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Wireless Test Bench Simulation

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Intel@ Math Kernel Library, <http://www.intel.com/software/products/mkl>

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Using Instrument Connectivity

Introduction

Transmitter wireless test benches support instrument connectivity. The following sections explain how to connect to instruments and describe the test benches' compatibility with Agilent Technologies instruments.

Connecting to Instruments

The wireless test benches rely on Connection Manager architecture for instrument connectivity. Connection Manager is the implementation of Agilent Technologies Connected Solutions for ADS.

A Connection Manager-based simulation is part of the *client* half of the Connection Manager client/server system, and operates through an instance of the Connection Manager server. You can think of the Connection Manager-based simulation as an interface into the measurement available on the server.

Detailed information about using Connection Manager, including functional concepts and server IO configuration is provided in *Connection Manager* (connectmui).

The Connection Manager architecture also provides instrument *discovery* and measurement *exploration*.

- *Discovery* makes it easy to identify the instruments that are connected to your server workstation, enabling the client to easily associate a particular instrument with a particular measurement.
- *Exploration* locates measurements on the server and describes a measurement's capabilities so a client can easily determine what a measurement does and how to use that measurement.

Instrument Discovery

The transmitter test benches provide interactive selection of the instrument before simulation. The *Signal to ESG* parameter category includes an Instrument parameter that is set to a string following a specific syntax as shown in this example:

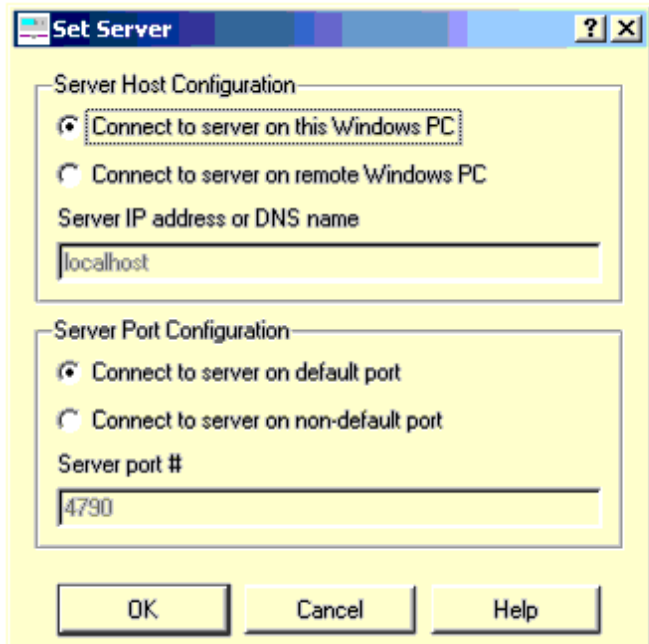
```
[GPIB::19::INSTR][localhost][4790]
```

To interactively select an instrument:

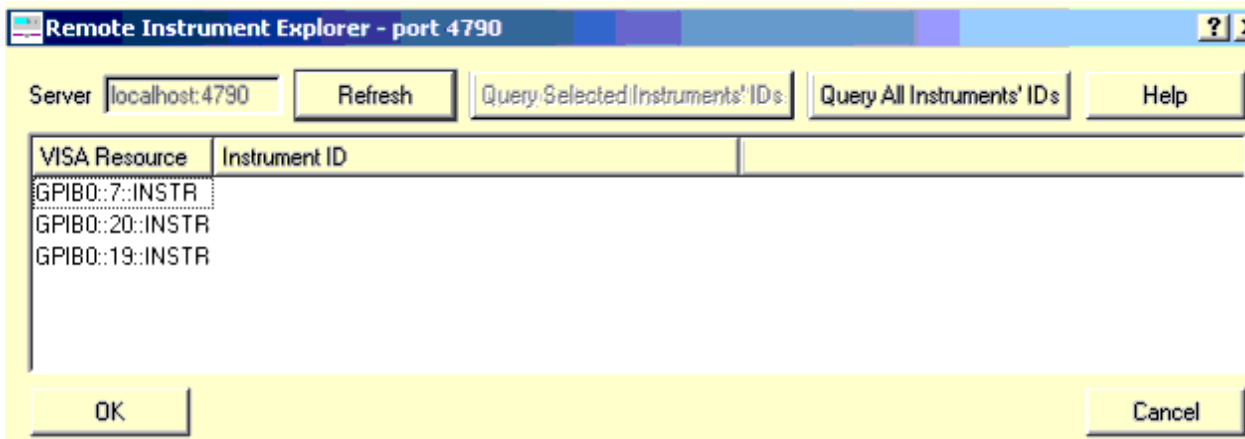
1. From the *Wireless Test Bench* component parameter dialog box, select the

ESG_Instrument parameter.

- Click the **Select Instrument** button to access the *Set Server* dialog box.

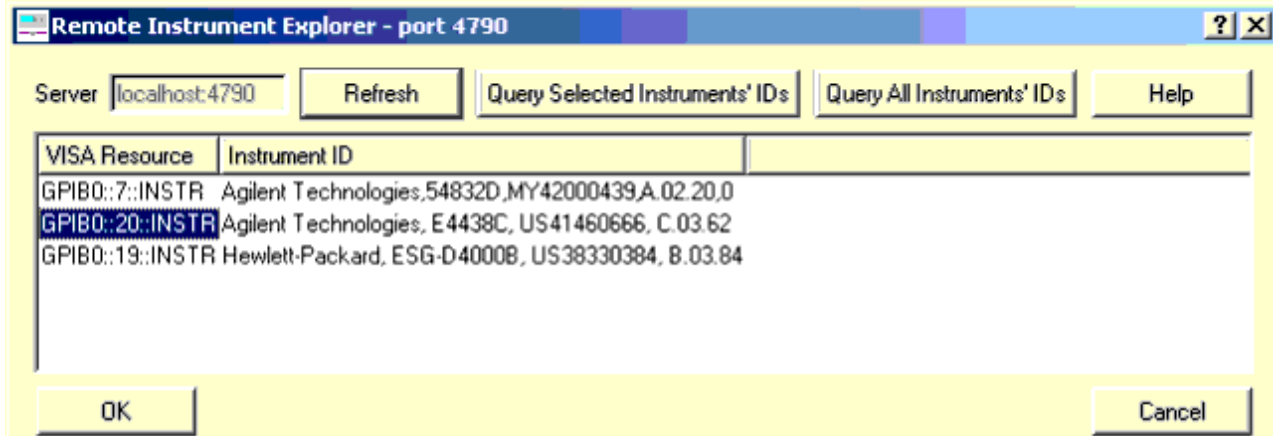


- If *Connect to server on remote Windows PC* is selected, enter the IP address or DNS name of the Windows PC on which an instance of the Connection Manager server is running.
- Enter the port number on which the server is waiting for incoming connection requests. Unless the server settings are changed manually, use the default port number **4790**.
- Click **OK** to access the *Remote Instrument Explorer* dialog box.



This dialog box shows the Visa Resource identifiers of all instruments that are currently connected to the workstation running the Connection Manager server. A Visa Resource identifier is like an IP address that can uniquely identify an instrument among all the instruments connected to the workstation through all available interfaces.

To map the Visa Resource identifiers to the associated instrument model number, select one or more of the Visa Resource entries and click the **Query Instruments' IDs** button. This tells the Connection Manager server to send the standard IEEE 488.2 identification command **IDN?* to the instrument(s). Most modern instruments that understand this command will respond with an identification string. After all selected instruments are queried, the Instrument IDs are displayed:



6. Select a specific instrument based on the Instrument ID string displayed and click **OK**.

Compatibility with Agilent Technologies Instruments

WLAN test benches, signal sources, and EVM measurements are compatible with the Agilent E4438C ESG Vector Signal Generator, and Agilent 89600 Series Vector Signal Analyzer; details are given in the following table.

WLAN Agilent Instrument Compatibility Information

WLAN Spec	ESG Models	VSA Models
SpecVersion= 1999	E4438C, Firmware Revision C.03.40 Option 417 - "802.11 WLAN" Software Personality (Signal Studio)	89600 Series, software version 4.xx/5.xx Option B7R - "WLAN Modulation Analysis"

TD-SCDMA test benches and signal sources are compatible with Agilent E4438C Signal Generator and Agilent 89600 Series Vector Signal Analyzer; details are given in the following table.

TD-SCDMA Agilent Instrument Compatibility Information

TD-SCDMA Spec	ESG Models	VSA Models
SpecVersion= 6-2002	E4438C, Firmware Revision C.03.40 Option 411 - "TD-SCDMA (TSM)" Software Personality (Signal Studio)	89600 Series, software version 4.xx/5.xx Option B7N - "3G Modulation Analysis"

3GPP FDD test benches and signal sources are compatible with Agilent E4406A VSA Series Transmitter Tester, Agilent PSA Series High-Performance Spectrum Analyzer, and Agilent 89600 Series Vector Signal Analyzer; details are given in the following table.

3GPP FDD Agilent Instrument Compatibility Information

3GPP Spec	ESG Models	VSA Models
SpecVersion= 3-2002	E4438C, Firmware Revision C.03.40 Option 400 - "3GPP W-CDMA FDD" Personality	E4406A, Firmware Revision A.06.03 Option BAF - "W-CDMA" Measurement Personality PSA, Firmware Revision A.04.07 Option BAF - "W-CDMA" Measurement Personality 89600 Series, software version 3.01/4.xx/5.xx Option B7N - "3G Modulation Analysis"

For more information about Agilent ESG Series of Digital and Analog RF Signal Generator and Options, visit

www.agilent.com/find/ESG .

For more information about Agilent PSG Series of Digital and Analog RF Signal Generator and Options, visit

www.agilent.com/find/PSG .

For more information about Agilent 89600 Series Vector Signal Analyzer and Options, visit

www.agilent.com/find/89600 .

For more information about Agilent PSA series High-Performance Signal Analyzer and Options, visit

www.agilent.com/find/psa

Using Wireless Test Bench Models

Introduction

Wireless test bench simulation is used to perform complex wireless system measurements using wireless test bench models. 3GPP FDD, EDGE, HSUPA, Mobile WiMAX, TD-SCDMA, Ultra-Wideband, and WLAN Wireless Design libraries provide pre-configured models as well as templates.

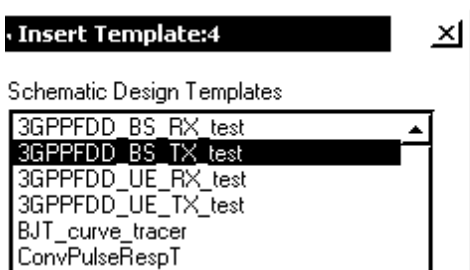
WTB simulation uses Circuit Envelope analysis along with the ADS Ptolemy Data Flow (DF) controller to perform Analog/RF and system cosimulation. Each wireless test bench model is packaged such that the RF designer avoids working with DF analysis parameters.

Working with WTB Template

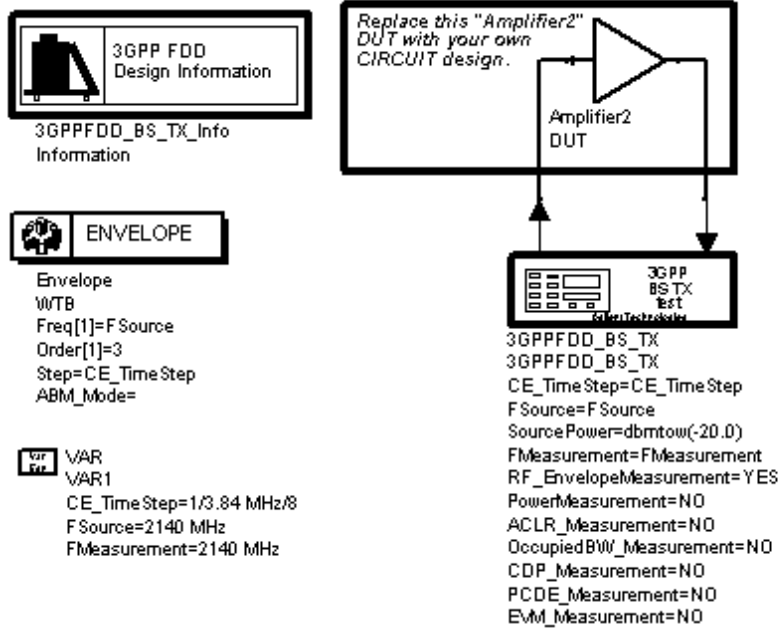
WTB Template is the starting point of the WTB simulation.

To insert a WTB template:

1. In an Analog/RF schematic window select **Insert > Template**.
2. In the popup *Insert Template* dialog box, choose one of the installed WTB templates, for example **3GPPFDD_BS_TX_test**, click **OK**.



3. Click *left* to place the template in the schematic window.



You are now ready to replace the DUT with your own RF design, select measurements, and set parameters. See [Setting Circuit Envelope Analysis Parameters](#), and [Setting up a Wireless Test Bench Model](#).

Setting up a Wireless Test Bench Model

Replace the Amplifier2 DUT with your own RF DUT, set the *required* parameters, and set *optional* parameters as necessary. The *required* parameters include setting simulation frequencies and selecting measurements; at least one measurement must be enabled for successful simulation. *Optional* parameters provide additional control of the selected measurements. These topics are discussed in the following sections:

- [Setting Required Parameters](#)
- [Setting Optional Model Parameters](#)

The following table describes the various types of parameter data entry fields in parameter dialog boxes.

Parameter Field Type	Description
String data entry field	Used to enter integer, real, complex, or string type of scalar data. Array and string type data must be enclosed in quotes.
String data entry field with multiple choices	This gives you multiple choices for the value of the parameter to select from. The pull down list field also enables you to type in the data directly. The last choice in the list specifies what the type-in value can be, such as an option index, a real value, etc. Use this mode to assign a variable to this type of parameter; then use the variable to either sweep or optimize the parameter.
Information fields	This non-editable information field provides information on a certain aspect of the WTB model.
Instrument selection field	This is a string data entry field followed by a button to launch the instrument-selection user interface. This type of parameter is used only when you enable ESG download. You can enter the instrument address directly or use the button to launch the instrument-selection user interface to interactively select the instrument and update the address.

Setting Required Parameters

After connecting the WTB model and DUT ports, double click on the WTB component to set the *Required Parameters* in the popup parameter dialog box. The number of parameters varies between different models. These parameters control the simulation and identify the selected measurements. They must have valid values and cannot be left blank. For detailed information about setting these parameters, click *Help* in the parameter dialog box.

Note You must set the required frequencies and select at least one measurement for successful simulations.

Setting Circuit Envelope Analysis Parameters

The WTB analysis is a cosimulation between an *Env* (Circuit Envelope) analysis and a DataFlow analysis to verify an RF design's system performance. The DataFlow analysis is pre-configured with the WTB model.

The RF designer must configure the Circuit Envelope analysis to ensure proper simulation. For details about setting the Circuit Envelope parameters, see *Envelope Simulation Parameters* (cktsimenv).

Simulation stop time is controlled by the selected measurements and their parameter values. The measurements and their parameters are located after the *Required Parameters*. If necessary for your measurement requirements, set the optional parameters for the WTB model. See [Setting Optional Model Parameters](#).

Setting Fast Cosimulation Parameters

When the *Circuit Envelope* controller dialog box is open, choose the Fast Cosim tab. Select *Enable Fast Cosim* to gain access to and set its parameters. Fast Cosim is also known as Automatic Verification Modeling (AVM).

Fast Cosim is a user-selected mode of operation, available for co-simulation that can significantly speed up Circuit Envelope simulations of Analog/RF circuits. When this mode is enabled, the analog subcircuit is characterized using a variety of Harmonic Balance simulations at the start of each wireless test bench simulation. During the actual wireless test bench simulation, this characterization data is then used to predict the response of the subcircuit instead of performing the full circuit simulation at each time point.

Since this characterization is normally done at the start of each WTB analysis sweep based on the full circuit level schematic, the overall capability is basically the same as if the actual circuit level representation is used throughout the Circuit Envelope simulation. For example, optimization of circuit level parameters, or swept parameters including bias, temperature or swept carrier frequency, will continue to operate as expected. These capabilities do not exist when the circuit is manually replaced with behavioral models.

This ability to predict the modulated response based on the Harmonic Balance characterization relies on the fact that many circuits, when used in relatively narrow band modulated applications, can have their nonlinearity represented as a static nonlinearity that is strictly a function of the instantaneous amplitude of the carrier. Many of these circuits (amplifiers and mixers) have little or no frequency response over the modulation bandwidth of interest; any frequency response effects that do exist can often be represented as a linear filter on the input or output of the nonlinearity.

Each output of the Analog/RF subcircuit is then characterized by the equation:

$$Out_k = (P_k(InputMag) - P_k(0)) \times e^{jInputPhase \times HarmGain} + P_k(0)$$

The $P_k(mag)$ functions are determined by the swept amplitude Harmonic Balance simulation. The *HarmGain* is the harmonic gain determined from the harmonic indices of the input and output frequencies.

If phase characterization has been enabled (setting the *Num. of phase pts* parameter to a non-zero value) each output is then characterized by this modified equation:

$$Out_k = P_k(InputMag, InputPhase)$$

In this case, $P_k(mag, phase)$ functions are determined by a 2D swept amplitude and swept phase Harmonic Balance simulation.

If the subcircuit nonlinearities are a function of the input phase, as in a nonlinear IQ demodulator, then the amplitude-only characterization is not accurate and the 2-dimensional amplitude and phase characterization must be used.

Note that the magnitude-only characterization assumes the output phase can be determined from the harmonic indices of the input and output frequencies. In certain rare cases, this can be ambiguous. For example, if the input frequency is *fund1* and the output frequency is $2 * fund1$, then the simulator assumes the output signal is generated by doubling the input frequency and so the input phase is doubled. However, if this $2 * fund1$

output frequency is actually generated by mixing with another LO source at the *fund1* frequency and the phase relationship is supposed to be linear, then the Fast Cosim results will be incorrect. If the mixer LO is operating at an independent *fund2* frequency, with a mixer output at *fund1 + fund2*, then the HarmGain of 1.0 is correctly determined. So, as with the IQ demodulator, if there are circuit sources operating at the same frequency as the input signal, caution must be used when enabling this Fast Cosim mode, and the 2D amplitude and phase characterization may be required.

In addition to the swept amplitude characterization, the Fast Cosim characterization also includes a small signal Harmonic Balance frequency sweep. In this case, the input amplitude is set to 0, and the small signal frequency is swept between +/- 0.5/ *TimeStep*. Note that even though the input amplitude is set to 0, a nonlinear analysis is still being done so any frequency translation effects due to internal mixers will be fully captured. An impulse response representing this frequency response can then be generated and placed (at the user's choice) on the input or the output of the nonlinear block. An additional delay can be added to the frequency response, so that the impulse can be made a more accurate representation of the frequency response. The user should set the number of frequency points high enough that any frequency response deviations are sufficiently sampled (a minimum of 4 samples every 360 degrees). The maximum duration of the impulse response will be approximately 0.75/ *FreqSpacing*, where

$$FreqSpacing = \frac{1}{2^N \times TimeStep}$$

N is determined so that 2^N is just larger than the user-specified number of frequency points.

In addition to the amplitude and frequency response characterization, nonlinear noise characterization is also done. A single value for the equivalent input noise for each output is determined, then added to the input signal prior to the above nonlinear and frequency response effects. In the case of multiple outputs, these equivalent noise sources are uncorrelated. So any correlation of the Analog/RF subcircuit added noise between multiple outputs is lost during this Fast Cosim mode. This noise characterization is implemented by selecting *Turn On All Noise* in the Envelope parameter group in the *Options* window. Normally, the frequency points used for noise characterization are the same as for small-signal response characterization in which a linear frequency sweep is used. Such a linear frequency sweep may require too many frequency points to properly capture narrow band noise such as 1/f noise. To handle 1/f noise characterization efficiently you can choose to set an independent log sweep on the Envelope controller's Fast Cosim tab in the *Characterization Options*.

In certain cases, the time spent doing this characterization can be eliminated if the user requests that the simulator use previous characterization. Once this mode is selected, then the user must make sure that the previous characterization is still valid, and that circuit parameters have not been changed (perhaps by optimization), biases have not changed, carrier frequencies have not changed, etc. The circuit should not have changed its connectivity within the WTB analysis environment. Also, the format and data in the dataset must be in the same expected configuration as when it was written by simulator.

In addition to the characterization and implementation portion of the Fast Cosim mode,

there is also a user-selectable verification step. If the user specifies a non-zero verification *Stop Time*, then the normal Circuit Envelope simulation is performed in parallel with the fast cosimulation predictions. The error over this verification is then calculated and output to determine how well these predictions are performing. If the behavior is unacceptable, as determined by the *Accept Tolerance*, then the Fast Cosim will be disabled and only the normal Circuit Envelope results will be used. Clearly, if used, this verification time should be set long enough to include a representative portion of the input signal. This may need to take into account the fact that many sources, due to channel filtering, take a while to generate their full amplitude outputs.

Limitations

While you may have selected the Fast Cosim mode, it may become disabled if:

- The RF DUT has more than one input from the WTB model or the input is not for an RF signal (non-zero carrier frequency).
- The Circuit Envelope *Step* is not an integer submultiple of the *WTB_TimeStep*. See the specific WTB documentation to understand how the *WTB_TimeStep* is set. *WTB_TimeStep* cannot be set directly by the user and is set by derivation from the other WTB model parameters.
- Verification was enabled but performance did not meet an acceptance level.
- The Envelope analysis includes an oscillator analysis.
- The input frequency was a mixing term and not harmonically related to a single fundamental.
- The input frequency does not exactly match an Envelope analysis frequency.
- There was a problem reading the previously generated dataset.

Fast Cosim is not available for use with WTBs performing Power Added Efficiency measurements.

Additional limitations of the Fast Cosim mode, that may not be automatically detected by the simulator unless verification is enabled, include:

- Envelope analyses parameters such as the Freq parameters should not be swept or optimized.

Setting Optional Model Parameters

The optional WTB model parameters are listed after *Required Parameters* in the parameter dialog box. Scroll down to see all of the parameters. Some parameters control the simulation run time, which you will use primarily to modify the simulation run time; otherwise, you rarely need to modify them.

Some parameters are for measurements listed in *Required Parameters*. Some of those parameters will also control the simulation run time. You may need to change parameters for the measurements you have selected.

For detailed information about setting these parameters, click *Help* in the parameter dialog box.

Performing Sweeps, Monte Carlo/Yield Analysis, and Optimizations

WTB model parameters can be included in Parameter Sweep, Monte Carlo/Yield Analysis, and Optimization Analysis.

Note
The SimInstanceName must always use "WTB1" for sweep or optimization controller regardless of the Envelope controller's instance name.

For information about Parameter Sweeps, see *Parameter Sweeps and Sweep Plans* (cktsim) in the *Using Circuit Simulators* (cktsim) documentation.

For information about Monte Carlo/Yield Analysis and Optimizations, see *Using Monte Carlo Yield Analysis* (optstat) in the *Tuning, Optimization, and Statistical Design* (optstat) documentation.

Viewing WTB Analysis Results

Introduction

You can view Wireless Test Bench measurement results immediately after a simulation is complete, or view results on previous collected datasets. For more information about using the data display, see the *Data Display* (data) documentation.

Note that a Wireless Test Bench (WTB) simulation in ADS consists of an Envelope controller on the top level, and a DF controller embedded in the hierarchy. You may notice that the dataset entries resulting from a WTB simulation differ from those expected from a Circuit Envelope simulation.

In a normal Circuit Envelope simulation, *time* and *freq* are in the dataset. Neither is present in a WTB simulation, even though an Envelope controller is on the top level schematic. This is because a WTB simulation is really a Ptolemy/Envelope cosimulation, so the independent variables will be *time* for timed signals and *Index* for numeric signals. The following example workspace includes some examples of dataset entries:

Workspace: WCDMA3G_RF_Verification_wrk

Design: 3GPPFDD_UE_TX_test

- RF_V.WTB.time (indep var: time)
- Meas_V.WTB.time (indep var: time)
- RF_Power.CCDF.CCDF.WTB.Index (indep var: Index)
- WTB1.WTB.time is a dummy variable, which has a value of 0 sec.

Viewing Simulation Results

You can view the results of a WTB simulation in the following two ways:

- At the end of a simulation a data display window automatically opens containing the measurement results.
- For simulation data collected earlier, build customized data display.

Each successful WTB simulation dataset contains information on the data display pages to display at the end of a simulation when Open Data Display when simulation completes is enabled (default). In this case, the opened data display window contains the various pages set up for every measurement enabled in the Wireless Test Bench Setup form.

To enable Open Data Display when simulation completes:

1. In the Analog RF schematic window, select **Simulate > Simulation Setup**.
2. In the *Simulation Setup* dialog box, enable the options **Open Data Display when simulation completes**.

To build a customized data display, pre-defined WTB data display template can be used:

1. In the Data Display window, select **Insert > Template**.
2. In the Component Library/Template Browser window, click on libraries **DDS Templates - Product**, then choose an appropriate data display template, for example, **3GPPFDD_BS_TX_Power**.
3. Click **OK** to insert selected data display template. Multiple data display templates can be inserted one by one sequentially.



Note

The automatically opened data display and the inserted data display template usually contains multiple data display pages. Use **View Previous Page** or **View Next Page** toolbar buttons to explore all pages.

Wireless Measurement Definitions

Introduction

The following sections briefly describe the most commonly used measurements in transmitter and receiver testing for WLAN, TD-SCDMA, and 3GPP FDD.

- Transmission Test Measurements
 - [RF Envelope](#)
 - [Constellation](#)
 - [Power](#)
 - [Spectrum](#)
 - [EVM](#)
- Receiver Test Measurements
 - [BER Measurements](#)
 - [Eb/No Definition](#)
- RF Power Amplifier Measurements
 - [Power Added Efficiency Measurements](#)

Transmission Test Measurements

RF Envelope

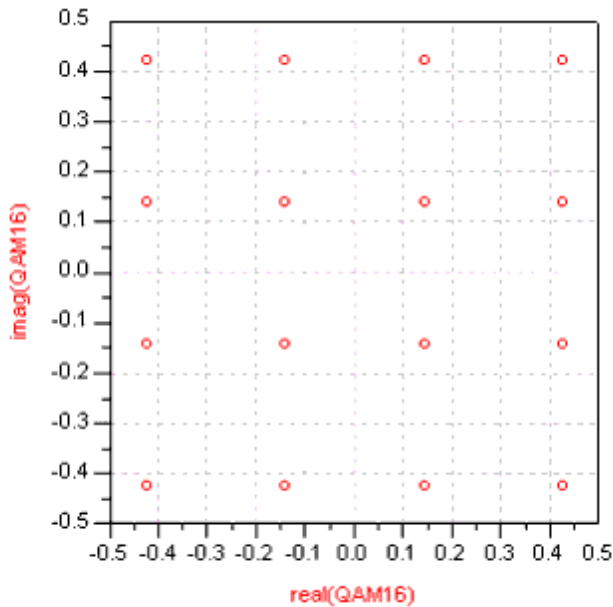
The RF envelope measurement shows the magnitude of the RF signal's envelope versus time. By observing a signal's RF envelope versus time you can see the signal's frame/burst structure. Some wireless standards specify a mask, to which the signal's RF envelope must conform. The mask is typically specified during the ramp up and ramp down transient of the signal.

Constellation

The constellation measurement shows in a graphical way the general quality of a signal. For a more accurate measurement of a signal's modulation quality an EVM analysis must be performed.

A constellation measurement is most appropriate when a QAM modulation scheme is used (directly or indirectly; for example WLAN 802.11a uses OFDM modulation, where a set of subcarriers is modulated using some QAM scheme). An ideal QAM signal will have a

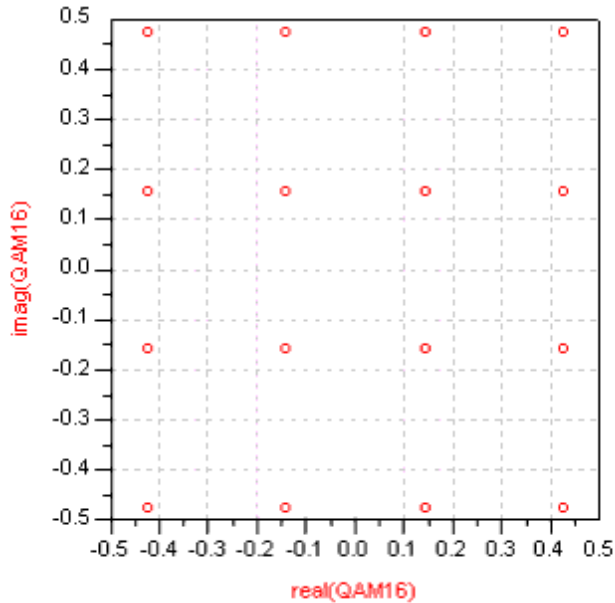
constellation that consists of a set of distinct points on the IQ plane. The following figure shows the constellation for an ideal 16-QAM signal. This constellation has 16 points and is symmetric around the X and Y axes. All points are equally spaced.



Constellation for Ideal 16-QAM Signal

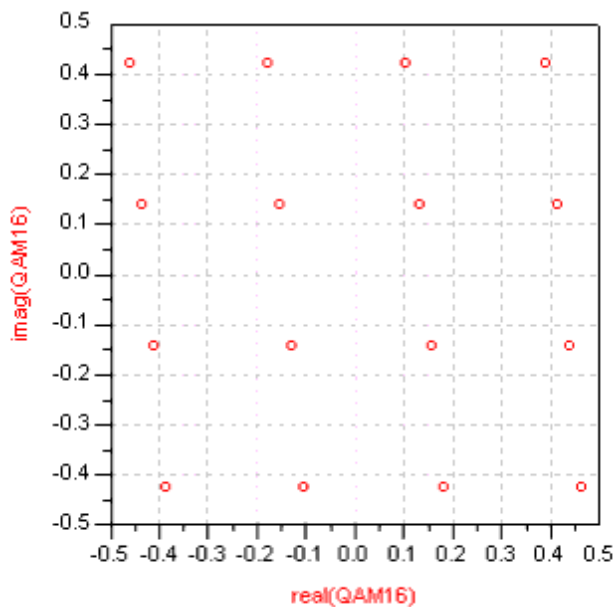
Different signal distortions modify the ideal constellation in different ways and so by looking at the constellation you can get some idea of what types of distortions are present in the signal. The following five illustrations show some examples of how signal distortions appear in the constellation.

The following figure shows the constellation for a 16-QAM signal with gain imbalance. This can be deduced by the fact that in the ideal constellation the span of the points across both axes is the same (approximately 0.425), whereas in the constellation with the gain imbalance the Y axis has a bigger span (approximately 0.475).



Constellation for 16-QAM Signal with Gain Imbalance

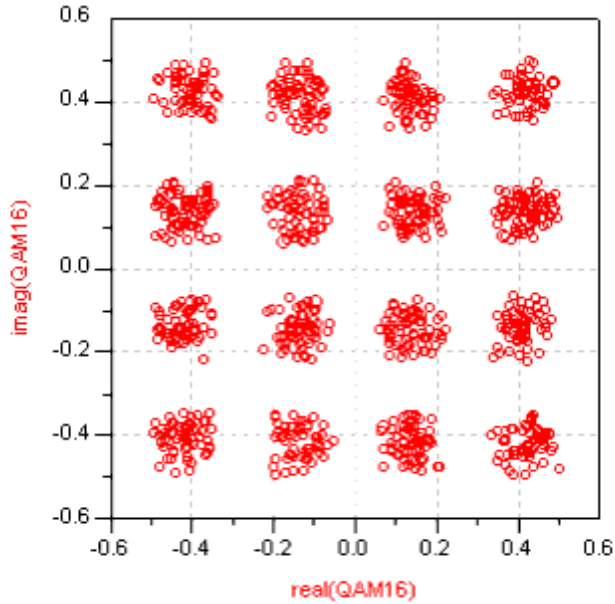
The following figure shows the constellation for a 16-QAM signal with phase imbalance. This can be deduced by the fact that in the ideal constellation the points are lined up parallel to the X and Y axes, whereas in the constellation with the phase imbalance the points are lined up parallel to the X axis but not to the Y axis.



Constellation for 16-QAM Signal with Phase Imbalance

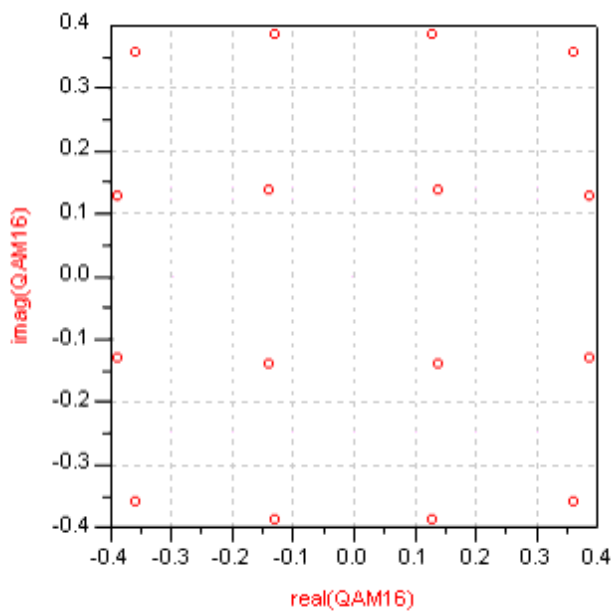
The following figure shows the constellation for a 16-QAM signal with ISI (intersymbol interference) and AWGN (additive white gaussian noise). Notice that instead of 16 distinct

points there are 16 clusters of points centered around the ideal 16-QAM points.



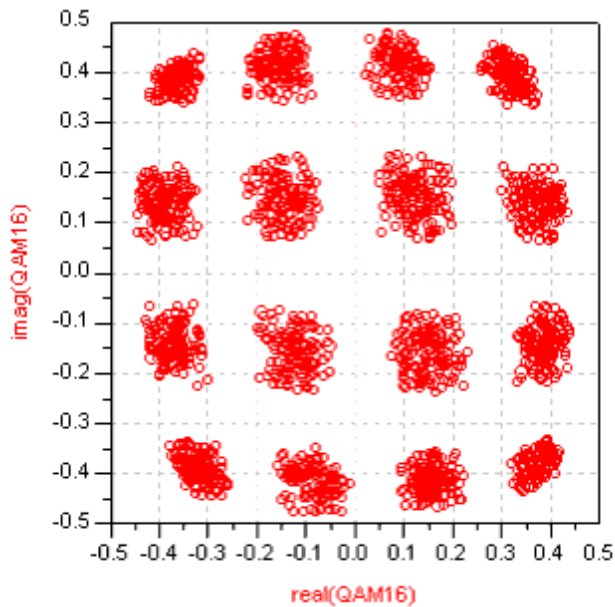
Constellation for 16-QAM Signal with ISI and AWGN

The following figure shows the constellation for a 16-QAM signal with gain compression (from a nonlinear amplifier). Notice how the outer points (especially the four corner points) that have the highest power have been compressed (moved closer to the center of the IQ plane).



Constellation for 16-QAM Signal with Gain Compression

The following figure shows the constellation for a 16-QAM signal that includes all of the distortions discussed above.



Constellation for 16-QAM Signal with Multiple Types of Distortion

Power

The power measurement is a set of power-related measurements that provides information about a signal's statistical properties. The power measurement includes:

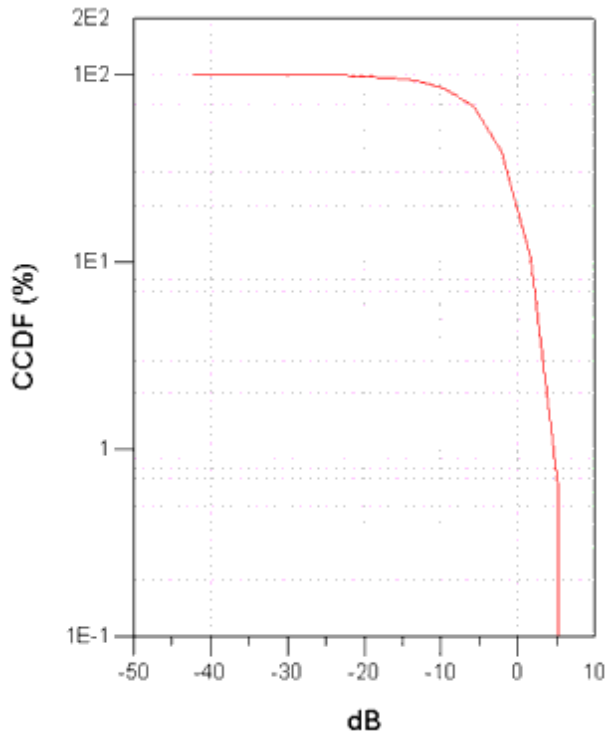
- Power vs. Time shows the instantaneous signal power versus time. Some wireless standards specify a mask, to which the signal's instantaneous power versus time waveform must conform. The mask is typically specified during the ramp-up and ramp-down transient of the signal.
- Total (Average) Power is the average signal power over the measurement duration. For signals that are transmitted in bursts or in slots this measurement should be performed only when the signal is active (on) and not during the idle intervals or inactive slots.
- Peak Power is the maximum instantaneous signal power over the measurement duration. Some standards define the peak power not as the absolute maximum instantaneous signal power but as the power level that is exceeded only for a small percentage (e.g. 1%) of the time.
- Peak to Average Ratio is the ratio of the peak signal power to the average signal power.
- Power Complementary Cumulative Distribution Function is defined as $CCDF = 1 - CDF$, where CDF is the cumulative distribution function of the signal's instantaneous power. If the probability density function of the signal's instantaneous power is $p(x)$, then

$$CDF(y) = \int_y^{\infty} p(x)dx$$

The power CCDF curve shows the probability that the instantaneous signal power will be higher than the average signal power by a certain amount of dB. The X axis of the CCDF curve shows power levels in dB with respect to the signal average power level (0 dB corresponds to the signal average power level). The Y axis of the CCDF curve shows the probability that the instantaneous signal power will exceed the corresponding power level on the X axis.

The following figure shows the CCDF curve for a WLAN 802.11a 54 Mbps signal. In the figure, you can see that the instantaneous signal power exceeds the average signal power (0 dB) for approximately 20% of the time. You can also see that the instantaneous signal power exceeds the average signal power by 5 dB for only 0.7% of the time.

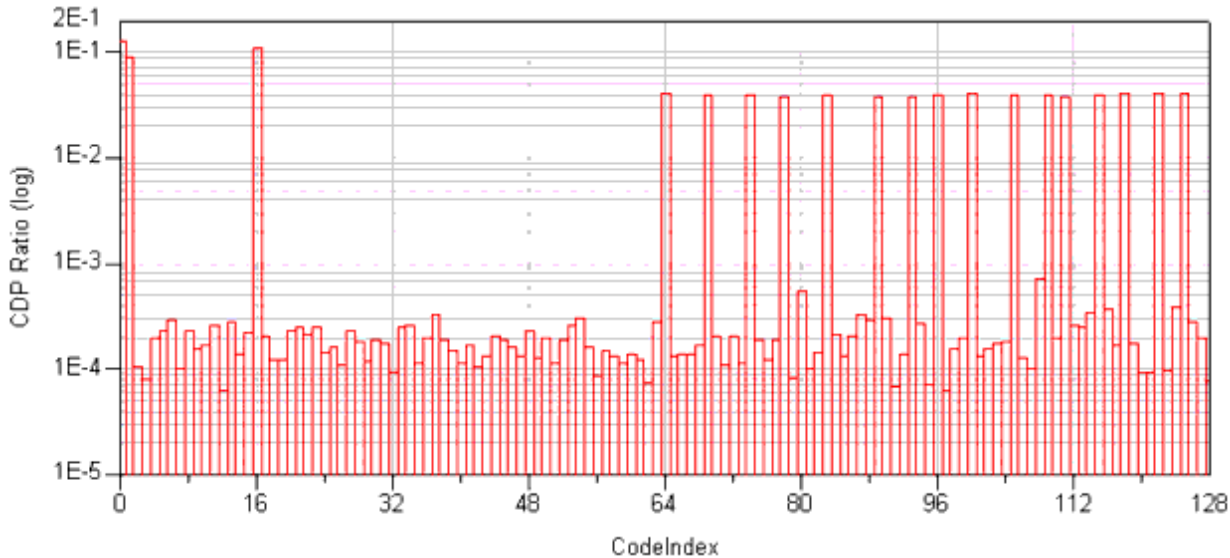
For signals that are transmitted in bursts or in slots this measurement should be performed only when the signal is active (on) and not during the idle intervals or inactive slots.



Power CCDF Curve for a WLAN 802.11a 54 Mbps Signal

- Code Domain Power (CDP)

For signals that use Code Division Multiple Access (CDMA) techniques, CDP is another useful power measurement. CDP shows the distribution of the signal's power in the code domain. The following figure shows the results of a CDP measurement for a 3GPP FDD Test Model 3 signal (based on 2000-12 version of the standard) with 16 DPCHs.

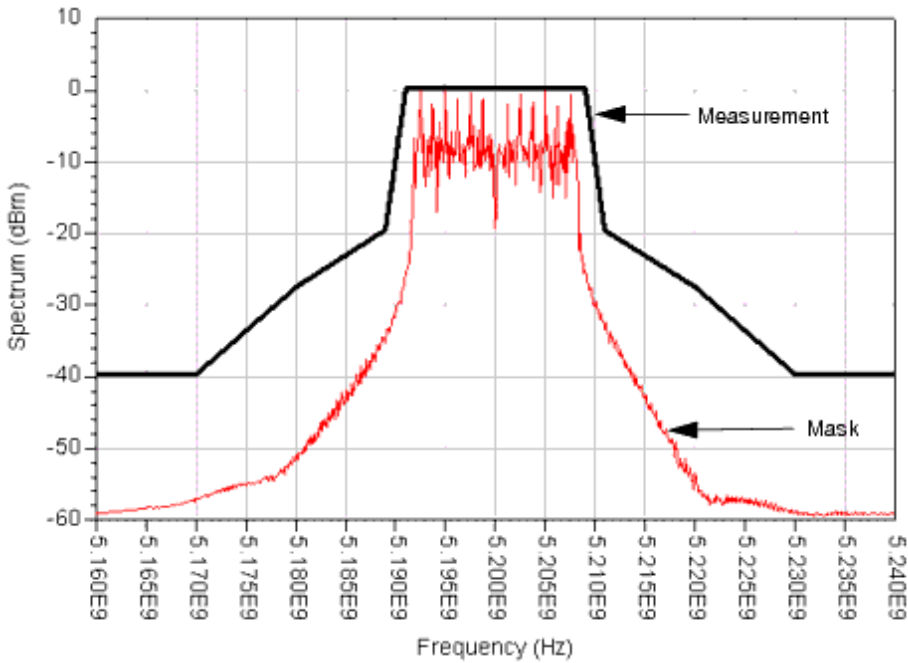


CDP Measurement for 3GPP FDD Test Model 3 Signal with 16 DPCHs

In the preceding figure, you can clearly see the 16 active DPCHs (occupying codes in the 64 to 128 range), as well as the primary CPICH (code 0), the P-CCPCH+SCH (code 1), and the PICH (code 16).

Spectrum

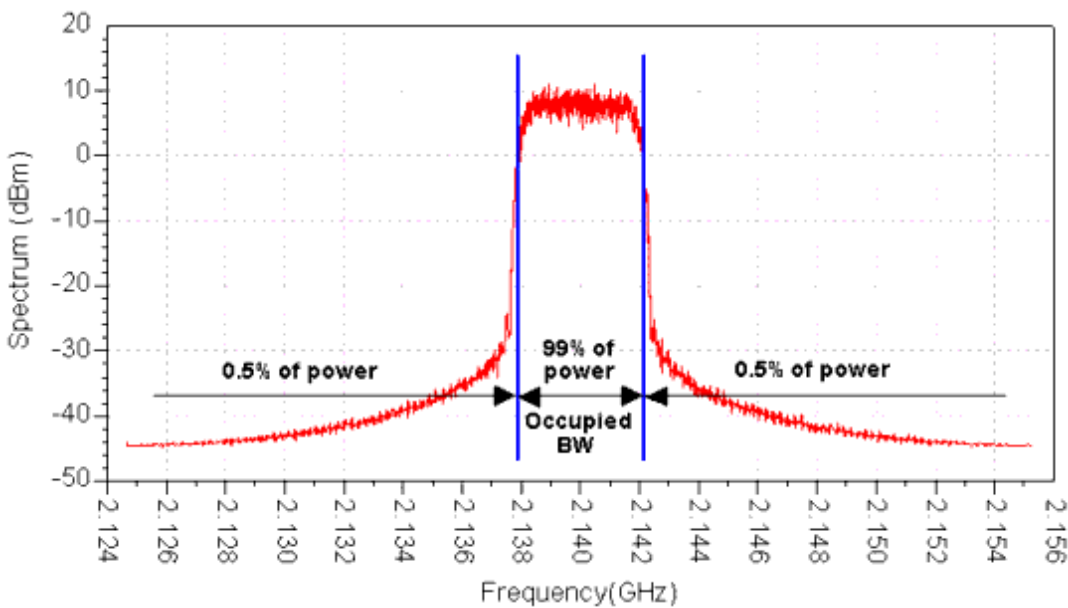
The spectrum measurement shows the spectrum of a signal that is the distribution of the signal's power in the frequency domain. Most wireless standards specify a mask, to which the signal's spectrum must conform. The need for the transmitted signal spectrum to conform to a spectral mask is so that the interference to adjacent channels is minimized and kept at acceptable levels. The following figure shows an example of a spectrum measurement and a spectral mask for a WLAN 802.11a signal.



Spectrum Measurement and Spectral Mask for WLAN 802.11a Signal

Some wireless standards specify additional spectrum related measurements. For example, the 3GPP FDD standard defines the following spectrum measurements:

- Adjacent channel leakage ratio (ACLR) is the ratio of the transmitted power to the power measured after a receiver filter in the adjacent channel(s).
- Occupied Bandwidth is the bandwidth that contains 99% of the signal's total transmitted power. The bandwidth is centered around the channel frequency so that the total power outside this bandwidth is split equally (0.5% of the total transmitted power) between the bands below and above it. The following figure shows the definition of the occupied bandwidth.



Occupied Bandwidth Definition

EVM

The EVM (error vector magnitude) measurement provides a metric for the modulation quality/accuracy of a signal. EVM is a measure of the difference between the measured signal and an ideal reference signal. While EVM may be defined differently in each wireless standard, the basic concept is described here.

Let $S(k)$, $k = 1, \dots, N$, be the ideal transmitted signal sampled at one sample per symbol (or chip) at the optimal (zero-ISI) instance. The actual transmitted signal can be modeled as

$$Z(k) = [C_0 + C_1(S(k) + E(k))]W^k$$

where:

$W = e^{Dr+jDa}$, accounts for both a frequency offset (Da radians/symbol phase rotation) and an amplitude change rate (Dr nepers/symbol)

C_0 is a complex constant representing origin offset

C_1 is a complex constant representing the arbitrary phase and output power of the transmitter

$E(k)$ is the residual vector error on sample $S(k)$

The sum square error vector is

$$\sum_{k=0}^{N-1} |E(k)|^2 = \sum_{k=0}^{N-1} \left| \frac{[Z(k)W^{-k} - C_0]}{C_1} - S(k) \right|^2$$

where C_0 , C_1 , W are chosen such as to minimize the above expression.

EVM (rms) is defined to be the rms value of $|E(k)|$ normalized by the rms value of $|S(k)|$. Therefore,

$$EVM(rms) = \frac{\sqrt{\frac{1}{N} \times \sum_{k=0}^{N-1} |E(k)|^2}}{\sqrt{\frac{1}{N} \times \sum_{k=0}^{N-1} |S(k)|^2}} = \frac{\sqrt{\sum_{k=0}^{N-1} |E(k)|^2}}{\sqrt{\sum_{k=0}^{N-1} |S(k)|^2}}$$

In addition to the EVM rms value, the EVM analysis provides other useful results, such as:

- Peak EVM
- Symbol (or chip) where the peak EVM occurs
- rms magnitude error (difference between the magnitudes of the ideal and reference signals)
- Peak magnitude error
- Symbol (or chip) where the peak magnitude error occurs
- rms phase error (difference between the phases of the ideal and reference signals)
- Peak phase error
- Symbol (or chip) where the peak phase error occurs
- Frequency error
- IQ offset (some wireless standards do not remove IQ offset from the measured signal and so this type of distortion is included in the EVM value)

For signals that use code division multiple access (CDMA) techniques, peak code domain error (PCDE) is another useful measurement related to EVM. To get the PCDE value, the error vector $E(k)$ is first projected on the code domain. This is done by calculating the inner-product between $E(k)$ and all the orthogonal vectors in the channelization code set (all codes belonging to the one spreading factor). Then the maximum projection is selected and normalized by the rms value of the reference signal.

Receiver Test Measurements

BER Measurements

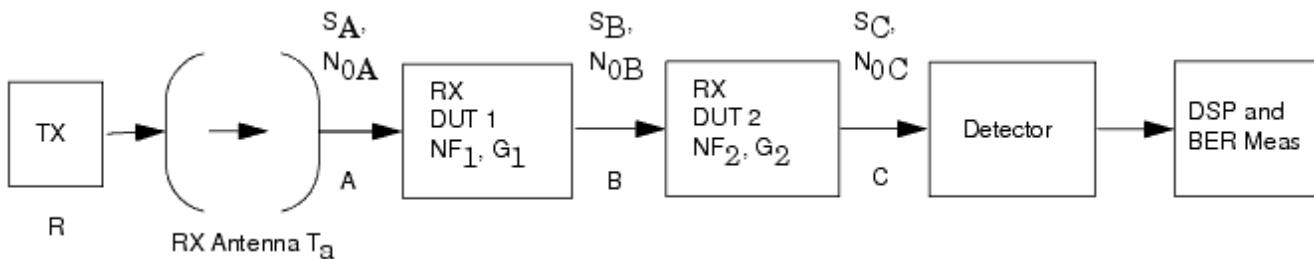
A receiver's performance is determined by its ability to receive and demodulate a wanted signal in the presence of noise and/or other interfering signals. Although there are several measurements used to test a receiver's performance, all of them measure the same quantity under different conditions. The measured quantity is the bit error rate. BER is the probability that a transmitted bit will be received and detected in error. Of course, better receivers have a lower BER.

Different wireless standards give different names to various BER measurements such as: Minimum Input Power Sensitivity, Minimum Input Level Sensitivity, Adjacent Channel Rejection, Adjacent Channel Selectivity, Reference Sensitivity Level, Dynamic Range, Blocking, Intermod. As mentioned earlier, all the above measurements are BER measurements under different conditions. These different conditions include additive white gaussian noise (AWGN), modulated interference signals, and CW interference signals. The interference signals can be in band and/or out of band. Typically, the standards specify that the BER should not exceed a certain value for certain power levels of the wanted and interfering signals, and a certain frequency offset (between the wanted signal's channel frequency and the frequency of the interfering signals).

E_b / N_o Definition

Bit error rate (BER) and frame and packet error rate (FER/PER) are typically reported with respect to E_b / N_o . This note defines E_b / N_o and relates it to signal to noise ratio (SNR). Distinction is made of local and system E_b / N_o . The following discussion is based on similar discussions published by Bernard Sklar (see [Eb/No References](#)).

For this discussion, the following figure illustrates a typical RF comm system receiver block diagram.



Typical RF Comm System Receiver Block Diagram

In the diagram above:

- The initial two blocks represent the transmitted signal and the propagation channel between the transmit and receive antennas. The transmitted signal contains data with bit time T_b with bit rate R bits/sec. The propagation channel includes significant attenuation and propagation effects (phase, amplitude, multi-path fading, etc.).
- A is the receiver antenna output.
- B is a mid point within the receiver system.
- C is the receiver system pre-detection point.
- RX DUT 1 is the receiver RF frontend and contains any lossy lines before the receiver and receiver front-end amplifiers, filters, and mixers. For this discussion it is defined with gain in dB (G_1) and noise figure in dB (NF_1).
- RX DUT 2 is the receiver backend and contains content before detection and includes amplifiers, filters, matched filter, and sampler. For this discussion it is defined with gain in dB (G_2) and noise figure in dB (NF_2).
- BER is then measured, typically with suitable DSP algorithms.

At each A, B, and C point in the system, there is a measurable value for the signal (S_A, S_B, S_C) and noise density (N_{0A}, N_{0B}, N_{0C}), where the signal is in Watts (W) and noise density is in Watts/Hz (W/Hz).

In this system (and for discussion purposes) the received desired signal has additive thermal noise contributions from the propagation path available at the receiver antenna output and from the receiver noise figures. Other noise contributors are ignored, such as interfering signals and nonlinear intermodulation products.

Thermal noise at the receiver antenna output is typically defined in terms of noise temperature in Kelvin. Call this T_A . Note that 290 K (16.85° C) corresponds to a noise power density of -173.975 dBm/Hz value.

The receiver antenna output noise power density is:

$$N_{0A} = k T_a, \text{ where } k \text{ is Boltzmann's constant.}$$

Receiver noise figures can also be represented in terms of noise temperature in Kelvin: $T = 290 (F-1)$ where $F = 10^{(NF/10)}$.

The RF DUT 1 and 2 have associated noise temperatures at T_1 and T_2 respectively.

$$T_1 = 290 (F_1 - 1); F_1 = 10^{(NF_1 / 10)}$$

$$T_2 = 290 (F_2 - 1); F_2 = 10^{(NF_2 / 10)}$$

T_1 represents the equivalent noise temperature due to RF DUT 1 defined at the input of RF DUT 1 and has associated noise power density: $k T_1$. This results in definition for N_{0B} as:

$$N_{0B} = G_1 (k T_a) + G_1 (k T_1) = G_1 k (T_a + T_1)$$

T_1 represents the equivalent noise temperature due to RF DUT 2 defined at the input of RF DUT 2 and has associated noise power density: $k T_2$. This results in definition of N_{0C} as:

$$N_{0C} = G_1 G_2 (k T_a) + G_1 G_2 (k T_1) + G_2 (k T_2) = G_1 G_2 k (T_a + T_1 + T_2 / G_2)$$

SNR is related to E_b / N_o in the following way:

$$SNR = \frac{S}{N} = \frac{\frac{E_b}{T_b}}{N_0 N_{BW}} = \frac{E_b R}{N_0 N_{BW}} = \frac{E_b}{N_0} \times \frac{R}{N_{BW}}$$

where:

SNR = signal-to-noise ratio (unitless)

S = signal power (W)

N = noise power (W)

E_b = bit energy (W / sec)

T_b = bit time (sec)

N_{BW} = receiver noise bandwidth (Hz)

N_0 = noise power density = N / N_{BW} (W/Hz)

R = data rate = $1 / T_b$ (1/sec)

E_b / N_0 = E_b over N_0 (unitless)

To provide a signal-to-noise figure that is independent on the receiver noise bandwidth, the signal-to-noise density is typically used.

$$\frac{S}{N_0} = \frac{E_b}{T_b N_0} = \frac{E_b R}{N_0} = \frac{E_b}{N_0} \times R$$

Thus, we now see the relationship between E_b / N_0 and S/N_0 and S/N .

$$\frac{E_b}{N_0} = \frac{S}{N} \times \frac{NBW}{R} = \frac{S}{R}$$

S/N_0 and E_b / N_0 values may be considered as local or system values. Local values are specific to the receiver system point where they are evaluated (points A, B, or C in the diagram); system values are independent of the receiver system point where they are evaluated.

Local values of S/N_0 and E_b / N_0 are directly measurable at each point in the system and are typically the preferred S/N_0 and E_b / N_0 values used by RF/analog designers.

At points A, B, and C, the local S/N_0 values are:

$$S_A / N_{OA} = S_A / (k T_a)$$

$$S_B / N_{OB} = (S_A G_1) / (k (T_a + T_1) G_1) = S_1 / (k (T_a + T_1))$$

$$S_C / N_{OC} = (S_A G_1 G_2) / (G_1 G_2 k (T_a + T_1) + G_2 k T_2) = S_A / (k (T_a + T_1 + T_2 / G_1))$$

System values of E_b / N_0 and S/N_0 are directly measurable only at the pre-detection system point (point C in the diagram). These are the system values because they characterize the overall system performance. The system values are typically the preferred S/N_0 and E_b / N_0 values used by System/DSP designers.

In all cases,

$$E_b / N_0 = S/N_0 / R$$

b 0 o

At point C, the local E_b/N_0 and S/N_0 values are the same as the system E_b/N_0 and S/N_0 values.

Summary

- Local S/N_0 and E_b/N_0 values are not the same at all points of measurement in the receiver.
- System S/N_0 and E_b/N_0 values are only measurable at the receiver pre-detection point (point C in the diagram), may be inferred at the other receiver points (points A and B) and have only one value defined for the system.
- Always specify if the S/N_0 or E_b/N_0 you are using is the Local or the System value.

In the Wireless Test Bench data displays, the E_b/N_0 value used is the local E_b/N_0 value at the receiver input, equivalent to point A in the diagram.

E_b/N_0 References

1. Sklar, Bernard, *Digital Communications: Fundamentals and Applications*, 2nd Edition, Prentice-Hall, N.J., 2001.
2. Sklar, Bernard, "RF Resign: Will the Real E_b/N_0 Please Stand Up," *Communication Systems Design*, April, 2003.

RF Power Amplifier Test Measurements

Power Added Efficiency (PAE) Measurements

In an RF power amplifier (PA), power added efficiency (PAE) is defined as the ratio of the difference of the output and input signal power to the DC power consumed. In other words:

$$PAE = (PRFOUT - PRFIN)/PDC$$

where:

PRFOUT = the RF PA output power delivered

PRFIN = the RF PA input power consumed

PDC= the RF PA input DC power consumed

For an RF wireless signal, the PAE is measured only during the time interval when the

wireless signal is 'ON'. A wireless signal typically has a frame format and often at some time during that frame the wireless signal power is zero, or some low level, that is not representative of the high power mode of the signal frame. The PAE value typically of interest is that value that occurs during the high power mode in the signal frame. Not all wireless technologies use the word 'frame' to represent their formatted signal segment. The word 'frame' here is use to mean 'burst', 'slot', 'subframe' or other nomenclature that is specific to a wireless technology. The frame based PAE measurement is made only during specific time gated time intervals within the signal frame.

References

1. Agilent Application Note "Characterizing Digitally Modulated Signals with CCDF Curves."
<http://literature.agilent.com/litweb/pdf/5968-6875E.pdf>
2. Agilent PN (Product Note) "Using Error Vector Magnitude Measurements to Analyze and Troubleshoot Vector-Modulated Signals."
<http://literature.agilent.com/litweb/pdf/5965-2898E.pdf>

Wireless Test Bench Basics

Introduction

ADS wireless test benches enable system designers to make wireless system measurements available to RF designers to validate RF designs for use with wireless systems.

Previously, RF designers used traditional Analog/RF measurements such as spectrum, TOI, etc. to validate their designs. Empirical methods used to map Analog/RF measurements to determine wireless system performance were error prone. Typically, they could not perform more complex wireless system measurements successfully such as EVM and BER. And, a system designer using ADS Ptolemy simulator could not easily deliver a system test bench to the RF designer for more accurate and complete RF verification.

Wireless test bench templates available in the Analog/RF schematic provide easy access to pre-configured ADS WTB models (the models are complete, so the RF designer does not need to know internal test bench details). By simply inserting a WTB template the RF designer need only replace Amplifier2 with their RF DUT, specify test bench test frequency and/or power levels, and rely on the other default settings.

WTB models are provided for RF transmitter, RF receiver, and RF power amplifier testing. Transmitter test models provide standards-specific wireless transmitter tests such as constellation, CCDF, and EVM. Transmitter models can be linked to Agilent signal generator test instruments to further enable designers to use the same test signals from the WTB models to test their RF designs as well as hardware prototype of their RF designs. Receiver test models provide standards-specific wireless receiver tests such as RF sensitivity. RF power amplifier test models provide tests such as power added efficiency that take into account the wireless signal frame structure and signal power gating characteristics.

The RF designer typically should use the WTB analysis after doing traditional measurements to achieve an acceptable performance from the RF designs. In the initial design stages the RF designer may have to stimulate the design with proper wireless standard signals.

Wireless sources are provided under Analog/RF Sources-Modulated-DSP-based library. These are configurable source components and their use model is similar to power sources such as P_1Tone; and, they can be used in different analyses such as Circuit Envelope, and S-parameter just like other sources.

Wireless sources generate RF signals that can be used in traditional simulations. Additionally, these can be used for wireless system measurements, such as WLAN EVM, using the set of wireless expressions. These wireless expressions can be used in MeasEqn block. For more complex receiver measurements, such as BER, you must use the wireless test bench models using the WTB analysis.

The wireless sources and expressions are useful in the initial phases of the RF development for traditional Analog/RF measurements. As the design matures, the RF designer must use WTB analysis and the corresponding wireless test bench models for more complete transmitter and transmitter system verification.

Wireless Test Bench Models

The following table lists the pre-configured wireless test bench models. These test benches provide comprehensive transmitter and receiver testing for 3GPP FDD, TD-SCDMA, and WLAN technologies. All measurements are performed according to wireless technology industry standard specifications. For details about using these models, see the online documentation:

3GPP FDD Wireless Test Benches (adswtb3g)

EDGE Wireless Test Benches (edgewtb)

HSUPA Wireless Test Benches (adswtbhsupa)

Mobile WiMAX Wireless Test Benches (adswtbwman_m)

RF Power Amplifier Test Benches (rfpwrampwtb)

TD-SCDMA Wireless Test Benches (adswtbtlds)

UWB Wireless Test Benches (adswtbuwb)

WLAN Wireless Test Benches (adswtbwlan)

Wireless Test Bench Models

WTB Model	Measurements	ESG Link
3GPPFDD_BS_TX: 3GPP FDD Base Station Transmitter Test	RF Envelope Power ACLR Occupied Bandwidth CDP PCDE EVM	Signals can be sent to an ESG
3GPPFDD_UE_TX: 3GPP FDD User Equipment Transmitter Test	RF Envelope Power ACLR ACLR in Switching Transients Occupied Bandwidth CDP PCDE	Signals can be sent to an ESG

	EVM	
3GPPFDD_BS_RX: 3GPP FDD Base Station Receiver Test	Reference Sensitivity Level Dynamic Range Adjacent Channel Selectivity Blocking Characteristics Intermodulation Characteristics	
3GPPFDD_UE_RX: 3GPP FDD User Equipment Receiver Test	Reference Sensitivity Level Maximum Input Level Adjacent Channel Selectivity Blocking Characteristics Intermodulation Characteristics	
3GPPFDD_RF_PAE: 3GPP FDD RF Power Amplifier Test	Power Added Efficiency	
EDGE_RF_PAE: EDGE RF Power Amplifier Test	Power Added Efficiency	
HSUPA_UE_TX: HSUPA User Equipment Transmitter Test	RF Envelope Power ACLR PCDE EVM	Signals can be sent to an ESG
WMAN_DL_802_16e_TX: Mobile WiMAX Downlink Transmitter Test	RF Envelope Power Constellation Spectrum EVM	Signals can be sent to an ESG
WMAN_DL_802_16e_RX_Sensitivity: Mobile WiMAX Downlink Receiver Sensitivity Test	Reference Sensitivity Level	
WMAN_UL_802_16e_TX: Mobile WiMAX Uplink Transmitter Test	RF Envelope Power Constellation Spectrum EVM	Signals can be sent to an ESG
WMAN_UL_802_16e_RX_Sensitivity: Mobile WiMAX Uplink Receiver Sensitivity Test	Reference Sensitivity Level	
RF_PAE_EVM_ACLR: RF Power Amplifier Test	Power Added Efficiency Error Vector Magnitude Adjacent Channel Leakage Ratio	
TDSCDMA_DnLnk_TX: TD-SCDMA Downlink Transmitter Test	RF Envelope Constellation Power Spectrum EVM	Signals can be sent to an ESG
TDSCDMA_UpLnk_TX: TD-SCDMA Uplink Transmitter Test	RF Envelope Constellation Power Spectrum EVM	Signals can be sent to an ESG
TDSCDMA_DnLnk_MultiCarrier_TX: TD-SCDMA Downlink Transmitter Test for Multi-carrier Signals	Power Spectrum	
TDSCDMA_DnLnk_RX_ACS:	Adjacent Channel Selectivity	

TD-SCDMA Downlink Receiver Test		
TDSCDMA_UpLnk_RX_Sensitivity: TD-SCDMA Uplink Receiver Test	Reference Sensitivity Level	
UWB_TX: Ultra-Wideband Transmitter Test	RF Envelope Power Constellation Spectrum EVM	
UWB_RX_Sensitivity: Ultra-Wideband Receiver Sensitivity Test	Reference Sensitivity Level	
WLAN_802_11a_TX: WLAN 802.11a/11g Transmitter Test	RF Envelope Power Constellation Spectrum Mask EVM	Signals can be sent to an ESG
WLAN_802_11a_RX_ACR: WLAN 802.11a/11g Receiver Test	Adjacent Channel Rejection	
WLAN_802_11a_RX_Sensitivity: WLAN 802.11a/11g Receiver Test	Minimum Input Power Sensitivity	
WLAN_802_11b_TX: WLAN 802.11b/11g Transmitter Test	RF Envelope Power Constellation Spectrum Mask EVM	Signals can be sent to an ESG
WLAN_802_11b_RX_Sensitivity: WLAN 802.11b/11g Receiver Test	Minimum Input Power Sensitivity	

Wireless Sources

The following table lists the wireless sources in A/RF schematic. These wireless sources provide standard compliant RF signals for WLAN, TD-SCDMA, and 3GPP FDD wireless technologies. In addition to the RF signal, the TD-SCDMA and 3GPP FDD sources provide baseband I and Q signals. These sources are highly configurable and can generate signals with different rates, power levels, impairments, etc. For details about these sources, see the online *Components* documentation *Sources, Modulated-DSP-Based (ccsrc)*.

Source Name	Description
WLAN_802_11a	WLAN 802.11a (OFDM) source
WLAN_802_11b	WLAN 802.11b (CCK/PBCC) source
TDSCDMA_DnLink	TD-SCDMA downlink source
TDSCDMA_UpLink	TD-SCDMA uplink source
3GPPFDD_DnLink	3GPP FDD downlink source
3GPPFDD_UpLink	3GPP FDD uplink source

Wireless Expressions

The following table lists the commonly used wireless expressions for testing 3GPP FDD, WLAN, and TD-SCDMA transmitters.

See *Measurement Expressions* (expmeas) for details about using these expressions.

Wireless Expressions

Measurement	Expression Name
Baseband signal in time-domain	real()
EVM measurement for WLAN DSSS/CCK/PBCC	evm_wlan_dsss_cck_pbcc()
EVM measurement for WLAN OFDM	evm_wlan_ofdm()
Magnitude of carrier in time-domain	mag()
Phase of carrier in time-domain	phase()
Power - CCDF [†]	power_ccdf()
Power - Peak	peak_pwr()
Power - Peak to Average	peak_to_avg_pwr()
Power - Power vs. Time	pwr_vs_t()
Power - Total	total_pwr()
Spectrum analyzer ^{††}	spectrum_analyzer()
Spectrum of carrier in dB	dB(fs())
Spectrum of carrier in dBm	dBm(fs())
Voltage	< named node > [1]

[†] The power_ccdf_ref() expression, which generates a reference curve for the Power-CCDF measurement, can be used in transmitter testing. This expression is not available in the Expression Builder.

^{††} The spectrum_analyzer() and fs() expressions can be used for spectrum measurement. Although spectrum_analyzer() uses fs() internally, it provides an easy way to set the measurement resolution bandwidth as well as video averaging.

RF Verification Examples

RF Verification examples demonstrate how to use wireless test benches, sources, and expressions. The examples can be accessed from the ADS Main window > *File* > *Open* > *Example* :

- *HSUPA* > *HSUPA_RF_Verification_wrk*
- *TDSCDMA* > *TDSCDMA_RF_Verification_wrk*
- *UWB* > *UWB_RF_Verification_wrk*
- *WCDMA3G* > *WCDMA3G_RF_Verification_wrk*
- *WLAN* > *WLAN_RF_Verification_wrk*
- *WMAN_M* > *WMAN_16e_OFDMA_RF_Verification_wrk*

Required Licenses

Licenses required to use wireless test bench models, wireless sources, and wireless expressions are listed in the following table.

Feature	Required Licenses
Wireless Test Bench Models, Sources, and Expressions (general)	sim_envelope sim_systeme
3GPP FDD W-CDMA Wireless Design Library for 3GPP FDD Wireless Test Bench Models, Sources, and Expressions	mdl_wcdma3g
EDGE Wireless Design Library for EDGE Wireless Test Bench Models	mdl_edge
HSUPA Wireless Design Library for HSUPA Wireless Test Bench Models	mdl_hsupa
Mobile WiMAX Wireless Design Library for Mobile WiMAX Wireless Test Bench Models	mdl_wimax_mobile
TD-SCDMA Wireless Design Library for TD-SCDMA Wireless Test Bench Models, Sources, and Expressions	mdl_tdscdma
Ultra-Wideband Wireless Design Library for Ultra-Wideband Wireless Test Bench Models	mdl_ultrawideband
WLAN Wireless Design Library for WLAN Wireless Test Bench Models, Sources, and Expressions	mdl_wlan