Agilent Technologies

Advanced Design System 2011.01

Feburary 2011
Bluetooth DesignGuide

Acknowledgments

Errata The ADS product may contain references to "HP" or "HPEESOF" such as in file names and directory names. The business entity formerly known as "HP EEsof" is now part of Agilent Technologies and is known as "Agilent EEsof". To avoid broken functionality and to maintain backward compatibility for our customers, we did not change all the names and labels that contain "HP" or "HPEESOF" references.

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Bluetooth DesignGuide QuickStart

The Bluetooth DesignGuide QuickStart provides an introduction to the content and use of the Bluetooth DesignGuide for the Agilent Advanced Design System (ADS).

The Bluetooth DesignGuide application package contains various system test benches and reference designs (for example, an optimal low-IF receiver) for the RF portion of the Bluetooth physical layer. It allows the investigation of system performance from simple EYE diagrams, to BER (bit error rate) when impairments such as AWGN, VCO phase noise, multipath, and/or co-channel, adjacent-channel, intermodulation and pulsed-RF interference are present. In many cases, the receivers EYE diagram can be observed in real time during simulation while adjusting the level of the signal or interferer via an interactive slider.

The DesignGuide also addresses few phase-lock-loop (PLL) and voltage-controlled oscillation (VCO) design issues and can help you select the best demodulator for your receiver.

To learn more, refer to *Bluetooth DesignGuide Reference* (dgblue).

Using DesignGuides

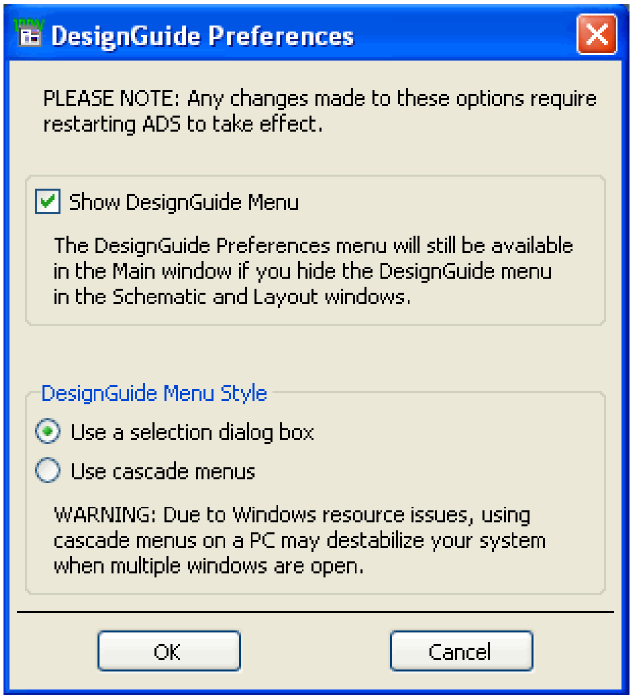
All DesignGuides can be accessed in the Schematic window using either the cascading menus or dialog boxes. Your preferred method can be configured in the Advanced Design System Main window.

Select the **DesignGuide** menu from Advanced Design System Main window.

The commands in the **DesignGuide** menu from Advanced Design System Main window are as follows:

- **DesignGuide Developer Studio** > **Start DesignGuide Studio** - This option is only available if you have installed the DesignGuide Developer Studio. Selecting it launches the initial Developer Studio dialog box.
- **DesignGuide Developer Studio** > **Developer Studio Documentation** - This option is only available if you have installed the DesignGuide Developer Studio. Selecting this brings up the DesignGuide Developer Studio documentation. You can also access this documentation by selecting **Help > Topics and Index > DesignGuides > DesignGuide Developer Studio** from any ADS program window.
- **Add DesignGuide** - This brings up a directory browser in which you can add a DesignGuide to your installation. This is primarily used with DesignGuides that are custom-built using Developer Studio.
- **List/Remove DesignGuide** - This brings up a list of your installed DesignGuides. To remove a Design Guide, select any you wish to uninstall and choose the **Remove** button.
- **Preferences** - This brings up a dialog box that allows you to:
    - Disable the DesignGuide menu commands (except *Preferences*) in the Main window. By unchecking this box, the complete DesignGuide menu and all of it's commands will be removed in the Schematic and Layout windows.

- Select the interface method you prefer (cascading menus or dialog boxes).



PLEASE NOTE: Any changes made to these options require restarting ADS to take effect.

☑ Show DesignGuide Menu

The DesignGuide Preferences menu will still be available in the Main window if you hide the DesignGuide menu in the Schematic and Layout windows.

DesignGuide Menu Style

● Use a selection dialog box

○ Use cascade menus

WARNING: Due to Windows resource issues, using cascade menus on a PC may destabilize your system when multiple windows are open.

You must close and restart the program for preference changes to take effect.

> **Note**
> On PC systems, Windows resource issues might limit the use of cascading menus. When multiple windows are open, your system could become destabilized. Thus the dialog box menu style might be best for these situations.

Accessing the Documentation

Accessing Documentation from ADS Schematic Window

To access the documentation for the DesignGuide from ADS Schematic Window, select:

- **DesignGuide** > **Bluetooth** > **Bluetooth DesignGuide Documentation**

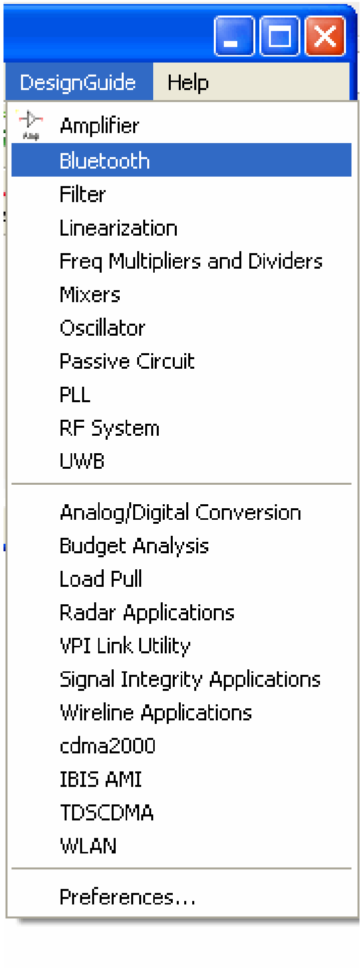
Accessing Documentation from any ADS program window

To access the documentation for the DesignGuide from any ADS program window, select:

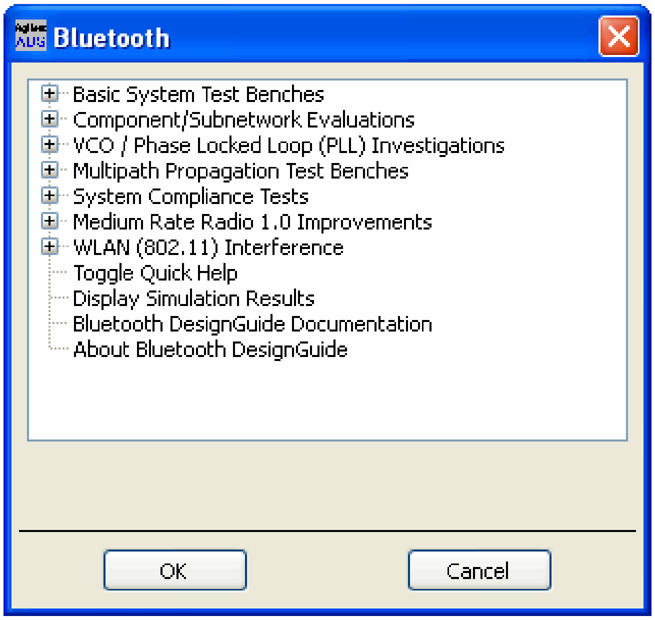
- **Help** > **Topics and Index** > **DesignGuides** > **Bluetooth**

The Bluetooth DesignGuide Menu

The **Bluetooth** DesignGuide menu, located in the Schematic window under DesignGuide, provides convenient access to test benches, subnetworks and data displays. It may be installed as a standalone, or along with other DesignGuides.



Selecting **Bluetooth** DesignGuide menu displays the Bluetooth dialog box.


Bluetooth
Basic System Test Benches
Component/Subnetwork Evaluations
VCO / Phase Locked Loop (PLL) Investigations
Multipath Propagation Test Benches
System Compliance Tests
Medium Rate Radio 1.0 Improvements
WLAN (802.11) Interference
Toggle Quick Help
Display Simulation Results
Bluetooth DesignGuide Documentation
About Bluetooth DesignGuide
OK
Cancel

The contents of the Bluetooth DesignGuide menu are divided into several categories:

- **Basic System Test Benches.** These test benches provide tutorial simulations using the Bluetooth RF segment and allow you to evaluate filtering options for the transmitter.

- **Component/Subnetwork Evaluations** . These simulations are designed to help you understand and validate many of the built-in subnetworks used in the system test benches.
- **VCO/Phase-Locked-Loop (PLL) Investigations.** These are simulations of phase-lock-looped topologies address timing and noise issues.
- **Multipath Propagation Test Benches.** These simulations include multipath models for investigating system performance under non-ideal indoor propagation conditions.
- **System Compliance Tests.** These system test benches are designed to evaluate sensitivity and blocking performance.
- **Medium Rate Radio 1.0 Improvements.** These simulations include two modulation formats for proposed enhancements to Bluetooth radios that allow them to operate at higher data rates.
- **WLAN (802.11) Interference.** An 802.11 signal source is combined with a Bluetooth radio to allow investigations of WLAN interference effects on Bluetooth performance.

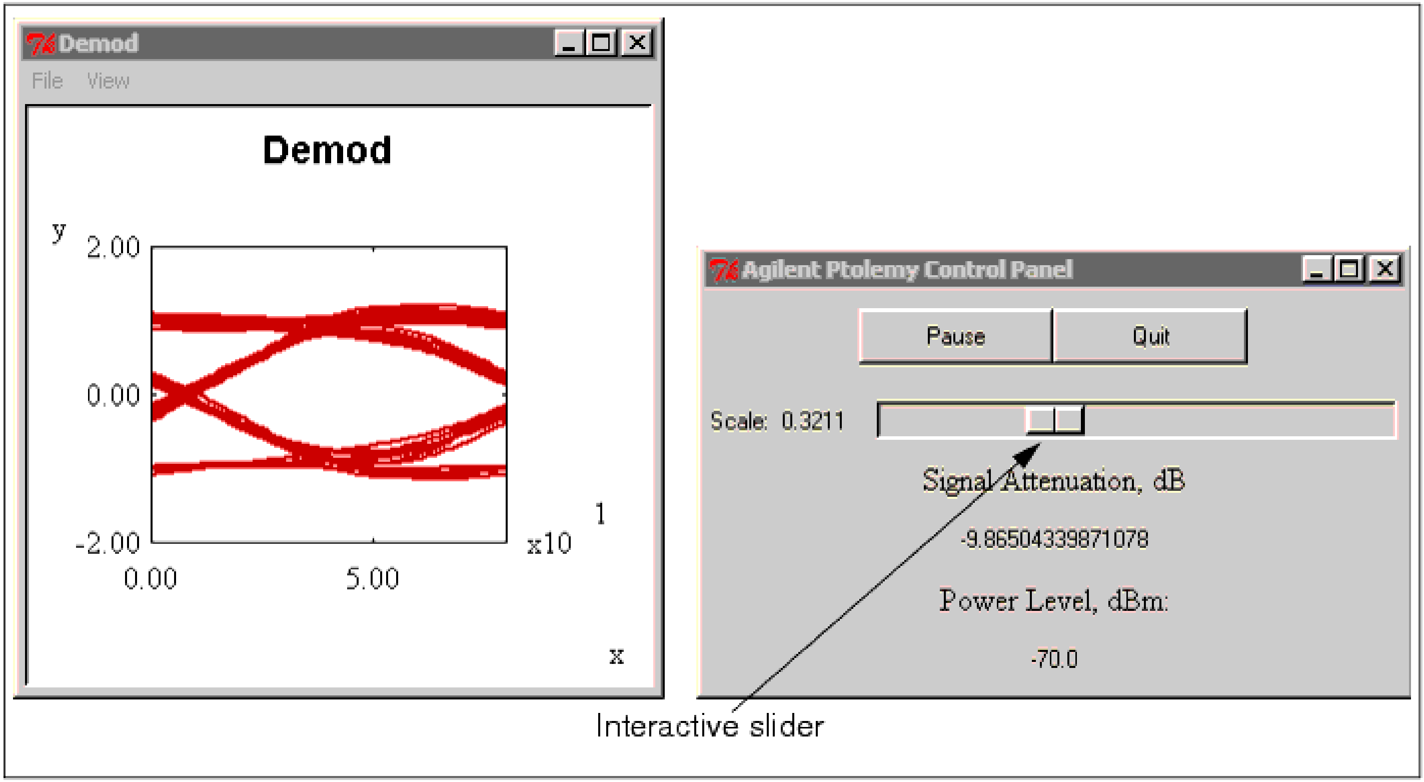
For each category, moving the cursor to the right will open a menu displaying the available items. Each selection (except those beginning with *Display*) will open a top-level test bench schematic and in many cases, a data display. The selections beginning with *Display* open additional data displays, after the test bench listed above it has opened. You can also access help, BlueTooth DesignGuide documentation and an About Bluetooth DesignGuide box from this menu.

Displaying Simulation Data

Some test benches have *real-time* Tk displays that open each time a simulation is performed. Other test benches automatically open one or more *Data Display* windows when selected. In several instances, for example a test bench that is capable of BER calculations, additional data displays are available. When a *Data Display* having the same name as the design has been closed, it can be re-accessed by selecting the *Display Simulation Results* option listed on the menu, once the test bench has opened.

Interactive Simulations

Some simulations using Tk displays have interactive *sliders* that allow a parameter to be adjusted during the simulation. To run a non-interactive simulation where output data is only collected by sinks, (i.e., time-domain or spectrum measurements), all Tk items must be de-activated. The *TkPowerControl*, *TkPowerControl2* or *TkPowerControl_ForRFOffset* subnetwork must also be de-activated and bypassed with a wire because it contains an interactive slider.



Scale: 0.3211

Signal Attenuation, dB

-9.86504339871078

Power Level, dBm:

-70.0

Interactive slider

Bluetooth DesignGuide Reference

This section contains application guidelines for using the test benches provided with the Bluetooth DesignGuide, including:

- Basic System Test Benches
- Component/Subnetwork Evaluations
- VCO/PLL (Phase Locked Loop) Investigations
- Multipath Propagation Test Benches
- System Compliance Tests
- Medium Rate Radio 1.0 Improvements
- WLAN (802.11) Interference

For a complete listing of test benches and subnetworks, refer to the section Test Benches and Subnetworks.

> **Note**
> This document assumes a basic understanding of ADS operations. To learn more, refer to *Schematic Capture and Layout* (usrguide). For access to the complete set of ADS online documentation, select *Help > Topics and Index* from any ADS program window.

Developing or Integrating a Bluetooth Solution

The DesignGuide provides tools for developing or integrating a Bluetooth solution:

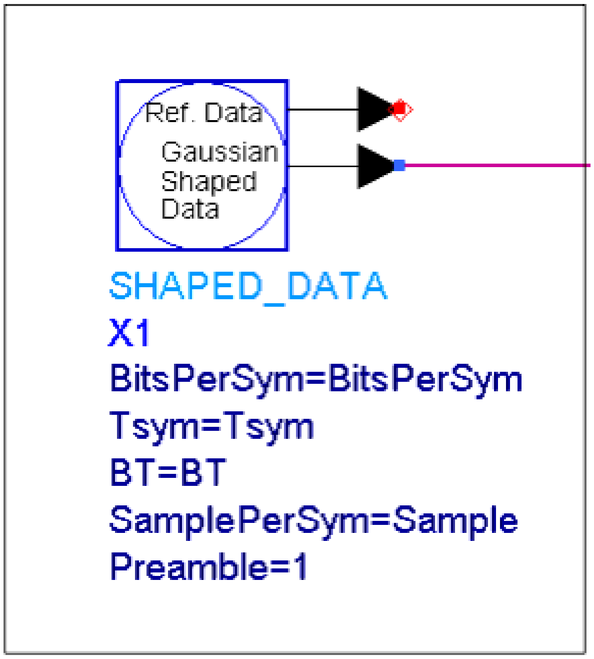
- **Designing a Bluetooth solution** - The DesignGuide supplies a reference receiver design that can be evaluated by comparing the measurements of your RF hardware and simulations of that RF hardware in an ADS model. Other tools target specific components of the Bluetooth physical layer. You should review the Basic System Test Benches, followed by the Component/Subnetwork Evaluations (emphasizing filter selection) before you begin. The VCO/PLL segment is useful if you are designing a synthesized source or need to optimize an existing design for good time-domain performance and phase noise characteristics. Test Benches supporting the newly proposed modulation formats for medium-rate operation are included. The System Compliance Tests focus on determining sensitivity and evaluating performance in the presence of interferers.
- **Integrating a Bluetooth solution** - For integration into a product, such as another wireless device, handset or any environment with other RF emitters, the DesignGuide provides simulation-based tools for evaluating system performance under various conditions. Before you begin, you should review the Basic System Test Benches, followed by the System Compliance Tests. The Multipath Propagation Test Benches model various indoor propagation conditions allowing you to observe their effect on system performance. The WLAN 802.11 Interference test bench (*requires the WLAN Design Library*) enables you to observe the effect of WLAN 802.11a and 802.11g interference on Bluetooth performance.
  Selected test benches are described in the following sections. For a complete list of available test benches refer to Test Benches and Subnetworks.

Basic System Test Benches

The basic system test benches provide an introduction to the Bluetooth RF interface. This section describes some of the main components and subnetworks in the DesignGuide.

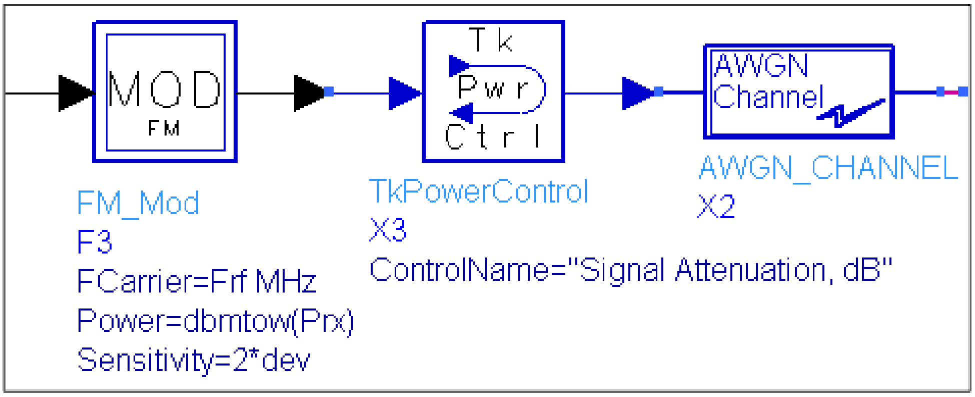
Ideal Transmit-Receive EYE Diagram (TEST_EYE)

This simulation is used to observe the EYE diagram created from the combined effects of a transmitter and the complete receiver. The system is built with the most basic components. SHAPED_DATA produces Gaussian-filtered MSK data according to the Bluetooth specification and an optional Preamble, which consists of the 10101010 sequence, can be included by setting Preamble > 1.

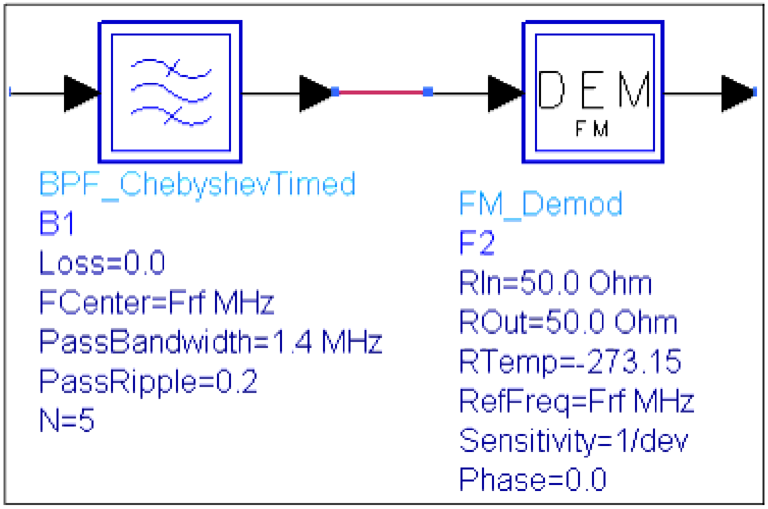


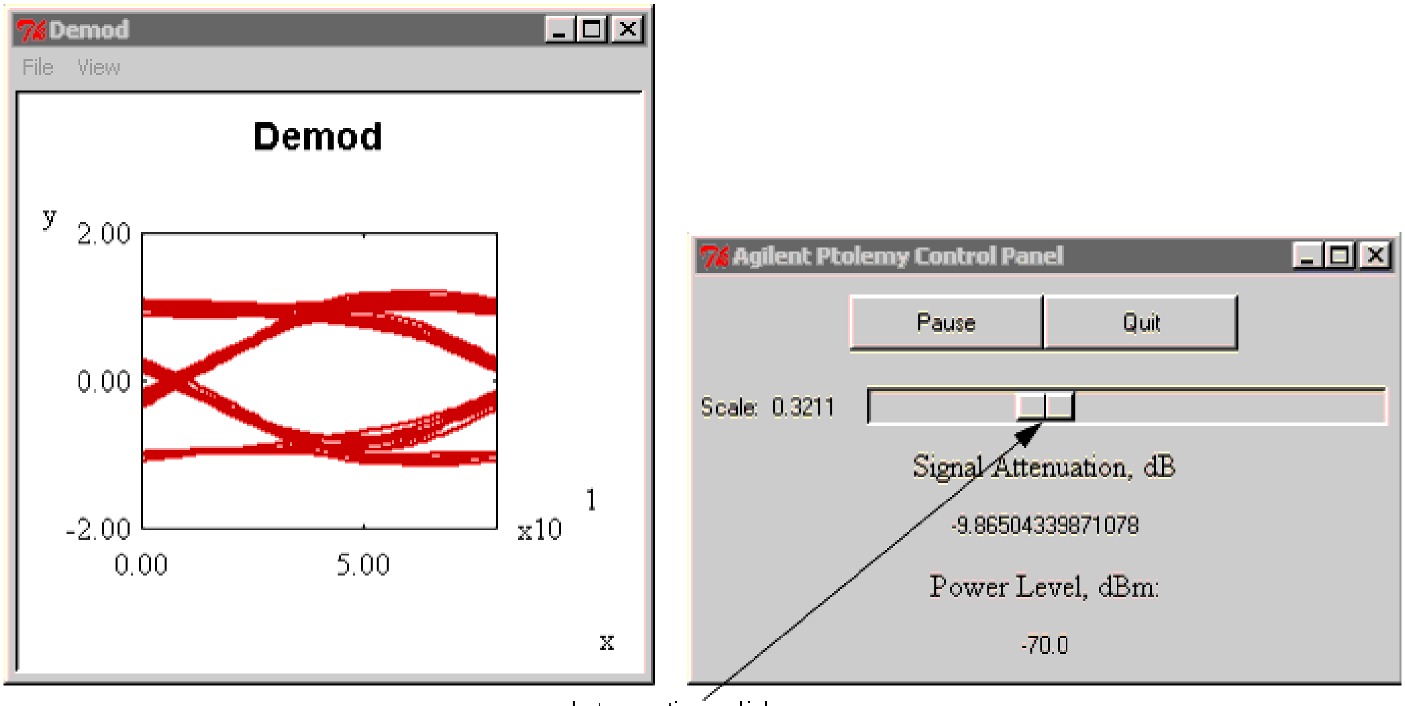
The SHAPED_DATA output is input into an ideal ADS FM modulator component. The TkPowerControl allows the signal level to be adjusted using an interactive slider. AWGN_CHANNEL adds thermal noise equal to -174 dBm/Hz to the signal.

Note
SHAPED_DATA, TkPowerControl and AWGN_CHANNEL are all subnetworks created for the Bluetooth DesignGuide. *AddNDensity*, a component available in recent releases of ADS, provides similar functionality to AWGN_CHANNEL but also allows the noise spectral density, in dBm/Hz, to be specified.



The signal is bandpass-filtered and ideally demodulated.





Scale: 0.3211

Signal Attenuation, dB

-9.86504339871078

Power Level, dBm:

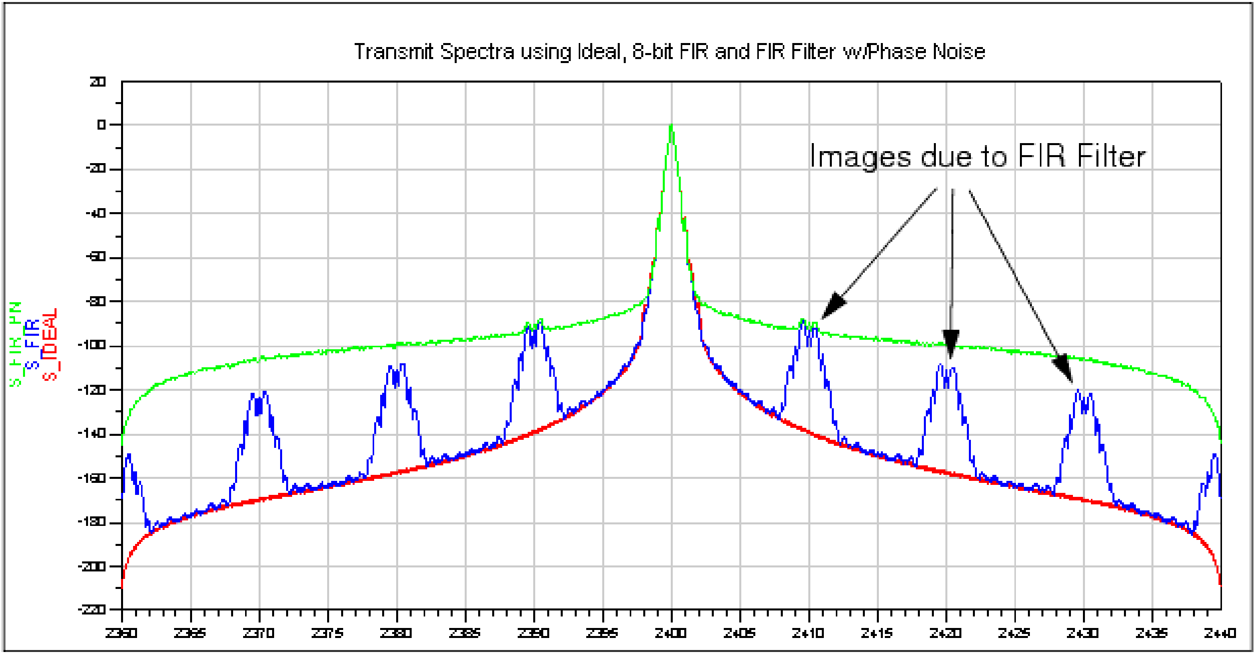
-70.0

Interactive slider

After scaling and conversion to floating-point, the EYE diagram is displayed on a TkPlot.

Transmit Spectrum (TEST_TX_SPECTRUM)

This test bench illustrates some of the filtering options for the Bluetooth transmitter. When the 8-bit FIR filter is used, images of the spectrum are seen at intervals related to the sampling rate. Note that because these images are below the phase noise sidebands they are adequately filtered out.
Additional analysis of the FIR filter can be found by selecting *Component/Subnetwork Evaluations > Transmit Filter (Gaussian FIR)* .

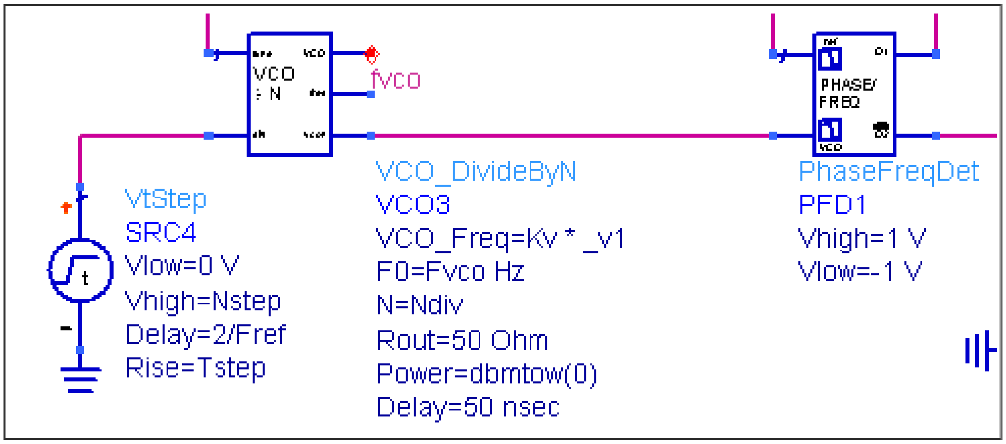


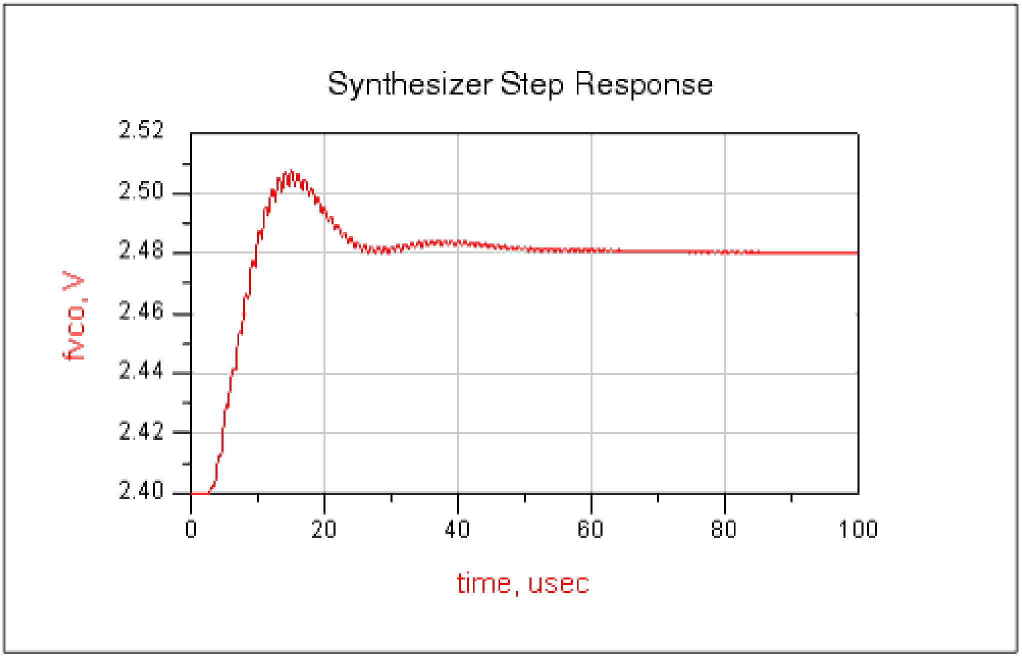
VCO/PLL (Phase Locked Loop) Investigations

These test benches provide a set of tools that assist in the design and optimization of signal sources for a Bluetooth implementation. These basic tools address key performance requirements. For the full PLL design flow, the ADS PLL DesignGuide is available.

VCO Response to Frequency Step (TEST_PLL_TR)

This test bench demonstrates the Bluetooth Fractional-N Synthesizer transient response to an 80-MHz step. The VCO frequency is 2.4 GHz and the reference frequency is 1 MHz. The output frequency is Fvco+N or 2.48 GHz. The loop bandwidth, fn, is 5 kHz.
This design, is simulated under the Transient controller using the VCO_DivideByN and PhaseFreqDet components. The PFD output is coupled to the RC loop filter using the voltage controlled current source (VCCS). The source frequency must settle to within +/- 20PPM in 200 µ. To understand how to optimize the loop filter, select *VCO Parameter Optimization*.





Component/Subnetwork Evaluations

Following are details on designs demonstrating component/subnetwork evaluations.

Channel Filter Impulse Response (TEST_FILTER_IMPULSE)

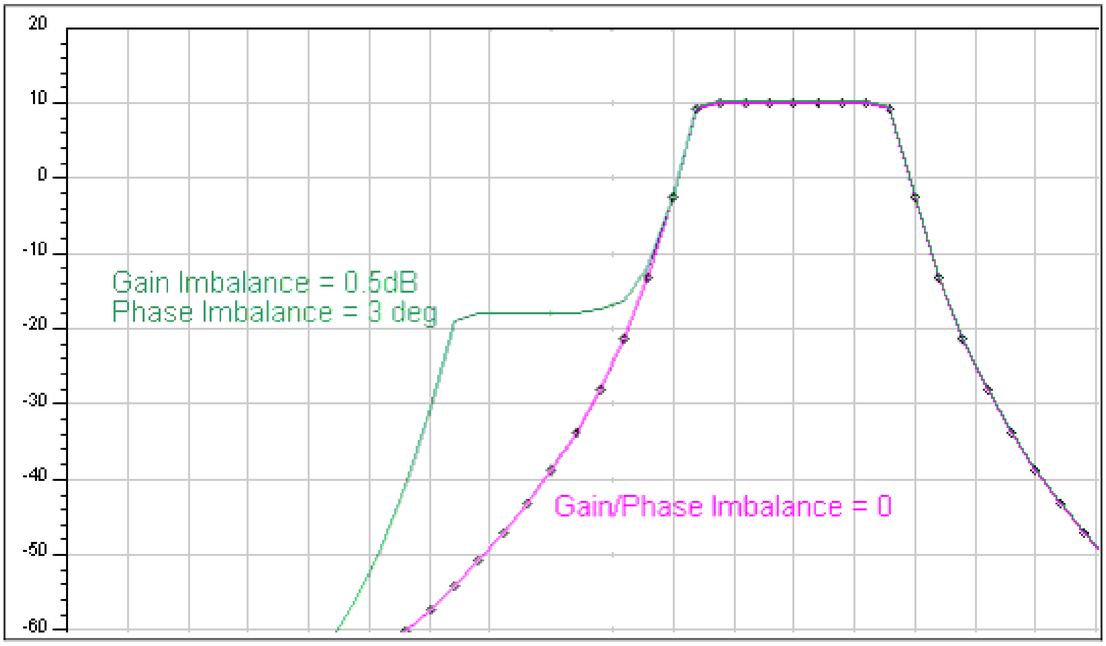
This test bench evaluates the impulse response of the Bessel filter used for pulse shaping in the Bluetooth receiver.

ADS has two simulation modes: Analog/RF and DSP. This test bench compares the impulse responses of the circuit (A/RF) and timed (DSP) models, which can be very similar. The A/RF model has an advantage in that its group delay at the edge of the passband can be controlled. Using it in a DSP design requires Transient cosimulation, which can be slower.

Channel Filter Swept Response (TEST_FILTER_COMPLEX)

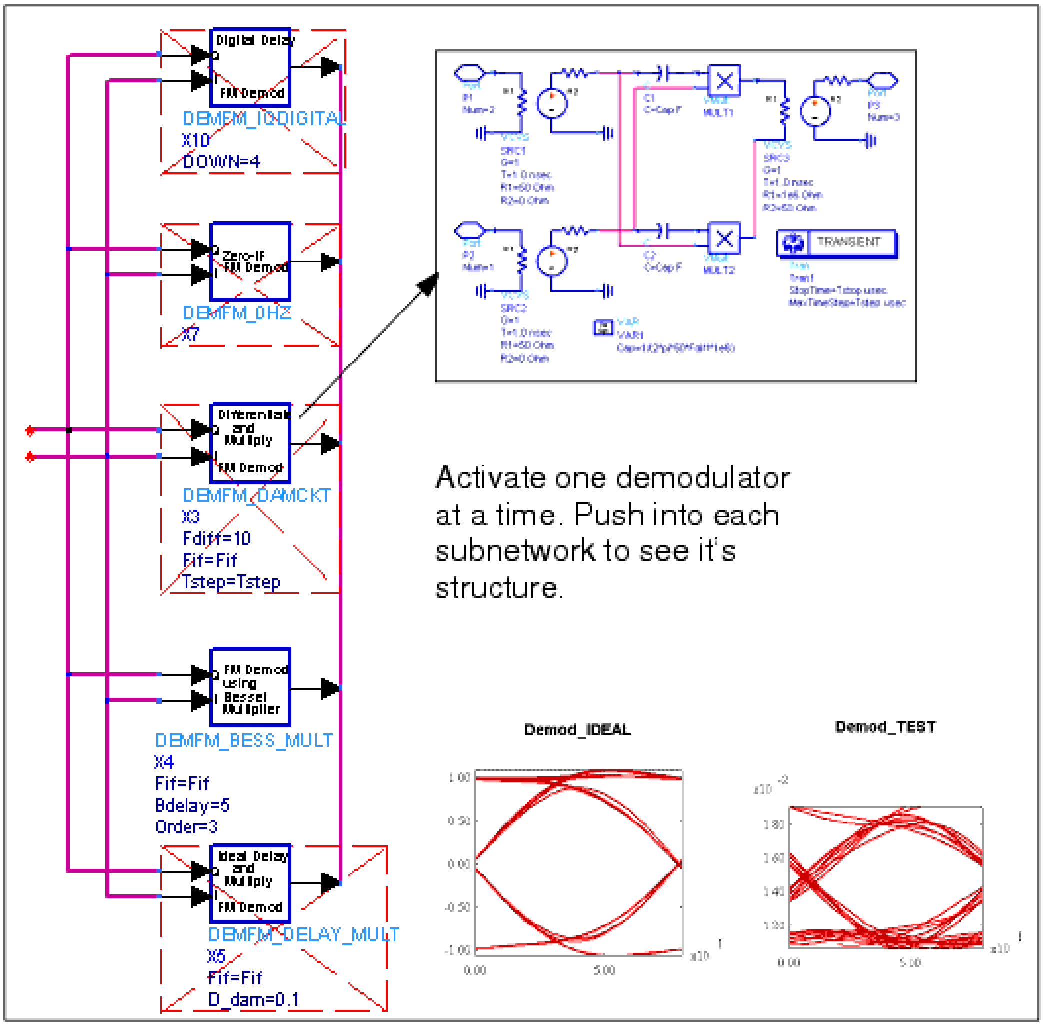
This test bench sweeps the complex receiver filter model used in the DesignGuide (FILTER_CHEB_COMPLEX).

Open Data Display TEST_FILTER_COMPLEX. Note that QAM_Demod is set for a gain imbalance of 0.5 dB and a phase imbalance of 3 degrees. The data display compares the swept RF response to the balanced condition.



FM Demodulator Selection (TEST_LOWIF_FMDEMOD)

An EYE diagram display allows observation of the relative performance of various demodulators. Due to the different output levels and the amount of residual DC for each demodulator, select *View* > *View ALL* on the Demod_TEST TkPlot to see the EYE diagram. Demodulator selection is important when designing a Bluetooth solution because receiver performance is often dependent upon the demodulator's performance. The DesignGuide provides a choice of several demodulators.



Activate one demodulator at a time. Push into each subnetwork to see it's structure.

For descriptions of each demodulator refer to Subnetworks. In the proceeding illustration DEMFM_BESS_MULT, a delay and multiply polyphase FM demodulator, is notable for its exceptional performance when compared to other demodulators. An additional test bench, available under *FM Demod Selection w/Channel Filter* uses a single complex Chebyshev channel filter in the receiver, instead of the *highpass/Chebyshev/limiter/Bessel* signal path used in *TEST_LOWIF_FMDEMOD*. Using this test bench puts additional requirements on the demodulator in exchange for a simpler signal path.

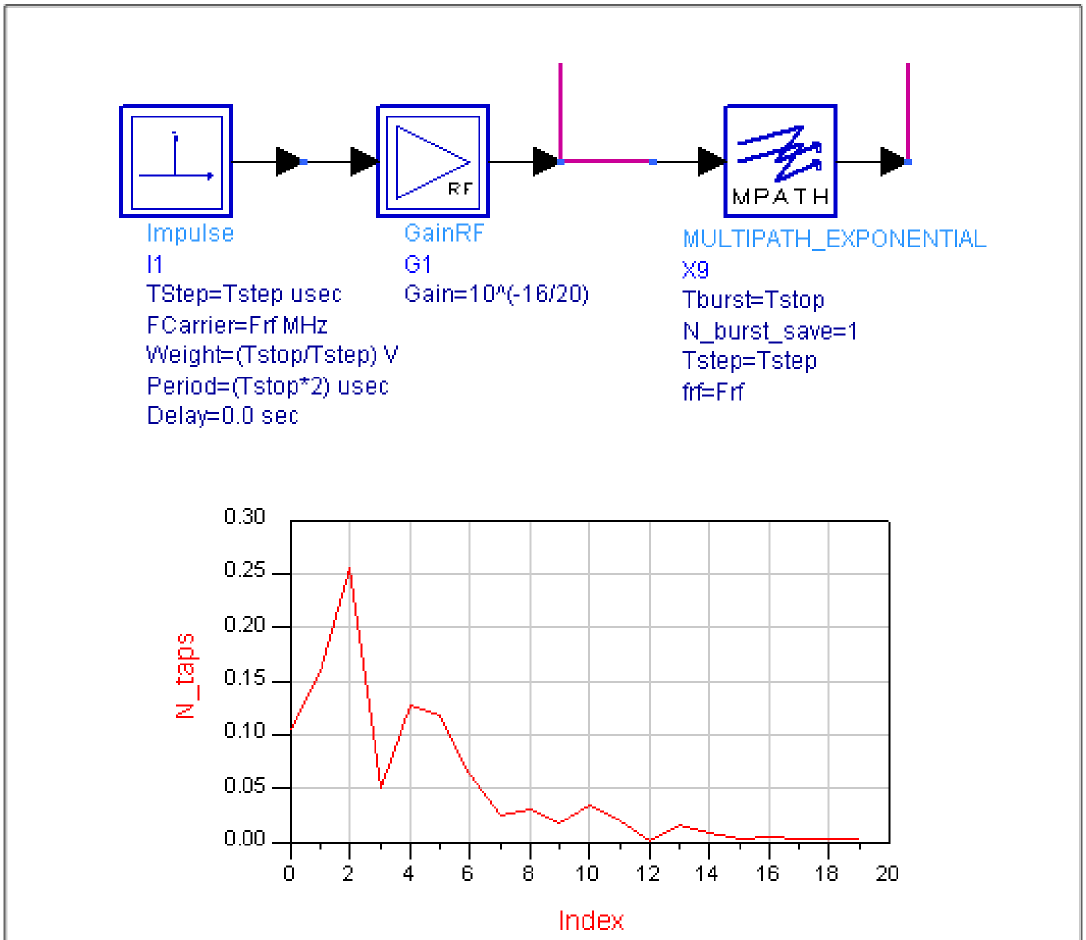
Multipath Propagation Test Benches

Following are summaries of test benches used for multipath propagation.

Multipath Impulse Response (TEST_MULTIPATH_IMPULSE)

This test bench evaluates the MULTIPATH_EXPONENTIAL model using an impulse input. The delay spread profile is shown in the associated data display. Due to the use of a moving average over 512 symbols, the data display will require several minutes to open (approximately 2 minutes for a Pentium III at 650 MHz under Windows NT). Select Display Impulse Response after the schematic is displayed to show the data display window.

Note
The multipath subnetwork requires a large memory space due to its complexity. Performance will be reduced on systems having less than 256 MB of RAM.



Tap coefficients for one burst (typical)

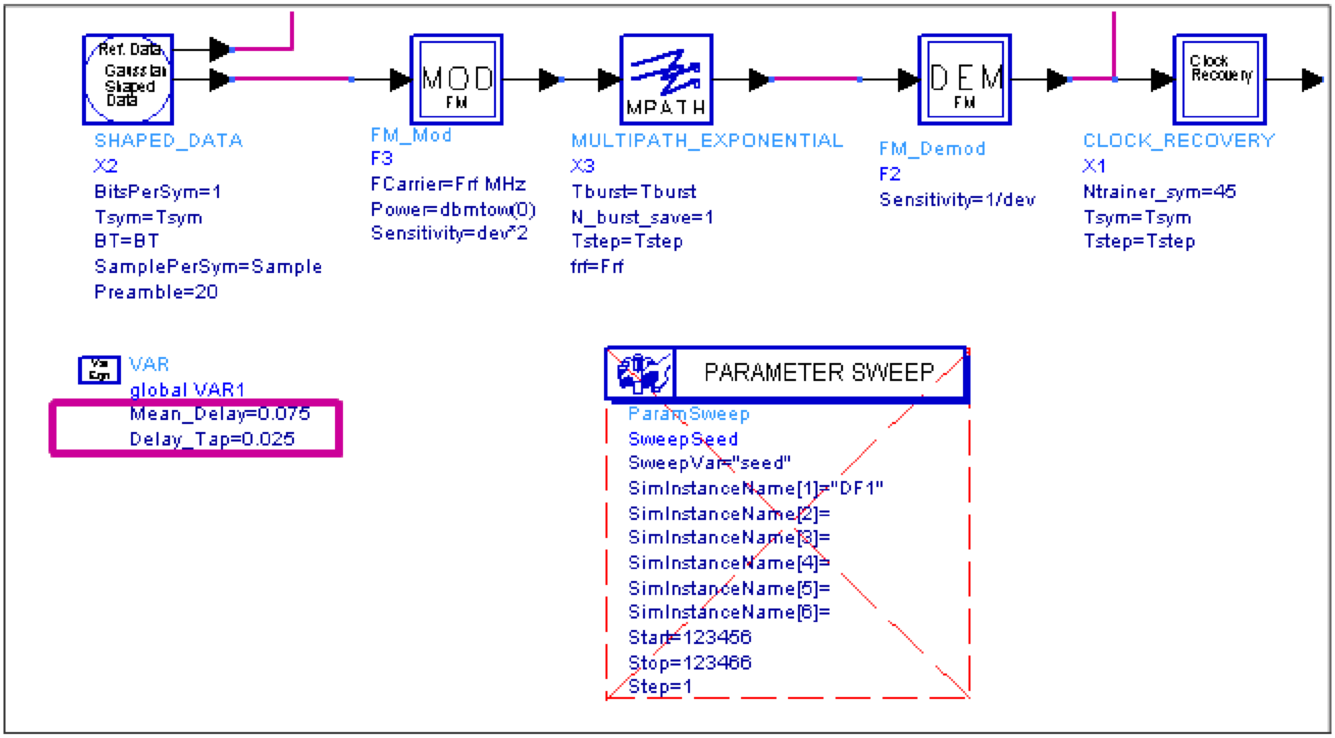
The MULTIPATH_EXPONENTIAL model implements an exponential power decay multi-path channel model that is widely used for indoor propagation. The mean excess delay and the tap delay can be specified in microseconds. Each tap coefficient has a Rayleigh power distribution, and a uniform phase distribution. For a specified value of time *Tburst*, the channel snapshot is kept fixed. For the next *Tburst* duration, a new channel snapshot is taken. The tap coefficients for each snapshot, the corresponding values of the RMS delay spread and the mean excess delay are all available. TK plots for these measurements can also be enabled.

The tap coefficients are calculated by:
r = exp(-Delay_Tap/Mean_Delay)
*a0 = 1/Mean_DelayDelay_Tap, a1= r*a0, a2 = r*a1,......, an = r*a(n-1)*

BER/Outage w/MPath, Noise, No Chan. Filter (TEST_MULTIPATH_BER_NOFILT)

This test bench calculates the BER without a channel filter, but includes multipath. It will usually exhibit ideal BER because the C/N is large (the transmit power is 0 dBm and no noise is included). The mean delay is larger than for the other multipath test benches, being set to 0.2 µ, and the tap delay is 0.05 µ. To observe channel outage, activate SweepSeed to vary the random seed value used by the Data Flow simulator. A channel with BER > 0.1% is considered to have caused a failed burst transmission. The simulation time is approximately 120 seconds (with PARAMETER SWEEP deactivated), for 250 bits using a Pentium III at 650 MHz under Windows NT with 256 MB RAM.

> **Note**
> Simulation time will increase significantly if less than 256 MB of RAM are available.



SHADED_DATA
X2
BitsPerSym=1
Tsym=Tsym
BT=BT
SamplePerSym=Sample
Preamble=20

FM_Mod
F3
FCarrier=Frf MHz
Power=dbmtow(0)
Sensitivity=dev^2

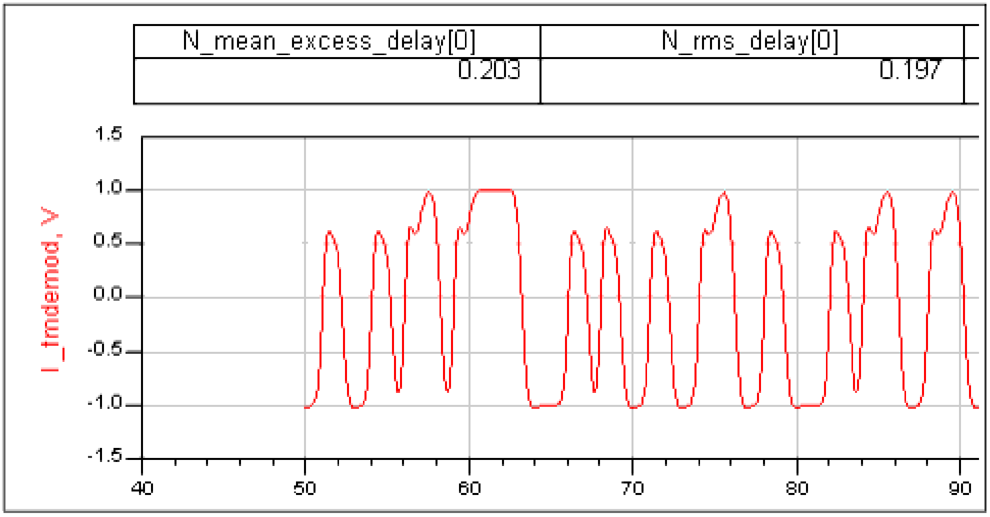
MULTIPATH_EXPONENTIAL
X3
Tburst=Tburst
N_burst_save=1
Tstep=Tstep
frf=Frf

FM_Demod
F2
Sensitivity=1/dev

CLOCK_RECOVERY
X1
Ntrainer_sym=45
Tsym=Tsym
Tstep=Tstep

VAR
global VAR1
Mean_Delay=0.075
Delay_Tap=0.025

PARAMETER SWEEP
ParamSweep
SweepSeed
SweepVar="seed"
SimInstanceName[1]="DF1"
SimInstanceName[2]=
SimInstanceName[3]=
SimInstanceName[4]=
SimInstanceName[5]=
SimInstanceName[6]=
Start=123456
Stop=123466
Step=1



N_mean_excess_delay[0]	N_rms_delay[0]
0.203	0.197

The preceding figure shows a portion of the output display for multipath (0.2 µ delay setting) with no channel filter at the output of the ideal FM demodulator. The Clock Recovery action accepts this distorted input and re-syncs the data. You may wish to vary this test bench by substituting other non-ideal demodulators, such as the subnetworks provided with the DesignGuide and observe their performance under multipath conditions.

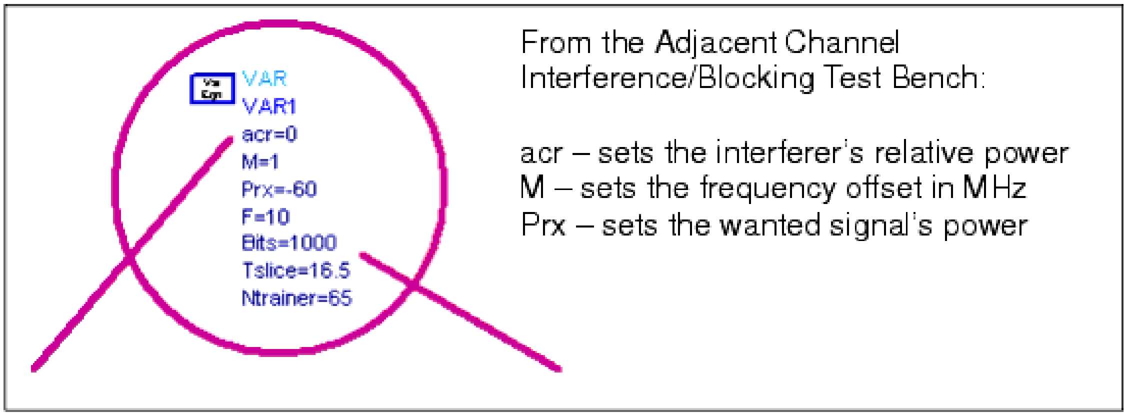
System Compliance Tests

Interferer Type	**Interferer level P[dBc]**	**Wanted signal level, P[dB]>reference sensitivity**
Co-Channel interference, C/I	11 dB	10
Adjacent (1 MHz) interference, C/I	0 dB	10

Each test bench sets up a starting condition according to Interference Performance Requirements. Conditions other than these can also easily be specified; for example, the adjacent interferer offset can be set to 1, 2, 3 or more MHz away from the wanted signal. An interactive slider provides for attenuating the interfering signal while observing the EYE diagram. For BER tests, the interactive slider is not used, and the appropriate components are de-activated as described on the test bench.

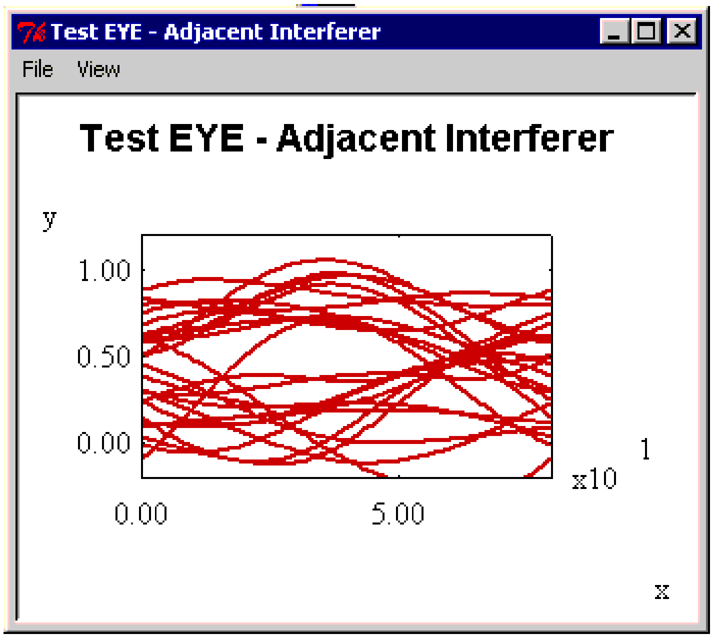
The system compliance tests available are:

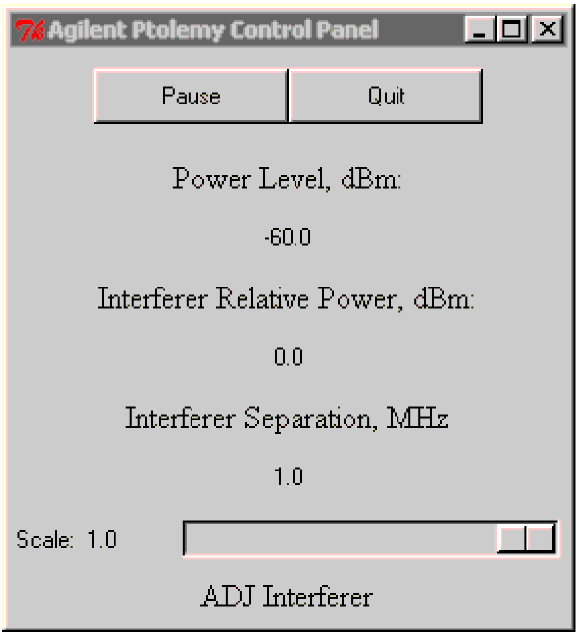
- Combined Co-Channel/Adjacent Channel test
- Intermodulation test
- Pulsed Interferer with 2nd-order Intercept (IP2) Test Bench.



From the Adjacent Channel Interference/Blocking Test Bench:

acr – sets the interferer's relative power
M – sets the frequency offset in MHz
Prx – sets the wanted signal's power


Test EYE - Adjacent Interferer
File
View
Test EYE - Adjacent Interferer
y
1.00
0.50
0.00
0.00
5.00
x10
1
x



Power Level, dBm:

-60.0

Interferer Relative Power, dBm:

0.0

Interferer Separation, MHz

1.0

Scale: 1.0

ADJ Interferer

The preceding graphics show the EYE diagram and Control Panel for the Adjacent Channel Interference Test Bench. Moving the slider to the left attenuates the interferer level.

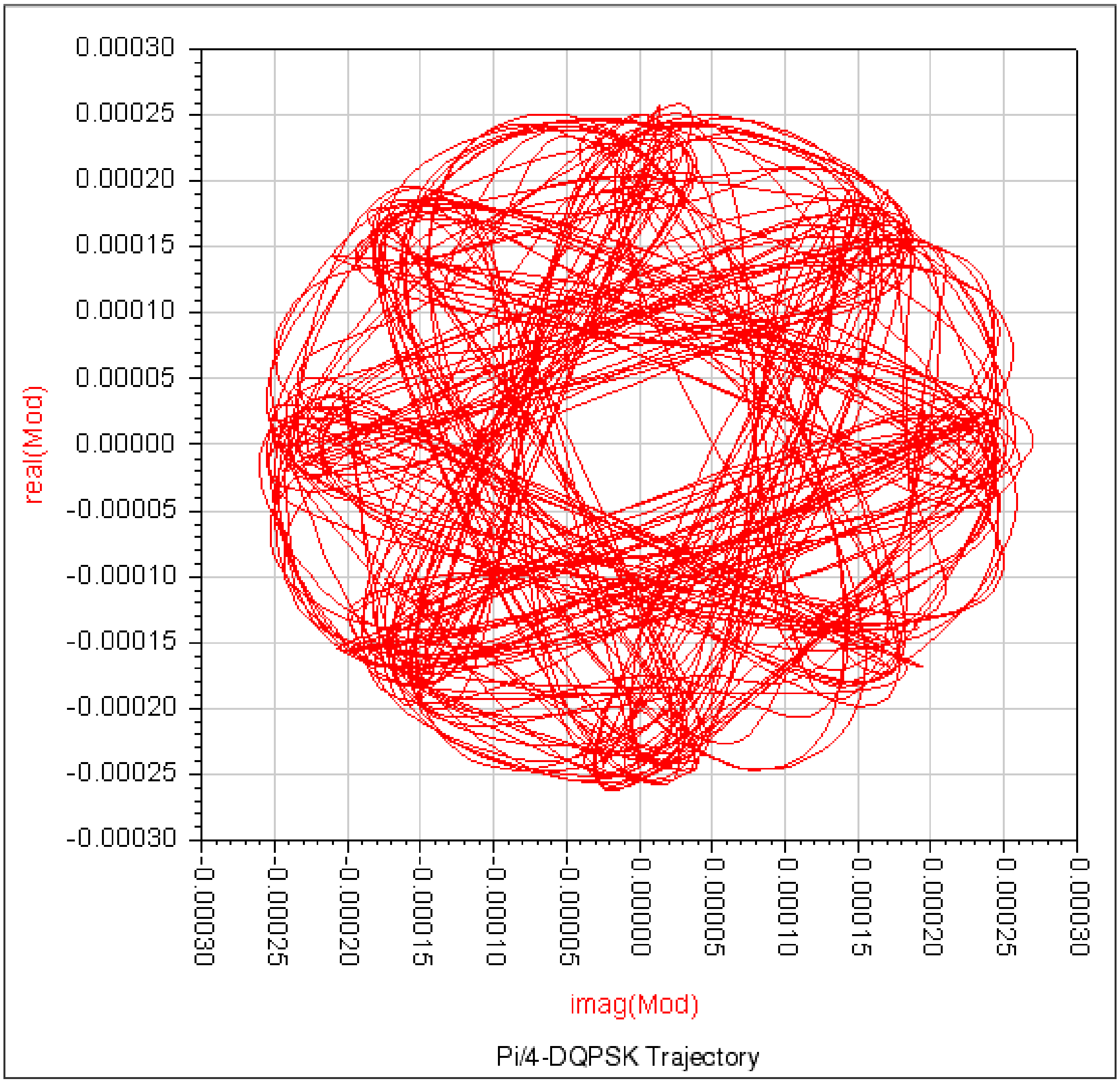
Medium Rate Radio 1.0 Improvements Test Benches

At the time of publication (Version 2.1.1 of this DesignGuide), proposals have been made to support higher data rates within the framework of the Bluetooth 1.0/1.1 Specification. Test benches which simulate the two modulation formats under consideration, Pi/4-DQPSK and 8-DPSK, for 2 and 3 Mbps respectively, are included.

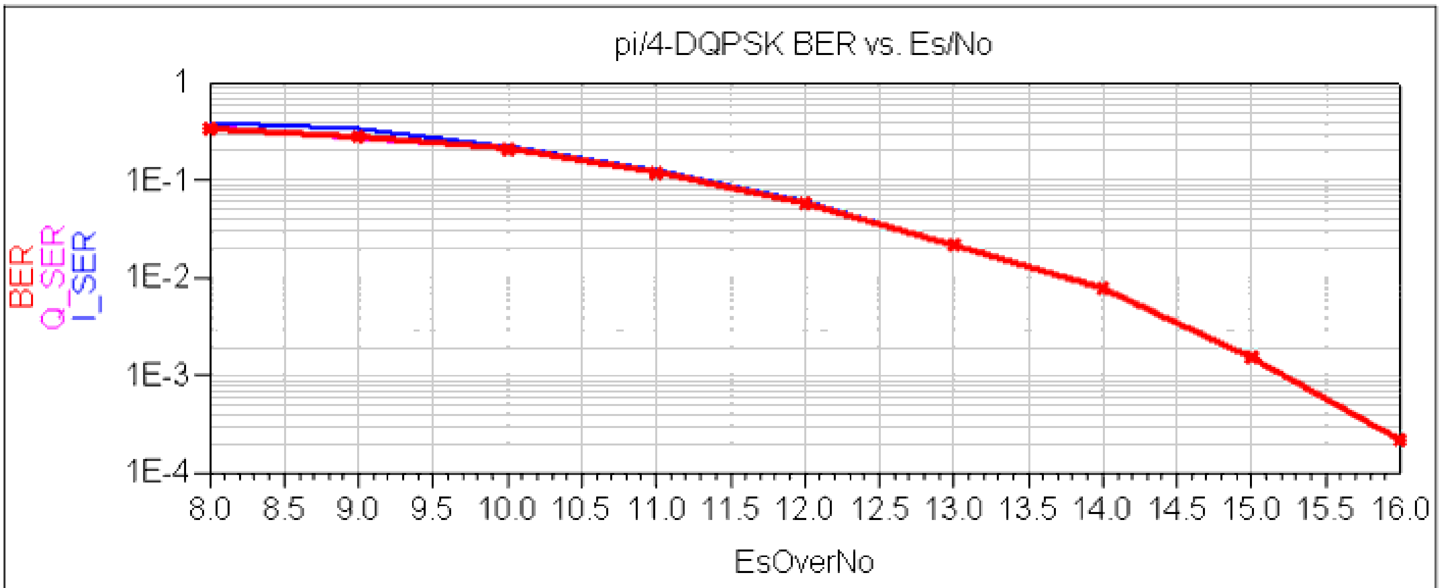
> **Note**
> Parameters have been set using the best information available but you are encouraged to obtain the latest Specifications from the Bluetooth SIG.

Ideal Pi/4-DQPSK Modem with EVM and BER (pi4DPQSK_Modem_Ideal)

This test bench models an ideal 2 Mbps radio with a variable-length GFSK preamble. Measurements of the modulated signal, such as spectrum mask and EVM are available. In addition, BER may be determined using a variety of methods. The default configuration will produce the dataset for the display *pi4DQPSK_Modem_Ideal_Mask.dds*, which includes Spectrum Mask, Trajectory, Input/Output Data, BER (short Monte Carlo estimate), RMS EVM and Peak EVM.

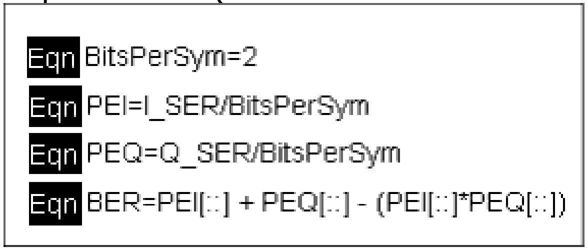


Some modulation formats, including Pi/4-DQPSK, are compatible with BER estimation using sampling reduction methods such as *Importance Sampling* . ADS provides this via the berIS component. Such methods reduce the BER simulation time by several orders of magnitude. However, certain guidelines must be followed. In particular, noise sources internal to the simulation should be set to 0, except for *AddNDensity*, which should be set to -174 dBm/Hz. The Receiver noise figure, determined by the variable F, should be set to 0. The berIS component will internally sweep *Es/No* during the simulation, providing the noise model. The simulation runs until the Relative Variance, *EstVar*, is met.



"Waterfall" curve generated using the berIS measurement.

When using berIS the symbol error rate (SER) for the I and Q symbols are found individually. They are combined during post-processing using the following Data Display expressions. (Refer to the berIS documentation for more information.)



Eqn BitsPerSym=2

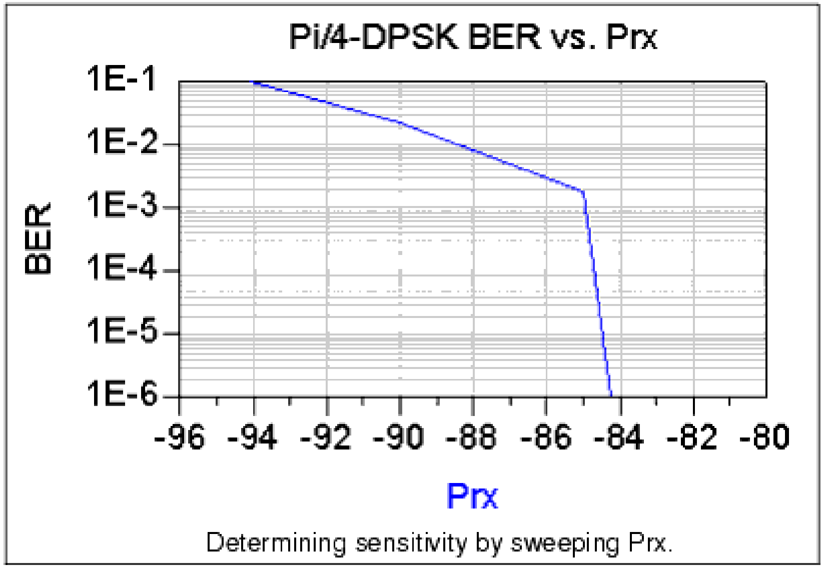
Eqn PEI=I_SER/BitsPerSym

Eqn PEQ=Q_SER/BitsPerSym

Eqn BER=PEI[::] + PEQ[::] - (PEI[::]*PEQ[::])

Medium Rate 2 Mbps Sensitivity and BER Test Bench (TEST_MR2_RECEIVER_SENSIVITY)

This test bench implements the 2 Mbps mode using interactive control to view EYE diagrams, output data and a real-time BER estimate as the received power is varied via a slider. The BER_TK subnetwork updates every 500 samples; the first value will be at 500-Tsave, (e.g., for Tsave =100), the display will update at 400, 900, 1400, et cetera. It may also be configured for BER using *Importance Sampling*. The transmitter and receiver are inside subnetworks, rather than at the top level design. A *berMC* measurement is also provided, for determining BER vs. a swept parameter other than *Es/No*, such as *Prx*.

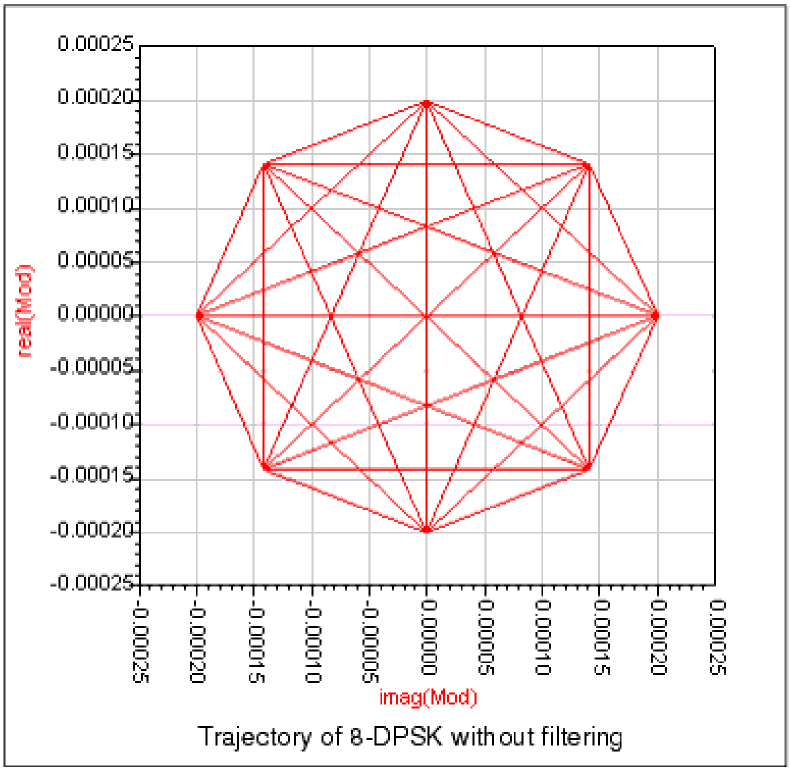


Ideal 8-DPSK Modem with EVM and BER (8DPSK_Modem_Ideal)

For 3 Mbps operation, 8-state Differential Phase Shift Keying (8-DPSK) has been proposed. This test bench provides an ideal modem with measurements for Spectrum Mask, EVM and BER. The radio has a variable-length GFSK preamble, implemented using an RF switch component to disconnect the GFSK source and connect the 8-DPSK source when the preamble is ended.

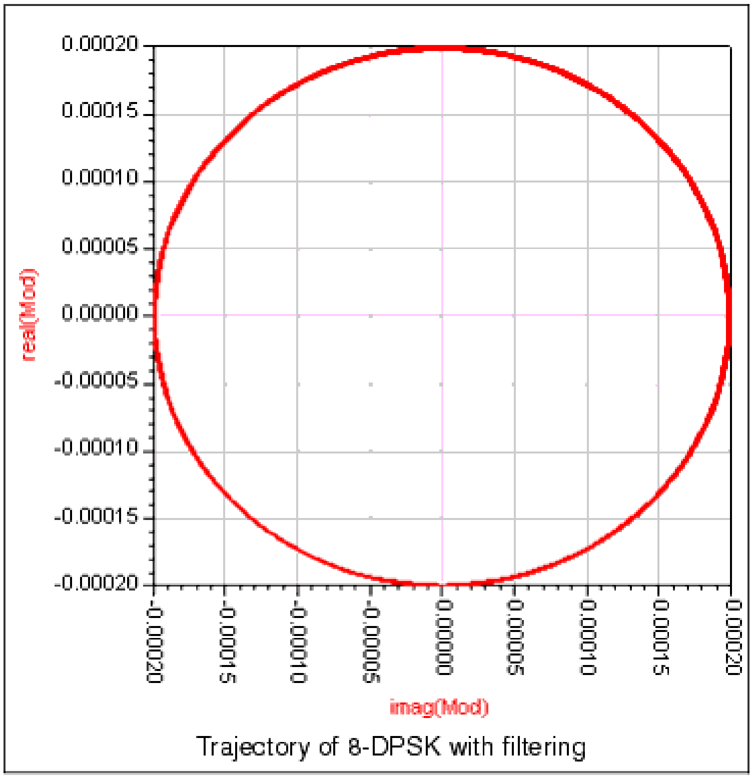
The 8-DPSK modem can be described as follows: Pseudo-random data in binary NRZ (non return to zero format, +/- 1V) from the timed Data component are differentially encoded using the *BinaryCoder* component. The *SymbolConverter* maps the data to 8-level Pulse Amplitude Modulated (PAM) symbols; there are 3 bits per symbol. Before the symbols can be phase modulated onto a carrier, scaling and offset must be applied. The phase modulator has a sensitivity of 360 degrees/volt. To properly map the 8 symbol levels to the correct phase-keying states, the input should be between -0.375 V and 0.500 V. The GainRF component scales the NRZ data by 2/0.875 = 0.4375. The DCShift offsets the signal by 0.5/8 = +0.0625 V.

Root raised-cosine pulse shaping has also been proposed. In the next two illustrations 8-DPSK IQ trajectory is first shown without any filtering in the transmitter and then with filtering applied. For practical rectangular pulse modems, equalization of f/sin(f) is also applied.



Trajectory of 8-DPSK without filtering

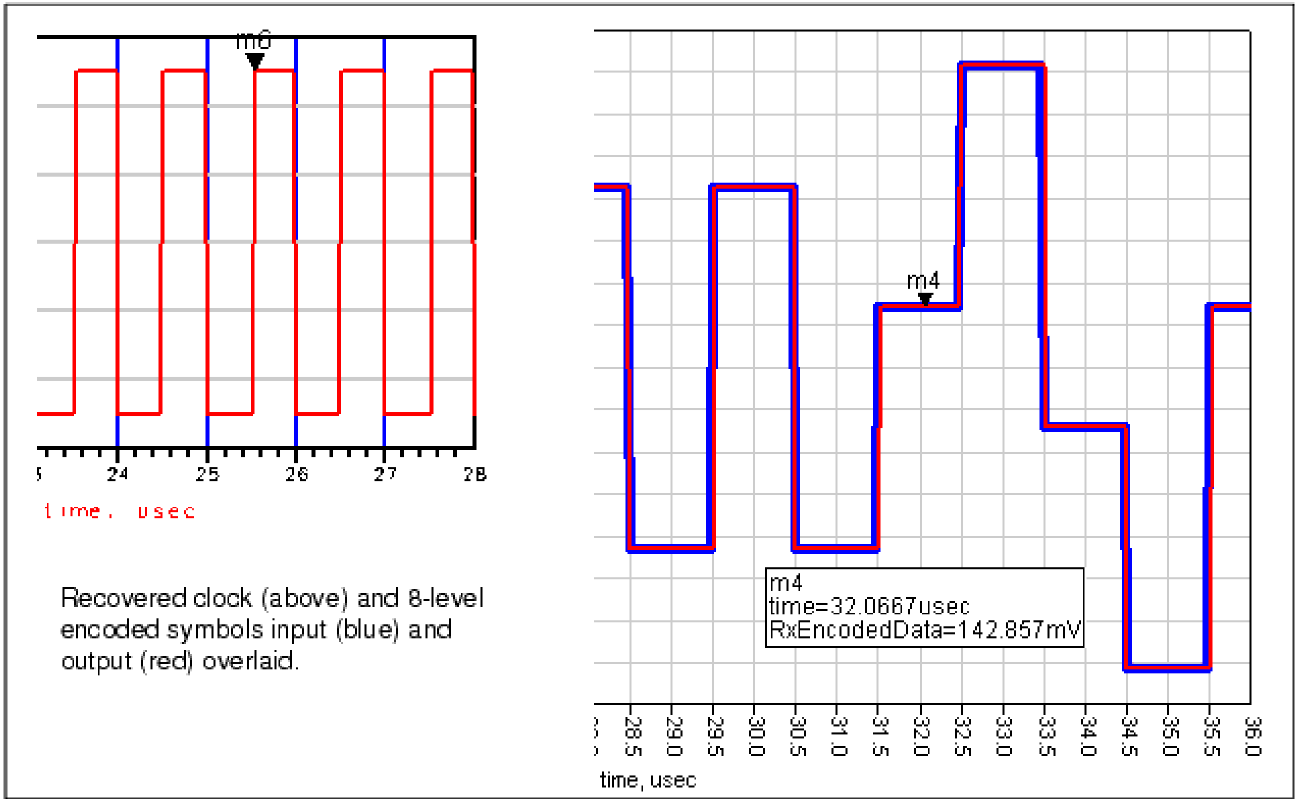
Raised-cosine filtering limits transitions to the unit circle. For a roll-off factor of 0.4 (proposed), the trajectory appears thus:



Trajectory of 8-DPSK with filtering

AddNDensity provides the channel noise model. The receiver uses clock recovery and hard decision decoding. The received signal is split to the clock recovery structure and to the quadrature demodulator. Following ideal demodulation of the I and Q parts of the signal, root raised cosine filters are applied. The clock recovery uses the GFSK preamble (alternating 101010.... pattern) to extract the clock, which is used to clock the I and Q SampleAndHold components. The *Quantizer2D* forces the sampled points to the nearest points on the 8-PSK constellation. This signal is applied to the PM_Demod. The PM_Demod output is inversely scaled and applied to a *SymbolConverter* set for PAM8 input and NRZ output. The BinaryCoder performs differential decoding to fully recover the output data.

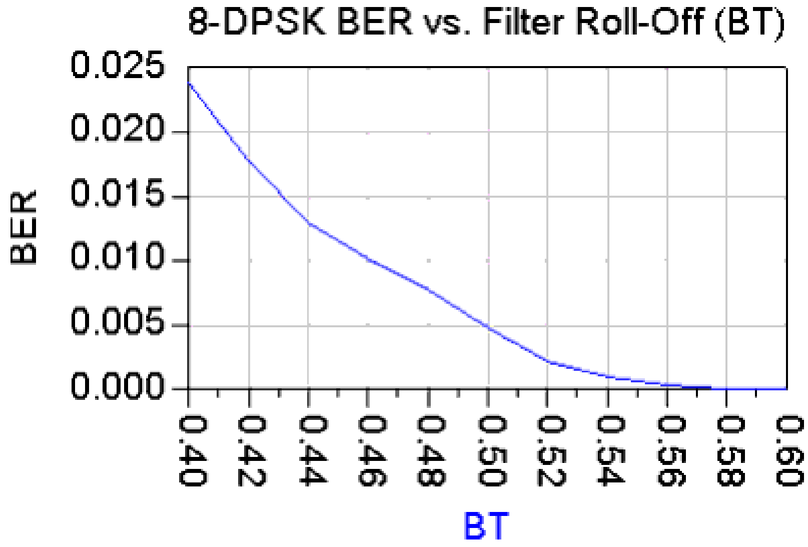
Measurement taps are provided to send input and output data, encoded input and output symbols, spectrum and trajectory data to the dataset. The display *8PSK_Modem_Ideal_Mask* shows all of these signals. Of particular interest is the recovered clock signal, on display page 2, and the encoded input and output symbols overlaid.



Recovered clock (above) and 8-level encoded symbols input (blue) and output (red) overlaid.

EVM and BER measurements are provided. BER is performed using the *berMC* component. Sampling reduction methods (such as *Importance Sampling*) are not applicable to constant-envelope modulation such as 8-DPSK. The *berMC* component will now control the simulation until *EstRelVariance* is achieved. It is not necessary to determine in advance how many samples are required for an accurate BER estimate. This is different from other test benches in the Bluetooth DesignGuide which have a "Numbits" variable to set the BER simulation length as a function of a swept parameter.

Of particular interest is the relation between the filter roll-off factor (variable BT) and error performance. It can be shown that a roll-off of 0.4 is not sufficient for acceptable performance; BT should be 0.60 or larger for best performance.

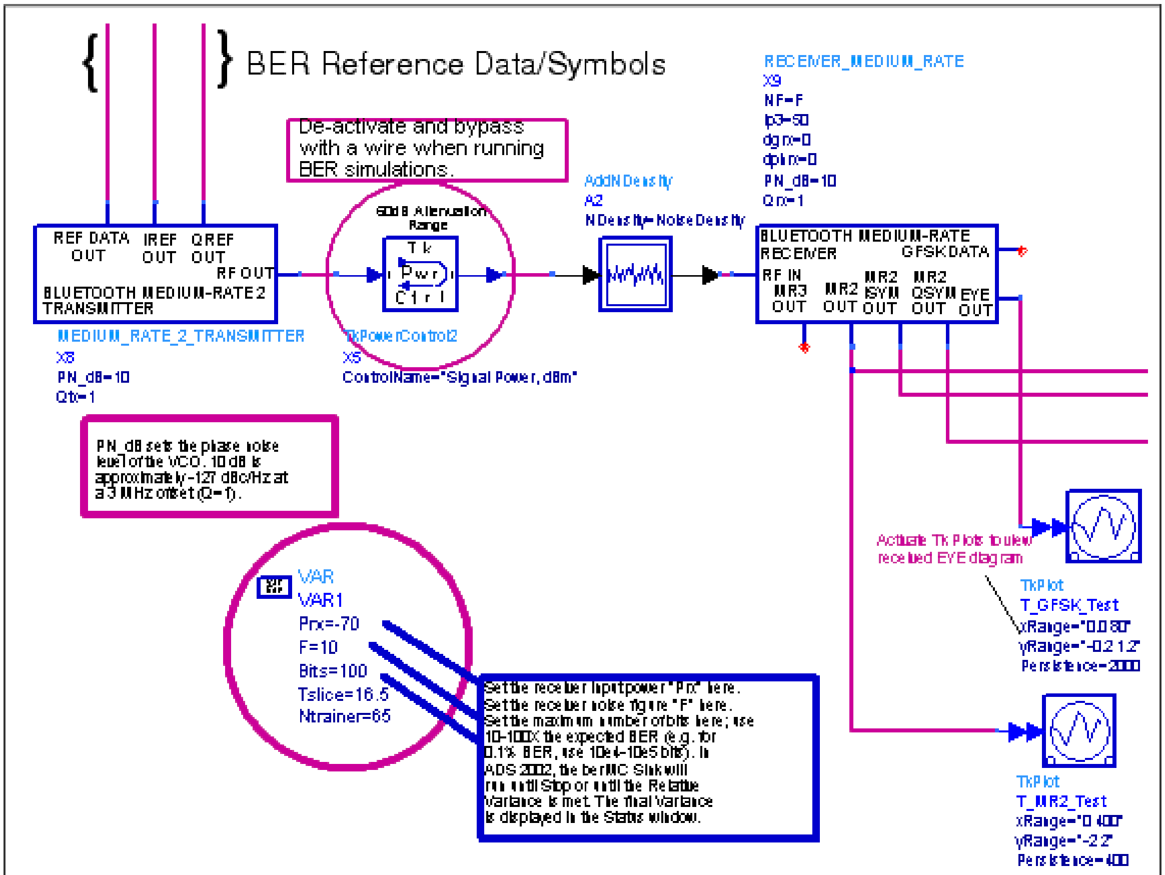


8-DPSK BER vs. raised-cosine filter rolloff (BT)

Medium Rate 3 Mbps Sensitivity and BER Test Bench (TEST_MR3_RECEIVER_SENSITIVITY)

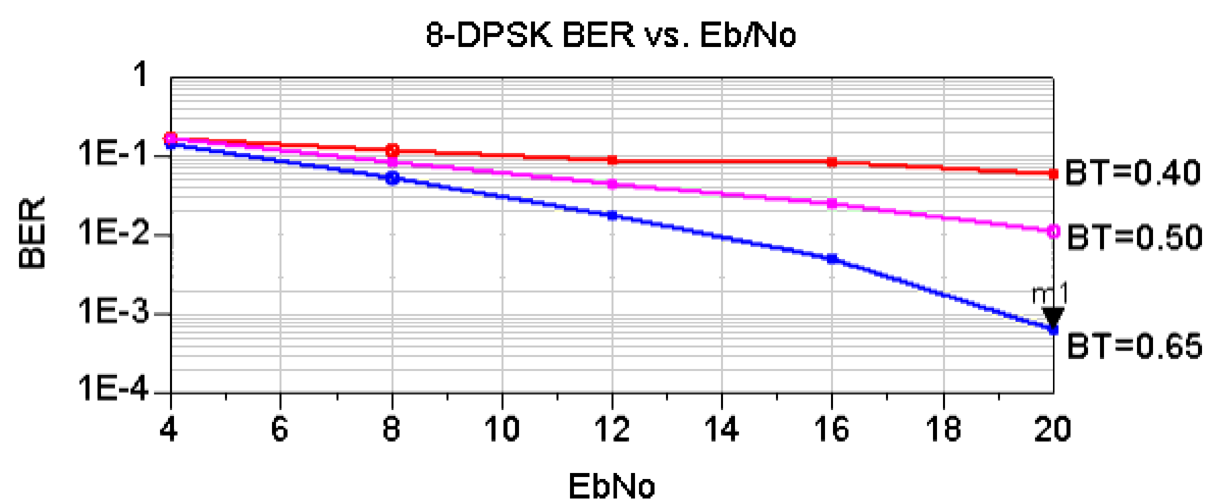
This test bench implements the 3Mbps mode using interactive control to view EYE diagrams, output data and a real-time BER estimate as the received power is varied via a slider. The BER_TK subnetwork updates every 500 samples; the first value will be at 500-Tsave, (e.g., for Tsave =100), the display will update at 400, 900, 1400, et cetera. The transmitter and receiver are inside subnetworks, rather than at the top level design. A *berMC* measurement is also provided, for determining BER vs. a swept parameter such as Prx or Eb/No.

For BER vs. Eb/No, the *AddNDensity* component is set via an expression to the correct noise density for each sweep point, using:
NoiseDensity=Prx-10*log(DataRate)-EbNo
where Prx is the signal power, DataRate is in bits/sec and Eb/No is in dB.


BER Reference Data/Symbols
De-activate and bypass with a wire when running BER simulations.
REF DATA OUT
IREF OUT
QREF OUT
RF OUT
BLUETOOTH MEDIUM-RATE 2 TRANSMITTER
MEDIUM_RATE_2_TRANSMITTER
X8
PN_dB=10
Qtx=1
60dB Attenuation Range
Tk Pwr Ctrl
TkPowerControl2
X5
ControlName="Signal Power, dBm"
AddNDensity
A2
NDensity=NoiseDensity
RECEIVER_MEDIUM_RATE
X9
NF=F
Ip3=50
dgnrx=0
dphrx=0
PN_dB=10
Qrx=1
BLUETOOTH MEDIUM-RATE RECEIVER
GFSK DATA
RF IN
MR3 OUT
MR2 OUT
MR2 ISYM OUT
MR2 QSYM OUT
EYE OUT
PN_dB sets the phase noise level of the VCO. 10 dB is approximately -127 dBc/Hz at a 3 MHz offset (Q=1).
VAR
VAR1
Prx=-70
F=10
Bits=100
Tslice=16.5
Ntrainer=65
Set the receiver input power "Prx" here.
Set the receiver noise figure "F" here.
Set the maximum number of bits here; use 10-100X the expected BER (e.g. for 0.1% BER, use 10e4-10e5 bits). In ADS 2002, the berMC Sink will run until Stop or until the Relative Variance is met. The final Variance is displayed in the Status window.
Activate Tk Plots to view received EYE diagram
TkPlot
T_GFSK_Test
xRange="0 080"
yRange="-0.2 1.2"
Persistence=2000
TkPlot
T_MR2_Test
xRange="0 400"
yRange="-2 2"
Persistence=400

Detail of TEST_MR2_RECEIVER_SENSITIVITY Schematic

In the following graph, EbNo is swept for 3 simulations at various values of BT. The 3 datasets are combined into one plot.



8-DPSK BER vs. Eb/No for 3 values of RF filter roll-off

Bluetooth Interference by 802.11 WLAN Signals

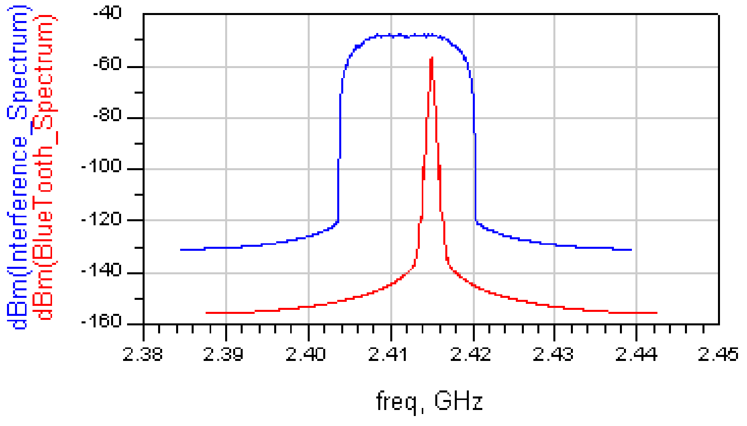
WLAN systems share the same 2.4 GHz band as Bluetooth. At present, the 802.11b system is operational in many regions, using direct-sequence spread-spectrum (DSSS) modulation. A new mode based upon the 802.11a specification, which uses OFDM (Orthogonal Frequency Division Multiplexing) in the 5 GHz band, has been proposed for use in the 2.4 GHz band and named *802.11g* . Therefore, it is of interest to be able to investigate the effects of both of these signals on Bluetooth performance. Two test benches are provided for this purpose. However, band-limited noise may be used as an approximate interference source and has been provided as an alternative.

Note
The 802.11b and 802.11a signal sources require the 5-GHz WLAN Design Library.

Bluetooth_with_80211b_Interference

This test bench provides an interactive slider that varies the power of the interferer as an EYE diagram is presented. Measurement items using the Agilent 89600 Vector Signal Analyzer (available only on PC platforms) are also provided along with setup files; these allow for demodulation and analysis of the Bluetooth and/or 802.11b signals in the interactive mode. Spectrum and BER measurements are also provided.

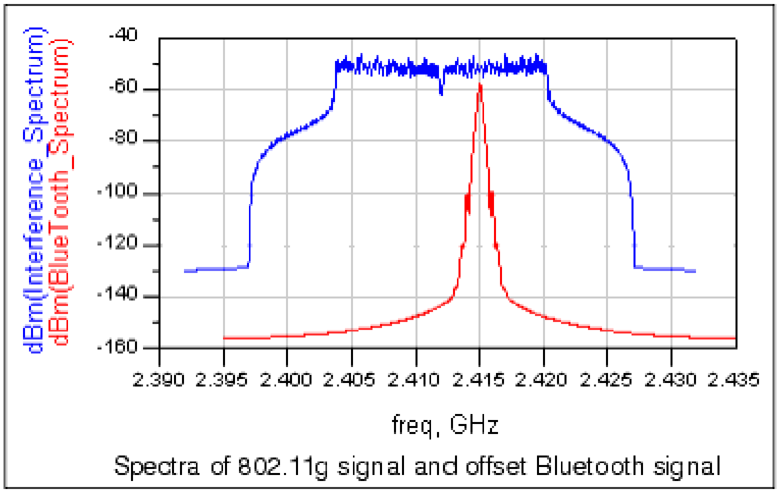
Note
Simulation time will increase significantly if less than 256 MB of RAM are available.



Spectra of 802.11b signal and offset Bluetooth signal

Bluetooth_with_80211g_Interference

This test bench provides an interactive slider that varies the power of the interferer as an EYE diagram is presented. Measurement items using the Agilent 89600 Vector Signal Analyzer (available only on PC platforms) are also provided along with setup files; these allow for demodulation and analysis of the Bluetooth and/or 802.11g signals in the interactive mode. Spectrum and BER measurements are also provided.



Spectra of 802.11g signal and offset Bluetooth signal

Test Benches and Subnetworks

Following are details on the available test benches and subnetworks.

Basic System Test Benches

TEST_TX_SPECTRUM The spectrum of the transmitter can be simulated here. The effects of phase noise and Gaussian filter quantization can be observed and compared to the allowed spectral template for various standards.

TEST_EYE This is a quick simulation to observe the eye diagram with the combined effects of the transmitter and the complete receiver.

TEST_TX_RX_EYE The eye diagram corresponding to the detailed-model (full transmitter and lowIF-receiver with phase noise and filters) end-to-end link can be simulated in this design.

Component/Subnetwork Evaluations

SHAPED_DATA This design models a 2 or 4 level Gaussian filtered data source. It includes an initial 2 level training sequence. Only the 2 level mode is applicable to Bluetooth.

SLICER This design extracts the average level of a de-modulated analog signal and uses this level as the slicing reference to a comparator input. The incoming analog signal is sliced into digital bits by the comparator. The slicer behavior is depicted in the display SLICER.

TEST_CHANNEL_FILTER The combined behavior of the highpass DC notch filters and the complex channel filter is simulated in this design.

TEST_FILTER_COMPLEX Complex channel filter behavior is simulated in this design.

TEST_FILTER_COMPLEX_TIME The time domain response of the complex channel filter is simulated in this design.

TEST_FILTER_IMPULSE The impulse response of circuit level and system level lowpass Bessel filters are compared in this simulation. These lowpass Bessel filters were used in the design of the bandpass complex Bessel filter. The system level model of the filter was preferred to speed the simulation; however, it needed an impulse response that was identical to that of the circuit level filter model.

TEST_GAUSSIAN_FIR_FILTER The Gaussian filter is implemented digitally as a 17-tap FIR filter with a 6-bit word length for each tap. The impulse response of the filter is simulated in this design. The impulse response is saved to a file. Data from this file is then used to define the tap coefficients of a FIR filter. The display TEST_GAUSSIAN_FIR_FILTER shows the impulse response.

TEST_LOWIF_FILTER_DEMOD This test bench is used for comparing and optimizing the combination of the channel filter along with various types of poly phase FM demodulators.

TEST_LOWIF_FMDEMOD Similar to the TEST_LOWIF_FILTER_DEMOD test bench, this design investigates the effect of a polyphase harmonic suppression band pass filter at the output of the hard limiters.

TEST_LOWIF_RECEIVER Similar to the TEST_LOWIF_FILTER_DEMOD test bench, with this design the entire receiver chain is investigated.

VCO/PLL (Phase Locked Loop) Investigations

TEST_PLL_SS RF synthesizer reference frequency spurs that occur due to a charge pump mismatch can be observed in this harmonic balance steady state simulation.

TEST_PLL_TR The transient response of the RF synthesizer is simulated in this test bench.

TEST_PLL_TR_linear This is the main test bench for optimizing the RF synthesizer parameters. The loop filter components are defined in terms of the parameters *z* (related to damping constant) and *fn* (related to loop bandwidth). The various results are shown in displays beginning with TEST_PLL_TR_linear.

Multipath Propagation Test Benches

TEST_MULTIPATH_ IMPULSE The impulse response of the multi-path channel is simulated in this design. The frequency response of the channel is obtained, with and without averaging done over any given modulation bandwidth, (e.g., 1 MHz for Bluetooth). The results are shown in the display TEST_MULTIPATH_ IMPULSE. At frequencies where there is a large relative channel loss without averaging, one can expect severe intersymbol interference due to multi-path. It can also be seen that the correlation bandwidth is approximately the inverse of the RMS delay spread.

TEST_MULTIPATH_POWER This design varies the channel snapshot, and measures the corresponding modulated signal average power at the output of the channel. The corresponding RMS delay spread values are also available. The display TEST_MULTIPATH_POWER_200_50_seed shows the simulation results for a 200 nsec delay spread using tap spacing of 50 nsec. A large number of channel snapshots were taken for the simulation. The pdf and cdf distributions of the multi-path loss are also shown.

TEST_MULTIPATH_EYE This design shows the TK plot of the FM demodulated eye diagram under multi-path conditions. The corresponding multi-path tap coefficients and RMS delay spread values are also shown.

TEST_MULTIPATH_ EXPONENTIAL This simulation shows the variations in both the mean power and the instantaneous modulated power for various channel snapshots, along with the corresponding delay spreads.

TEST_MULTIPATH_BER This simulation measures the BER for various channel snapshots. It is useful for computing the channel outage when the signal-to-noise ratio is large. See display TEST_MULTIPATH_BER for one particular channel snapshot. It shows the eye diagram, the channel snapshot, the recovered and transmitted bits, the BER, and the RMS delay spread. For channel outage simulations, only the BER should be enabled and the seed and/or frequency varied over a large number of points.

TEST_MULTIPATH_BER_AWGN Similar to TEST_MULTIPATH_BER, it includes additive white Gaussian channel noise. The input signal power level to an ideal receiver (0 dB noise figure) can be set. It shows the BER for both channel noise and multi-path. For channel outage simulations, only the BER should be enabled, along with the channel power measurement if required. For an example, see display TEST_MULTIPATH_BER_AWGN (100 nsec delay spread simulation for channel outage) in which the signal power was set 3 dB above the 1% sensitivity level (AWGN case without multi-path).

TEST_MULTIPATH_BER_NOFILT Similar to TEST_MULTIPATH_BER, this design does not include a channel filter. It shows the ideal BER under large signal-to-noise conditions.

System Compliance Tests

TEST_RECEIVER_ADJ The receiver adjacent channel rejection is simulated in this test bench. Notably, the rejection at alternate channel frequency, the image frequency, and the alternate channel-to-image frequency are simulated with this test.

TEST_RECEIVER_CCR The co-channel rejection of the receiver can be simulated with this test.

TEST_RECEIVER_TEST_INTERMOD The effects of two-tone jammers due to third order receiver non-linearity and the reciprocal mixing of these jammers due to phase noise are simulated with this test.

TEST_RECEIVER_SENSITIVITY The receiver sensitivity in an additive white Gaussian noise channel at -174 dBm/Hz is simulated in this design.

TEST_RECEIVER_IP2 The effect of out-of-band pulsed jammers on the receiver sensitivity is modeled in this design. The pulsed jammers produce pulsed DC offsets in the baseband quadrature signal paths. The relative power of the jammer and the co-channel rejection of the receiver are the variables that can be set in the top level simulation. Thus, the required IP2 is computed and used in the top level BER simulation.

TEST_MR2_RECEIVER_SENSIVITY This test bench implements the 2 Mbps mode using interactive control to view EYE diagrams, output data and a real-time BER estimate as the received power is varied via a slider. It may also be configured for BER using *Importance Sampling* . The transmitter and receiver are inside subnetworks, rather than at the top level design. A *berMC* measurement is also provided, for determining BER vs. a swept parameter other than Es/No, such as Prx.

TEST_MR3_RECEIVER_SENSIVITY This test bench implements the 3Mbps mode using interactive control to view EYE diagrams, output data and a real-time BER estimate as the received power is varied via a slider. The transmitter and receiver are inside subnetworks, rather than at the top level design. A *berMC* measurement is also provided, for determining BER vs. a swept parameter such as Prx or Eb/No.

Bluetooth with 802.11 Interference Test Benches

Bluetooth_with_80211b_Interference This test bench provides an interactive slider that varies the power of the interferer as an EYE diagram is presented. Measurement items using the Agilent 89600 Vector Signal Analyzer (available only on PC platforms) are also provided along with setup files; these allow for demodulation and analysis of the Bluetooth and/or DSSS 802.11b signals in the interactive mode. Spectrum and BER measurements are also provided.

Bluetooth_with_80211g_Interference This test bench provides an interactive slider that varies the power of the interferer as an EYE diagram is presented. Measurement items using the Agilent 89600 Vector Signal Analyzer (available only on PC platforms) are also provided along with setup files; these allow for demodulation and analysis of the Bluetooth and/or OFDM 802.11g signals in the interactive mode. Spectrum and BER measurements are also provided.

Subnetworks

AGC This block is used at the output of the MULTIPATH_EXPONENTIAL block to set the mean output power to a fixed level, instead of letting it vary with each channel snapshot. It measures the mean power of the signal coming from the MULTIPATH_EXPONENTIAL block in a small time window, then it adjusts the gain to set the mean power at the design level.

AWGN CHANNEL Models the thermal noise of an RF channel at -174 dBm/Hz.

> **Note**
> *AddNDensity*, a component available in recent releases of ADS, may be used in placed of AWGN_CHANNEL. It allows the Noise Density to be directly specified in dBm/Hz.

BER_TK Provides real-time calculation of Bit Error Rate by exclusive-OR comparison of two bit streams. Input data should be downsampled to 1 sample per bit. Requires top-level variables Tsave and bitRate.

BroadBandNoiseSource80211b Provides a filtered noise source that approximates the 802.11b signal; for use when the WLAN Design Library is not available, or when system resources prevent use of the 802.11b signal source.

BroadBandNoiseSource80211g Provides a filtered noise source that approximates the 802.11g signal; for use when the WLAN Design Library is not available.

CLOCK_RECOVERY Used for bit-timing recovery and sampling of sliced data in the receiver. This subnetwork extracts the bit timing from an initial stream of data, and then freezes the recovered block phase after *Ntrainer_sym* bits. It also samples the de-modulated bits at the middle point of each using the recovered clock.

DEMFM_OHZ A zero-IF polyphase FM demodulator that includes a down converter from low-IF to zero-IF.

DEMFM_BESS_MULT A *delay and multiply* polyphase FM demodulator using a Bessel filter to implement the delay. This unique method provides exceptional performance when compared to the other demodulators.

DEMFM_DAMCKT A *differentiate and multiply* polyphase FM demodulator at the Analog/RF circuit level.

DEMFM_DELAY_MULT A system level *delay and multiply* polyphase FM demodulator.

DEMFM_IQDIGITAL A polyphase digital FM demodulator.

FILT_HP_50KHZ N1 A first-order highpass filter generated from the DSP filter designer in ADS. It is used in RECEIVER to remove DC following down-conversion.

FILT_LP_N1 A first-order lowpass filter.

FILTER_BESSEL_COMPLEX A polyphase bandpass filter with Bessel response.

FILTER_BESSELckt A circuit level (Analog/RF) subnetwork used in FILTER_BESSELckt_COMPLEX.

FILTER_BESSELckt_COMPLEX A complex filter subnetwork used in DEMFM_BESS_MULT.

FILTER_CHEB_COMPLEX A complex filter subnetwork used as a channel filter in RECEIVER.

MEDIUM_RATE_2_TRANSMITTER A 2Mbps transmitter using Pi/4-DQPSK modulation with a variable-length GFSK preamble.

MEDIUM_RATE_3_TRANSMITTER A 3 Mbps transmitter using 8-DPSK modulation with a variable-length GFSK preamble.

MIXER_COMPLEX A complex mixer used in the system-level implementation of polyphase bandpass filters.

MULTIPATH_EXPONENTIAL This design implements an exponential power decay multi-path channel model that is widely used for indoor propagation. The mean excess delay and tap delay can be specified in microseconds. Each tap coefficient has a Rayleigh power distribution and a uniform phase distribution. For a specified value of time *Tburst,* the channel snapshot is kept fixed. For the next *Tburst* duration, a new channel snapshot is taken. The tap coefficients for each snapshot, the corresponding values of the RMS delay spread and the mean excess delay are all available. TK plots for these measurements can also be enabled.

MULT_RF_BB A subnetwork used in MULTIPATH_EXPONENTIAL.

MULTIPATH_TAP_C A subnetwork used in MULTIPATH_EXPONENTIAL to generate random noise and phase characteristics according to the exponential tap coefficients.

OSC_PN A system-level RF oscillator with phase noise.

OSC_PN_FMMOD A baseband phase noise generator used as modulation input voltage to an FM modulator.

PLL_TR_linear Used in TEST_PLL_NOISE and TEST_PLL_TR_linear.

POWER Output is a signal that has a value equal to the input signal power in dBm. It is useful in evaluating the effect of multi-path fading.

POWER_GATED Time-gated version of POWER.

TRANSMITTER This transmitter is used in most test benches. It is constructed using SHAPED_DATA and OSC_PN_FMMOD, plus an ideal FM modulator. Top-level parameters include the phase noise level and Q.

RECEIVER The Bluetooth receiver has a front-end low-noise amplifier that models the noise figure and the third-order intercept point. It is followed by a quadrature amplitude demodulator that includes the phase and gain imbalance. The local oscillator for this demodulator/down converter includes the phase noise. The output of the quadrature amplitude demodulator is a 1 MHz low IF complex signal comprising the in-phase and quadrature phase signals. These signals are highpass filtered to remove DC offsets due to local oscillator self mixing, and to remove time varying DC offsets as a result of second-order non-linearity effects on out of band pulsed jammers. After the highpass filters, there is a complex channel filter with quadrature inputs and outputs. This filter is centered at 1 MHz and has an asymmetric positive and negative frequency response. The quadrature outputs of the channel filter are hard limited and then demodulated by a complex FM demodulator. This FM demodulator can be implemented in several ways. The preferred solution is to have a complex Bessel filter that implements a delay, with the delay signals cross-multiplied with the input signals and then summed at the output. The combination of the complex channel filter and this Bessel filter have to be carefully designed to produce the minimum distortion of the de-modulated signal. The demodulator and signal have unwanted high-frequency components that are removed by the data filter. The data slicer then converts the demodulated analog signal into digital bits.

RECEIVER_IP2 The effect of out of band pulsed jammers on receiver sensitivity is modeled in the RECEIVER_IP2 design, otherwise similar to RECEIVER. The pulsed jammers produce pulsed DC offsets in the baseband quadrature signal paths. The relative power of the jammer and the co-channel rejection of the receiver are variables that can be set in the TEST_RECEIVER_IP2 top-level simulation. Based on this, the required IP2 is calculated and used in the top level BER simulation.

RECEIVER_MEDIUM_RATE A composite subnetwork which contains receivers for GFSK and both medium rate formats.

SHAPED_DATA This subnetwork implements both 2 and 4 level pulse shaping for GFSK modulation. A {10101010.....} preamble, its length determined by the Preamble parameter defined in a VAR block in the top-level design, is inserted at the start of simulation.

> **Note**
> This component has been slightly modified in Version 2.1.1 in that a *IntToFloat* component has been inserted between the *Bits* and *Trainer* components. Under some conditions, ADS will report an error concerning signal types without this added component.

sub_80211g_Source Part of the *802.11g* Signal Source

sub_80211b_5p5Mbps_CCK_Source Part of the *802.11b* Signal Source

sub_CRC_Generator, sub_DataCounter and **sub_ScrambleWithReset** Used within

sub_80211b_5p5Mbps_CCK_Source