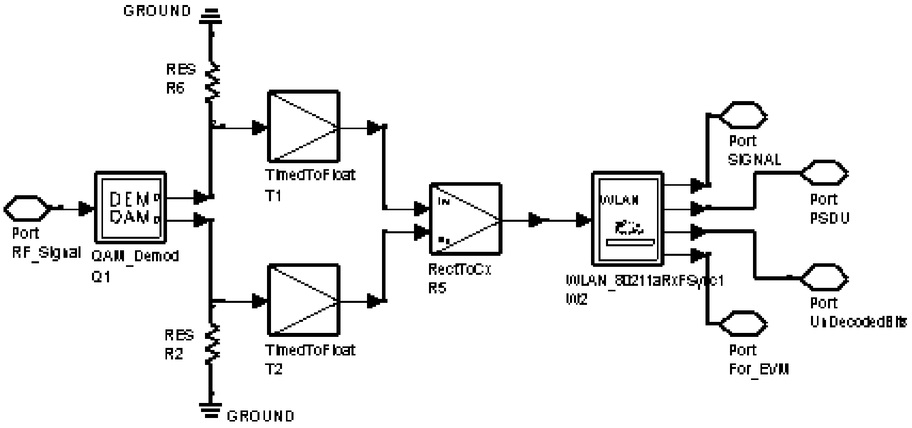
SignalSource parameters are contained in Signal_Generation_VARs; Noise, Receiver, and BERPER parameters are contained in RF_Channel_Measurement_VARs.

The SignalSource subnetwork (see the following figure) generates an IEEE 802.11a signal source based on user settings.



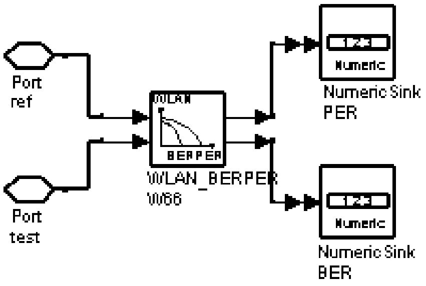
WLAN_80211a_RF Schematic

The Receiver subnetwork (see the following figure) receives an IEEE 802.11a RF signal and demodulates the signal as bits stream; it also detects the start of frame and the transition from short sequences to channel estimation sequences, estimates complex channel response coefficients for each subcarrier, transforms the symbol into subcarrier received values; it performs phase estimation from the pilot subcarrier, subcarrier derotation according to the estimated phase, and division of each subcarrier value with a complex estimated channel response coefficient.



WLAN_80211a_RF_RxFSync Schematic

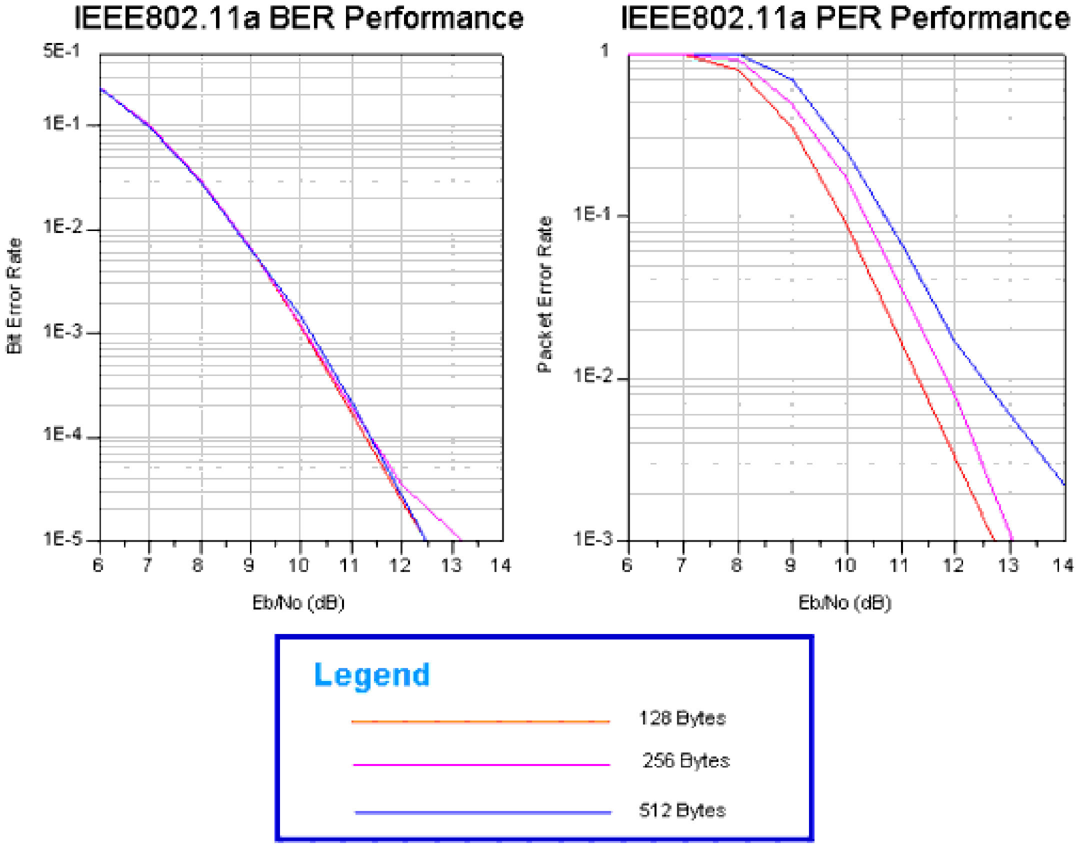
The BERPER subnetwork (see the following figure) measures system BER and PER.



WLAN_80211a_BERPER Schematic

Simulation Results

Simulation results displayed in WLAN_80211a_36Mbps_AWGN_System.dds are shown in the following figure.



WLAN_80211a_36Mbps_AWGN_System Simulation Results

For BER performance, when Eb/N0 is above 10dB, the curve for the 128-byte burst is slightly different from the 256-byte burst and the 512-byte burst curves; this is because the bit number of the 128-byte curve is approximately 10 million fewer than the 256-byte and the 512-byte curves, which are approximately 20 and 40 million bits, respectively. We can conclude that the BER performance for different burst lengths are the same when enough test bits are used.

For PER performance, it shows that the performance of the 128-byte curve is better than that of the 256-byte curve, which is better than that of 512-byte curve. We can conclude that the longer the burst length the worse the PER performance.

Benchmark

- Hardware platform: Pentium IV, 1.8 GHz, 512 MB memory
- Software platform: Windows XP, ADS 2002
- Data points: Eb/N0 value is set from 4 to 15 dB.
- Simulation time: 1, 2 and 4 hours for 128-, 256-, and 512-byte burst lengths,

respectively

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. John G. Proakis, Digital Communications, third edition, McGraw-Hill, Inc. 1995.

BER Performance, AWGN Channel 64-QAM Modulation

WLAN_80211a_48Mbps_AWGN_Perfect

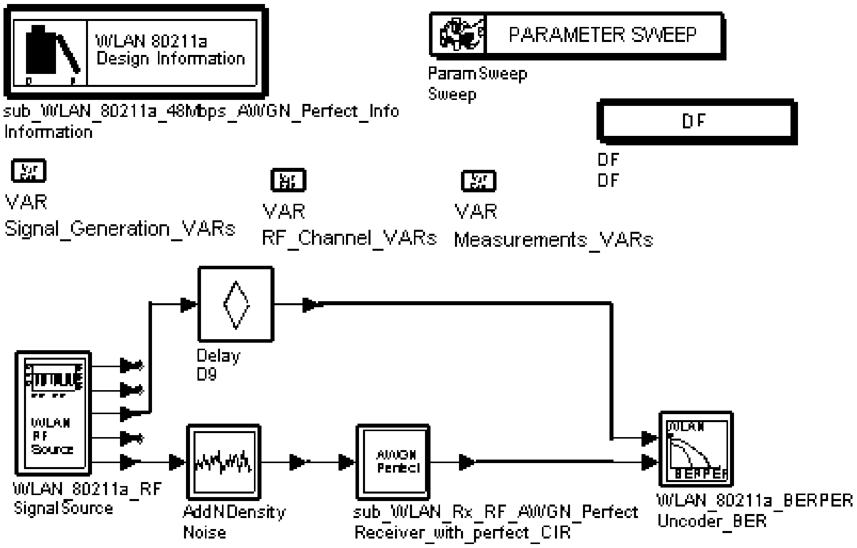
Features

- Raw data rate = 72 Mbps, modulation = 64-QAM
- Length and Order default settings = 1000 bytes and 6, respectively
- Gaussian simulation channels
- Without channel coding and interleaving
- BER curve displayed

Description

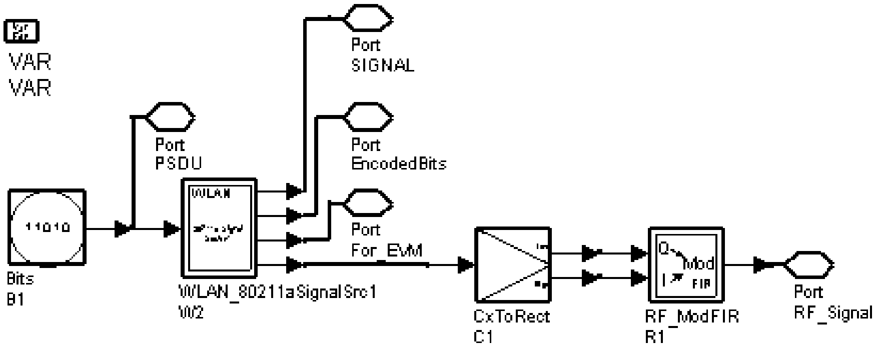
This design shows raw BER performance under AWGN channel with perfect channel estimator. In this design, the data rate is 48 Mbps; the raw data rate is 72 Mbps because there is not channel coding. The guard interval ratio is 1/4 and modulation mode is 64-QAM.

The top-level schematic for this design is shown in the following figure.



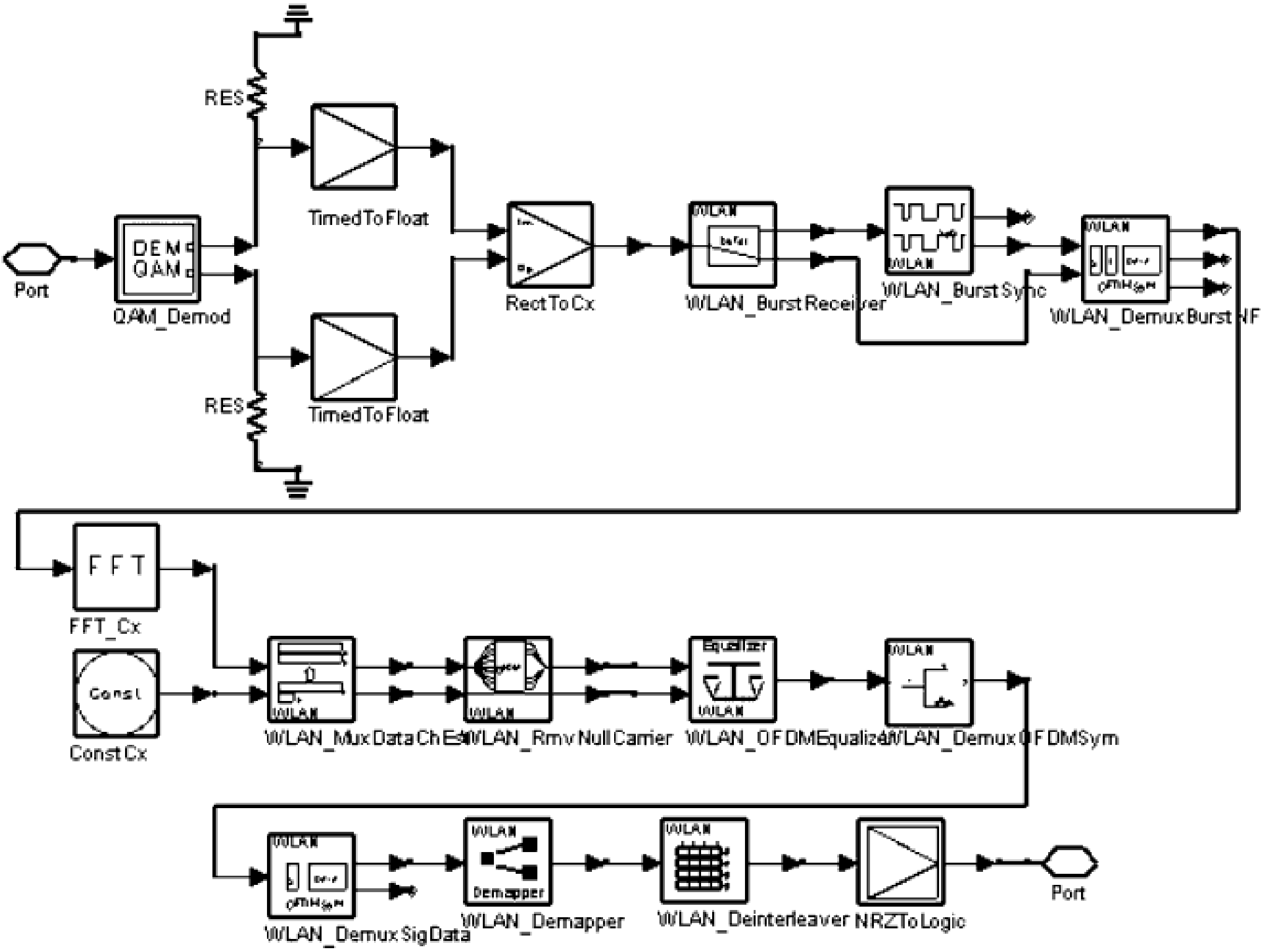
WLAN_80211a_48Mbps_AWGN Schematic

The SignalSource subnetwork (see the following figure) generates an IEEE 802.11a signal source based on user settings.



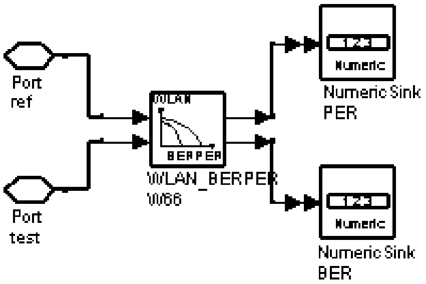
WLAN_80211a_RF Schematic

The sub_WLAN_Receiver_AWGN_Perfect subnetwork (see the following figure) detects the start of frame and the transition from short sequences to channel estimation sequences, establishes fine timing (with one sample resolution), and divides each subcarrier value with an ideal channel response coefficient.



sub_WLAN_Rx_RF_AWGN_Perfect Schematic

The BERPER subnetwork (see the following figure) measures system BER and PER.



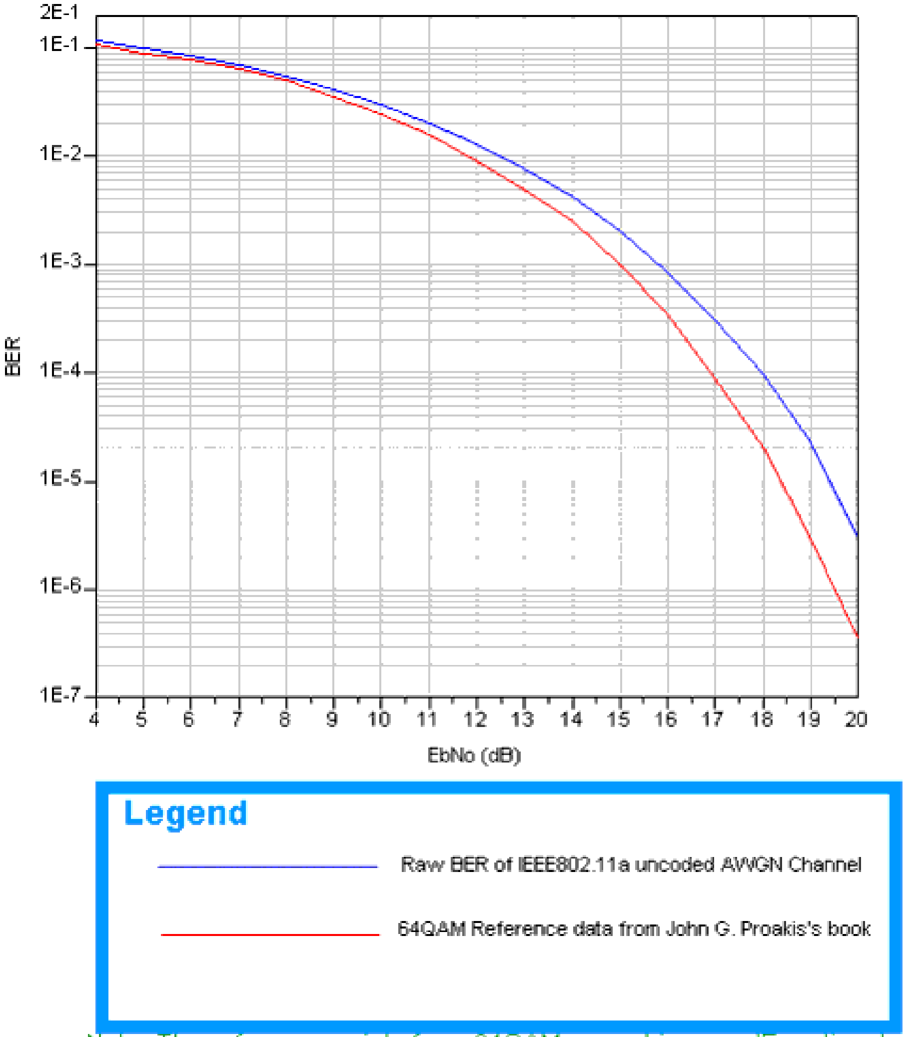
WLAN_80211a_BERPER Schematic

Notes

Order in Signal_Generation_VARs can be set to 6, 7 or 8.

Simulation Results

Simulation results are shown in the following figure.



Note: The reference points from 64QAM are set in page 'Equations'

Gaussian Channel BER of Different Eb/N0

The red curve, calculated from Figure 5-2-16 [2], shows the symbol error rate. The symbol error rate is converted into the bit error rate; ps is the probability of a symbol error, pb is the probability of a bit error. The relation between ps and p_b is

$$p_s = 1-(1-p_b)^{n_b}$$

where nb = number of bits per symbol. Assuming the modulation signal is Gray coded, p_b <<1, then

$$p_s = 1-(1-p_b)^{n_b} \approx 1-(1-n_b \times p_b)$$

So,

$$p_b \approx \frac{1}{n_b} \times p_s$$

In this design, the modulation is 64-QAM, nb=6, the red curve was converted from [2] using a dividing factor of 6; the blue curve shows the BER of this design and the difference is less than 0.4 dB. Simulation results of this design are consistent with the theoretical results.

Benchmark

- Hardware platform: Pentium III, 800 MHz, 512 MB memory
- Software platform: Windows NT 4.0, ADS 2002
- Data points: Eb/N0 value is set from 4 to 20 dB
- Simulation time: approximately 2 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. John G. Proakis, Digital Communications, third edition, McGraw-Hill, Inc. 1995.

BER and PER Performance,

Fading Channel 36 Mbps
WLAN_80211a_36Mbps_Fading_System

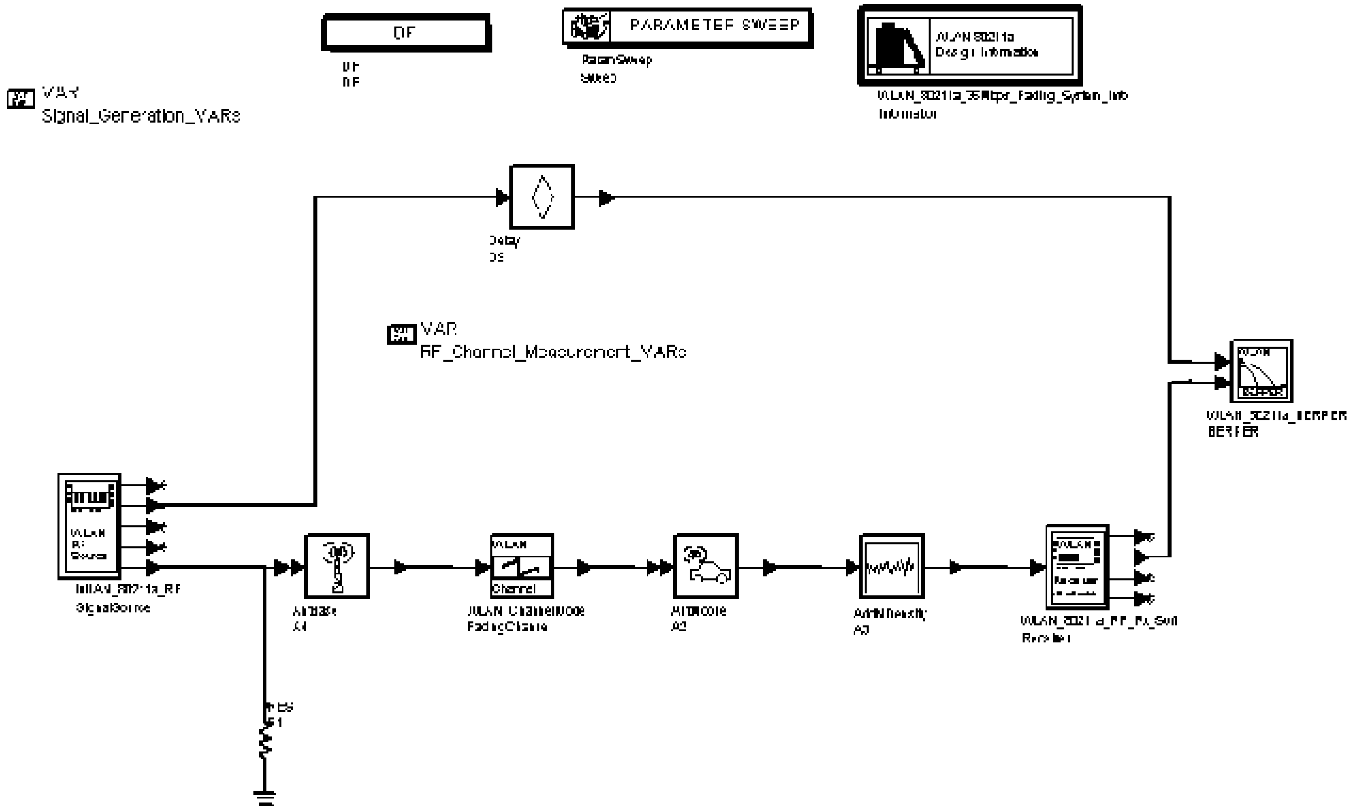
Features

- Data rate=36Mbps, coding rate=3/4, modulation=16-QAM, velocity=0 km/hr
- Length and Order parameter default settings = 512 and 7, respectively
- BER and PER vs. Eb/N0 under fading channel curves displayed

Description

This design shows system performance with 36 Mbps data rate and channel coding under fading channel. A burst length of 512 bytes is simulated.

The top-level schematic for this design is shown in the following figure. SignalSource parameters are contained in Signal_Generation_VARs; Noise, Receiver, and BERPER parameters are contained in RF_Channel_Measurement_VARs.



WLAN_80211a_36Mbps_Fading_System Schematic

According to reference 2, five model types have been designed. Model A, an 18-tap fading channel corresponding to a typical office environment for NLOS conditions and a 50ns average rms delay spread, is used 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. The characteristics of this model are listed in the following table.

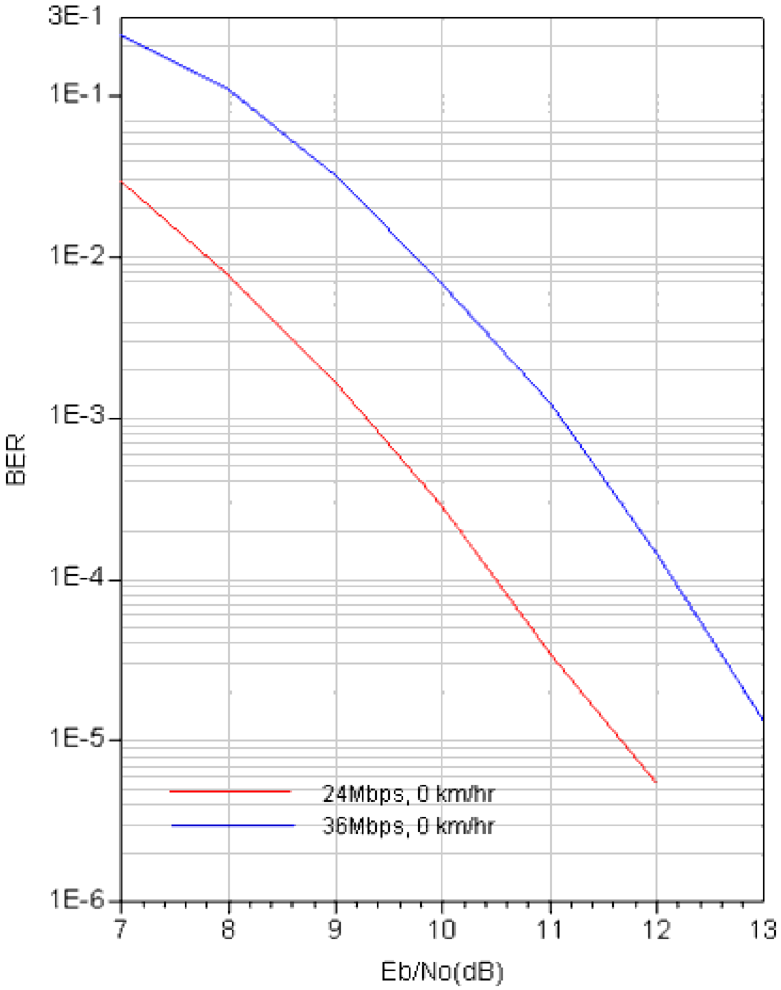
Model A Characteristics

Tap Number	Delay (ns)	Average Relative Power (dB)	Ricean K	Doppler Spectrum
1	0	0.0	0	Class
2	10	-0.9	0	Class
3	20	-1.7	0	Class
4	30	-2.6	0	Class
5	40	-3.5	0	Class
6	50	-4.3	0	Class
7	60	-5.2	0	Class
8	70	-6.1	0	Class
9	80	-6.9	0	Class
10	90	-7.8	0	Class
11	110	-4.7	0	Class
12	140	-7.3	0	Class
13	170	-9.9	0	Class
14	200	-12.5	0	Class
15	240	-13.7	0	Class
16	290	-18.0	0	Class
17	340	-22.4	0	Class
18	390	-26.7	0	Class

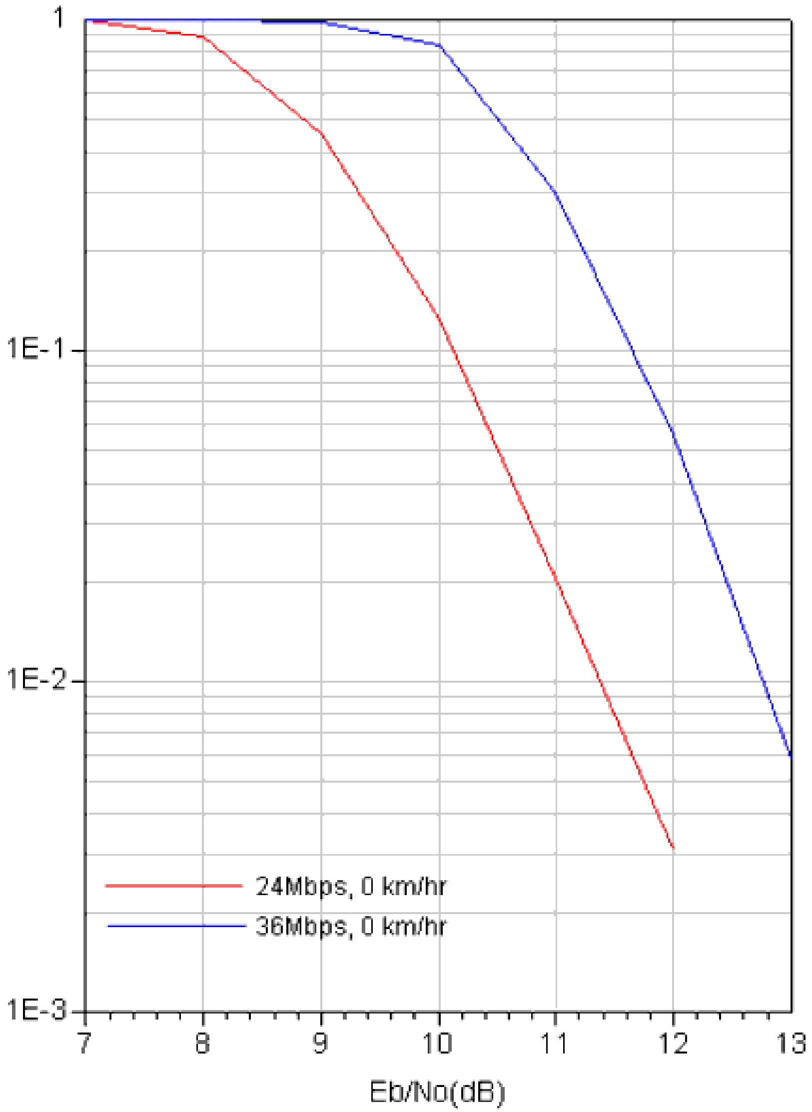
Simulation Results

Simulation results displayed in WLAN_80211a_36Mbps_Fading_System.dds are shown in the following two figures.

For PER performance, the WLAN_80211a_36Mbps_Fading_System is approximately 2 dB worse than that of WLAN_80211a_24Mbps_Fading_System.



802.11a Fading Channel BER Performance



802.11a Fading Channel PER Performance

Benchmark

- Hardware platform: Pentium III, 500 MHz, 512 MB memory
- Software platform: Windows NT 4.0, ADS 2002
- Data points: Eb/N0 values is set from 10 to 15 dB
- Simulation time: 50 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. Channel Models for HIPERLAN/2 in Different Indoor Scenarios, ETSI EP BRAN

3ER1085B 30 March 1998.

80211a Practical Systems

Receiver Test Benches

802.11a Receiver Specifications- Sensitivity

Defined as the minimum RF signal level required to achieve a Packet Error Rate (PER) <10% at PSDU length of 1,000 bytes.

802.11a Receiver Specifications-Adjacent Channel Rejection

The desired signal strength is set at 3dB above the rate-dependent sensitivity, the interfering signal is raised until 10% PER is reached for a PSDU length of 1,000 bytes. The power difference between the interfering signal and the desired signal is the adjacent channel rejection.

Note
Due to the increased bandwidth required by adjacent and alternate channel simulations, it is necessary to decrease the simulation time step by a factor of 2 to 4 times, and to increase the order of the IFFT/FFT from 6 to 8 or 9. The simulation time will correspondingly increase with these changes. Also, at this time data displays and datasets may not be provided for some alternate channel test benches.

802.11a Receiver Specifications-Alternate Channel Rejection

The desired signal strength is set at 3dB above the rate-dependent sensitivity; the interfering signal is raised until 10% PER is reached for a PSDU length of 1000 bytes. The power difference between the interfering signal and the desired signal is the adjacent channel rejection.

Zero-IF Receiver Test Benches

The Zero-IF receiver topology is desirable for use in 802.11a systems for various reasons of cost, complexity and performance. However, it is prone to generating dc offsets due to Local Oscillator (LO) leakage. Also, an automatic gain control (AGC) capability is required in any receiver implementation. The WLAN DesignGuide provides a test bench to investigate these effects.

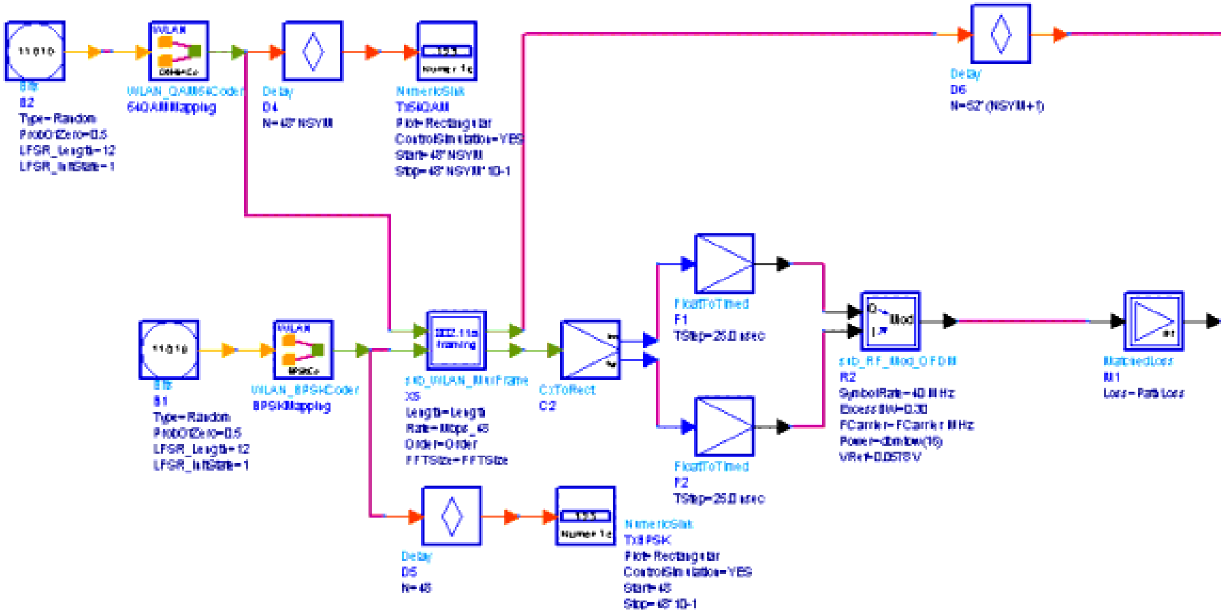
Receiver Dynamic Range, CCA and AGC Test Bench

Test bench name: *Test_AGCSettling_WLAN_80211a*
Specification reference: Section 17.3.10.4, Section 17.3.3, Section 17.3.10.5

The 802.11a modulation requires a linear transmitter and receiver chain. This linearity requirement creates a difficult challenge for the receiver design. Typically, an automatic gain control (AGC) is used in the receiver to ensure that the linearity requirements are met. This model includes a fast, digital AGC that settles within ~5 µ. From the 802.11a standard (Section 17.3.3), the receiver design has 8 µ to perform a signal detection, settle AGC, select diversity (if any), run coarse freq offset adjust and timing recovery.

In this model, AGC runs on the first 5-6 short symbols of the preamble, which produce a fairly constant envelope waveform. The variable AGC settling time (in µ) defines how long AGC runs. Selection of this value is a tradeoff between the dynamic range of the receiver (the dynamic range required of the AGC), AGC step size and step timing, and the aforementioned functions that also need to run in the 8 µ of 10 short symbols.

The top-level model includes a transmitter block, a path loss block, and a receiver block. To run quick simulations to observe various points in the receiver and AGC sections, enable the TKShowValues and TKPlots to observe real-time effects. For more detailed analyses, disable these blocks and enable the TimedSinks at the various points on the top-level model. The major points of interest include: Filtered_AGCDetout, RSSI_CCA_Indicator, ReceiverEVM, and AGC_Value. A data display is set up, Test_AGCSettling_WLAN_80211a, which includes the outputs of many of these time sinks. If you are interested in the performance of AGC vs. the entire RX dynamic range, enable the ParameterSweep for PathLoss and this will sweep the input signal to the receiver from -4 to -64 dBm.



Following are the variables used in the simulation

Data=48

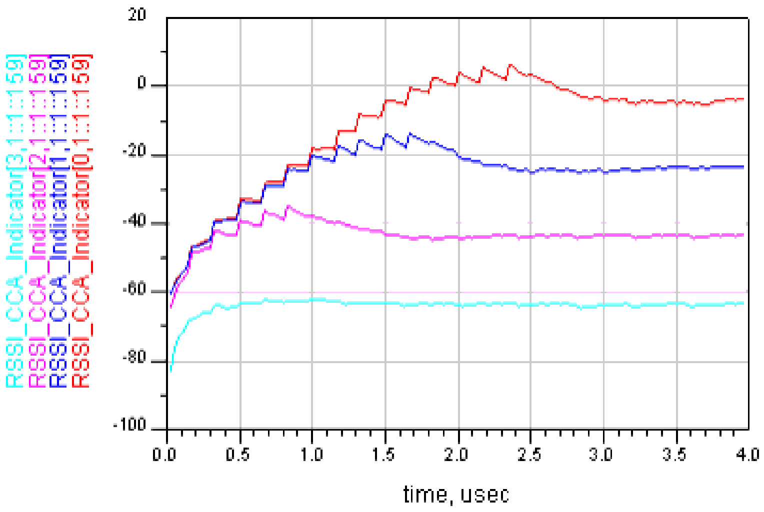
VAR
VAR5
Det0P1dB=0
DCCompDelay=0
Bits=195
Tslice=66.5+DCCompDelay
Ntrainer=50+DCCompDelay
FBDCCompClkPeriod=2.66
FBDCCompClkPeriod2=2.66
InjectedDC=0
MixerLOtoRFPhaseShift=0
MixerLOtoRFIsolation=200
PathLoss=20
Foffset=0
AGCLoss=0

VAR
VAR6
BitsPerSym=1
Tsym=1
SamplePerSym=100
Tstep=2.5/SamplePerSym
TStep=Tstep
AGCsettlingtime=5
Tstart=DCCompDelay
Tstop=Bits+Tstart
RFFiltLoss=2
LNAGain=30
LNANF=2.5
Matchloss=3
BB2Gain=30
BB1Gain=30

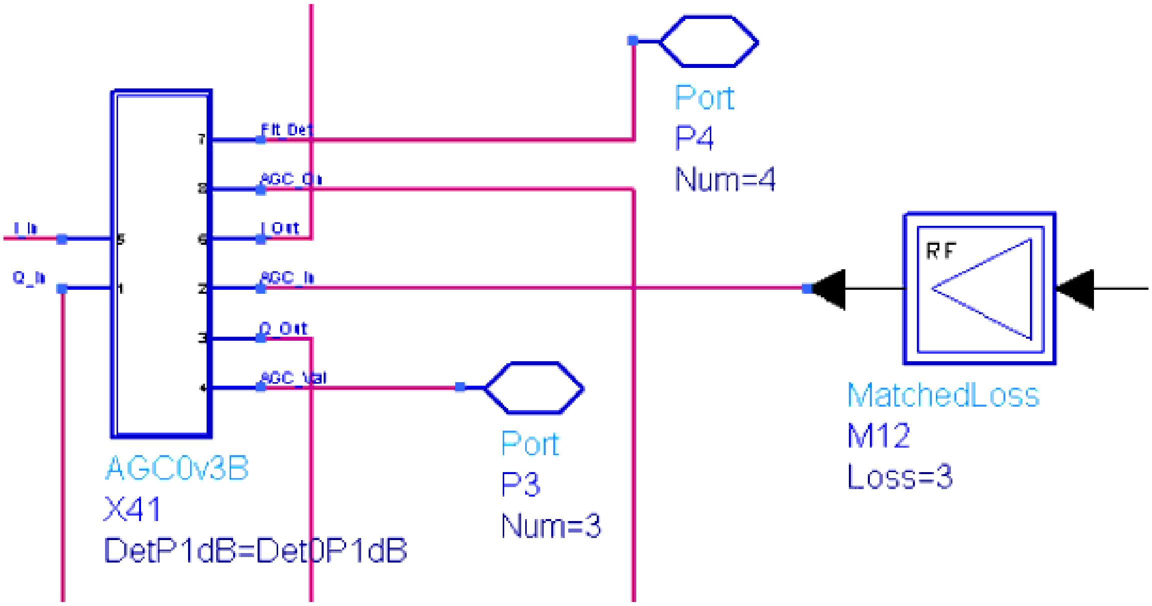
VAR
VAR2
N=int ((16+8*Length+6)/192)
LL=16+8*Length+6-192*N
KK=if (LL==0) then 0 else 1 endif
NSYM=N+KK

VAR
VAR1
FCarrier=5200
FreqOffset=50
Length=256
Order=7
FFTSize=128

The data display shows many key parameters of the 8021.11a receiver. One of the most critical items is in this design is AGC settling time vs. EVM or BER/PER. The data display shows plots of AGC vs. time, RSSI (received signal strength indicator) vs. time, EVM vs. time and other important design considerations.



The receiver (push into RECEIVER_ZIF_AGC) used in this model includes a RX Frontend component (RF filter, T/R Switch, and LNA), a DEM QAM mixer, a pair of linear baseband amplifiers (BB1), followed by an AGC block, with the last blocks being a pair of nonlinear baseband amplifiers (BB2). The typical parameters for each stage are defined at the top-level model: LNAGAIN, LNANF, BB2Gain, etc. For this model it was assumed that the non-linear effects of all stages prior to BB2 could be ignored.

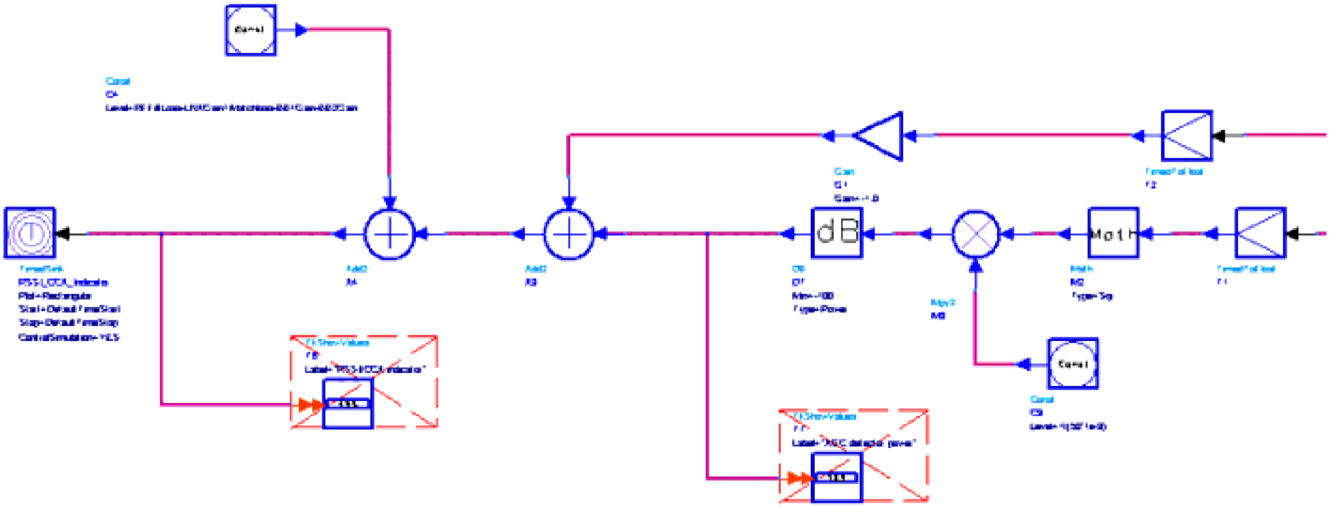


OFDM systems such as 802.11 have a large >10 dB peak-to-average signal value. This requires a backoff from P1dB for BB2 to keep this stage from compressing. This backoff is determined by the variable Det0P1dB on the top-level model. This variable defines the output signal level of BB2 that the AGC attempts to maintain. For example, if Det0P1dB=17 dBm, the digital AGC will try to keep the output of BB2 to +17dBm. Consequently, the backoff is determined by BB2 P1dB - Det0P1dB.

As previously mentioned, the digital AGC always tries to keep the output envelope of the BB2 pair at a constant level. It does this by first calculating the signal amplitude, at BB2 output, by the math function SQRT(I^2+Q^2). This level is then compared with 5 detector levels that control 4 different AGC states: -5 dB, -1 dB, +1 dB, and +5 dB. The digital AGC works by comparing the input signal amplitude with 5 threshold values and applying an appropriate gain adjustment to attempt to keep the BB2 output constant. For example, if the input signal is greater than the defined AGC trip point (Det0P1dB) by >5 dB, then the threshold for the -5 dB AGC is triggered, this results in a 5 dB increase in attenuation for that AGC time step. A similar comparison is made for the next time step. Eventually, if the signal is within the dynamic range of the receiver, AGC should converge between the +1 and -1 dB AGC trip points, when this occurs no more AGC is applied. Similarly, if the signal is too small or AGC overshoots its defined value, attenuation can be taken out with the +1 and +5 dB stages. Due to its complexity, the AGC is not shown here, but you can push into AGC0v3B to view it after loading the design.

The AGC model uses a few parameters that are important to note. The AGC time step is defined by the clock that feeds the 5 CounterSyn blocks. AGC can make a step every 0.167 µ. AGC is disabled or frozen by toggling Port 8 which disables the AGC step clock. The current AGC model has 96 dB of dynamic range defined by the two constant blocks set to 0 and -96 dB. There are several ports available to monitor real-time AGC functions in this model such as detector output.

This model also calculates RSSI/CCA with the blocks in the top-level. These take the measured detector value at the output of BB2, subtract all linear gains of all receiver blocks, and add the AGC value to calculate an input referred power.



Specification reference: IEEE802.11a-1999 Sections 17.10.2 and 17.10.3

IEEE802.11a section 17.3.10.2 specifies adjacent channel rejection requirements; section 17.3.10.3 specifies alternate channel rejection requirements.

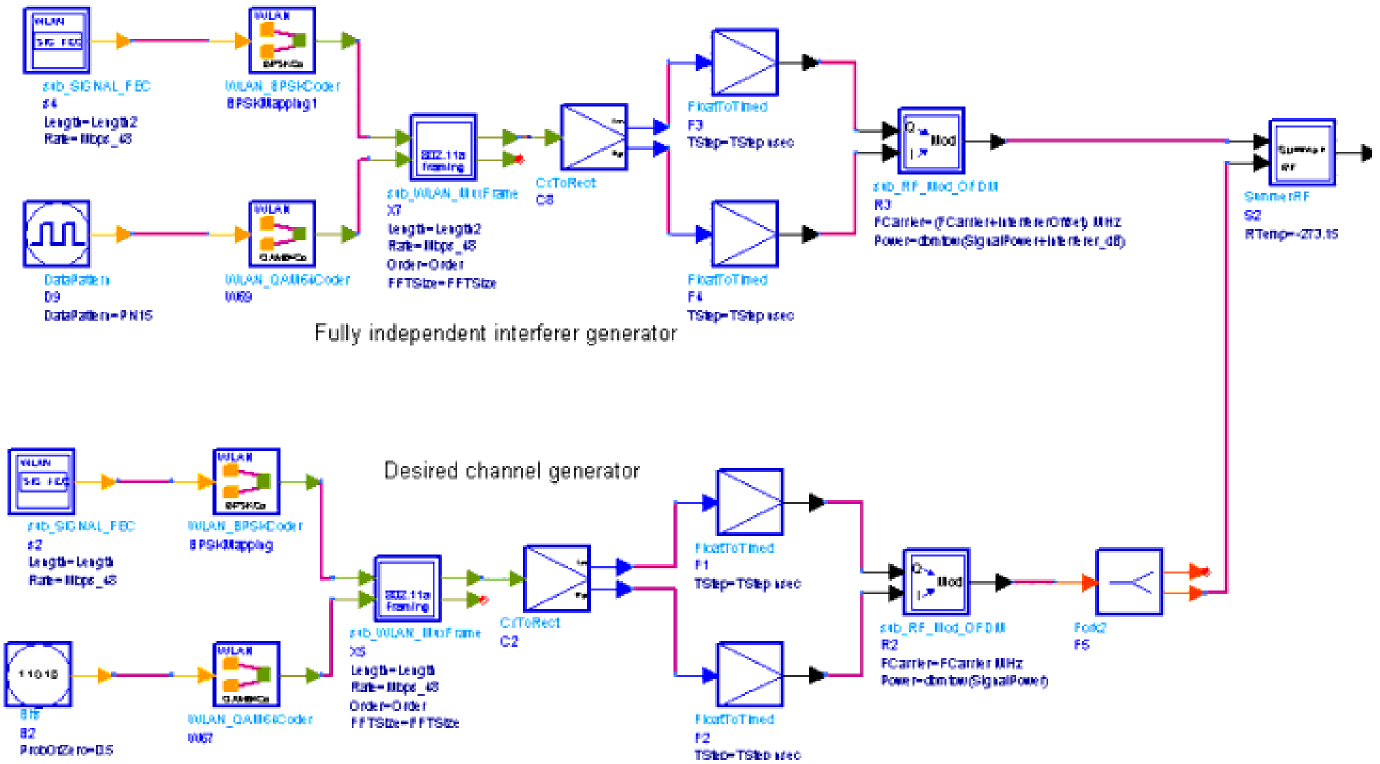
Adjacent channel centers in IEEE 802.11a are offset from the desired channel center by 20 MHz; alternate channels are offset by 40 MHz.

In this example, the data rate is 48 MHz. To perform adjacent channel rejection testing at this data rate, the specification requires the desired channel power input to the receiver be -63 dBm. An adjacent channel also applied at -63 dBm must not cause the packet error rate (PER) to exceed 10%. To perform alternate channel rejection testing at this data rate, the desired channel power input to the receiver is -63 dBm. An alternate channel applied at -47 dBm must not cause the PER to exceed 10%.

WLAN library components are used to generate the short preamble, the long preamble, the signal field and the data of the 802.11a transmit signal. The final module in the 802.11a signal generator is the sub_RF_Mod_OFDM block. Transmit filtering is applied at baseband in the sub_RF_Mod_OFDM module and the IQ baseband signal is mixed to the RF frequency specified by the Fcarrier variable. The power level output from the signal generator is set in dBm by the SignalPower variable.

Two options for generating the interferer signal are provided.

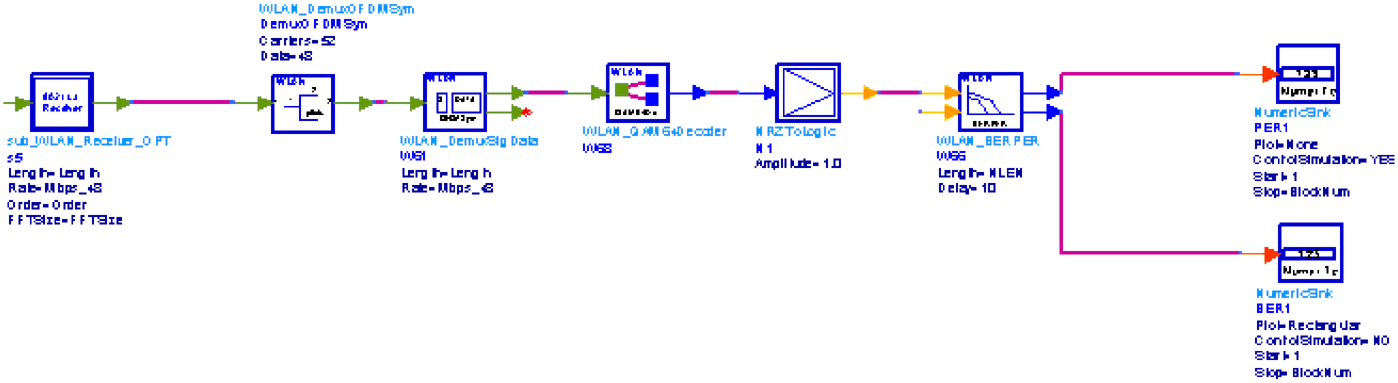
- The interferer is produced by delaying and amplifying a copy of the desired channel signal. This technique runs more quickly, but results may be affected by correlation between the interferer and desired channels.
- A separate 802.11a signal generator is used to produce the interfering signal. To ensure that the desired and interfering channels are uncorrelated, the interferer generator uses a different data set and OFDM packet length than the desired channel. The packet length of the desired signal is set by the Length variable. The packet length of the interferer is set by the "Length2" variable. Using this interferer generation technique, simulations with BlockNum equal to 30 required about 3 times more time to run the same simulations using delayed desired signal as the interferer.



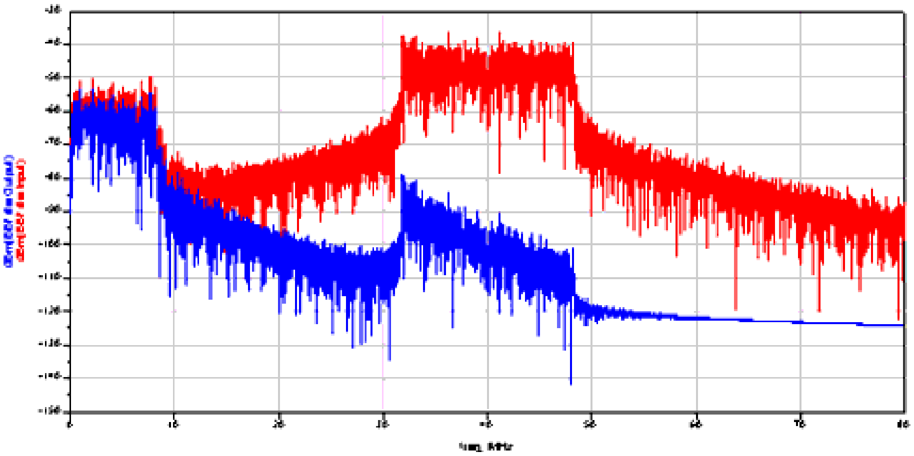
Both options use the *Interferer_dB* level variable to set the signal level of the interferer in dB relative to the desired signal and the *InterfererOffset* variable to set the frequency offset of the interfering channel from the desired channel in MHz.

The interferer and desired channel signals are combined and input to the Zero IF Receiver block. The RF section of the ZIF receiver represents the loss and gain of filters, matching circuits, and RF amplifiers. Following the receiver RF stage, the desired signal is mixed down to baseband IQ signals. Baseband filters provide rejection of the interfering adjacent or alternate channel signals. The automatic gain correction of the ZIF receiver is disabled, and fixed gain blocks are installed to replace it. This simplification reduces simulation time and should not affect adjacent or alternate channel rejection. The output of the ZIF receiver goes to amplifier block G6. The signal level required by the demodulation modules of the receiver is a function of the *Order* variable. Gain block G6 provides this required signal level adjustment.

WLAN library components demodulate the baseband IQ signal into digital data. The WLAN_BERPER module compares the demodulated signal data output to the data input to the signal generator. The BER and PER are then calculated and output to data sinks.



The display provides plots of the RF signal spectrum at the input the ZIF receiver input. The spectrum at the filter input and the output on one receiver baseband signal path is also plotted. A plot also shows the BER and PER values as PPDU frames are received.



Base-Band Spectrum at Filter input and Output

80211a Transmitter System Test Using Instrument Links

Introduction

WLAN_80211a_ESGc_wrk Workspace for IEEE 802.11a transmitter test and verification design example is described in this section.

- WLAN_80211a_ESGc for generating 11a OFDM signal and Sending the signal to ESG4438C to test WLAN OFDM Transmitter components.

Specification Requirements

Receiver performance requirements are listed in the following table.

Receiver Requirements

Data Rate	Modulation Accuracy - EVM
36 Mbps	11.2%
54 Mbps	5.6

Transmitter System Test Using ADS-ESGc Link

WLAN_80211a_ESGc

Signal Parameters

- Data rate is 54 Mbps
- OFDM modulation
- PSDU length is 512 octets
- Carrier is 5.8 GHz

Description

This example demonstrates how to use the ADS-ESGc link to test an OFDM transmitter system. Hardware and software requirements and setup information are provided.

Hardware Requirements

- Agilent E4438C signal generator with 100 MHz clock rate and 6 GHz carrier frequency.
- Agilent 89641A Vector Signal Analyzer (VSA) with 6 GHz carrier frequency or 89640A with 2.7 GHz carrier frequency plus PSA E4440A as a down-converter.

Software Requirements

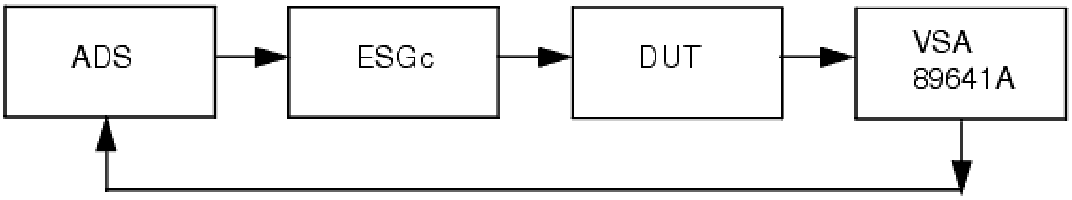
- Advanced Design System (ADS) version 2003A or later with WLAN option
  - To run complex designs of WLAN systems, 500 MB RAM and 500 MB virtual space is required.
- Agilent Instrument Library version 2003A with GPIB and/or LAN interface component model.

PC Setup and Software Installation

1. Install ADS version 2003A or later version on your PC (Win2000, XP).
2. Install WLAN library.
3. Install ADS instruments library and set up the IO library using VISA layer for communicating to instruments.

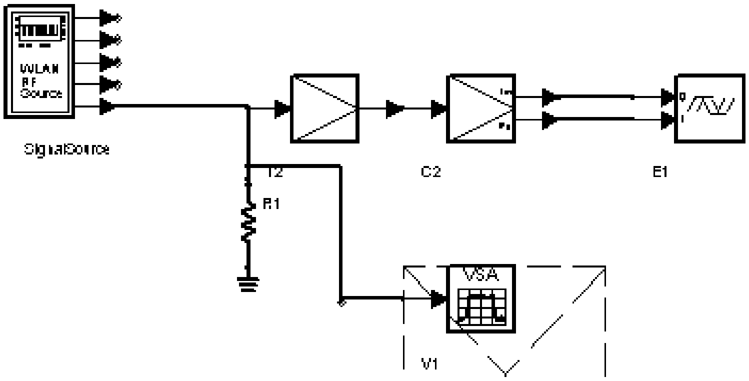
WLAN-ESGC Link Setup

1. Connect ADS, ESGC, the device under test (DUT), and Agilent 89641A as shown in the following figure. With this setup users can bring waveforms captured from VSA back to ADS for performing BER/PER or other performances in ADS.



Test Setup

2. Switch on all instruments and the PC.
3. Start ADS and load schematic design WLAN_80211a_ESGc for signal generation as shown in the following figure.



WLAN Transmitter Test Using ADS-ESGc Link

In the design, the model WLAN 802.11a OFDM signal source with hierarchical structure can generate an RF WLAN OFDM signal with specific data rate, burst length, symbol clock, carrier frequency, and power. All signal parameters can be easily modified in the top level of the design. Var blocks Signal Generation and RF_Measurement are designed for ease of setting key parameters. The data rate is set to 54 Mbps. The signal sent to ESG4438CSink E1, the ADS-ESGc interface for driving the Arb signal generator in ESGc.
Key parameters for ESG4438Csink E1 must be set properly.

- *Interface* is the HPIB/GPIB interface or IP address. In this example we set Interface=141.121.237.165 (IP address).
- *Address* is the instrument address. We set it to 20 (the ESGc address).
- *Start* and *Stop* define the signal sequence length sent to ESGc that must be carefully set to keep the signal sequence contents an integer number of burst. In the example Workspaces for transmitter and receiver tests, *Start* is set to 0 and *Stop* is automatically set by an equation in the RF_Measurement block. For understanding the way to calculate the *Stop* , steps are described as below:
    - Calculate the number of OFDM symbols per burst for WLAN data:

      NSyPB = ceiling [(16 + 8 × Length + 6) /NDBPS]
      where *NDBPS* is the number of data bits per OFDM Symbols, and Length is the octet number of PSDU (physical layer convergence procedure service data units). *NDBPS* depends on data rate as shown in the following table.

WLAN Signal Parameters Specified by IEEE 802.11a Standard

Data Rate (Mbps)	Modulation	Coding Rate (R)	Coded Bits per Subcarrier (NBPSC)	Coded Bits per OFDM Symbol (NCBPS)	Data Bits per OFDM Symbol (NDBPS)
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
27	16-QAM	9/16	4	192	108
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

In this example, WLAN signal Length =512 and data rate=54 Mbps. Based on the table, NDBPS=216. From the equation for number of OFDM symbols, NSyPS=20.

Total number of samples per burst:

NSaPB = (preamble (short and long) time
+ signal time + idle time + NSyPS × 4) / tstep
For this example, preamble time =16 μ, signal plus GI=4 μ, and the idle time set to 4 μ
NSaPB = (20 + 4 + 4 × 20) × 1000/12.5 = 8320

ESGc Settings

The ARB generator in ESGc is driven by the WLAN RF signal source in ADS through HPIB/LAN. Follow the ESGc setup sequence:

ARB Settings

1. Press panel button **Mode** > **Dual ARB**
2. Press **ARB on/off** to **ARB off**
3. Press **ARB set up**
4. Set the **ARB sample clock** to **80 MHz** for this example
5. Set the **ARB Reference** to **Int**
6. Set the **Reconstruction Filter** to **Through**
7. Press **Select/Waveform** and select the name of the file defined in the model ESG4438CSink, for example **wlan_24**
8. Press panel button **Mod On/Off** to ensure **Mod On**
9. Press panel button **RF On/Off** to ensure **RF On**
10. Press **Frequency** and set to **5.8 GHz**
11. Press **Amplitude** and set to **-5dBm**
12. Press **ARB On/Off** to ensure **ARB On**

Set up the design under test.

1. The DUT can be any component in a transmitter. As an example, we test a power amplifier called TT-64 as the DUT. The expected performances are: output power 17 dBm for carrier 5.8 GHz.
2. Connect the input to the ESGc and Output to VSA89641A.
3. Make sure the power supply is set properly and turned on.

VSA 89641A Settings

The VSA 89641A must be connected to a PC that has an IEEE 1394 card and VSA software with WLAN flavor (option B7R) installed. When installing the VSA software, the IEEE 1374 option must be turned on.
To set up the measurement settings:

1. Click **MeasSetUp** and set the demodulator type by clicking **Modulator** , then select **Wireless Networking** > **DSSS/OFDM/PBCC**
2. Click **Frequency** , then enter the correct *center frequency* and frequency *span* (you

can use the **full span** button).

To set up the input settings: click **Input** , then set **data format** to **hardware** .

The VSA software settings for transmission test can now be saved as a *set* file; for example, *11a.set* . The saved *set* file can then be called and will use the above settings. A *set* file has been made that can be found in the data directory under this Workspace: make sure you use the correct *set* file.

Under this setting, the EVM is measured to see if the power amplifier can be used as a transmitter power amplifier based on IEEE 802.11a std. Simulation results are compared to the standard.

Simulation Results

EVM = 1.2%, which is less than the standard value 11.2%. So, the EVM passes the test.

Benchmark

- Hardware platform: Pentium IV 1.8GHz, 512 MB memory
- Software platform: Windows 2000, ADS 2002C
- Simulation time: approximately 10 minutes

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

80211b Signal Source

Introduction

WLAN_80211b_SignalSource_wrk design examples are described in this section.

- WLAN_80211_LowRate generates IEEE 802.11 burst with different data rates.
- WLAN_80211b_CCK generates IEEE 802.11b CCK burst with different data rates.
- WLAN_80211b_PBCC generates IEEE 802.11b PBCC burst with different data rates.

1 and 2 Mbps Signal Source

WLAN_80211_LowRate

Features

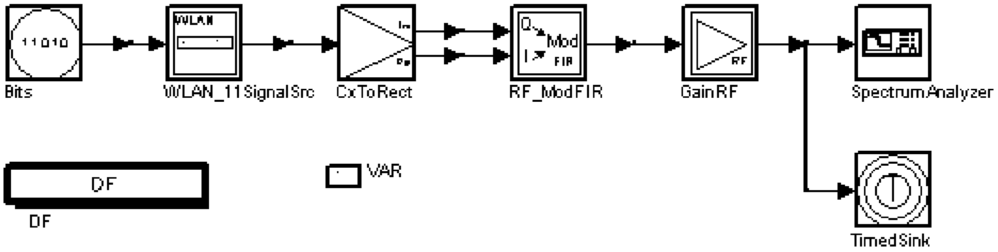
- 1 and 2 Mbps configurable signal source, adjustable data rate by setting Rate in VAR1
- Adjustable sample rate by setting OverSampling in VAR1

Description

This design is an example of IEEE 802.11 low rate signal source (1 Mbps and 2 Mbps) at various data rates with idle between two consecutive bursts; ramp bits are not appended to the data.

The top-level schematic for this design is shown in the following figure. Parameters that can be user-modified are contained in VAR1 User_Defined_Variables. Other parameters should be set according to the specification.

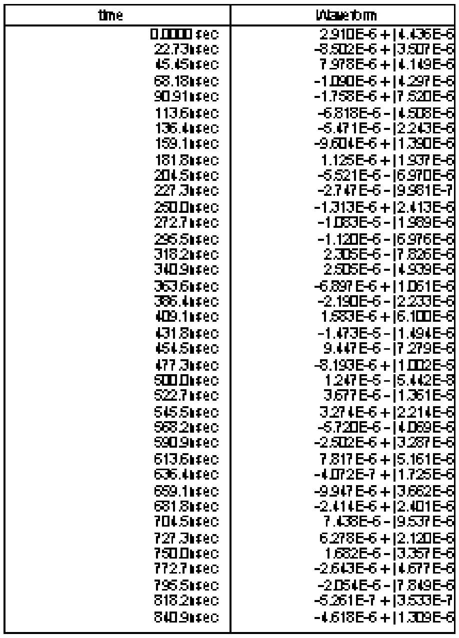
Note
If the sample rate is changed, the parameter VRef used in model RF_ModFIR must be re-calibrated.



WLAN_80211_SignalSource Schematic

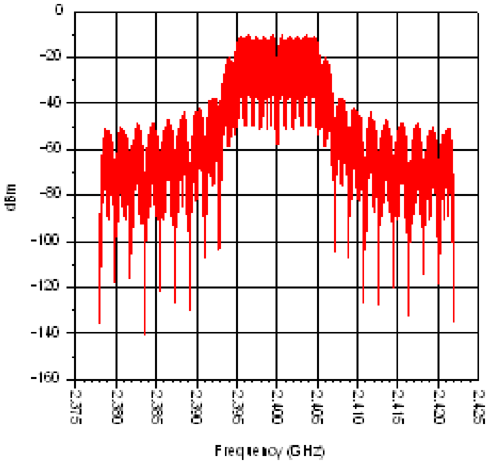
Simulation Results

Simulation results displayed in WLAN_80211_LowRate.dds are the RF waveform data (see the first of the following two figures) and the transmit spectrum (see the second figure).



time	Waveform
0.0000 sec	2.910E-6 + j4.436E-6
22.73 nsec	-8.502E-6 + j3.507E-6
45.45 nsec	7.978E-6 + j4.149E-6
68.18 nsec	-1.090E-6 + j4.297E-6
90.91 nsec	-1.758E-6 + j7.520E-6
113.6 nsec	-6.818E-6 - j4.508E-6
136.4 nsec	-5.471E-6 - j2.243E-6
159.1 nsec	-9.604E-6 + j1.390E-6
181.8 nsec	1.125E-6 + j1.937E-6
204.5 nsec	-5.521E-6 - j6.970E-6
227.3 nsec	-2.747E-6 - j9.981E-7
250.0 nsec	-1.313E-6 + j2.413E-6
272.7 nsec	-1.083E-5 - j1.989E-6
295.5 nsec	-1.120E-6 - j6.976E-6
318.2 nsec	2.305E-6 - j7.826E-6
340.9 nsec	2.505E-6 - j4.939E-6
363.6 nsec	-6.897E-6 + j1.061E-6
386.4 nsec	-2.190E-6 - j2.233E-6
409.1 nsec	1.583E-6 + j6.100E-6
431.8 nsec	-1.473E-5 - j1.494E-6
454.5 nsec	9.447E-6 - j7.279E-6
477.3 nsec	-8.193E-6 + j1.002E-5
500.0 nsec	1.247E-5 - j5.442E-8
522.7 nsec	3.677E-6 - j1.361E-5
545.5 nsec	3.274E-6 + j2.214E-6
568.2 nsec	-5.720E-6 - j4.069E-6
590.9 nsec	-2.502E-6 + j3.287E-6
613.6 nsec	7.817E-6 + j5.161E-6
636.4 nsec	-4.072E-7 + j1.725E-6
659.1 nsec	-9.947E-6 + j3.662E-6
681.8 nsec	-2.414E-6 + j2.401E-6
704.5 nsec	7.438E-6 - j9.537E-6
727.3 nsec	6.278E-6 + j2.120E-6
750.0 nsec	1.682E-6 - j3.357E-6
772.7 nsec	-2.643E-6 + j4.677E-6
795.5 nsec	-2.054E-6 - j7.849E-6
818.2 nsec	-5.261E-7 + j3.533E-7
840.9 nsec	-4.618E-6 + j1.309E-6

RF Waveform Data of 802.11 Low Rate Signal Source



RF Transmit Spectrum of 802.11 Low Rate Signal Source

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 1 minute

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

CCK Signal Source with Idle and Ramp Time

WLAN_80211b_CCK

Features

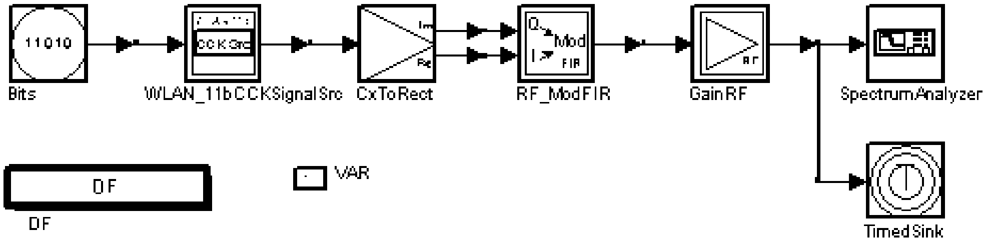
- 5.5 and 11 Mbps configurable signal source with CCK modulation, adjustable data rate by setting Rate in VAR1
- Adjustable sample rate by setting OverSampling in VAR1

Description

This design is an example of IEEE 802.11b CCK modulation signal source with long PLCP at various data rates; idle and ramp times are added between two consecutive bursts.

The top-level schematic for this design is shown in the following figure. Parameters that can be user-modified are contained in VAR1 User_Defined_Variables. Other parameters should be set according to the specification.

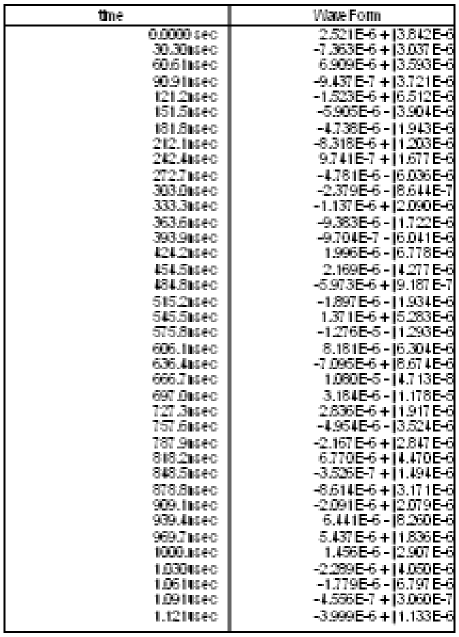
Note
If the sample rate is changed, the parameter VRef used in model RF_ModFIR must be re-calibrated.



WLAN_80211b_CCK Schematic

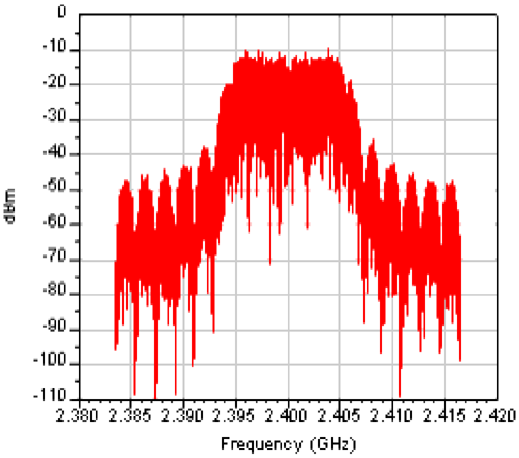
Simulation Results

Simulation results displayed in WLAN_80211b_CCK.dds are the RF waveform data (see the first of the following two figures) and transmit spectrum (see the second figure).



time	Wave Form
0.0000 sec	2.521E-6 + j3.842E-6
30.30nsec	-7.363E-6 + j3.037E-6
60.61nsec	6.909E-6 + j3.593E-6
90.91nsec	-9.437E-7 + j3.721E-6
121.2nsec	-1.523E-6 + j6.512E-6
151.5nsec	-5.905E-6 - j3.904E-6
181.8nsec	-4.736E-6 - j1.943E-6
212.1nsec	-8.318E-6 + j1.203E-6
242.4nsec	9.741E-7 + j1.677E-6
272.7nsec	-4.781E-6 - j6.036E-6
303.0nsec	-2.379E-6 - j8.644E-7
333.3nsec	-1.137E-6 + j2.090E-6
363.6nsec	-9.383E-6 - j1.722E-6
393.9nsec	-9.704E-7 - j6.041E-6
424.2nsec	1.996E-6 - j6.778E-6
454.5nsec	2.169E-6 - j4.277E-6
484.8nsec	-5.973E-6 + j9.187E-7
515.2nsec	-1.897E-6 - j1.934E-6
545.5nsec	1.371E-6 + j5.283E-6
575.8nsec	-1.276E-5 - j1.293E-6
606.1nsec	8.181E-6 - j6.304E-6
636.4nsec	-7.095E-6 + j8.674E-6
666.7nsec	1.080E-5 - j4.713E-8
697.0nsec	3.184E-6 - j1.178E-5
727.3nsec	2.836E-6 + j1.917E-6
757.6nsec	-4.954E-6 - j3.524E-6
787.9nsec	-2.167E-6 + j2.847E-6
818.2nsec	6.770E-6 + j4.470E-6
848.5nsec	-3.526E-7 + j1.494E-6
878.8nsec	-8.614E-6 + j3.171E-6
909.1nsec	-2.091E-6 + j2.079E-6
939.4nsec	6.441E-6 - j8.260E-6
969.7nsec	5.437E-6 + j1.836E-6
1000.nsec	1.456E-6 - j2.907E-6
1.030usec	-2.289E-6 + j4.050E-6
1.061usec	-1.779E-6 - j6.797E-6
1.091usec	-4.556E-7 + j3.060E-7
1.121usec	-3.999E-6 + j1.133E-6

RF Waveform data of 802.11b CCK modulation signal source



RF Transmit Spectrum of 802.11b CCK Modulation Signal Source

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 1 minute

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

PBCC Signal Source with Idle and Ramp Time

WLAN_80211b_PBCC

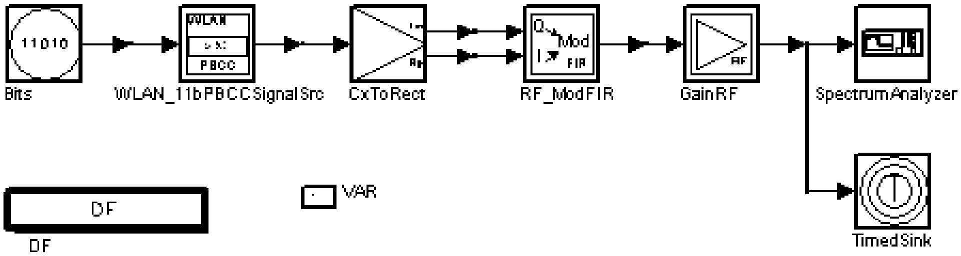
Features

- 5.5 and 11 Mbps configurable signal source with PBCC modulation, adjustable data rate by setting Rate in VAR1
- Adjustable sample rate by setting OverSampling in VAR1

Description

This design is an example of IEEE 802.11b PBCC modulation signal source with long PLCP at various data rates; the idle and ramp times are added between two consecutive bursts. The top-level schematic for this design is shown in the following figure. Parameters that can be user-modified are contained in VAR1 User_Defined_Variables. Other parameters should be set according to the specification.

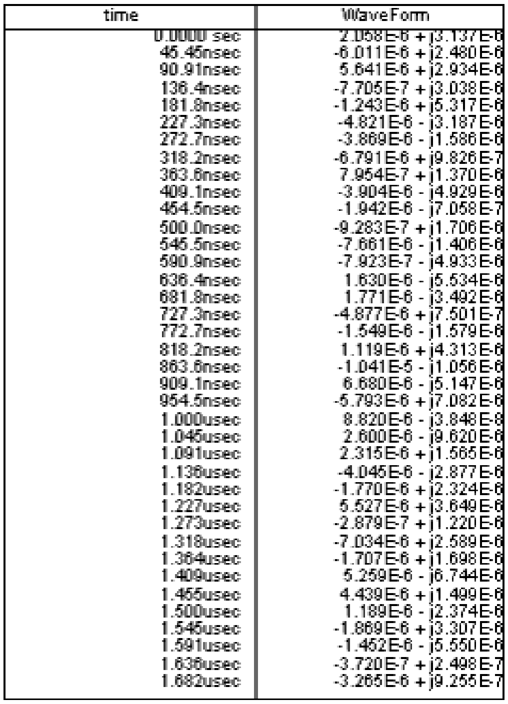
Note
If the sample rate is changed, the parameter VRef used in model RF_ModFIR must be re-calibrated.



WLAN_80211b_PBCC Schematic

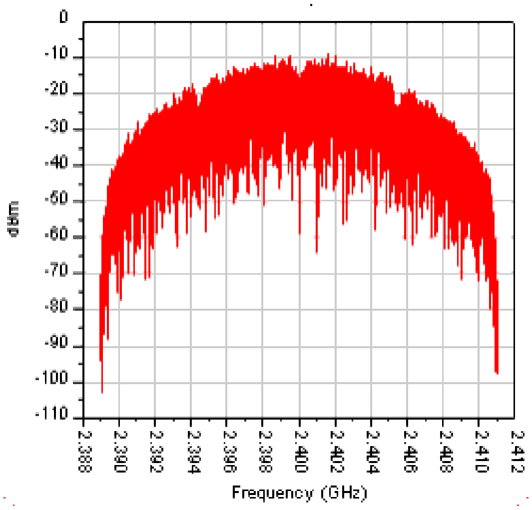
Simulation Results

Simulation results displayed in WLAN_80211b_PBCC.dds are the RF waveform data (see the first of the following two figures) and transmit spectrum (see the second figure).



time	WaveForm
0.0000 sec	2.058E-6 + j3.137E-6
45.45nsec	-6.011E-6 + j2.480E-6
90.91nsec	5.641E-6 + j2.934E-6
136.4nsec	-7.705E-7 + j3.038E-6
181.8nsec	-1.243E-6 + j5.317E-6
227.3nsec	-4.821E-6 - j3.187E-6
272.7nsec	-3.869E-6 - j1.586E-6
318.2nsec	-6.791E-6 + j9.826E-7
363.6nsec	7.954E-7 + j1.370E-6
409.1nsec	-3.904E-6 - j4.929E-6
454.5nsec	-1.942E-6 - j7.058E-7
500.0nsec	-9.283E-7 + j1.706E-6
545.5nsec	-7.661E-6 - j1.406E-6
590.9nsec	-7.923E-7 - j4.933E-6
636.4nsec	1.630E-6 - j5.534E-6
681.8nsec	1.771E-6 - j3.492E-6
727.3nsec	-4.877E-6 + j7.501E-7
772.7nsec	-1.549E-6 - j1.579E-6
818.2nsec	1.119E-6 + j4.313E-6
863.6nsec	-1.041E-5 - j1.056E-6
909.1nsec	6.680E-6 - j5.147E-6
954.5nsec	-5.793E-6 + j7.082E-6
1.000usec	8.820E-6 - j3.848E-8
1.045usec	2.600E-6 - j9.620E-6
1.091usec	2.315E-6 + j1.565E-6
1.136usec	-4.045E-6 - j2.877E-6
1.182usec	-1.770E-6 + j2.324E-6
1.227usec	5.527E-6 + j3.649E-6
1.273usec	-2.879E-7 + j1.220E-6
1.318usec	-7.034E-6 + j2.589E-6
1.364usec	-1.707E-6 + j1.698E-6
1.409usec	5.259E-6 - j6.744E-6
1.455usec	4.439E-6 + j1.499E-6
1.500usec	1.189E-6 - j2.374E-6
1.545usec	-1.869E-6 + j3.307E-6
1.591usec	-1.452E-6 - j5.550E-6
1.636usec	-3.720E-7 + j2.498E-7
1.682usec	-3.265E-6 + j9.255E-7

RF Waveform Data of 802.11b PBCC Modulation Signal Source



RF Transmit Spectrum of 802.11b PBCC Modulation Signal Source

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002
- Simulation time: approximately 1 minute

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

80211b Transmitter

Introduction

WLAN_80211b_Tx_wrk IEEE 802.11b transmitter test and verification design examples are described in this section.

- WLAN_80211b_TxEVM: measures error vector magnitude and tests the transmit modulation accuracy.

Error Vector Magnitude Measurements

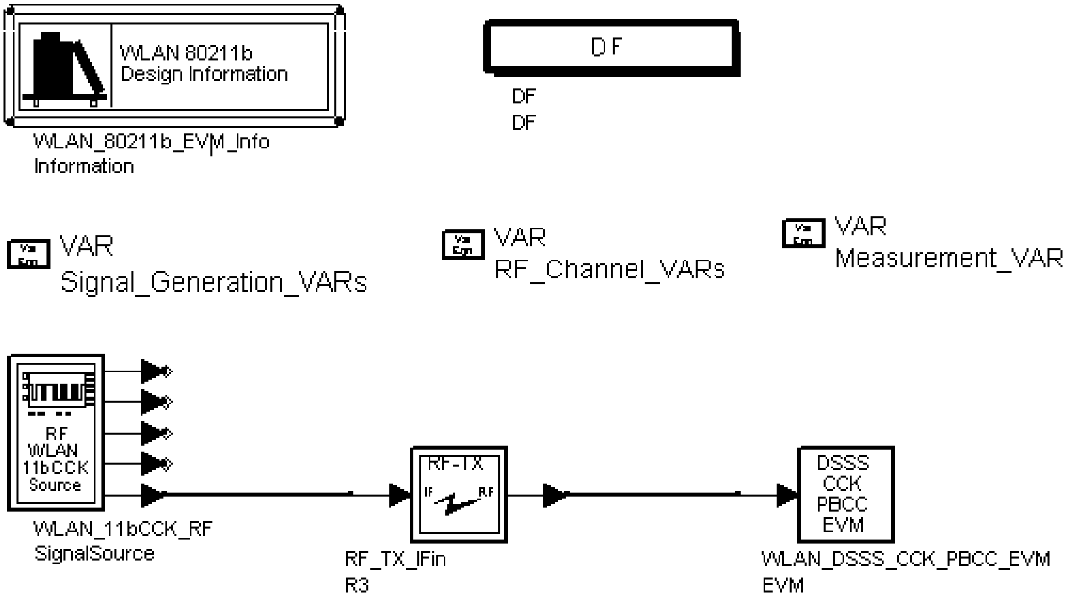
WLAN_80211b_TxEVM

Features

- IEEE 802.11b configurable signal source, adjustable data rate
- Adjustable sample rate
- CCK modulation

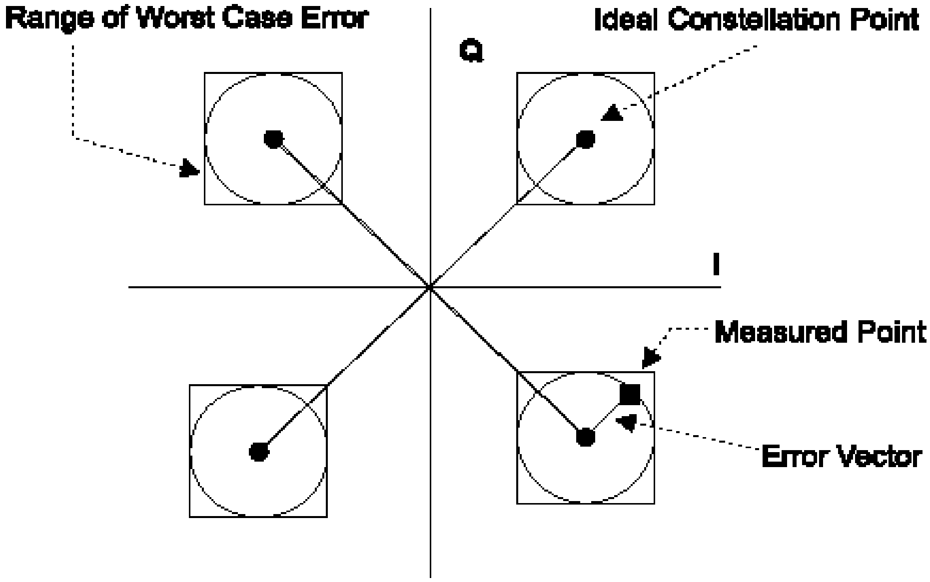
Description

This design tests IEEE 802.11b transmit modulation accuracy by measuring the EVM. The schematic for this design is shown in the following figure.



WLAN_80211b_TxEVM Schematic

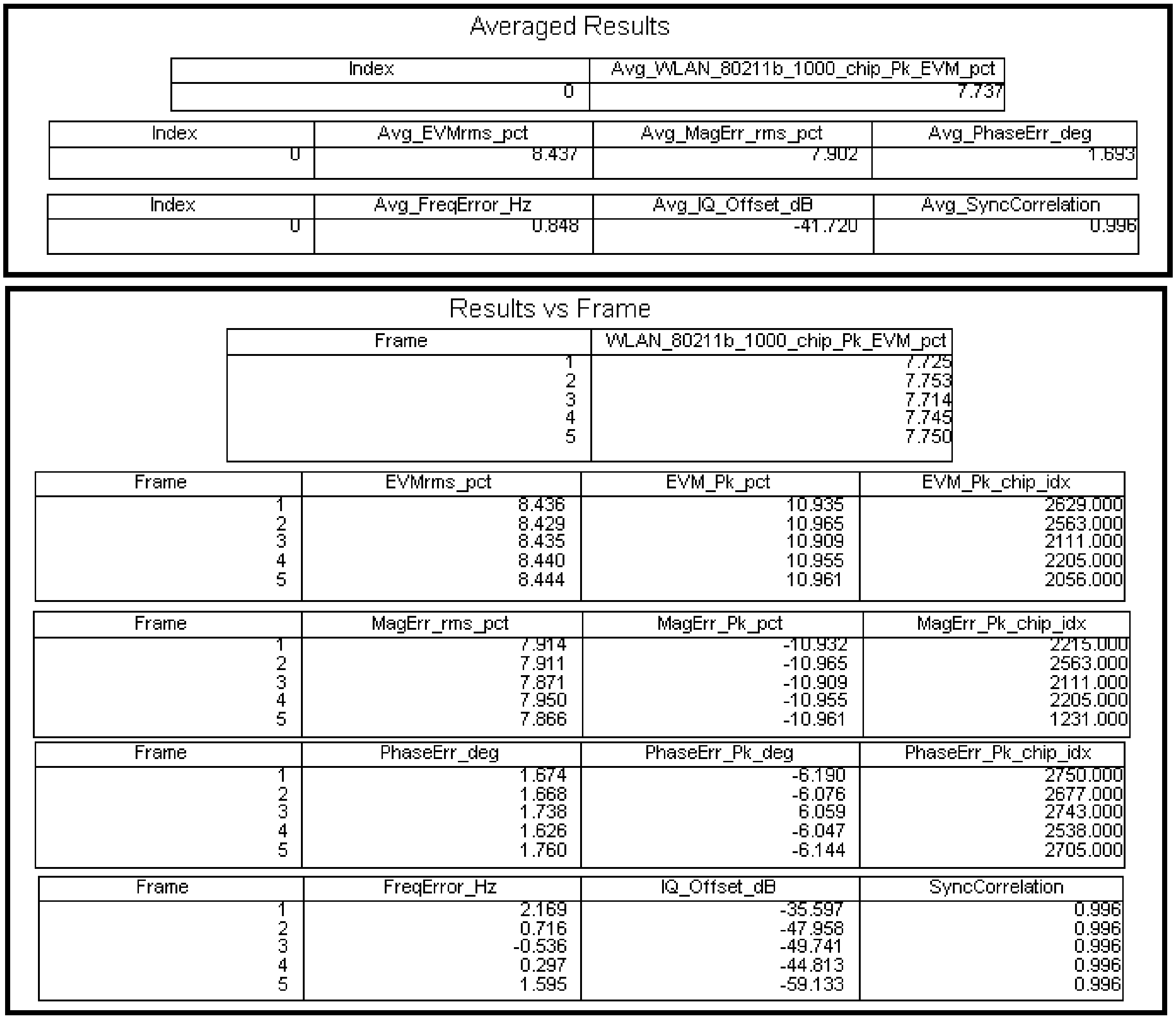
Measurements in this design are based on IEEE Standard 802.11b-1999 section 18.4.7.8. The transmit modulation accuracy requirement for the High Rate PHY is based on the difference between the actual transmitted waveform and the ideal signal waveform. Modulation accuracy is determined by measuring the peak vector error magnitude during each chip period. Worst-case vector error magnitude cannot exceed 0.35 for the normalized sampled chip data. The ideal complex I and Q constellation points associated with DQPSK modulation, (0.707,0.707), (0.707, -0.707), (-0.707, 0.707), (-0.707, -0.707), must be used as the reference. These measurements must be from baseband I and Q sampled data after recovery through a reference receiver system. The measurement example is shown in the following figure.



Modulation Accuracy Measurement Example

Simulation Results

Simulation results displayed in WLAN_80211b_TxEVM.dds are shown in the following figure. The EVM results are smaller than the specification requirements.



Averaged Results

Index	Avg_WLAN_80211b_1000_chip_Pk_EVM_pct
0	7.737

Index	Avg_EVMrms_pct	Avg_MagErr_rms_pct	Avg_PhaseErr_deg
0	8.437	7.902	1.693

Index	Avg_FreqError_Hz	Avg_IQ_Offset_dB	Avg_SyncCorrelation
0	0.848	-41.720	0.996

Results vs Frame

Frame	WLAN_80211b_1000_chip_Pk_EVM_pct
1	7.725
2	7.753
3	7.714
4	7.745
5	7.750

Frame	EVMrms_pct	EVM_Pk_pct	EVM_Pk_chip_idx
1	8.436	10.935	2629.000
2	8.429	10.965	2563.000
3	8.435	10.909	2111.000
4	8.440	10.955	2205.000
5	8.444	10.961	2056.000

Frame	MagErr_rms_pct	MagErr_Pk_pct	MagErr_Pk_chip_idx
1	7.914	-10.932	2215.000
2	7.911	-10.965	2563.000
3	7.871	-10.909	2111.000
4	7.950	-10.955	2205.000
5	7.866	-10.961	1231.000

Frame	PhaseErr_deg	PhaseErr_Pk_deg	PhaseErr_Pk_chip_idx
1	1.674	-6.190	2750.000
2	1.668	-6.076	2677.000
3	1.738	6.059	2743.000
4	1.626	-6.047	2538.000
5	1.760	-6.144	2705.000

Frame	FreqError_Hz	IQ_Offset_dB	SyncCorrelation
1	2.169	-35.597	0.996
2	0.716	-47.958	0.996
3	-0.536	-49.741	0.996
4	0.297	-44.813	0.996
5	1.595	-59.133	0.996

EVM results

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002C
- Simulation time: approximately 4 minutes

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

80211b Receiver

Introduction

WLAN_80211b_Rx_wrk Workspace for IEEE 802.11b receiver test and verification design examples are described in this section.

- WLAN_80211b_RxMinInput_Sensitivity minimum receiver sensitivity measurement.
- WLAN_80211b_RxMaxInput_Sensitivity minimum receiver sensitivity measurement.

Specification Requirements

Receiver performance requirements are:

- Data rate: 11 Mbps
- Modulation type: CCK
- PSDU length: 1024 octets
- Minimum sensitivity: -76 dBm
- Maximum sensitivity -10 dBm

Receiver Minimum Input Level Sensitivity Measurement

WLAN_80211b_RxMinInput_Sensitivity

Features

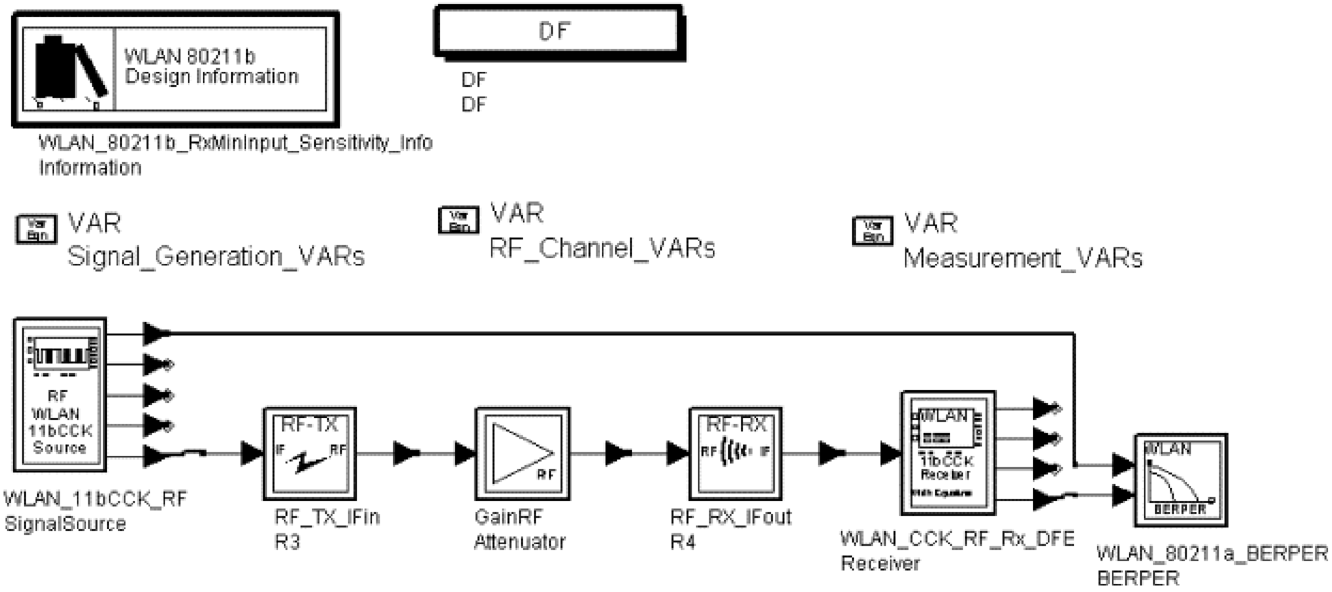
- Data rate is 11 Mbps
- CCK modulation
- PSDU Length is 1024 octets
- NF is 10 dB

Description

This design is an example of WLAN 802.11b receiver minimum input level sensitivity measurement. According to [1] 18.4.8.1, the packet error rate (PER) must be less than 8% at a PSDU length of 1024 octets for an input level of -76dBm measured at the antenna. This PER must be specified for 11 Mbps CCK modulation.

The schematic for this design is shown in the following figure. Parameters that can be changed by users are contained in Signal_Generation_VARs, RF_Channel_VARs, and

Measurement_VARs.



WLAN_80211b_RxMinInput_Sensitivity Schematic

Simulation Results

Simulation results displayed in WLAN_80211b_RxMinInput_Sensitivity.dds are shown in the following figure. BER and PER at given input levels are simulated.

Index	BER	PER
200	0.000	0.00

WLAN_80211b_RxMinInput_Sensitivity.dds

Benchmark

- Hardware platform: Pentium IV 1.8GHz, 512 MB memory
- Software platform: Windows 2000, ADS 2002c
- Simulation time: approximately 85 minutes

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the

2.4 GHz Band," 1999.

Receiver Maximum Input Level Sensitivity Measurement

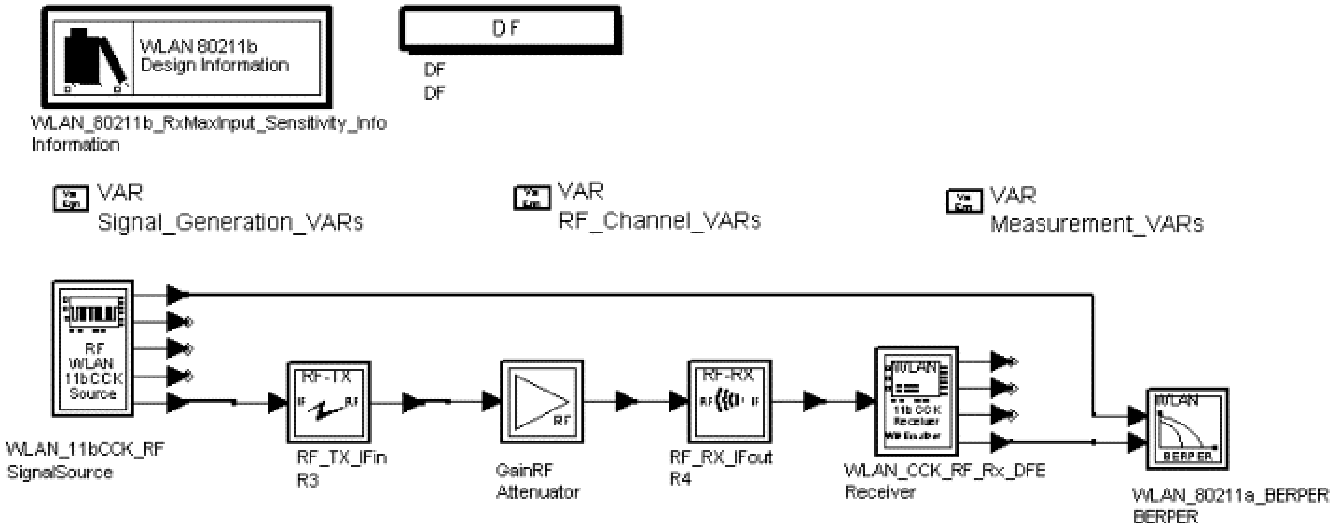
WLAN_80211b_RxMaxInput_Sensitivity

Features

- Data rate is 11 Mbps
- CCK modulation
- PSDU Length is 1024 octets
- NF is 10 dB

Description

This design is an example of WLAN 802.11b receiver minimum input level sensitivity measurement. According to [1] 18.4.8.1, the packet error rate (PER) must be less than 8% at a PSDU length of 1024 octets for a maximum input level of -10dBm measured at the antenna. This PER shall be specified for 11 Mbps CCK modulation. The schematic for this design is shown in the following figure. Parameters that can be changed by users are contained in Signal_Generation_VARs, RF_Channel_VARs, and Measurement_VARs.



WLAN_80211b_RxMaxInput_Sensitivity Schematic

Simulation Results

Simulation results displayed in WLAN_80211b_RxMaxInput_Sensitivity.dds are shown in the following figure. BER and PER at given input levels are simulated.

Index	BER	PER
200	0.000	0.00

WLAN_80211b_RxMaxInput_Sensitivity.dds

Benchmark

- Hardware platform: Pentium IV 1.8GHz, 512 MB memory
- Software platform: Windows 2000, ADS 2002C
- Simulation time: approximately 95 minutes

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

802.11b CCK BER and PER Performance

Introduction

WLAN_80211b_PER_wrk design examples are described in this section.

- WLAN_80211b_5_5Mbps_AWGN_System: BER and PER performance for 802.11b 5.5 Mbps systems with CCK modulation under AWGN channel.
- WLAN_80211b_11Mbps_AWGN_System: BER and PER performance for 802.11b 11 Mbps systems with CCK modulation under AWGN channel.

For any digital communication system, the relationship between received signal power to noise-power spectral density P_s/N_0 and received bit energy to noise-power spectral density E_b/N_0 is as follows:

$$\frac{P_s}{N_0} = \frac{E_b}{N_0}R_b$$

where Rb = data rate(bits/s), and solving for N_o in dBm/Hz, we can obtain,

$$N_0((dBm)/(Hz)) = P_s(dBm) - 10\times\log(R_b) - (E_b/N_0)(dB)$$

So, in WLAN_80211b_PER_wrk, we can achieve NDensity according to above function.

BER and PER Performance, AWGN Channel 5.5 Mbps

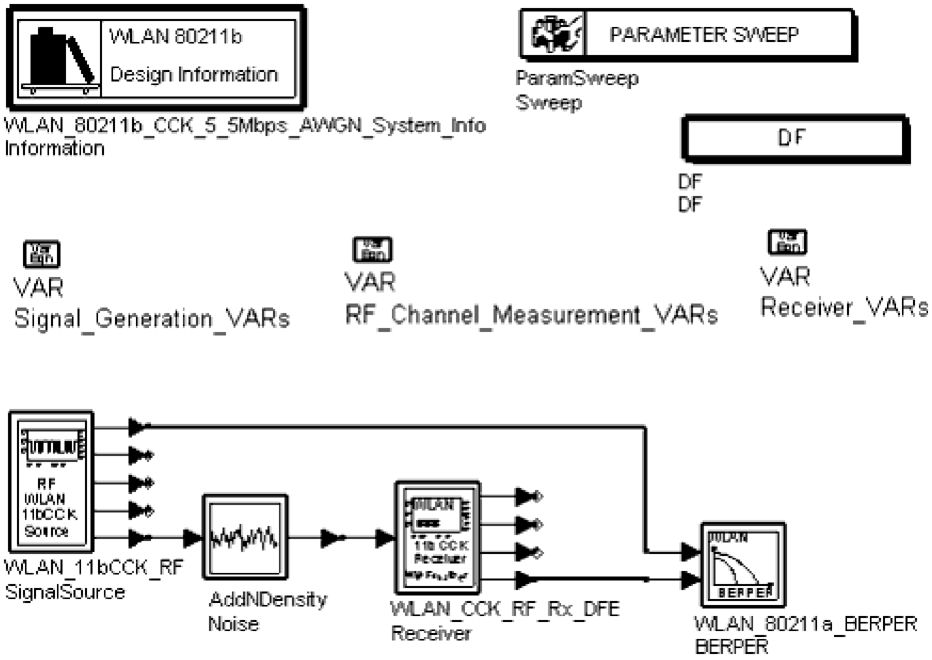
WLAN_80211b_5_5Mbps_AWGN_System

Features

- Data rate = 5.5Mbps, modulation = CCK
- Carrier frequency offset between transmitter and receiver is 50 kHz
- BER and PER vs. Eb/N0 on AWGN channel curves are displayed

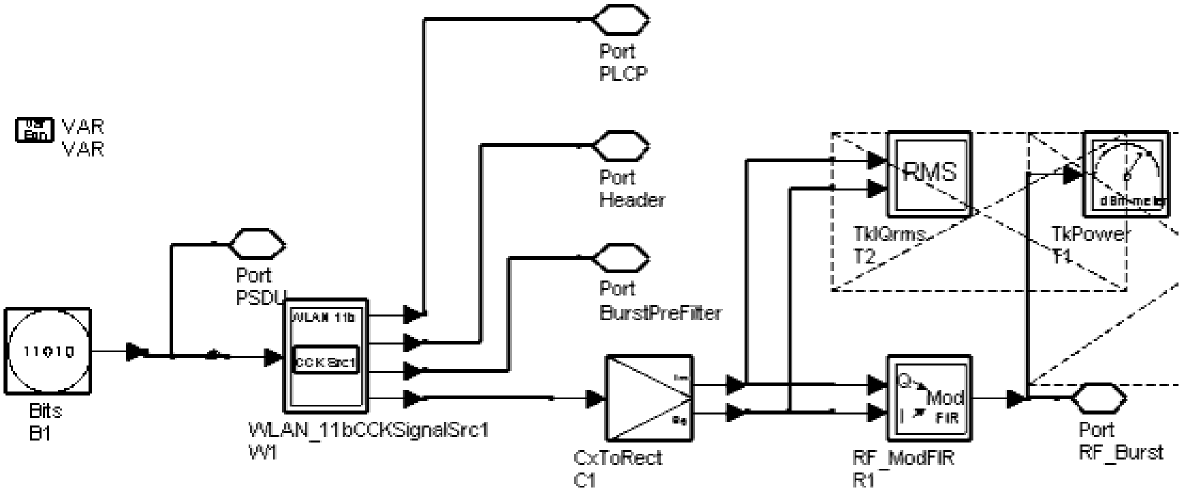
Description

This design shows system performance of 802.11b with 5.5Mbps data rate and CCK modulation on an AWGN channel. A burst length of 500 bytes is simulated.
The top-level schematic is shown in the following figure. This design contains SignalSource, Noise, Receiver, and BERPER subnetworks. SignalSource parameters are contained in Signal_Generation_VARs; Noise and BERPER parameters are contained in RF_Channel_Measurement_VARs; Receiver parameters are contained in the Receiver_VARs.



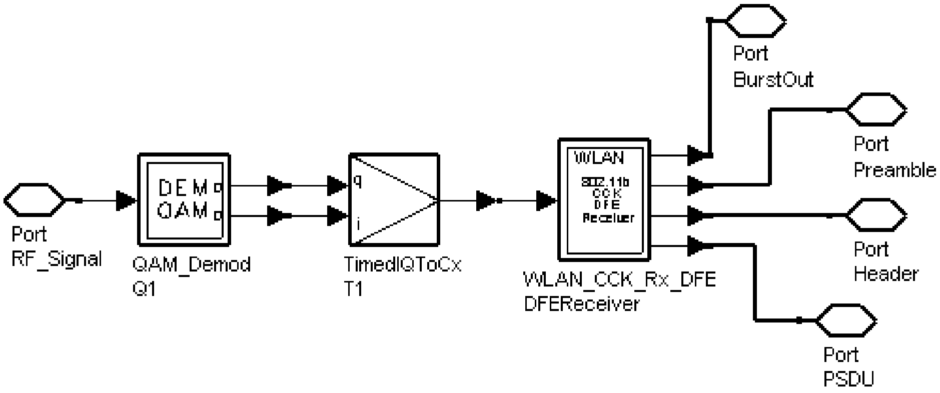
WLAN_80211b_5_5Mbps_AWGN_System Schematic

The SignalSource subnetwork (see the following figure) generates a signal source based on user settings.



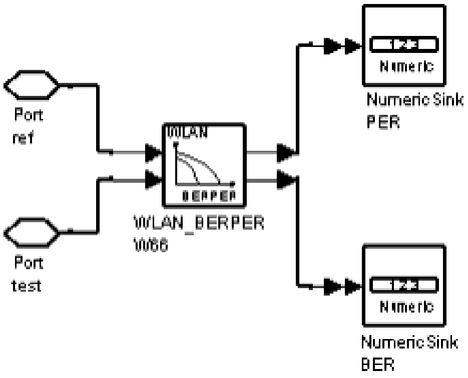
Signal Source Subnetwork Schematic

The Receiver subnetwork (see the following figure) receives an RF signal and demodulates the signal as bit streams; it also detects the start of frame and completes the transition from received sequences to frequency offset estimation sequences, estimates the frequency offset caused by the carrier differences between transmitter and receiver. A decision feedback equalized is implemented to equalize the received signal and remove the fixed rotation caused by frequency offset. The equalized signal is then fed into the CCK demodulator and demodulated into bit streams.



Receiver Subnetwork Schematic

The BERPER subnetwork, (see the following figure) measures system BER and PER.

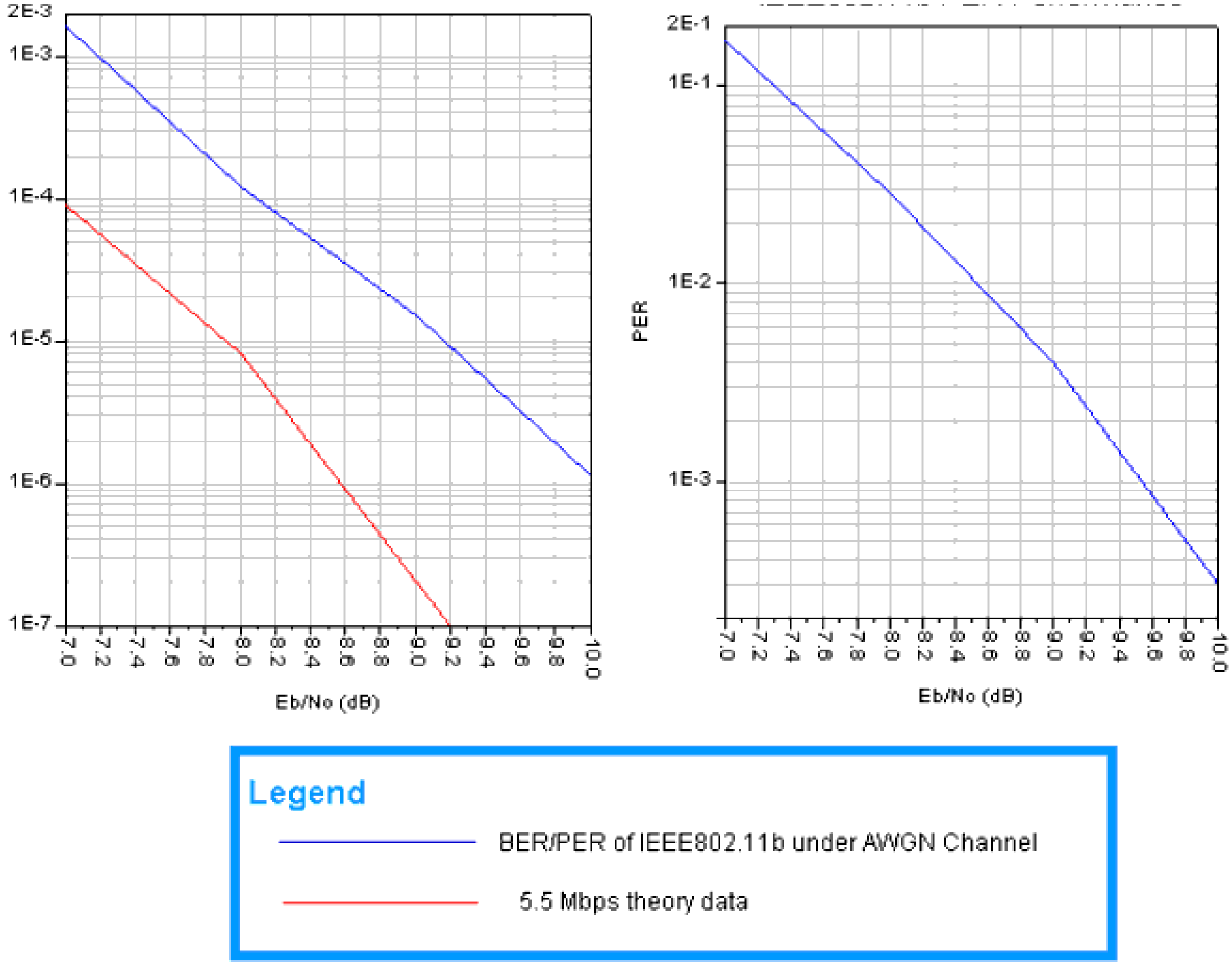


BERPER Subnetwork Schematic

Simulation Results

Simulation results displayed in WLAN_80211b_5_5Mbps_AWGN_System.dds are shown in the following figure.

Reference data points are shown in page Equations.



Simulation Results

Benchmark

- Hardware platform: Pentium IV, 1.8 GHz, 512 MB memory
- Software platform: Windows XP, ADS 2003A
- Data points: Eb/N0 values is set from 7 to 10 dB
- Simulation time: 1.5 hours

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4GHz Band," 1999.
2. Intersil, "Direct Sequence Spread Spectrum Baseband Processor with Rake Receiver and Equalizer," Data Sheet, FN4856.2, December 2001.

BER and PER Performance, AWGN Channel 11 Mbps

WLAN_80211b_11Mbps_AWGN_System

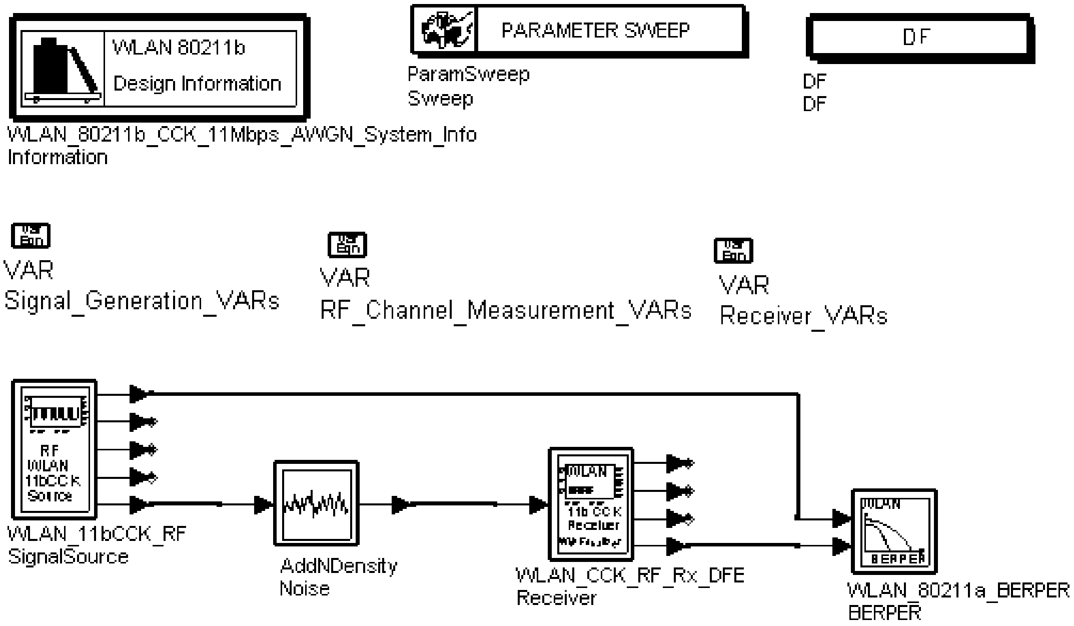
Features

- Data rate = 11 Mbps, modulation = CCK
- Carrier frequency offset between transmitter and receiver = 50 kHz
- BER and PER vs. Eb/N0 on AWGN channel curves are displayed

Description

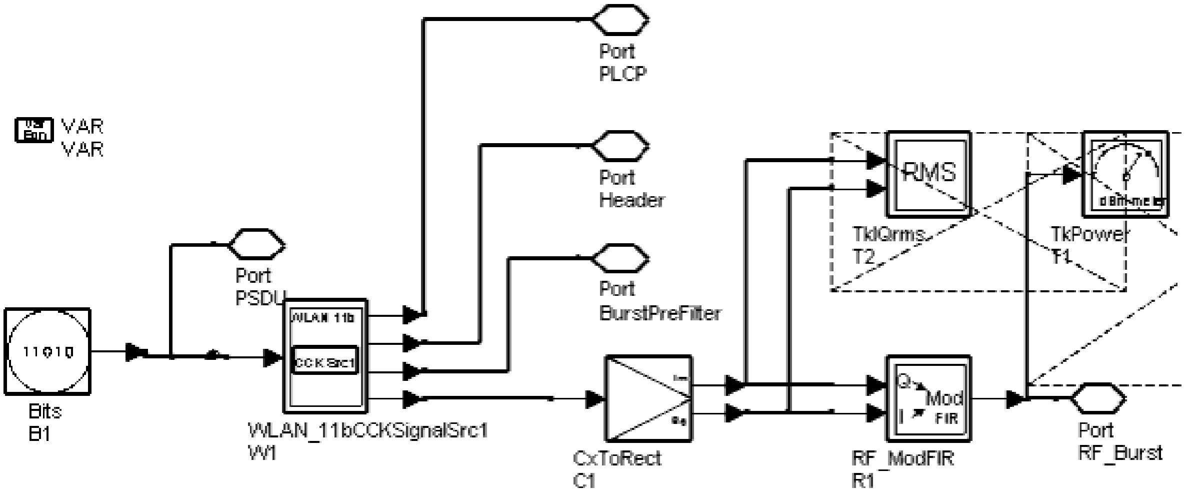
This design shows system performance with 11 Mbps data rate and CCK modulation on an AWGN channel. A burst length of 500 bytes is simulated.

The top-level schematic is shown in the following figure. This design contains SignalSource, Noise, Receiver, and BERPER subnetworks. SignalSource parameters are contained in Signal_Generation_VARs; Noise and BERPER parameters are contained in RF_Channel_Measurement_VARs; Receiver parameters are contained in Noise_Vars.



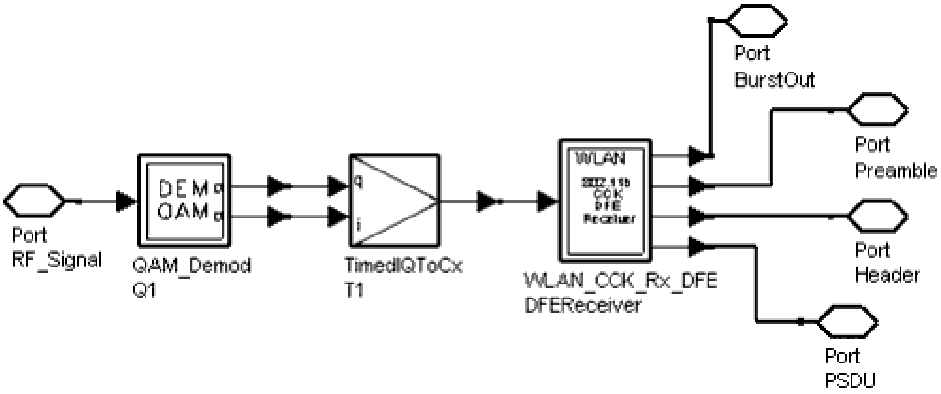
WLAN_80211b_11Mbps_AWGN_System Schematic

The SignalSource subnetwork (see the following figure) generates a signal source based on user settings.



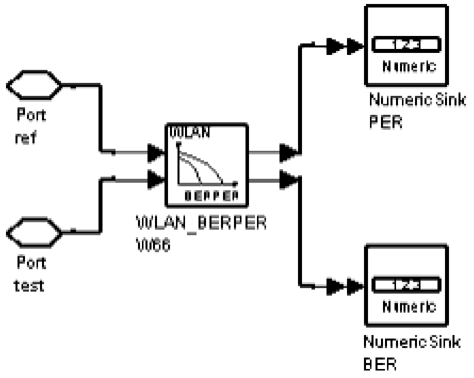
Signal Source Subnetwork Schematic

The Receiver subnetwork (see the following figure) receives an RF signal and demodulates the signal into bit streams; it also detects the start of frame and completes the transition from received sequences to frequency offset estimation sequences, estimates the frequency offset caused by the carrier differences between transmitter and receiver. A decision feedback equalized is implemented to equalize the received signal and remove the fixed rotation caused by frequency offset. The equalized signal is then fed into the CCK demodulator and demodulated into bit streams.



Receiver Subnetwork Schematic

The BERPER subnetwork (see the following figure) measures system BER and PER.

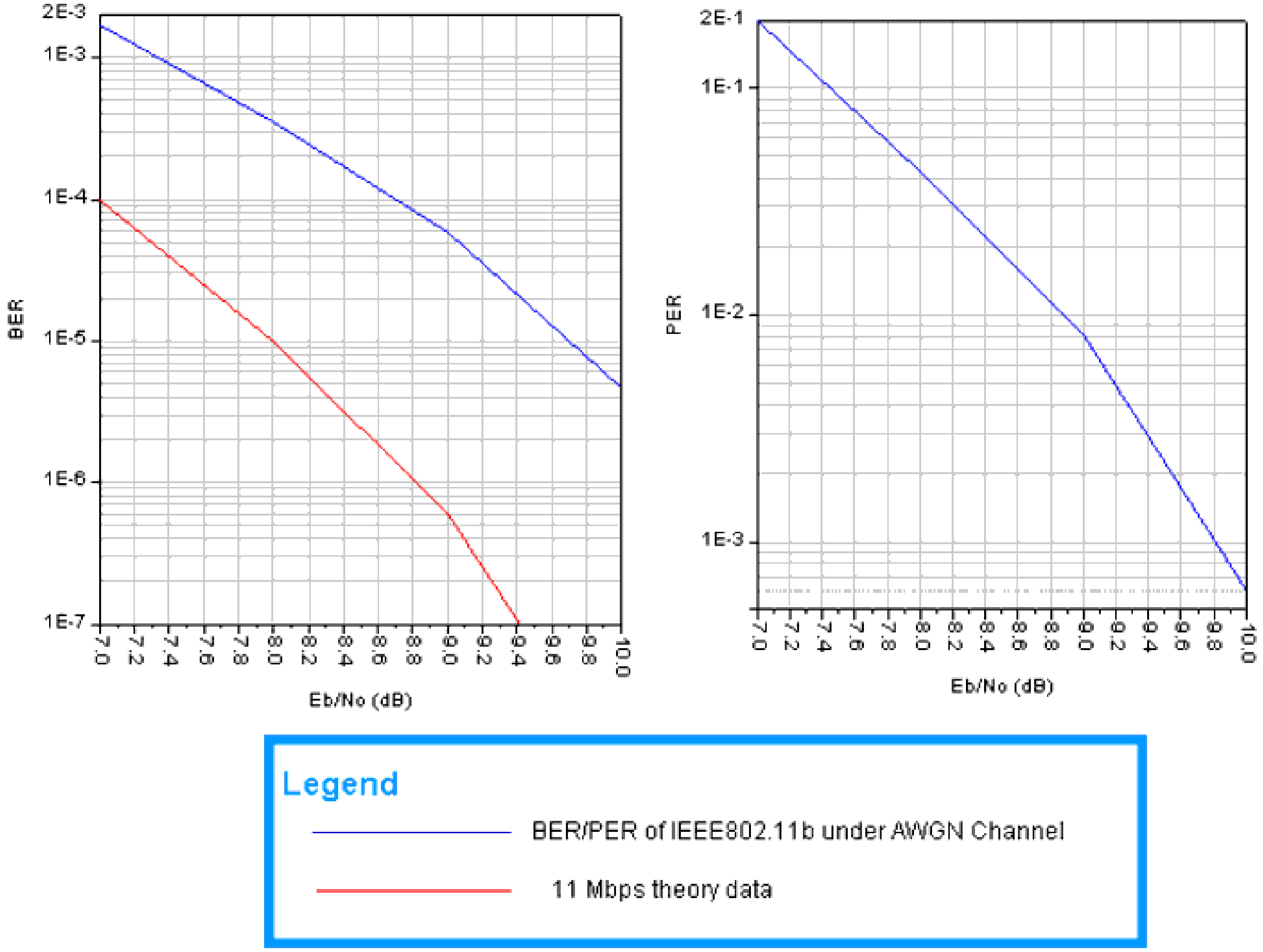


BERPER Subnetwork Schematic

Simulation Results

Simulation results displayed in WLAN_80211b_11Mbps_AWGN_System.dds are shown in the following figure.

Reference data points are shown in page Equations.



Simulation Results

Benchmark

- Hardware platform: Pentium IV, 1.8 GHz, 512 MB memory
- Software platform: Windows XP, ADS 2003A
- Data points: Eb/N0 values is set from 7 to 10 dB
- Simulation time: 1.5 hours

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4GHz Band," 1999.
2. IIntersil, "Direct Sequence Spread Spectrum Baseband Processor with Rake Receiver and Equalizer," Data Sheet, FN4856.2, December 2001.

80211b Transmitter Test Using Instrument Links

Introduction

WLAN_80211b_ESGc_wrk Workspace for IEEE 802.11b transmitter test design example is described in this section.

- WLAN_80211b_CCK_ESG4438C for generating CCK signal and sending the CCK signal to ESG 4438C to test WLAN CCK transmitter components.
- WLAN_80211b_25M_ESGc for providing adjacent channel test environment for testing CCK transmitter components.

Specification Requirements

Transmitter performance requirements are:

- Data rate: 11 Mbps
- Modulation type: CCK
- PSDU length: 1024 octets
- Modulation accuracy - EVM: 35%

Basic Transmitter System Test Using ADS-ESGc Link

WLAN_80211b_CCK_ESG4438C

Signal Parameters

- Data rate is 5.5 Mbps
- CCK modulation
- PSDU length is 100 octets

Description

This design demonstrates how to use the ADS-ESGc link to test a WLAN 802.11b/802.11g CCK transmitter system. Hardware and software requirements and setup information are provided.

Hardware Requirements

- Agilent E4438C signal generator with 100 MHz clock rate and 6 GHz carrier frequency.
- Agilent 89641A Vector Signal Analyzer (VSA) with 6 GHz carrier frequency or 89640A with 2.7 GHz carrier frequency.

Software Requirements

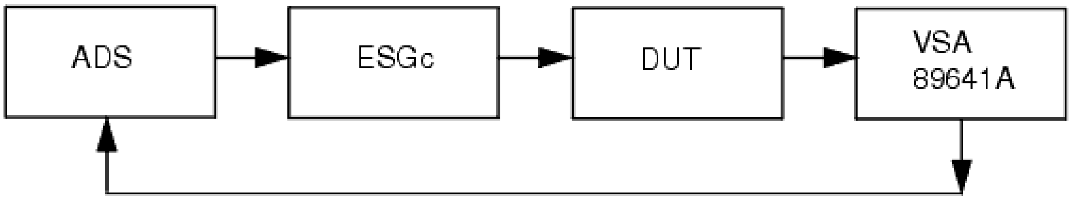
- Advanced Design System (ADS) version 2003A with WLAN option
  - To run complex designs of WLAN systems 500 MB RAM and 500 MB virtual space is required.
- Agilent Instrument Library version 2003A with GPIB and/or LAN interface component model.

PC Setup and Software Installation

1. Install ADS version 2003A or later version on your PC (Win2000, XP)
2. Install the WLAN Design Library.
3. Install ADS instruments library and set up the IO library using VISA layer for communicating to instruments

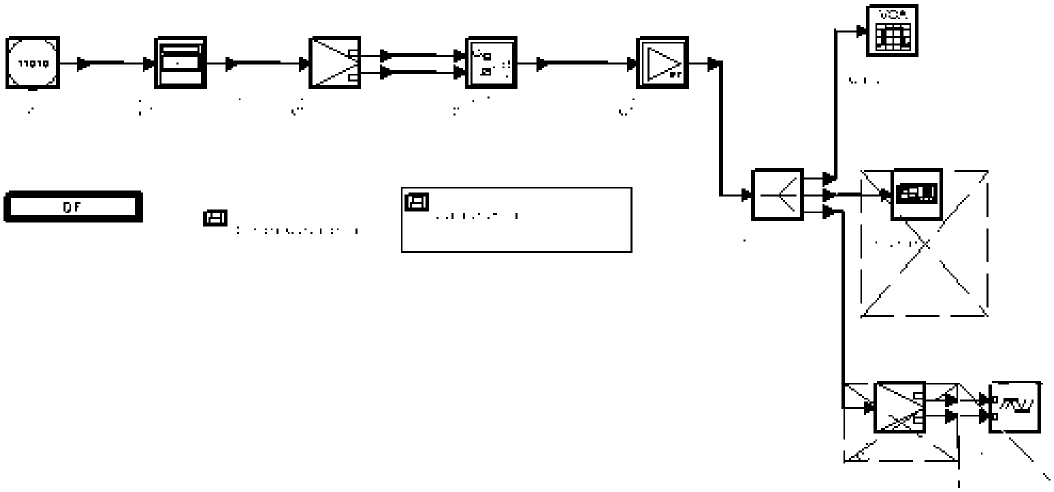
WLAN-ESGC link Setup

1. Connect ADS, ESGC, the device under test (DUT), and Agilent 89641A (or 89640A) as shown in the following figure. With this setup users can bring waveforms captured from VSA back to ADS for performing BER/PER performance in ADS.



Transmitter Test System setup for WLAN 802.11b System

2. Switch on all instruments and the PC.
3. Start ADS and load schematic design WLAN_80211b_CCK_E4438C for signal generation as shown in the following figure.



Signal Generation Design for CCK Transmitter

In the design, the model WLAN 802.11b/802.11g CCK signal source with hierarchical structure can generate an RF WLAN CCK signal with specific data rate, burst length, symbol clock, carrier frequency, and power. All signal parameters can be easily modified in the top level of the design. Two Var blocks (Signal Generation and RF_Measurement) are designed for ease of setting key parameters.The data rate is set to 5.5 Mbps. The signal is sent to ESG4438CSink E1, the ADS-ESGc interface for driving the Arb signal generator in ESGc.

Key parameters for the ESG4438Csink E1 must be set properly.

- *Interface* is the HPIB/GPIB interface or IP address. In this example we use the IP address to set this parameter Interface=141.121.237.165 (IP address).
- *Address* is the instrument address. We set it to 20 (the ESGc address).
- *Start* and *Stop* define the signal sequence length sent to ESGc that must be carefully set to keep the signal sequence contents an integer number of burst. In the example Workspace, *Start* is set to 0, and *Stop* is set by an equation in RF_Var block.
  Stop is calculated as described next.
  Stop=[RampTime × 11e6 × 2+Idletime × 11e6+PLCP+PSDU]*Ratio;
  where Ramptime and Ideltime in μ are the 11b Signal Source parameters, PLCP = 192 × 11 for Long PLCP preamble, PLCP = (72+48/2) × 11 for short PLCP preamble.
  PSDU = Octets × 8 × 2 for 5.5 Mbps, PSDU = Octets × 8 for 11 Mbps.
  Ratio is determined by the 11b Signal Source parameter, Oversampling:
  Ratio=2: OverSampling=0
  Ratio=2.5: OverSampling=1
  Ratio=3: OverSampling=2
  Ratio=3.5: OverSampling=3
  Ratio=4: OverSampling=4
  Ratio=4.5: OverSampling=5
  Ratio=5: OverSampling=6
  Ratio=5.5: OverSampling=7
  Ratio=6: OverSampling=8
  Ratio=6.5: OverSampling=9
  Ratio=7: OverSampling=10
  Ratio=7.5: OverSampling=11
  Ratio=8: OverSampling=12

ESGc Settings

ARB generator in ESGc is driven by WLAN RF signal source in ADS through HPIB/LAN.
Follow the ESGc setup sequence

ARB Settings

1. Press panel button **Mode** > **Dual ARB**
2. Press **ARB on/off** to **ARB off**
3. Press **ARB set up**
4. Set the **ARB sample clock** to **80 MHz** for this example
5. Set the **ARB Reference** to **Int**
6. Set the **Reconstruction Filter** to **Through**
7. Press **Select/Waveform** and select the name of the file defined in the model ESG4438CSink, for example **wlan_24**
8. Press panel button **Mod On/Off** to ensure **Mod On**
9. Press panel button **RF On/Off** to ensure **RF On**
10. Press **Frequency** and set to **2.4 GHz**
11. Press **Amplitude** and set to **-5dBm**
12. Press **ARB On/Off** to ensure **ARB On**

Set up the design under test.

1. The DUT can be any component in a transmitter. As an example, we test a power amplifier as the DUT. The expected performances are listed are: output power 15 dBm for carrier 2.4 GHz.
2. Connect the input to the ESGc and Output to VSA89641A.
3. Make sure the power supply is set properly and turned on.

VSA 89641A Settings

The VSA 89641A must be connected to a PC that has an IEEE 1394 card and VSA software with WLAN flavor (option B7R) installed. When installing the VSA software, the IEEE 1374 option must be turned on.
Set up the measurement settings:

1. Click **MeasSetUp,** then set the demodulator type by clicking **Modulator** , then select **Wireless Networking** > **DSSS/CCK/PBCC**
2. Set frequency:
    - Click **Frequency** , then enter the correct **center frequency** and frequency **span** (you can use the **full span** button).

Set up the input settings:

1. Click **Input** , then set **data format** to **hardware** .

The VSA software settings for transmission test can now be saved as a set file for example, *11b.set* . The saved set file can then be called and will use the above settings. A set file has been made that can be found in the data directory under this Workspace; make sure you use the correct set file.

Under this setting, the EVM is measured to see if the power amplifier can be used as a transmitter power amplifier based on IEEE 802.11b std. Simulation results are compared to the standard.

Simulation Results

EVM = 3%, that is less than the standard value 35%.

Benchmark

- Hardware platform: Pentium IV 1.8GHz, 512 MB memory
- Software platform: Windows 2000, ADS 2002C
- Simulation time: approximately 10 minutes

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

Transmitter Test Under Adjacent Channel Environment

WLAN_80211b_25M_ESGc

Features

- Data rate is 11 Mbps
- CCK modulation
- PSDU length is 1024 octets
- In-channel carrier: 2.412 MHz, adjacent channel carrier: 2.437 MHz
- Adjacent channel power is 35 dB higher than in-channel

Description

This design tests a WLAN IEEE 802.11b CCK transmitter under adjacent channel environment. Hardware and software requirements and setup information are provided.

Hardware Requirements

- Agilent E4438C Signal generator with 100 MHz clock rate and 6 GHz carrier frequency.
- Agilent 89641 A Vector Signal Analyzer (VSA) with 6GHz carrier or Agilent 89640A with 2.7 GHz carrier frequency plus PSA E4440A as a down-converter.

Software Requirements

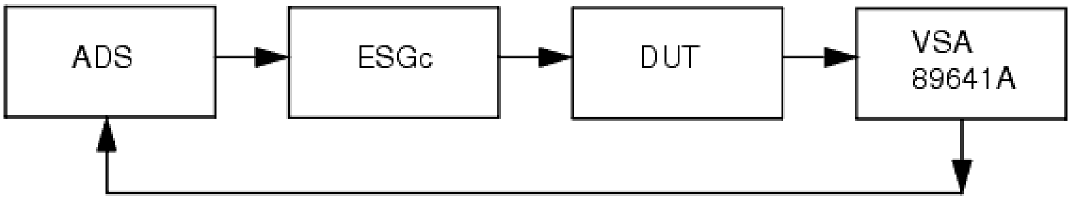
- Advanced Design System (ADS) version 2003A or later with WLAN option
  - To run complex designs of WLAN systems 500 MB and 500 M bytes virtual space is required.
- Agilent Instrument Library version 2003A with GPIB and/or LAN interface component model.

PC Setup and Software Installation

1. Install ADS version 2003A or later version on your PC (Win2000, XP).
2. Install WLAN library.
3. Install ADS instruments library for and set up the IO library using VISA layer for communicating to instruments.

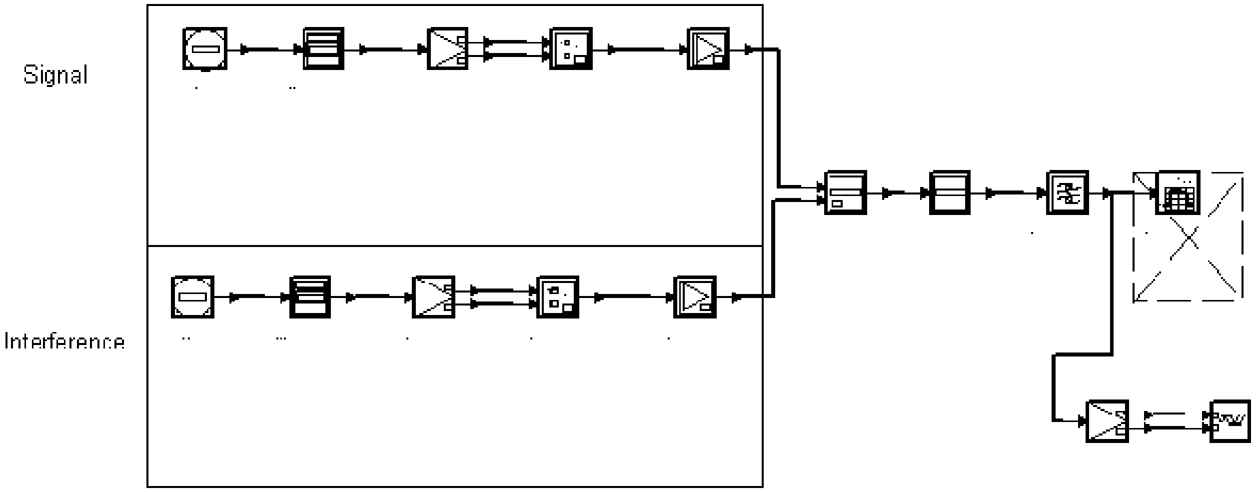
WLAN-ESGC Link Setup

1. Connect ADS, ESGC, the device under test (DUT), and Agilent 89641A as shown in the following figure. With this setup users can bring waveforms captured from VSA back to ADS for performing BER/PER performance in ADS.



Test Setup

2. Switch on all instruments and the PC.
3. Start ADS and load schematic design WLAN_80211b_CCK_E4438C for signal generation as shown in the following figure.



Signal Generation for Adjacent Channel Test

In the design, the model WLAN 802.11b/802.11g CCK Signal Source with hierarchical structure can generate an RF WLAN CCK signal with specific data rate, burst length, symbol clock, carrier frequency, and power. All signal parameters can be easily modified in the top level of the design. Two Var blocks (Signal Generation and RF_Measurement) are designed for ease of setting key parameters. The data rate is 5.5 M bps. The signal is sent to ESG4438CSink E1, the ADS-ESGc interface for driving the Arb signal generator in ESGc.
Key parameters for ESG4438Csink E1 must be set properly.

- *Interface* is the HPIB/GPIB interface or IP address. In this example we set Interface=141.121.237.165 (IP address).
- *Address* is the instrument address. We set it to 20 (the ESGc address).
- *Start* and *Stop* define the signal sequence length sent to ESGc that needs to be set very carefully to keep the signal sequence contents an integer number of burst. In our example Workspaces for transmitter and receiver tests, *Start* and *Stop* have been set automatically. For understanding the way to calculate them the process steps are described in the schematic design.

ESGc Settings

The ARB generator in ESGc is driven by the WLAN RF signal source in ADS through HPIB/LAN. Follow the ESGc setup sequence.
Set up the ARB.

1. Press panel button **Mode** > **Dual ARB**
2. Press **ARB on/off** to **ARB off**
3. Press **ARB set up**
4. Set the **ARB sample clock** to **80 MHz** for this example
5. Set the **ARB Reference** to **Int**
6. Set the **Reconstruction Filter** to **Through**
7. Press **Select/Waveform** and select the name of the file defined in the model ESG4438CSink, for example **wlan_24**

8. Press panel button **Mod On/Off** to ensure **Mod On**
9. Press panel button **RF On/Off** to ensure **RF On**
10. Press **Frequency** and set to **5.8 GHz**
11. Press **Amplitude** and set to **-5dBm**
12. Press **ARB On/Off** to ensure **ARB On**

Set up the design under test.

1. The DUT can be any component in a transmitter. As an example, we test a power amplifier called TT-64 as the DUT. The expected performances are: output power 17 dBm for carrier 5.8 GHz.
2. Connect the input to the ESGc and Output to VSA89641A.
3. Make sure the power supply is set properly and turned on.

VSA 89641a Settings

The VSA 89641A must be connected to a PC that has an IEEE 1394 card and VSA software with WLAN flavor (option B7R) installed. When installing the VSA software, the IEEE 1374 option must be turned on.
Set up the measurement settings:

1. Click **MeasSetUp** and set demodulator type by clicking **Modulator** ; then select **Wireless Networking** > **DSSS/CCK/PBCC.**
2. Set frequency:
    - Click **Frequency** and enter the correct **center frequency** and frequency **span** (you can use **full span** button).

Set up the input settings:

1. Click **Input** and set **data format** to **hardware** .

The VSA software settings for transmission test can now be saved as a set file; for example, *11b.set* . The saved set file can then be called and will use the above settings. A set file has been saved in the data directory under this Workspace: make sure you use the correct set file.

Simulation Results

Simulation results displayed in WLAN_80211b_RxMaxInput_Sensitivity.dds are shown in the following figure. BER and PER at given input levels are simulated.

Index	BER	PER
200	0.000	0.00

WLAN_80211b_RxMaxInput_Sensitivity.dds

Benchmark

- Hardware platform: Pentium IV 1.8 GHz, 512 MB memory
- Software platform: Windows 2000, ADS 2002C
- Simulation time: approximately 85 minutes

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

802.11g EVM and BER-PER Performance

Introduction

WLAN_ 80211g_wrk design examples are described in this section.

- WLAN_80211g_OFDM_TxEVM: measures error vector magnitude and relative constellation error and tests the transmit modulation accuracy for an OFDM signal.
- WLAN_80211g_CCK_TxEVM: measures error vector magnitude and relative constellation error and tests the transmit modulation accuracy for a CCK signal.
- WLAN_80211g_OFDM_36Mbps_Fading_System: BER and PER performance for 36 Mbps systems on a fading channel.
- WLAN_80211g_CCK_11Mbps_AWGN_System: BER and PER performance for 11 Mbps systems with CCK modulation on an AWGN channel.

Error Vector Magnitude and Relative Constellation Error Measurements

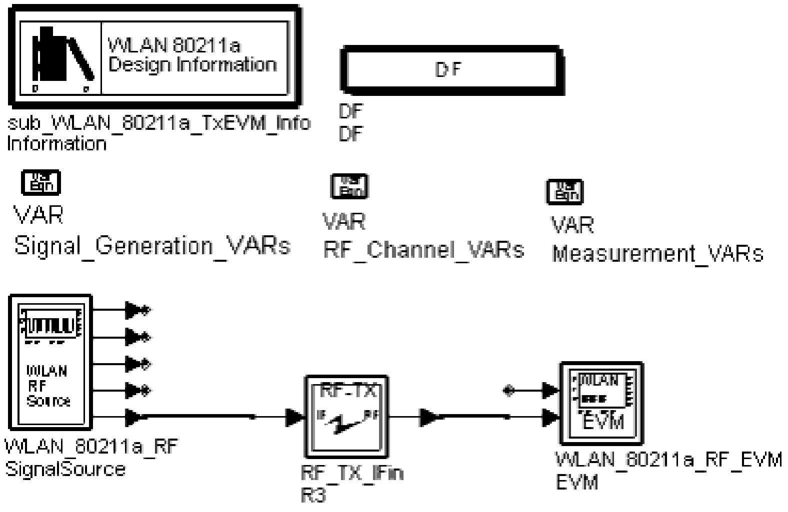
WLAN_80211g_OFDM_TxEVM

Features

- IEEE 802.11g configurable signal source, adjustable data rate
- Adjustable sample rate
- Constellation display
- Integrated RF section

Description

This design tests IEEE 802.11g transmit modulation accuracy and transmitter constellation error by measuring the EVM. The schematic for this design is shown in the following figure.



WLAN_80211g_OFDM_TxEVM Schematic

Measurements in this design are based on IEEE Standard 802.11a-1999 section 17.3.9.6. The transmit modulation accuracy test must be performed by instrumentation capable of converting the transmitted signal into a stream of complex samples at 20 Msamples per second or more, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, dc offsets, phase noise, and so on. A possible embodiment of such a setup is converting the signal to a low IF frequency with a microwave synthesizer, sampling the signal with a digital oscilloscope and decomposing it digitally into quadrature components.

The sampled signal must be processed in a manner similar to an actual receiver, according to the following, or equivalent steps:

- Start of frame must be detected.
- Transition from short sequences to channel estimation sequences must be detected, and fine timing (with one sample resolution) must be established.
- Coarse and fine frequency offsets must be estimated.
- The packet must be de-rotated according to estimated frequency offset.
- The complex channel response coefficients must be estimated for each subcarrier.
- For each data OFDM symbol: transform the symbol into subcarrier received values, estimate the phase from the pilot subcarriers, de-rotate the subcarrier values according to estimated phase, and divide each subcarrier value with a complex estimated channel response coefficient.
- For each data-carrying subcarrier, find the closest constellation point and calculate the Euclidean distance from it.
- Calculate the RMS average of all errors in a packet:

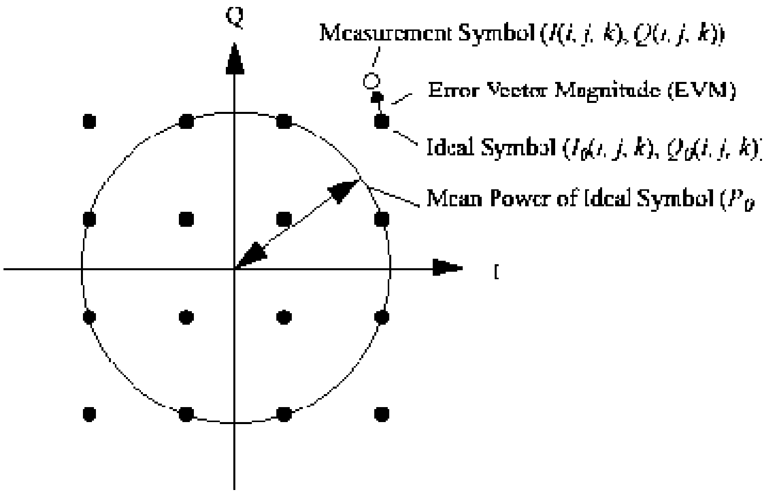
$$Error_{RMS} = \frac{\sum_{i=1}^{N_f} \sqrt{\frac{\sum_{j=1}\left[\sum_{k=1}\{(I(i,j,k)-I_0(i,j,k))^2+(Q(i,j,k)-Q_0(i,j,k))^2\}\right]}{52L_P \times P_0}}}{N_f}$$

where:

L_P is the length of the packet

N_f is the number of frames for the measurement

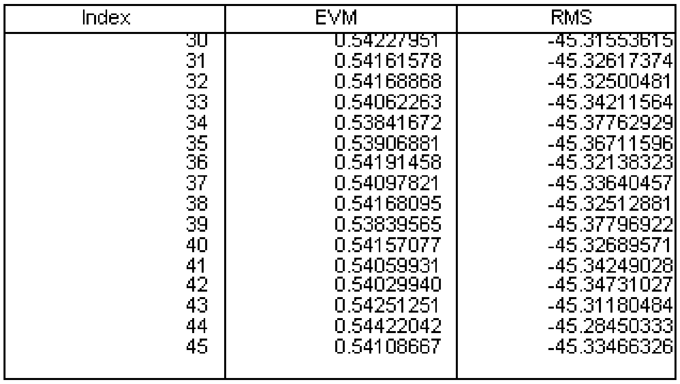
($I_0(i, j, k)$, $Q_0(i, j, k)$) denotes the ideal symbol point of the *i*th frame, *j*th OFDM symbol of the frame, *k*th subcarrier of the OFDM symbol in the complex plane ($I(i, j, k)$, $Q(i, j, k)$) denotes the observed point of the *i*th frame, *j*th OFDM symbol of the frame, *k*th subcarrier of the OFDM symbol in the complex plane (see the following figure).



Constellation Error

P_0 is the average power of the constellation.

The vector error on a phase plane is shown in the following figure.



Index	EVM	RMS
30	0.54227951	-45.31553615
31	0.54161578	-45.32617374
32	0.54168868	-45.32500481
33	0.54062263	-45.34211564
34	0.53841672	-45.37762929
35	0.53906881	-45.36711596
36	0.54191458	-45.32138323
37	0.54097821	-45.33640457
38	0.54168095	-45.32512881
39	0.53839565	-45.37796922
40	0.54157077	-45.32689571
41	0.54059931	-45.34249028
42	0.54029940	-45.34731027
43	0.54251251	-45.31180484
44	0.54422042	-45.28450333
45	0.54108667	-45.33466326

EVM and Relative Constellation Error of 54 Mbps

The test must be performed over at least 20 frames (N_f) and the RMS average must be taken. The packets under test must be at least 16 OFDM symbols long. Random data must be used for the symbols.

The EVM and relative constellation RMS error, averaged over subcarriers, OFDM frames, and packets, cannot exceed a data-rate dependent value according to the following table.

Allowed EVM and Relative Constellation Error

Data Rate (Mbps)	Relative Constellation Error (dB)	EVM (% RMS)
6	-5	56.2
9	-8	39.8
12	-10	31.6
18	-13	22.3
24	-16	15.8
36	-19	11.2
48	-22	7.9
54	-25	5.6

Simulation Results

Simulation results displayed in WLAN_80211g_TxEVM.dds are shown in the preceding figure for EVM and relative constellation error of 54 Mbps. The EVM is less than 0.6%; the constellation error is approximately -45dB which is much smaller than the specification requirements given in the preceding table.

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2001
- Simulation time: approximately 30 minutes

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.

Error Vector Measurement for a CCK Signal

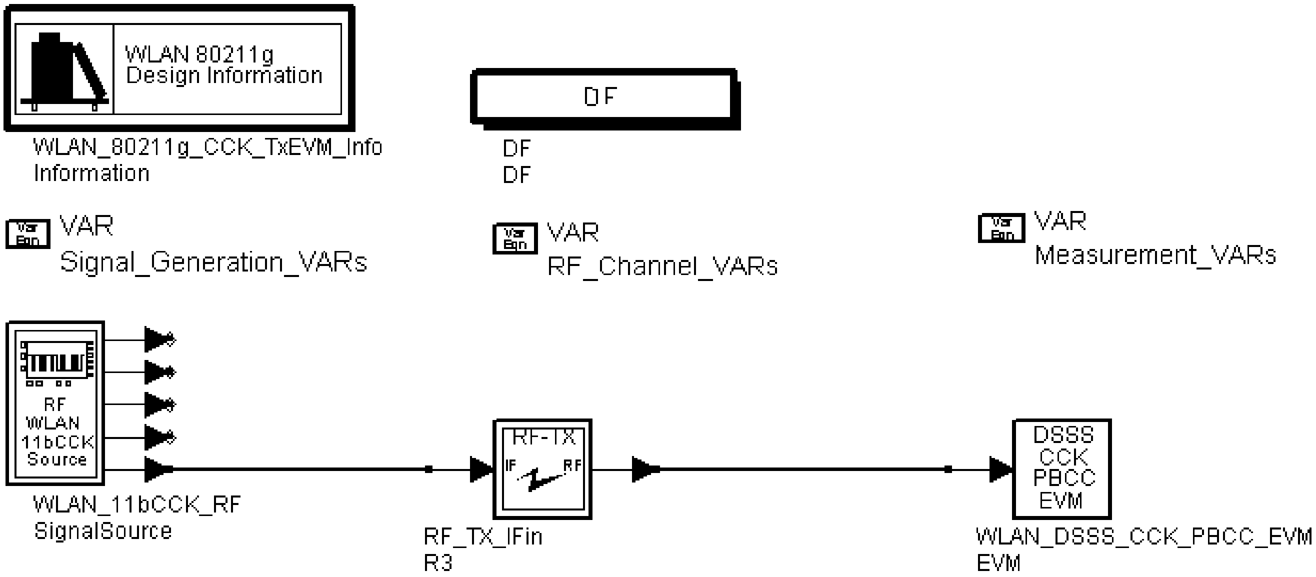
WLAN_80211g_CCK_TxEVM

Features

- IEEE 802.11g configurable signal source, adjustable data rate
- Adjustable sample rate
- CCK modulation

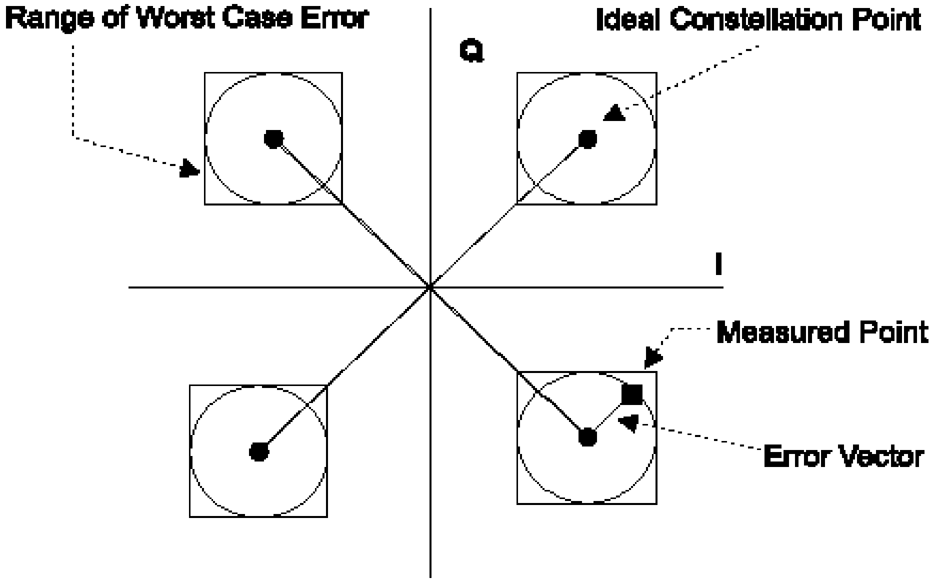
Description

This design tests IEEE 802.11g transmit modulation accuracy by measuring the EVM. The schematic for this design is shown in the following figure.



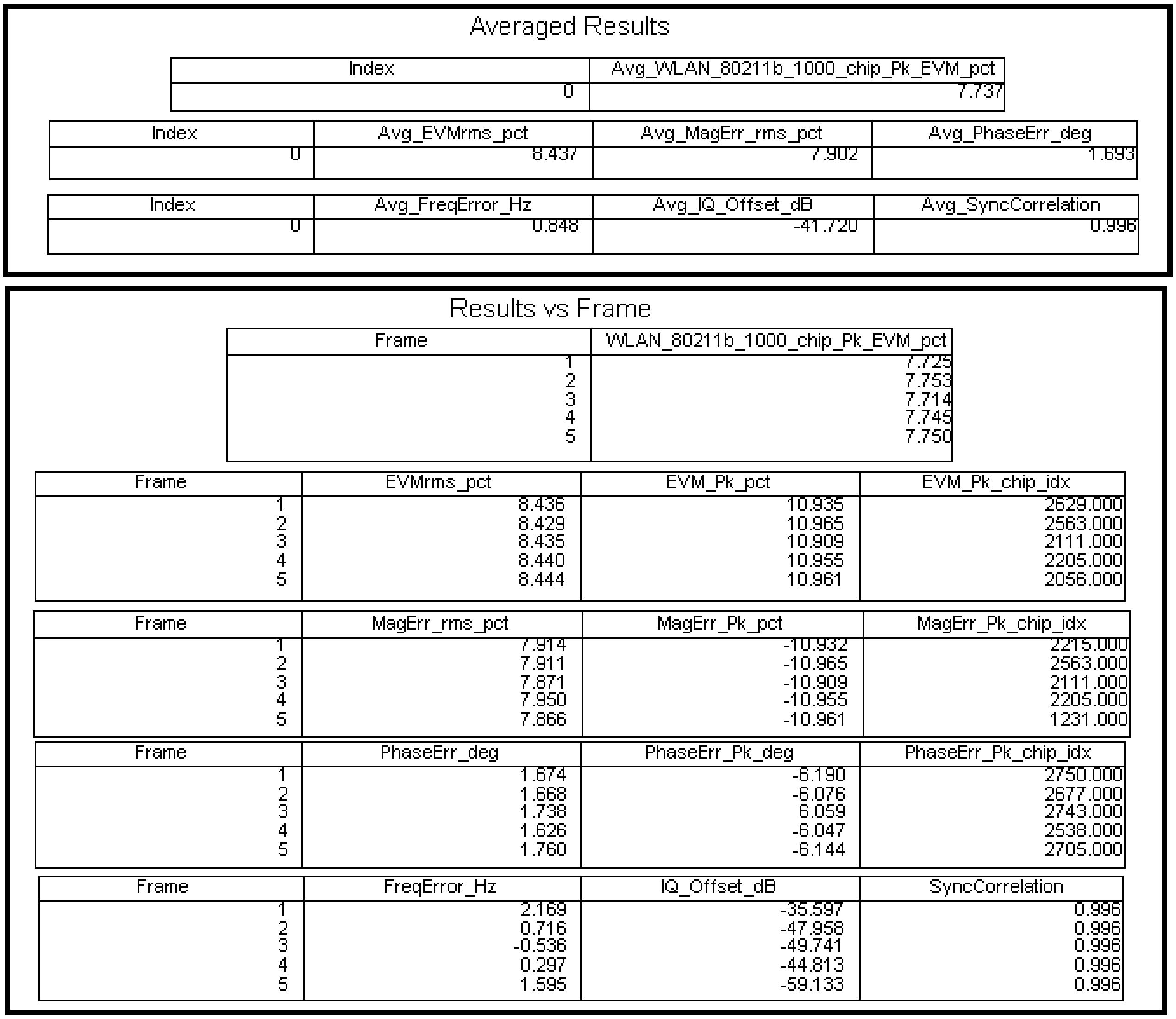
WLAN_80211g_CCK_TxEVM Schematic

Measurements in this design are based on IEEE Standard 802.11b-1999 section 18.4.7.8. The transmit modulation accuracy requirement for the high rate PHY is based on the difference between the actual transmitted waveform and the ideal signal waveform. Modulation accuracy is determined by measuring the peak vector error magnitude during each chip period. Worst-case vector error magnitude cannot exceed 0.35 for the normalized sampled chip data. The ideal complex I and Q constellation points associated with DQPSK modulation, (0.707,0.707), (0.707, -0.707), (-0.707, 0.707), (-0.707, -0.707), will be used as the reference. These measurements are from baseband I and Q sampled data after recovery through a reference receiver system. The measurement example is shown in the following figure.



Simulation Results

Simulation results displayed in WLAN_80211g_TxEVM.dds are shown in the following figure. The EVM results smaller than the specification requirements.



Averaged Results

Index	Avg_WLAN_80211b_1000_chip_Pk_EVM_pct
0	7.737

Index	Avg_EVMrms_pct	Avg_MagErr_rms_pct	Avg_PhaseErr_deg
0	8.437	7.902	1.693

Index	Avg_FreqError_Hz	Avg_IQ_Offset_dB	Avg_SyncCorrelation
0	0.848	-41.720	0.996

Results vs Frame

Frame	WLAN_80211b_1000_chip_Pk_EVM_pct
1	7.725
2	7.753
3	7.714
4	7.745
5	7.750

Frame	EVMrms_pct	EVM_Pk_pct	EVM_Pk_chip_idx
1	8.436	10.935	2629.000
2	8.429	10.965	2563.000
3	8.435	10.909	2111.000
4	8.440	10.955	2205.000
5	8.444	10.961	2056.000

Frame	MagErr_rms_pct	MagErr_Pk_pct	MagErr_Pk_chip_idx
1	7.914	-10.932	2215.000
2	7.911	-10.965	2563.000
3	7.871	-10.909	2111.000
4	7.950	-10.955	2205.000
5	7.866	-10.961	1231.000

Frame	PhaseErr_deg	PhaseErr_Pk_deg	PhaseErr_Pk_chip_idx
1	1.674	-6.190	2750.000
2	1.668	-6.076	2677.000
3	1.738	6.059	2743.000
4	1.626	-6.047	2538.000
5	1.760	-6.144	2705.000

Frame	FreqError_Hz	IQ_Offset_dB	SyncCorrelation
1	2.169	-35.597	0.996
2	0.716	-47.958	0.996
3	-0.536	-49.741	0.996
4	0.297	-44.813	0.996
5	1.595	-59.133	0.996

EVM Results

Benchmark

- Hardware platform: Pentium III 450 MHz, 512 MB memory
- Software platform: Windows NT 4.0 Workstation, ADS 2002c
- Simulation time: approximately 4 minutes

References

1. IEEE Standard 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer Extension in the 2.4 GHz Band," 1999.

BER and PER Performance, Fading Channel 36 Mbps

WLAN_80211g_OFDM_36Mbps_Fading_System

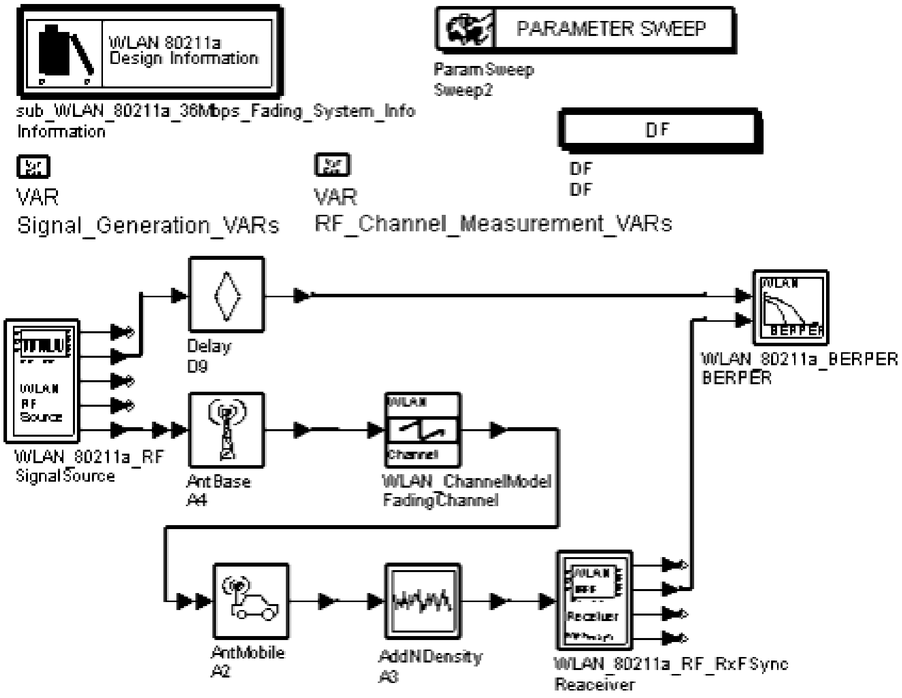
Features

- Data rate=36Mbps, coding rate=3/4, modulation=16-QAM, velocity=0 km/hr
- Length and Order parameter default settings = 512 and 7, respectively
- BER and PER vs. Eb/N0 on fading channel curves displayed

Description

This design shows system performance with 36 Mbps data rate and channel coding on fading channel. A burst length of 512 bytes is simulated.

The top-level schematic for this design is shown in the following figure. SignalSource parameters are contained in Signal_Generation_VARs; Noise, Receiver, and BERPER parameters are contained in RF_Channel_Measurement_VARs.



WLAN_80211g_OFDM_36Mbps_Fading_System Schematic

According to reference [2], five model types have been designed. Model A, an 18-tap fading channel corresponding to a typical office environment for NLOS conditions and a 50ns average rms delay spread, is used 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. The characteristics of this model are listed in the following table.

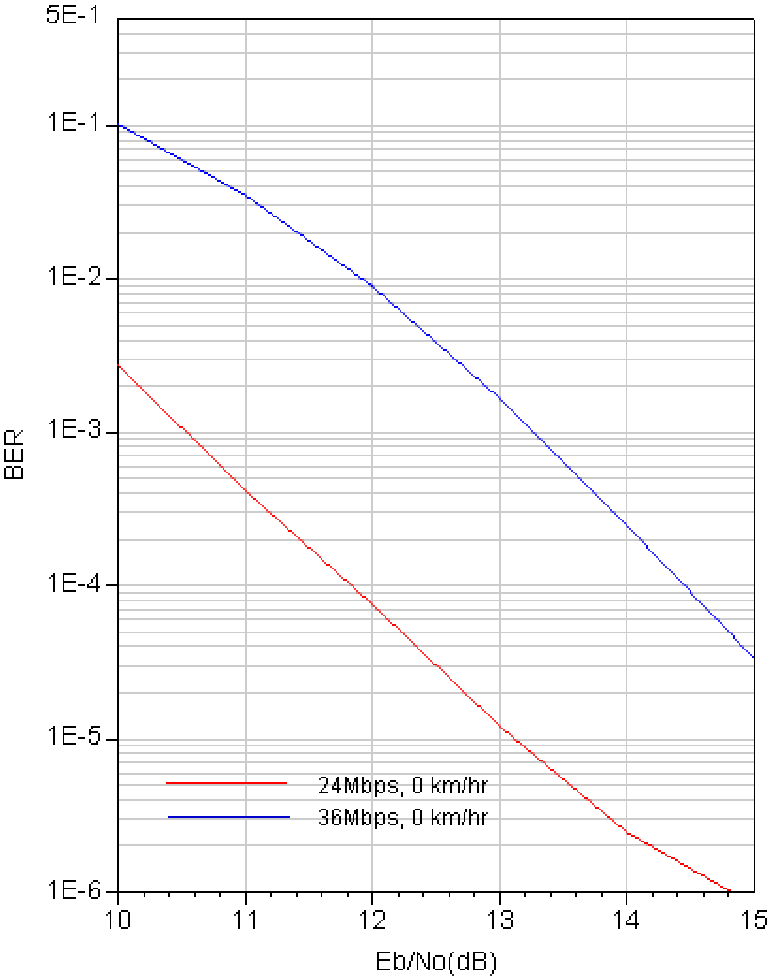
Model A Characteristics

Tap Number	Delay (ns)	Average Relative Power (dB)	Ricean K	Doppler Spectrum
1	0	0.0	0	Class
2	10	-0.9	0	Class
3	20	-1.7	0	Class
4	30	-2.6	0	Class
5	40	-3.5	0	Class
6	50	-4.3	0	Class
7	60	-5.2	0	Class
8	70	-6.1	0	Class
9	80	-6.9	0	Class
10	90	-7.8	0	Class
11	110	-4.7	0	Class
12	140	-7.3	0	Class
13	170	-9.9	0	Class
14	200	-12.5	0	Class
15	240	-13.7	0	Class
16	290	-18.0	0	Class
17	340	-22.4	0	Class
18	390	-26.7	0	Class

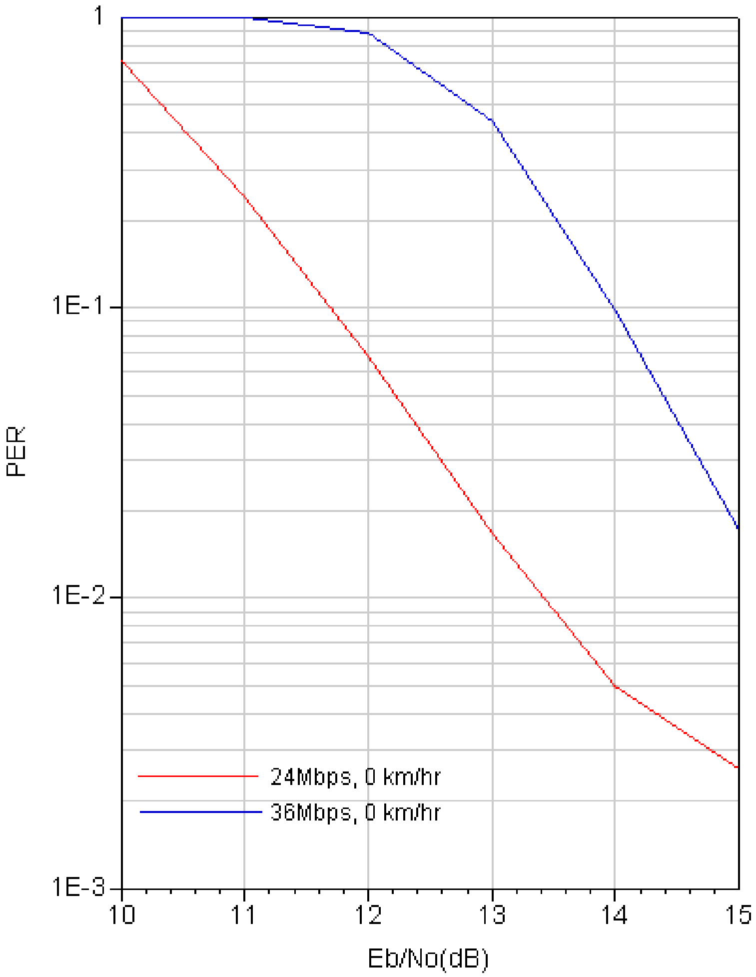
Simulation Results

Simulation results are shown in the following two figures.

For PER performance, the WLAN_OFDM_80211g_36Mbps_Fading_System is approximately 2 dB worse than that of WLAN_80211g_24Mbps_Fading_System.



Fading Channel BER Performance



Fading Channel PER Performance

Benchmark

- Hardware platform: Pentium III, 500 MHz, 512 MB memory
- Software platform: Windows NT 4.0, ADS 2002
- Data points: Eb/N0 values is set from 10 to 15 dB
- Simulation time: 50 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. Channel Models for HIPERLAN/2 in Different Indoor Scenarios, ETSI EP BRAN 3ER1085B 30 March 1998.

BER and PER Performance, AWGN Channel 11 Mbps for CCK Signal

WLAN_80211g_CCK_11Mbps_AWGN_System

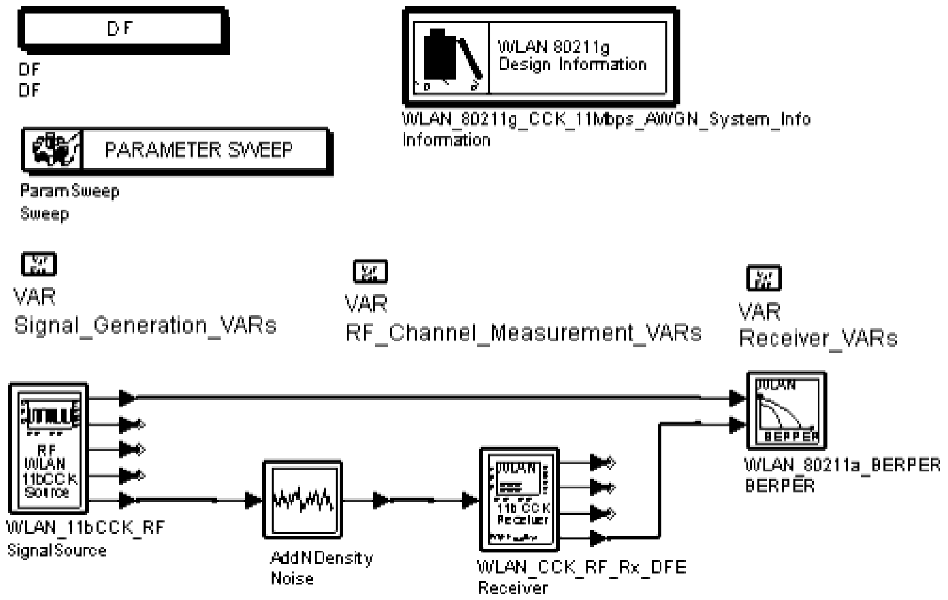
Features

- Data rate = 11Mbps
- Modulation = CCK
- Carrier frequency offset between transmitter and receiver = 50 kHz
- BER and PER vs. Eb/N0 on AWGN channel curves are displayed

Description

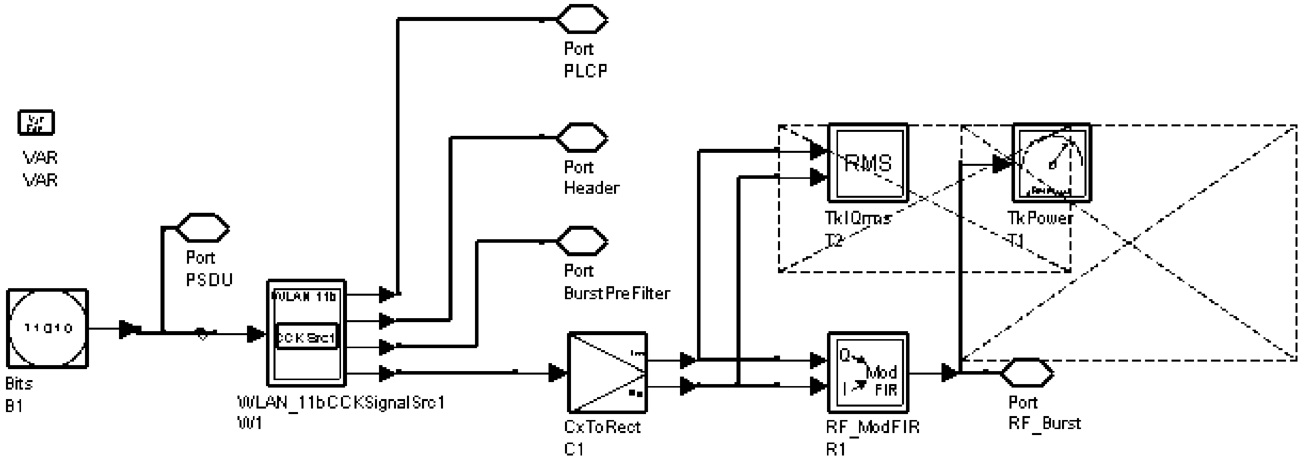
This design shows system performance of 802.11g with 11Mbps data rate and CCK modulation on an AWGN channel. A burst length of 500 bytes is simulated.

The top-level schematic is shown in the following figure. This design contains SignalSource, Noise, Receiver, and BERPER subnetworks. SignalSource parameters are contained in the Signal_Generation_VARs; Noise and BERPER parameters are contained in the RF_Channel_Measurement_VARs; and, Receiver parameters are contained in the Receiver_VARs.



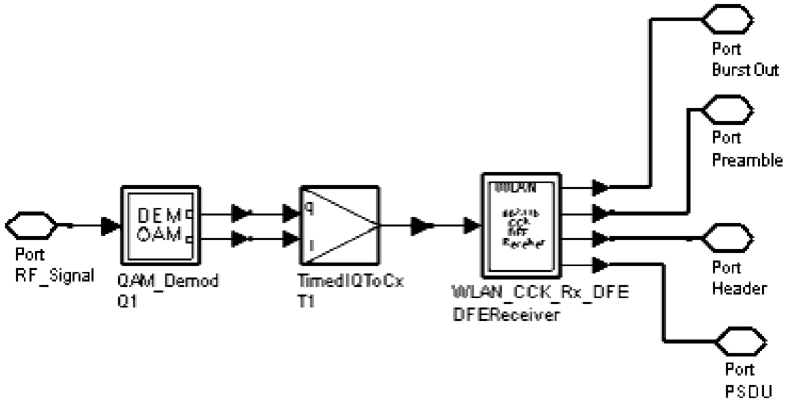
WLAN_80211b_11Mbps_AWGN_System Schematic

The SignalSource subnetwork (see the following figure), generates a signal source based on user settings.



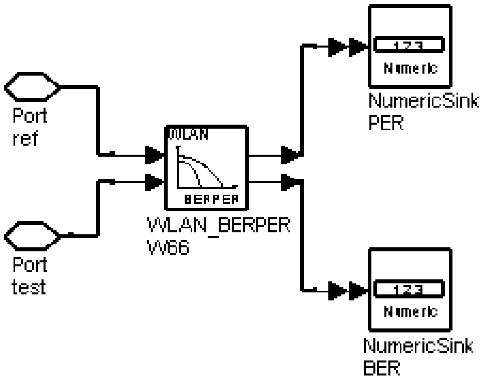
SignalSource Subnetwork Schematic

The Receiver subnetwork (see the following figure) receives an RF signal and demodulates the signal as bit streams; it also detects the start of frame and completes the transition from received sequences to frequency offset estimation sequences, estimates the frequency offset caused by carrier differences between transmitter and receiver. A decision feedback equalizer is implemented to equalize the received signal and remove the fixed rotation caused by frequency offset. The equalized signal is then fed into the CCK demodulator and demodulated into bit streams.



Receiver Subnetwork Schematic

The BERPER subnetwork (see the following figure) measures system BER and PER.

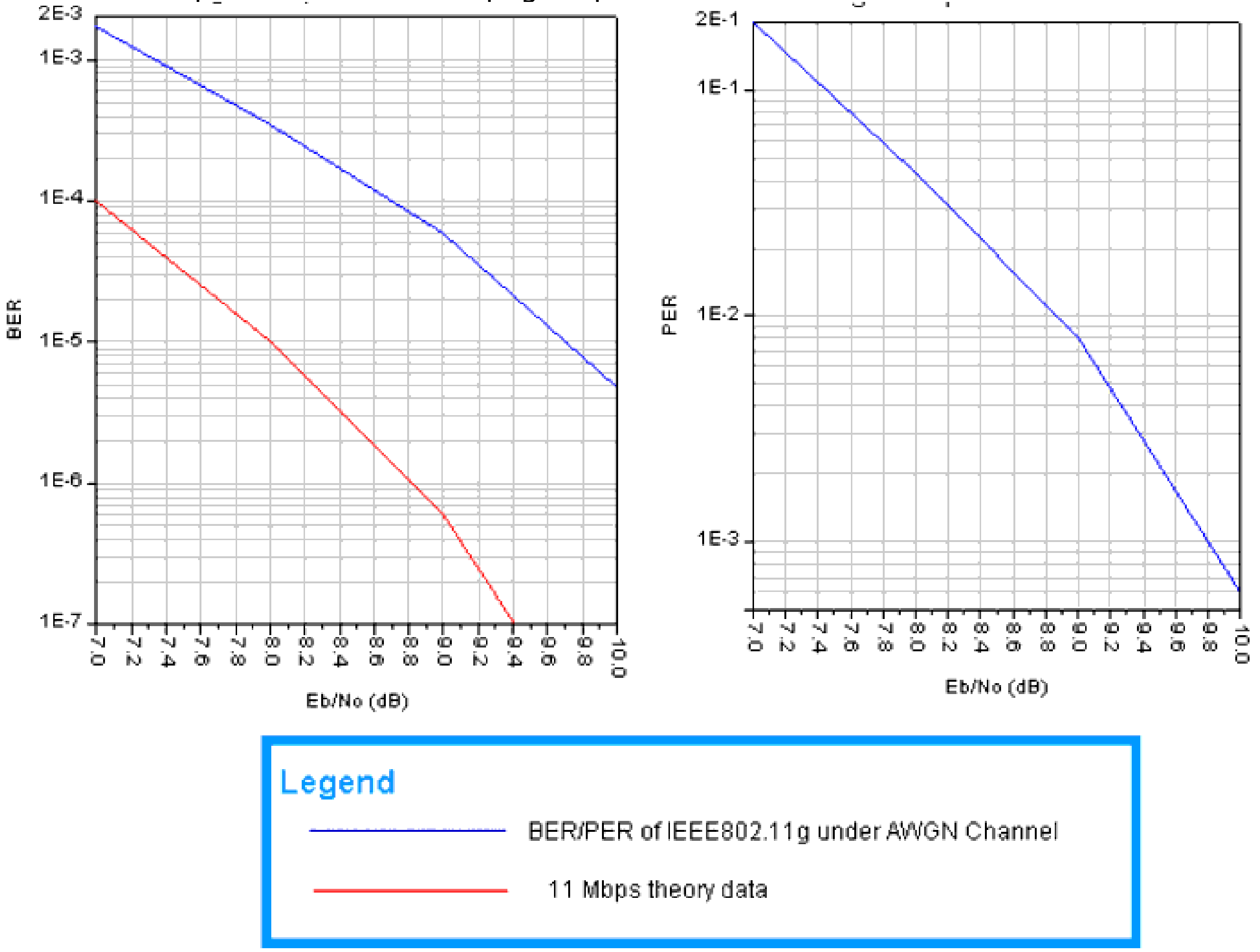


BERPER Subnetwork Schematic

Simulation Results

Simulation results are shown in the following figure.

Reference data points are shown in page Equations.



Simulation Results

Benchmark

- Hardware platform: Pentium IV, 1.8 GHz, 512 MB memory
- Software platform: Windows XP, ADS 2003A
- Data points: Eb/N0 values is set from 7 to 10 dB
- Simulation time: 1.5 hours

References

1. IEEE Standard 802.11a-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," 1999.
2. Intersil, "Direct Sequence Spread Spectrum Baseband Processor with Rake Receiver and Equalizer," Data Sheet, FN4856.2, December 2001.